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COMPARISON OF MULTIPLE BEAM COVERAGE TO EARTH COVERAGE FOR A MARITIME SATELLITE SYSTEM

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16. Abstract

Preliminary tradeoff comparisons are analyzed for a possible baseline L-Band maritime communications satellite system. Primary emphasis is given to major shipping routes with secondary coverage elsewhere. A low cost satellite configuration is postulated based on a Thor-Delta class satellite. Computer analyses are conducted to assess tradeoffs between satellite antenna complexity, in terms of multiple beam vs. earth coverage, and user access delay time and shipboard antenna complexity in terms of gain. Tentative conclusions show that under the constraints imposed by weight (but disregarding reliability) multiple beam satellite coverage vs. earth coverage may result in from 3 to 5 dB reduction in shipboard antenna gain. This reduction is based strictly on a link power margin point of view. In making the comparisons user access delay was an arbitrating factor. Many other system tradeoffs must also be considered. The methodology and computer programs prepared for the preliminary analyses reported herein are the main contributions at this time. The results of these analyses should be useful in establishing maritime satellite system guidelines.

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PREFACE

This study was performed in the Satellite Systems Branch at the Transportation Systems Center (TSC) for the Office of Telecommunications and the U.S. Coast Guard, Department of Transportation. The objective of this work was to consider the use of a multiple feed, multiple beam satellite antenna to reduce the complexity of the shipboard antenna in a maritime communications satellite system.

The author wishes to recognize the significant contribution made to this report by Alex Robb of the Service Technology Corporation. Mr. Robb extended a computer program which he had developed previously with Leo Keane, then of DOT/TSC, for a similar study for the aeronautical satellite system. He modified it to incorporate shipboard antenna patterns and a more extensive multipath model which the author specified. He also developed subroutines to permit the counting of ships within specified beam contours, efficient allocation of available channels to beams and calculation of access times.

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1. INTRODUCTION

A baseline design of a MARSAT system has been proposed[1] using an earth coverage satellite antenna and a 10 dB shipboard antenna. This system was shown to yield the equivalent of ten 45 dB-Hz voice channels using a Thor-Delta launch vehicle. As determined by the extensive analysis in Reference 2, the 10 dB antenna found necessary for the earth coverage system would require a fairly expensive pointing mechanism due to its required gain and the greater than hemispherical coverage necessitated by rolling and pitching motions of the ship in high seas.

If a multiple beam satellite antenna system were to be used to cover the same area as the earth coverage beam assumed in the baseline design, the gain and complexity of the user antenna could be reduced, or alternatively, more channels could be provided with the same satellite dc power. The primary motivating objective force of this study was the possible reduction in complexity of the user antenna.

For this study the computer program developed in the Multibeam Aeronautical Satellite System Design Study[3] has been adapted for the maritime case and utilized to synthesize multiple beam coverage of the Atlantic and Pacific oceanic regions by a single geostationary maritime voice communication satellite. Multiple beam systems are developed for shipboard antenna gains of 4, 7, 10 and 13 dB and are compared to similar systems with earth coverage satellite antennas. This report describes the models used in the program for satellite and shipboard antennas, multipath, and queueing, and the results of the system study. A detailed description of the computer program is available in Reference 4.

For this study the following constraints and parameter values were chosen:

System R.F. frequency:	1550 MHz
Satellite configuration:	Single Thor-Delta launched spinner per ocean; 100 watts of r.f. power available at antenna
Shipboard antennas:	Tracking in azimuth and elevation with boresight gains of 4, 7, 10 & 13 dB
System coverage:	Atlantic & Pacific Oceans-primary goal to cover major shipping routes, secondary goal to maximize oceanic area coverage; 15° minimum elevation angle.
Service:	Voice only, demand assignment
Signal quality:	45 dB-Hz
Ship distributions:	Taken from Reference 5 - distributions include all merchant ships (excluding fishing vessels) over 100 gt. The distributions are shown in Figures 7 and 8
Message characteristics:	average message arrival rates: 0.81 x 10^{-5} calls/ship/sec; average length of call: 7 minutes
Channel assignments:	channels permanently assigned to beams - cannot be switched as traffic load varies between beams

2. DEVELOPMENT OF MODELS FOR COMPUTER PROGRAM

2.1 SATELLITE ANTENNA MODEL

The satellite antenna was modeled as in Reference 3 by a modified Bessel function to the -3 dB point, and beyond by a linear approximation tangent at the -3 dB point. The modified Bessel function was

$$\mathrm{GAIN}_{\mathrm{SAT}}\ (\mathrm{dB}) = 20 \log \cos \left(\frac{2\pi (R/\lambda) \sin\beta}{2.55} \right)$$

where R = antenna radius

λ = wavelength

β = angle off boresight

This equation gives a boresight gain of 0 dB. The actual peak gain of the antenna was included separately in the link budget. The satellite antenna was assumed RHC with 0 dB ellipticity.

2.2 SHIPBOARD ANTENNA MODEL

Representative antenna patterns for 13, 10, 7, and 4 dB shipboard antennas were required for the study. Following the recommendations of Reference 2, a short backfire element was assumed for the 13 dB case and antenna patterns shown in Figure 1 were obtained from Reference 6. For the purposes of the study, a tracking system was assumed with tracking error included in the gain figure. The effect of dynamic tracking error on the multipath rejection of the antenna was considered beyond the scope of the study, but could be significant with certain combinations of beam width and tracking system performance. The antenna patterns for the 10, 7, and 4 dB cases were derived from the 13 dB case by widening the beam proportionately.

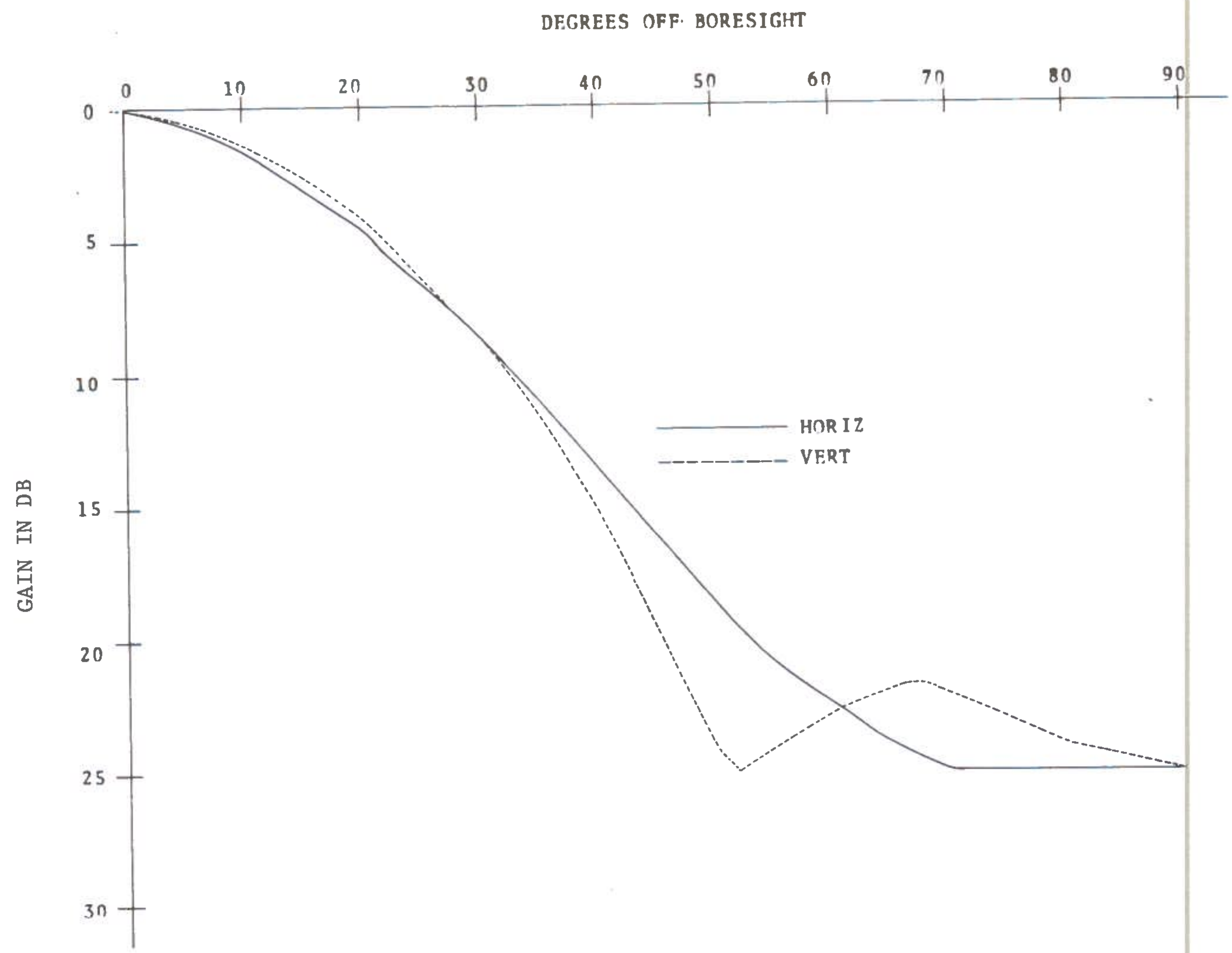

Figure 1. Antenna Pattern for 13 dB Antenna

2.3 MULTIPATH MODEL

For the purposes of the study, a 100% diffuse multipath model was assumed although the program is equipped with a multipath model in which the multipath to be simulated can be expressed in percent specular plus percent diffuse.

It was assumed that all reflections contained 180° phase shifts of the horizontal component and 0° phase shift of the vertical component. The receiving antenna was assumed circularly polarized of the same sense as the satellite antenna. The satellite antenna was assumed to transmit equal signals of vertical and horizontal polarization (0 dB ellipticity). The ship antenna receives the direct horizontal and vertical signals at peak voltage gain (pointing error assumed zero) and adds the signals. The reflected horizontal and vertical signals are multiplied by their corresponding voltage reflection coefficients (Figure 2) and are multiplied by the antenna voltage gain corresponding to the elevation angle of reception of the reflected signal. Since phase reversal of the horizontal reflected signal is assumed, and the receiving antenna is circularly polarized, the difference of the horizontal and vertical reflected components is taken. The ratio K is computed:

$$K = 20 \log \frac{X}{Y}$$

where X is the difference in horizontal and vertical voltage components of the reflected signal; Y is the sum of horizontal and vertical voltage components of the direct signal.

The ratio K is then used to determine fade margins based on the work of Norton et al[7]. For the study, fade margins were selected which would be exceeded less than 2% of the time (i.e. 98% exceedance channel). These fade margins are shown in Figures 3-6.

2.4 SHIP DISTRIBUTION MODELS & COUNTING PROCEDURES

Although complete area coverage of the Atlantic and Pacific is required or at least desirable, there are definite concentrations

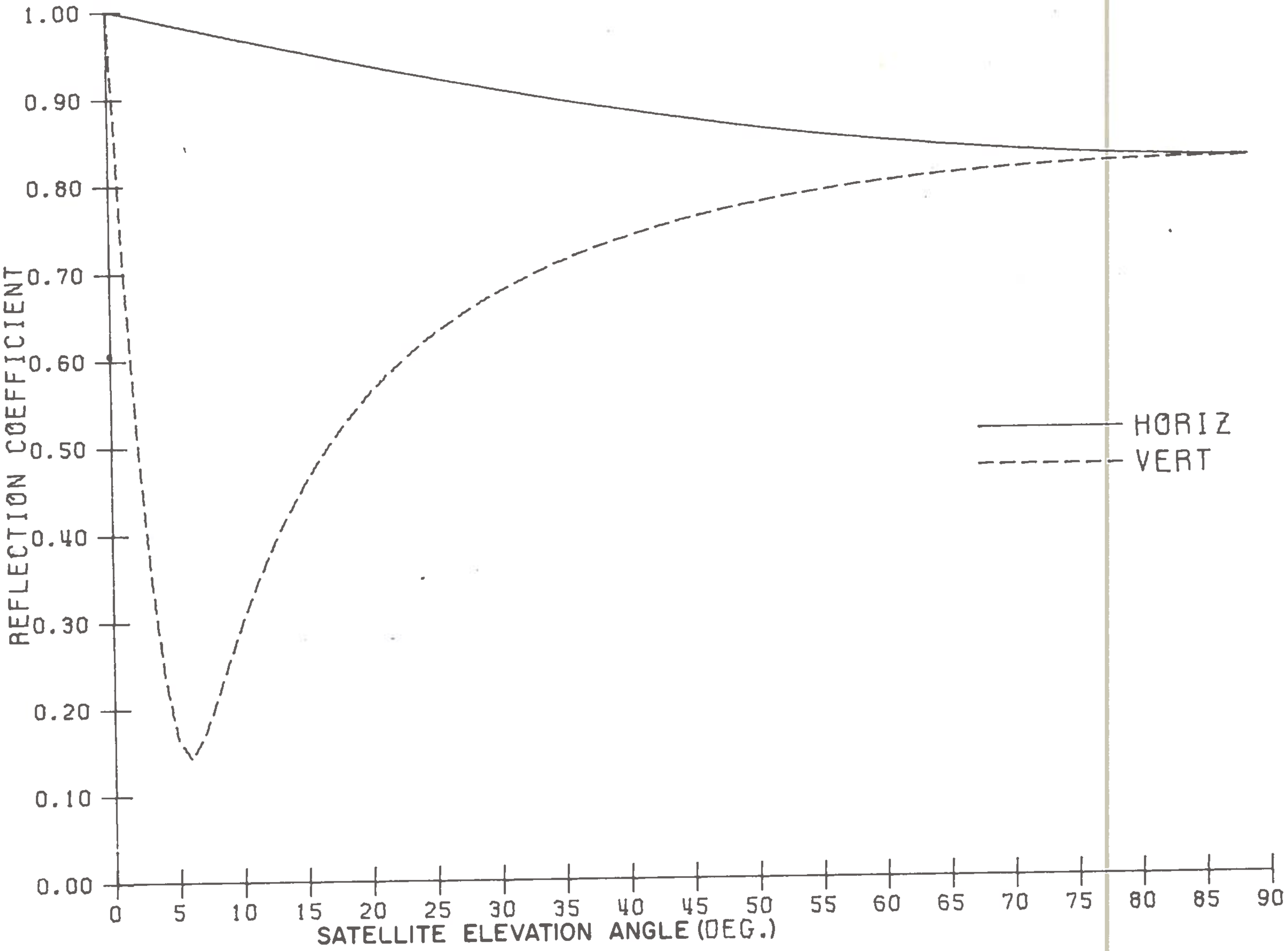

Figure 2. Magnitude of Smooth-Earth Reflection Coefficient for Sea Water as a Function of Elevation Angle

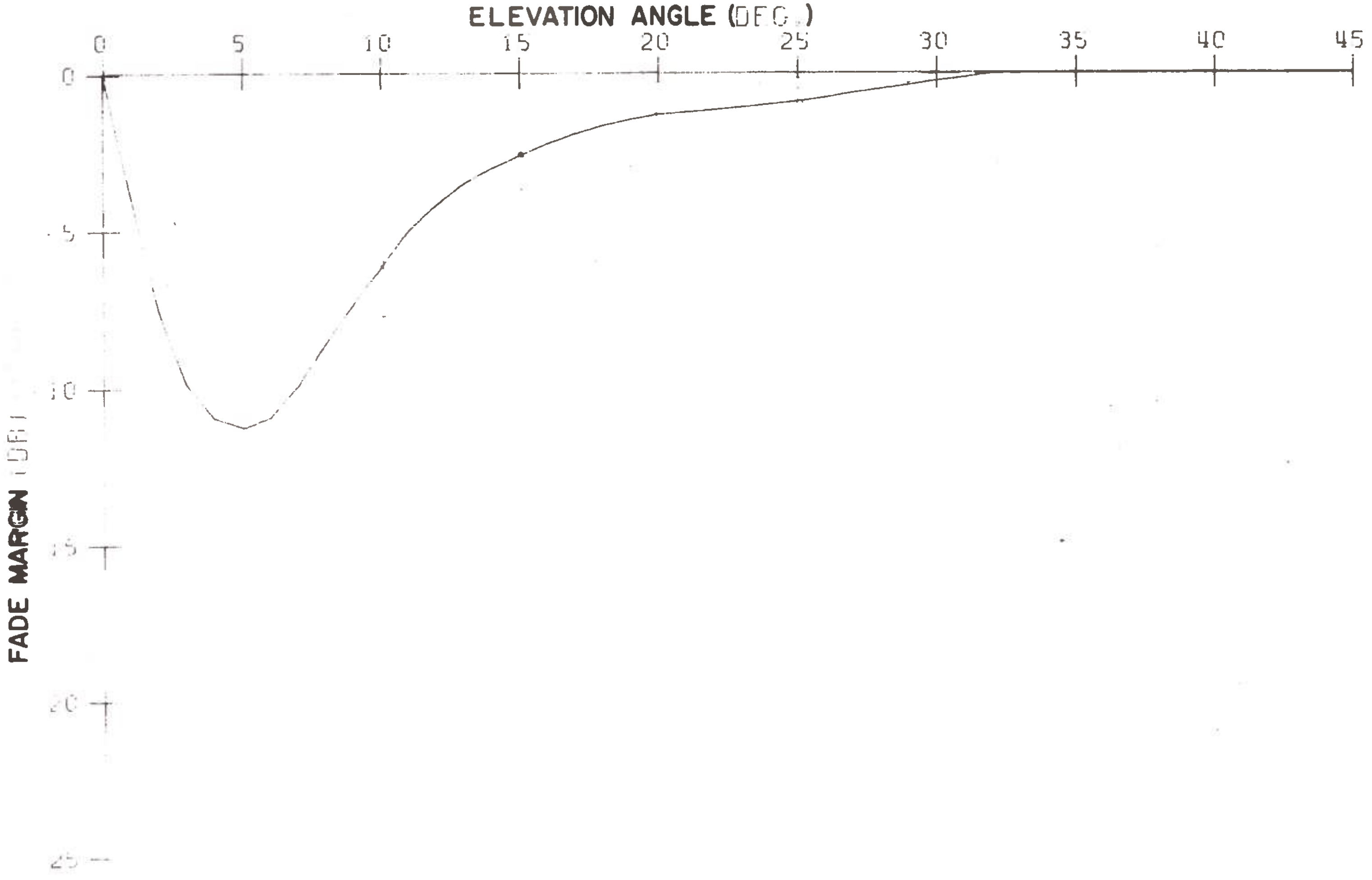

Figure 3. Fade Margin vs. Elevation Angle for 13 dB Antenna

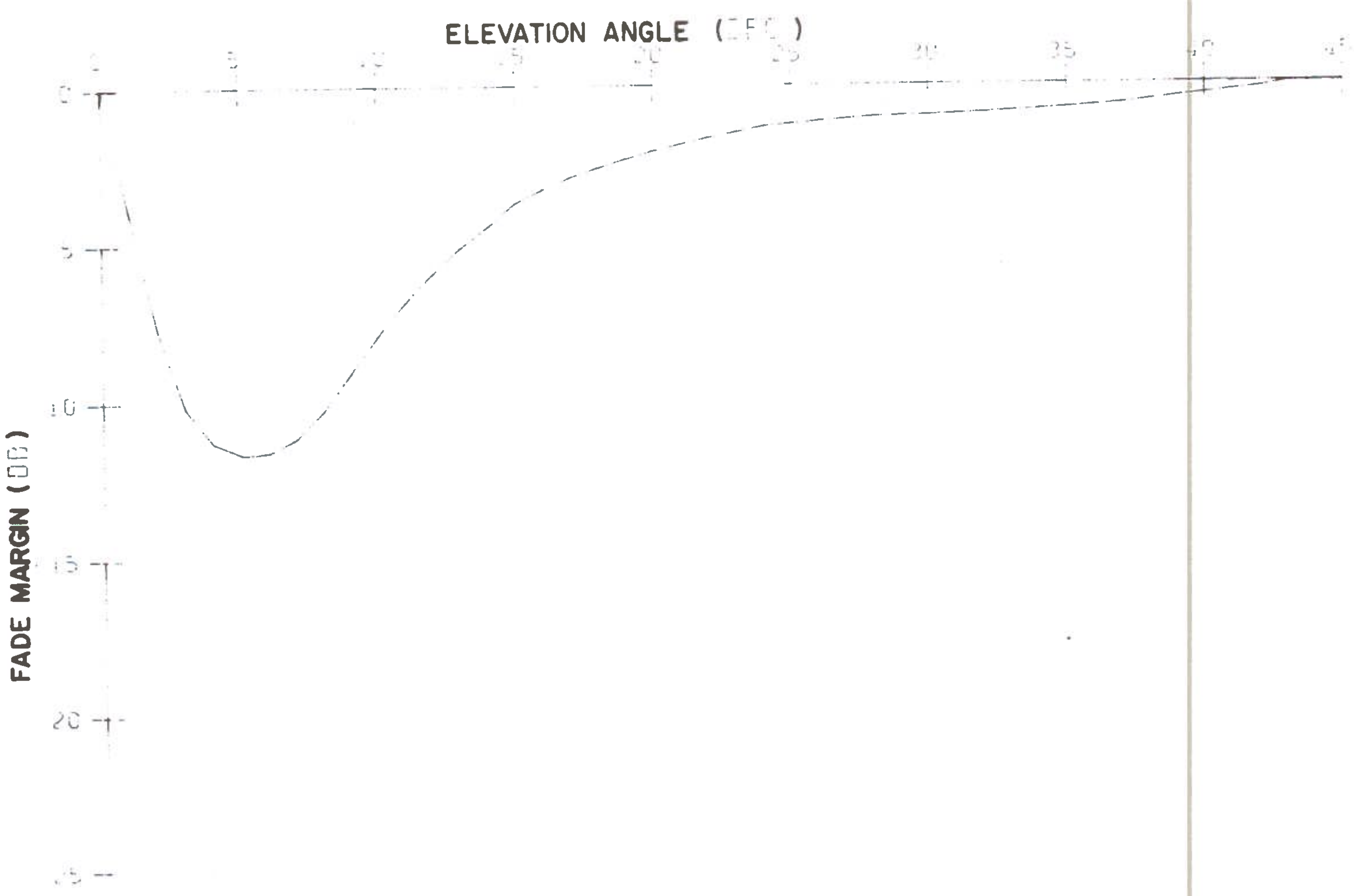

Figure 4. Fade Margin vs. Elevation Angle for 10 dB Antenna

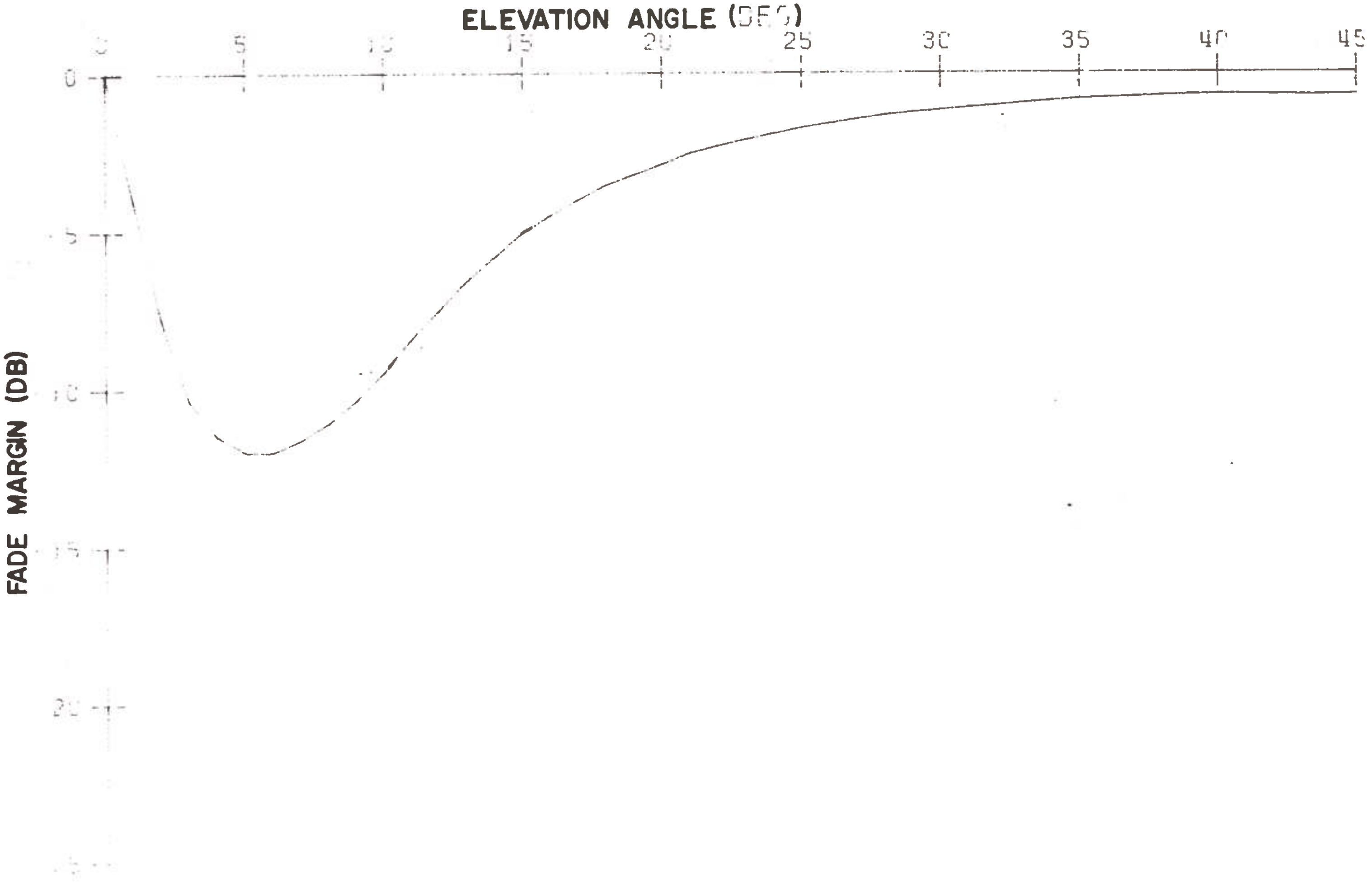

Figure 5. Fade Margin vs. Elevation Angle for 7 dB Antenna

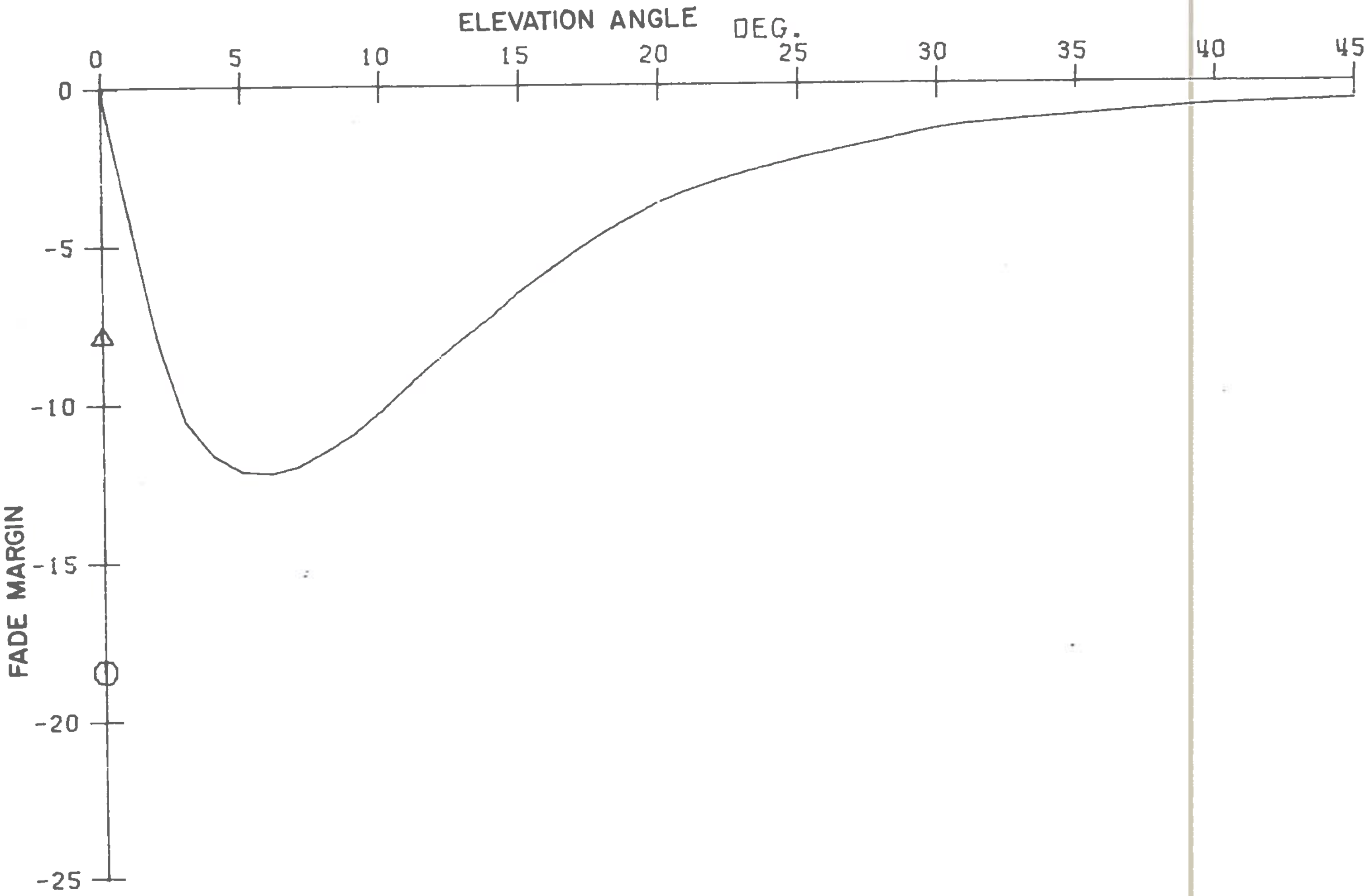

Figure 6. Fade Margin vs. Elevation Angle for 4 dB Antenna

of traffic in certain regions of both oceans which influence the design of multiple beam area coverage systems. For instance, if complete coverage of the Pacific were to be effected by five beams of equal area coverage, the areas of coverage would contain significantly different numbers of ships. If an equal number of channels were assigned to each beam, the service in one coverage area would be characterized by a much greater access time due to a disproportionate number of ships being in that area. Thus it is important to know how many ships are included in each beam's coverage area. A subprogram was included to count the number of ships in each beam. The ship distribution data used for the study was obtained from Figure 18a of Vol. I of Reference 5, and is shown in Figures 7 and 8 for the Atlantic and Pacific, respectively. This distribution was constructed from arrival and departure listings from Lloyd's List and shows the worldwide average distribution of merchant ships (excluding fishing vessels) over 100 gt. A more detailed description of the derivation of the distribution is contained in pp. 57-60 of Vol. I of Reference 5. The resulting input data for the program consisted of a listing of the average number of ships in each 5° latitude by 5° longitude section of the Atlantic and Pacific.

2.5 CHANNEL ALLOCATION AND QUEUEING MODELS

Once the beams have been chosen and the number of ships per beam determined, it is of interest to determine, for a given total number of channels fixed by spacecraft power and antenna gain, how the channels should be allocated among the beams to assure relatively uniform values of access time in the beams. If the satellite has the capability to switch any or all channels to any beam, then this subprogram is unnecessary, but due to the complexity and possible degradation of system reliability accompanying such a switching system, less extensive switching systems or permanent assignment of channels to beams may be desirable. To analyze these cases, and to compare them to the full switching model in terms of average system access time and uniformity of access time among beams, a queueing subprogram was added. This model, for multiple exponential channels[8] computes access time versus number

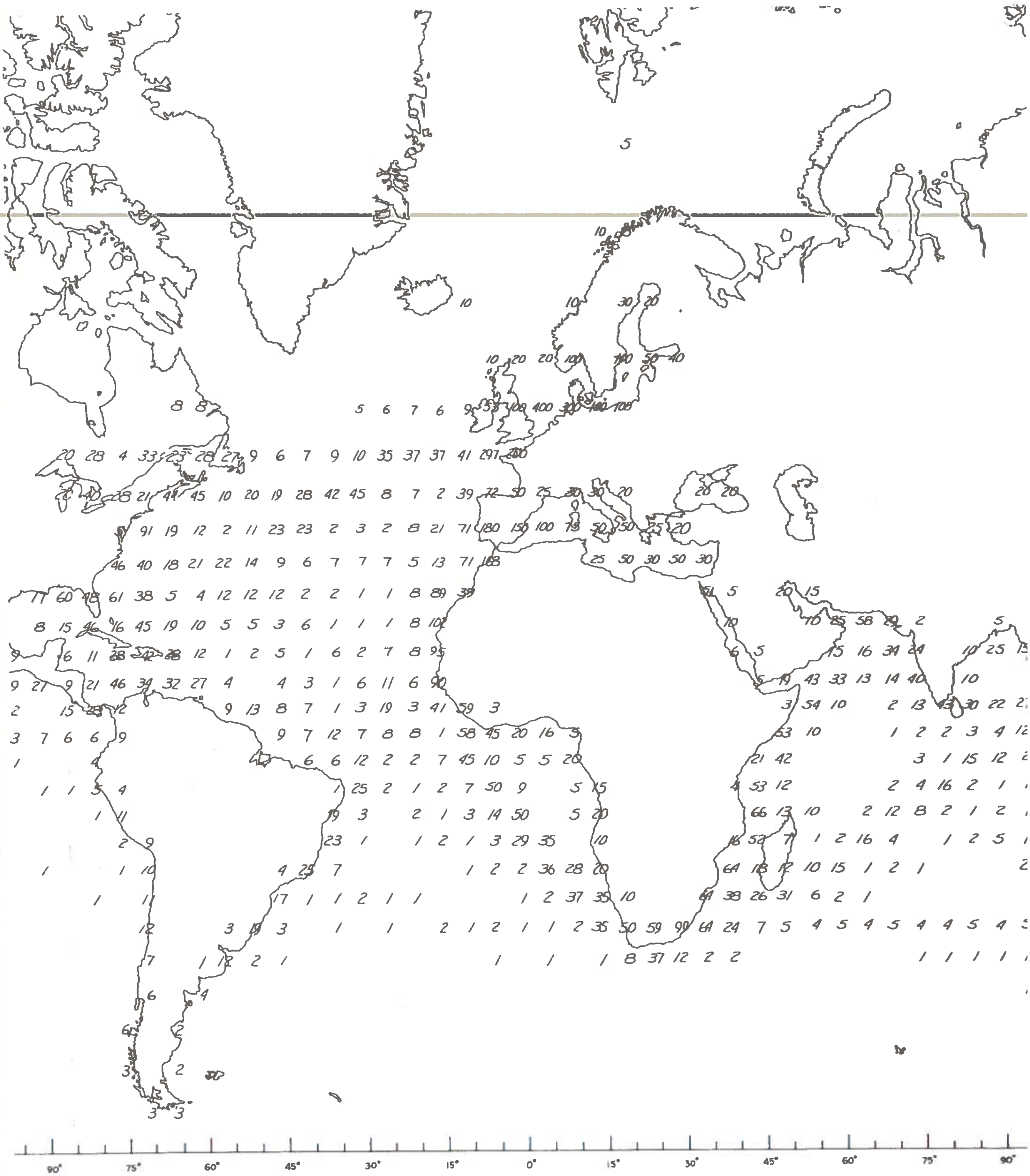

Figure 7. Ship Distribution - Atlantic (From Ref. 5)

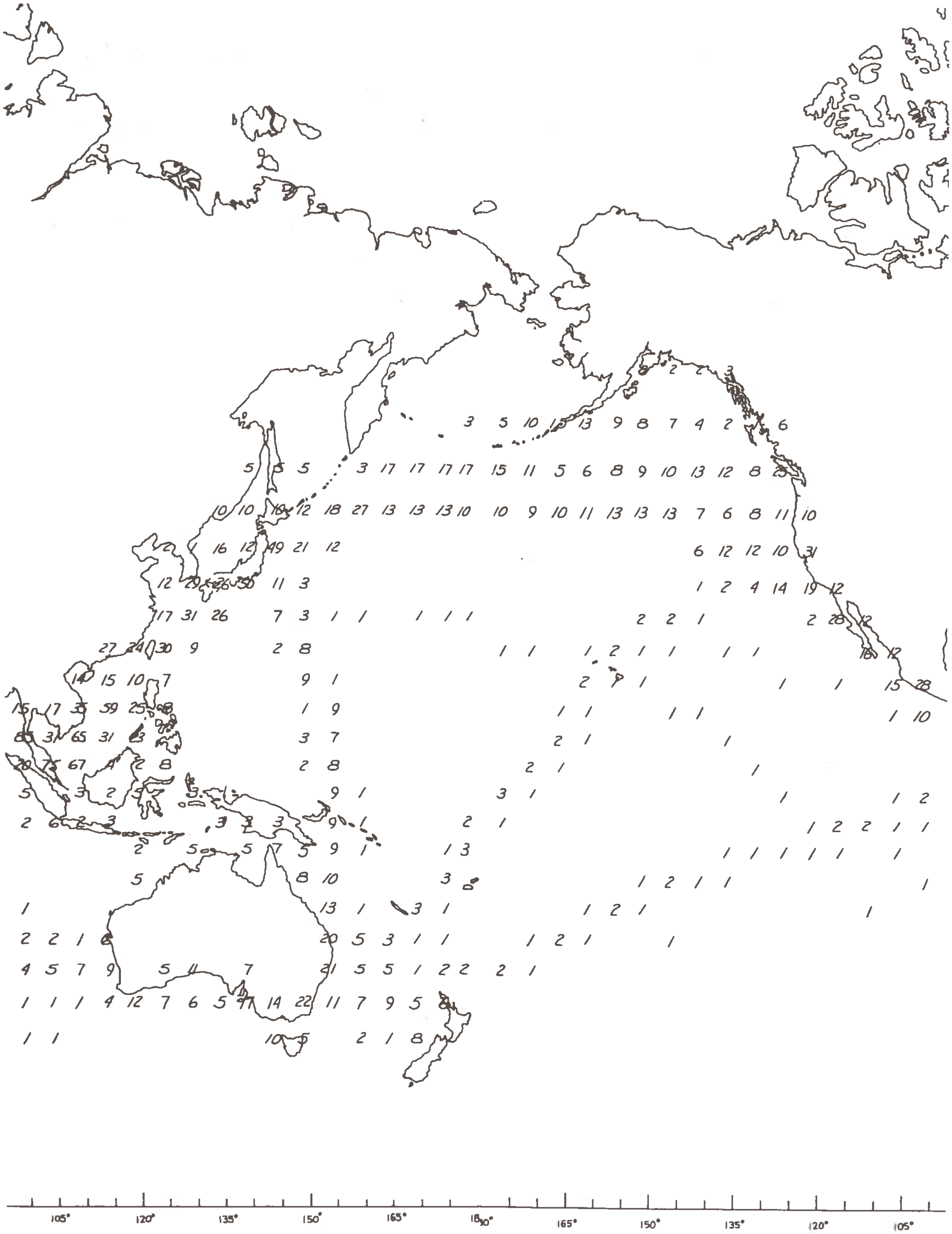

Figure 8. Ship Distribution - Pacific (From Ref. 5)

of channels assigned to a beam based on input parameters defining the average arrival rate of calls and the average message length. The subprogram will take the total number of channels, allocate them among the beams proportional to the individual ship counts and calculate access times for all beams. The spread of the access times is compared to a chosen maximum; if greater, the subprogram reallocates channels to attain an increase in uniformity.

For this study average message arrival rate was taken as 0.81 x 10^{-5} calls/ship/sec; average length of call was 7 minutes.

3. DESIGN OF A MULTIPLE BEAM SYSTEM FOR THE PACIFIC

Reviewing the beam patterns of Reference 3, it was determined that Pacific maritime coverage could be effected reasonably well using the same 6.2° antenna size. Beam positions were chosen to effect complete coverage of all major shipping routes and as much area coverage as possible with one satellite. It was found that five beams are necessary for adequate coverage and the subsatellite point was chosen to be 165° W. To achieve maximum coverage the boresight directions of the five antennas were chosen to intersect the earth at the coordinates shown in Table 1.

TABLE 1. COORDINATES OF BORESIGHT EARTH INTERSECTIONS FOR THE FIVE BEAM PACIFIC CASE

Beam	Latitude	Longitude
1	23 S	173 W
2	8 S	121 W
3	23 N	155 W
4	48 N	162 E
5	10 N	138 E

Using these beam positions, a comparative study was performed using each of the four shipboard antenna models described in Section 2. For each shipboard antenna, a family of constant gain contours was plotted, which included the effects of the satellite antenna gain, space loss and multipath margin. The contour was chosen that most closely achieved coverage to the 15° elevation angle contour. A link budget was then performed for the value of shipboard antenna gain and gain contour to establish the required value of satellite transmitter power per channel necessary to establish 45 dB-Hz signal quality on the chosen contour.

To establish a basis for direct comparison of the performance of the multiple beam system to an earth coverage system, the above procedure was performed first for an earth coverage satellite antenna and the results are presented in Table 2 and Figures 9 - 12.

TABLE 2. SATELLITE R.F. POWER PER CHANNEL VS. ANTENNA GAIN FOR EARTH COVERAGE SATELLITE ANTENNA

Ship Antenna Gain (dB)	Satellite r.f. Power per Channel (watts)	Performance Difference Between Successive Values of Gain (dB)
4	76	4.0
7	30.3	4.6
10	10.5	3.9
13	4.3	

The procedure was then repeated for the multiple beam system with beam intersection coordinates as given in Table 1. The results are presented in Table 3 and Figures 13-16.

TABLE 3. SATELLITE R.F. POWER PER CHANNEL VS. USER ANTENNA GAIN FOR 5 BEAM SYSTEM

Ship Antenna Gain (dB)	Satellite r.f. Power per Channel (watts)	Performance Difference Between Successive Values of Gain (dB)
4	21.4	4.0
7	8.5	4.5
10	3.0	4.4
13	1.1	

In Table 4 the five beam system for each user antenna gain is compared to the corresponding baseline earth coverage system.

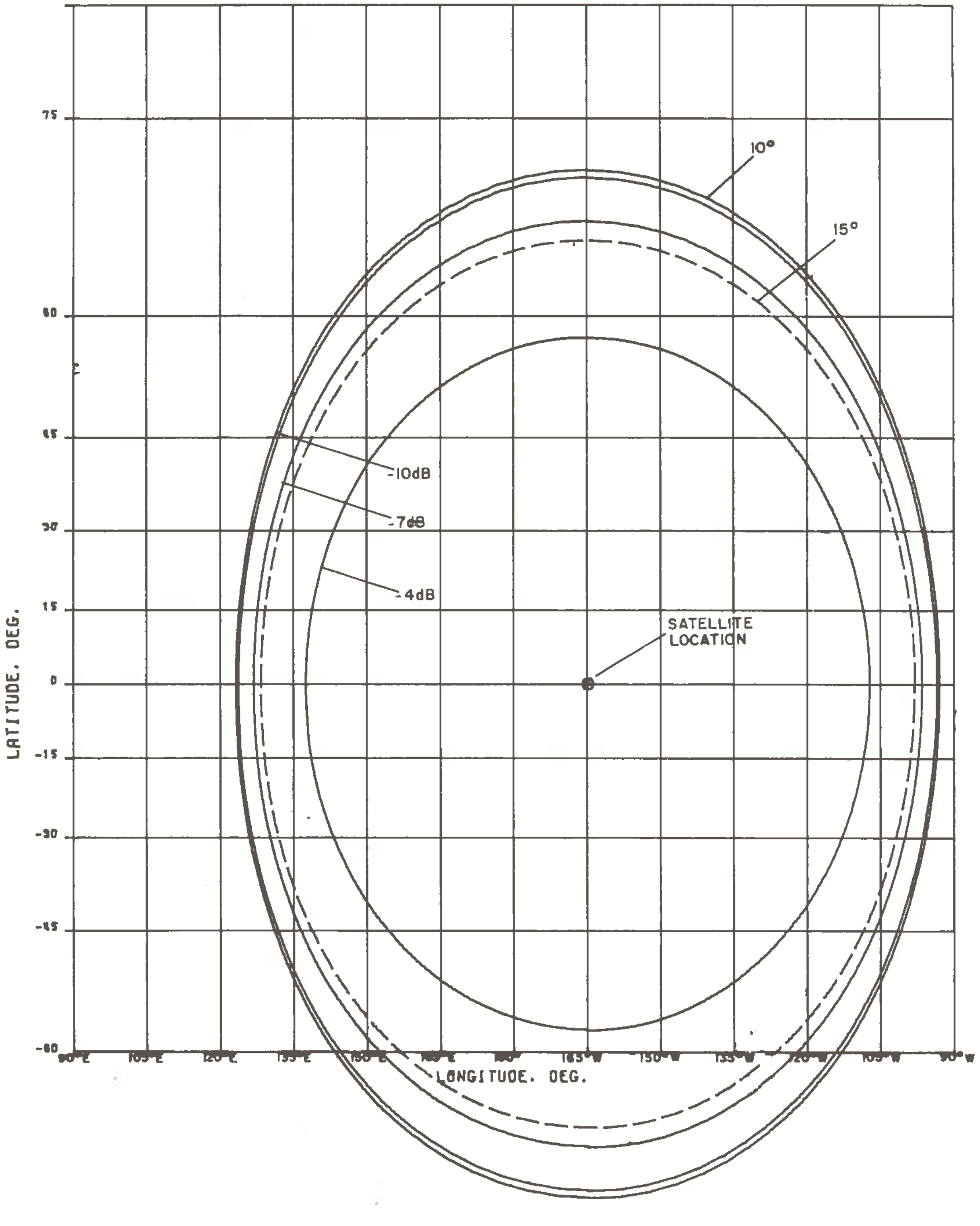

Figure 9. Earth Coverage Contours for 13 dB Antenna

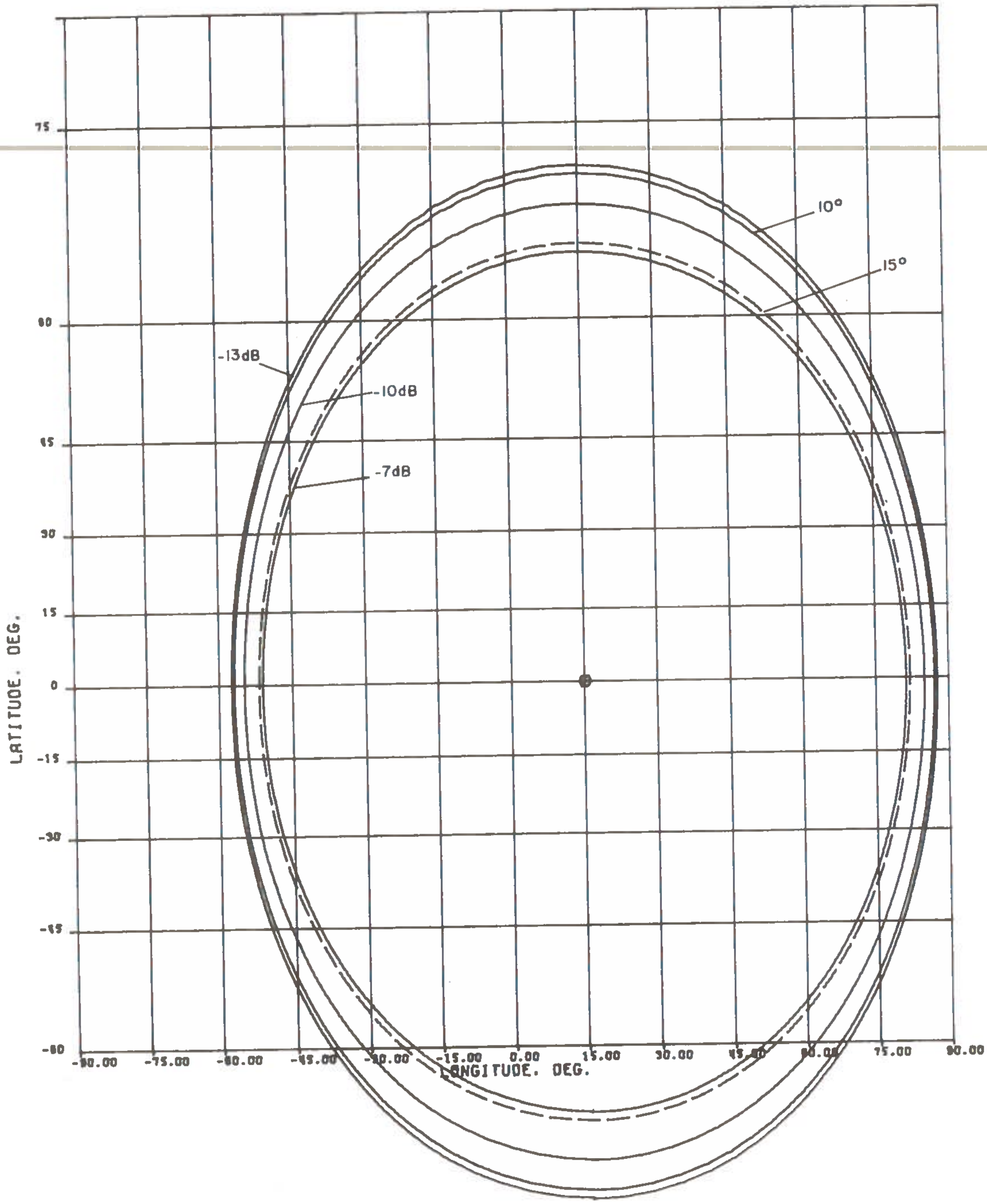

Figure 10. Earth Coverage Contours for 10 dB Antenna

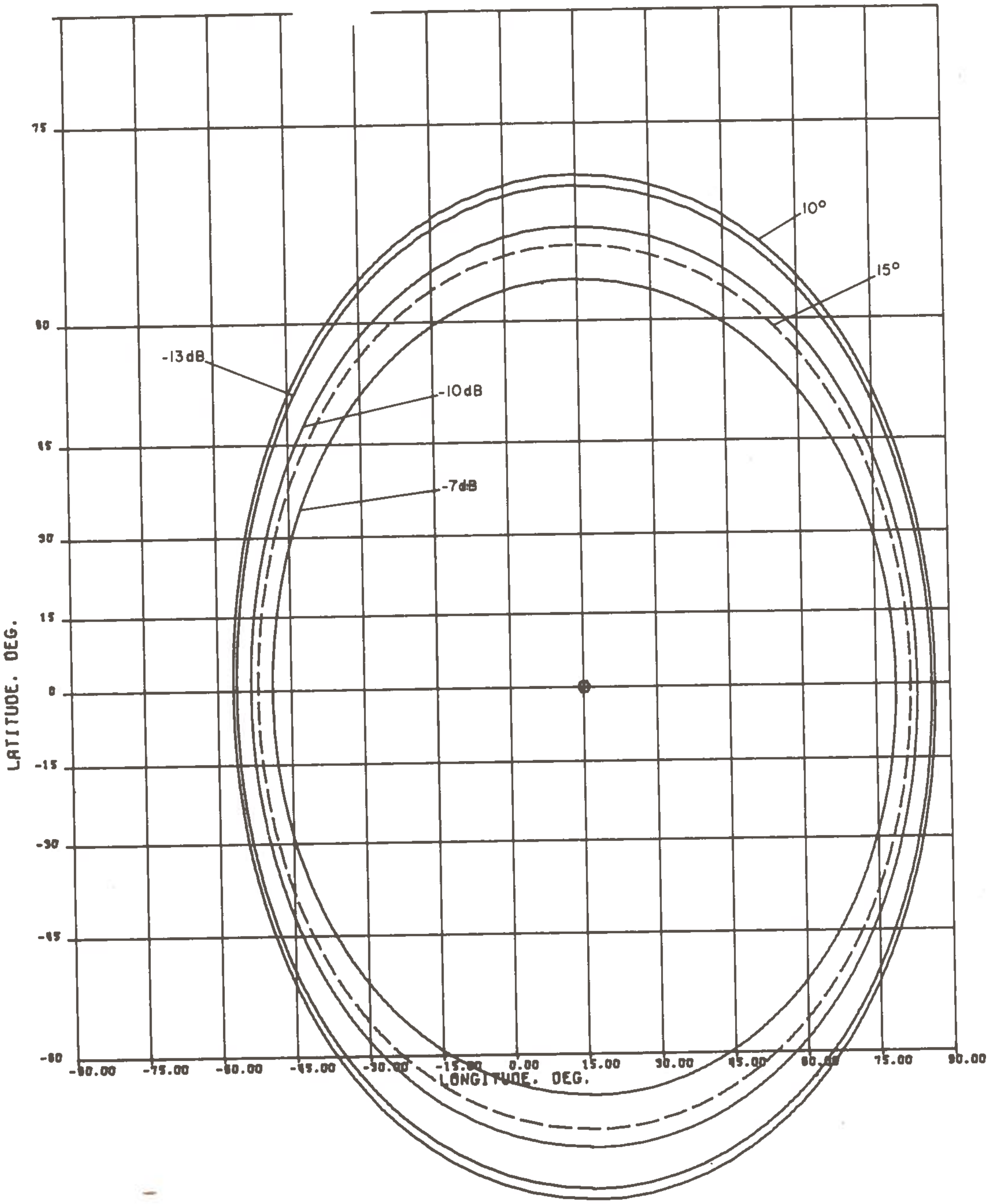

Figure 11. Earth Coverage Contours for 7 dB Antenna

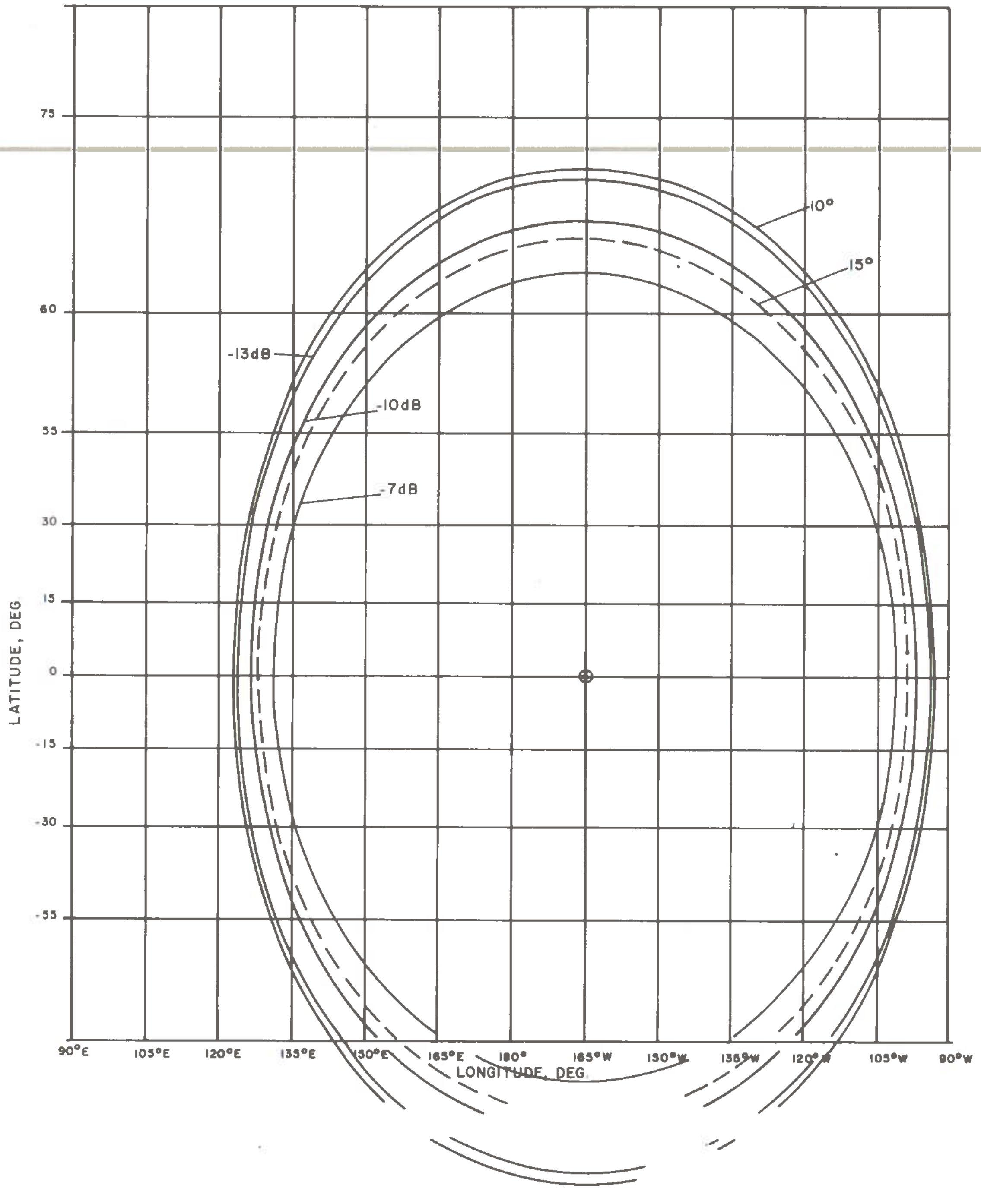

Figure 12. Earth Coverage Contours for 4 dB Antenna

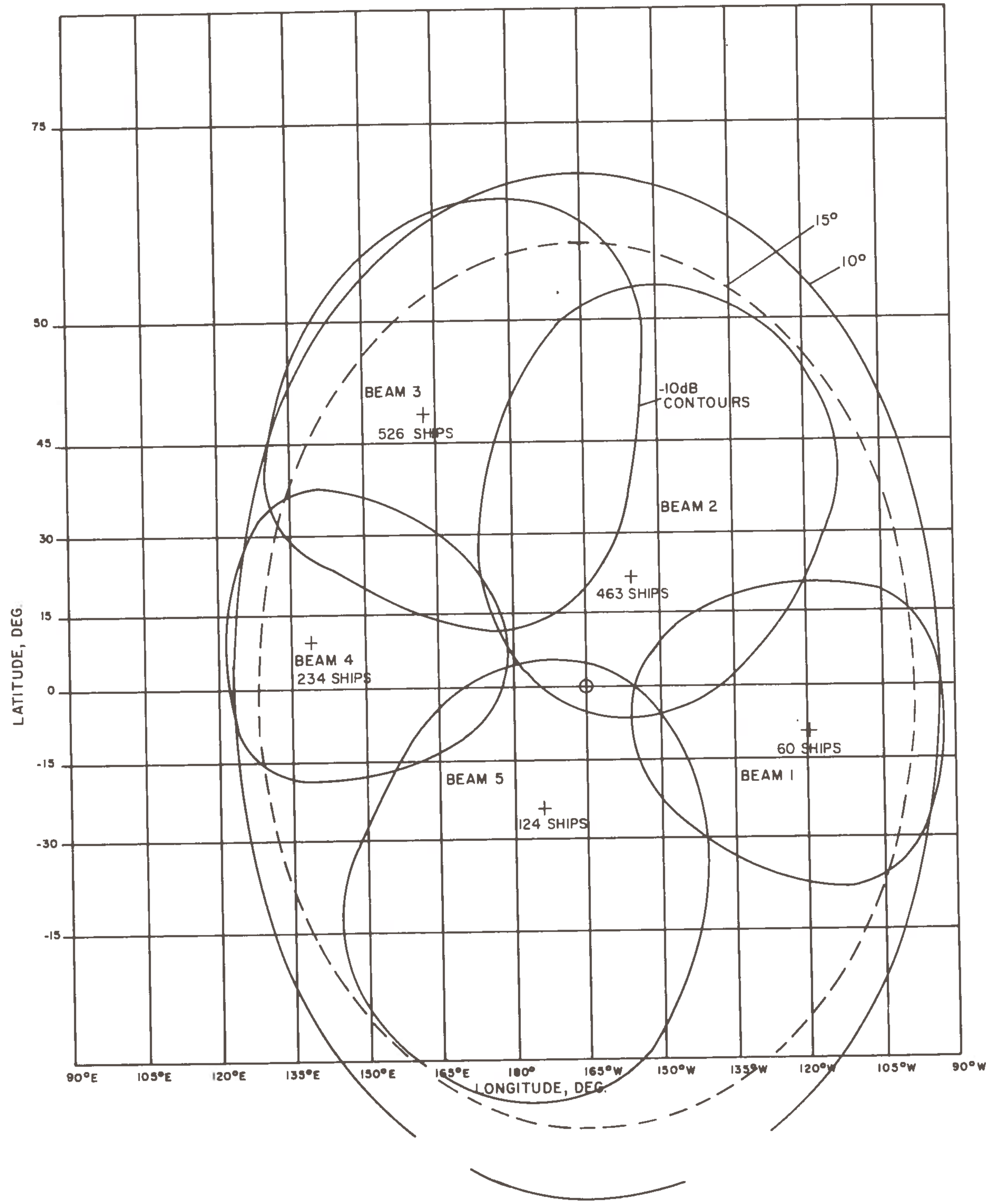

Figure 13. Five Beam Pacific Coverage for 13 dB Antenna

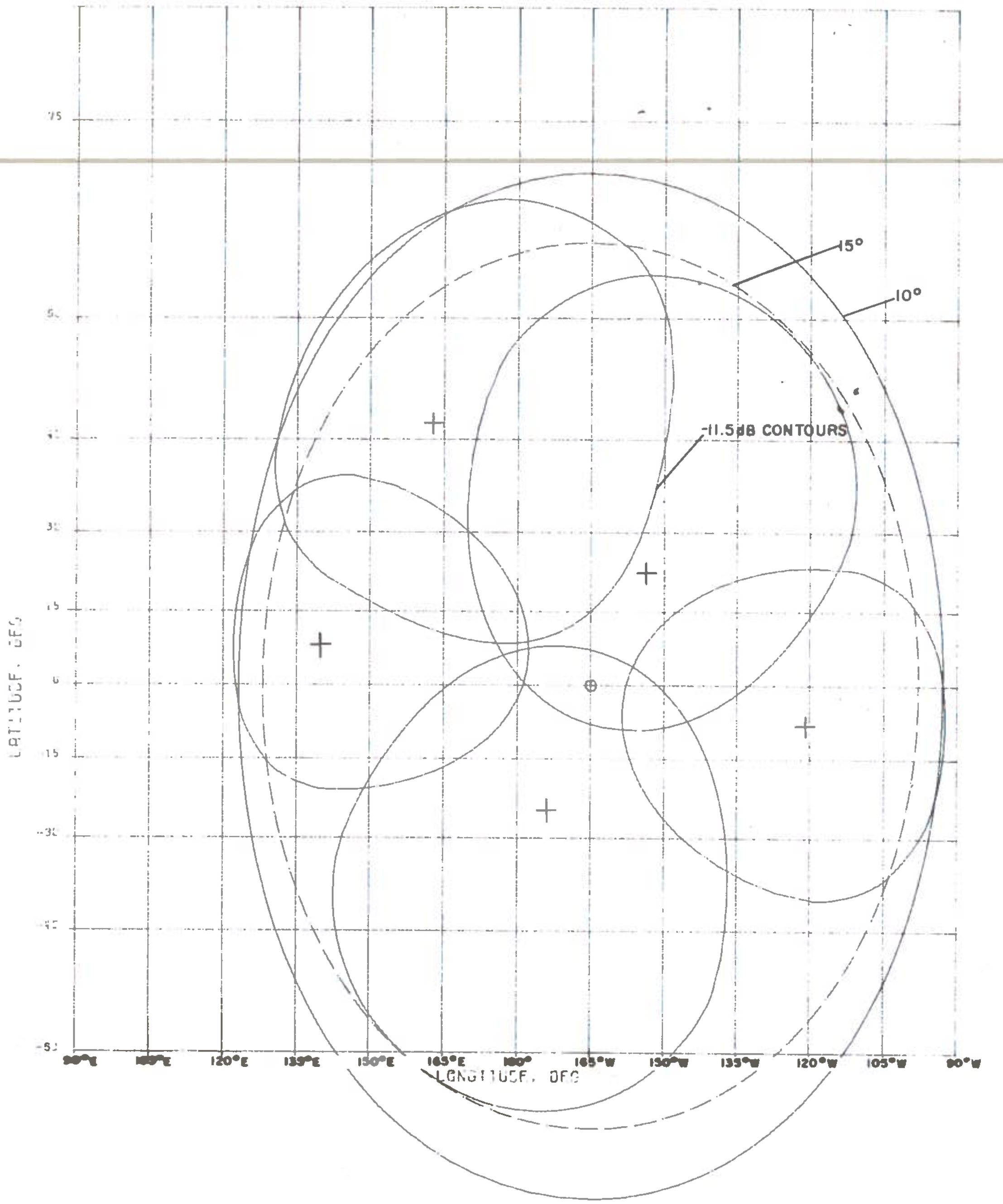

Figure 14. Five Beam Pacific Coverage for 10 dB Antenna

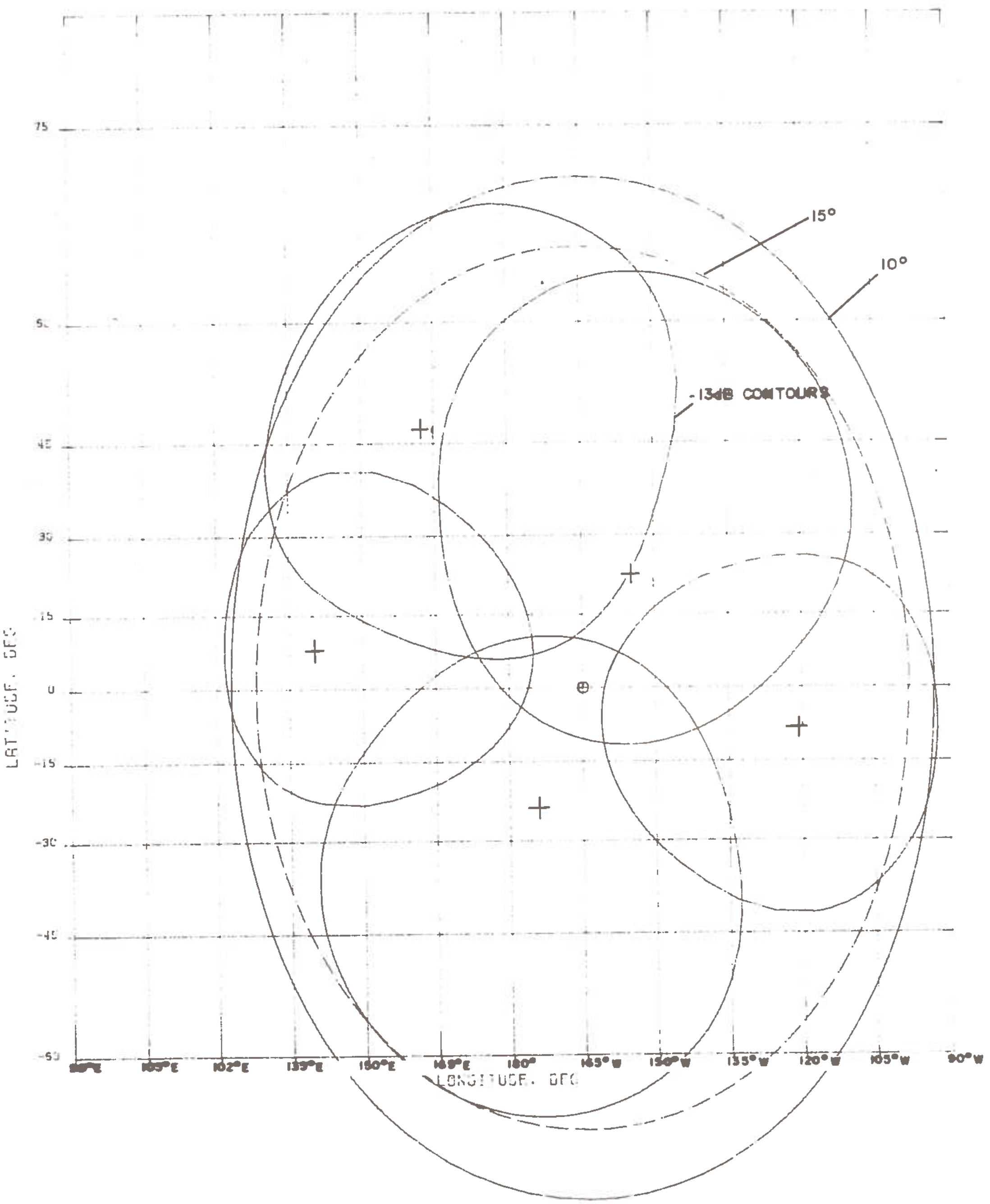

Figure 15. Five Beam Pacific Coverage for 7 dB Antenna

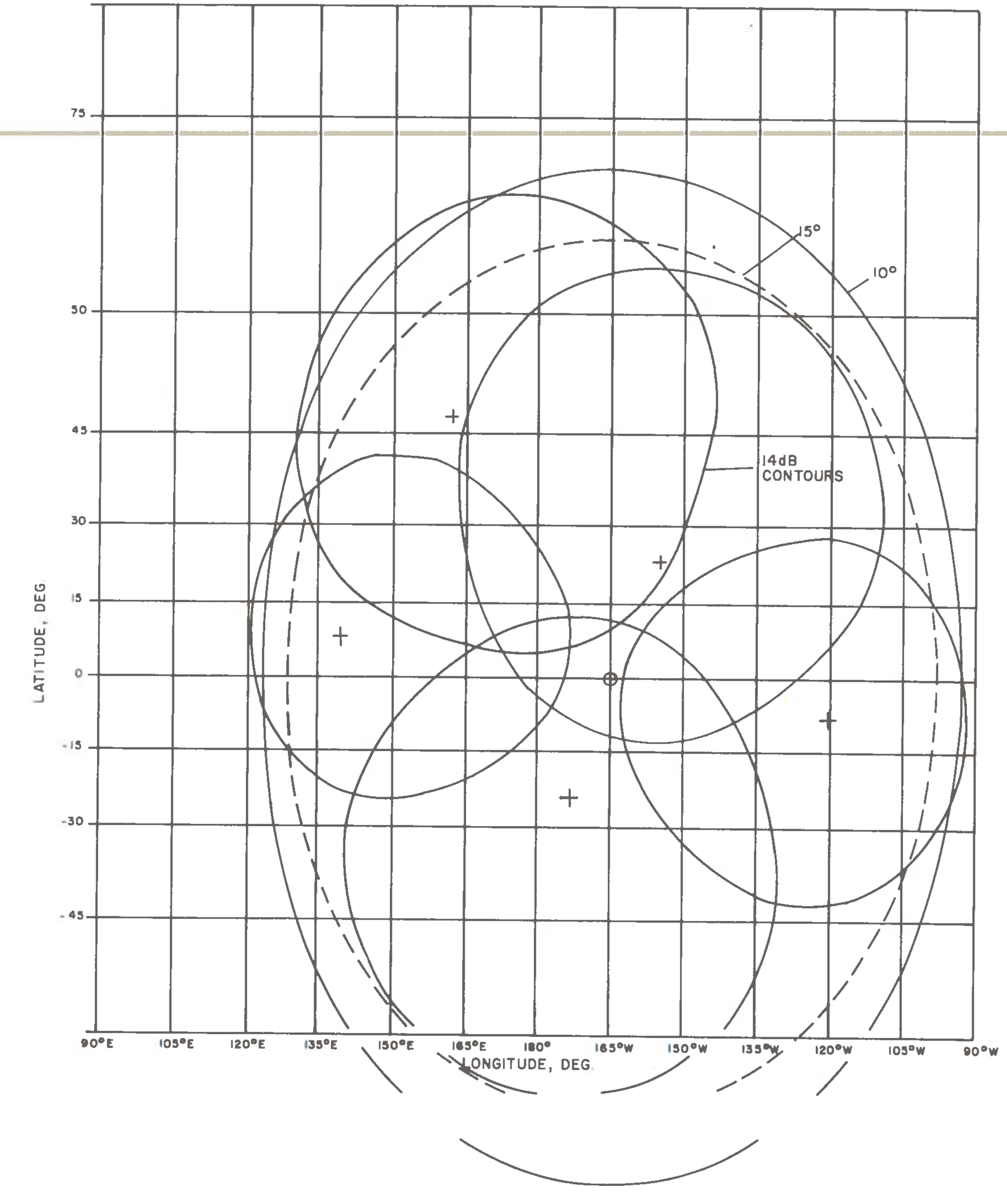

Figure 16. Five Beam Pacific Coverage for 4 dB Antenna

TABLE 4. COMPARISON OF 5 BEAM SYSTEMS TO BASELINE EARTH COVERAGE SYSTEMS

Ship Antenna Gain (dB)	Earth Coverage Watts per Channel	5 Beam Watts per Channel	Improvement for 5 Beam over Earth Coverage (dB)	Improvement assuming 1 dB coupling lo (dB)
4	76	21.4	5.5	4.5
7	30.3	8.5	5.5	4.5
10	10.5	3.0	5.4	4.4
13	4.3	1.1	5.9	4.9

As can be seen in the fourth column of Table 4, the 5 beam system shows a 5.5-6 dB advantage over the earth coverage system with the same user antenna. From this, however, must be subtracted any coupling or switching losses which are peculiar to the multibeam system. For coupling loss between feeds of the multiple beam satellite antenna a value of 1 dB is assumed.

So far the five beam multiple beam system has shown a significant power saving over the baseline earth coverage system. We must now consider accessing complications peculiar to the multiple beam system and their impact on the comparison. There are two cases to consider: (1) channels permanently assigned to each of the multiple beams, (2) channels which can be switched at will to any beam. This study mainly examines Case 1.

CASE 1 - Channels Permanently Assigned to Each of the Multiple Beams

Two major factors to be considered here are: (a) in a queueing system of this type, as the total number of accessible channels is decreased, the utilization factor of the channels must be decreased to maintain a constant average access time; (b) in choosing beam positions to maximize area coverage, some beams may have such a low average population of users as to be unable to efficiently utilize a single channel.

Considering (a) first, in going from an earth coverage system to a multiple beam system with no switching, the total number of channels must increase to maintain the same access time. This can be seen from the curves of Figure 17 showing access time vs. number of channels for various numbers of ships. An earth coverage channel serving 1000 ships requires 4 channels for a 10 minute average access time. If these same 1000 ships were served by a non-overlapping five beam system with an equal distribution of 200 ships per beam, each beam would require two channels to achieve the same average waiting time. Thus, in this idealized example it is necessary to more than double the total number of system channels to counteract the increases in access time. This decreases the comparative advantage over the earth coverage system by more than 3 dB. This penalty can be seen to decrease as the system becomes larger. For the Pacific system under consideration, serving 1000-1200 ships, the penalty would decrease the relative advantage listed in the last column of Table 4 to 1-2 dB. A partial compensation for this loss is to be expected due to the inherent overlap of the area coverage beams. Many ships would lie in the pattern of more than one antenna and could be assigned to use the one with the lower instantaneous communication load. At present, the computer program does not have the capability to analyze the effects of overlap on utilization factor, but it is being modified to do this. For this report, we will manually inspect the overlap in the beam coverage for 5 beams Pacific pattern for 13 dB user antenna (Figure 13) to obtain a rough idea of what improvement can be expected.

First, the accessing situation of the five beam Pacific system with 13 dB user antenna will be analyzed neglecting overlap. For this, the ship distribution models described in Section 2.4, and the queueing models described in Section 2.5 are utilized. The ship counting and queueing subroutines perform the following calculations:

(1) count the total number of ships inside each contour;

(2) assign a given total number of channels among the beams as proportional as possible to the number of ships in the beams;

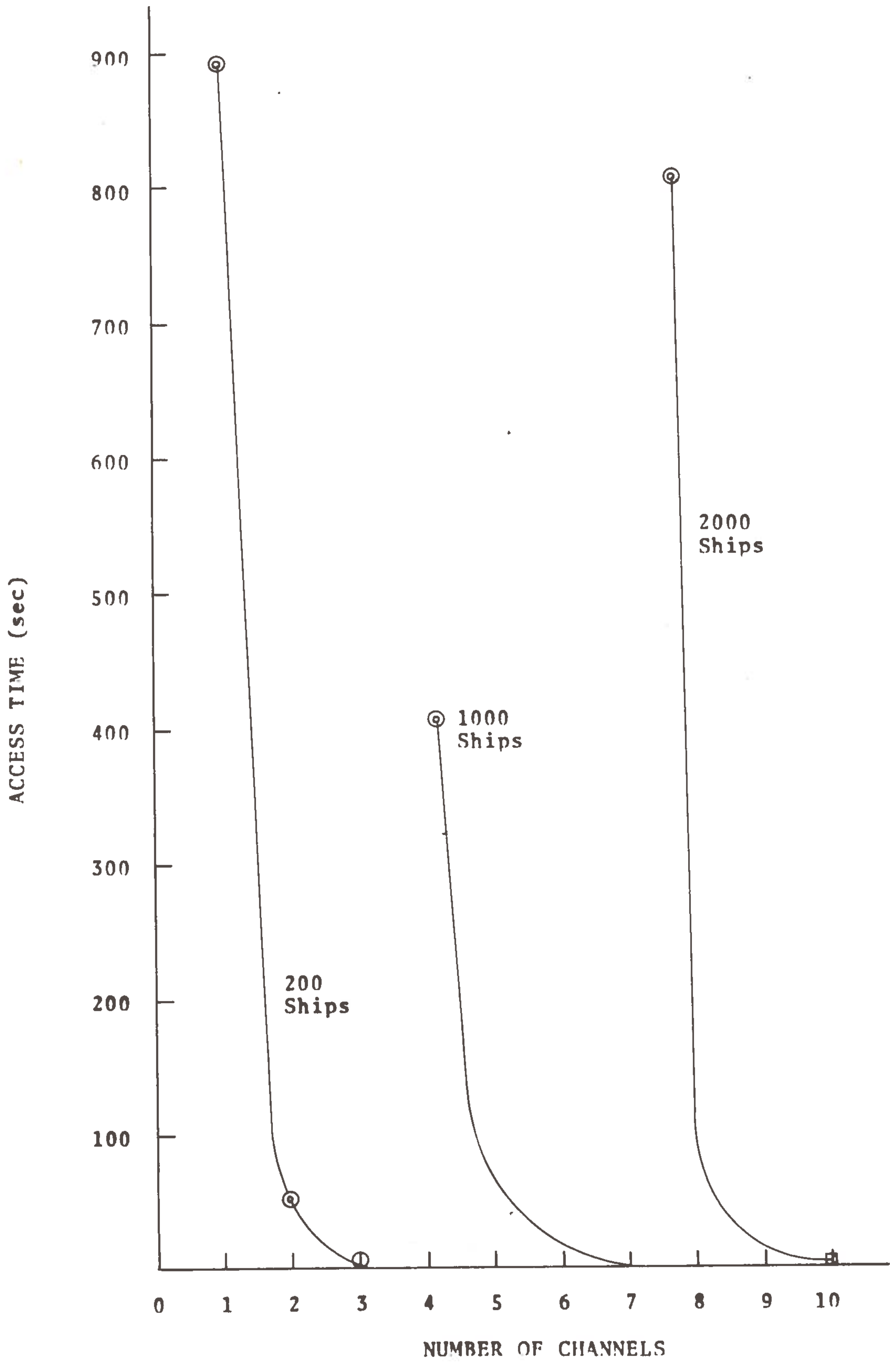

Figure 17. Access Time vs. No. Channels for Various Numbers of Ships

(3) compute access times for each of the five beams;

(4) equalize and minimize average access times by reassigning channels from low access time beams to high access time beams.

From this procedure is obtained an illustration of (1) the unevenness of ship population per beam due to the area coverage requirement, and; (2) the problem of efficient channel utilization due to the unevenness and small ship counts.

The number of ships per beam, as shown in Figure 13, ranges from 60 to 526. Table 5 gives the channel assignments and access times generated for the above case for an average access time in the order of 100 sec.

TABLE 5. SHIP COUNTS, CHANNEL ASSIGNMENTS AND ACCESS TIME FOR THE 13 dB, 5 BEAM PACIFIC SYSTEM WITH FIXED CHANNEL ASSIGNMENTS NEGLECTING OVERLAP

Beam	No. Ships Counted	Channels Assigned	Access Time (sec)
1	60	1	108
2	463	3	68
3	526	3	107
4	234	2	79
5	124	1	307
Earth Coverage System	1407	6	95

It is seen that the multibeam system requires ten channels. An earth coverage system under the same conditions, would require six channels.

As explained previously, the computer program does not compensate for overlap, i.e., some ships appear in more than one beam. It was desired to determine the extent of the overlap and estimate its effect on the results. By visual examination it was determined that approximately 20% of the total number of ships appeared in more than one beam (essentially all of the overlap occurred between beams 2, 3, 4 of Figure 13). The number of ships common to each set of overlapping beams was determined and one half of the ships were assigned to each beam. The channel assignment and access time calculations were again performed, and the results appear in Table 6.

TABLE 6. SHIP COUNTS, CHANNEL ASSIGNMENTS AND ACCESS TIME FOR THE 13 dB, 5 BEAM PACIFIC SYSTEM WITH FIXED CHANNEL ASSIGNMENTS CONSIDERING OVERLAP

Beam	No. Ships Counted	Channels Assigned	Access time (sec)
1	60	1	108
2	378	2	296
3	465	2	702
4	178	1	645
5	124	1	307
Earth Coverage System	1205	5	195

It should be pointed out that the large fluctuations in calculated access times are due to the small numbers of channels involved. Adding or subtracting a channel from a two channel system changes the system average utilization factor drastically with a resulting large change in access time. In all cases above, adding a channel would have resulted in an access time less than 100 seconds and subtracting a channel would have resulted in an access time greater than one half hour.

A comparison can now be made between the five-beam system and the earth coverage system. A total of seven channels is necessary in the five beam case vs. five channels in the earth coverage case. This can be expressed as a 1.5 dB comparative loss for the multibeam system which, when subtracted from the 4.5-5 dB relative advantage from Table 4, results in a 3.0 to 3.5 dB advantage depending on user antenna. It is considered beyond the scope of this study to determine the weight or power penalties the multibeam system would incur due to its larger antenna, multiple feed structure, multichannel rotary r.f. joint etc., but we must consider that some degradation of the nominal 100 watts of r.f. power available in the earth coverage system will occur. Thus we can conclude from Table 4 that the minimum value of shipboard antenna would be 6-7 dB. This is above the practical gain limit for an array of switched reflectors[2] and would require a slaved antenna. Thus it is concluded that for the particular set of assumptions we have taken the development of a multiple-beam satellite system for the Pacific with fixed channel allocations for the purpose of decreasing the complexity and cost of the user antenna is not warranted.

If the user antenna gain could be dropped to the 4-5 dB range where a simple array of switched reflectors could be used, the cost to the user would be significantly reduced, possibly enough to justify development of the satellite.

CASE 2 - Channels Which Can Be Switched to Any Beam

This system will have the same channel requirements and access times as the earth coverage system. Thus for our case it would not have the 1.5 dB accessing loss but instead would have a loss associated with the switching function and the additional weight and complexity of the spacecraft. For the purposes of this report, it is assumed that these losses would equal or exceed the 1.5 dB accessing loss of the permanent assignment system resulting in a less desirable system.

4. DESIGN OF A MULTIPLE BEAM SYSTEM FOR THE ATLANTIC

It is evident from an examination of the ship distributions, (Figures 7 & 8) that the Atlantic poses a quite different coverage problem than the Pacific. The Atlantic water area between 60° N and 45° S latitude is much smaller than the Pacific area; the traffic density is much higher in general, and there is an extremely high concentration of traffic in the region of the European coastline. Thus, the requirement for area coverage, which was of main concern in the Pacific, becomes secondary. The Atlantic design problem is to furnish enough channels with the available satellite r.f. power to achieve reasonable access times. Area coverage can be attained from a satellite located above 30° W longitude with two 6.2° beams having boresight intersection of 45° N latitude, 52° W longitude and 18° S latitude, 25° W longitude (see Figure 18).

The high concentration of traffic off the coast of Europe suggests use of a higher gain satellite beam in this area supplementing the northern area coverage beam. The size and position of the high gain beam were chosen to serve coastal traffic from the southern tip of Norway to the eastern tip of Africa. This goal was achieved with a 3.1 beam with boresight intersecting the earth at 35° N latitude, 15° W longitude. The beam's coverage region is shown for the four antenna models in Figure 18. The efficacy of this beam placement is evident from the ship counts for the three beams presented in Table 7.

TABLE 7. SHIP COUNTS FOR THREE BEAM SYSTEM FOR ATLANTIC. 13 dB USER ANTENNA ASSUMED. (COUNT FOR UPPER 6° BEAM DOES NOT INCLUDE THOSE SHIPS IN AREA COMMON WITH 3° BEAM)

Beam	No. of Ships	% of Total
Upper 6°	1530	25
Lower 6°	1276	21
3°	3348	54
Total in all beams	6154	100

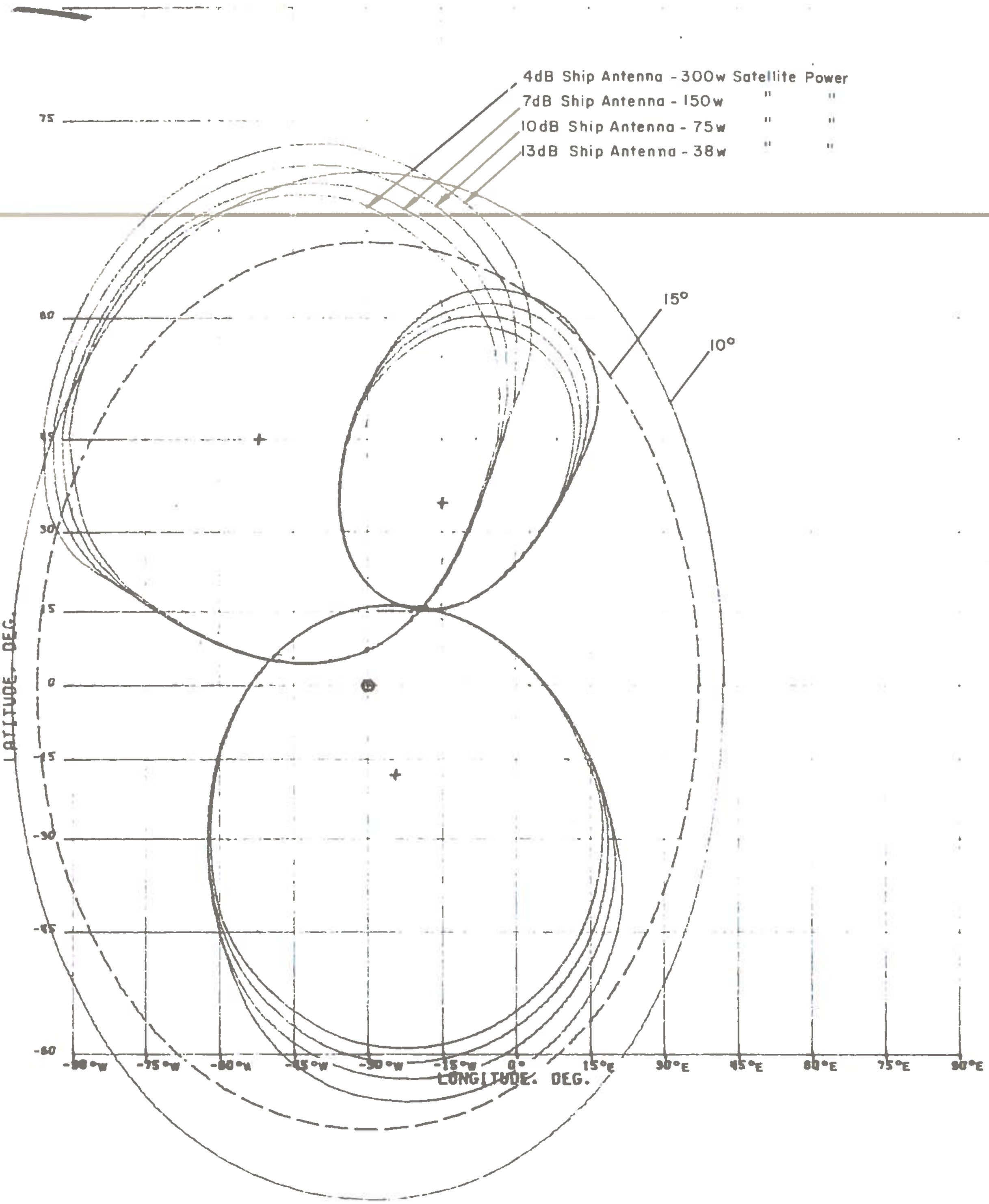

Figure 18. Three Beam Atlantic Coverage Contours for Four Antennas (Coverage decreases in lower gain antennas due to decrease in multipath discrimination)

Over 50% of the total traffic in the Atlantic can be served by this beam at a 6 dB saving in satellite r.f. power per channel compared to the 6.2° beam. Next, the queueing subprogram determined the number of channels necessary in each beam to achieve reasonable access times. This data is presented in Table 8.

TABLE 8. CHANNEL ALLOCATIONS AND ACCESS TIMES FOR THE 3 BEAM ATLANTIC SYSTEM

Beam	No. of Ships	No. of Channels	Access Time (sec)
Upper 6°	1530	6	222
Lower 6°	1276	5	338
3°	3348	12	122

Performing link budgets for the coverages shown in Figure 4, it is determined that 38 watts are required for the 13 dB user antenna, 75 watts for the 10 dB antenna, 150 watts for the 7 dB antenna and 300 watts for the 4 dB antenna.* Channel spacing was assumed for IM distortion reduction - if spectrum is not available, power amplifier backoff will be required with a corresponding increase in required power per channel. For equivalent coverage from an earth coverage antenna, approximately 20 channels would be required at 5.4 watts per channel for a total of 108 watts for the 13 dB case. Thus it can be seen that the 3 beam Atlantic system with fixed channel assignments offers a significant 4-5 dB advantage in satellite power reduction but cannot offer substantial simplification of the user antenna. The advantage of a multiple beam configuration is greater for the Atlantic than for the Pacific for three reasons:

1) the required area coverage is significantly smaller;

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*The contours plotted for the Altantic were not adjusted for equal coverage as in the Pacific case. Thus we see the decreasing coverages due to inferior multipath rejection of the lower gain antennas in Figure 18, and the simple 3 dB relationships in the link budgets.

2) the overall ship density is greater;

3) there is an intense concentration of traffic in one area, permitting the efficient use of a high gain spot beam with a significant number of channels.

5. CONCLUSIONS

This preliminary study has compared the performance of a multiple beam satellite antenna to an earth coverage antenna for a geostationary maritime voice communications system for the particular set of assumptions outlined in the Introduction. It was shown for the Pacific case that approximately 3 dB of additional gain can be expected from the multiple beam antenna neglecting weight and reliability penalties due to the increased complexity of the antenna and feed system. It was concluded that this advantage would not be sufficient to materially reduce the cost and complexity of the required shipboard antenna.

In the system developed for the Atlantic, a 4-5 dB advantage (again neglecting weight penalties) was seen compared to an earth coverage system. The increased performance relative to the Pacific case was due to the higher ship densities in the Atlantic and the intense concentration of traffic in the area of northern Europe, permitting use of a spot beam.

Although the multibeam system would not afford the desired simplification of the user antenna in the Atlantic under the present set of assumptions, the 4-5 dB advantage could make the system cost effective under other sets of assumptions and for purposes other than simplifying the shipboard antenna. Under a continuing program, the methodology developed in this study will be used to investigate the cost effectiveness of the multiple beam concept vs. earth coverage under other sets of assumed system requirements and configurations such as:

1) Multiple satellite per ocean systems with and without navigation and/or surveillance capability;
2) 5° & 10° elevation angle limits;
3) Various assumed ship distributions based on estimates of participation growth;
4) Voice plus data systems;
5) Data only systems;

6) Channels switchable between beams;
7) Systems with more than one class of user antenna;
8) Systems with satellite antenna size optimized for desired coverage area.

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