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Boulder Laboratories

AIRBORNE TELEVISION COVERAGE IN THE PRESENCE OF CO-CHANNEL INTERFERENCE

BY

MARTIN T. DECKER

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Predictions are made of the coverage to be expected from a network of airborne television transmitters operating in the UHF television band. Various system performance and interference conditions are assumed. The results are presented in a series of graphs with probability of service as a function of receiving location and in terms of the total effective area of a station or network of stations. System requirements for a coverage approaching 100% of a large area are indicated.

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INTRODUCTION

A study of some of the technical factors involved in the planning of an airborne television network has been undertaken by the National Bureau of Standards under the sponsorship of the Ford Foundation. In a previous report [Decker, 1959], the predicted coverage for a single airborne station was described for a variety of operating conditions. This report considers the problems of large area coverage, i.e., the operation of a network of airborne stations in the presence of interfering signals from co-channel airborne stations. Technical considerations include expected coverage, equipment requirements for a specified coverage, interference from co-channel stations, optimum geographical spacing of stations, and number of stations and channels required for a specified large area coverage. These factors are, of course, interrelated, and compromises between various requirements will be necessary. In general, economic factors are also involved in the decisions and compromises of the planning stages. This aspect has not been considered in this report, except that a range of equipment quality parameters has been chosen which is well within the capabilities of current production techniques.

This study has resulted in a series of graphs which present a statistical description of coverage in two forms. The first of these is the probability that at a given location a specified picture quality, or better, will be available for at least some minimum percentage of the time. This probability is a function of the geographic location of the receiving site with respect to the desired and interfering transmitting stations. It is shown graphically as contours of location probability of service for various operating conditions of the system. The second form of the results of the calculations is a summation of "effective area" of a station or of a network of stations and may be expressed in square kilometers. For the case of a network of transmitters serving a large area, it is also convenient to express this effective area as a percentage of the area receiving a specified service.

METHODS OF COMPUTATION

The method used to determine the effect of interfering signals is basically that described by a special committee of the Federal Communications Commission [FCC 1950] . The method is also briefly outlined by Norton, Staras and Blum [1952] . A simplified version has recently been published by Livingston [1960] . The method used is one of a number of methods which have been proposed for calculating the service area of broadcast type systems. The random nature of the variations in signal strength with time, location, and some equipment characteristics dictates that the method chosen must be capable of handling these variations on a statistical basis. The methods which have been proposed generally involve a compromise between 1) simplifying assumptions which decrease the accuracy of the results, and

2) complexity of calculation which increases time and expense of computation. For example, in some methods, the problem of interference from more than one source is avoided by the simplifying assumption that only one interfering source will be important and all others may be neglected. This is evidently unsatisfactory when there are a number of signals of approximately equal magnitude, as may well be the case in some geographical configurations of stations. Other methods do not consider the effects of system "quality" in terms of transmitter power, receiver noise figure, or various system losses. The method chosen for considering interfering signals is admittedly complex, and yet it is felt to be necessary in order to adequately assess the effects of various system parameters.

Without presenting in detail the steps involved in the computation (for which the reader is referred to the FCC document), a few comments on this method and some of the underlying assumptions are listed here.

As in the previous report [Decker, 1959, hereafter referred to as Technical Note 35], the description of signal strength is in terms of "basic transmission loss" and its variations. It is applicable to both desired and interfering stations. Technical Note 35 contained a series of curves showing basic transmission loss as a function of distance for propagation over a smooth earth. These curves illustrated the effects of energy reflected from a smooth surface, resulting in destructive addition of signals at certain locations. While these minima of signal strength, or "nulls", may or may not occur in practice, depending upon the local terrain conditions, their possible adverse effects should not be overlooked. In many cases where nulls exist, an appropriate antenna height may be selected to take advantage of relatively broad lobe maxima.

In these computations it is assumed that if nulls do exist at a given location, and satisfactory receiving antenna height cannot be found, then diversity receiving antennas will be used. The maximum receiving antenna height is taken to be 30 meters.

Signal variations with time at any fixed location are assumed to be log-normally distributed, i.e., decibel values of hourly medians are normally distributed. The standard deviation of this time distribution of signals is a function of distance from the transmitter and is derived empirically from long-term measurements.

The signal level which is exceeded for a fixed percentage of time will vary from location to location in the area surrounding a station. This is a result of the irregularity of the terrain. This location variation is also assumed to be a log-normally distributed function, with a standard deviation of 6 db.

A further assumption is that the desired signals are not correlated with signals from interfering stations, either with respect to time or location variations. This appears to be a reasonable assumption when the signals arrive at the receiver from different directions [Kirby and Capps, 1956].

In this method, the power contained in interfering signals is added, so that any number of interfering signals combine to produce an effective interfering field. These various signals are modified by the directivity of the receiving antenna, depending on their direction of arrival, and by the appropriate desired-to-undesired signal ratios which may be required for satisfactory television reception. The noise power at the input to the receiver is also included as part of the undesired signal which must be overcome for satisfactory operation. The approximate method for adding log-normal probability distributions is described in the FCC document [1950] and also by Fenton [1960].

To estimate time variations of multiple interfering fields, the assumption is made that the resultant signal power from these sources, exceeded for a specified percentage of time, is equal to the sum of all the individual power levels exceeded for that same percentage of time. This implies the further assumption that signals arriving from various interfering sources are correlated with each other, but not with the desired signal. It was demonstrated in the FCC document that this is a good approximation when time availability is $\geq 90\%$, regardless of true correlation coefficient.

"Service," as defined in this study, exists at a receiving location during any hour for which the hourly median signal received from the desired transmitting station exceeds the hourly median of the sum of the receiver noise power and interfering signal power after specified signal-to-noise and signal-to-signal ratios have been taken into account. These ratios must therefore be adequate to provide the require picture quality in the presence of any short-term or within-the-hour variations of the signals. The percent of hours for which this service is available is referred to as "time availability" of service. The required time availability has been fixed in this study at 99%. Thus, a given location either has this service, or it does not; a map showing the service area of a given station could be similar to Figure 1. In this hypothetical picture, the black areas represent those locations in which the service requirements have been met. The summation of all these areas in this case is a useful quantity--the effective service area.

The statistical nature of the variations with location and the fact that we are not considering a specific geographical area enable us to predict only the likelihood (or probability) that any location will receive the specified 99% time availability of service. The predicted effective area may then be obtained by summing the incremental areas, multiplied by the probability of service in that area. The utility of the effective area concept is that it provides a realistic basis upon which to make determinations and comparisons of the effects of any parameters on the coverage obtained. Where there is a probability of service from more than one station, the probability of getting satisfactory service from at least one of these stations is computed from

$$p = 1 - (1 - p_1)(1 - p_2) \ldots (1 - p_n)$$

where p_1, p_2, . . . p_n are the probabilities of service for the individual stations.

An alternative representation of the service provided by a station consists of contours which indicate the probability that locations will receive the specified signal quality for 99% of all hours. In a specific case these contours might be quite irregular as a result of the particular terrain involved. In this study, however, an "average" station is considered, and the resulting contours are smooth and symmetrical. In the absence of interference, they appear as circles centered on the transmitting station, and departure from the circles is the result of interfering fields from stations operating on the same channel.

THE SYSTEM PARAMETERS

A measure of equipment performance is provided by "maximum allowable basic transmission loss" as explained in Technical Note 35. The formula for the computation of this quantity is

$$L_{b(max)} = P_t - L_t + G_t + G_r - L_r - 10 \log b - F - R + 204$$

where:

P_t = Transmitter power, db above 1 watt

L_t = Transmitter line losses, db

G_t = Transmitting antenna gain, db above an isotropic radiator

G_r = Receiving antenna gain, db above an isotropic radiator

L_r = Receiver line losses, db

b = Effective bandwidth in cycles per second

F = Receiver noise figure, db. For a discussion of effective noise figure see Barsis, et al. [1961].

R = Signal-to-noise ratio required at the receiver input for satisfactory receiver performance, db

204 db is a constant equal to - 10 log kT, where k is Boltzmann's constant, and the reference temperature, T, is 288.39°K.

A higher number for $L_{b(max)}$ could indicate better equipment performance resulting from improved receiver characteristics, greater antenna gains, better transmission lines, or more transmitter power. Values considered in this study range from 135 db to 150 db for single station coverage, while values of 140 db and 145 db are used in the interference computations. A typical set of values for the terms in the $L_{b(max)}$ equation was given in Technical Note 35. It is repeated here for illustration:

P_t	=	30 dbw	L_r	=	3 db
L_t	=	1 db	b	=	6 Mc/s
G_t	=	5 db	F	=	10 db
G_r	=	20 db	R	=	37 db

These values result in a maximum allowable transmission loss of 140.2 db. The same value of $L_{b(max)}$ could, of course, be obtained in other ways. For example, by increasing the transmitter power and allowing a comparable decrease in antenna gains.

In addition to the gain value for the receiving antenna, it is also necessary to consider its ability to reject undesired signals arriving from directions other than that of the desired signal. Here two directivity patterns have been used, as illustrated in Figure 2. Antenna No. 2 represents the better antenna since it has a greater rejection for signals outside its main beam than Antenna No. 1.

Acceptable picture quality is defined in terms of signal-to-noise ratios or desired signal-to-interfering signal ratios at the input to the receiver. The quality of pictures as a function of these ratios and the "off-set" of co-channel picture carriers has been studied by a number of authors and organizations [RCA, 1950; Beherend, 1957; Chapin, et al. 1958; Middlekamp, 1958; TASO, 1959; Dean, 1960; Towlson and Young, 1960; Fine, 1961]. In evaluating these effects, subjective judgments are made and not all viewers will agree as to an acceptable ratio. Selection of the proper ratio then becomes a statistical process.

The required signal-to-noise ratio is included in the expression for maximum allowable transmission loss, $L_{b(max)}$. Fine [1961] gives a value of 35 db for a "fine" picture and 30 db for a "passable" picture.

It is possible to reduce the adverse effects of interfering co-channel signals by maintaining a carefully controlled frequency difference, or "off-set," between co-channel stations. Further improvement can be obtained by the operation of geographically adjacent stations on different antenna polarizations [Kuppelhoff, 1954; Peterson, 1958; C.C.I.R., 1959] . These two factors are combined here to obtain the protection ratio, P, as indicated in the various curves and graphs. Values of 27, 20, and 12 db have been used. It should be noted that the doppler effects of the aircraft motion will make the use of very precise (± a few c/s) off-set impractical, but that off-sets which require a stability of ± 1000 c/s may be used.

A radio frequency of 785 Mc/s has been used to compute the propagation effects. This frequency was chosen as the center of the upper half of the UHF television band, and should be representative of the performance in that portion of the frequency spectrum. Certain comparisons of single station coverage were made at 575 and 785 Mc/s in Technical Note 35.

Aircraft flight altitudes for the computations involving co-channel interference are 7500 meters and 10,000 meters. The aircraft was assumed to be flying in a circle of 15 km radius. At any given receiving location, the performance is computed as though the desired aircraft were on the far side of its circle and all interfering aircraft on the near side of their circles.

Two geographical configurations of co-channel stations have been considered for the interference computations. It is realized that an actual network of stations would probably not have a symmetrical arrangement. However, it is likely that the stations, as they become more numerous, would tend to approach a triangular lattice arrangement, as illustrated in Figure 3. This three-channel triangular lattice is taken to be the most saturated arrangement of stations, while the least saturated case (other than no interference) is the case for two isolated co-channel stations.

RESULTS

In the absence of interference from co-channel stations,the integrated "effective area," as previously defined, may be shown graphically with maximum allowable transmission loss and transmitting antenna height as parameters. This is illustrated in Figure 4. The advantages to be gained by improving system quality or increasing aircraft height are evident from this figure, and could be compared with the cost of providing these improvements. An experimental system, currently planned (1961), operates in the range of 140 db to 145 db $L_{b(max)}$ and at an aircraft height somewhat below 7,500 m.

As mentioned previously, the results of the study considering the effects of interference are presented in two forms. The first of these is a series of diagrams showing contours of constant probability that locations will receive a specified signal quality for 99% of all hours. The general effect (on the contours) of bringing stations closer together in the simple two-station case is illustrated in Figure 5a. For the conditions assumed and at a separation of 700 km, the contours are nearly circular, indicating that very little mutual interference exists. As the station separation is decreased to 600 km and 500 km, interfering effects are evident.

When considering the contour diagram of a single station in a network of stations, it is likely that more than one interfering station will have to be considered. An idealized "triangular lattice" arrangement of stations has been selected to represent this more nearly "saturated" arrangement of stations. The arrangement of stations in this case is illustrated in Figure 3. Note that any station in the network will be surrounded by six co-channel stations at 60^{o} intervals at a uniform separation distance. This is the "co-channel separation." Other co-channel stations which may contribute interfering fields are located at greater distances as illustrated. In this study, interference is assumed to be produced by co-channel stations only, and the stations labeled B and C in Figure 3 do not interfere with the A stations. All channels are considered, however, when the area served by a three-channel network is computed. Figure 5b is an example showing the effect of changing the co-channel separation in a triangular lattice. For simplicity, only the 90% contours are shown. While a qualitative idea of the change in service area of a single station may be obtained from this type of representation, it does not show the change in effective area per channel, an important parameter which will be discussed in detail later.

The contour diagrams for the various conditions considered are arranged in a "catalog," Figures 9 through 56. The table of contents may be consulted to determine the figure number illustrating any specific combination of 1) maximum allowable basic transmission loss, $L_{b(max)}$, 2) receiving antenna, 3) protection ratio, 4) aircraft height, and 5) geographical configuration. The diagrams are arranged so that the effect of changing co-channel separation only may be seen in a single figure. That is, for a given combination of the first four parameters listed above, all diagrams for different separation distances are included in one figure. In some cases, the contours for the shorter separation distances have been omitted since the resulting service areas were too small to be of interest. The contour diagrams for the triangular lattice also show for reference the interference-free service contours as dashed lines.

The second method of presenting the results of this study involves the use of the "effective area" concept as explained in the section on methods of computation. When considering the area served by more than one station, it is important to recall that the area served by a single station, as illustrated by Figure 1, is not really bounded by a single fixed contour, but service is available to decreasing percentages of the area out to great distances. It follows, that in order to cover a high percentage of a given area, a certain amount of overlapping and interference will inevitably occur. Hence, the area served by n stations is not necessarily n times the area served by one isolated station. However, in a network of stations and for the application under consideration, the effective area of a single station is not the most valuable criterion. A better method for examining the performance of a network of stations will show the percentage of a large area which will receive a specified service. Here we have considered the network of stations to be arranged in a triangular lattice, and the area to be large enough so that the departures from uniformity at the edges of this area may be neglected. The actual minimum area required to make this approximation valid will depend on the separation distance of stations in the triangular lattice. For the largest separations considered, this area would be on the order of half of the United States.

The resulting integrations are shown graphically in Figures 6 and 7. Information in Figure 6 is for an aircraft height of 7,500 meters, while Figure 7 is for 10,000 meters. In each of the figures, the percent of a large area receiving a specified service from at least one station is plotted versus the separation of co-channel stations. The percent of area that could be served by a single channel or by three channels is indicated in each case. The relatively high percentage in the single channel case is a result of the nature of the airborne system as well as the use of directional receiving antennas. However, it is clear that the single channel arrangement will not provide service to more than about three-quarters of a large area. In order to achieve a "blanket" coverage, additional channels are required. Area coverage approaching 100% can be achieved with the three-channel systems.

Some estimate of the total number of stations required to serve an area such as the continental United States may be made using Figures 6 and 7. With the assumption that stations operating on channels A, B and C are arranged in the ideal triangular lattice of Figure 3, the approximate number of stations in the United States is as shown in the following table:

TABLE I

Co-Channel Separation km	Total Number of Stations
600	75
700	55
800	42
900	33
1000	27

The percentage of this area which has satisfactory service available may be read from the various curves in Figures 6 and 7. It is very likely that in any firm plan for large area coverage there would be departures from the ideal triangular lattice of stations. Hence, numbers such as those given here are only approximations.

In the calculations for the better receiving antenna (No. 2), it is assumed that this antenna is used at all locations. It is clear that this very good antenna would not be required at all locations in order to achieve the coverage shown in the curves labeled "antenna No. 2." Figure 8 is included to give an indication of the percent of receiving locations which would actually require an antenna with better performance than that of antenna No. 1 in order to achieve the coverage of the "antenna No. 2" curves. These locations would require antenna performance better than No. 1 but in no case better than No. 2. The figure shows that the number of locations requiring a better antenna is a relatively small part of the total.

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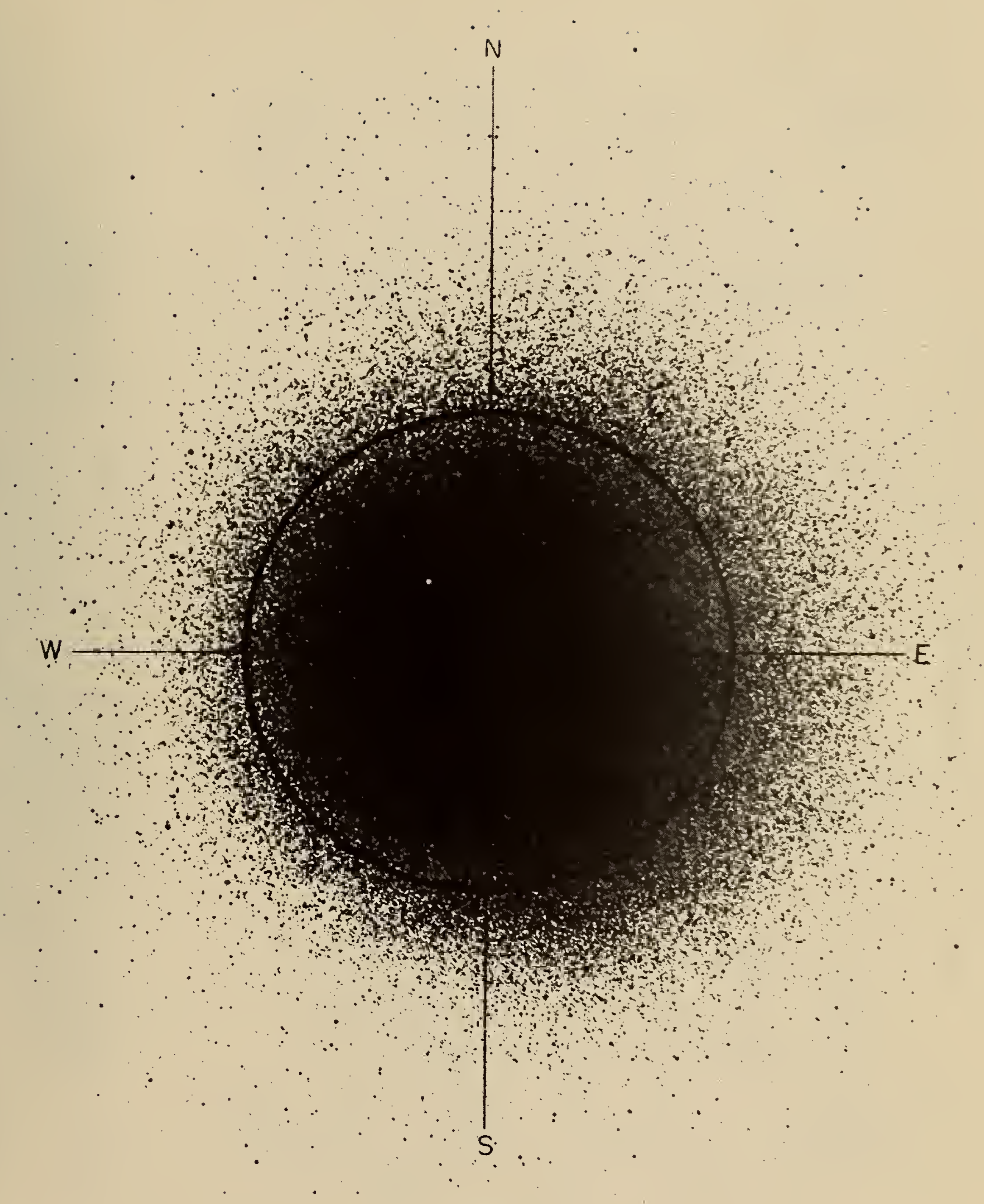
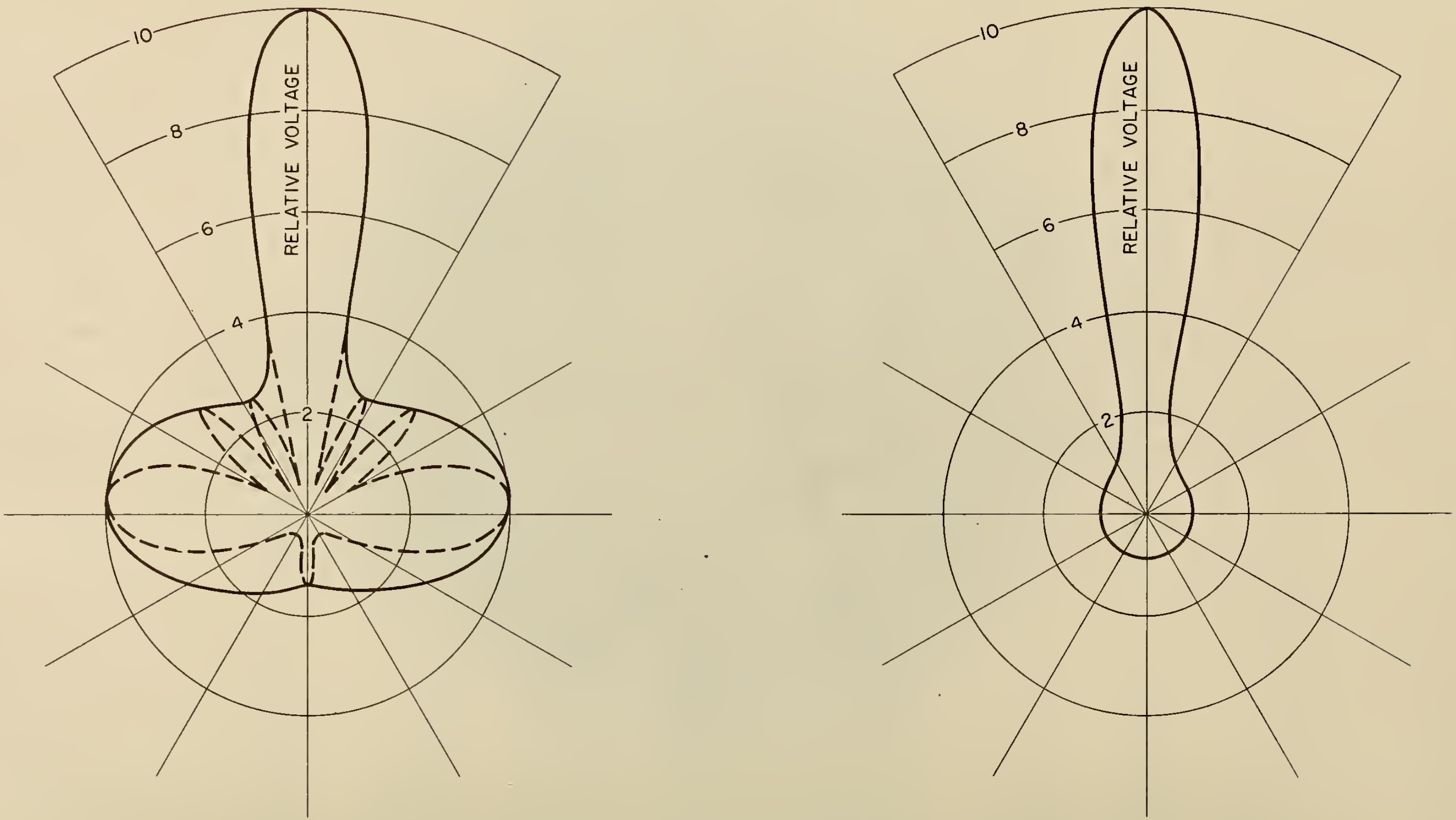


Figure I

RELATIVE VOLTAGE PATTERNS FOR RECEIVING ANTENNAS



ANTENNA N° 1
GAIN APPROXIMATELY 13 db

ANTENNA N° 2
GAIN APPROXIMATELY 18 db

Figure 2

LOCATION OF STATIONS IN A
THREE CHANNEL TRIANGULAR GRID
THE THREE CHANNELS ARE LABELED A, B, AND C

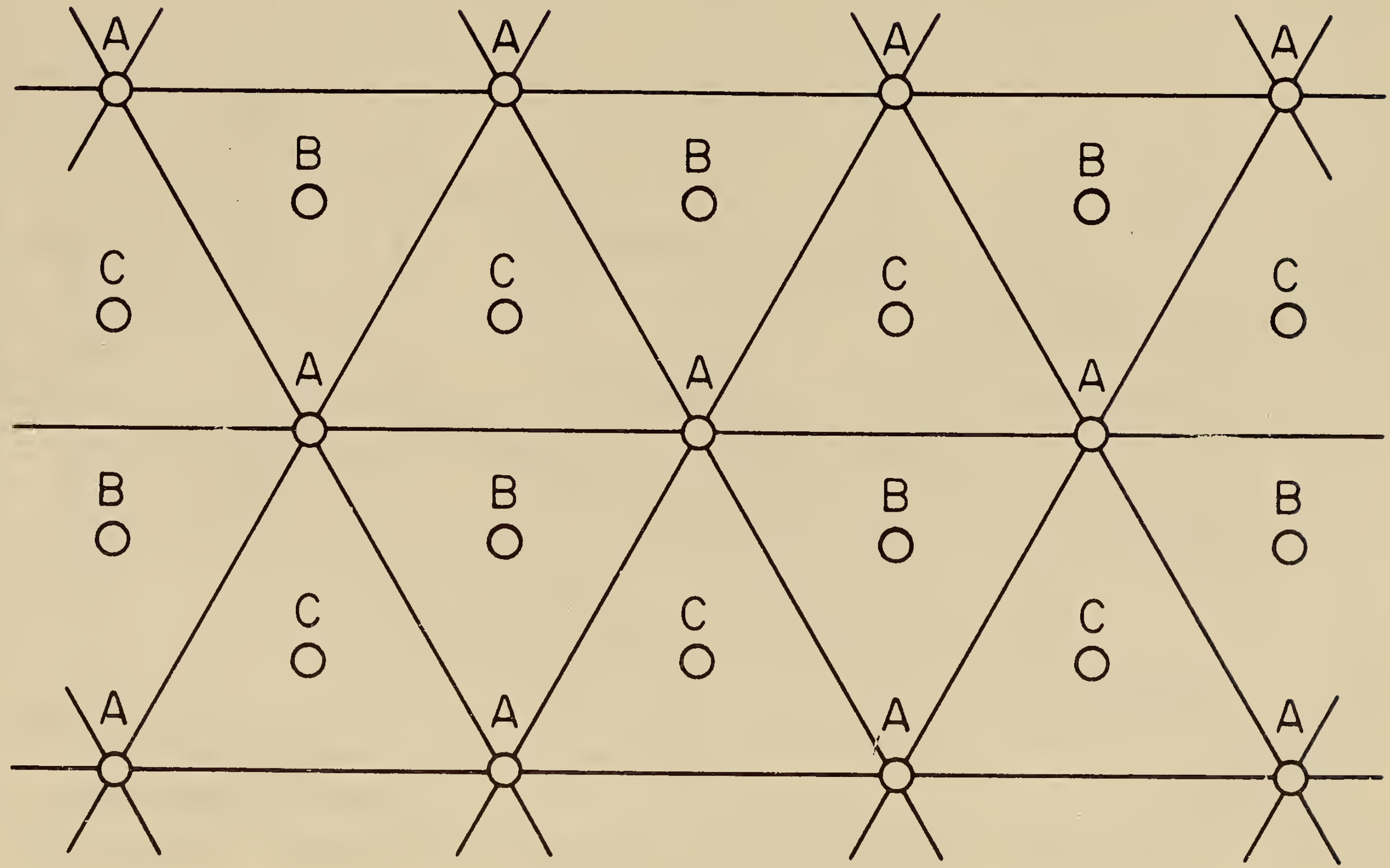


FIGURE 3

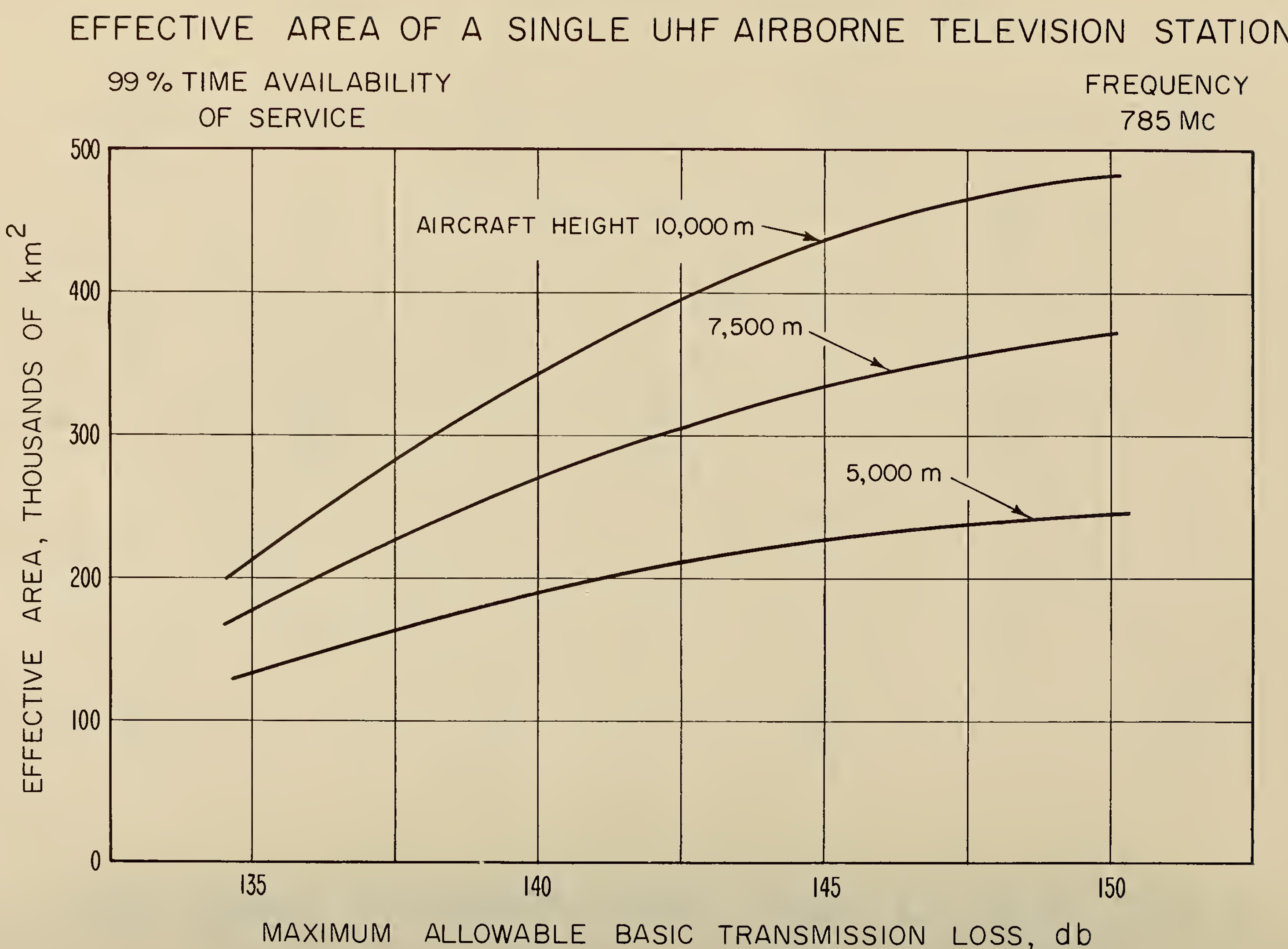

EFFECTIVE AREA OF A SINGLE UHF AIRBORNE TELEVISION STATION
99 % TIME AVAILABILITY OF SERVICE
FREQUENCY 785 Mc
AIRCRAFT HEIGHT 10,000 m
7,500 m
5,000 m
EFFECTIVE AREA, THOUSANDS OF km²
0
100
200
300
400
500
135
140
145
150
MAXIMUM ALLOWABLE BASIC TRANSMISSION LOSS, db

Figure 4

CONTOURS OF LOCATION PROBABILITY OF SERVICE FOR TWO ISOLATED CO-CHANNEL AIRBORNE TELEVISION STATIONS

99% TIME AVAILABILITY OF SERVICE
CO-CHANNEL PROTECTION RATIO 20 db
MAXIMUM ALLOWABLE TRANSMISSION LOSS 140 db

TRANSMITTER HEIGHT 7500 m
RECEIVING ANTENNA No 2
FREQUENCY 785 Mc

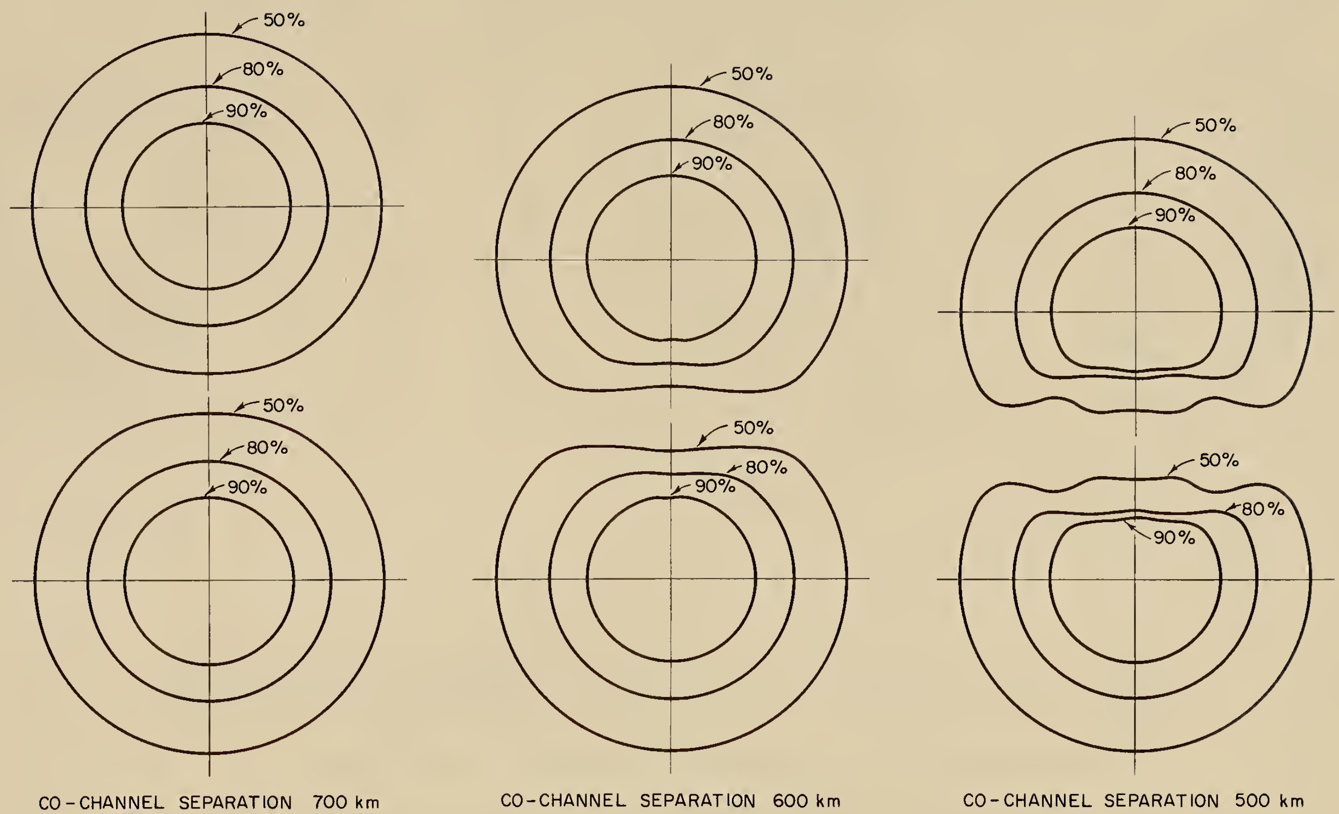
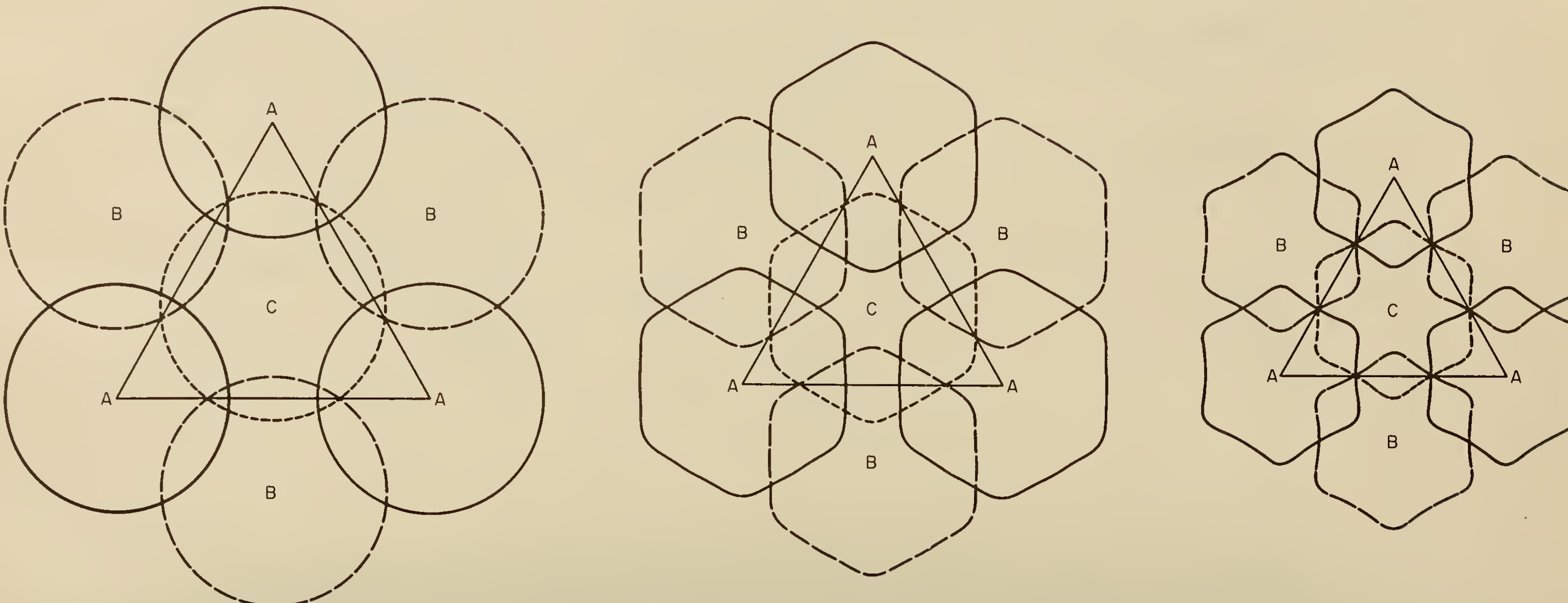


Figure 5a

CONTOURS OF LOCATION PROBABILITY OF SERVICE FOR AIRBORNE TELEVISION STATIONS IN A THREE-CHANNEL TRIANGULAR LATTICE

90% LOCATION PROBABILITY CONTOURS ONLY ARE SHOWN

99% TIME AVAILABILITY OF SERVICE		TRANSMITTER HEIGHT	7500 m
CO-CHANNEL PROTECTION RATIO	20 db	RECEIVING ANTENNA	Nº 2
MAXIMUM ALLOWABLE TRANSMISSION LOSS	145 db	FREQUENCY	785 Mc



CO-CHANNEL SEPARATION 800 km

CO-CHANNEL SEPARATION 700 km

CO-CHANNEL SEPARATION 600 km

Figure 5b

PERCENT OF LARGE AREA WHICH RECEIVES 99 PERCENT TIME AVAILABILITY OF SERVICE FROM STATIONS IN A TRIANGULAR LATTICE

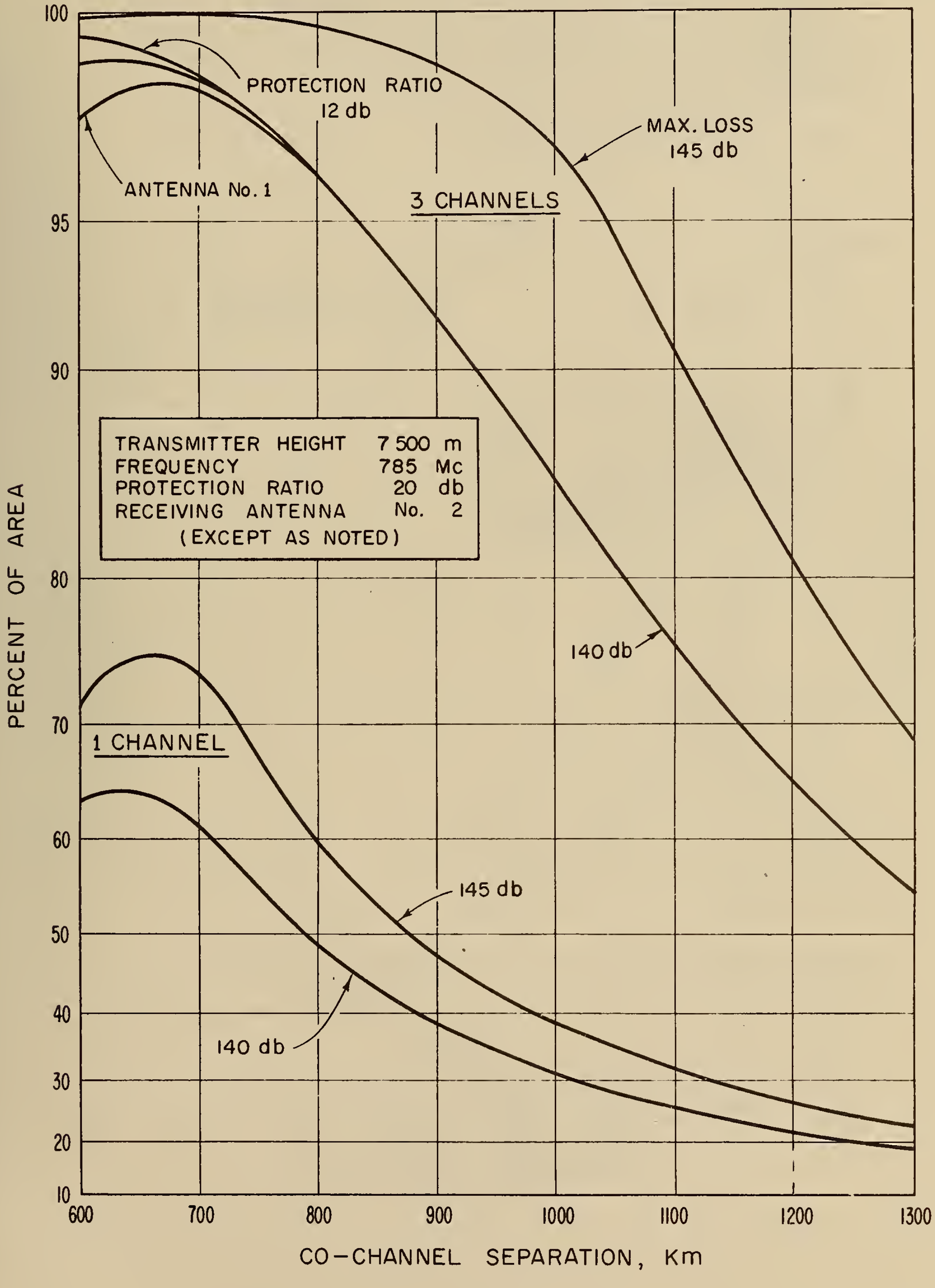


Figure 6

PERCENT OF LARGE AREA WHICH RECEIVES 99 PERCENT TIME AVAILABILITY OF SERVICE FROM STATIONS IN A TRIANGULAR LATTICE

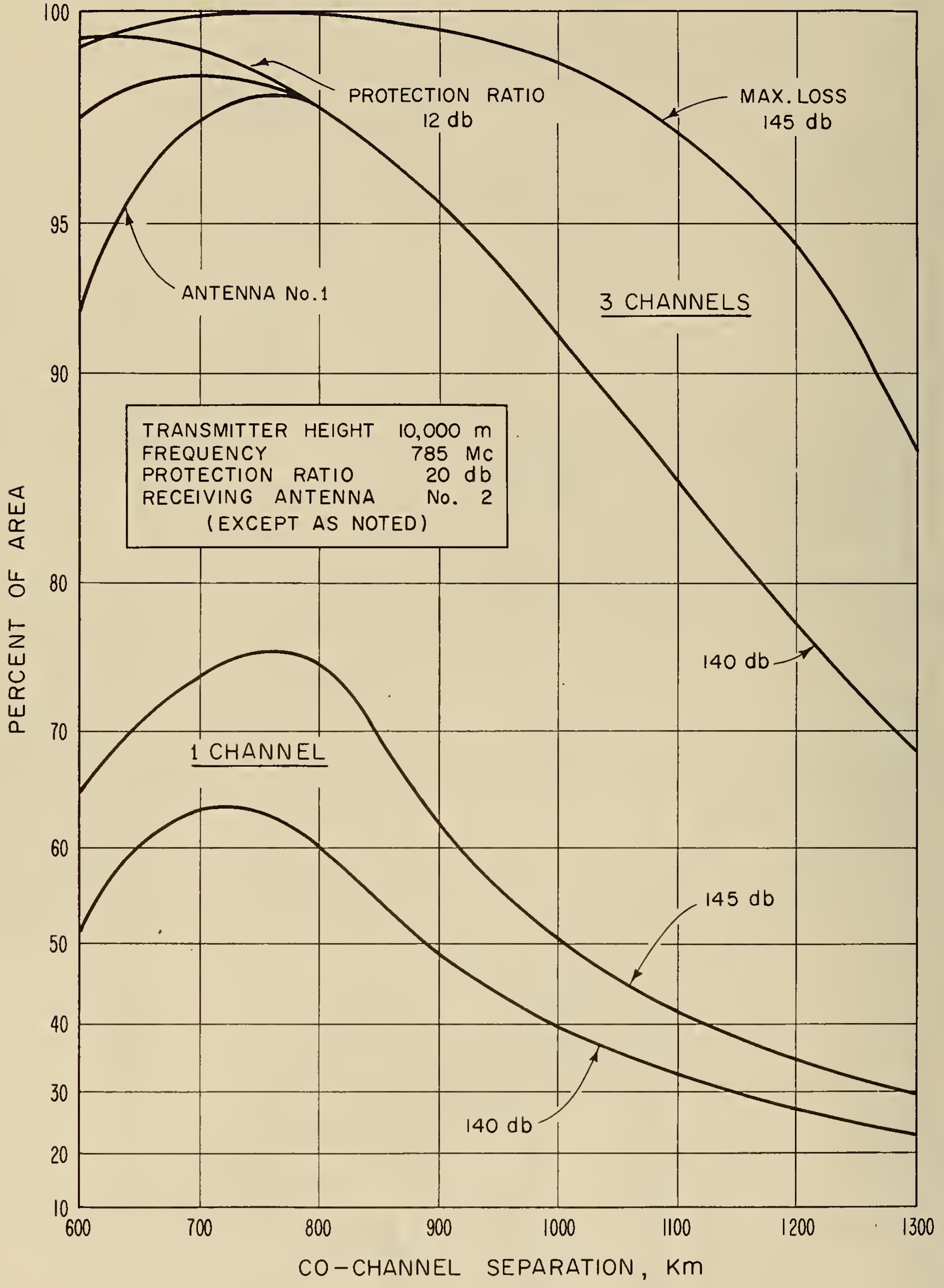


Figure 7

PERCENTAGE OF LOCATIONS REQUIRING RECEIVING ANTENNA PERFORMANCE BETTER THAN THAT OF ANTENNA Nº 1 TO ACHIEVE EFFECTIVE AREA COVERAGE EQUAL TO THAT OBTAINED WITH ANTENNA Nº 2 AT ALL LOCATIONS

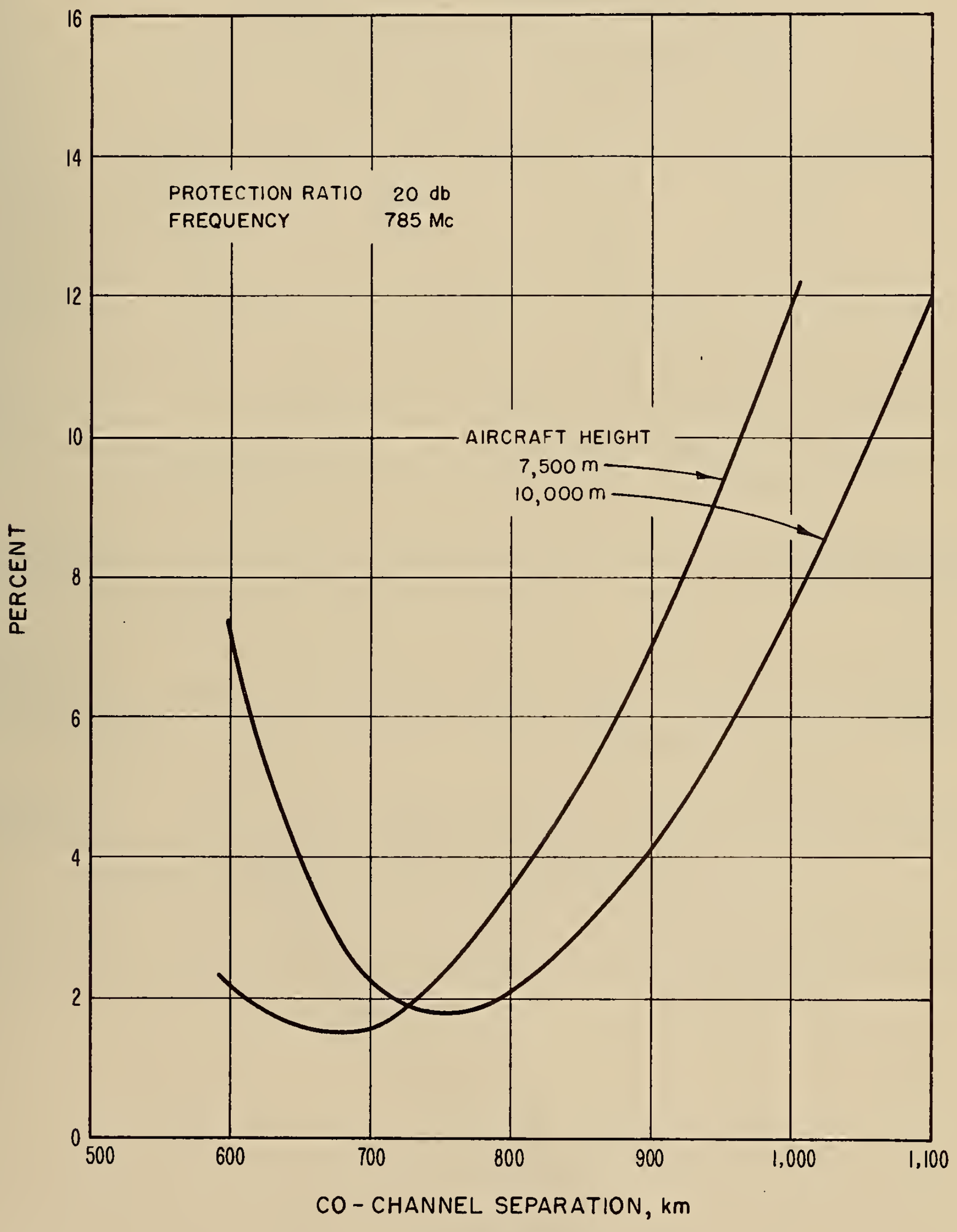


Figure 8

TABLE OF CONTENTS FOR CONTOUR DIAGRAMS

Figures 9 through 20

CONTOURS OF LOCATION PROBABILITY OF SERVICE

ONE INTERFERING STATION

Aircraft Height, H_t	7500 meters
Aircraft Flight Radius	15 km
Frequency	785 Mc
Time Availability of Service	99 %

$L_{b(max)}$ = Maximum Allowable Basic Transmission Loss

P = Protection Ratio

D = Co-channel Separation Distance

H_t = 7500 Meters
ANTENNA Nº 1

$L_{b\,(max)} = 140$ db
P = 12 db

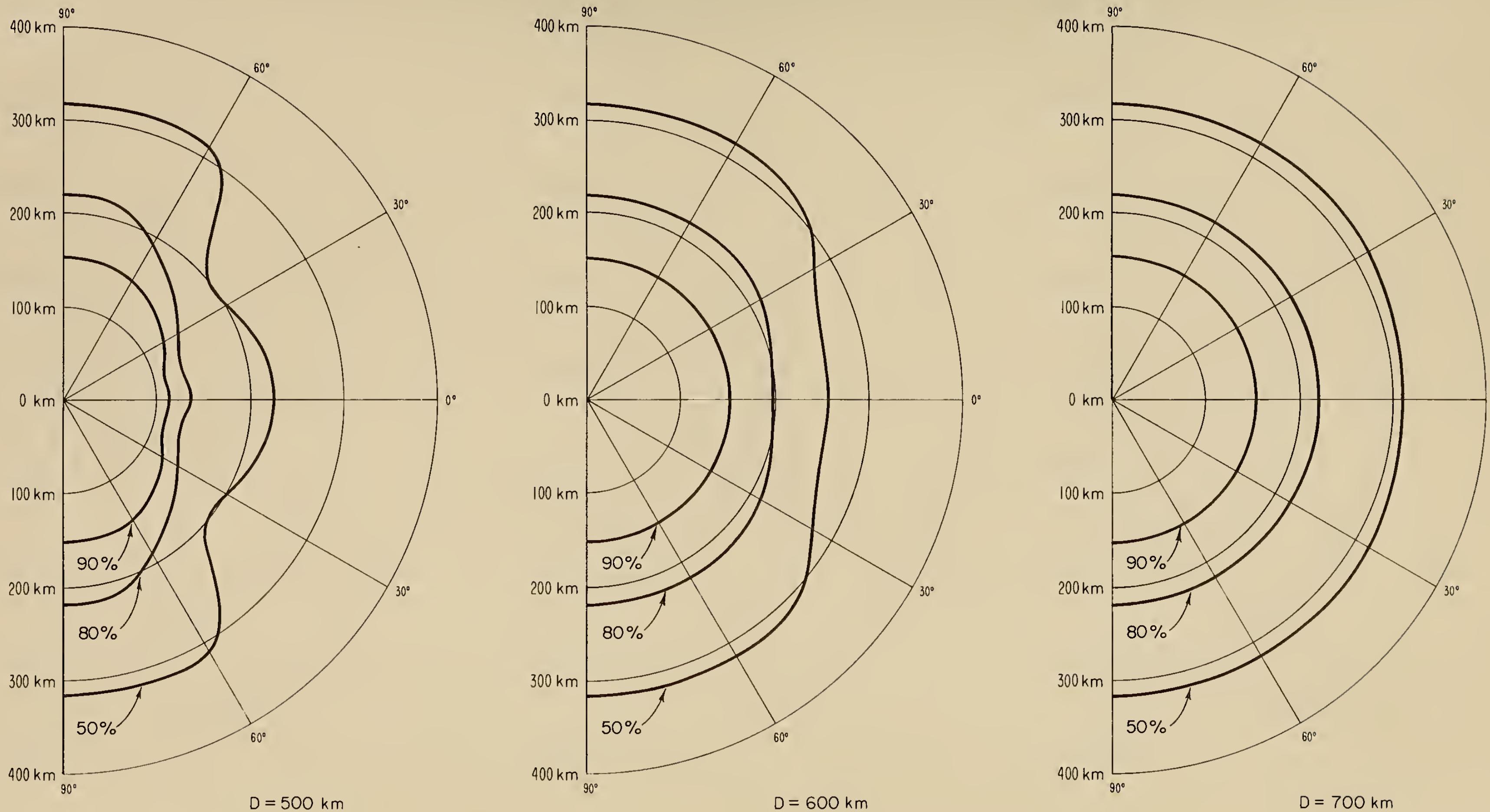


Figure 9

H_t = 7500 Meters $L_{b(max)}$ = 140 db

ANTENNA Nº 1 P = 20 db

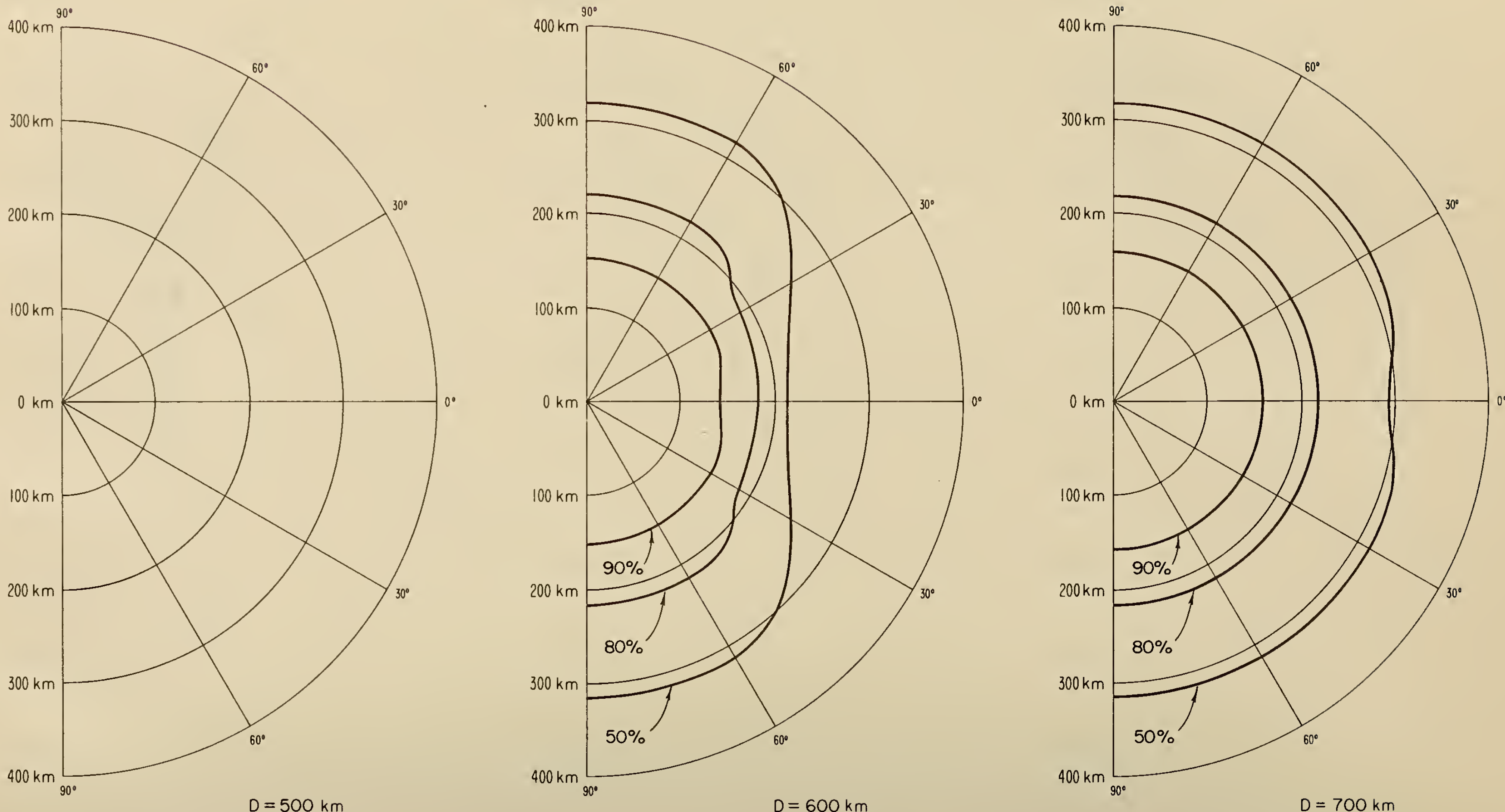


Figure 10

H_t = 7500 Meters
ANTENNA N° 1

$L_{b\,(max)}$ = 140 db
P = 27 db

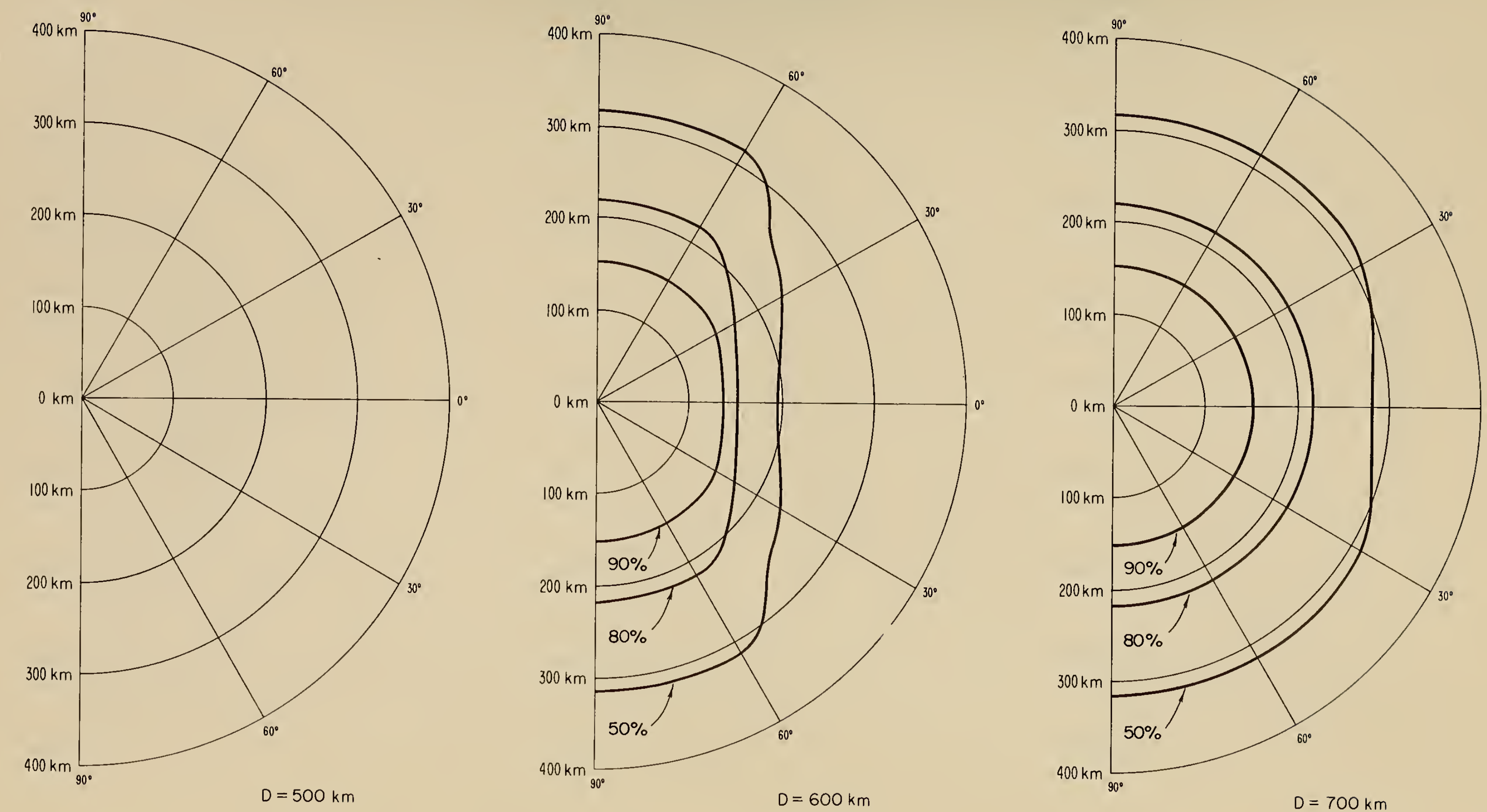


Figure 11

H_t = 7500 Meters $L_{b\,(max)}$ = 140 db

ANTENNA N° 2   P = 12 db

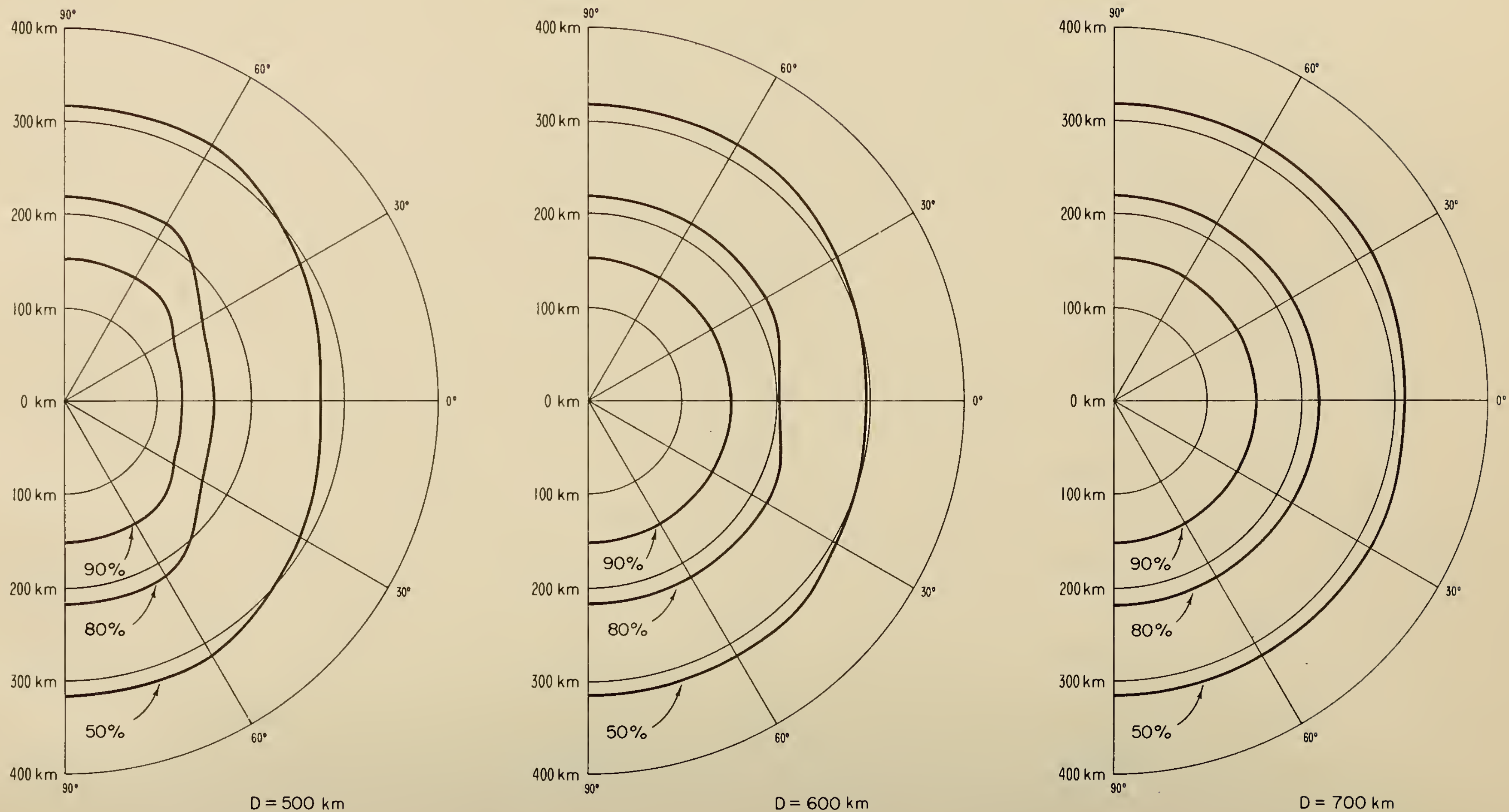


Figure 12

H_t = 7500 Meters $\qquad L_{b\,(max)}$ = 140 db

ANTENNA N° 2 $\qquad$ P = 20 db

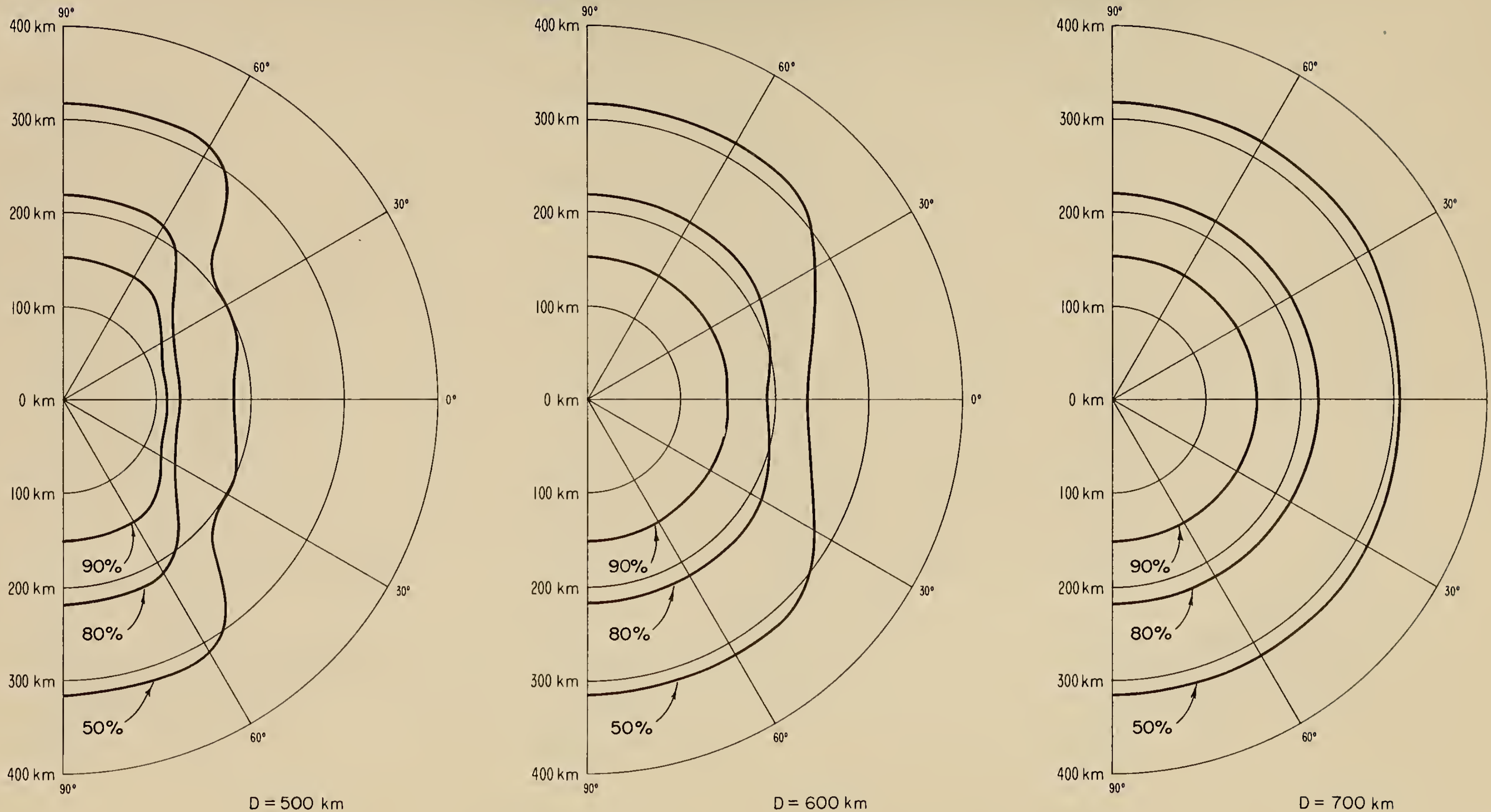


Figure 13

H_t = 7500 Meters $\qquad L_{b\,(max)}$ = 140 db

ANTENNA N° 2 $\qquad P$ = 27 db

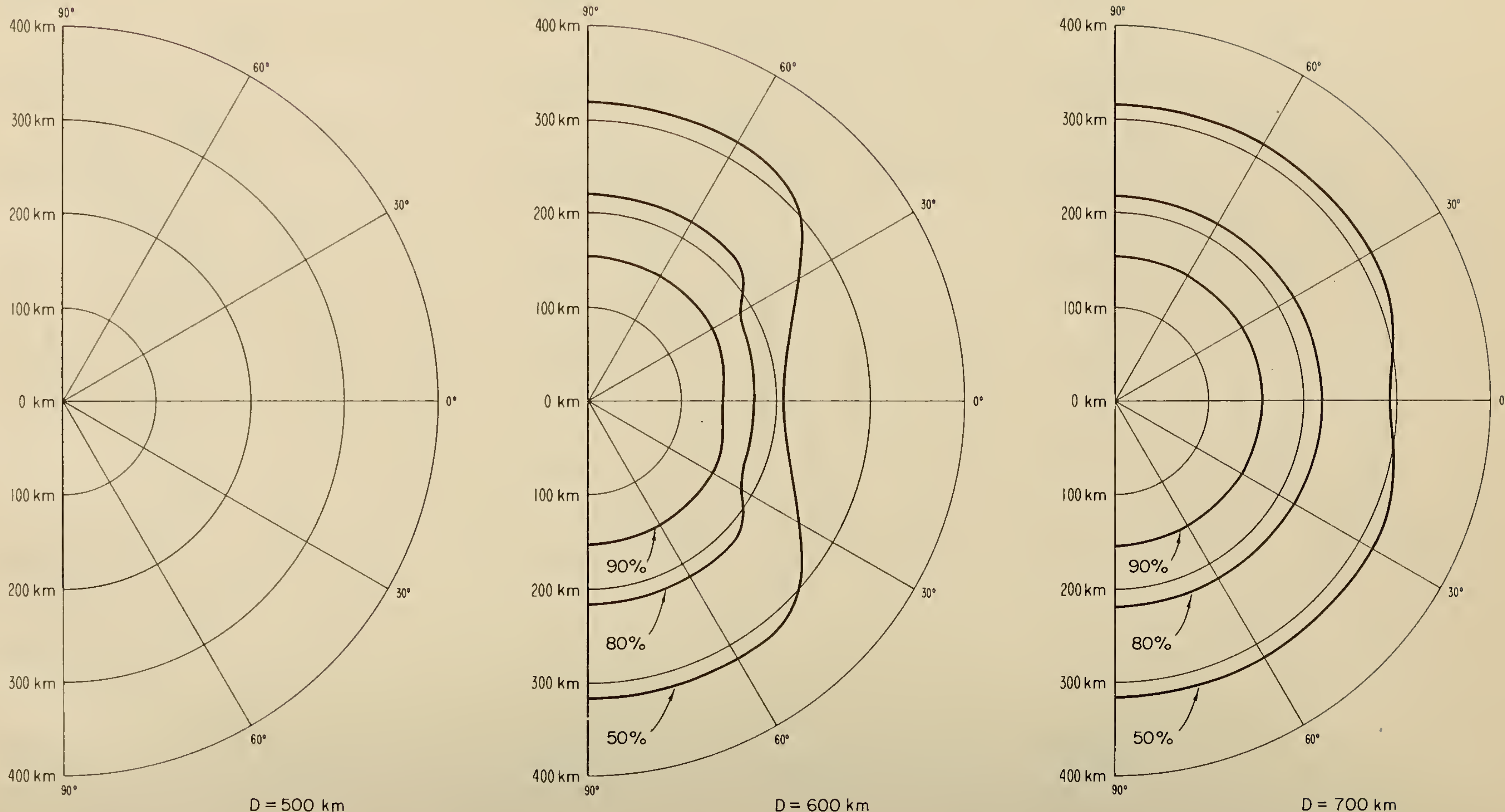


Figure 14

H_t = 7500 Meters $L_{b(max)}$ = 145 db

ANTENNA Nº 1   P = 12 db

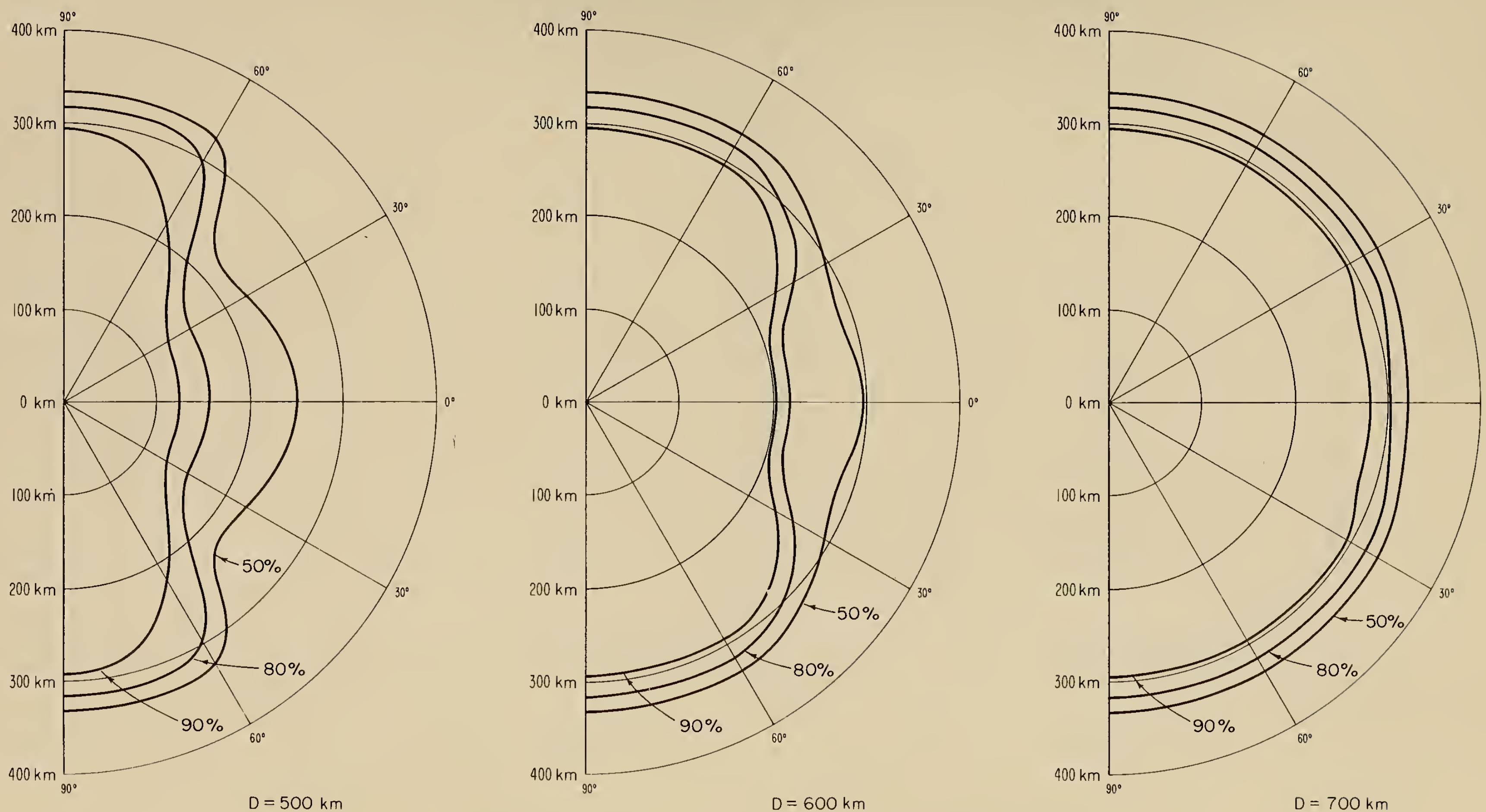


Figure 15

H_t = 7500 Meters

ANTENNA N° 1

$L_{b\,(max)}$ = 145 db

P = 20 db

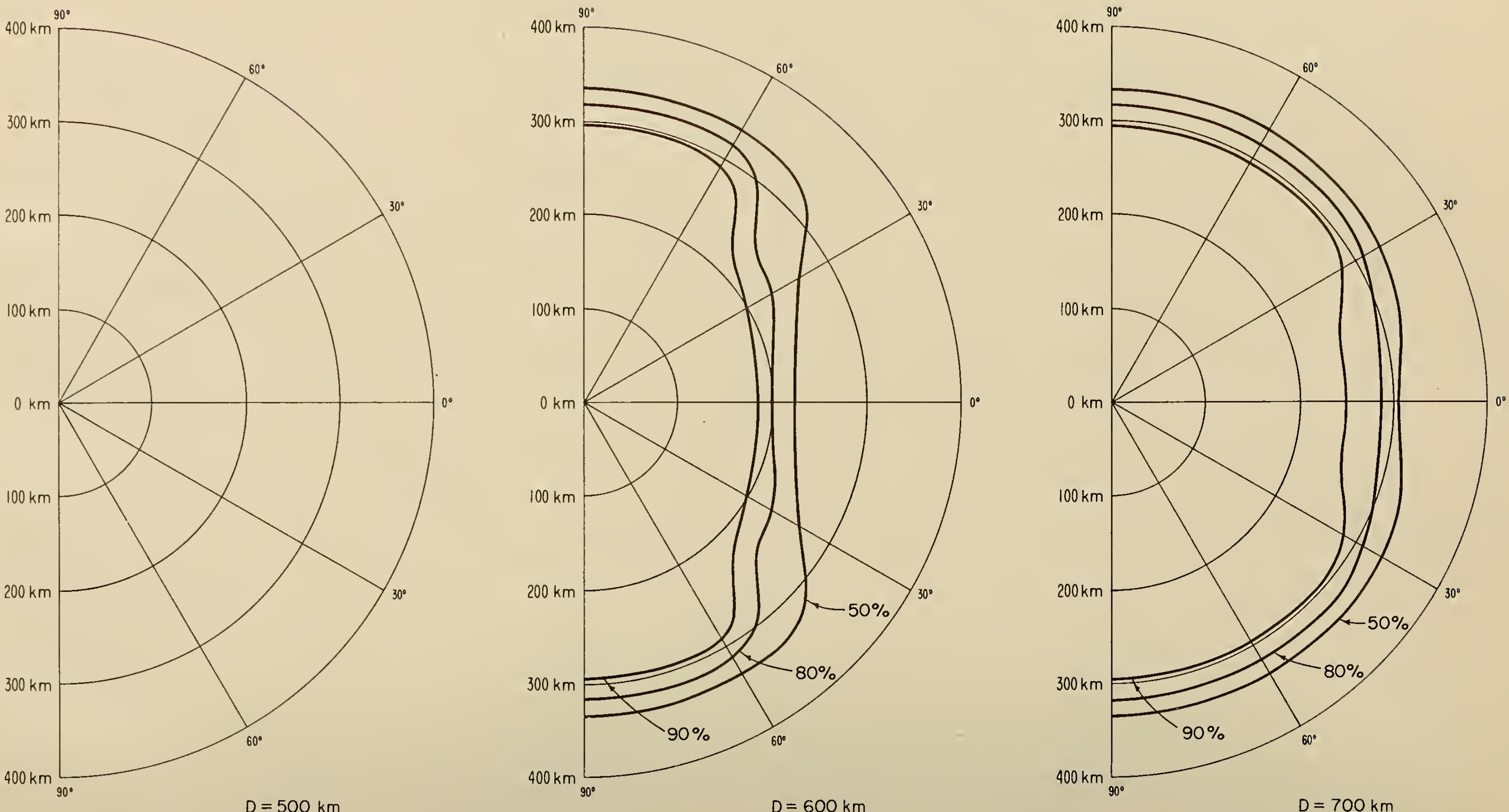


Figure 16

H_t = 7500 Meters $\quad$ $L_{b\,(max)}$ = 145 db

ANTENNA Nº 1 $\quad$ P = 27 db

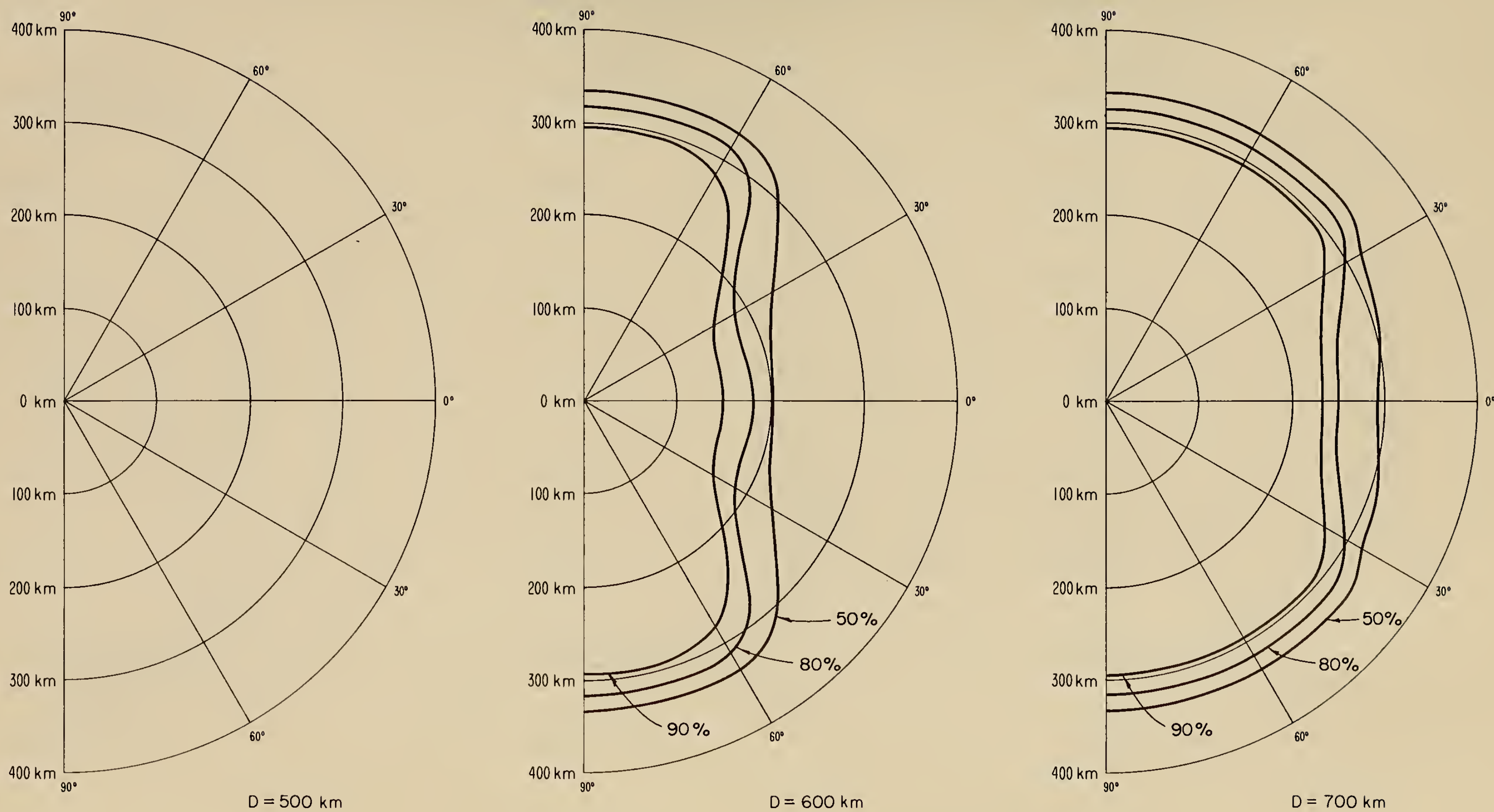


Figure 17

H_t = 7500 Meters

ANTENNA Nº 2

$L_{b\,(max)}$ = 145 db

P = 12 db

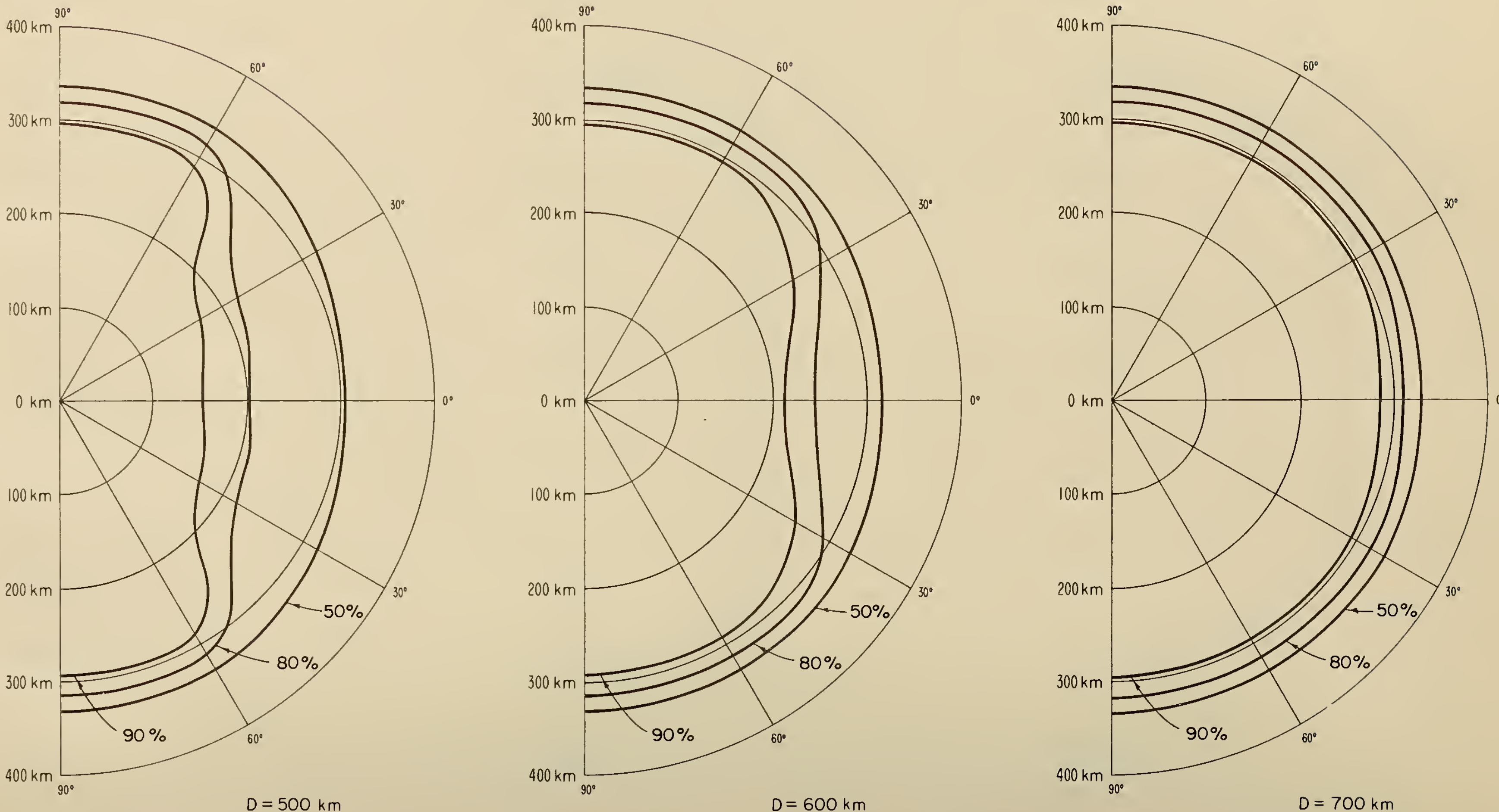


Figure 18

H_t = 7500 Meters

ANTENNA N° 2

$L_{b\,(max)}$ = 145 db

P = 20 db

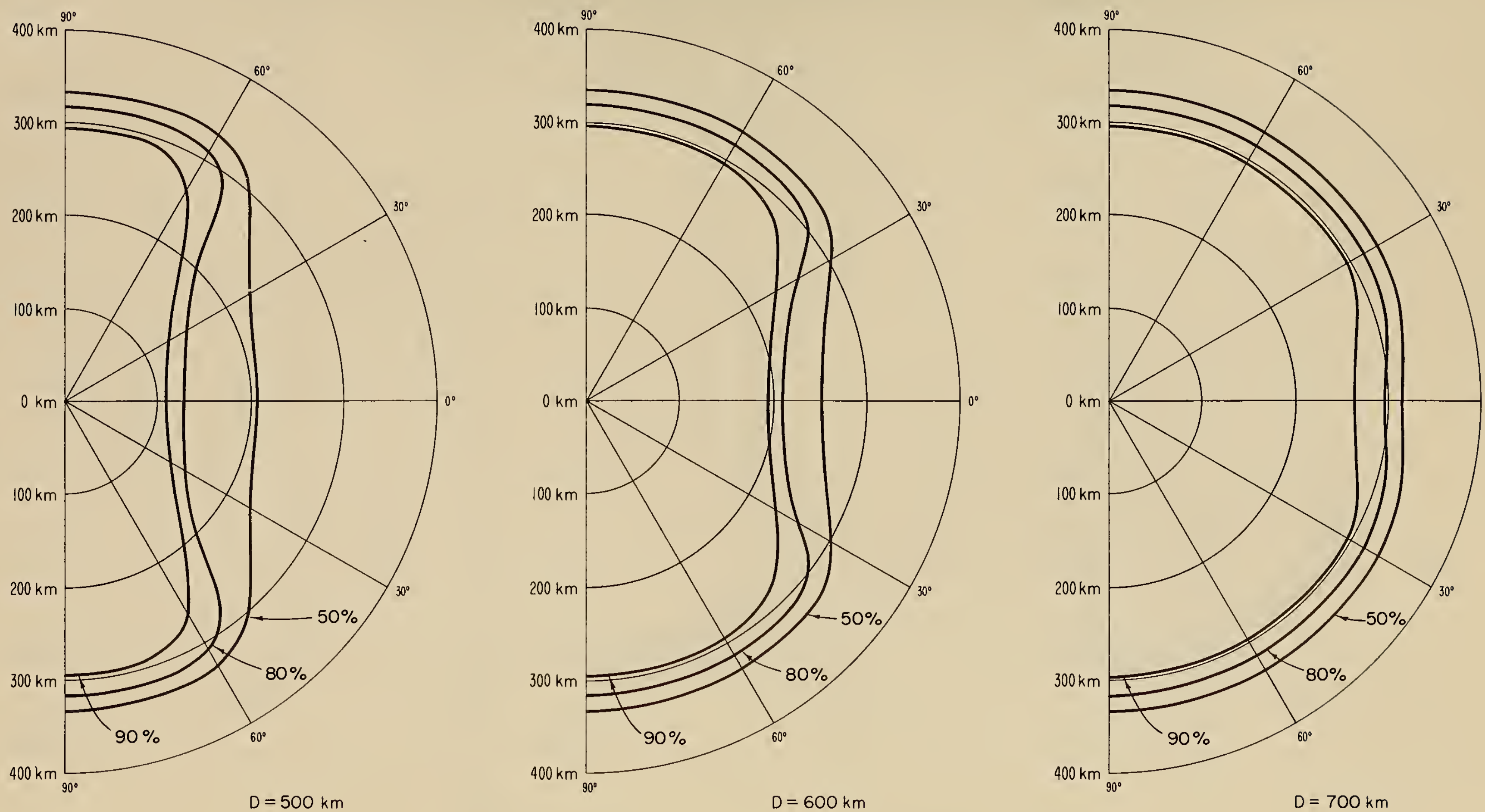


Figure 19

H_t = 7500 Meters $\qquad$ $L_{b\,(max)}$ = 145 db

ANTENNA Nº 2 $\qquad$ P = 27 db

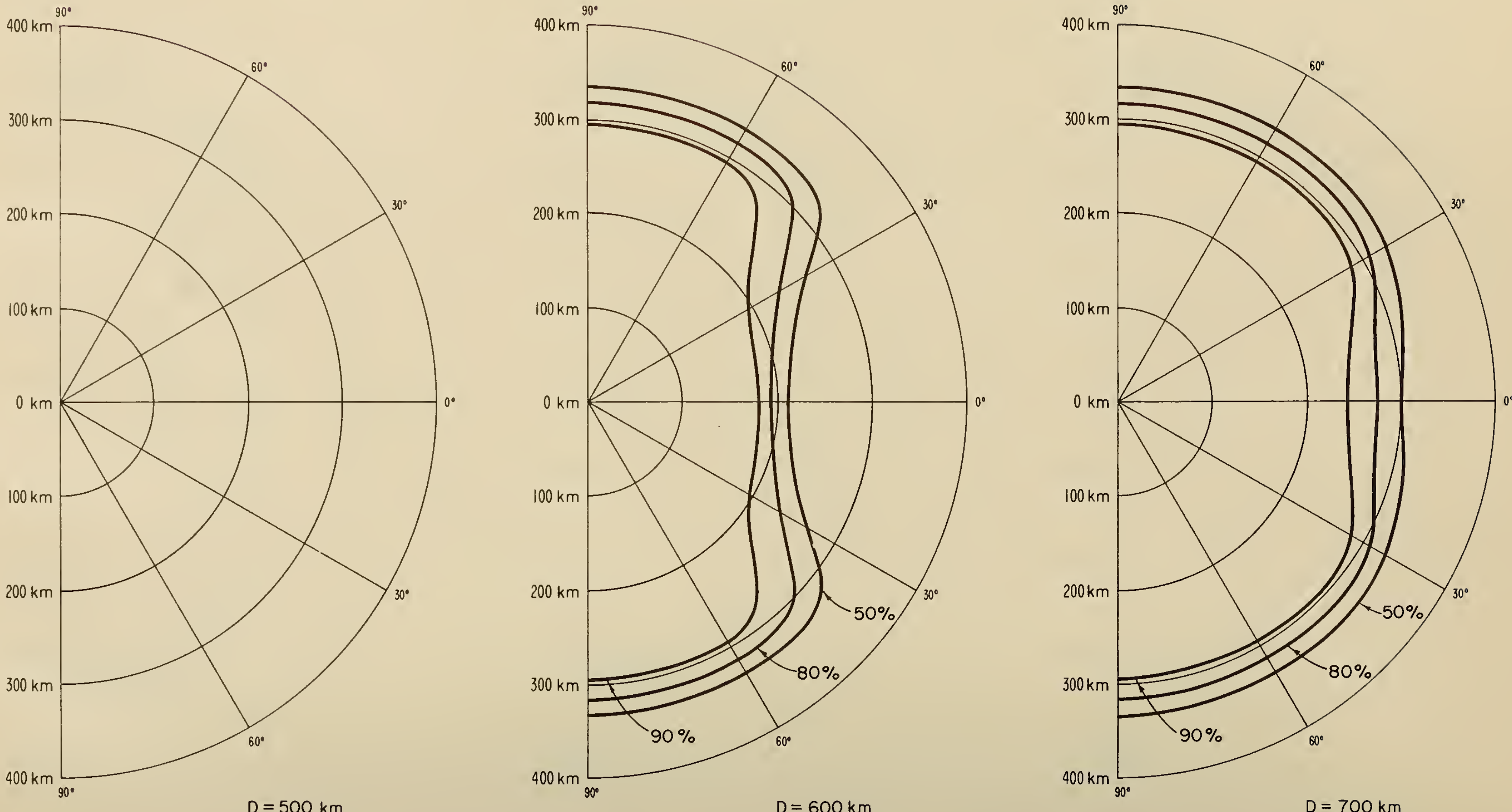


Figure 20

Figures 21 through 32

CONTOURS OF LOCATION PROBABILITY OF SERVICE

STATIONS IN A TRIANGULAR LATTICE

Aircraft Height, H_t .... 7500 meters

Aircraft Flight Radius .... 15 km

Frequency .... 785 Mc

Time Availability of Service .... 99 %

$L_{b(max)}$ = Maximum Allowable Basic Transmission Loss

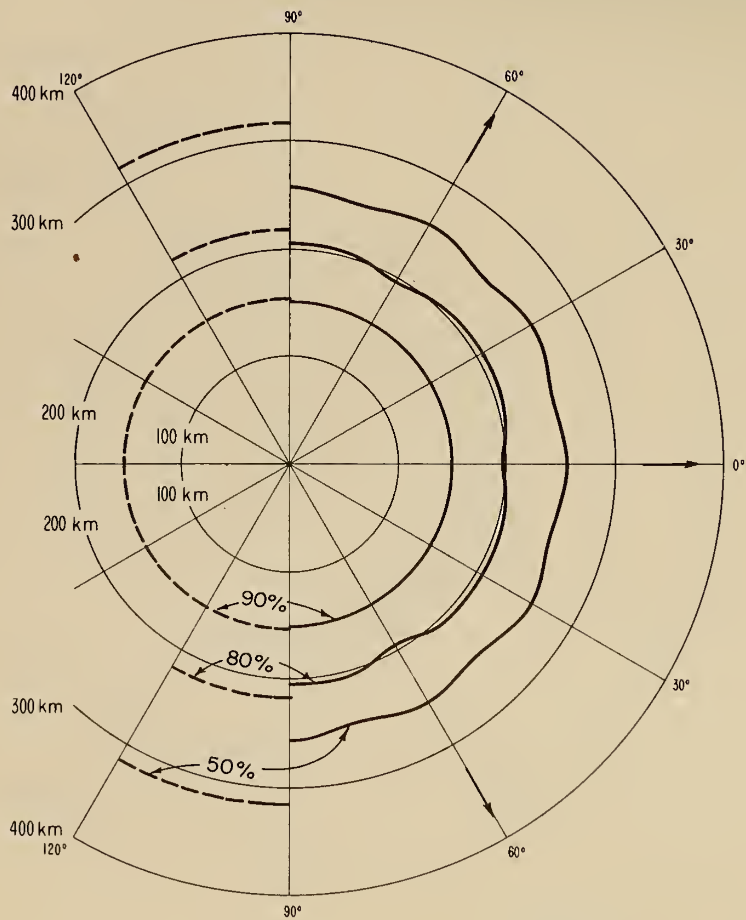
P = Protection Ratio

D = Co-channel Separation Distance

Dashed lines indicate interference-free contours

H_t = 7500 Meters
ANTENNA Nº 1

$L_{b(max)}$ = 140 db
P = 12 db



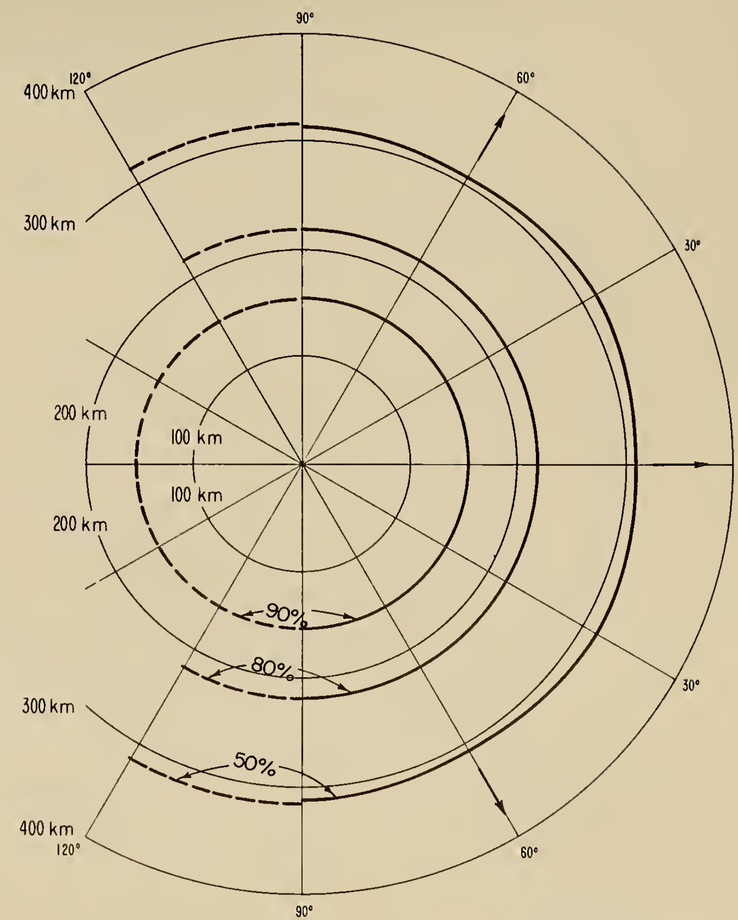


Figure 21

H_t = 7500 Meters
ANTENNA N° 1

$L_{b(max)}$ = 140 db
P = 20 db

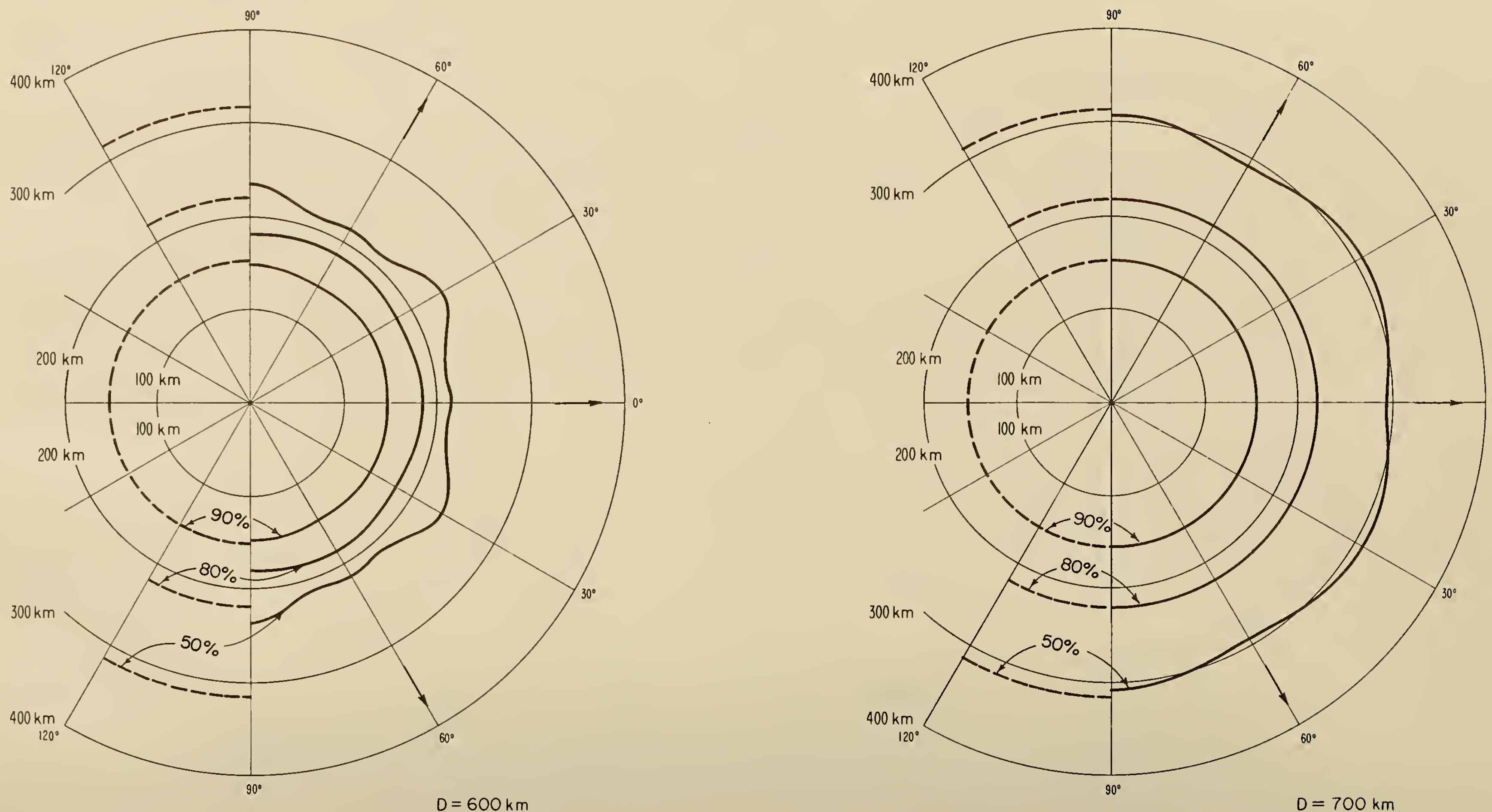
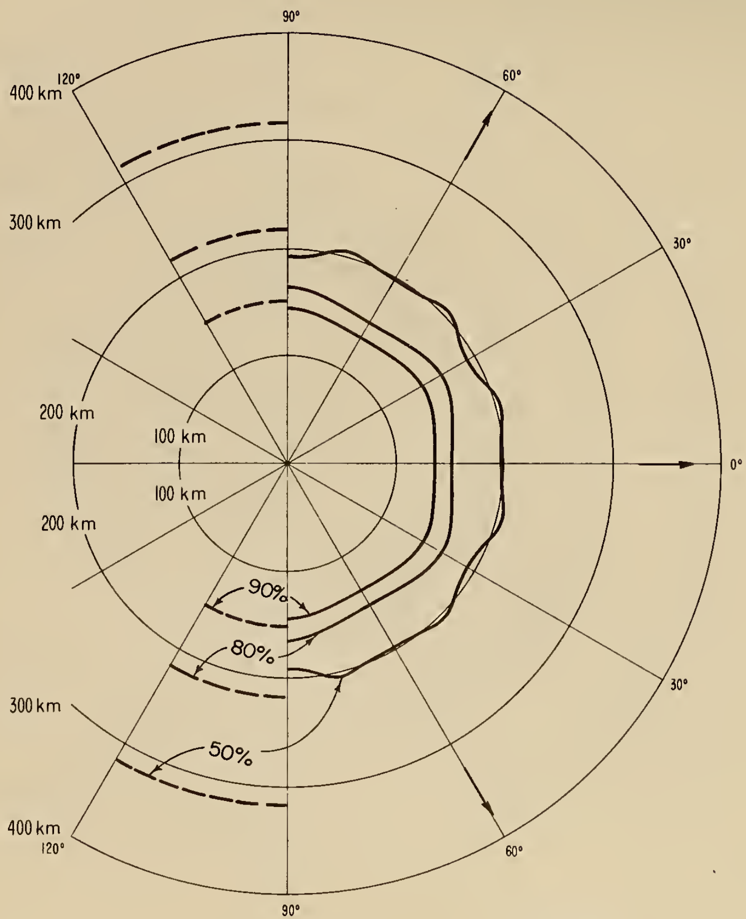


Figure 22

H_t = 7500 Meters
ANTENNA N° 1

$L_{b(max)}$ = 140 db
P = 27 db



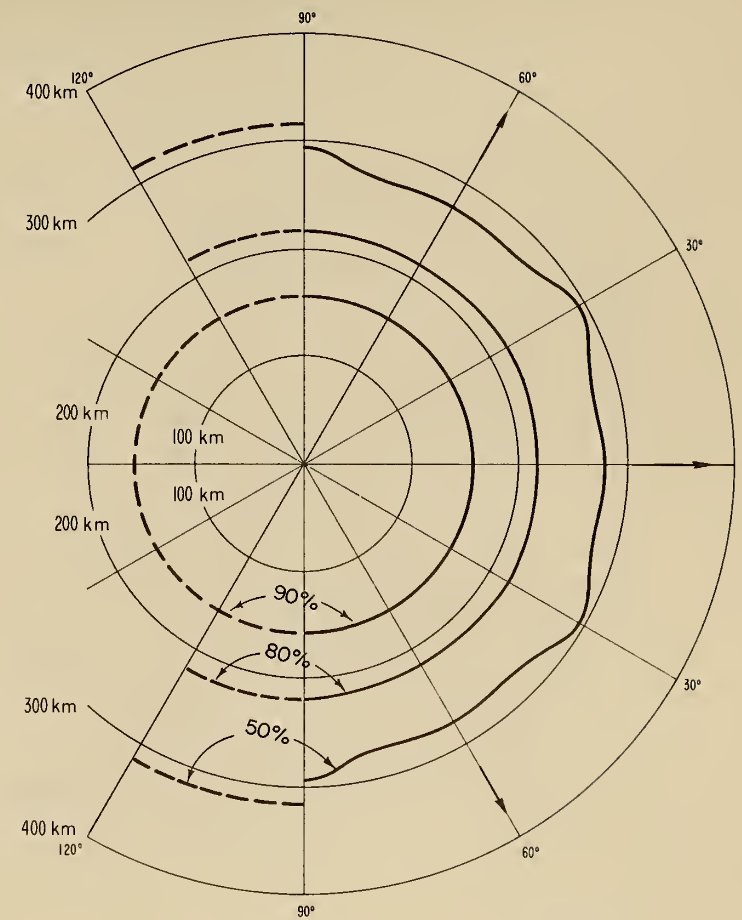
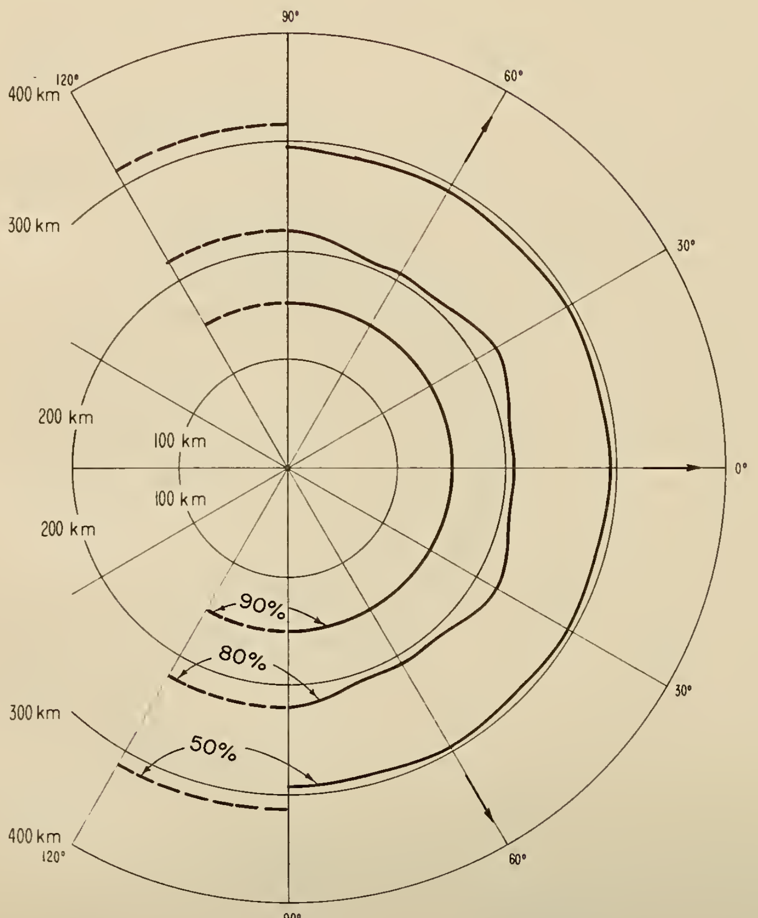


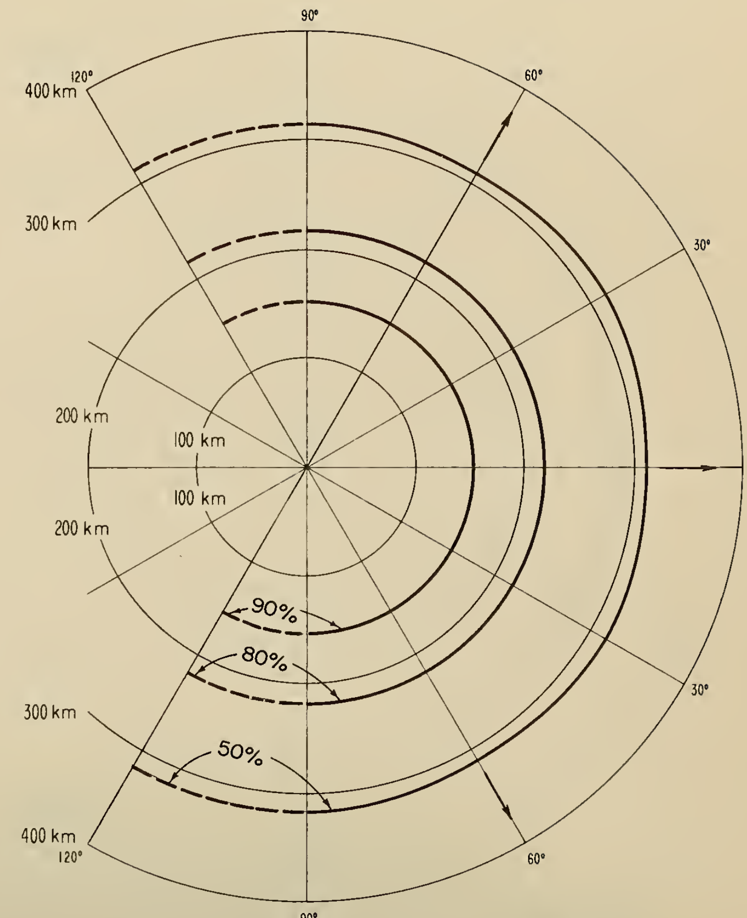
Figure 23

H_t = 7500 Meters
ANTENNA Nº 2

$L_{b(max)}$ = 140 db
P = 12 db



D = 600 km

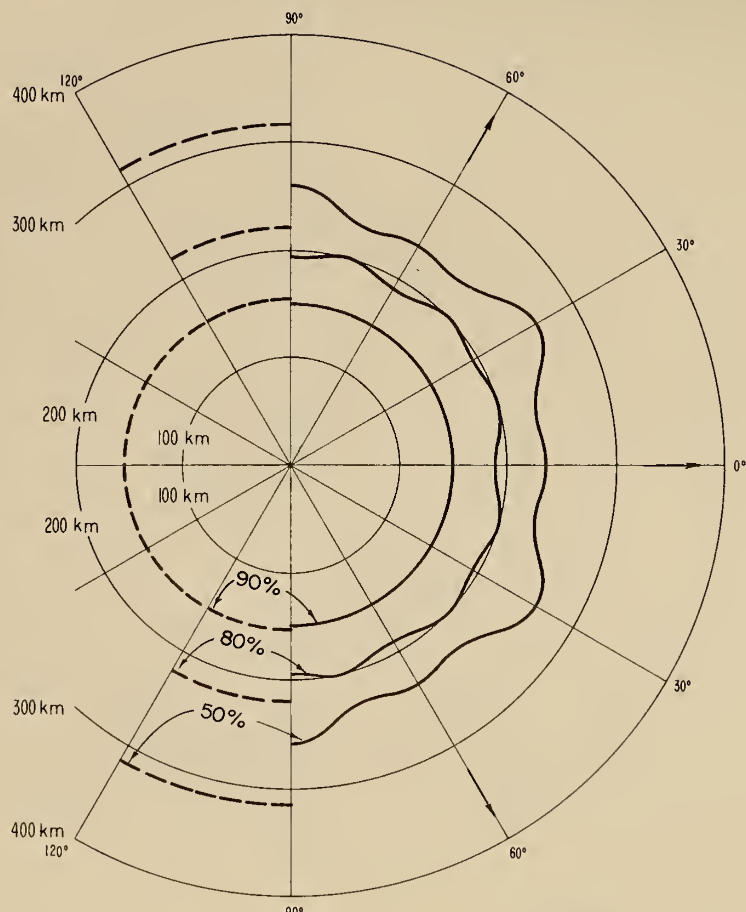


D = 700 km

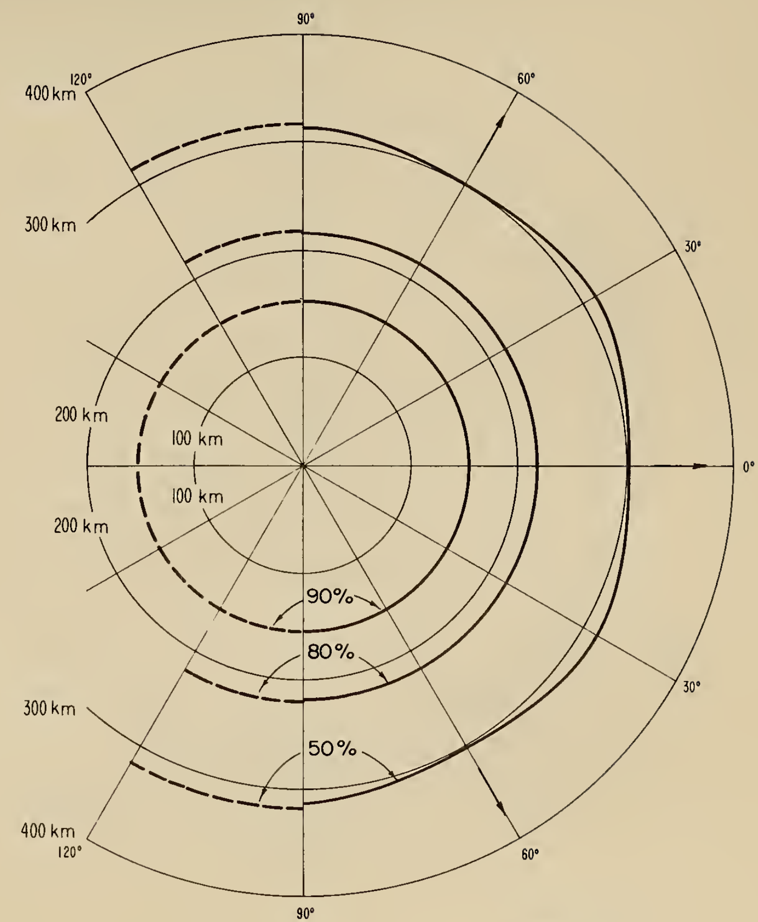
Figure 24

H_t = 7500 Meters
ANTENNA Nº 2

$L_{b(max)}$ = 140 db
P = 20 db



D = 600 km

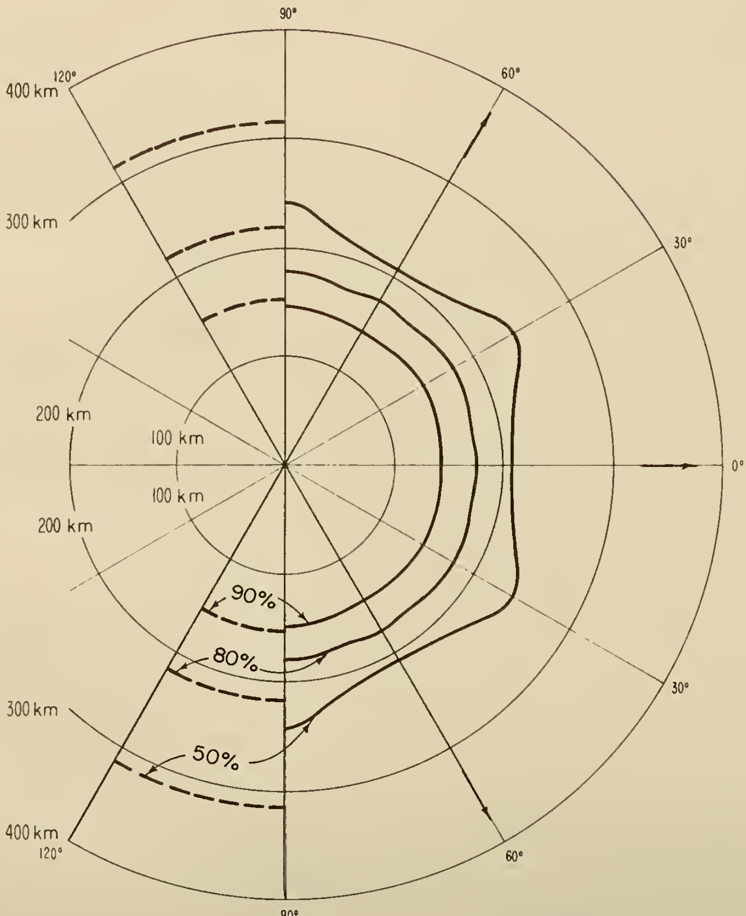


D = 700 km

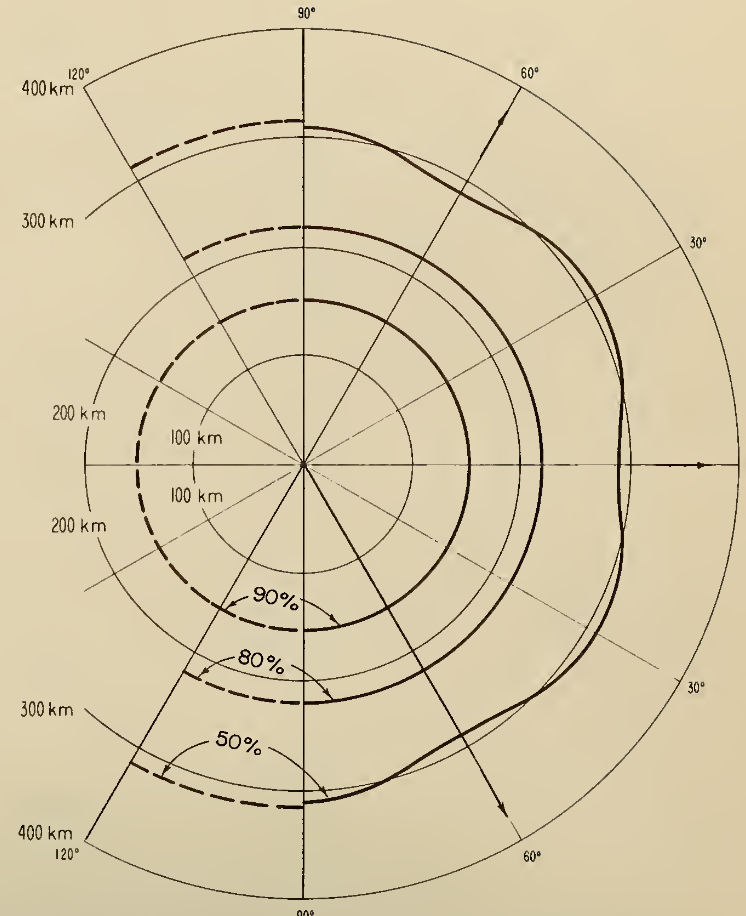
Figure 25

H_t = 7500 Meters
ANTENNA Nº 2

$L_{b(max)}$ = 140 db
P = 27 db



D = 600 km

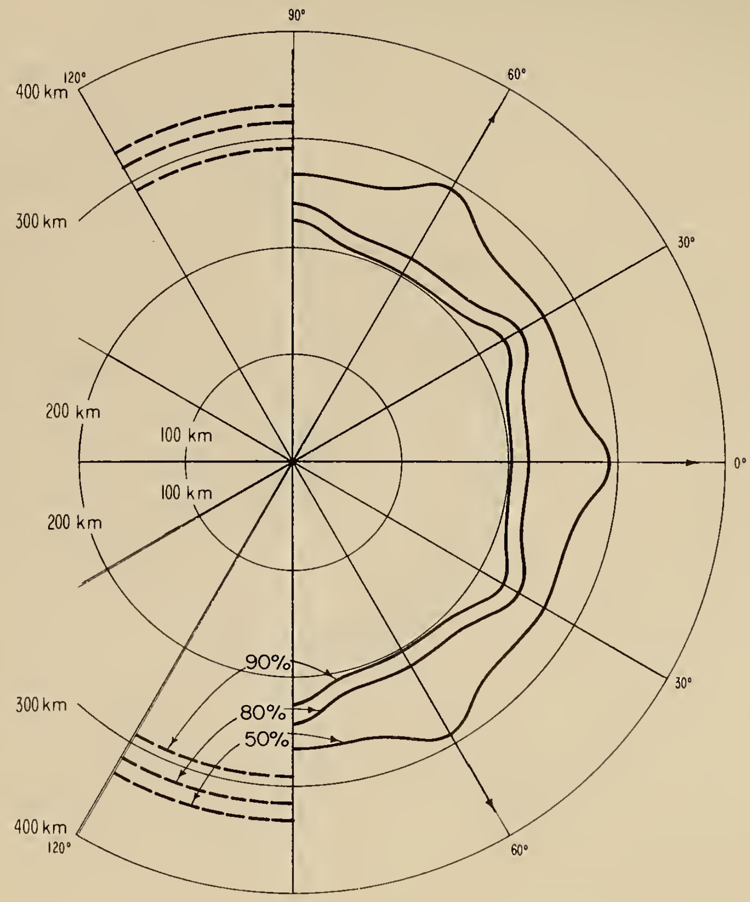


D = 700 km

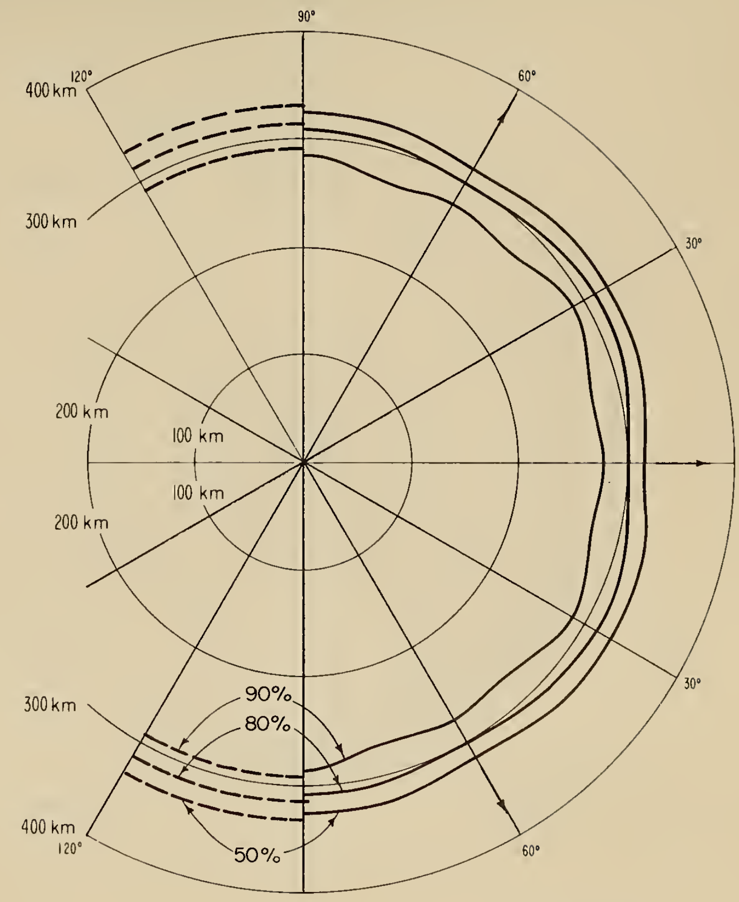
Figure 26

H_t = 7500 Meters
ANTENNA N° 1

$L_{b(max)}$ = 145 db
P = 12 db



D = 600 km



D = 700 km

Figure 27

H_t = 7500 Meters
ANTENNA Nº 1

$L_{b(max)}$ = 145 db
P = 20 db

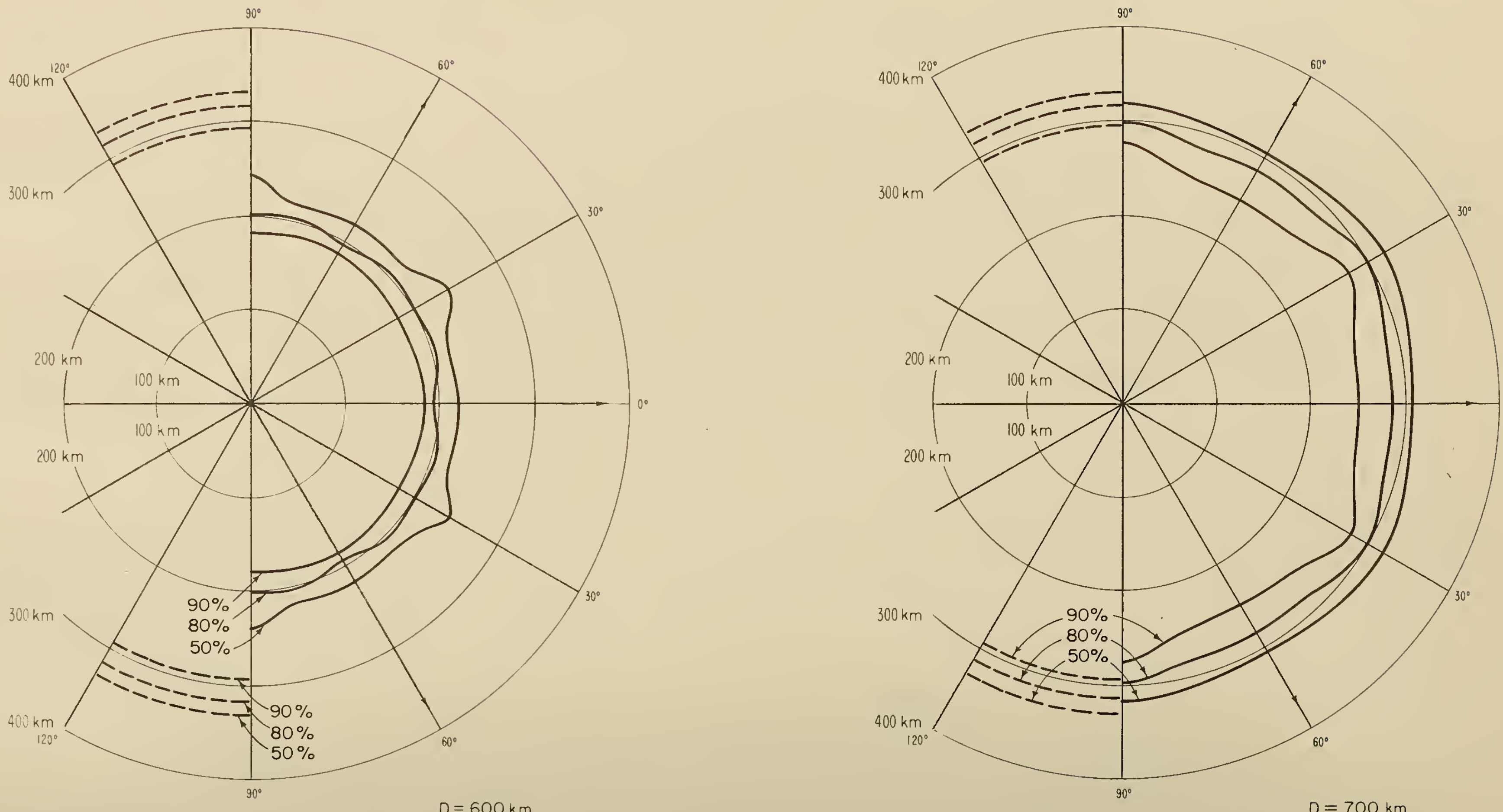


Figure 28

H_t = 7500 Meters $\qquad L_{b(max)}$ = 145 db

ANTENNA N° 1 $\qquad P$ = 27 db

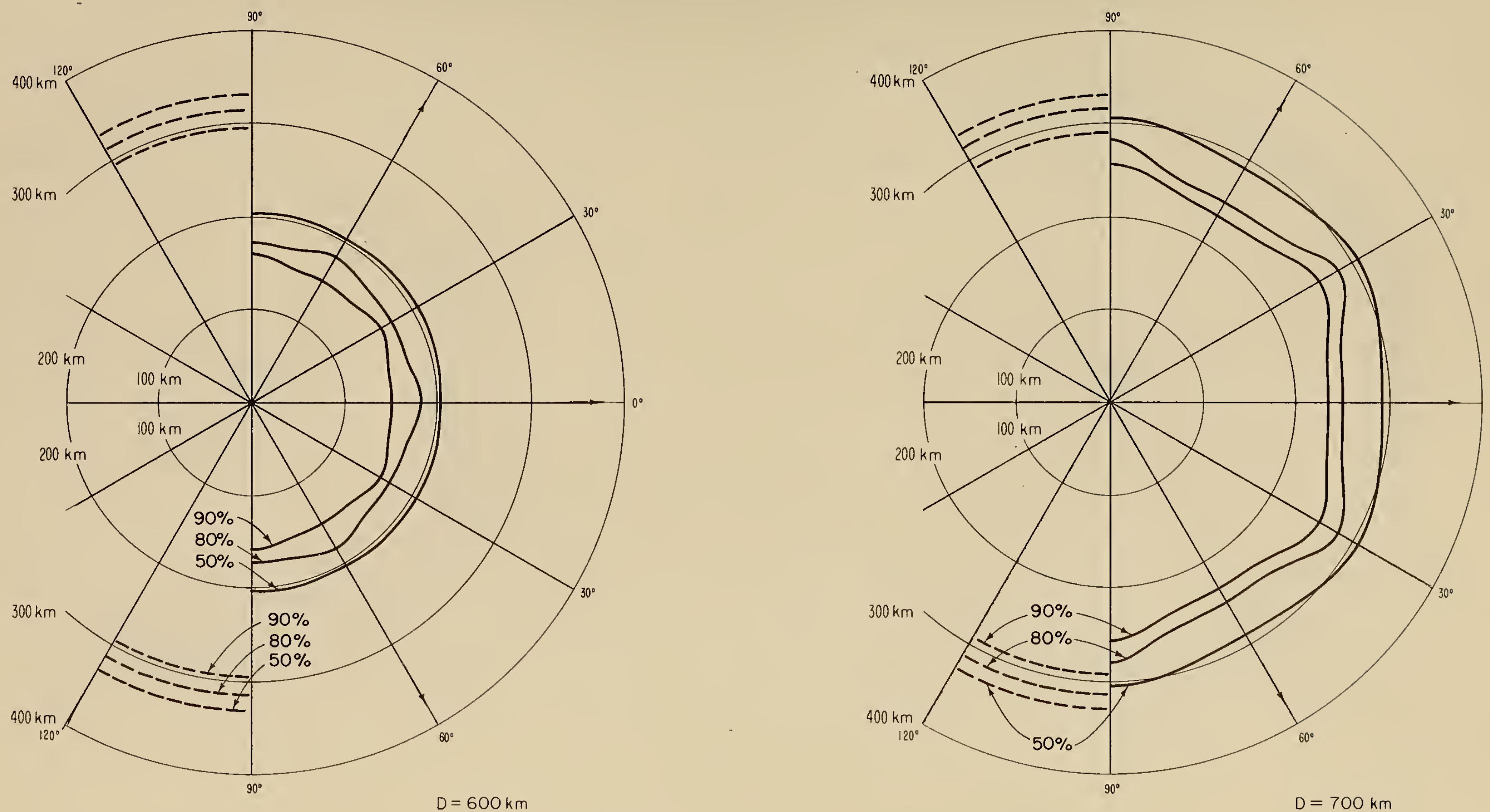
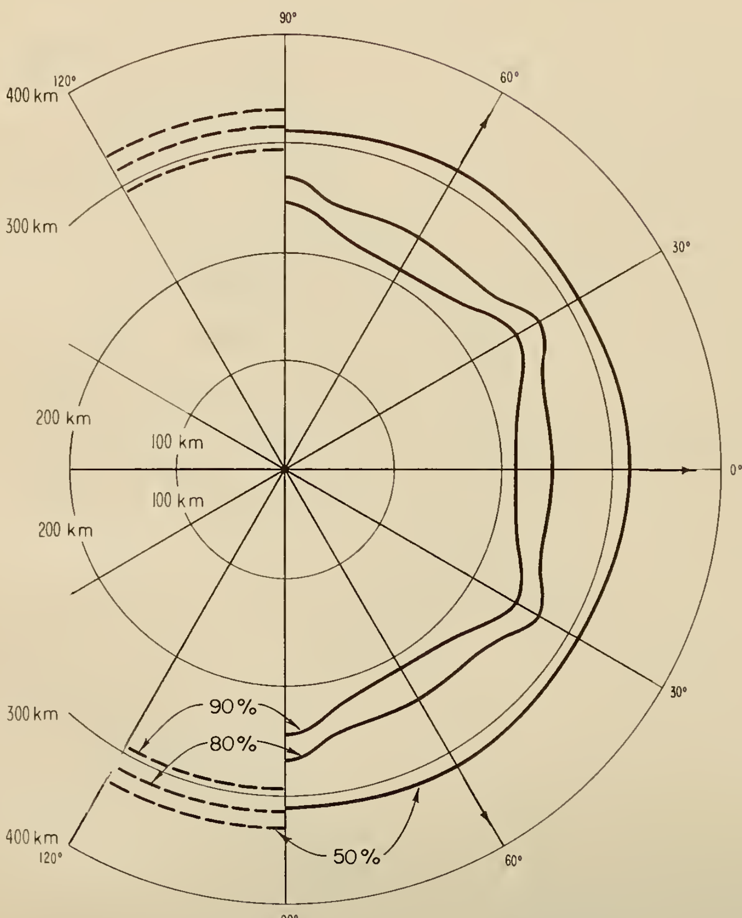


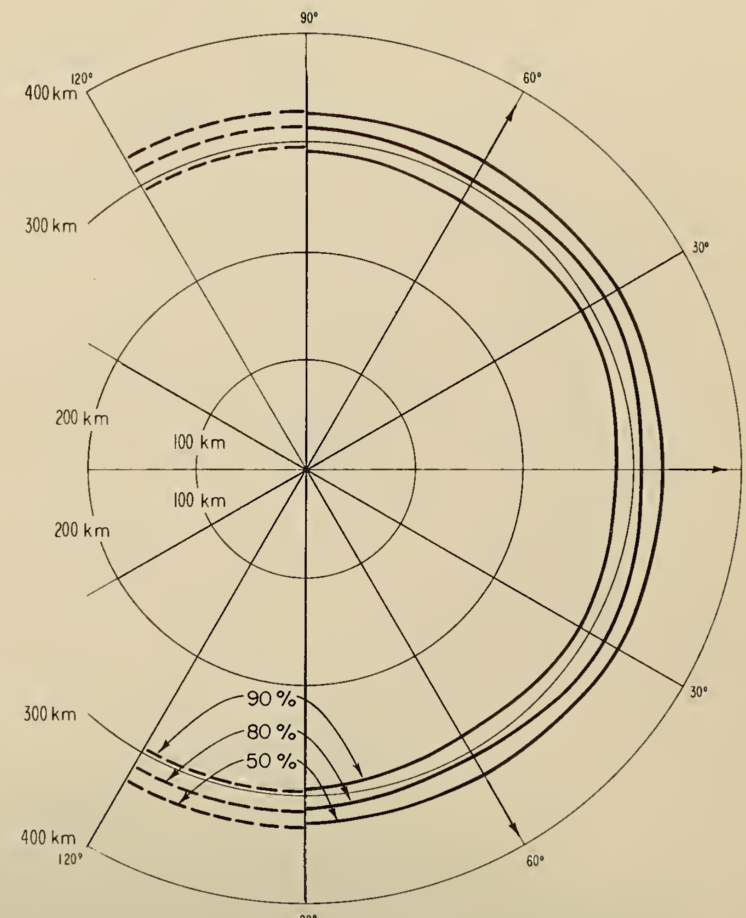
Figure 29

H_t = 7500 Meters
ANTENNA N° 2

$L_{b(max)}$ = 145 db
P = 12 db



D = 600 km

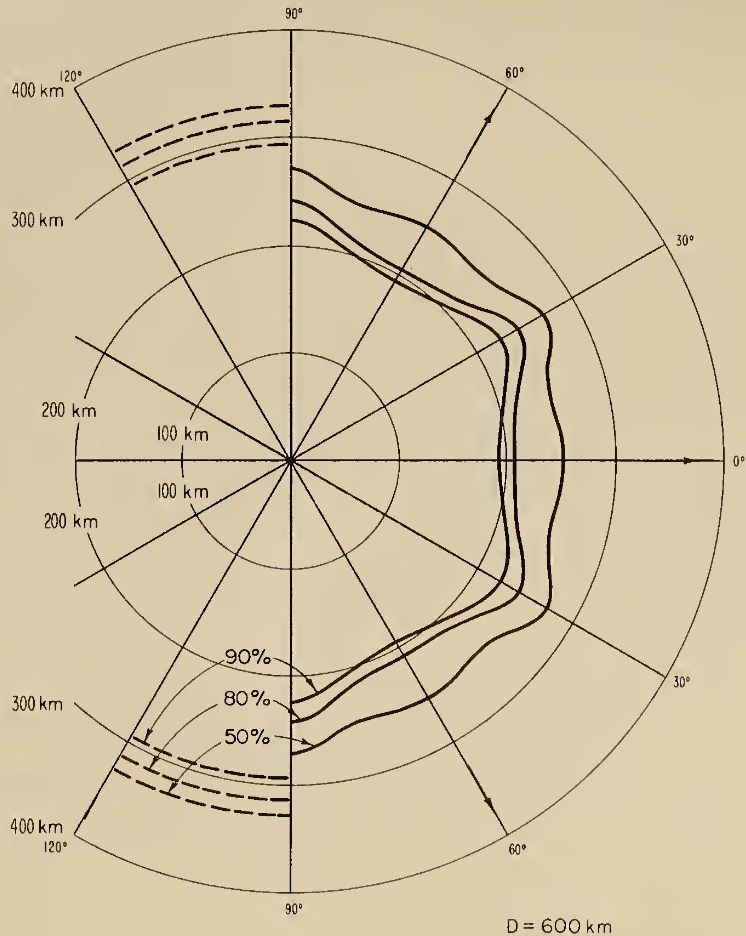


D = 700 km

Figure 30

H_t = 7500 Meters
ANTENNA №. 2

$L_{b(max)}$ = 145 db
P = 20 db



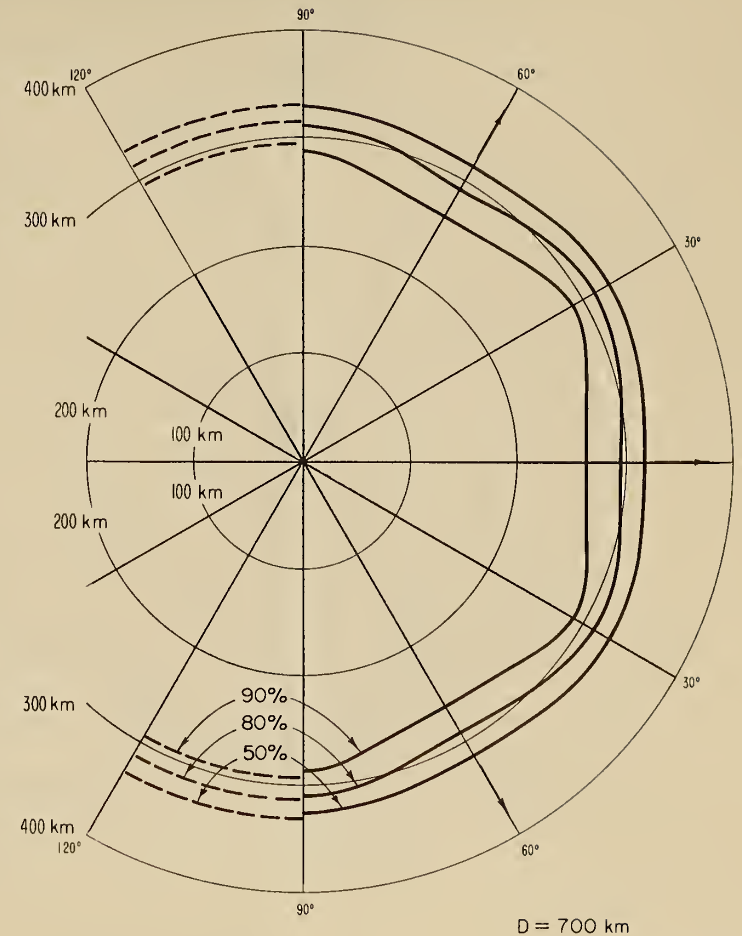


Figure 31

H_t = 7500 Meters
ANTENNA N° 2

$L_{b(max)}$ = 145 db
P = 27 db

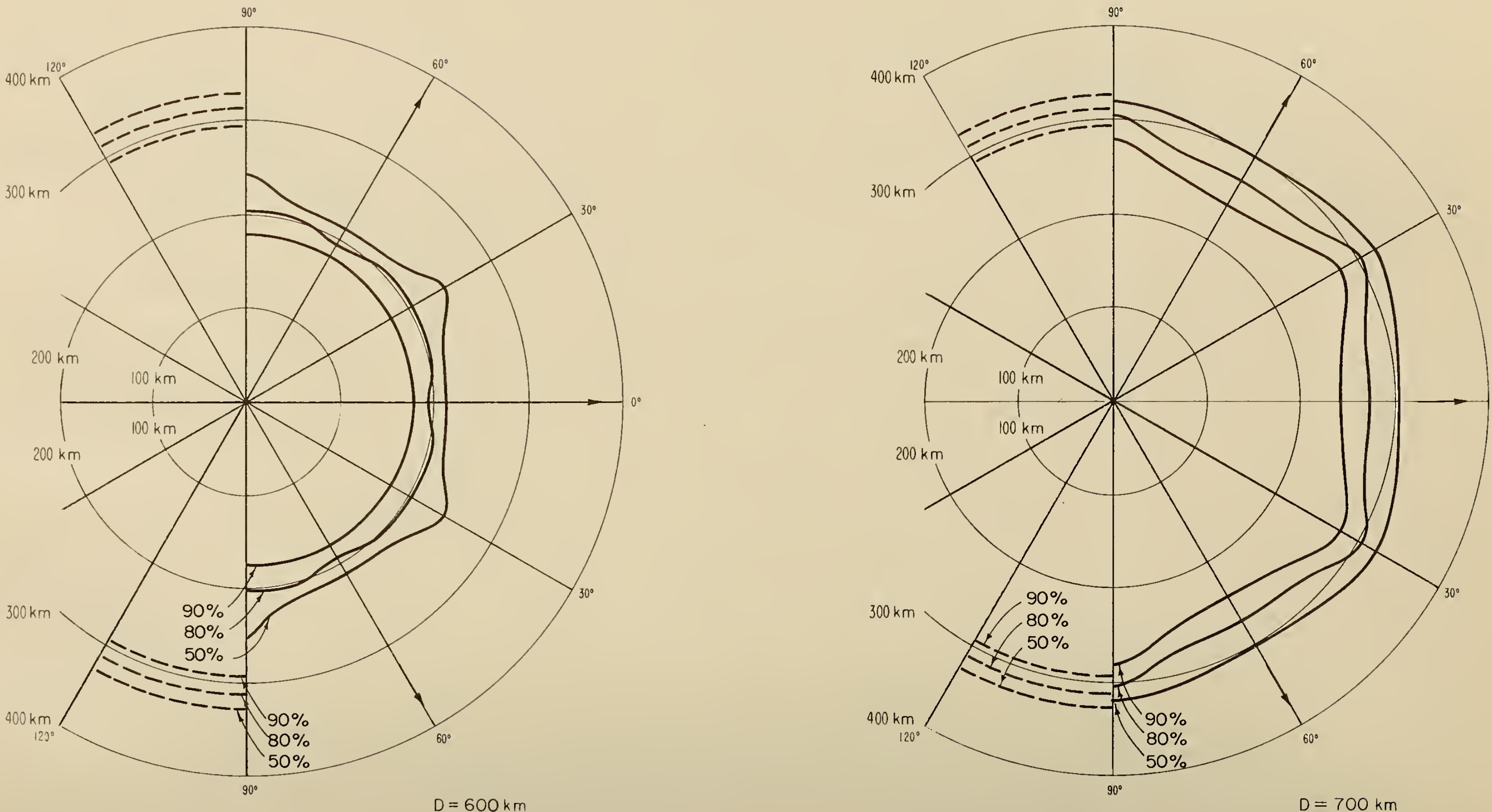


Figure 32

Figures 33 through 44

CONTOURS OF LOCATION PROBABILITY OF SERVICE

ONE INTERFERING STATION

Aircraft Height, H_t	10,000 meters
Aircraft Flight Radius	15 km
Frequency......................	785 Mc
Time Availability of Service.......	99 %

$L_{b(max)}$ = Maximum Allowable Basic Transmission Loss

P = Protection Ratio

D = Co-channel Separation Distance

H_t = 10,000 Meters $\qquad L_{b\,(max)} = 140$ db

ANTENNA N? 1 $\qquad P = 12$ db

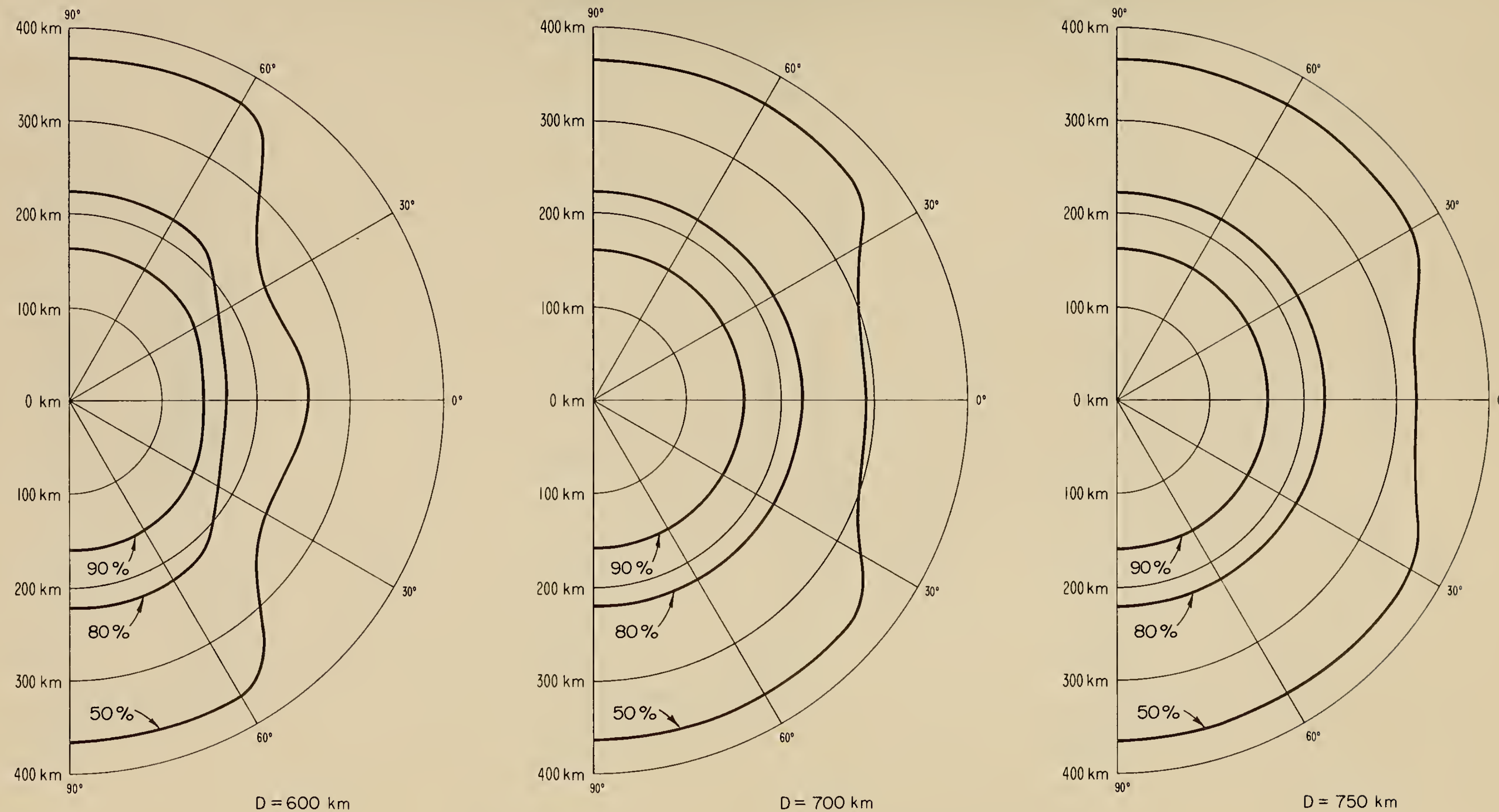


Figure 33

H_t = 10,000 Meters
ANTENNA Nº 1

$L_{b\,(max)}$ = 140 db
P = 20 db

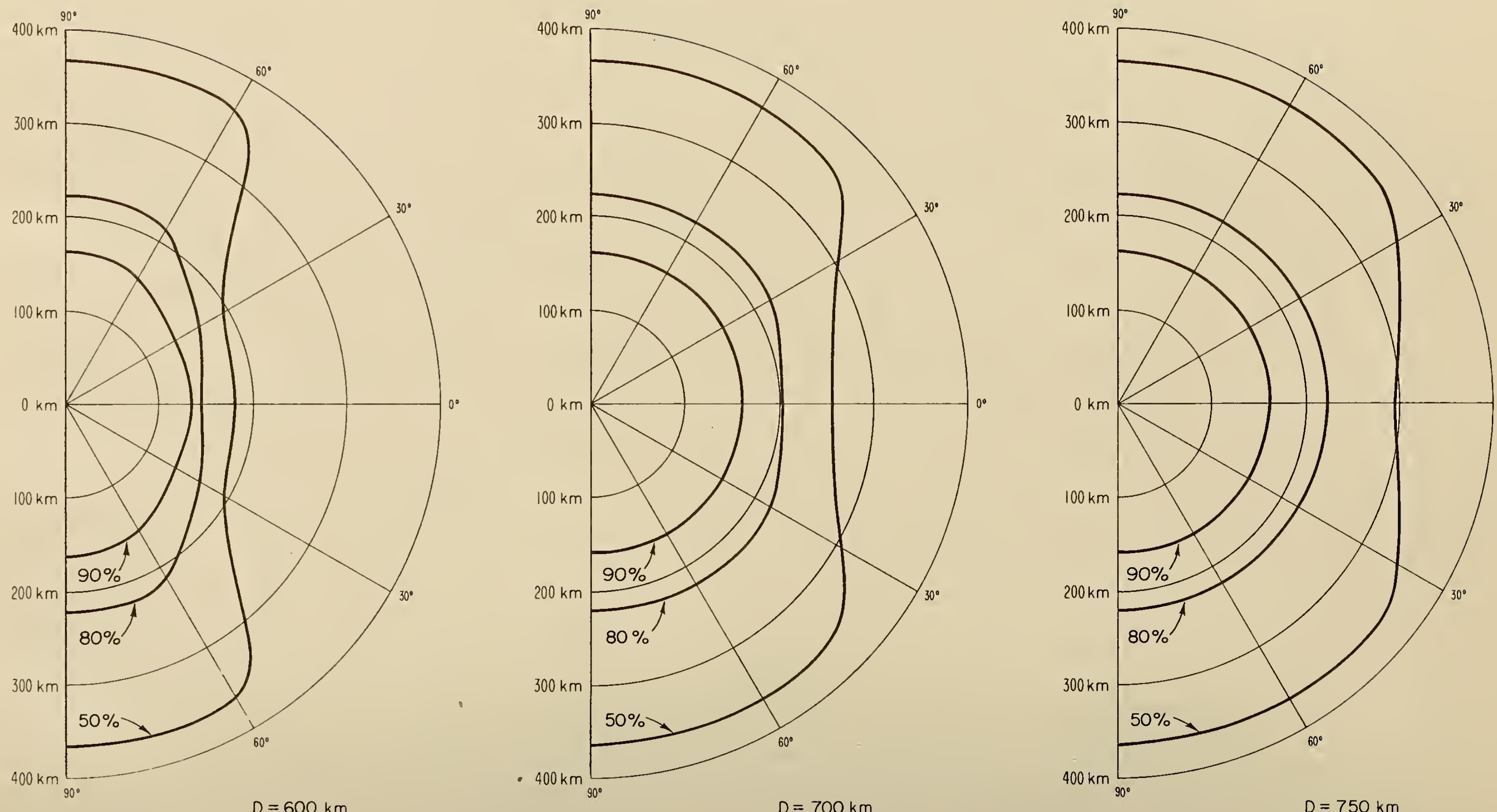


Figure 34

$H_t = 10{,}000$ Meters $\qquad L_{b\,(max)} = 140$ db

ANTENNA Nº 1 $\qquad P = 27$ db

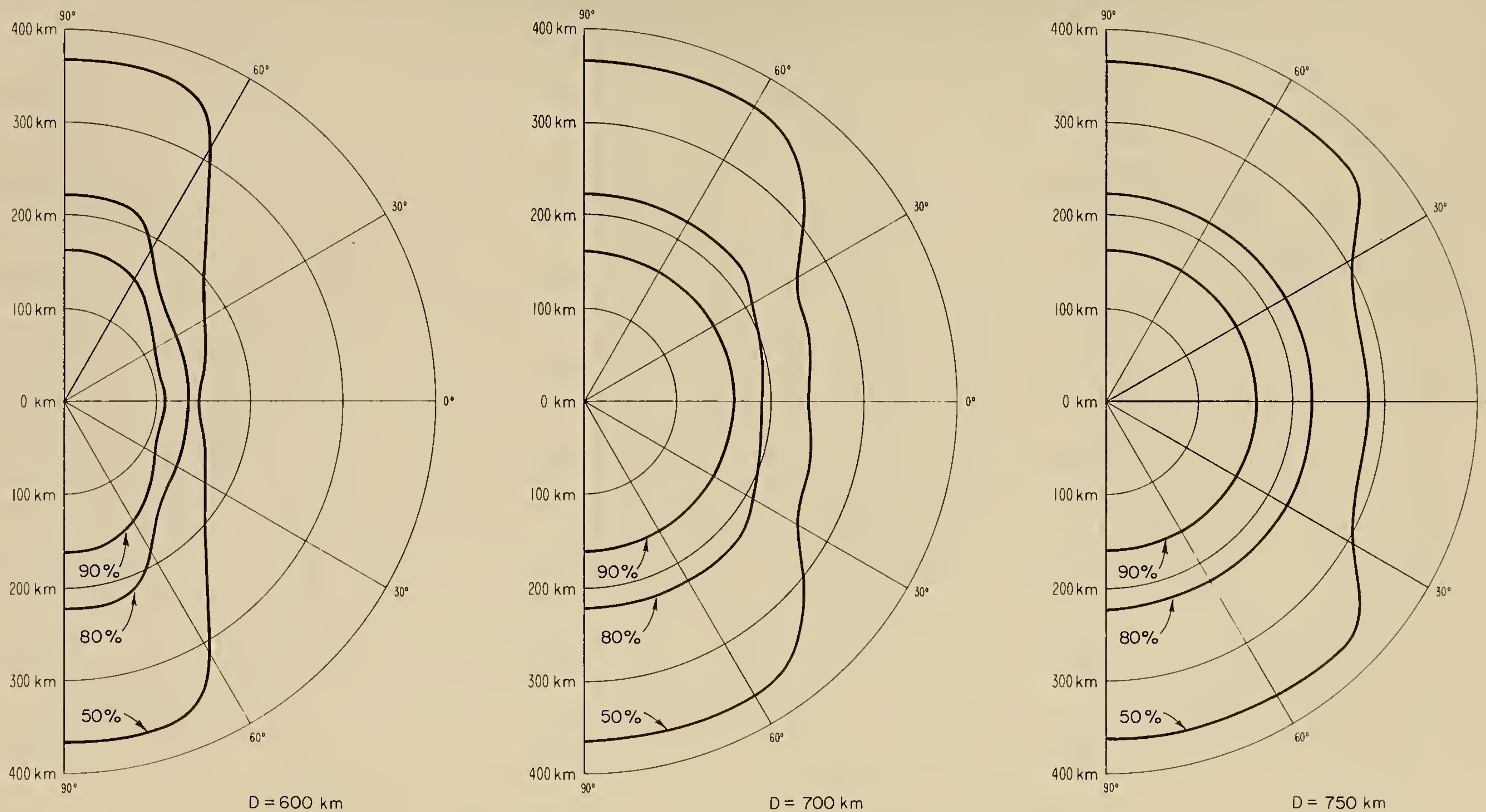


Figure 35

H_t = 10,000 Meters
ANTENNA Nº 2

$L_{b\,(max)}$ = 140 db
P = 12 db

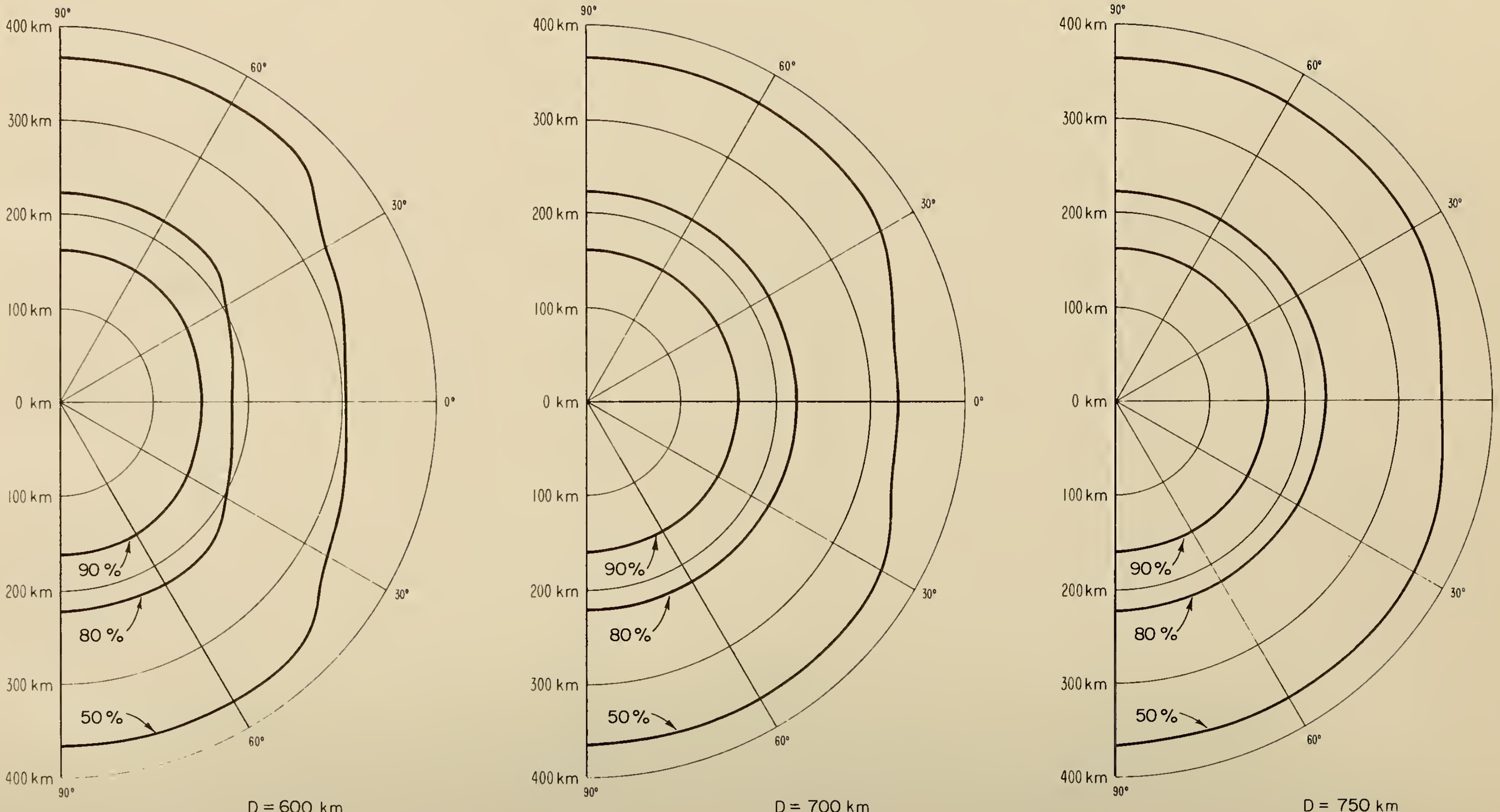


Figure 36

H_t = 10,000 Meters
ANTENNA Nº 2

$L_{b\,(max)}$ = 140 db
P = 20 db

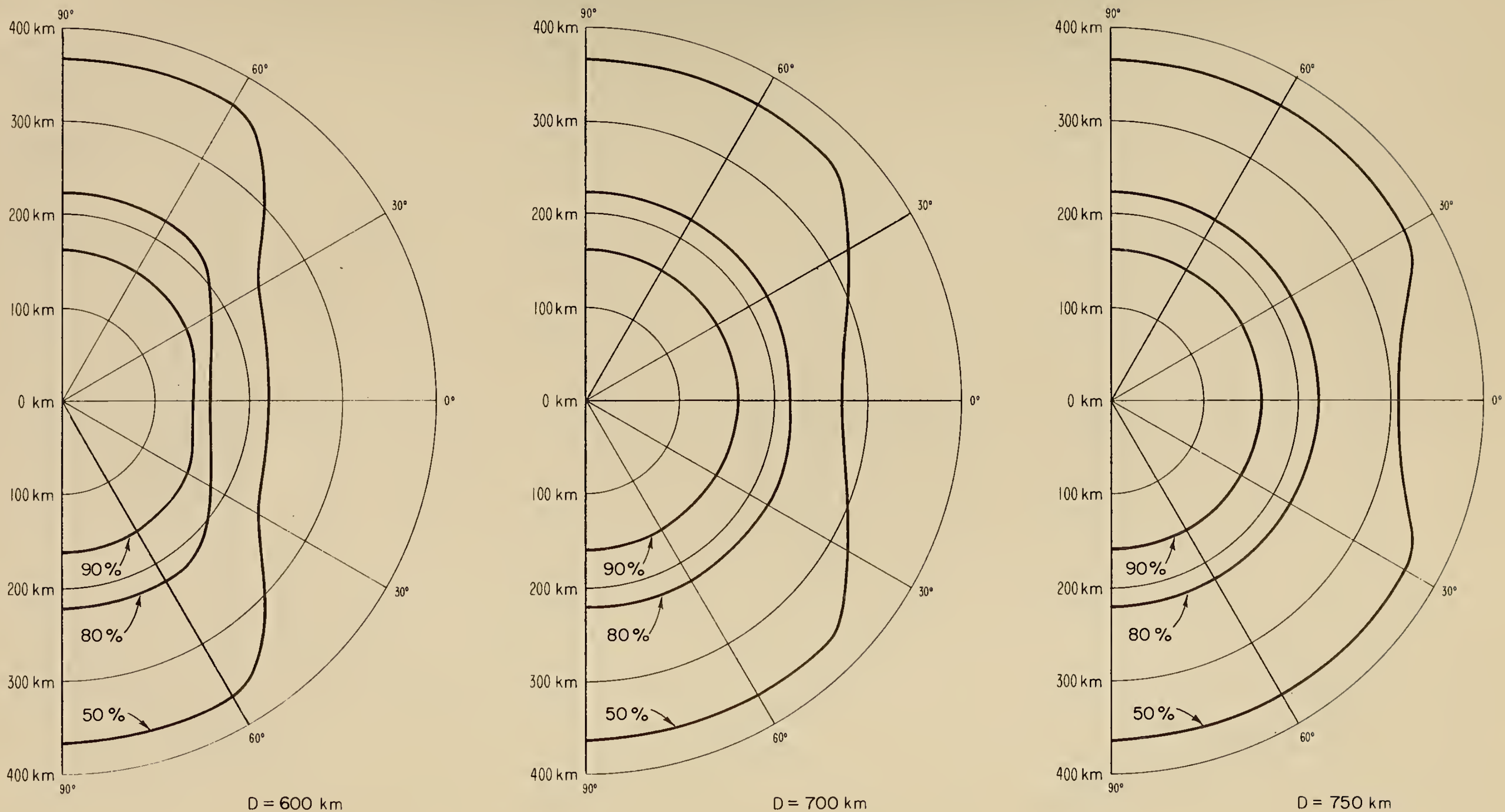


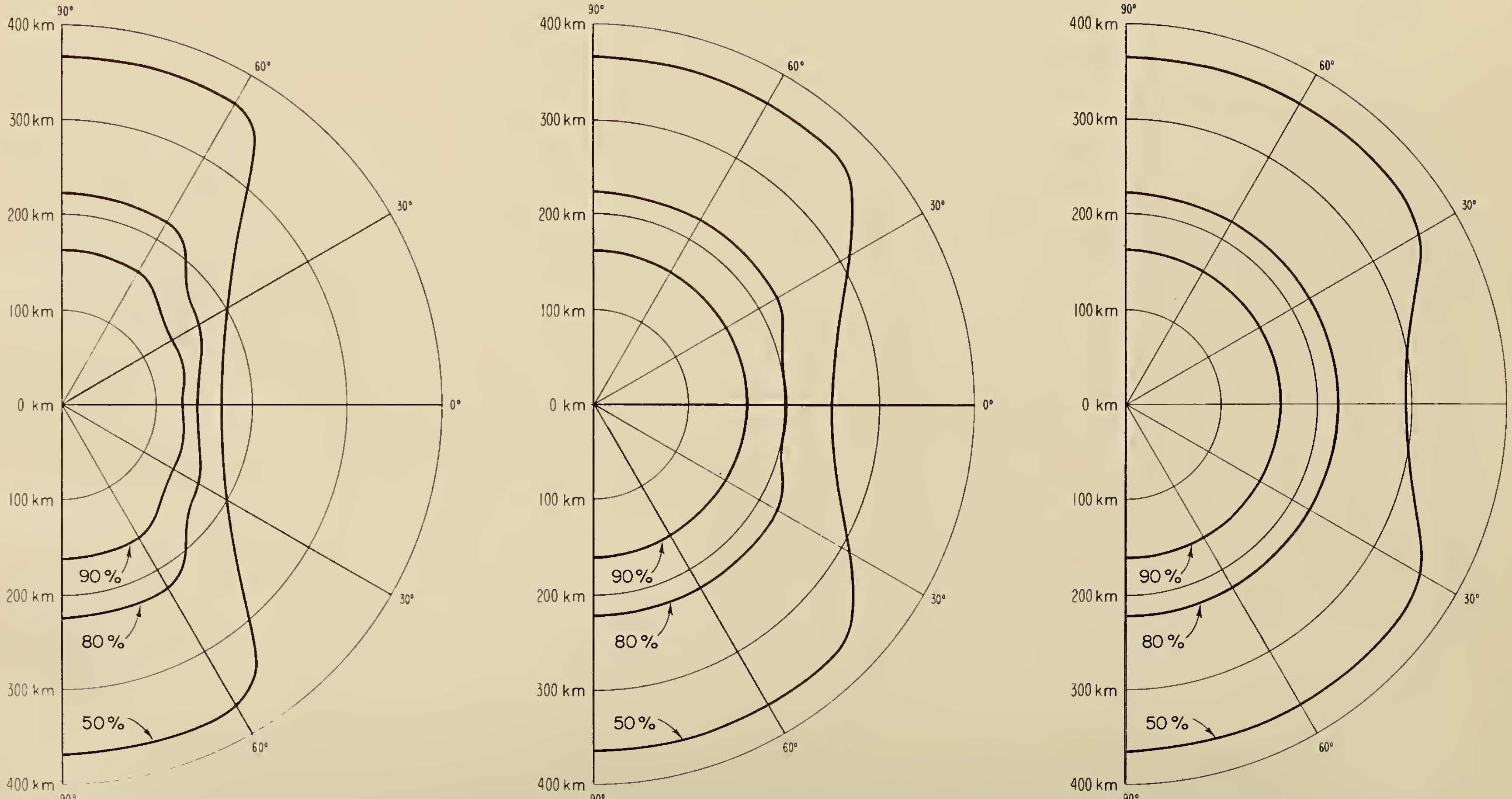
Figure 37

H_t = 10,000 Meters

ANTENNA Nº 2

$L_{b\,(max)}$ = 140 db

P = 27 db



D = 600 km D = 700 km D = 750 km

Figure 38

H_t = 10,000 Meters $\quad$ $L_{b(max)} = 145$ db

ANTENNA Nº 1 $\quad$ P = 12 db

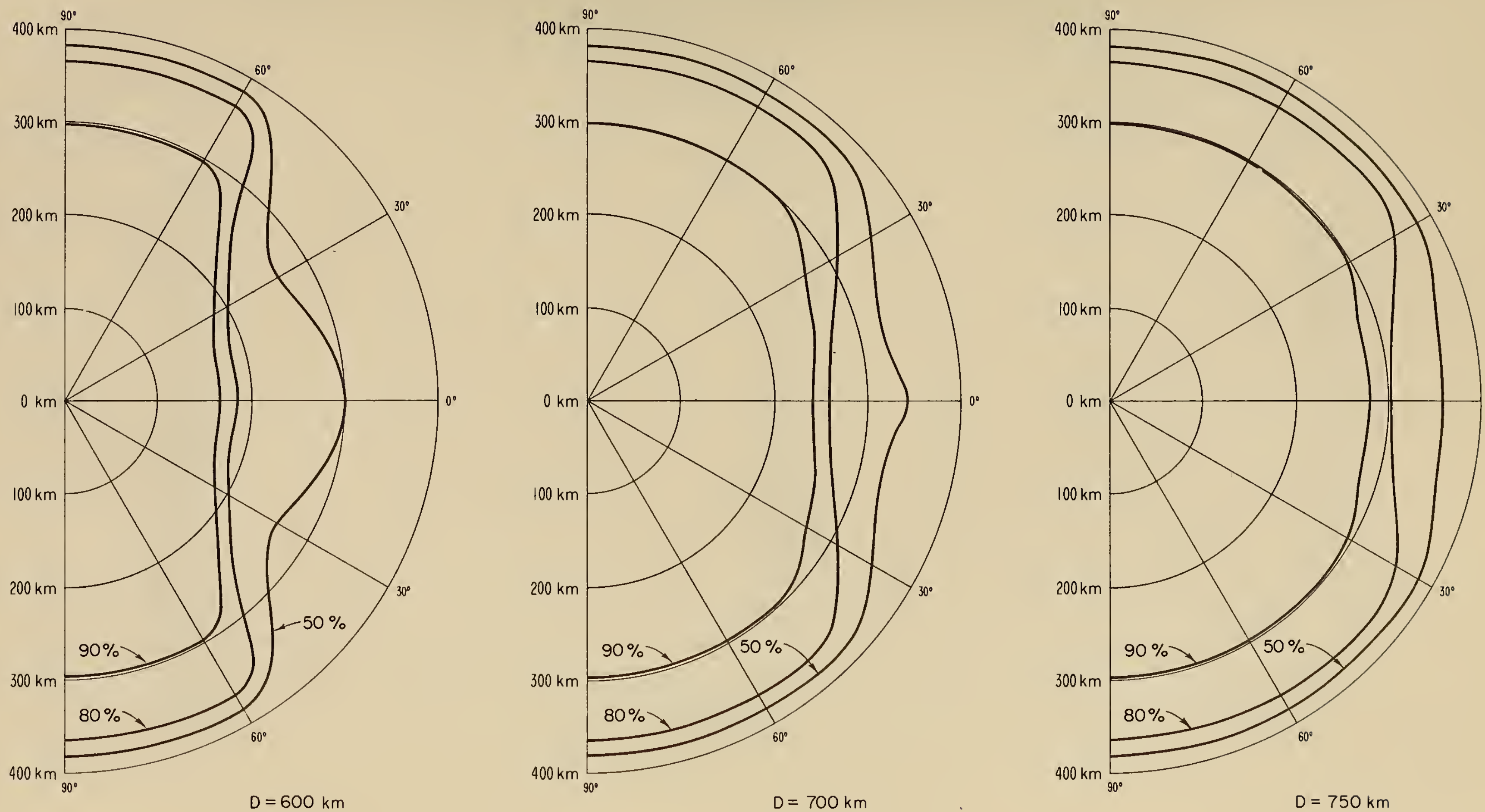


Figure 39

H_t = 10,000 Meters
ANTENNA Nº 1

$L_{b\,(max)}$ = 145 db
P = 20 db

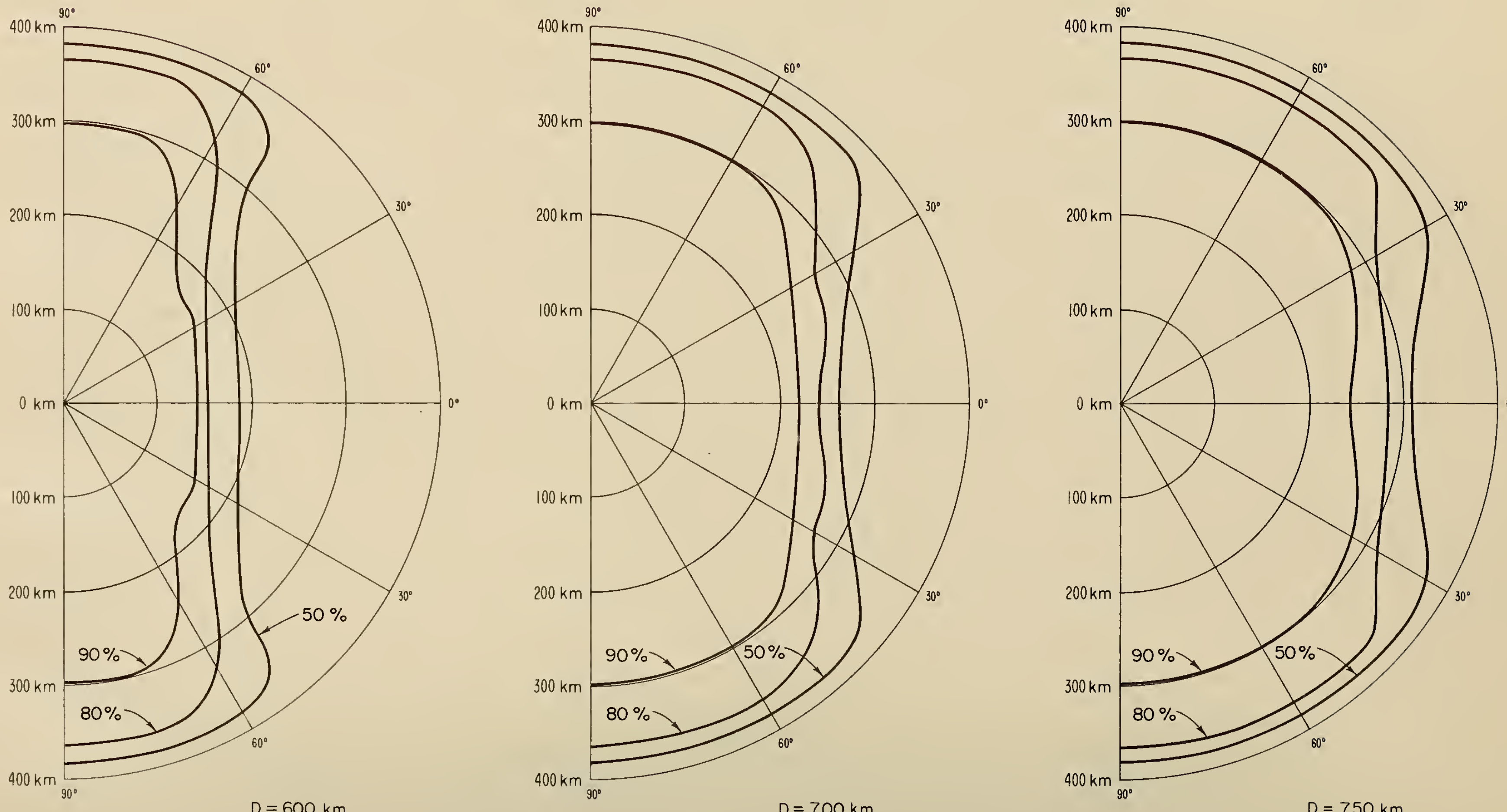


Figure 40

H_t = 10,000 Meters

ANTENNA N° 1

$L_{b\,(max)}$ = 145 db

P = 27 db

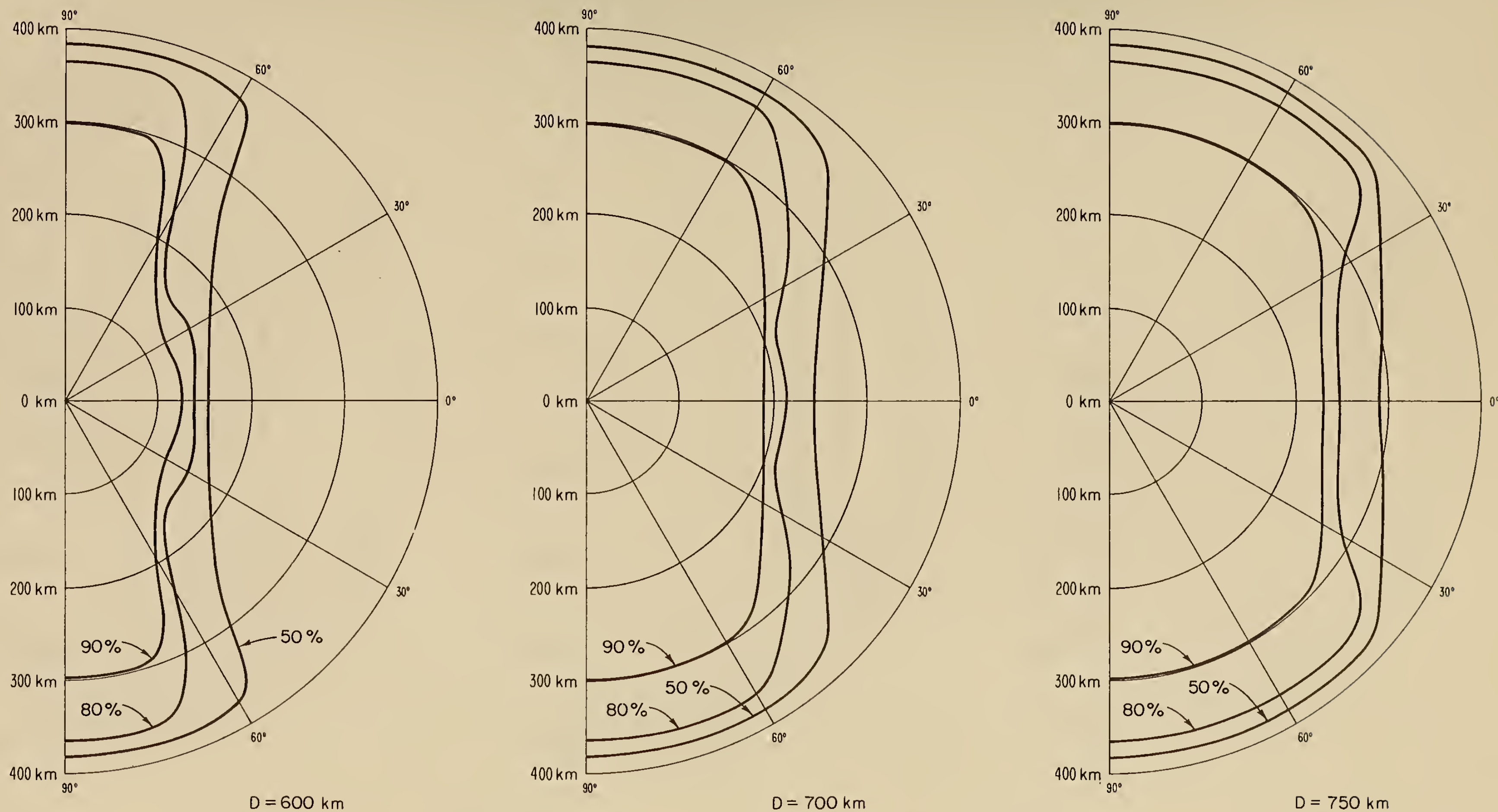
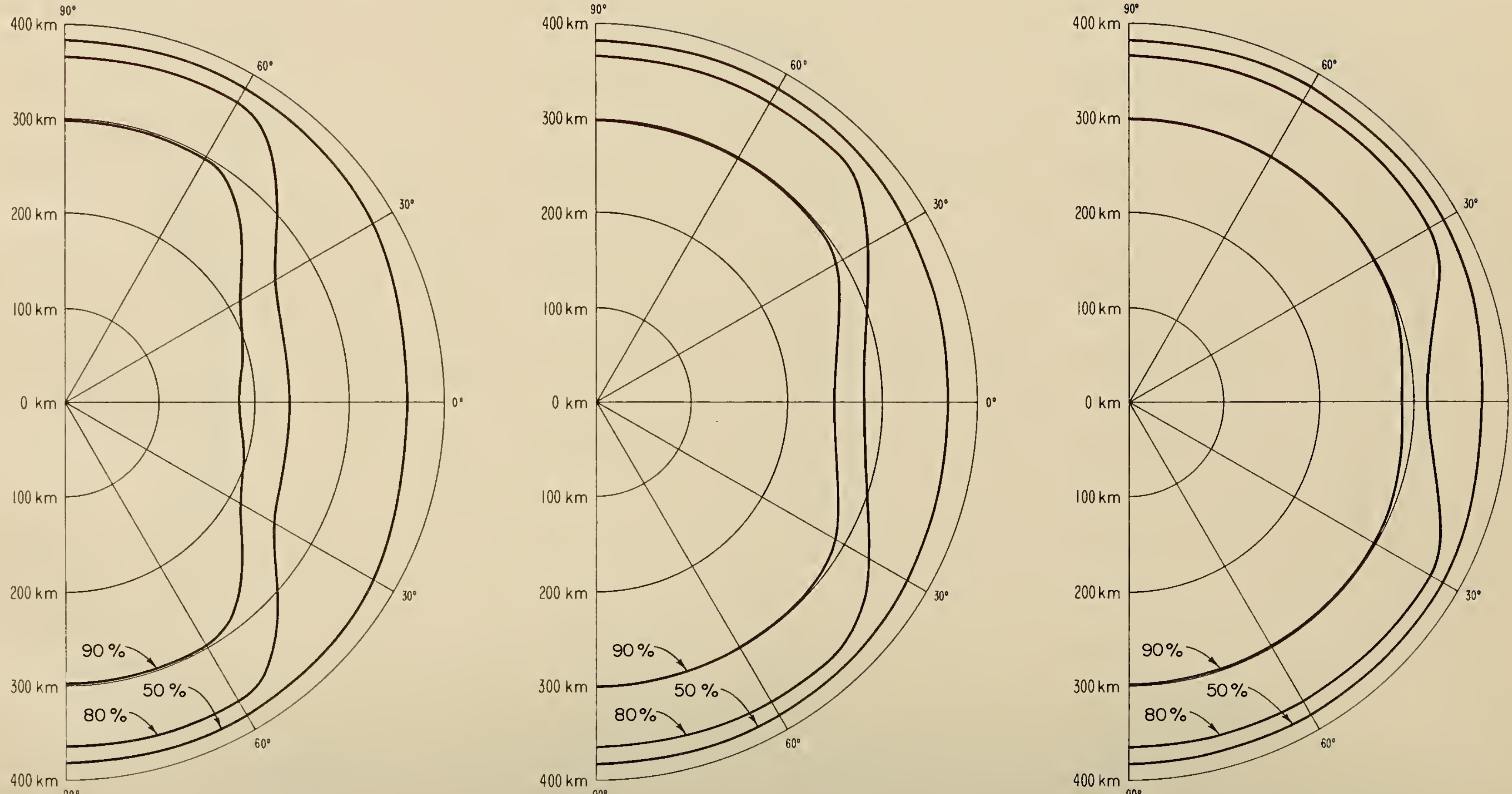


Figure 41

$H_t = 10{,}000$ Meters $\qquad L_{b(max)} = 145$ db

ANTENNA N° 2 $\qquad P = 12$ db



D = 600 km $\qquad$ D = 700 km $\qquad$ D = 750 km

Figure 42

H_t = 10,000 Meters $L_{b\,(max)}$ = 145 db

ANTENNA Nº 2 P = 20 db

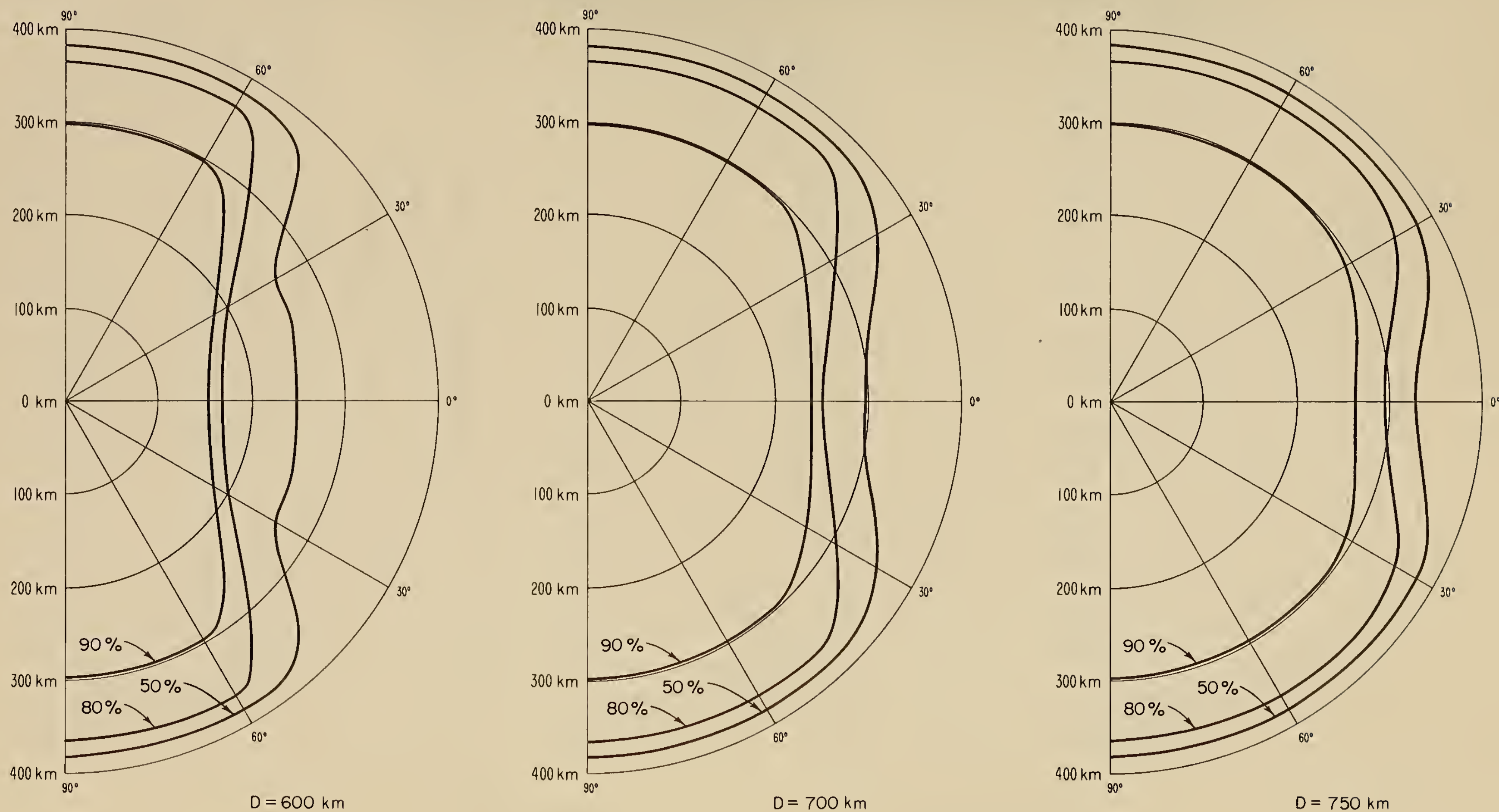


Figure 43

H_t = 10,000 Meters $\qquad L_{b\,(max)}$ = 145 db

ANTENNA Nº 2 $\qquad$ P = 27 db

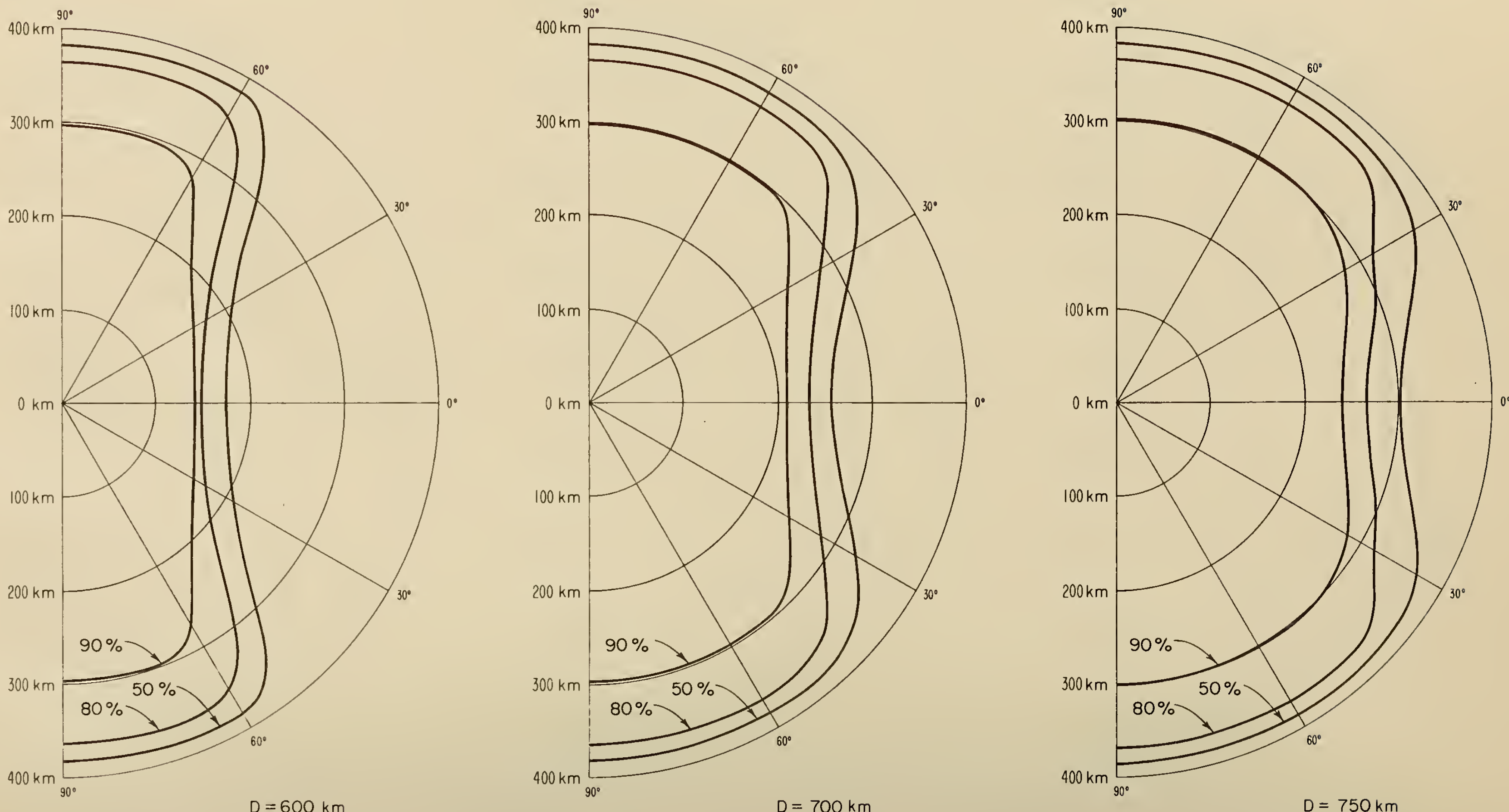


Figure 44

Figures 45 through 56

CONTOURS OF LOCATION PROBABILITY OF SERVICE

STATIONS IN A TRIANGULAR LATTICE

Aircraft Height, H_t	10,000 meters
Aircraft Flight Radius	15 km
Frequency......................	785 Mc
Time Availability of Service.......	99 %

$L_{b(max)}$ = Maximum Allowable Basic Transmission Loss

P = Protection Ratio

D = Co-channel Separation Distance

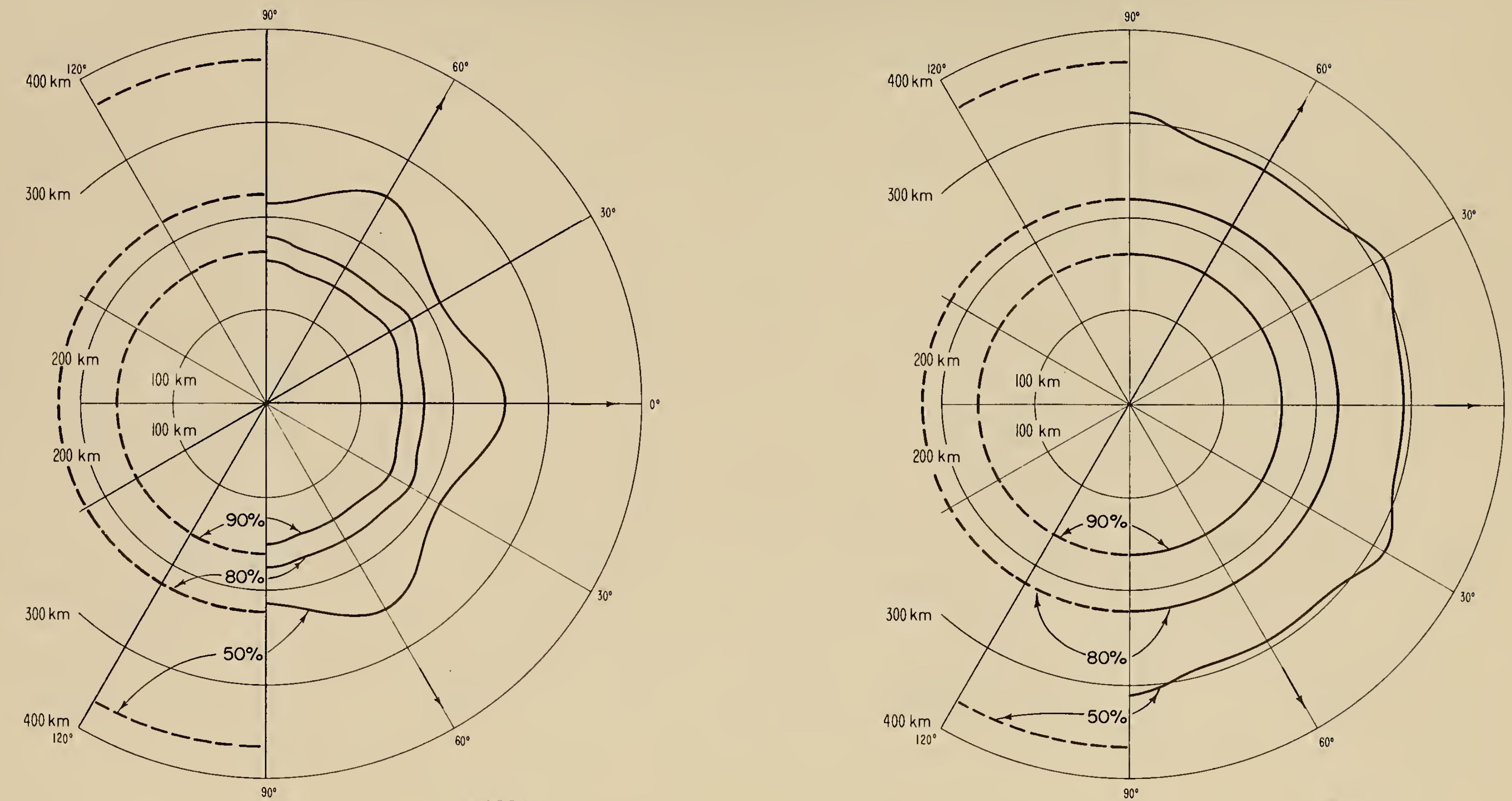
Dashed lines indicate interference-free contours

H_t = 10,000 Meters

ANTENNA N° 1

$L_{b\,(max)}$ = 140 db

P = 12 db



D = 600 km

D = 700 km

Figure 45

H_t = 10,000 Meters
ANTENNA N° 1

$L_{b\,(max)}$ = 140 db
P = 20 db

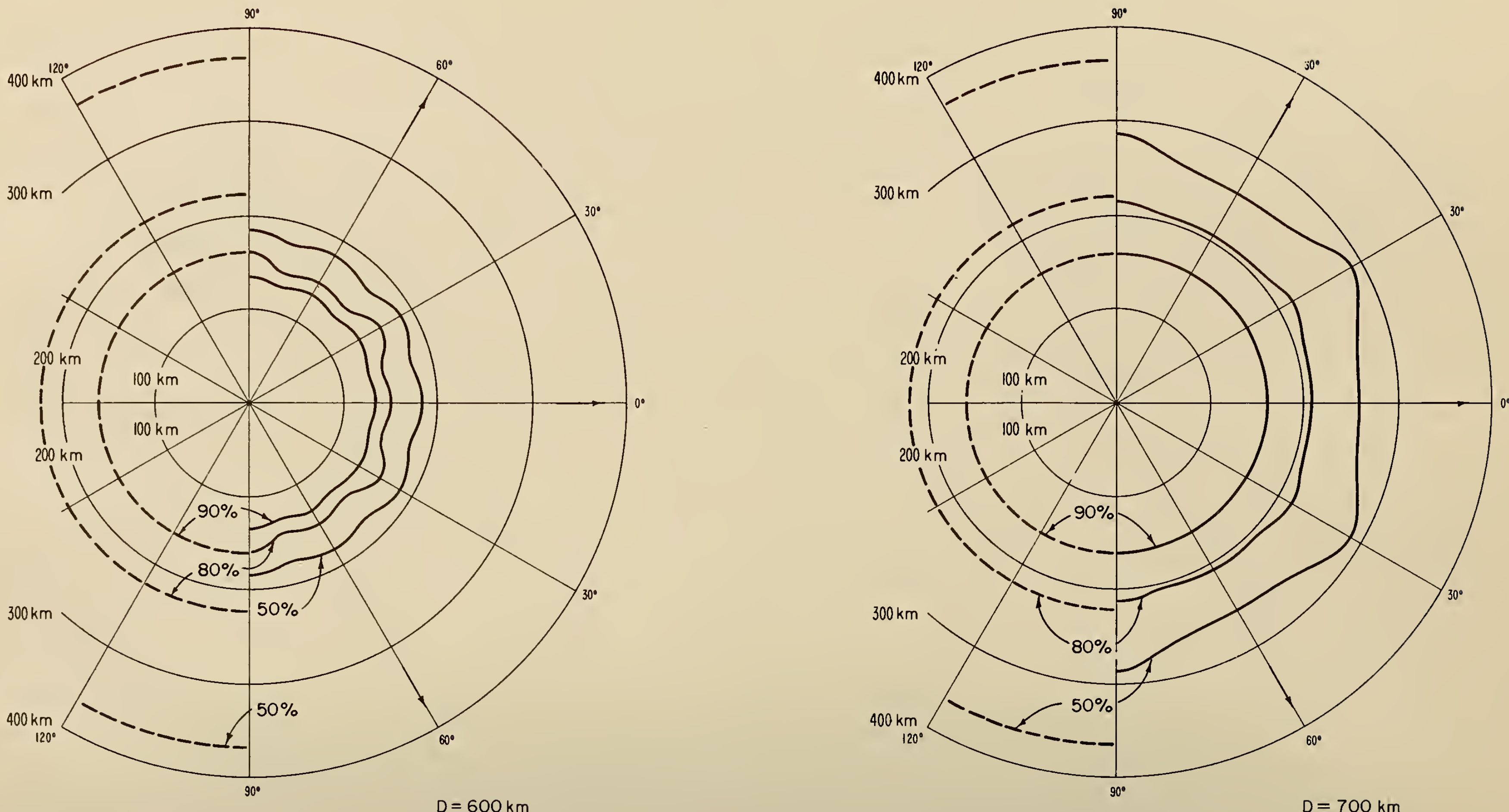


Figure 46

H_t = 10,000 Meters
ANTENNA Nº 1

$L_{b(max)} = 140$ db
$P = 27$ db

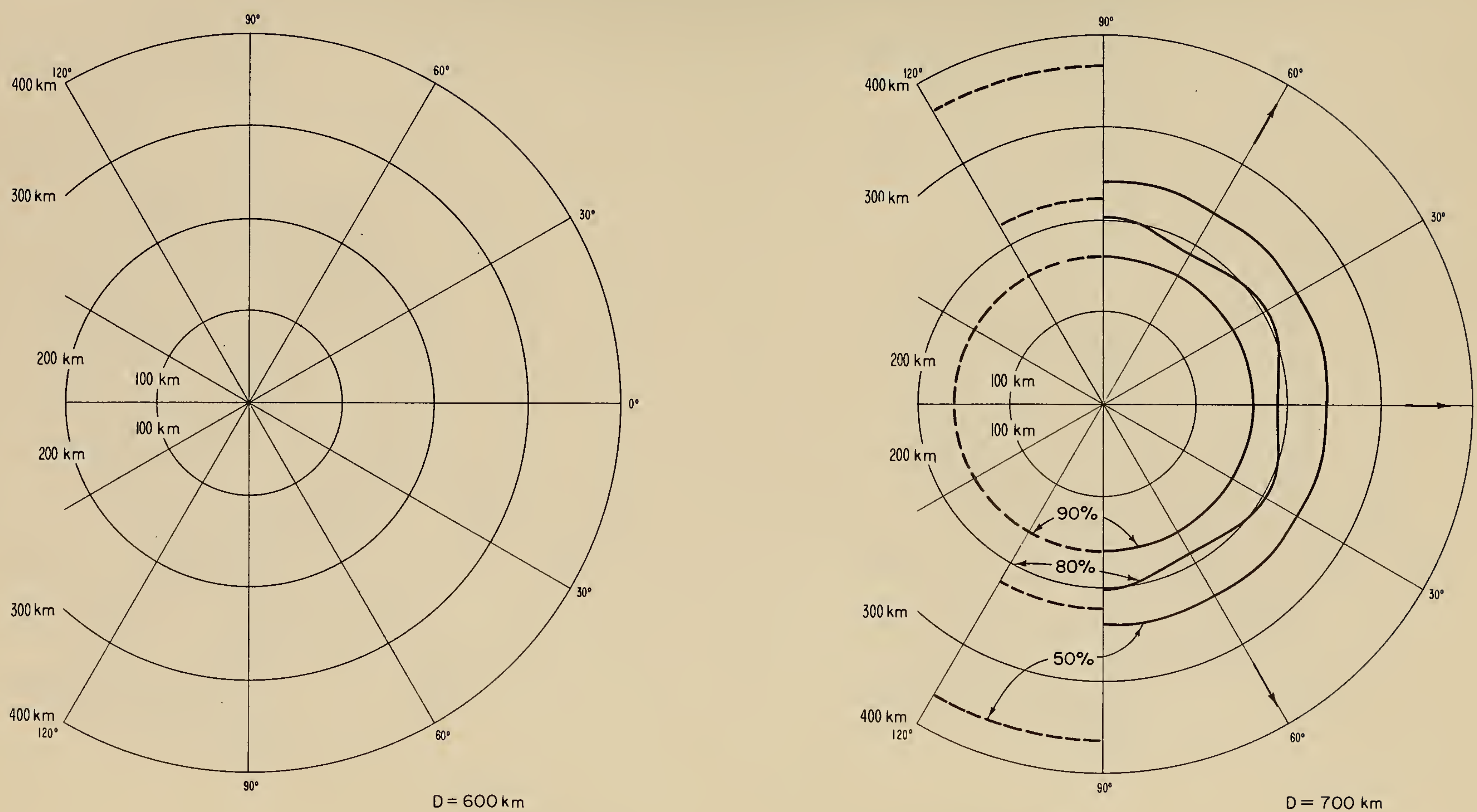


Figure 47

H_t = 10,000 Meters
ANTENNA Nº 2

$L_{b(max)} = 140$ db
$P = 12$ db

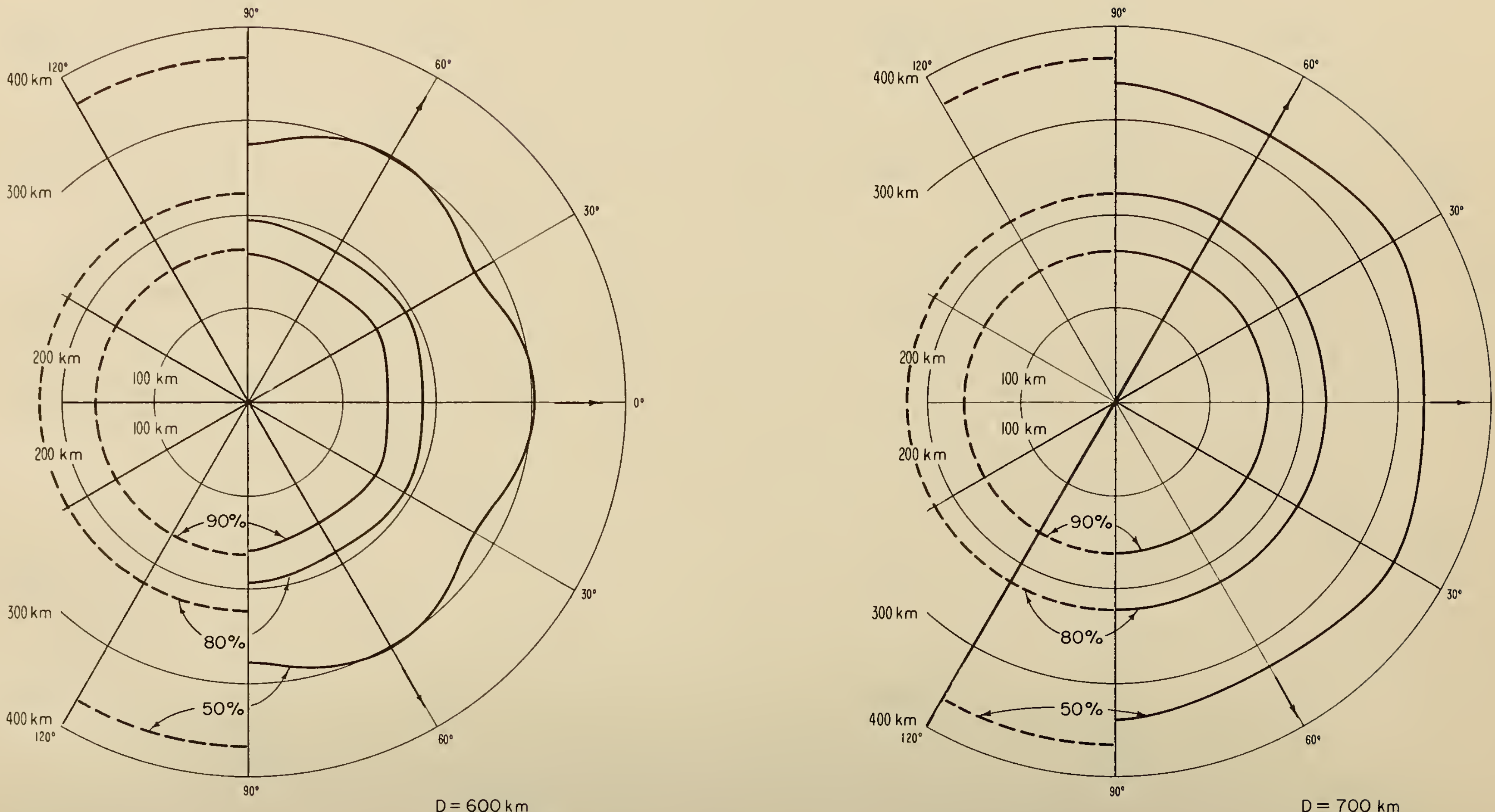


Figure 48

H_t = 10,000 Meters
ANTENNA N° 2

$L_{b\,(max)}$ = 140 db
P = 20 db

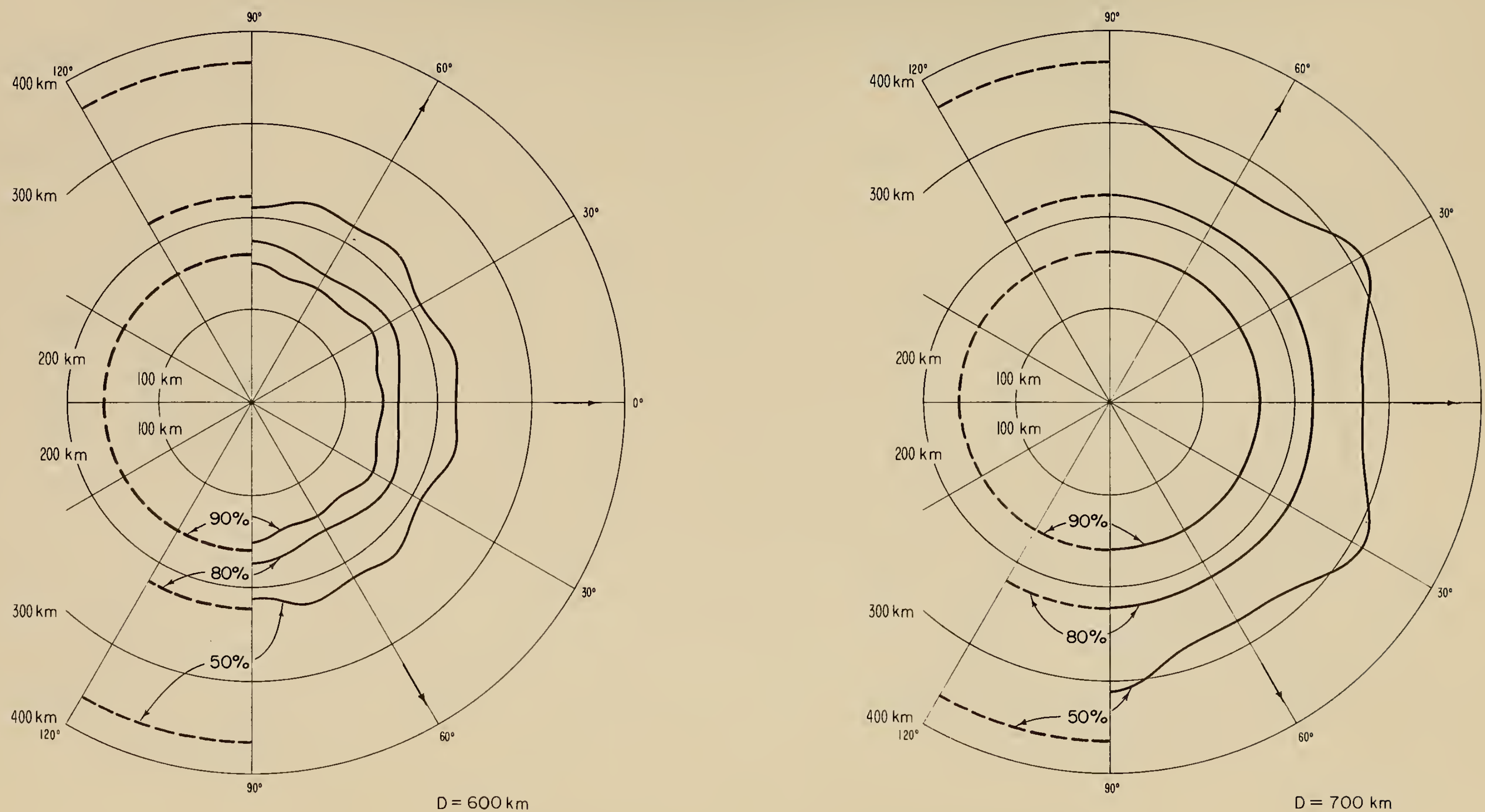


Figure 49

H_t = 10,000 Meters

ANTENNA N° 2

$L_{b(max)}$ = 140 db

P = 27 db

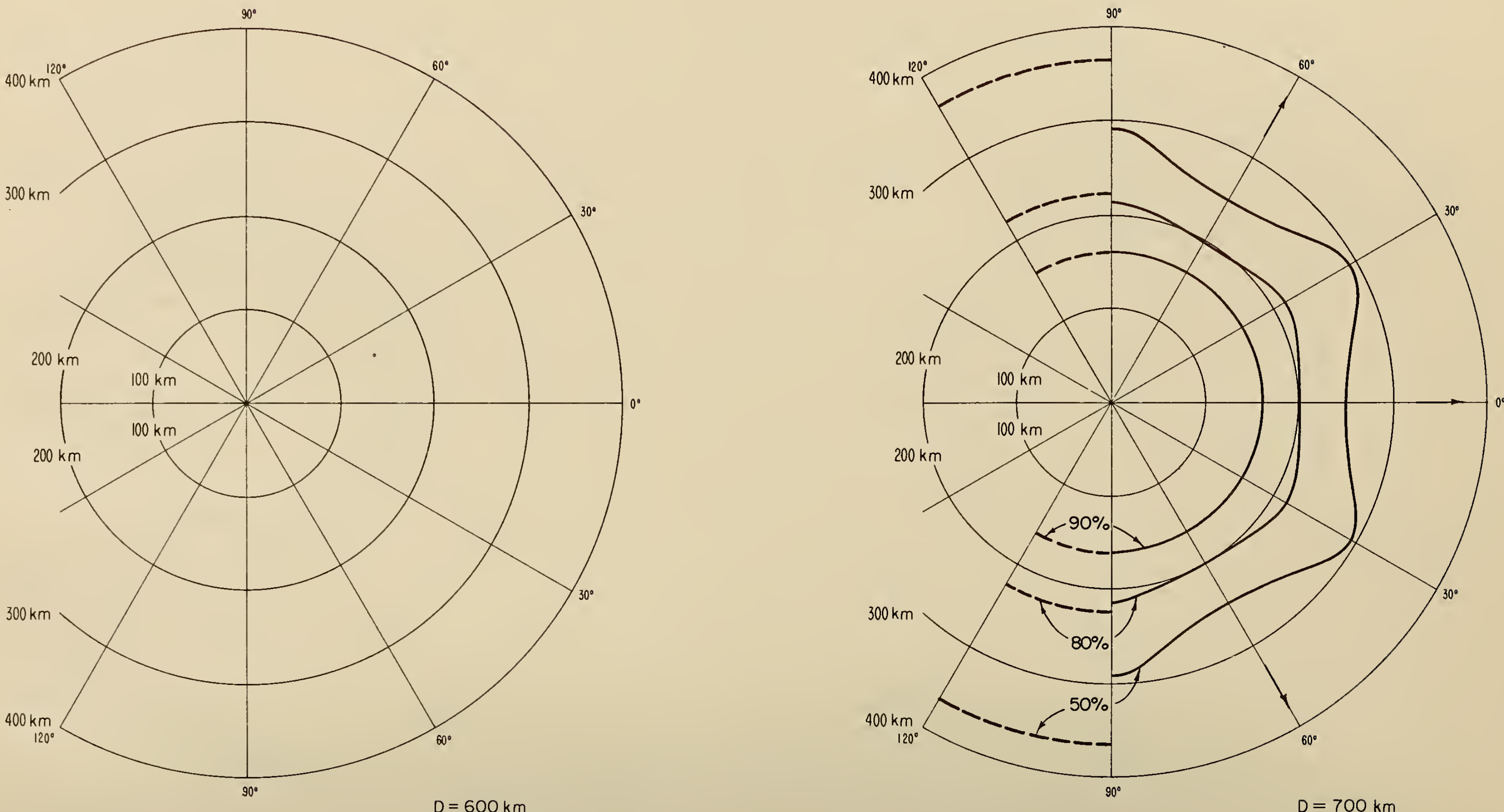


Figure 50

H_t = 10,000 Meters
ANTENNA N° 1

$L_{b(max)}$ = 145 db
P = 12 db

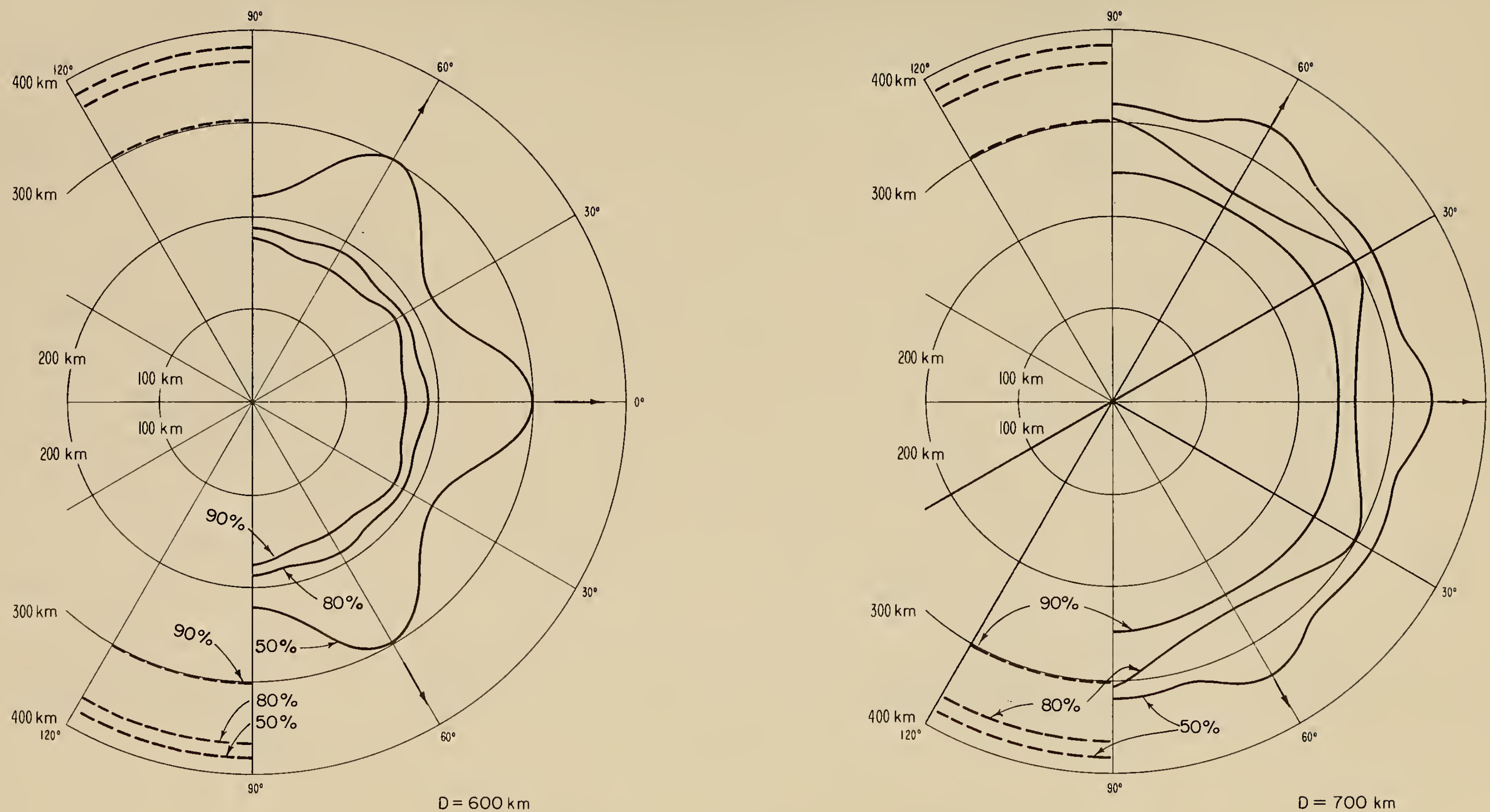
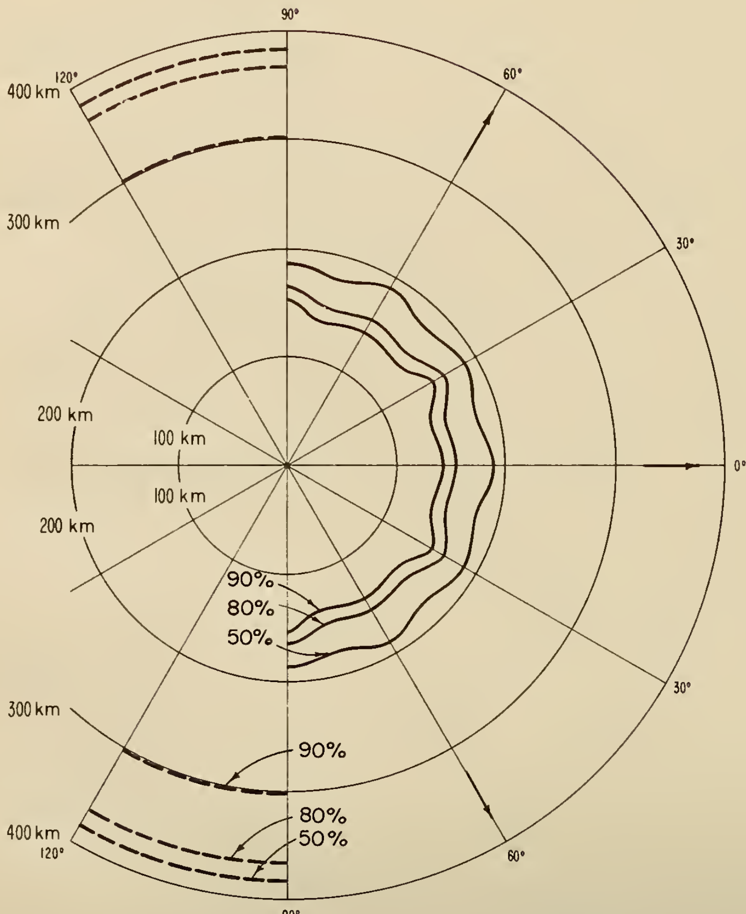


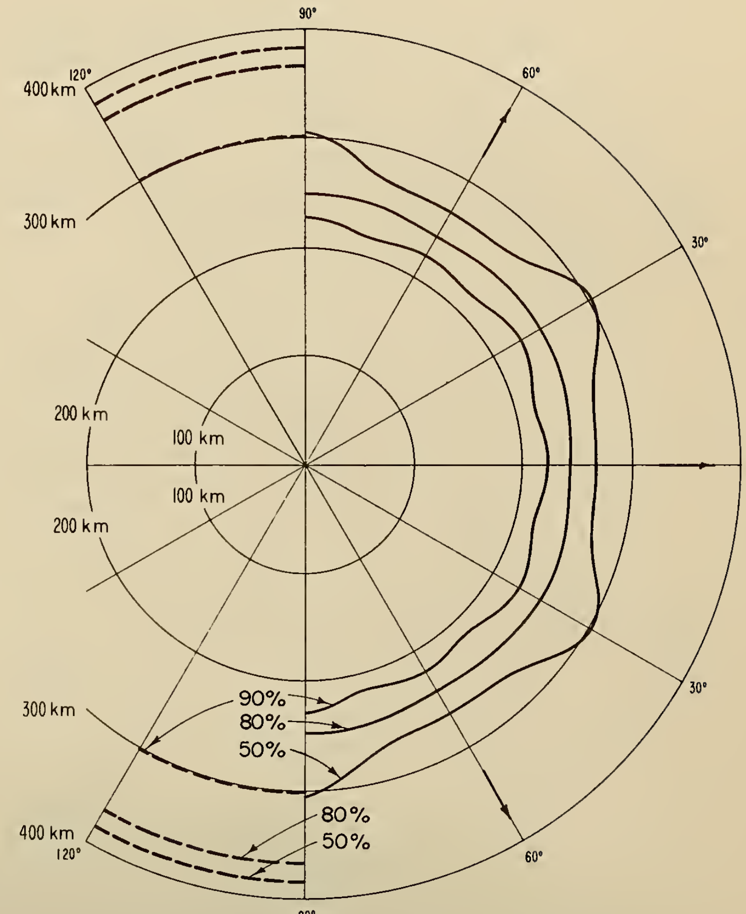
Figure 51

H_t = 10,000 Meters
ANTENNA Nº 1

$L_{b(max)}$ = 145 db
P = 20 db



D = 600 km

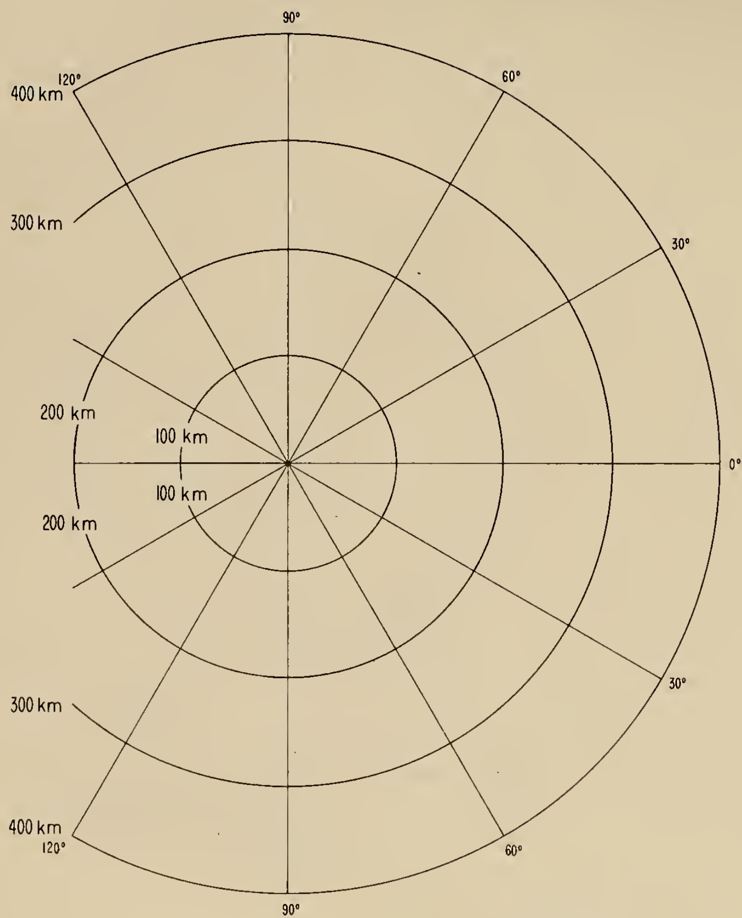


D = 700 km

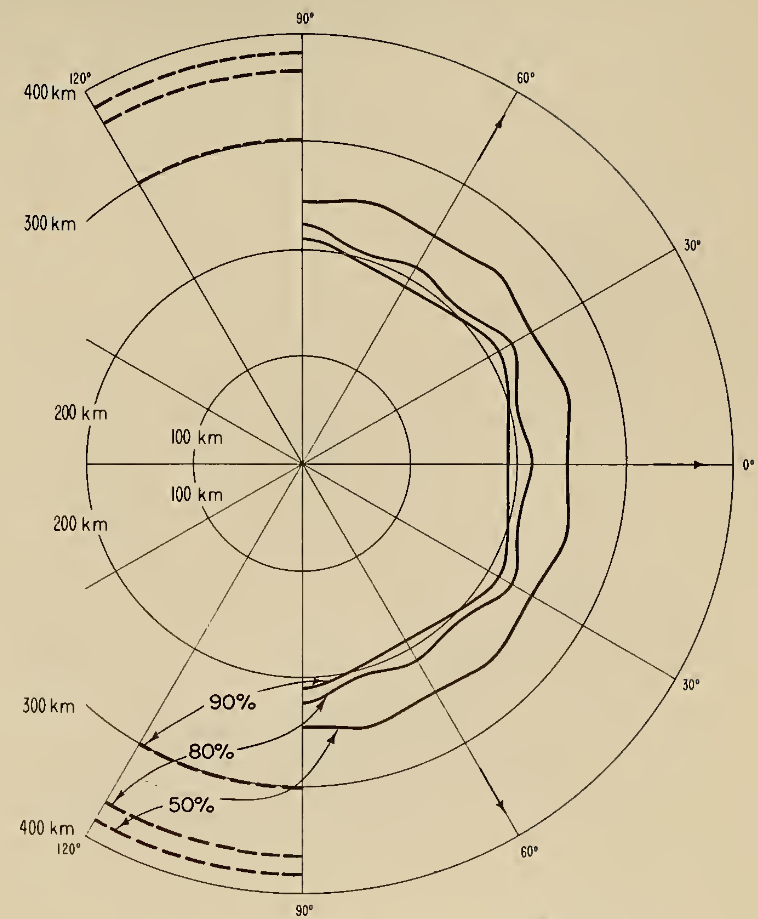
Figure 52

H_t = 10,000 Meters
ANTENNA Nº 1

$L_{b(max)}$ = 145 db
P = 27 db



D = 600 km

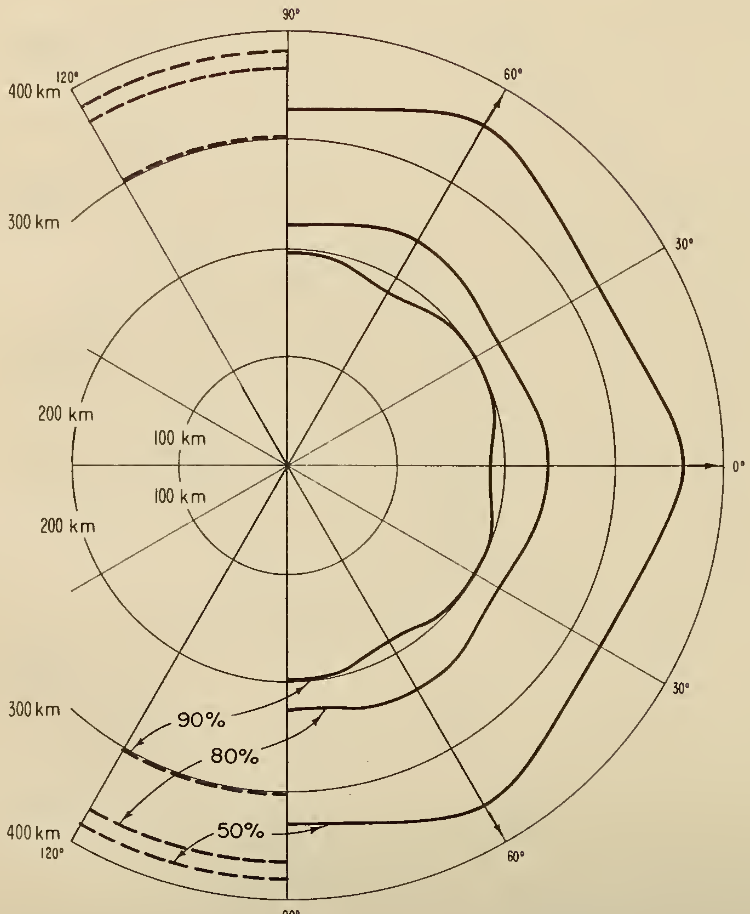


D = 700 km

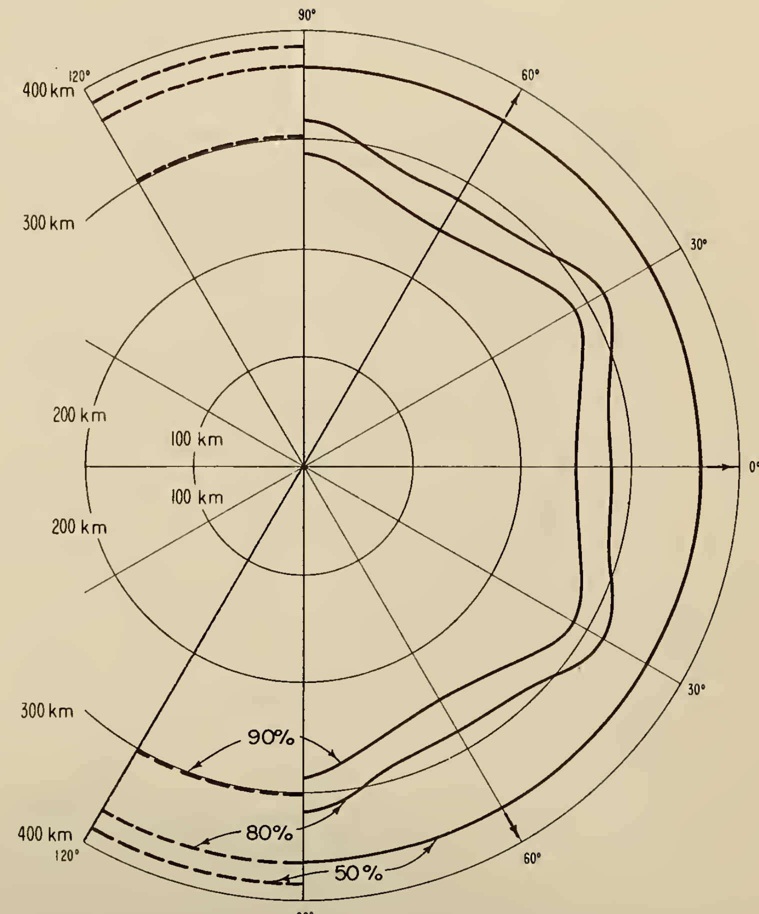
Figure 53

H_t = 10,000 Meters
ANTENNA Nº 2

$L_{b(max)}$ = 145 db
P = 12 db



D = 600 km

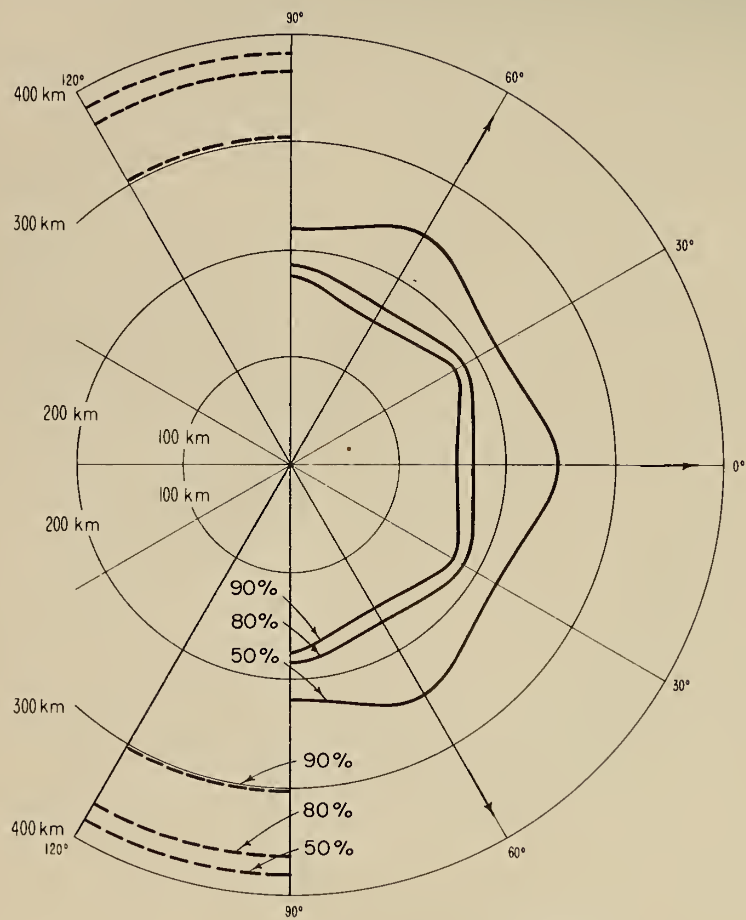


D = 700 km

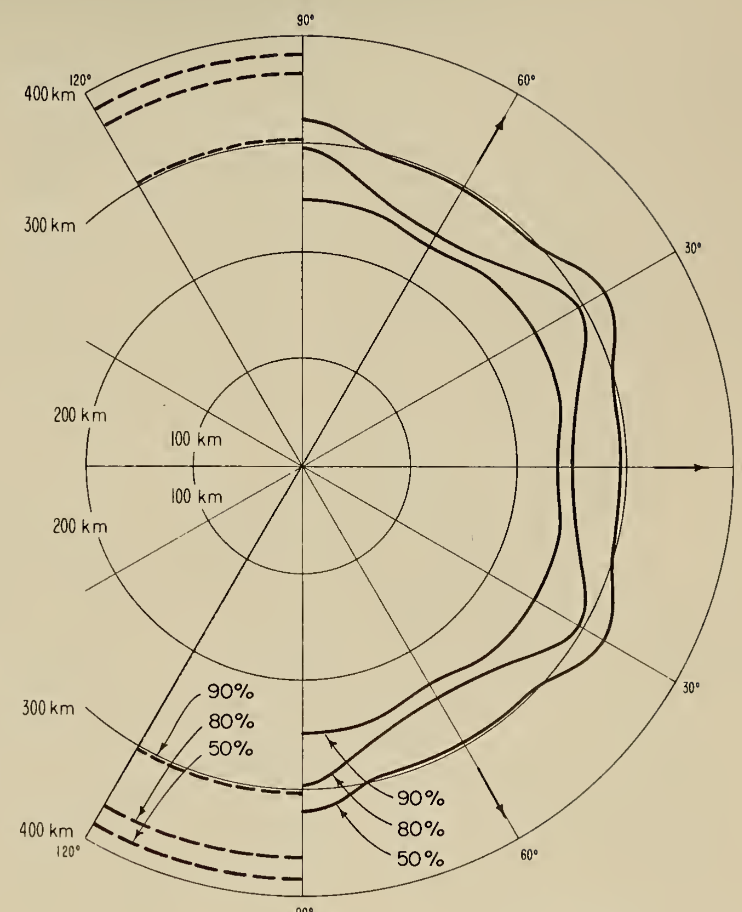
Figure 54

H_t = 10,000 Meters
ANTENNA N° 2

$L_{b(max)}$ = 145 db
P = 20 db



D = 600 km

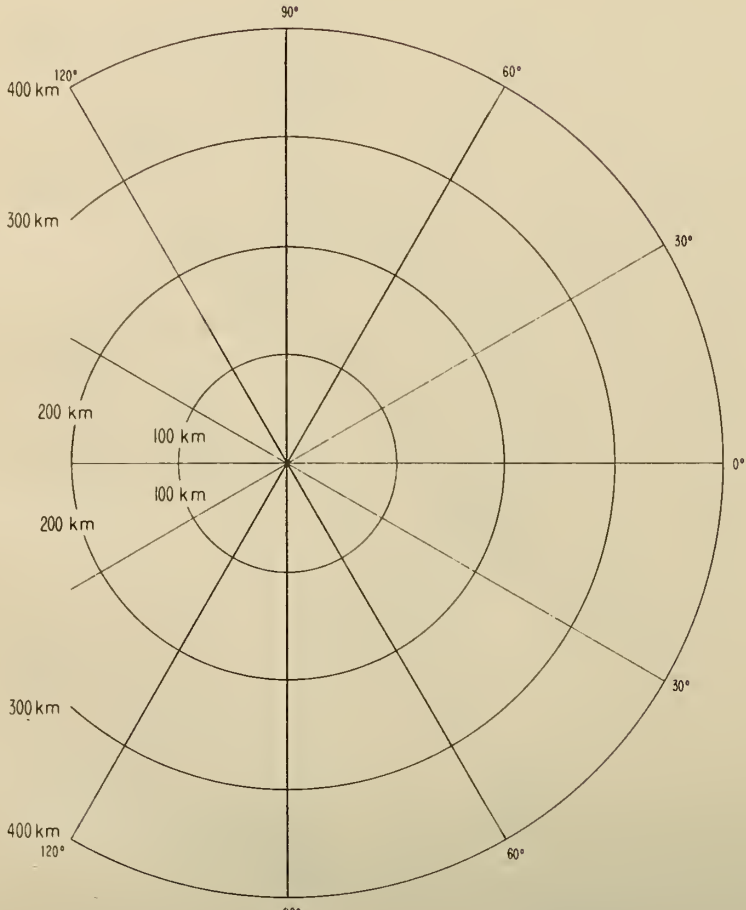


D = 700 km

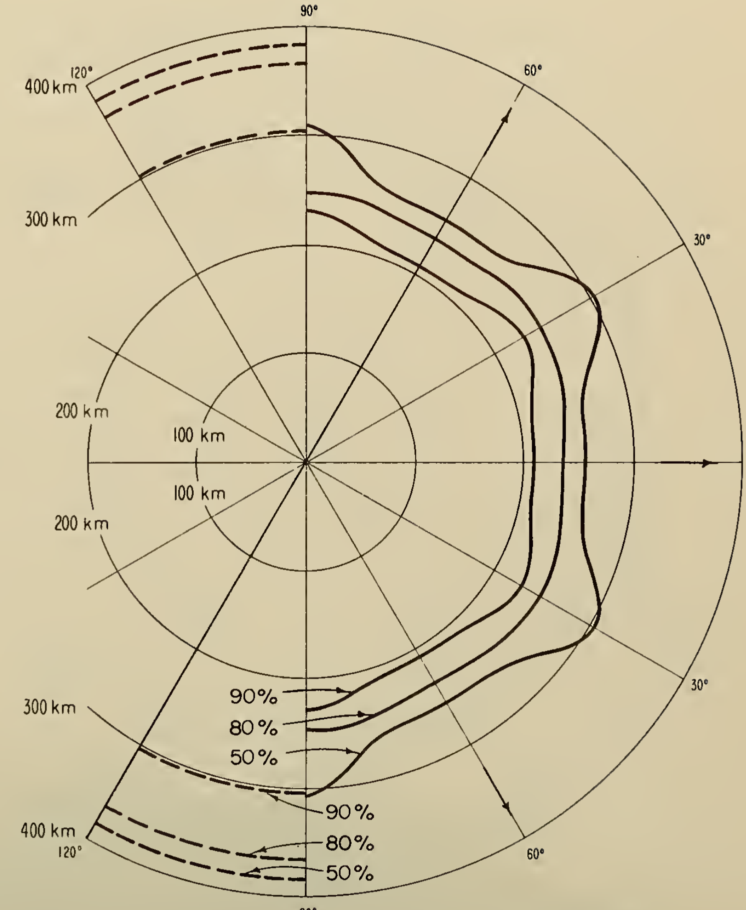
Figure 55

H_t = 10,000 Meters
ANTENNA Nº 2

$L_{b(max)}$ = 145 db
P = 27 db



D = 600 km



D = 700 km

Figure 56

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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