U.S. DEPARTMENT OF COMMERCE/Environmental Science Services Administration

Technical Memorandum

Institute for Telecommunication Sciences and Aeronomy IERTM-ITSA - 26

FREQUENCY SHARING WITH AIR TRAFFIC CONTROL SATELLITES

By

Gary D. Gierhart

Institutes for Environmental Research

Boulder, Colorado

January 1967

Institutes for Environmental Research

Institute for Telecommunication Sciences and Aeronomy

Ionospheric Telecommunications Laboratory

Tropospheric Telecommunications Laboratory

Space Disturbances Laboratory

Aeronomy Laboratory

325 South Broadway
Boulder, Colorado 80302

U.S. DEPARTMENT OF COMMERCE • John T. Connor, Secretary

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

Robert M. White, Administrator

INSTITUTES FOR ENVIRONMENTAL RESEARCH

George S. Benton, Director

Institutes for Environmental Research Technical Memorandum I.T.S.A. 26

J52361427

January 1967

FREQUENCY SHARING WITH AIR TRAFFIC CONTROL SATELLITES

Gary D. Gierhart

Tropospheric Telecommunications Laboratory

Institute for Telecommunication Sciences and Aeronomy

BOULDER, COLORADO

FOREWORD

This report has been prepared by the Institute for Telecommunication Sciences and Aeronomy for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FA-66-WAI-112. The contents of this report reflect the views of I. T. S. A., which is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FREQUENCY SHARING WITH AIR TRAFFIC CONTROL SATELLITES

Gary D. Gierhart

Technical information relevant to the solution of frequency sharing problems in the VHF band that are associated with the use of VHF for the aircraft/satellite link of a synchronous satellite air traffic control system is included in this report. Specifically, estimates are given of (1) the desired-to-undesired RF signal ratios available at the satellite when interference from a multitude of conventional air traffic control facilities is considered, and (2) the extent to which the service range of conventional air traffic control facilities may be reduced because of interference caused by transmissions from a satellite. The results are applicable to either co-channel or adjacent-channel interference problems, and may be easily modified to accommodate a variety of system parameter changes.

1. INTRODUCTION

Increasing air traffic density together with fast high-flying aircraft have made the use of reliable air traffic control systems more imperative than ever before. Traffic control is now inadequate in areas such as the North Atlantic where direct communication with ground stations is difficult. The use of a satellite to relay communications for such areas is being contemplated. Frequency sharing problems between air traffic control satellites and other communication facilities must be considered.

This report is intended to provide the Federal Aviation Agency with technical information relevant to the solution of frequency sharing problems in the VHF band which are associated with the use of VHF for the aircraft/satellite link of a synchronous satellite air traffic control (ATC) system. Specifically, this report deals with the estimation of (1) desired-to-undesired RF signal ratios available at the satellite when interference from a multitude of conventional ATC facilities is considered, and, (2) the extent to which the service range of a conventional ATC facility may be reduced because of interference caused by transmissions from a satellite.

The results given are applicable to either co-channel or adjacent-channel interference problems, and may be easily modified to accommodate a variety of system parameter changes. Specific examples of several such modifications have been included. However, an estimate of the desired-to-undesired signal power ratios required for satisfactory service (protection ratios) must be made by the user in order to apply these results to interference problems as they are expressed in terms of the signal power ratios available under various conditions. An experimental program to determine protection ratios for some of the system combinations that might be encountered in developing a satellite ATC system is being initiated by the Federal Aviation Agency.

2. SYSTEM PARAMETERS

The system parameters used for the purposes of this study are discussed in this section. These parameters were selected on the basis of information contained in the technical literature, discussions with FAA personnel, and the author's analysis of the systems involved. All nonsatellite stations considered in this study were assumed to require, for satellite observation, a look angle that is greater than 0.5^{o} relative to a horizontal plane located at the point of observation; i.e., these stations are within $\sim$5000 n mi of a point on the earth's surface that is directly below the satellite. A wide variety of parameters could be considered in a study of this type, but because of the urgent need for some specific results a very restricted set of parameters was selected. However, the results can be easily modified to allow for changes in some of the noncritical parameters.

2.1 Satellite ATC System

The restricted nature of this study limits the requirements for satellite ATC system parameters to those involved in the VHF satellite/aircraft link. A specific set of parameters had to be selected for this study even though the parameters to be used in the final system design are unknown. In fact, it is not certain that VHF frequencies will be used for satellite system. The parameters selected are tabulated in table 1.

Literature dealing directly with satellite ATC systems [DeZoute, 1965; McClure and Dute, 1964; Miller, 1965; and Spence, 1966] was used as a guide in selecting parameters. Although some consideration was given to the practical and theoretical problems associated with the various parameters involved, the equipment configuration implied should be regarded simply as a reasonable illustration of a possible system, and not as an "optimum" configuration.

TABLE 1

Satellite ATC system parameters

(VHF aircraft/satellite link only)

Item	Aircraft Terminal	Satellite Terminal
Frequency	~130 MHz	~130 MHz
Modulation	FM-voice	FM-voice
Modulation index	1.4	1.4
RF bandwidth	20 kHz	20 kHz
Audio bandwidth	3 kHz	3 kHz
Audio signal-to-noise	20 dB	20 dB
Carrier signal-to-noise	12.3 dB	12.3 dB
FM improvement	7.7 dB	7.7 dB
Line loss	1.5 dB	1.5 dB
Receiver noise figure	4 dB	4 dB
Antenna noise temperature	1,823°K	1,532°K
Effective receiver input noise temperature	1,585°K	1,608°K

Table 1 (Continued)

Item	Aircraft Terminal	Satellite Terminal
Effective receiver noise level	-153.0 dBW	-153.6 dBW
Antenna gain *	5 dB **	16 dB
Antenna beamwidth	***	30°
Antenna polarization	Vertical	Left-hand circular
Polarization loss	3 dB	0 dB
Transmitter power	13.4 dBW	14 dBW
Fading margin	1.7 dB	1.7 dB

The RF bandwidth was chosen to fit comfortably in a 25-kHz channel and still pass the third pair of sidebands associated with a 3 kHz audio frequency. These are the only "significant" sidebands [Panter, 1965] for the 3 kHz tone if the modulation index is 1.4. An FM improvement relative to an equivalent AM system [Baghdady, 1961] of 7.7 dB is possible with this modulation index provided that the receiver is operating above its threshold of "full improvement" [Panter, 1965]. This requires a receiver input carrier-to-noise ratio of about 12 dB.

---

* Relative to isotropic radiator

** Maximum gain 5 dB, median gain 4 dB, and minimum gain 3 dB in direction of satellite

*** Horizontal beamwidth $\sim 90^{\circ}$, vertical beamwidth $\sim 65^{\circ}$, with beam orientated $\sim 35^{\circ}$ above horizon

Noise temperature calculations are based on Baghdady [1961], and Rosenfeld [1965]. Noise temperatures caused by cosmic noise, sun, earth, and received noise were included in the calculations along with the effect of transmission line loss. The noise temperatures associated with the sun were found to be less than 700° K because of the wide antenna beams involved.

To avoid fading caused by Faraday rotation it is necessary for one or both of the antennas to be circularly polarized. The left-handed circularly polarized satellite antenna assumed would provide some rejection of right-handed elliptically polarized transmissions from conventional ATC ground stations.

In order to avoid multipath fading caused by reflection from the earth, vertical polarization, a beam that is tilted up, and a minimum look angle of 12° were assumed for the aircraft antenna. The reflection coefficient for a vertically polarized wave can, under these conditions, be significantly lower than that for horizontally polarized wave. Discrimination provided against the reflected ray by a low reflection coefficient coupled with that obtained from antenna directivity should allow reflections from the earth to be neglected. A polarization loss of 3 dB is included because the use of a circularly polarized aircraft antenna is not anticipated.

Transmitter powers were calculated by considering the time variability associated with transmission over the aircraft/satellite link along with a median basic transmission loss of 167 dB for the link. In view of the very small time variability (see section 3.1), the 1.7 dB fading margin is sufficient to assure that an audio signal-to-noise ratio of at least 20 dB is available for more than 99.9 % of the time. Allowance (safety factor) for variation of equipment performance was not included.

2.2 Typical ATC Facility

Conventional VHF ATC facilities are considered as the source of interference to the aircraft/satellite link of the satellite ATC system in this study. Such facilities consist of a ground station and the aircraft it serves. The need to consider interference caused by a large number of conventional facilities, and the difficulties that would be involved in an exact description of any one particular facility during a specific interval of time have dictated the "typical facility" approach. For this study all conventional facilities are assumed to have characteristics identical to those of a "typical" ATC facility. The system parameters assumed for the "typical" ATC facility are tabulated in table 2.

TABLE 2

Typical ATC facility system parameters

Item	Aircraft Terminal	Ground Terminal
Frequency	~130 MHz	~130 MHz
Modulation	AM-voice	AM-voice
RF bandwidth	40 kHz	40 kHz
Audio bandwidth	3 kHz	3 kHz
Line loss	3 dB	2 dB
Antenna gain	(See figure 1.)	0 dB
Antenna polarization (transmit)	Vertical	Right-hand elliptical
Transmitter power	14 dBW	17 dBW

Documents dealing directly with the conventional ATC system [FAA 1963, 1965a, and 1965b] were used as a guide in selecting these parameters. Exact values for them would be expected to depend on the particular facility and the aircraft types involved during a particular time period. The parameters selected are intended to provide an estimate of average or typical conditions.

The discrete* distribution assumed for the gain of the aircraft antenna is shown in figure 1. This distribution is based on an analysis of gain data for a number of aircraft antenna configurations. Several of the gain data distributions for which the final distribution was taken as representative are also shown in figure 1.

* Because some of the initial calculations discussed here are more easily performed with discrete distributions, discrete random variables were used to describe the typical ATC facility.

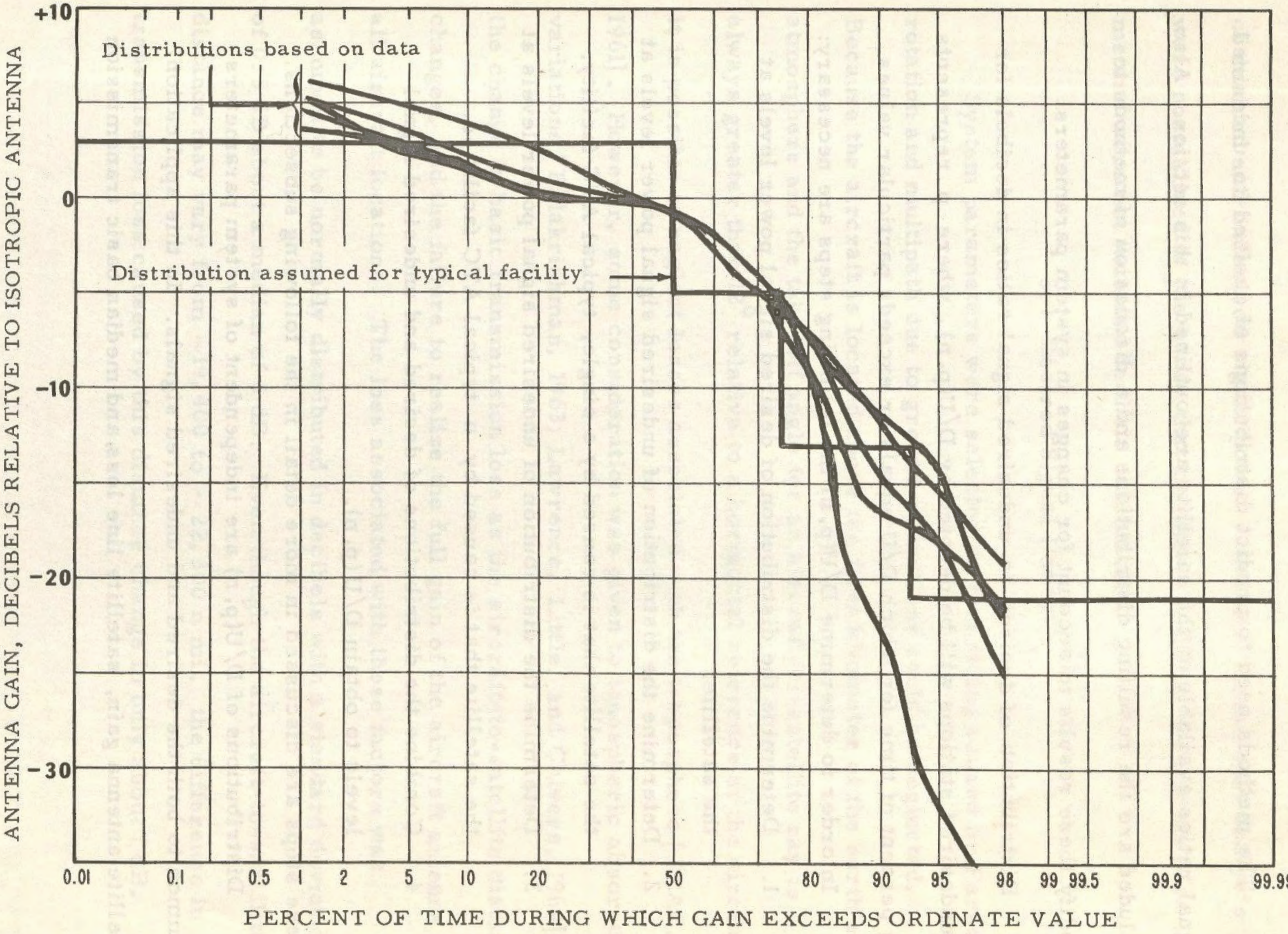

Figure 1. Distribution of aircraft antenna gain for typical facility.

B- 50382

3. INTERFERENCE AT THE SATELLITE

The methods used to predict distributions of desired-to-undesired signal ratios available at the satellite are outlined in this section. Also included are the resulting distributions and a discussion of methods to modify these results to account for changes in system parameters.

Distribution of desired-to-undesired signal ratios in decibels for n undesired stations will be denoted by D/U(p, n), where p represents the percent of time for which D/U equals or exceeds particular values.

In order to determine D/U(p, n) the following steps are necessary:

1. Determine the distribution of desired signal power levels at the satellite.
2. Determine the distribution of undesired signal power levels at the satellite that is caused by a single, typical ATC facility.
3. Determine the distribution of undesired signal power levels at the satellite that is caused by n typical ATC facilities.
4. Combine the distributions of desired and undesired signal levels to obtain D/U (p, n).

These steps are discussed in more detail in the following subsections.

Distributions of D/U(p, n) are independent of system parameters common to both the desired and undesired signals. In this application, satellite antenna gain, satellite line loss, and median basic transmission loss may be treated as common to both signals. Therefore, the values of desired and undesired signal power calculated during this analysis were normalized in the sense that the above mentioned common parameters were not included in their calculation.

3.1 Desired Signal Power

System parameters were selected so that fading caused by Faraday rotation and multipath due to ground reflections could be neglected. Because the aircraft is located above the first kilometer of the earth's atmosphere and the take-off angle for an aircraft-to-satellite ray is always greater than 12° relative to a horizontal reference at the aircraft it is possible to neglect losses associated with the troposphere [JTAC, 1961]. However, some consideration was given to ionospheric absorption variations [Balakrishman, 1963; Lawrence, Little, and Chivers, 1964], the change in basic transmission loss as the aircraft-to-satellite distance changes, and the failure to realize the full gain of the aircraft antenna at all aircraft locations. The loss associated with these factors was assumed to be normally distributed in decibels with a standard deviation of 0.5 dB about a median of 0 dB. Even though the aircraft-to-satellite distance may vary from ~19,400 to ~22,300 n mi, the difference in transmission loss caused by this distance change in only about 1 dB.

Thus, the "normalized" desired signal power will be normally distributed in decibels with a standard deviation of 0.5 dB and a median value of 12.9 dBW. The median was calculated as follows:

Transmitter power*	(+)	13.4 dBW
Polarization loss*	(-)	3 dB
Line loss*	(-)	1.5 dB
Antenna gain *	(+)	4 dB
Median normalized power for aircraft (desired)/satellite link		12.9 dBW

Values of desired and undesired signal power calculated for this analysis were normalized in the sense that items common to both systems were not included. Specifically, satellite antenna gain, satellite line loss, and median basic transmission loss were not included in normalized power calculations.

3.2 Undesired Signal Power from a Single Facility

The distribution of normalized signal power at the satellite from the typical ATC facility (section 2.2) was developed by combining normalized power developed for a typical airborne terminal and a typical ground based terminal. This combination was made by calculating the probability of obtaining certain discrete power levels when it is assumed that, (1) the ground based terminal and airborne terminal do not transmit at the same time, (2) the time during which transmission occurs is equally divided between the two, and (3) no transmissions occur during 5 % of the

* See table 1.

time. Discrete distributions of the power available from each type of terminal along with the discrete distribution resulting from the combination process are shown in figure 2. The mean and variance of the power distribution (expressed in watts) for a typical facility were calculated from the discrete distribution and were found to be 11.52 W and 196.27 W^2, respectively.

Statistics for power received from the airborne terminal were developed by assuming that, (1) the aircraft antenna gain effective for a direct ray to the satellite is statistically independent of the gain effective for a ray reaching the satellite via ground reflection, (2) the gain statistics shown in figure 1 are applicable to both rays, (3) the phase angle between the two signals is uniformly distributed between 0 and 2π [Norton, et al. 1955], and (4) the reflection coefficient of the earth is unity. In order to obtain the proper values of normalized power, the distribution developed using these considerations was modified by the addition of 9 dB. This constant was calculated as follows:

Transmitter power *	(+) 14 dBW
Power increase due to modulation	(+) 1 dB
Line loss *	(-) 3 dB
Polarization loss	(-) 3 dB
Normalization constant for aircraft (undesired)/ satellite link	9 dBW

* See table 2.

Normalized power statistics for the ground terminal were developed by using the "standard propagation curves for earth-space links" given by Rice, et al. [1966] for $\theta_o = 0.03$ rad and a frequency of 2 GHz, and making a minor correction to account for the lower frequency being considered in this study. A factor of 8 dBW was used to make the conversion to normalized power, and it was calculated as follows:

Transmitter power*	(+) 17 dBW
Power increase due to modulation	(+) 1 dB
Line loss*	(-) 2 dB
Polarization loss	(-) 10 dB
Gain due to ground reflection	(+) 2 dB
Antenna gain*	(+) 0 dB
Normalization constant for ground terminal (undesired)/satellite link	8 dBW

In order to communicate with circularly polarized antennas [Reed and Russell, 1964; Jasik, 1961] it is necessary that the antennas have the same polarization sense (right-handed or left-handed). The loss due to a polarization mismatch between the ground station antenna (right-hand elliptical) and the satellite antenna (left-hand circular) was estimated to be 10 dB.

3.3 Undesired Signal Power from Multiple Facilities

Distributions of normalized signal power at the satellite due to n typical ATC facilities were developed by combining the powers

* See table 2.

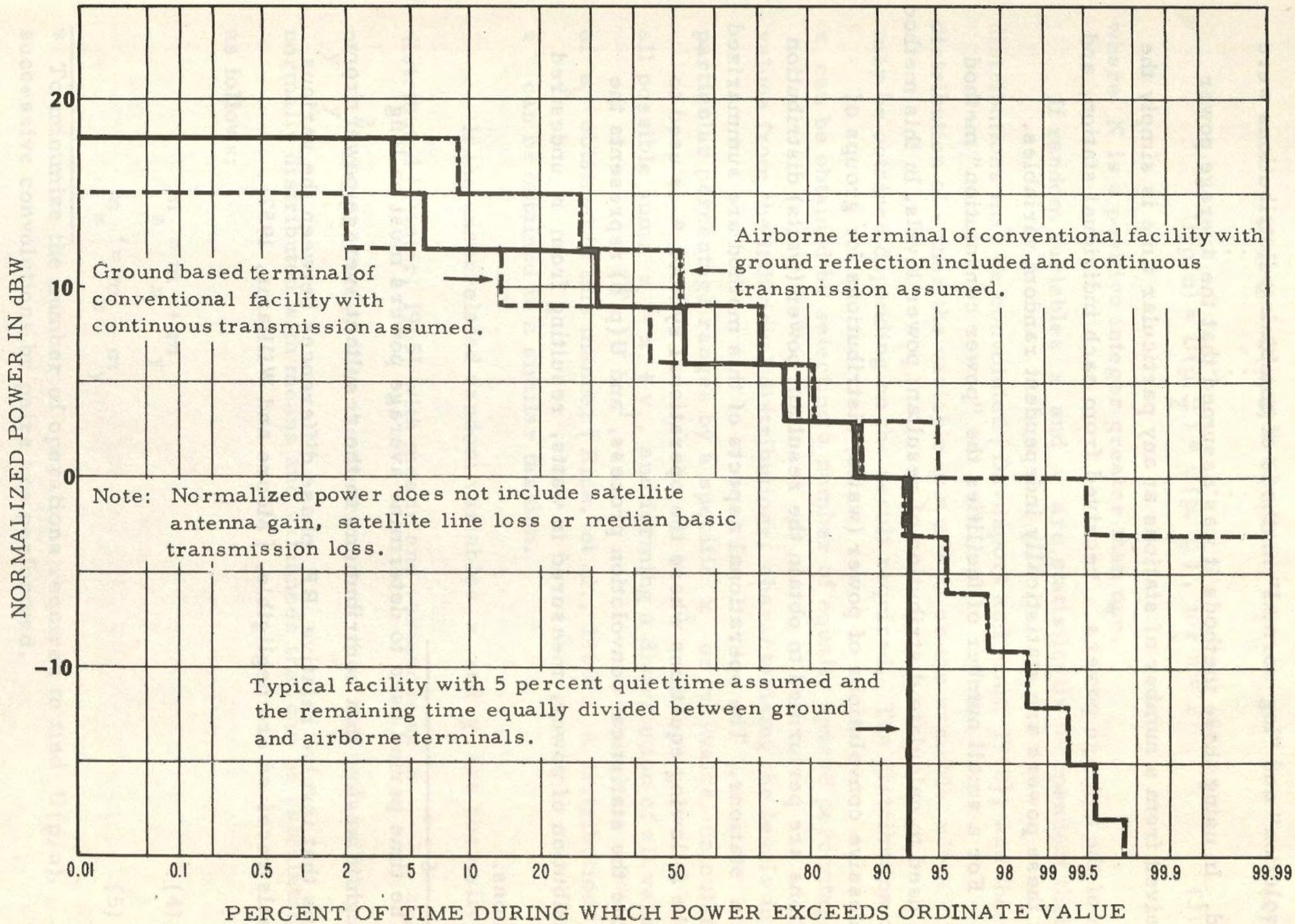

Figure 2. Development of power distribution for typical facility.

B-50382

expected from the various stations by statistical means. The "power convolution" and "log-normal" methods of combining distributions were used. In using these methods it was assumed that the average power received from a number of stations at any particular time is simply the sum of the average powers * received from each individual station, and that these powers are statistically independent random variables.

For a small number of facilities the "power convolution" method was used to calculate distribution of resultant power levels. In this method successive convolutions of power (watts) distributions for groups of stations are performed to obtain the resultant power (watts) distribution for n stations. The operational aspects of this method are summarized by the following equations where the operational symbol * is used to denote the statistical convolution process, and U(p, n) represents the distribution of power, measured in watts, resulting from n undesired stations.

---

* The time period used to determine average powers must be long enough to assure that contributions to the resultant average power from terms that involve relative RF phase differences between the various signals received are negligible, [Moore and Williams, 1957] .

$$U(p, 2) = U(p, 1) * U(p, 1) \quad (1)$$

$$U(p, 4) = U(p, 2) * U(p, 2) \quad (2)$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$U(p, n) = U(p, \frac{n}{2}) * U(p, \frac{n}{2}), \text{ for } n = 2^N, \quad (3)^*$$

where N is a positive integer greater than one.

If random variables x and y are statistically independent their distributions may be convoluted [Davenport and Root, 1958], and the distribution of either the variable $z = x + y$, or the variable $z' = x - y$ may be obtained depending on the result required. The distribution of z can be obtained by selecting a number of equally spaced percentage values from the individual distributions, characterizing the levels in particular percentage ranges by a specific x_i or y_j value, calculating all possible sums $z_k = x_i + y_j$, and forming a distribution of all values of z_k obtained in this manner [Rice, et al., 1966]. A distribution for z' can be obtained in a similar fashion.

If the uncorrelated random variables x and y are normally distributed [Panter, 1965] with means and variances of m_x, σ_x^2 and m_y, σ_y^2 respectively, then the distributions of z and z' will be normally distributed with means and variances that can be calculated as follows:

$$m_z = m_x + m_y \quad (4)$$

$$m_z' = m_x - m_y \quad (5)$$

---

* To minimize the number of operations required to find U(p, n), successive convolutions by pairs are performed.

$$\sigma_z^2 = \sigma_{z'}^2 = \sigma_x^2 + \sigma_y^2 \quad . \qquad (6)$$

However, the power (watts) distribution for a typical ATC facility is not approximated very well by a normal distribution and this simple procedure could not be used.

A simplified version of the log-normal method given by Norton, Staras, and Blum [1952] was used for values of n greater than 16. This simplification results from the assumptions that the same distribution describes the power radiated by each undesired facility and that the power levels received from the various facilities are statistically independent. Because the log-normal method assumes that the power (watts) resulting from one or several stations is log-normally distributed, it could not be used for small values of n. The relationships used to calculate the mean, M_n, and variance σ_n^2, of the normally distributed dBW resulting from n stations by using the mean, α in watts, and variance, μ in watts^2, of a typical ATC facility are given below:

$$M_n = \left[\ln (n\alpha) - \frac{1}{2} \left(\frac{\sigma_n}{10 \log_{10} e} \right)^2 \right] 10 \log_{10} e \quad \text{dBW} \qquad (7)$$

$$\sigma_n^2 = \left(10 \log_{10} e \right)^2 \ln \left[1 + \frac{n\mu}{(n\alpha)^2} \right] \quad \text{dB}^2 \quad . \qquad (8)$$

Here ln means natural logarithm.

Values of M_n and σ_n calculated for several values of n are tabulated in table 3 along with the corresponding values of $n\mu$, $n\alpha$, and $10 \log_{10} n\alpha$.

TABLE 3

Results of log-normal calculations

n	$n\mu$ watts^2	$n\alpha$ watts	$10 \log_{10} n\alpha$ dBW	M_n dBW	σ_n dB
1	196.27	11.52	10.6	8.7	4.13
2	392.54	23.04	13.6	12.4	3.23
4	785.08	46.08	16.6	16.0	2.44
8	1,570.16	92.16	19.7	19.3	1.79
n	$n\mu$ watts^2	$n\alpha$ watts	$10 \log_{10} n\alpha$ dBW	M_n dBW	σ_n dB
16	3,140.32	184.32	22.7	22.5	1.29
32	6,280.64	368.64	25.7	25.6	0.92
10^2	1.9627×10^4	1.152×10^3	30.6	30.6	0.53
10^3	1.9627×10^5	1.152×10^4	40.6	40.6	0.17
10^4	1.9627×10^6	1.152×10^5	50.6	50.6	0.05
10^5	1.9627×10^7	1.152×10^6	60.6	60.6	0.00

It can be shown that M_n approaches $10 \log_{10} n\alpha$ and σ_n approaches zero as n approaches infinity. Values tabulated in table 3 indicate that M_n may be taken as $10 \log_{10} n\alpha$ for n larger than 32 and that σ_n may be taken as 0 for n larger than 10^4. This means that power received from n facilities, where n is larger than 10^4, can be assumed to have a constant level given by,

$$M_n = A + N \text{ dBW} \tag{9}$$

where

$$A = 10 \log_{10} \alpha \text{ dBW} \tag{10}$$

and

$$N = 10 \log_{10} n \text{ dB}. \tag{11}$$

Distributions of undesired power $U_{dBW}(p, n)$, developed by using the methods just discussed are shown in figure 3 for several values of n along with the distribution of power received from the desired station. This figure is intended to illustrate five points:

1. The period of time for which 0 W of power is expected from undesired facilities diminishes rapidly as n increases.
2. Although the log-normal method should not be used for small values of n it yields results that are close to those obtained by the power convolution method for values of n as small as 16.
3. The variation of undesired power about its median level decreases significantly as n increases.
4. The power received from a single undesired station is greater than that received from the desired station during a significant fraction of the time.

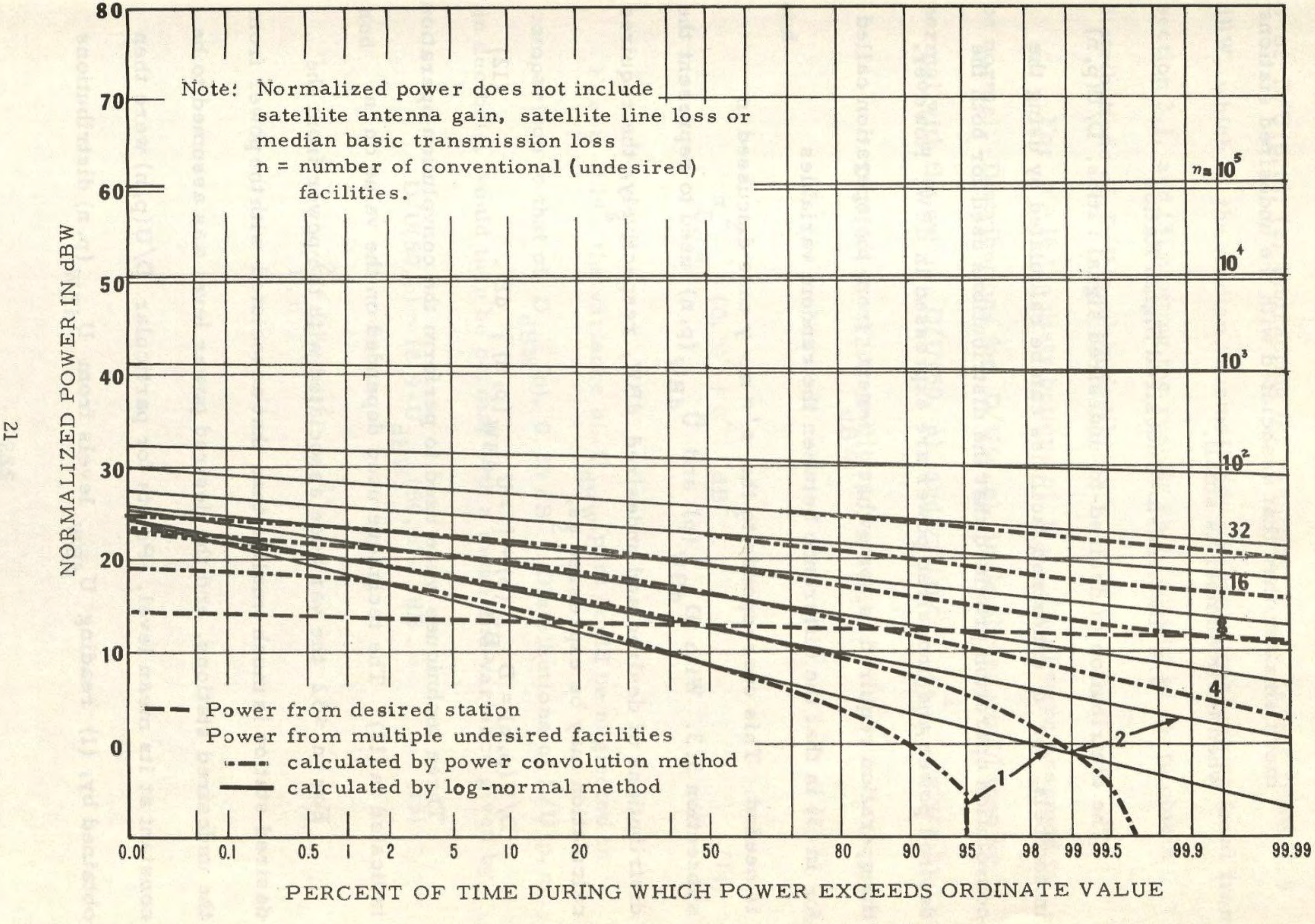

Figure 3. $U_{dBW}(p, n)$ at satellite terminal.

B-50382

5. The time variability associated with the desired station is much smaller than that associated with the undesired stations when their number is small.

3.4 Desired-to-Undesired Signal Ratios

The distribution of desired-to-undesired signal ratios, $D/U(p,n)$ in decibels, for n undesired facilities can be calculated by using the convolution operation provided that the distributions used for both the desired power and undesired power are expressed in dBW. However, the operation required is somewhat different from the operation called for in (3) in that the difference between the random variables is needed. This corresponds to the $z' = x - y$ case discussed in subsection 3.3. With $D_{dBW}(p)$ and $U_{dBW}(p,n)$ used to represent the distributions of desired and undesired dBW, respectively, the required calculation may be expressed as,

$$D/U(p,n) = D_{dBW}(p) * [\, -U_{dBW}(p,n)\,] \text{ dB} . \quad (12)$$

Three techniques were used to perform the convolution operation indicated in (12). The technique used depended on the value on n.

For $n \leq 32$ the variance associated with the power from the desired station is much smaller than that associated with the power from the undesired stations, and the desired power level was assumed to be constant at its mean level. Points for particular $D/U(p,n)$ were then obtained by, (1) reading U_{dBW} levels from $U_{dBW}(p,n)$ distributions (fig. 3) corresponding to percentage values of 100-p where p is the p of $D/U(p,n)$, (2) subtracting the resulting U_{dBW} levels from 12.9 dBW, which is the median "normalized" desired signal power level from section 3.1, and (3) plotting the results as a function of p to obtain distributions of $D/U(p,n)$ in decibels.

For $n \geq 16$ the distributions of $U_{dBW}(p,n)$ were assumed to be normal. Distributions for $D/U(p,n)$, in decibels, would then be normal with the mean, $D/U(50, n)$, and variance, $\sigma^2_{D,n}$, given by

$$D/U(50,n) = 12.9 - U_{dBW}(50, n) \text{ dB}, \tag{13}$$

and

$$\sigma^2_{D,n} = (0.5)^2 + \sigma^2_n \text{ dB}^2. \tag{14}$$

For $n \geq 10^4$ the variance of $U_{dBW}(p,n)$ could be neglected in comparison to that of $D_{dBW}(p)$, 0.25 dB^2. Distributions of $D/U(p,n)$, in decibels, would then be normal with a mean and variance given by

$$D/U(50,n) = 12.9 - U_{dBW}(50,n) \text{ dB}, \tag{15}$$

and

$$\sigma^2_{D,n} = (0.5)^2 \text{ dB}^2. \tag{16}$$

The above discussion indicates that two techniques were used to obtain D/U(p, n) distributions for $n = 16$ and $n = 32$. The results obtained are shown in figure 4 along with the other D/U(p, n) distributions determined for this study. Dashed lines are used to show distributions resulting from the use of the technique discussed above for $n \leq 32$.

Figure 4 is particularly useful when satisfactory service for the satellite is defined in terms of the desired-to-undesired signal ratio (protection ratio) that must be available or exceeded. For example, if in a co-channel application a protection ratio of 6 dB is required, then the percentage of time for which satisfactory service would be expected is 38, 9, 0.5, and ~0 for interference from 1, 2, 4, and more than 4 typical ATC facilities, respectively. As another example, suppose that a signal ratio of -60 dB could be tolerated for adjacent-channel interference and that it is desired to have service ~100 % of the time, then interference from 10^6 adjacent-channel typical facilities could be tolerated.

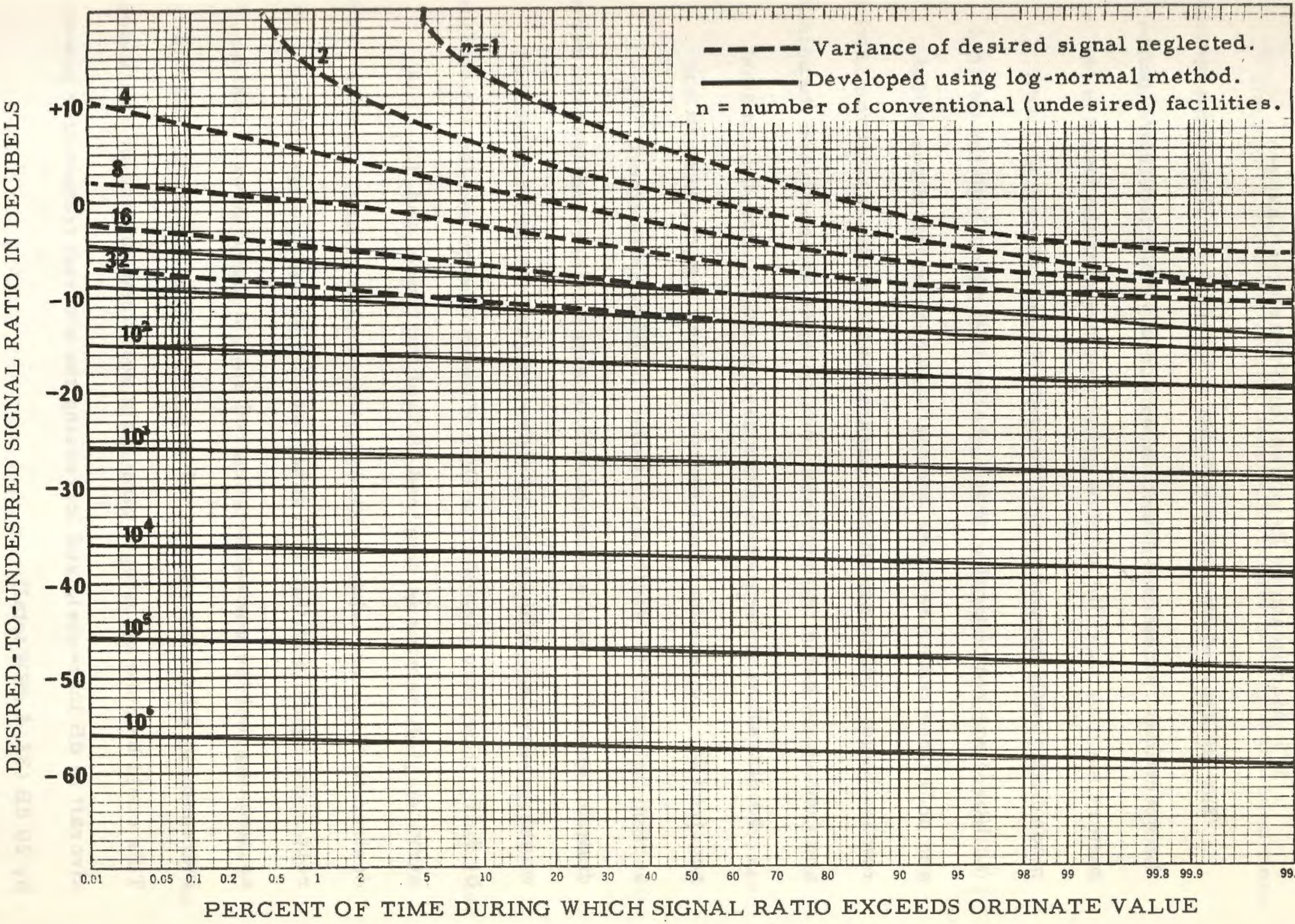

Figure 4. D/U(p, n) at satellite terminal.

B- 37039

3.5 Modifications Required for Parameter Changes

The D/U(p, n) distributions shown in figure 4 are dependent upon the specific parameters outlined in section 2. However, some parameters such as satellite antenna gain (provided that the beam is not made sufficiently narrow to discriminate against some undesired facilities) are noncritical in that a change will affect both the desired and undesired power equally, and the D/U(p, n) distributions would remain valid. Other noncritical parameters are line loss at the satellite and free space basic transmission loss between the earth and the satellite.

Modification of the parameters used in calculating the constant required for conversion to normalized desired signal power in subsection 3.1 would necessitate a similar modification to the D/U(p, n) distributions; i.e., an increase of 3 dB in aircraft (desired) transmitter power would require that D/U values read from figure 4 also be increased by 3 dB. For example, if (1) a D/U of 15 dB is required for satisfactory service, (2) service is required 98 % of the time, and (3) it is desired to frequency-share with 4 conventional facilities, then the -8 dB read from figure 4 at the 98 % level for n = 4 may be interpreted as meaning that the normalized desired station signal power must be increased by 23 dB in order to achieve the desired frequency sharing. This could be done by using a circularly polarized antenna on the desired aircraft (3 dB increase), and increasing the aircraft transmitter power by 20 dB (33.4 dBW total).

The figure 4 curves can be used to estimate interference conditions that might exist if the 1,540 - 1,570 MHz band were used for the aircraft/satellite link if various assumptions are made. One possible set of such assumptions is as follows:

1. The distributions for desired and undesired power at the satellite terminal would remain unchanged in shape even though the levels might change.

2. The transmitter powers involved in providing the typical facility service are increased by 22 dB in order to overcome the increase in basic transmission loss caused by the increase in frequency.

3. The 22 dB increase in basic transmission loss for the aircraft-to-satellite link is overcome by using a circularly polarized aircraft antenna (3 dB gain), increasing the gain of the aircraft antenna by 6 dB (10 dB total), increasing the aircraft transmitter power by 9 dB (22.4 dBW total), and increasing the gain of the satellite antenna by 4 dB (20 dB total).

This set of assumptions would require that D/U values obtained from figure 4 be decreased by 4 dB. If, an increase of aircraft transmitter power of 13 dB is assumed instead of a 4 dB increase in satellite antenna gain, then figure 4 could be used directly.

Figure 4 may also be used to estimate interference conditions caused by VHF extended range facilities [DeZoute, 1964; Grann, 1965] if it is assumed that the distributions for undesired power at the satellite remain unchanged in shape even though the levels involved may change. This requires that the constants used to convert to normalized power for the airborne and ground stations differ from those discussed in subsection 3.2 by about the same amount. An estimate of these constants for an extended range facility may be made as follows:

	Ground Station	Airborne Station
Transmitter power	(+) 33 dBW	(+) 27 dBW
Line loss	(-) 2 dB	(-) 1 dB
Polarization loss	(-) 3 dB	(-) 3 dB
Reflection gain	(+) 2 dB	0 dB
Antenna gain *	(+) - 4 dB	(+) 4 dB
Extended range constants	26 dBW	27 dBW

These constants are 2 dB greater than those of subsection 3.2. Therefore, D/U values read from figure 4 should be <u>decreased</u> by 11 dB when this analysis is considered reasonable for extended range facilities.

The modifications discussed in this subsection were included to illustrate how the curves shown in figure 4 can be used to estimate

---

* It is assumed that the extended range facility is oriented such that only side-lobe antenna gain is realized in the direction of the satellite.

interference conditions when system parameters differ from those assumed in developing the curves. Various assumptions are required to make these estimates, and their validity may be somewhat questionable in some cases. For example, the side-lobe antenna gains assumed in the discussion of extended range could be in error by several dB. Better estimates can be made for situations in which the system parameters differ from those assumed for this analysis by repeating the analysis for the specific parameters of interest.

4. INTERFERENCE TO CONVENTIONAL ATC FACILITIES

This section deals with the affect of satellite transmissions on the service range of conventional ATC facilities that are directly illuminated by the satellite. A "worst case" approach was taken to this problem and curves were developed to show the <u>maximum</u> service range reduction that could be required to overcome interference from the satellite versus the normal service range of conventional ATC facilities for various levels of desired-to-undesired signal ratios. It was assumed that conventional ATC facilities are most sensitive to interference at airborne receiving stations.

The distribution of undesired power available at an airborne receiving station of a conventional facility from the satellite may be obtained from the distribution labeled "airborne terminal with ground reflection included" in figure 2 by adding -153.5 dB to the indicated power levels. This conversion constant is determined as follows:

Satellite transmitter power	(+) 14 dBW
Satellite antenna gain	(+) 16 dB
Satellite line loss	(-) 1.5 dB
Median basic transmission loss	(-) 167 dB
	- 138.5 dBW

Aircraft transmitter power	(+) 14 dBW
Power increase due to modulation	(+) 1 dBW
	15 dBW

then, -138.5 - 15 = -153.5 dB is the constant required to convert normalized undesired power received at the satellite (from a conventional airborne terminal) to the actual undesired power received at a conventional airborne terminal (from the satellite). The first group of items represent the additional factors that need to be considered and the second group are factors that were considered in the normalized power calculation for figure 2, but should not be considered here. If it is assumed that the satellite transmits continuously, the distribution shown in figure 2 (for airborne terminal) may be used directly as an estimate of the undesired power received from the satellite by an aircraft using conventional ATC provided the level adjustment just discussed is made. For example, an estimate of the maximum interfering power can be made by reading the highest level on the figure 2 distribution (19 dBW) and adding -153.5 to it; i.e., 18 - 153.5 ≅ -135 dBW.

For analysis of the conventional ATC maximum service range reduction that could be required to overcome interference from the satellite the normal service range of conventional ATC facilities was defined as the range at which the desired (from ground station) power input to an aircraft receiver is -123 dBW (~5 μ V across 50 Ω), and the maximum undesired (from satellite) power at the aircraft receiver input was taken as -135 dBW. Under these conditions the minimum desired-to-undesired signal ratio, D/U (min), at the normal service range is 12 dB.

To estimate the maximum reduction in service range required to assure D/U (min) levels greater than 12 dB it was assumed that the desired signal will increase as the distance (altitude fixed) to the ground station is decreased and that the lowest increase, ΔD, in desired power for a decrease in distance from the normal range, R_N, to a reduced range, R_R, is given by,

$$\Delta D = 20 \log_{10} \frac{R_N}{R_R} \text{ dB} . \qquad (17)$$

The distance dependence in (17) is the same as that associated with transmission loss in free space. Equation (17) can be rearranged to give the range reduction, ΔR, required to achieve ΔD; i.e.,

$$\Delta R = R_N - R_R = R_N\left(1 - 10^{-\frac{\Delta D}{20}}\right), \quad R_R \le R_N. \quad (18)$$

Values of D/U(min) are related to ΔD by,

$$D/U(min) = 12 + \Delta D \text{ dB}, \quad R_R \le R_N. \quad (19)$$

Equations (18) and (19) were used to develop the curves shown in figure 5. The relationship between R_N, ΔR, and D/U(min) are shown by this figure. For example, if a D/U(min) of 12 dB or less is sufficient to assure satisfactory service for the conventional ATC facility, then no reduction in the normal range would be caused by interference from the satellite. If, on the other hand, a D/U(min) of 18 dB is required and the normal service range is 200 n mi, then the maximum reduction of operating range expected because of interference from the satellite is 100 n mi and the operating range would be reduced from 200 to 100 n mi.

If the normal service range is near or beyond the radio horizon, then the service range reduction indicated by figure 5 would be expected to be more than sufficient to assure satisfactory service for distances equal to or less than the normal service range reduced by the indicated amount; i.e., the range reduction indicated for these cases is expected to be too large by an amount that will be dependent upon the propagation

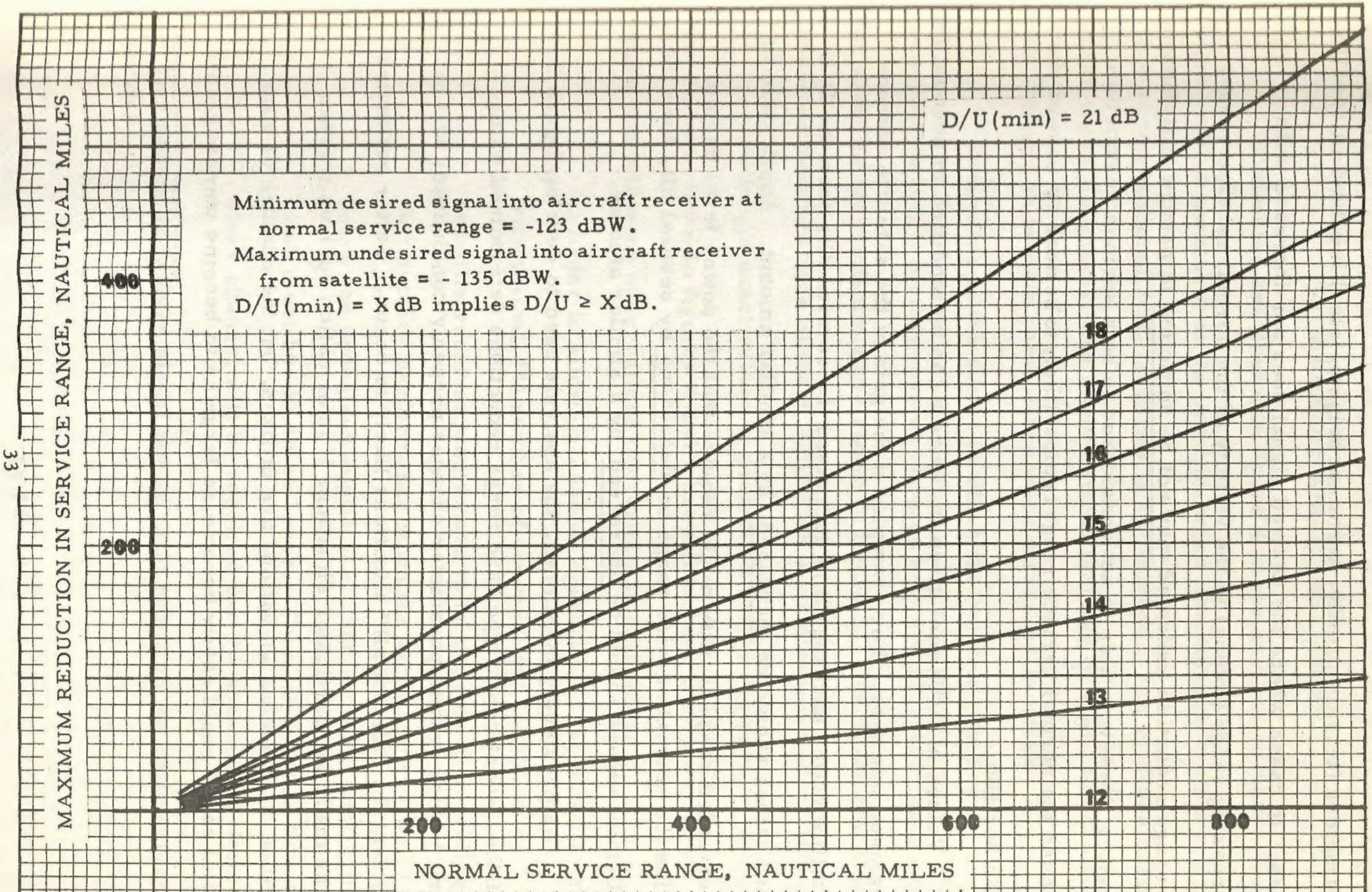

Figure 5. Conventional ATC facility service range reduction due to interference from satellite.

parameters (terrain profile, terminal heights, etc.) involved in specific cases. In cases where the desired signal does not increase with decreasing range (lobing) in the vicinity of the normal service range, the range reduction indicated may not be sufficient to assure satisfactory service. However, this is not considered to be a serious restriction because the normal service range is most likely to be near or beyond the radio horizon.

Values of D/U(min) given in figure 5 can be modified to account for parameter changes. For example, if the gain of the satellite antenna (satellite power unchanged) is decreased by several dB, then the D/U (min) values should be increased by a similar amount. Application to an extended range facility might require that the power level used to define the normal service range be decreased by several dB, then the D/U(min) values should be decreased by a similar amount.

As previously mentioned, the analysis used to develop figure 5 is of the "worst case" type, and range reductions determined using figure 5 (with system parameter changes properly considered) will be sufficient for "almost all" situations likely to occur. Better estimates can be made for particular situations if information such as terrain profiles, and antenna elevations are utilized, but the number of such special cases could easily become so large as to become unmanageable.

5. SUMMARY AND CONCLUSIONS

Estimates are shown in figure 4 of the desired-to-undesired RF signal ratios available at the satellite when interference from a multitude of conventional ATC facilities is considered. The methods used to make these estimates, and modifications that can be made to account for changes in system parameters were discussed in section 3.

Estimates of the extent to which the service range of a conventional ATC facility may be reduced because of interference caused by satellite transmissions are shown in figure 5. The development and possible modifications of these estimates were discussed in section 4.

Although exact values of protection ratios required to interpret the curves shown in figures 4 and 5 are not known, it is possible to make the following observations concerning interference:

1. In order to allow co-channel operation of the satellite system with a small (4) number of conventional facilities the satellite receiver would have to be capable of providing satisfactory performance when the desired signal is 10 dB below the undesired signal; i.e., the required protection ratio* must be -10 dB or lower. Thus, it is likely that a clear channel will be required for the satellite system.

---

* Desired-to-undesired signal power ratio required for satisfactory service.

2. Significant service range reductions will be encountered for conventional facilities if they are operated co-channel with the satellite system if a protection ratio higher than 12 dB is required. This may provide another reason for a clear channel assignment to the satellite system.

3. A required adjacent-channel protection ratio at the satellite as high as -30 dB would allow adjacent-channel operation with a significant number (10^3) of conventional facilities. However, the allowed number of stations must be divided between two channels since there are two adjacent channels.

4. A service range reduction for conventional facilities because of adjacent-channel interference from the satellite would not be expected, because a required protection ratio as high as 12 dB could be tolerated.

These observations might have to be changed to some extent as changes in system parameters are considered. In particular, this analysis has assumed that all stations are within the horizon of the satellite, and frequency sharing on a co-channel basis between a satellite system and conventional ATC facilities should be possible if the conventional facilities are located beyond the horizon of the satellite by a sufficient distance.

6. REFERENCES

Baghdady, E. J. (1961), Lectures on Communication System Theory, (McGraw-Hill, New York, N. Y.).

Balakrishnan, A. V. (1963), Space Communications, (McGraw-Hill, New York, N. Y.).

Davenport, W. V., Jr., and W. L. Root (1958), Random Signals and Noise, (McGraw-Hill, New York, N. Y.).

DeZoute, O. J. (1965), Future Satellite Communication Subsystem Investigation, FAA Interim Report No. RD-65-77.

DeZoute, O. J. (Oct. 1964), Long Distance VHF Communications System Test at Barnstable, Massachusetts, FAA Report No. RD-64-139.

FAA (Sept. 1963), Antenna, VHF, Circularly Polarized, FAA Specification No. FAA-E-2019.

FAA (June 1965a), VHF/UHF Air/Ground Communications Frequency Engineering Handbook, FAA Handbook No. 6050, 4A.

FAA (Aug. 1965b), Radio Frequency Management Principles and Practices! General, Organization and Functions, FAA Handbook No. 6050, 8.

Grann, O. T. (April 1965), FAA High Gain Air/Ground/Air VHF/UHF Troposcatter System, FAA Report No. RD-65-40.

Jasik, H. (1961), Antenna Engineering Handbook, (McGraw-Hill, New York, N. Y.).

JTAC (March 1961), Frequency Allocations for Space Communications, (Joint Technical Advisory Committee, New York, N. Y.).

Lawrence, R. S., C. G. Little, and H. J. A. Chivers (Jan. 1964), A Survey of Ionospheric Effects Upon Earth-Space Radio Propagation, Proc. IEEE 52, No. 1, 4-27.

McClure, G. W., and J. C. Dute' (May 1964), Survey and Analysis of Long-Distance Communications Techniques, FAA Report No. RD-64-7.

Miller, B. (Oct. 1965), Satellites Offer Wide Use by Airlines, Aviation Week and Space Technology 83, No. 17, 86.

Moore, R. K. and C. S. Williams, Jr. (Feb. 1957), Radar Terrain Return at Near-Vertical Incidence, Proc. IEEE 45, No. 2, 228-238.

Norton, K. A., H. Staras and M. Blum (Feb. 1952), A Statistical Approach to the Problem of Multiple Radio Interference to FM and Television Service, Trans. IRE PGAP-1.

Norton, K. A., L. E. Vogler, W. V. Mansfield, and P. J. Short (Oct. 1955), The Probability Distribution of the Amplitude of a Constant Vector Plus a Rayleigh-Distributed Vector, Proc. IRE 43, No. 10, 1354-1361.

Panter, P. F. (1965), Modulation, Noise, and Spectral Analysis, (McGraw-Hill, New York, N. Y.).

Reed, H. R. and C. M. Russell (1964), Ultra High Frequency Propagation, (Boston Technical Publishers, Lexington, Mass.).

Rice, P. L., A. G. Longley, K. A. Norton, and A. P. Barsis (1966), Transmission Loss Predictions for Tropospheric Communication Circuits, NBS Technical Note 101 (Revised).

Rosenfeld, M. M. (May 1965), Noise in Aerospace Communications, Electro-Technology 75, No. 5, 40-43.

Spence, R. E. (July 1966), Future Role of Satellites in Air Traffic Control, IEEE Spectrum 3, No. 7, 112-115.