TM-71-2034-2

TECHNICAL MEMORANDUM

EVA VHF COMMUNICATIONS WITH LM ON APOLLO 15 TRAVERSES

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TITLE- EVA VHF Communications with LM on Apollo 15 Traverses

TM- 71-2034-2

DATE- August 16, 1971

FILING CASE NO(S)- 320

AUTHOR(S)-I. I. Rosenblum

FILING SUBJECT(S) (ASSIGNED BY AUTHOR(S))- Lunar Surface VHF, Apollo 15 EVA-LM Link, Propagation Loss Model for Lunar Terrain

ABSTRACT

EVA VHF communications capability to LM on Apollo 15 traverses is evaluated using loss predictions for diffraction for an isolated rounded obstacle. The basis for this choice of analysis method is discussed and the method is applied to the Hadley-Apennine landing site. VHF signal requirements for the LM used in this study are based on a recently completed link analysis, by MSC, covering the LM S-Band communication (VHF relay) modes planned for the mission surfaces activities.

Predictions for the Apollo 15 Lunar Roving Vehicle (LRV) traverses indicate that voice communication at 70% word intelligibility (WI) will generally be available on most of each traverse but that PAM telemetry at 20% data loss will show negative margins for most points of Traverses I and II. The analysis for the walking traverses indicates that the principal areas of VHF communication difficulty will be in the region of the Hadley Rille edge on Traverses I and II and in the region of the secondary crater cluster on walking Traverse III.

The data in this report was presented to the Apollo Program Office as part of the Apollo 15 mission planning and some general comparisons with the preliminary MSC data were discussed in these meetings. It is suggested that VHF signal strength data from the Apollo 15 mission traverses be used to verify the propagation model.

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TECHNICAL MEMORANDUM

I. INTRODUCTION

Apollo 15 surface exploration was planned to use the Lunar Roving Vehicle (LRV) which will provide - through the Lunar Communications Relay Unit (LCRU) - direct communications to Earth from the immediate vicinity of the LRV. However, VHF communication capability between the Astronauts and LM is of interest from two practical considerations;

(a) As a partially redundant path (for voice and biomedical telemetry signals) for the LCRU-Earth link, and

(b) As a backup in the event of a malfunction in the LCRU and/or LRV.

The adequacy of predicted VHF performance of the astronaut-LM link would help resolve the question of whether or not the astronauts, in the event of an "in transit" LRV failure, would need to remove the LCRU from the LRV and take it with them on their return traverse to LM. In addition, alternate walking traverses have been defined for contingency use on Apollo 15[1] in the event the LRV is not available for use on the lunar surface. For these traverses, the capability of the astronaut backpack equipment to provide VHF communications (voice and telemetry) to LM becomes a significant factor.

This memorandum covers the VHF communications analysis carried out on the Apollo 15 traverses. The section which follows outlines the method of analysis used. Communications capability in the general vicinity of each planned stopping point of the LRV traverses is evaluated in terms of signal margins for voice and telemetry signals and using this data and other margin data for other locations in the general traverse areas, contours of communications coverage are developed which are then applied to the walking traverses. The results and conclusions are given in Sections III and IV. All analysis results reported here are based on traverse plans for Apollo 15 which were obtained by the writer from Mr. James W. Head in March 1971 and subsequent revision for the LRV traverses obtained in May 1971.

II. ANALYSIS METHOD

The terrain at the Hadley-Apennine region north site is characterized by sharp relief features including Hadley Rille, the Apennine Front, hill formations and deeply cratered areas. The terrain is not smooth and it is not flat (see Figure 1).

Several methods of communications analysis that have in the past been applied to lunar surface signal prediction were considered for the Apollo 15 traverses. The geometric optics solution[2] was regarded as inappropriate because much of each traverse was beyond the line-of-sight. The Bremmer series[2,3,4] was not used because the terrain itself represents a significant departure from the smooth spherical surface assumed in that analysis model. Knife-edge diffraction loss predictions[5,6] were rejected because, in general, the terrain intervening between LM location and traverse points of interest was found to be characterized by rounded crests and frequently by expansive elevated areas, rather than by sharp edges.

The Bullington "empirically derived" model in use at MSC,[7,8] which correlates shadow loss with H/λ (ratio of height to obtain line-of-sight conditions to wavelength), also was not used because:

(a) The model is based on large-scale variations in field strength data collected in the New York City - New Jersey area for a valley approximately 12 miles in extent; the applicability of the derived model to the small-scale "hill" structures of the lunar landscape appears questionable.

(b) The validity and accuracy of the model appears to be suspect for applications to the terrain regions just on the other side of terrain obstacles, based on comparisons with diffraction loss calculations.

The method chosen to evaluate the Apollo 15 traverses is to use diffraction loss calculations for propagation over an isolated rounded obstacle. Using this model, the diffraction loss of the obstructing terrain, relative to free space attenuation, is found as a function of the diffraction angle, the separation distances between the transmitter, obstacle, and receiver and the obstacle radios of curvature. This method is described in the National Bureau of Standards Technical Note #101 (revised), "Transmission Loss Predictions for Topographic Communication Circuits".(9) This method was also used by the writer in prior VHF lunar surface signal analysis.(10) In addition, results with this method are obtained with what is believed to be sufficient accuracy. Indeed in a background reference, Dougherty and Maloney(12) reported remarkable agreement (within about 3 dB) between observed diffraction losses over Colorado mountain ridges and values computed at frequencies of 179.75 MHz and 191.75 MHz using the rounded obstacle diffraction formulas. See Figure 2 (from Reference 12). In summary, when considered against the Bullington model, the rounded obstacle model is clearly advantageous and has been selected because:

1. The model takes into account the specific radius of curvature of the obstacle (the Bullington model does not).

2. The model is applicable to arbitrary obstacle/receiver geometry and can be used to develop specific predictions for each point of interest (the Bullington model is a gross prediction of median loss for a valley area).

3. An approximation is present in the Bullington model in that its derivation involved, in effect, fitting non knife-edge data to one factor in the knife-edge diffraction formula.

In applying this method to the Apollo 15 traverses, a radial line is drawn on the topographic base map between the LM location and the desired point on the traverse (see Figure 3). The points where the line crosses the elevation contours are taken to define the terrain relief along the propagation path.

The terrain region providing the dominant obstacle to the line-of-sight path is examined and points are selected from which the crest radius of curvature can be found by data fitting to a circular arc. Frequently it is found desirable to calculate a composite radius rather than a single radius depending on the number of data points available in the obstacle crest area - in order to obtain a radius of curvature value that is compatible with the path geometry. The diffraction angle and path distances are found from the geometry by iterative solution for the points of tangency to the rounded obstacle of the LM and EVA propagation path lines (see Figure 4).

The total diffraction loss in dB for propagation over a rounded obstacle is defined as:

$$A(v,\rho) = A(v,0) + A(0,\rho) + U(v\cdot\rho) \qquad (1)$$

Here A(v,0) is the knife-edge (zero radius) diffraction loss calculated for the applicable frequency (f), diffraction angle (θ) and path distances (r_1, r_2 and r_3). The variable v is the usual dimensionless parameter of the Fresnel-Kirchhoff diffraction formula and is found from the expression:

$$v = 2.583 \cdot \theta \cdot [f \cdot r_1 \cdot r_2/(r_1 + r_2)]^{1/2} \qquad (2)$$

In this study the function A(v,0), in dB, is repreted by the approximation formula:

$$A(v,0) = 6.08 - 0.005v^4 + 0.159v^3 - 1.7v^2 + 9.3v \qquad (3)$$

for $v < 3$ and by

$$A(v,0) = 12.953 + 20 \text{ Log } v \quad (4)$$

$$\text{for } v \geq 3$$

The parameter ρ is the index of curvature for the crest radius, a, and is found from:

$$\rho = 0.676 \cdot a^{1/3} \cdot f^{-1/6} \left[\frac{r_3}{(r_1 \cdot r_2)}\right]^{1/2} \quad (5)$$

where f = frequency in megahertz and a, r_1, r_2, and r_3 are given in kilometers.

The theoretical curve values for the component $A(0,\rho)$ in dB are approximated by:

$$A(0,\rho) = 5.86 + 1.49\rho^3 + 1.46\rho^2 + 6.49\rho \quad (6)$$

$$+ 10 \exp(-2.3\rho)$$

The last term in Equation 6 provides an average allowance for terrain foreground effects such as reflection by terrain features between each antenna and its horizon.

The loss component dependent on the product $v \cdot \rho$, i.e., $U(v \cdot \rho)$ is approximated in dB by:

$$U(v \cdot \rho) = (43.6 + 23.5\, v \cdot \rho) \log_{10} (1 + v \cdot \rho) - 6.7\, v \cdot \rho - 6.0 \quad (7)$$

$$\text{for } v \cdot \rho < 2.0 \text{ and by:}$$

$$U(v \cdot \rho) = 22(v \cdot \rho) - 20 \log_{10}(v \cdot \rho) - 14.13 \quad (8)$$

$$\text{for } v \cdot \rho \geq 2.0$$

Figure 5 plots the rounded obstacle attenuation function $A(v,\rho)$ for a range of variations in v and ρ and provides a direct comparison of rounded obstacle losses with knife-edge losses (ρ=o curve).

The VHF signal margin is found by adding the rounded obstacle loss to the free space loss and other losses associated with the rf path and subtracting the total from the maximum allowable total link transmission loss for the Extravehicular Astronaut (EVA) to Lunar Module (LM) link, as illustrated in Figure 6.

In this study the following values were assumed:

LM antenna height = 8.24 meters

EVA antenna height = 1.83 meters

Frequency = 259.7 MHz

The frequency 259.7 MHz was used in this study because the weaker link of the EVA-LM and LM-EVA pair, i.e., the link from the astronaut to the LM, operates at this frequency.

In evaluating system capability, values for total allowable link loss were based on recent data developed by MSC and reported by C. K. Land in an April 27, 1971 memorandum.[13] This memorandum provided link analysis curve data relating allowable path loss to % word intelligibility and % data loss on the PAM telemetry for the S-Band modes planned for Apollo 15. For convenience in this report the reference 13 curve data for total allowable loss is adjusted by 3dB to reflect the additional 3dB specification loss (allowed in Reference 13) for EVA cable loss to obtain a transmitter black box to receiver black box total allowable link loss. This facilitated the individual identification of key loss parameters associated with the rf cabling, rf components and antenna gains, referred to in this report as rf losses.

The adjusted total allowable link losses are tabulated in Figure 7. These are S-Band Mode 10A* values

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*Mode 10A is planned for Traverse I on Apollo 15. It is a LM downlink FM configuration for S-Band, using high power and steerable antenna, that provides dual EVA voice, EKG data and PLSS status, LM telemetry, and TV.

but are used in this analysis for all traverses as a simplification since Mode 7A** values are, practically speaking, the same. Values for EKG signal transmission are not available.

The rf losses that were used in this analysis are illustrated in Figure 8 and are tabulated below:

EVA antenna	-2.0 dB
EVA cable and triplexer	-1.7 dB
LM diplexer and cable	-2.5 dB
LM antenna (dependent on azimuth)	-3.0 dB or 0.0 dB
Total	-9.2 dB or -6.2 dB

The EVA antenna gain factor is taken from pattern data and corresponds to average gain for the standing position. The second and third factors above were determined after discussion with MSC personnel; they reflect loss measurements on flight hardware (not necessarily Apollo 15).

The values used for the LM antenna pattern loss were chosen to reflect not only the azimuth of the specific radial path from LM to EVA for a nominal LM landing orientation but also to consider the likelihood of off-nominal orientation of the spacecraft in vertical and azimuth at landing. To do this, the average pattern gain (loss), within a 10° cone about the nominal look angles was used. Figure 9 shows the reference pattern data used; the result was, for most traverse points, a value of -3dB.

Distance and elevation data were taken from a 1:15,840 scale topographic map with contours at 10 meters which was originally issued in January 1971 and reissued in February 1971, by the Mapping Sciences Laboratory, NASA MSC.

**Mode 7A is planned for Traverse II and III on Apollo 15. It provides downlink PM configuration, low power transmission and steerable antenna for voice, EKG and PLSS data.

III. ANALYSIS RESULTS FOR LRV TRAVERSES

The LRV traverses used in this study are shown in Figure 10.

Analysis results are shown in tabular form in Figure 11.

Link margin conditions predicted for 70% word intelligibility performance are indicated graphically in the traverse layout of Figure 12 along with margin conditions predicted for 20% data loss telemetry. Figure 13 gives the link margin conditions for 90% WI voice.

The approximate contours corresponding to zero (0) link margin conditions for 70% WI voice and 20% data loss telemetry are given in Figures 14 and 15 respectively.

On the assumption that 70% WI and 20% data loss telemetry represent the lowest performance levels that will yield operationally useful voice and telemetered data, the results here indicate that acceptable voice can be expected at all traverse stop points except point 1 on Traverse I, point 4 on Traverse II and point 11 on Traverse III. The times currently planned for these stops are 15 minutes, 20 minutes and 19 minutes respectively. The predicted performance for telemetry is not as favorable: most of Traverses I and II and point 11 of Traverse III will be below zero link margin conditions for 20% data loss performance.

IV. ANALYSIS RESULTS FOR WALKING TRAVERSES

The preliminary traverses used in this study are shown in Figure 16. Some revisions to the walking traverses, aimed primarily at shortening Traverse II in the vicinity of point i, are currently being considered but are not available at this time. If adopted for the final mission plan, however, the traverses would, for the most part, be substantially as shown in Figure 16.

While a point-by-point evaluation of each traverse stop is needed to obtain the full picture of walking traverse margin predictions, a good indication of what VHF communications capability will exist can be gained by making use of the zero (0.0) margin contours developed from the LRV traverse stop points and supplemental data points.

Figure 17 and 18 show the walking traverses overlaid with the 70% WI and 20% data loss coverage contours. As seen voice and data communication difficulties arise in the area of the rille investigation on Traverse I and in the region of the secondary crater cluster on Traverse III. Walking Traverse II follows closely the planned LRV Traverse I and consequently the coverage prediction would be essentially the same, namely: voice difficulties at point C and negative margins in the telemetry link along the rille edge.

V. CONCLUSIONS AND SUMMARY

It is concluded from this analysis that for the Astronaut-LM relay link:

a. On the Apollo 15 LRV traverses, VHF voice communication providing 70% word intelligibility will be available at roughly 80% of the point stops; loss of voice communication is expected at LRV stops 1, 4, and 11. PAM telemetry (20% data loss) will generally not be available on Traverses I and II but will be on Traverse III.

b. On the walking traverses, two regions of difficulty with VHF relay communications through the LM are predicted 1) along the rille edge and 2) during passage through the secondary crater cluster.

c. Predicted voice coverage is good enough to suggest that on their emergency return to LM the astronauts need not take with them the LCRU (from the LRV) in the event of an LRV failure during a traverse.

d. The rounded obstacle diffraction loss model is a valuable and workable analysis technique for predicting signal strength conditions. In conjunction with traverse planning data and topographic information, specific quantitative values of VHF signal level can be generated for any point in the mapped area. Such predictive data is clearly useful in assessing communications risks of alternate traverses.

e. VHF signal strength data from the Apollo 15 mission traverses could be used to verify the propagation model.

2034-IIR-vh

I. I. Rosenblum

Attachments
Figures 1 - 18

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13. Land, C. K., "EVCS/LM/MSFN Performance for Apollo 15," EE8 Memorandum No. EE8-71-102, April 27, 1971, MSC, Houston, Texas.

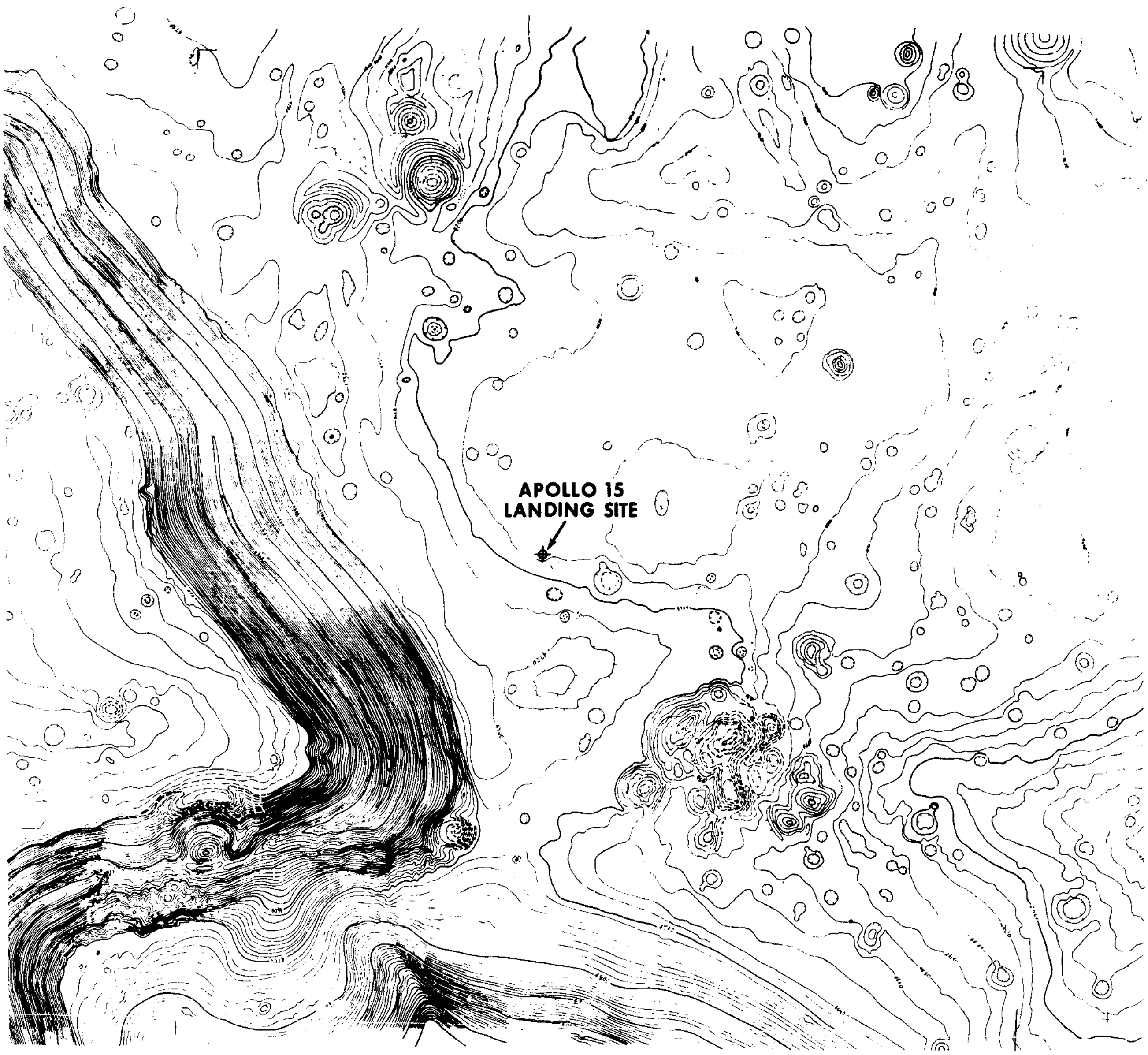


FIGURE 1 - HADLEY APENNINE NORTH SITE

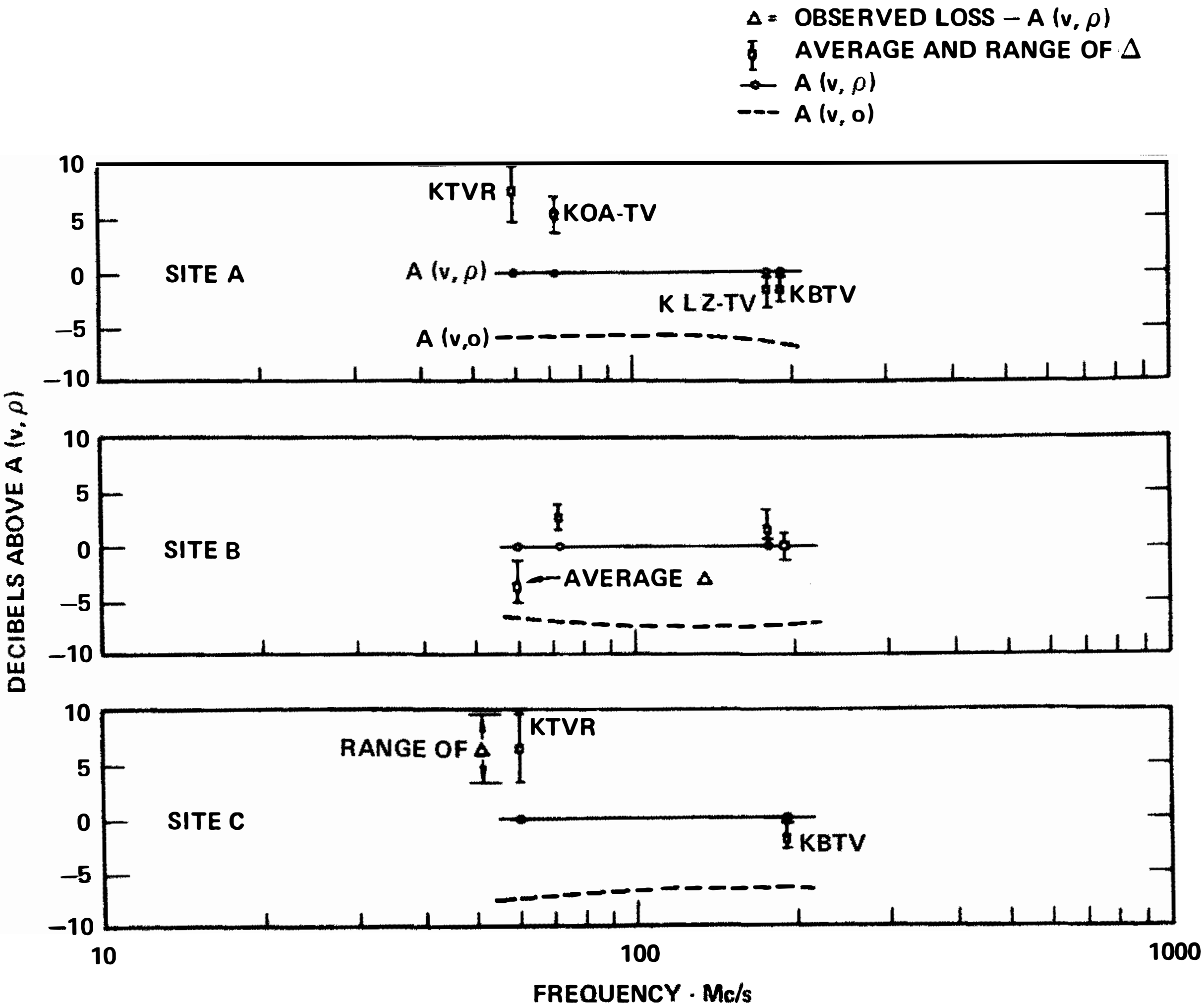


FIGURE 2 - OBSERVED DIFFRACTION LOSS AND KNIFE-EDGE LOSS, A (v, o) RELATIVE TO ROUNDED OBSTACLE LOSS, A (v, ρ). (TAKEN FROM REFERENCE 12)

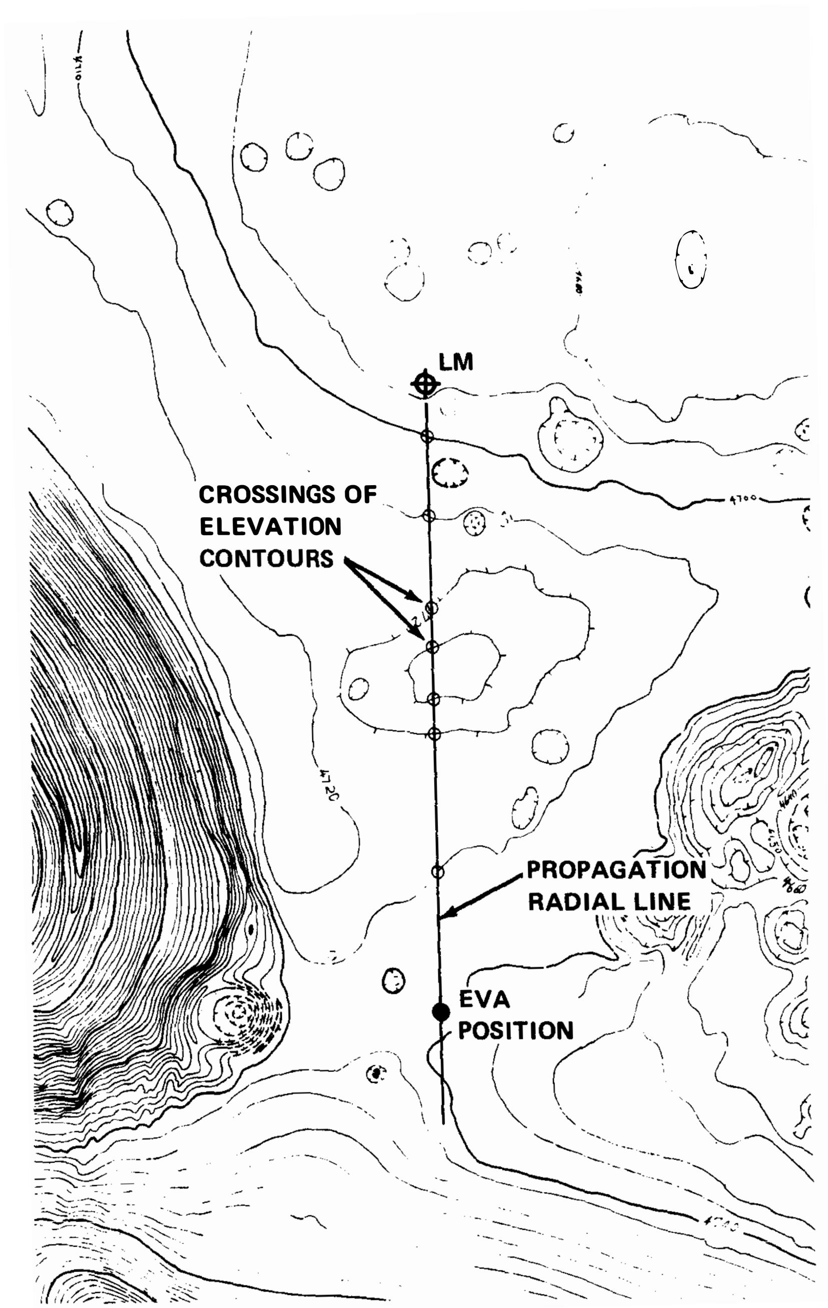


FIGURE 3 - DEFINITION OF TERRAIN OBSTACLE USING PROPAGATION RADIAL AND ELEVATION COUNTOURS

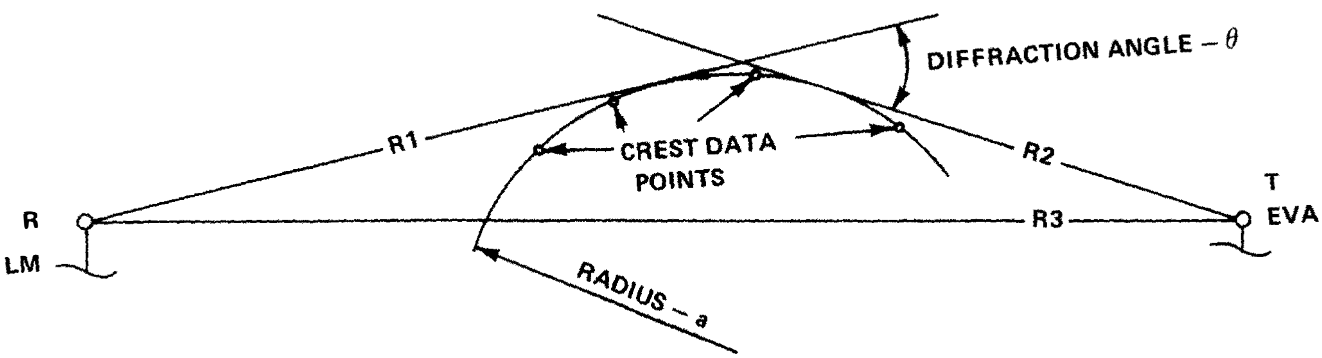


FIGURE 4 - GEOMETRY FOR CALCULATION OF DIFFRACTION LOSS FOR ROUNDED OBSTACLE

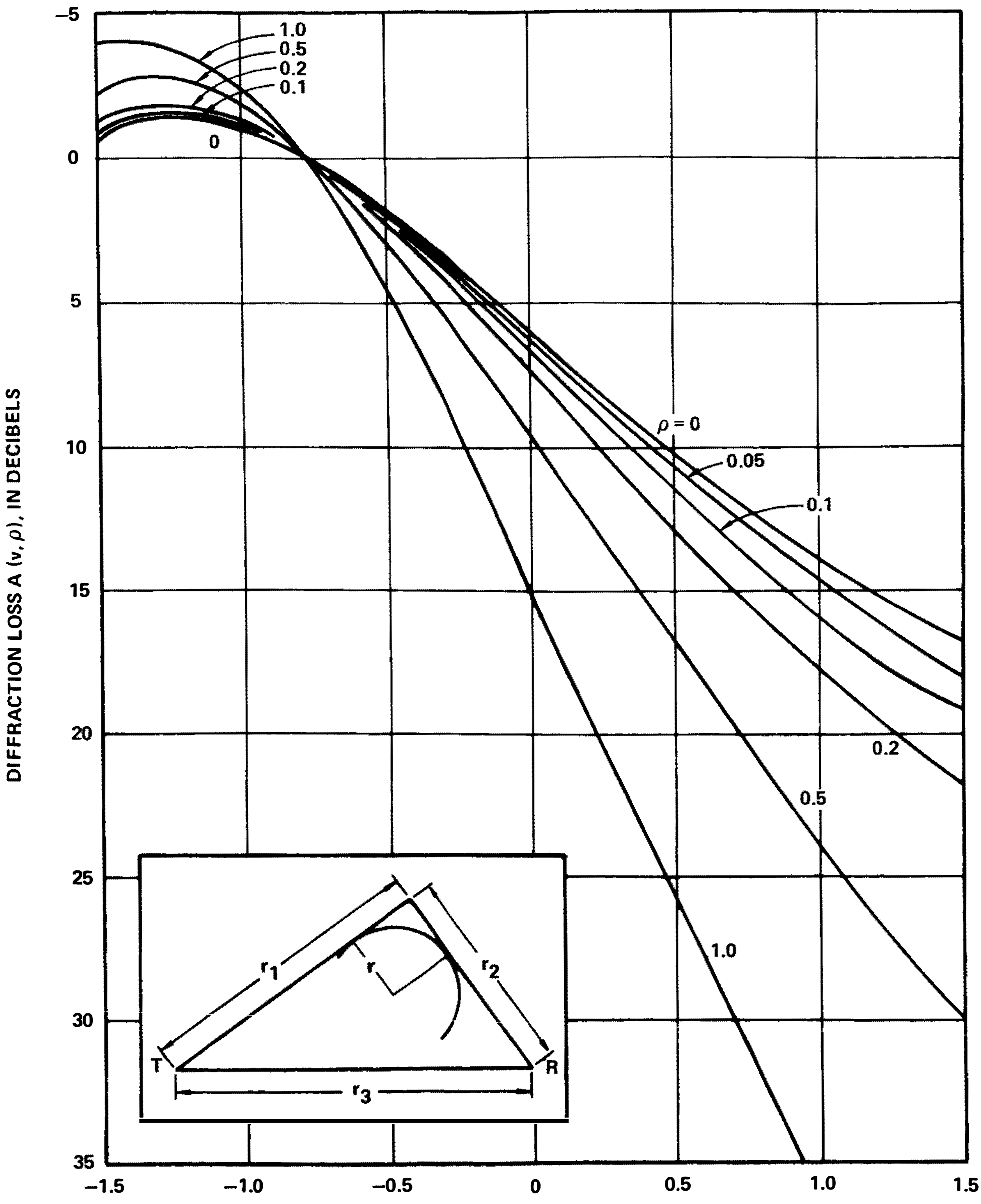


FIGURE 5 - DIFFRACTION LOSS, A (v, ρ), FOR A ROUNDED OBSTACLE

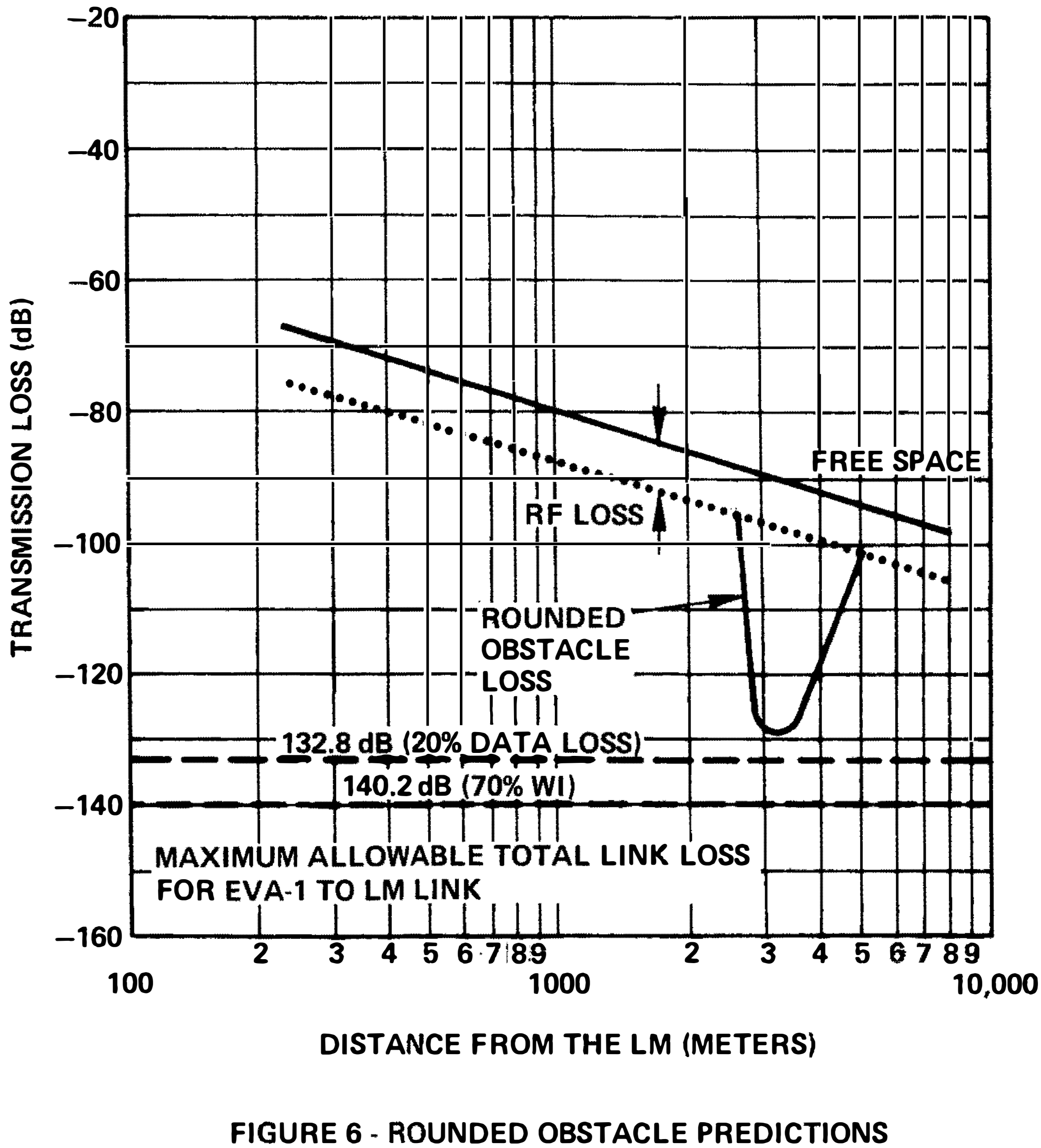


FIGURE 6 - ROUNDED OBSTACLE PREDICTIONS

SIGNAL	ALLOWABLE TOTAL LINK LOSS* (dB)
90% WI VOICE	129.9
70% WI VOICE	140.2
50% WI VOICE	142.2
5% DATA LOSS PAM TELEM.	129.4
20% DATA LOSS PAM TELEM.	132.8
80% DATA LOSS PAM TELEM.	135.5

*BASED ON MSC MEMORANDUM OF APRIL 27, 1971, EE8-71-102.

FIGURE 7 - MAXIMUM ALLOWABLE LINK LOSSES

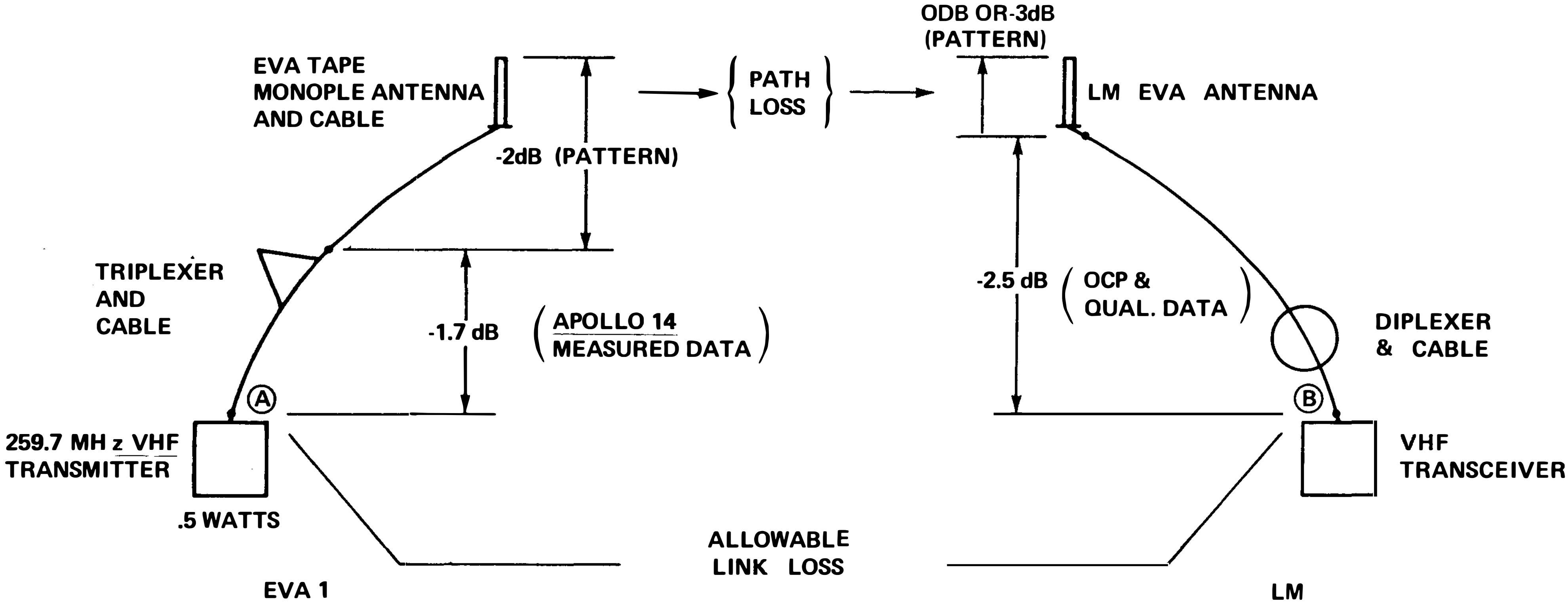
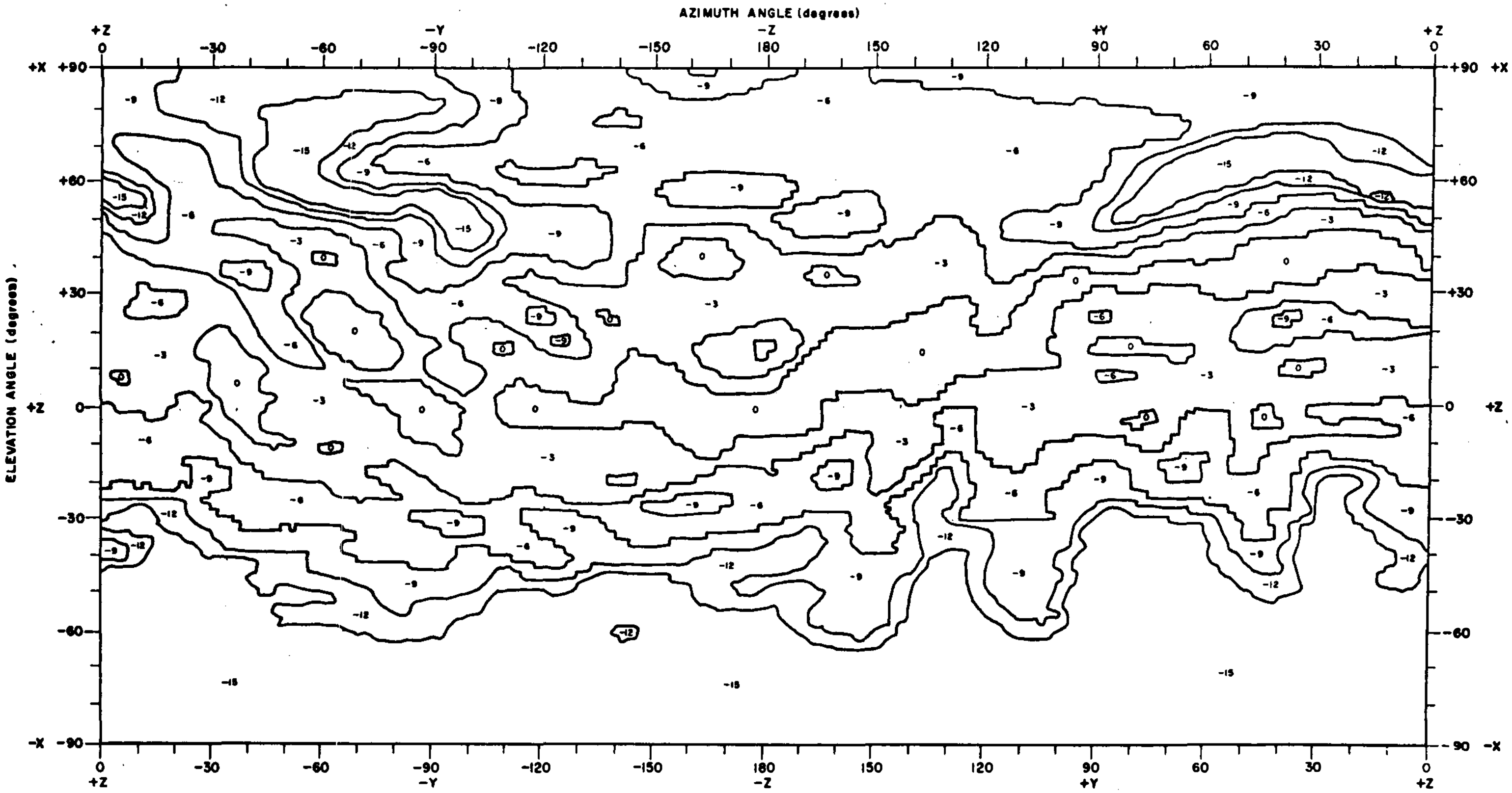
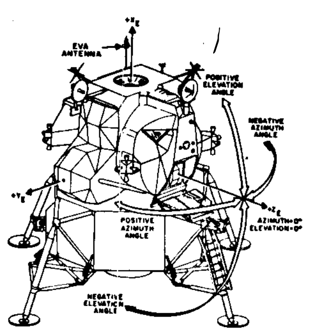


FIGURE 8 - RF LOSS FACTORS





Volume II LM Data Book
Subsystem Performance Data - Communications

THE NUMBERS SHOWN WITHIN AN AREA REPRESENT THE ANTENNA GAIN IN DB, MEASURED WITH RESPECT TO A LINEARLY POLARIZED ISOTROPIC RADIATOR. LOCATION IS DERIVED FROM PROJECTION TO THE SURFACE OF A SPHERE.

ANTENNA PATTERN
VHF EVA
CHANNEL B 259.7 MHZ
6 JULY 1966

FIGURE 9 - LM VHF (EVA) ANTENNA PATTERN (259.7 MHz)

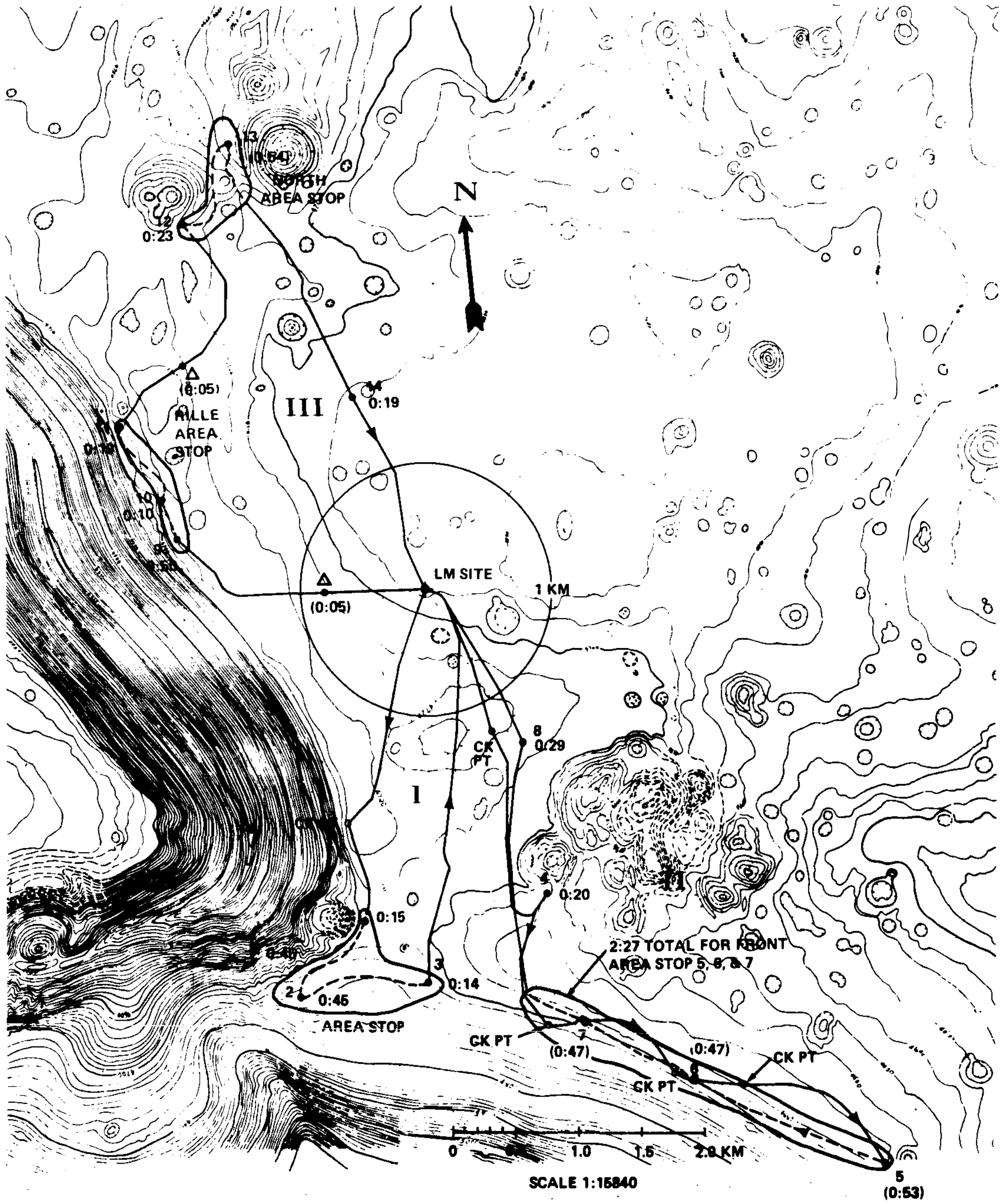


FIGURE 10 - APOLLO 15 LRV TRAVERSES

						LOSSES				MARGINS					
PT	DIST M	ELEV M	RAD KM	TO,TE ° °	ALPH °	FS dB	RF dB	RO dB	TOT. LINK dB	90 WI dB	70 WI dB	50 WI dB	05 DL dB	20 DL dB	80 DL dB
(I)															
1a	1965	4720	51.9	1.2, .2	1.0	86.6	9.2	37.3	133.1	- 3.2	7.1	9.1	- 3.7	- .3	2.4
1	2675	4703	26.1	1.4, -1.6	3.0	89.3	9.2	53.3	151.8	-21.9	-11.6	- 9.6	-22.4	-19.0	-16.3
2	3400	4730	36.7	1.4, .3	1.1	91.4	9.2	32.4	132.9	- 3.0	7.3	9.3	- 3.5	- .1	2.6
3	3100	4713	2.3	1.7, - .5	2.2	90.6	6.2	30.4	127.1	2.8	13.1	15.1	2.3	5.7	8.4
(II)															
4	2600	4680	15.9	1.6, -1.8	3.4	89.0	9.2	51.7	149.9	-20.0	- 9.7	- 7.7	-20.5	-17.1	-14.4
5	5800	4675	16.5	1.0, - .5	1.5	96.0	6.2	31.1	133.3	- 3.9	6.4	8.4	- 4.4	- 1.0	1.7
6	4400	4700	11.8	1.5, - .3	1.9	93.6	9.2	33.3	136.1	- 6.3	4.0	6.0	- 6.8	- 3.4	- .7
7	3610	4695	15.0	1.6, - .6	2.2	91.9	9.2	38.5	139.6	- 9.7	.6	2.6	-10.2	- 6.8	- 4.1
7a	3590	4710	4.0	1.9, - .4	2.3	91.8	9.2	32.4	133.4	- 3.5	6.8	8.8	- 4.0	- .6	2.1
8	1425	4715	10.6	1.4, -1.1	2.5	83.8	6.2	40.1	130.1	- .2	10.1	12.1	- .7	2.7	5.4
(III)															
Δ	800	4710	13.5	1.1, 1.1	.0	78.8	9.2	23.3	111.3	18.6	28.9	30.9	18.1	21.5	24.2
9	2000	4720	16.0	1.1, - .6	1.7	86.8	9.2	34.9	130.9	- 1.0	9.3	11.3	- 1.5	1.9	4.6
10	2210	4720	26.3	.9, - .2	1.1	87.7	9.2	32.3	129.2	.7	11.0	13.0	.2	3.6	6.3
11	2750	4715	5.5	.9, -3.3	4.2	89.5	9.2	46.8	145.5	-15.6	- 5.3	- 3.3	-16.1	-12.7	-10.0
Δ	2600	4730	21.5	.7, .7	.0	89.0	9.2	20.9	119.1	10.8	21.1	23.1	10.3	13.7	16.4
12	3450	4730	.3	.6, .6	.0	91.5	9.2	13.5	114.2	15.7	26.0	28.0	15.2	18.6	21.3
13	3830	4745	14.9	.3, .3	.0	92.4	9.2	15.9	117.5	12.4	22.7	24.7	11.9	15.3	18.0
14	1600	4689	14.9	.1, .1	.0	84.8	9.2	17.5	111.5	18.4	28.7	30.7	17.9	21.3	24.0

FIGURE 11 - VHF MARGINS AT APOLLO 15 LRV TRAVERSE STOPS

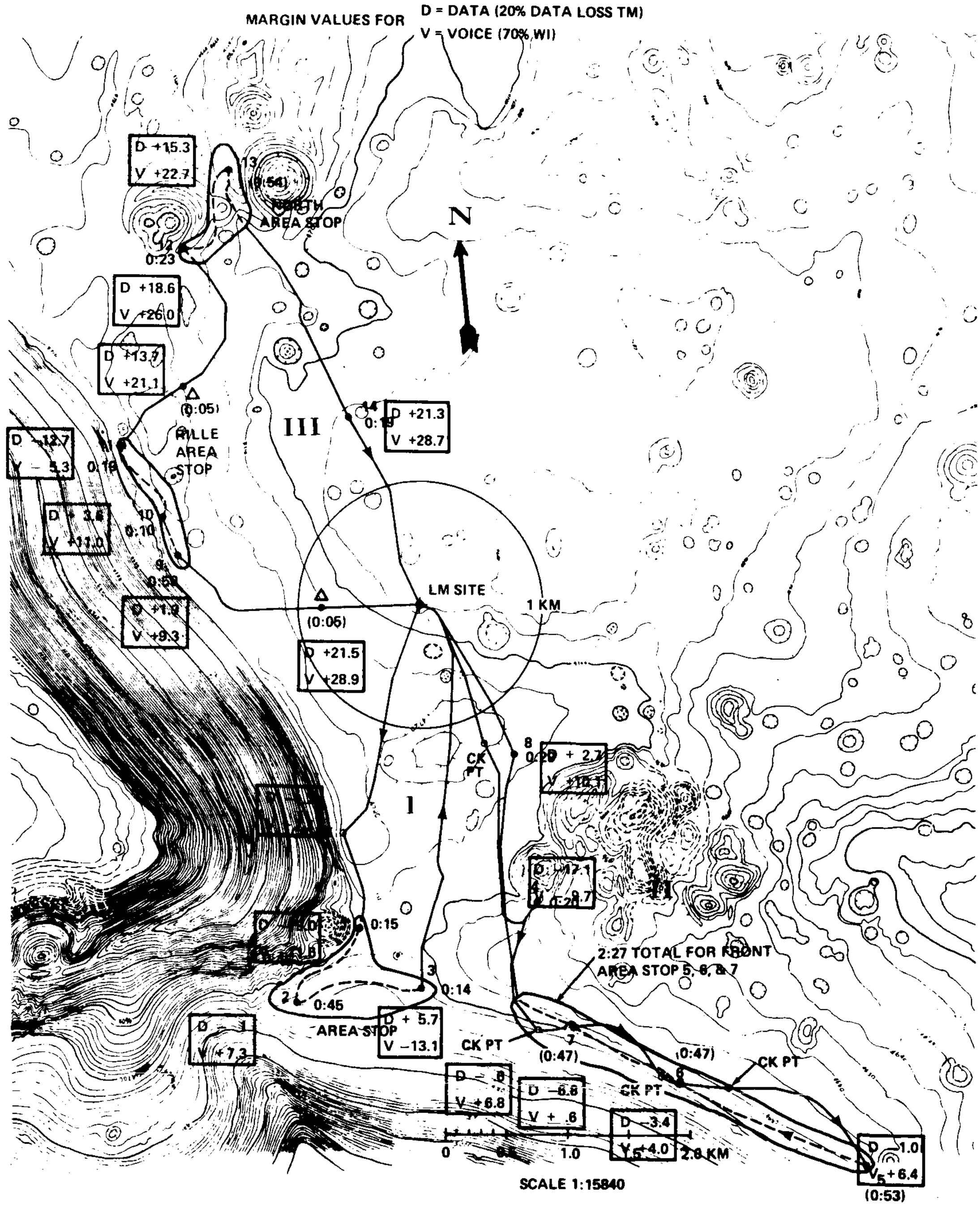


FIGURE 12 - LINK MARGIN VALUES FOR 70% WI VOICE & 20 % DATA LOSS TM
EVA-TO-LM VHF COMMUNICATIONS
APOLLO 15 LRV TRAVERSES

MARGIN VALUES FOR V = VOICE (90% WI)

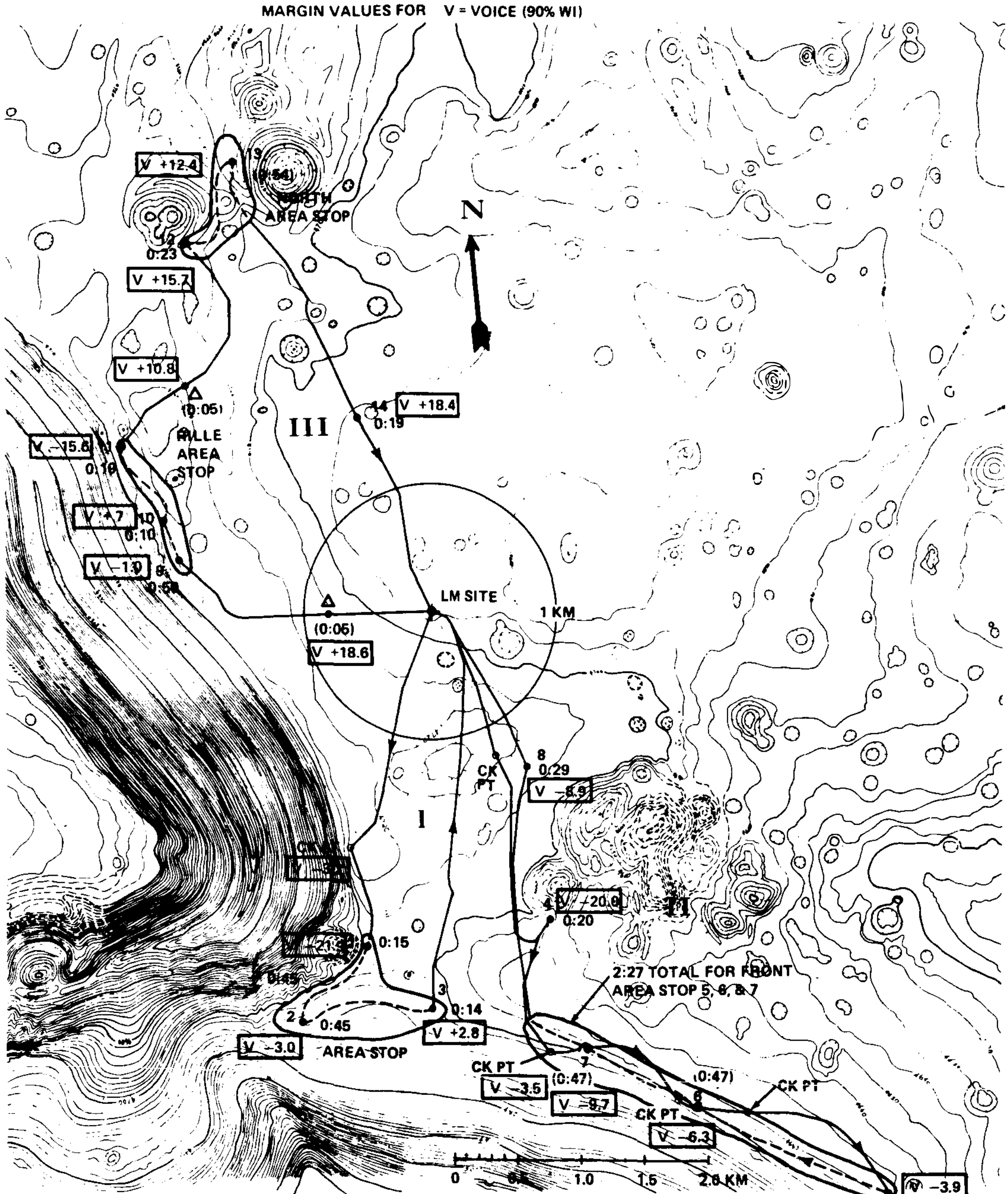


FIGURE 13 - 90% WI VOICE LINK MARGINS – EVA TO LM – VHF COMMUNICATIONS
APOLLO 15 LRV TRAVERSES

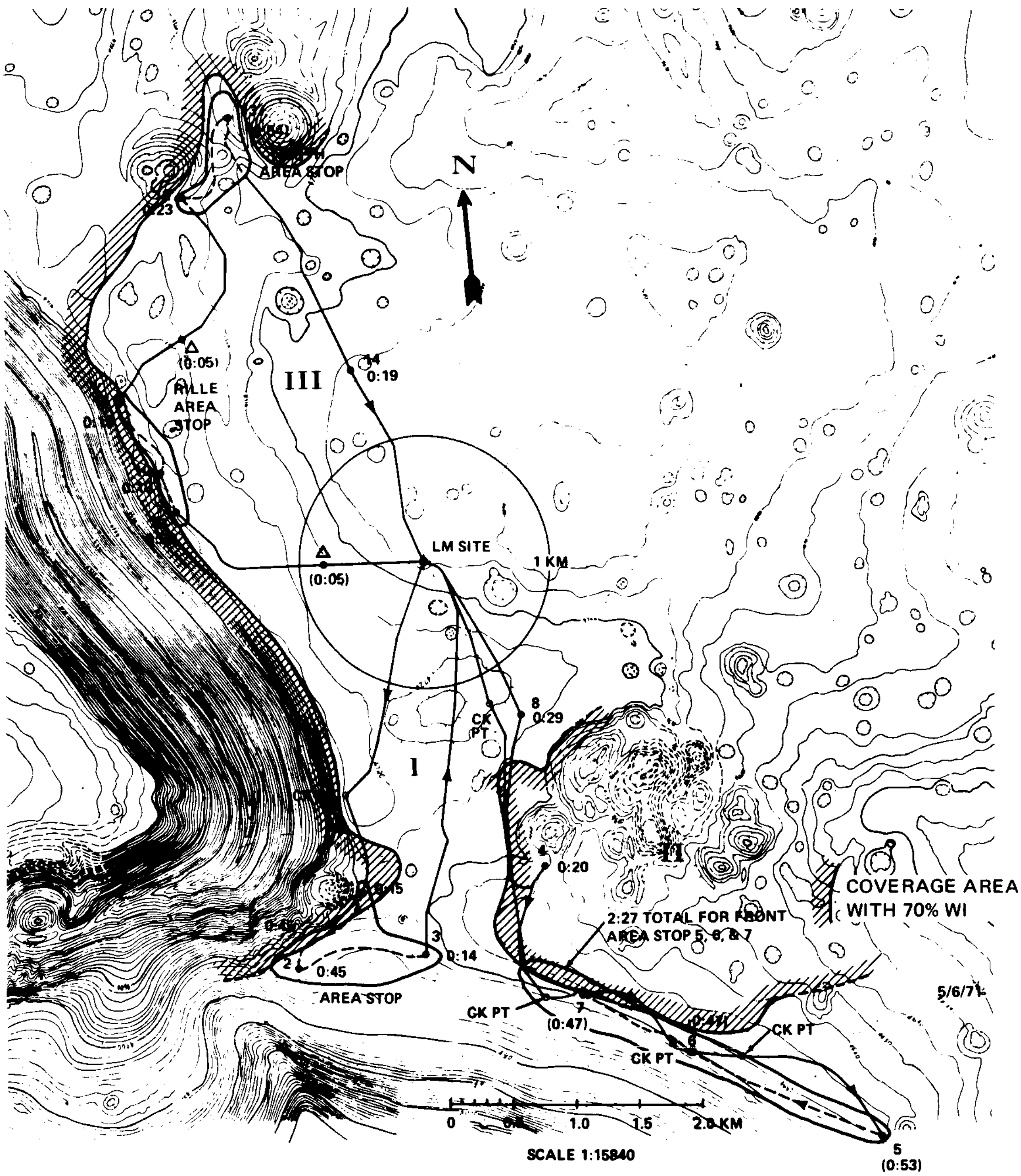


FIGURE 14 - CONTOUR FOR 70% WI COVERAGE AND APOLLO 15 LRV TRAVERSES EVA-TO-LM VHF COMMUNICATIONS

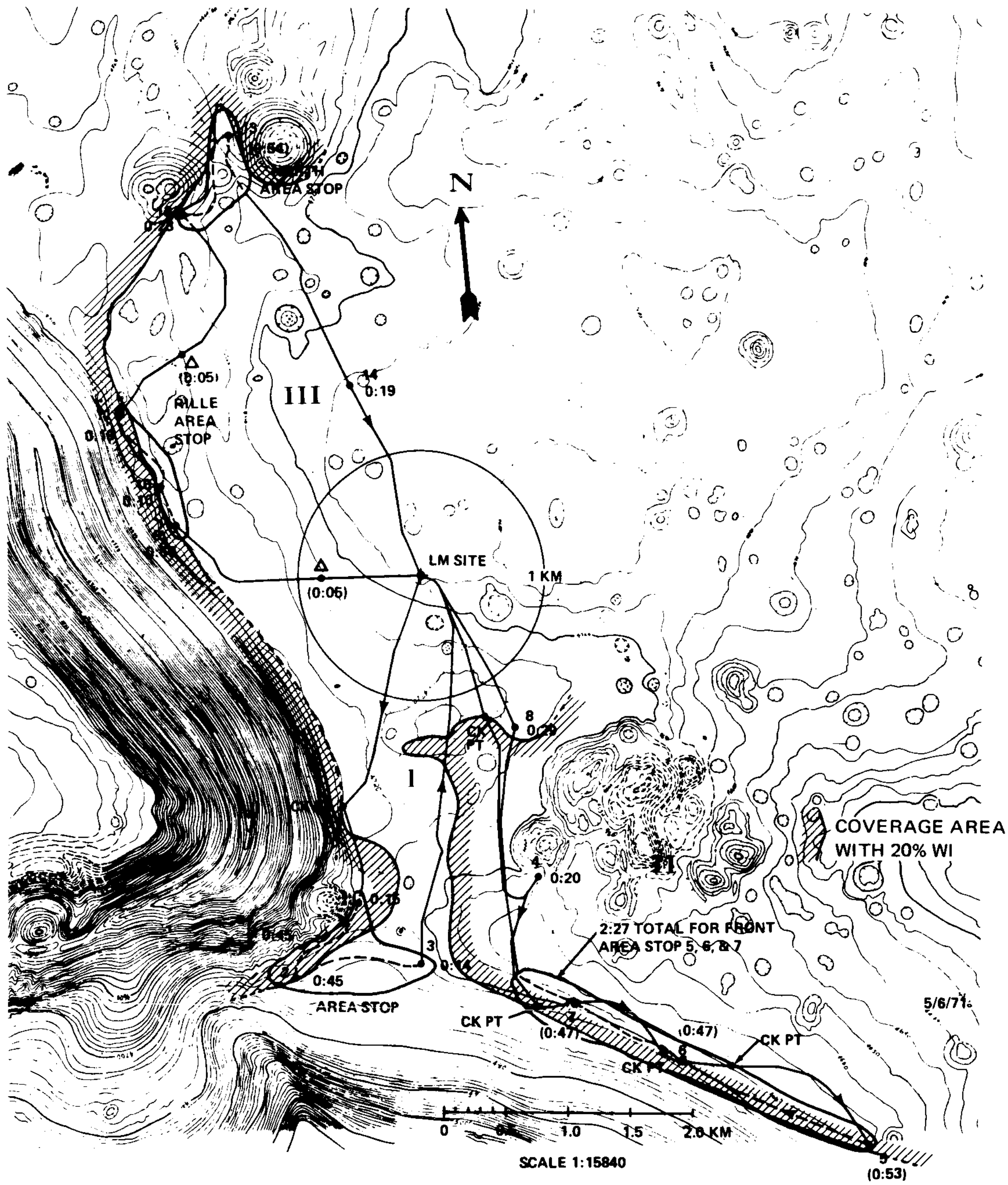


FIGURE 15 - CONTOUR FOR 20% DATA LOSS PAM TELEMETRY COVERAGE AND APOLLO 15 LRV TRAVERSES – EVA-TO-LM VHF COMMUNICATIONS

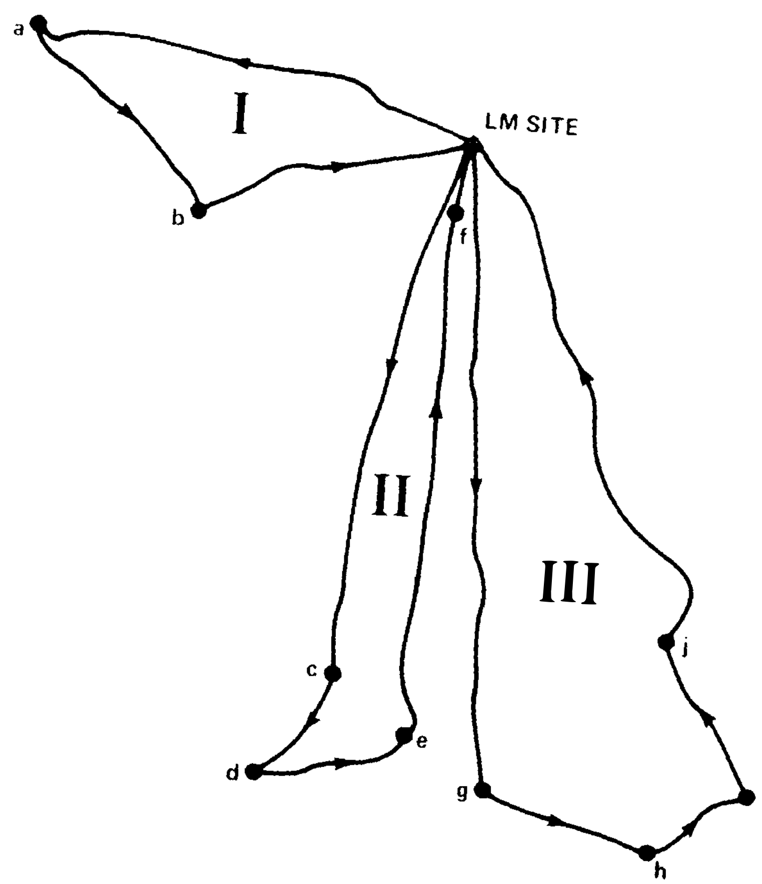


FIGURE 16 - APOLLO 15 WALKING TRAVERSES

FIGURE 17 - CONTOUR FOR 70% WI COVERAGE AND APOLLO 15 WALKING TRAVERSES EVA-TO-LM VHF COMMUNICATIONS

FIGURE 18 - CONTOUR FOR 20% DATA LOSS PAM TELEMETRY COVERAGE AND APOLLO 15 WALKING TRAVERSES – EVA-TO-LM VHF COMMUNICATIONS