OT TECHNICAL MEMORANDUM 74-164

PROPAGATION ASSESSMENT FOR FACSFAC LINKS

SAN CLEMENTE IS. / PT. LOMA AND NORTH IS. / IMPERIAL BEACH

OT

U.S. DEPARTMENT OF COMMERCE / Office of Telecommunications

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H.T. DOUGHERTY
J.J. TARY

U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

Betsy Ancker-Johnson, Ph. D.
Assistant Secretary for Science and Technology

OFFICE OF TELECOMMUNICATIONS
John M. Richardson, Acting Director

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OFFICE OF TELECOMMUNICATIONS
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PREFACE

At the request of the Naval Electronic Systems Command, Southwest Division (MIPR-4-4300, 19 September 1973), a limited consulting service has been provided by the Institute for Telecommunication Sciences, Office of Telecommunications, Department of Commerce in connection with specific portions of the Fleet Area Control and Surveillance Facility Microwave System (FACSFAC). Recommendations were requested to improve the presently constituted SCI/PI and NORIS/IB microwave path performance.

In response, Dr. H. T. Dougherty and Mr. J. J. Tary of OT/ITS visited the FACSFAC installations (10-14 Dec. 74) for: on-site inspection of the microwave facilities, discussions with on-site personnel, and the review of related documentation. This report, resulting from these activities, briefly describes the propagation aspects of the problem links and evaluates the likely sources of performance degradation. Specific recommendations and cautions contained in the text are itemized in the Abstract and Conclusions.

We wish to thank, for their courteous, informative cooperation, the personnel of FACSFAC and NAVELECSYSCOM SOWEST DIV, which contributed materially to the OT/ITS completion of this study.

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by

H. T. Dougherty and J. J. Tary*

ABSTRACT

This report reviews the available documentation for two links of the FACSFAC microwave system and the findings of on-site inspections. It is recommended that the present maintainance program be supplemented by additional performance monitoring. This should include periodic calibration of received signal levels and the periodic measurement of the combiner performance, receiver-quieting, and idle-channel noise.

At present, one microwave link does not appear to have sufficient clearance for high-reliability performance. Repositioning the lower terminal to a higher elevation will remedy this situation.

A second microwave link does not have sufficient frequency diversity spacing, at present, to offset deep fading due to sea-surface reflection. The frequency diversity separation should be increased or replaced by space diversity. However, this should not preceed a complete check-out and refurbishing of antennas at both terminals. Path obstruction does not appear to be the major cause of outages, with the possible temporary exception of super-structure traversing the path when a ship moves into or out of Marginal-Wharf Berth L. If this latter case occurs often enough to become a problem in the future or if implementing improved diversity is not feasible, then use of an offpath passive reflector (to replace the present path) should be explored further. Proper positioning of a billboard passive reflector could prove a most effective remedy for the multipath due to sea-reflections.

Key Words: Diversity, Microwave Fading, Path Obstruction.

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* The authors are with the Institute for Telecommunication Sciences, Office of Telecommunications, Department of Commerce, Boulder, Colorado.

1.0 INTRODUCTION

Fading on fixed point-to-point, microwave, line-of-sight systems is a dynamic condition attributable to the variations with time of the radio refractive index structure along the propagation path. In anticipation of the occurrence of fading mechanisms, microwave system design incorporates appropriate remedies to eliminate, or compensate for, their potential impact upon system performance. Beyond that, proper maintain-ance, performance monitoring, and periodic inspection of the path for changes in the terrain (including structures) are still required to maintain the desired system performance.

For some microwave systems, the desired performance may not be fully achieved due to unanticipated aspects of the fading mechanisms. For example, predictions of the time variations of the radio refractive index are rarely available, and so, this very crucial factor must often by estimated. Similarly, buildings, antennas, etc. may be subsequently con-structed along a microwave preopagation path. When a reduced performance is experienced despite proper maintainance pro-cedures, the propagation path properly becomes a suspect. Most long-established operational systems do not incorporate adequate provisions for monitoring and recording the character-istics of non-equipment outages (their occurrence, duration, time of occurrence, short-term signal behavior, combiner efficiency, etc.). Until such a capability is incorporated, as in new and planned systems, the diagnosis of propagation outages is usually limited by funding to on-site inspections and review of the systems design.

It is well to start this report with a very brief review of microwave fading mechanism; this is covered in Section 2. Section 3 examines the San Clemente Is./Point Loma (SCI/PL) path in the light of these fading mechanism; Section 4 simi-larly examines the North Island/Imperial Beach (NORIS/IB) path.

Section 5 summarizes the conclusions relative to both paths. Section 6 is the list of references, and Section 7 lists most of the formulas employed for Sections 3 and 4.

2.0 MICROWAVE FADING

Microwave fading on line-of-sight paths may be considered under two catagories [1], multipath fading and power fading. Each results from the interaction of the transmitted microwave signal with the atmosphere and terrain. Each catagory may be characterized in terms of the resulting received-signal behavior, remedial techniques are available to reduce their impact on system performance.

2.1 Multipath Fading

Multipath fading results, as the refractive index gradient of the atmosphere varies, from the interference between the direct wave (free-space field) and:

- M1) the specular component of surface-reflected waves;
- M2) the non-specular (random) component of reflected waves; or
- M3) additional direct paths due to atmospheric layers, elevated or near the surface.

Some of these are illustrated in figure 1. The depths of fades encountered can be quite severe, depending upon the effective reflection coefficients or the relative amplitudes of the component waves. Multipath Mechanisms M1 and M3 can produce fades persisting for minutes. During such fades, multipath mechanism M2 can interact to provide even deeper, more rapid, fades with durations of seconds. All of these mechanisms are characterized by a median near the free-space level. The multipath fading tends to be slowest during afternoon hours. For overwater propagation paths, two-component multipath (direct plus sea-reflected or two direct

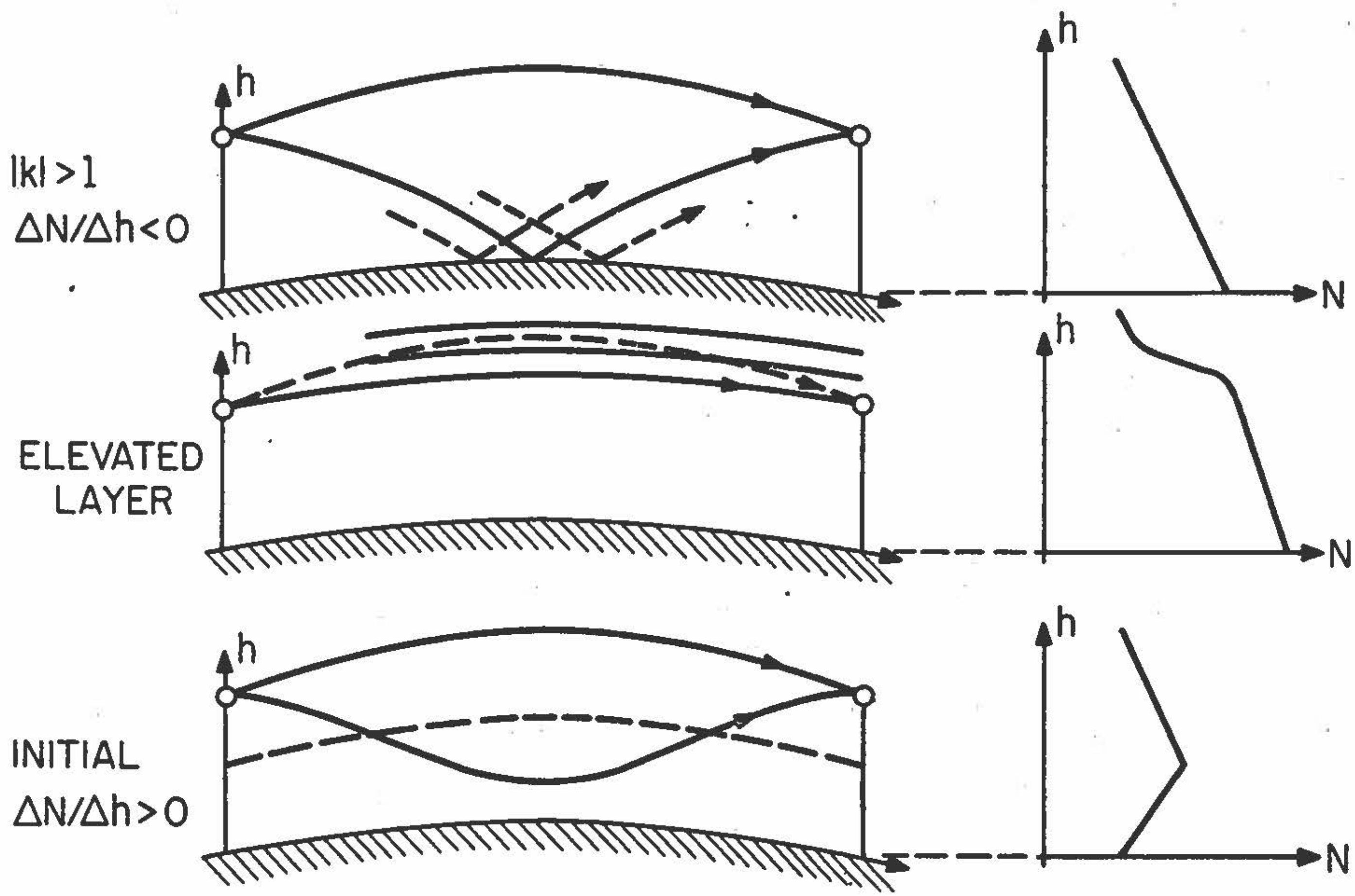


Figure 1. Multipath Fading Mechanisms [1]. N is the refractivity, h is height above the surface, $\Delta N/\Delta h$ is the refractivity gradient, and k is the effective earth-radius factor.

atmospheric paths) can produce the steep time distribution of figure 2 [1]. For more than two components (multiple direct atmospheric paths or multiple terrain reflections), the distributions are less steep, approaching the Rayleigh time-distribution as in figure 3 [1,2,3]. Since multipath fading is frequency and space dependent, the most common remedy is space and/or frequency diversity [1,4,5]. When the multipath results from surface reflectons, some path geometries permit the elimination of the surface reflections by positioning the antenna so that the immediate foreground obstructs all but the direct path. In the absence of adequately obstructing foreground, a protective fence may accomplish the same purpose [6].

2.2 Attenuation or Power Fading

Attenuation or Power Fading results from the partial isolation of the transmitting and receiving antennas because of:

- A1) intrusion of the earth's surface, building, or atmospheric layers into the propagation path (upper illustration in figure 4);
- A2) antenna decoupling due to variation of the refractive index gradient (too narrow an antenna beam);
- A3) partial reflection from elevated layers interpositioned between the (transmitter and receiver) terminal antenna elevations (middle illustration in figure 4);
- A4) "ducting" layers, atmospheric ducts containing only one of the terminal antenna elevations (lower illustration in figure 4); and
- A5) precipitation along the propagation path.

Each of these are characterized by a marked decrease in signal level for extended periods (minutes to hours) of time.

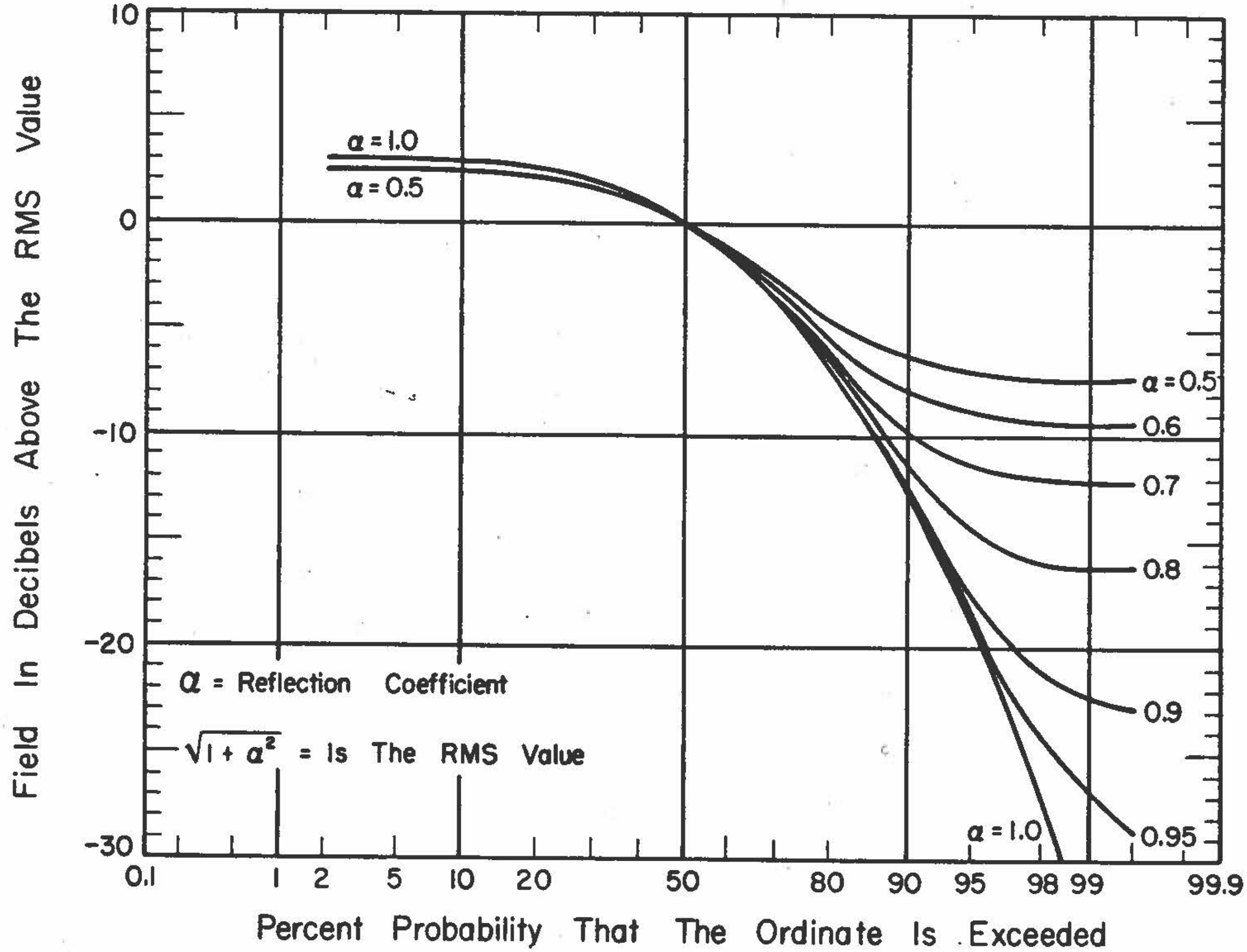


Figure 2. Two Component Fading Time Distributions [1].

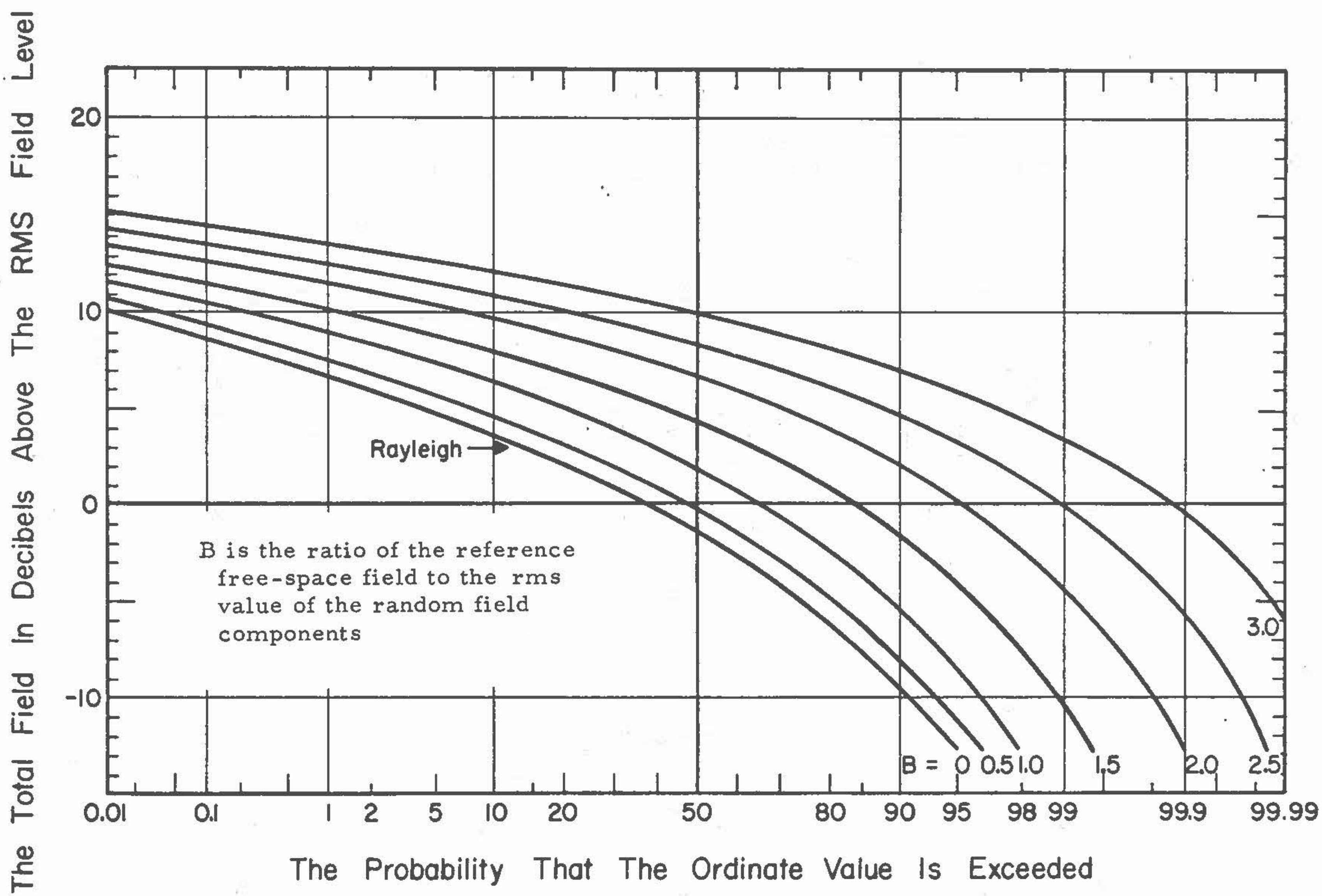


Figure 3. Multicomponent Fading Time Distributions [1, 2].

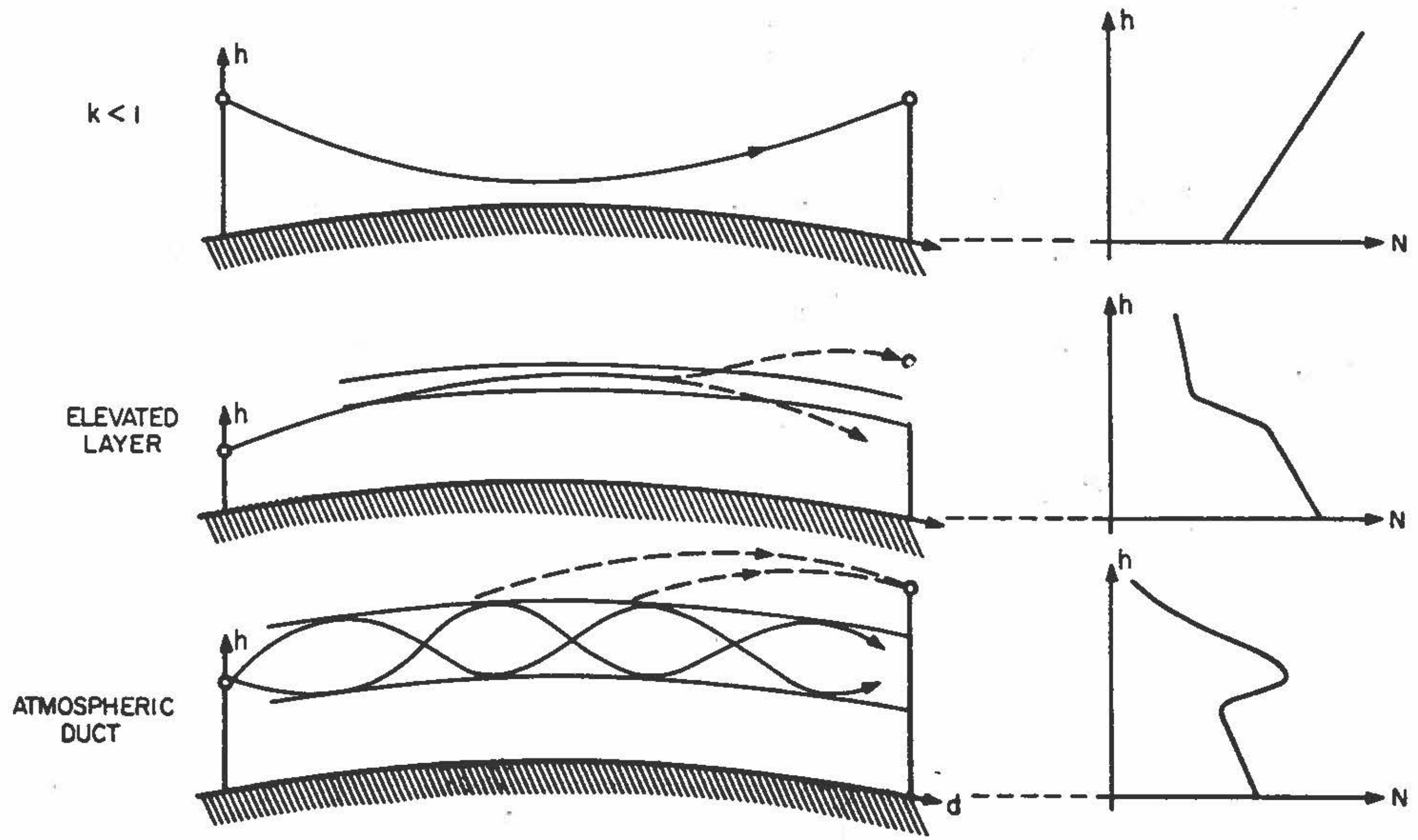


Figure 4. Attenuation Fading Mechanisms [1]. N is the refractivity, h is the height above the surface, and k is the effective earth-radius factor.

The attenuation or power fading mechanisms tend to be <u>relatively</u> insensitive to change in frequency or antenna positioning, hence the <u>usual</u> frequency or space diversity separations are not helpful. Attenuation mechanism A1 is remedied by inceasing the antenna elevations so that the propagated wave will adequately clear the surface over the range of refractivity gradients expected. This is usually provided for by specifying an adequate clearance; some designers use 0.6 of the 1st Fresnel Zone for k = 2/3 [7]. Mechanism A2 is offset by increasing the antenna beamwidth, although this also reduces the antenna gain. A3 and A4 are avoided by either positioning the antenna terminals so both lie above or below the expected layer elevations or by disparate terminal elevations which increase the wave's angle of incidence at the layer. A5 is avoided by an increased power margin or alternative propagation routes.

Very commonly, fading remedies are combined. For example, at a receiving terminal an antenna will be mounted sufficiently high on a tower to protect against the likelyhood of the A1 power fading mechanism; then a second antenna will be spaced further down the same tower to provide space diversity as protection against the M1 and M3 multipath fading mechanisms. The system is then protected against a variation of the atmosphere over a wide range of effective k values (k-type fading [1]) which includes the A1 power fading often associated with small values of k and the multipath fading that may be associated with larger k values. Occasionaly, a marked improvement in system performance may be observed by increasing the separation for space diversity. This may result only because the initial separation was inadequate protection against multipath; however, this may also result (when the spacing is already adequate for multipath) because the increase in spacing was achieved by raising the upper antenna, thereby improving the protection against

Table I. San Clemente/ Pt. Loma Path Parameters*

No.	Item	Mt. Thirst		Pt. Loma
1	†path length, d		70.8	
2	†upper antenna height	2010		140
3	**lower antenna height	1985		115
4	actual transmission frequencies in gigahertz	7.14, 7.5		7.32, 7.68
5	average frequency in gigahertz, chosen for computations		7.41	
6	dish antenna diameter in feet, D	10		10
7	antenna half-power beam width in milliradians	16		16
8	antenna gain in decibels above isotropic	45.6		45.6
9	†transmission power in dBm, P_t		37.0	
10	basic transmission loss in decibels, L_{bo}		151.0	
11	direct-path received power in dBm, P_r		-22.8	
12	propagation path minimum height, $H_o(k=4/3)$		74.5	
13	distance from Pt. Loma to path minimum, d_o		9.0	
14	1st Fresnel-Zone clearance at d_o, H_{IF}		74.5	
15	effective earth-radius factor for a grazing condition, k_g		1.094	
16	grazing angle for reflection in milliradians, ψ		0.74	
17	effective reflection coefficient, R		0.41	
18	reflection point distance from Pt. Loma, d_2		11.7	
19	reflected path phase delay, normalized to 360°, $\varphi/360°$		0.45	
20	initial direct path elevations in milliradians, $\theta_{oi}(k=4/3)$, i=1, 2	-11.7		-1.7
21	lower antenna effective height, $H'(k=4/3)$	236.5		46.7
22	frequency diversity ratio, $\Delta f/f$		0.05	
23	frequency diversity reflection protection in decibels, A		16	
24	frequency diversity refraction protection in decibels, A		22	
25	maximum fade due to sea-surface reflection, in dB		4.6	

†Distances are given in statute miles, heights are given in feet, and power is given in decibels above 1.0 mW.
*See Appendix for appropriate formulas.
**The antenna heights above MSL, H_1 and H_2 where $H_1 > H_2$, are used for the calculation of the path parameters.

the A1 power fading. If an expected lobing pattern is determined for vertical displacement of a terminal antenna, then $0.5\Delta\ell$ (i.e., one half of the expected null-to-null vertical spacing $\Delta\ell$) is a most suitable spacing for space diversity. Just as the lobing pattern is cyclical, so is this suitable spacing; an odd multiple of it provides maximal diversity protection, an even multiple provides a minimal diversity protection. Actually, the lobing pattern will show a changing null-to-null separation with height or with effective k value, but this $0.5\Delta\ell$ spacing is recommended; an increased spacing ($1.5\Delta\ell$, $3\Delta\ell$, etc.) achieved by raising the upper antenna will improve the protection against A1 power fading. Spacings of even multiples ($\Delta\ell$, $2\Delta\ell$, etc.) are to be avoided.

At one time or other, each of the above fading mechanisms is active on the FACSFAC SCI/PL and NORIS/IB microwave links, although M1, M3, and A1 are the most significant.

3.0 SAN CLEMENTE ISLAND/POINT LOMA PATH

The SCI/PL path is a long overwater path whose significant geometrical parameters [8] are listed as items 1 through 3 in Table I. These are nominal values in that they adequately indicate the effects of path geometry; the system manuals [8] do not accurately specify all of them. For example, "miles" is an ambiguous unit, but will be taken here as statute miles; for performance prediction purposes, the height above terrain of an antenna mounted on a tower is required rather than the height of the tower itself.

3.1 Power Fading

From the Table I values, the direct path (between the lower antennas at each terminal) will approach to within 74.5 ft of the surface at 9 st mi from the Pt. Loma terminal, for an effective earth radius factor k=4/3 ($\Delta N/\Delta h$ = -39.25 N units/km or -12 N units/kft). That is, for k = 4/3 one

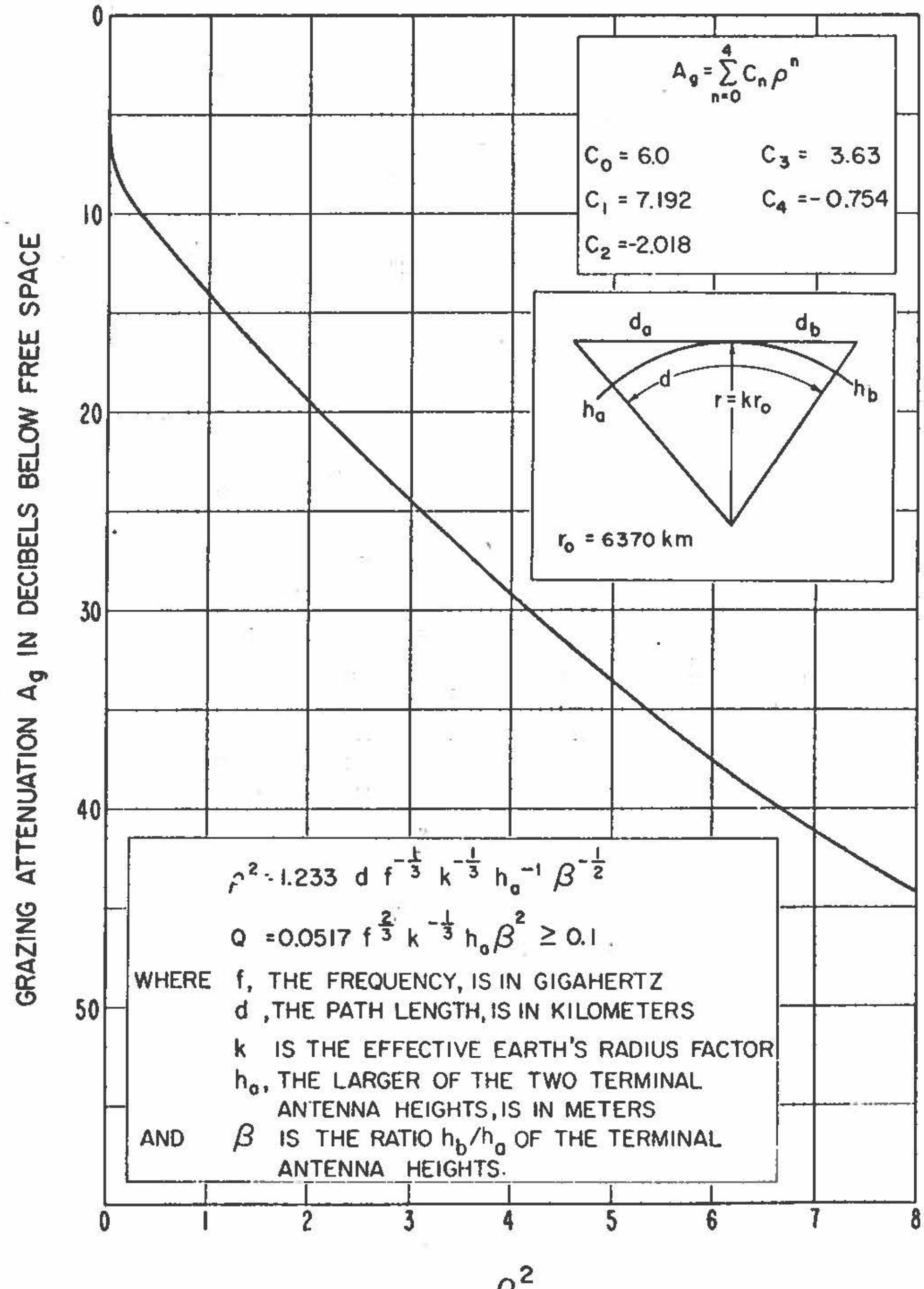


Figure 5. Attenuation due to diffraction over a smooth spherical earth at grazing conditions, $k = k_g$ [1, 11, 12, 13].

determines Table I item 20 from Appendix formula 3 as -1.7 mrad. This minimum occurs at 9 st mi, Table I item 13, as determined from Appendix formula 4. The path minimum, Table I item 12, is determined as 74.5 ft from Appendix formula 6 for k=4/3. This is essentially in agreement with a figure 1 (although not the text) of a previous estimate [9]. This 74.5 ft clearance is slightly more than a first Fresnel-Zone clearance (74.2 ft given as Table I item 14 from formula 7 in the appendix) at the same point along the path, so this path is clearly line-of-sight for k=4/3. The received signal level would then approximate the free-space level of -22.8 dBm. This is given in Table I item 11, determined from Table I items 8, 9, and 10 according to appendix formula 2. The Table I item 10, the free-space basic transmission loss, is determined from Table I items 1 and 5 by appendix formula 1.

Table I values also indicate [1,4] that for grazing conditions (Table I item 15, appendix formula 8), k_g= 1.094, the direct path for the lower antennas is barely line-of-sight. The corresponding gradient for this grazing condition is approximately -13 N units/km or -4 N units/kft, a value encountered in the San Diego region for appreciably more than 2% of the fall and winter radiosonde data [10]. For this grazing condition ($k=k_g$), the attenuation (diffraction loss [10,11]) may be determined from figure 5 as 12 dB; that is, the signal will drop 12 dB below the free-space level (to -34.8 dBm).

Note that if the path length of 70.8 mi had referred to nautical miles rather than statute miles, the associated k_g value would have been 1.45, corresponding to a gradient of about -14.8 N units/kft which is observed or exceeded for approximately 50% of the time in the vicinity of San Diego. Hence, the unit "miles" can be seriously ambiguous.

From processed surface-refractivity-gradient data [10], we observe that the surface gradients in the San Diego region are positive ($k \leq 1.0$) in the seasons represented by the months of May, August, November, and February for respectively 1, 1, 7, and 5% of the radiosonde observations. For $k=1$, the SCI/PL path is transhorizon (beyond line-of-sight) and the total diffraction loss [11,12,13] would exceed 30 dB. That is, the signal will drop more than 30 dB below the free-space value to less than -52.8 dBm.

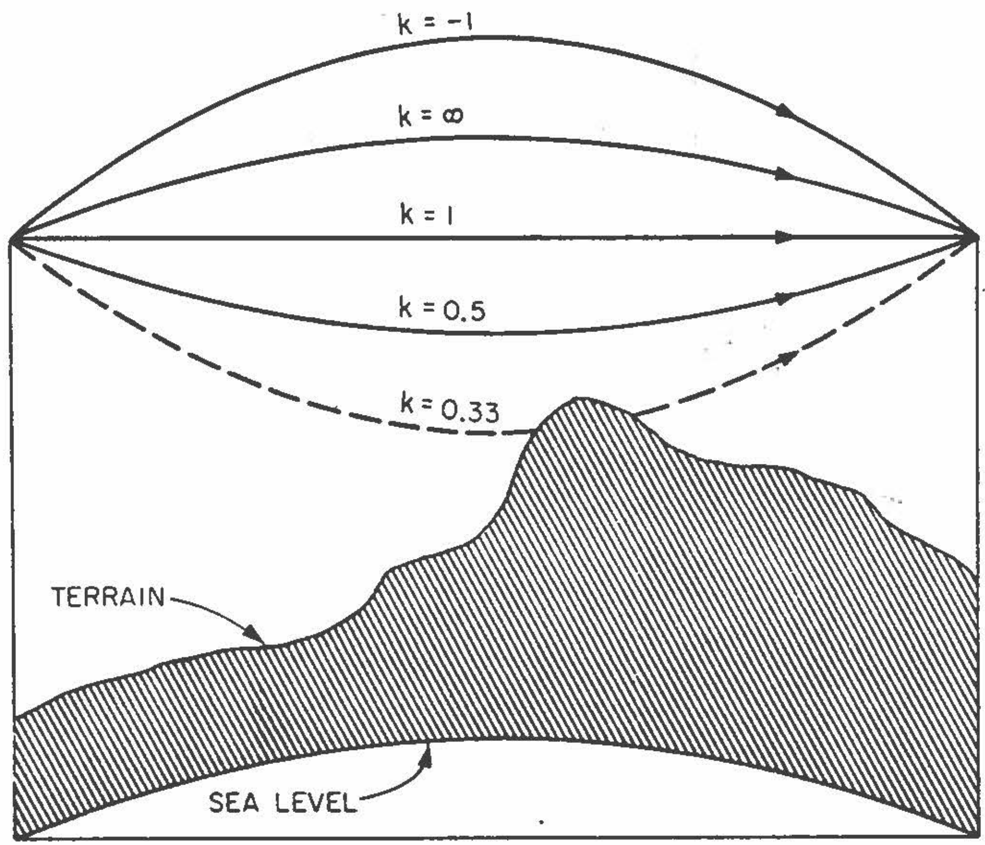
One might be tempted to conclude from this that the severe transhorizon diffraction loss for $k=1.0$ would be experienced or exceeded for 3.5% (or 1/4 of 1 + 1 + 7 + 5) of the year. That would be somewhat pessimistic, since the positive gradients for $k \leq 1$ are observed only over the first several hundred feet above the surface. Although these positive gradients will extend sufficiently above the surface to include the Point Loma antenna, they are not likely to extend to the height of the San Clemente Island antenna heights. Despite the k values observed for 3.5% of the time (as appropriate in the vicinity of the surface and the Pt. Loma antennas), when the refraction effect is averaged over the entire path to heights which include the SCI antennas, the effective k value is likely to exceed the $k=1$ value for 100-3.5 or 96.5 percent of the time. Short of a detailed analysis of the available radiosonde data and ray tracing to determine average k values over the first 2000 ft of elevation in the San Diego region (which, although feasible, has not been done or published to the authors' knowledge), one can not document the percentage of time the path clearance will be inadequate. Although one could not, therefore, disprove the contrary assertions of the initial propagation survey [14], we feel it is hazardous indeed to state that the path clearances are presently adequate to insure 99.99 percent reliability. Therefore, the attenuation or power-fading mechanism A1 of the above Section 2.2 appears to be a significant source of difficulty for the SCI/PL path; path clearances should be increased by raising the Pt. Loma antenna terminals (see Section 3.3).

For the antenna beamwidths involved (item 7 in Table I) and the range of k values expected, the mechanism A2 should not be a significant limitation, particularly if the antennas are directed at or slightly above the elevation angles of Table I (item 20). See Figure 6 as an illustration of how the launch angle and angle-of-arrival are influenced by the path's k value, although the antenna gain pattern is fixed in space.

As pointed out in a previous study [13], rainfall can provide an attenuation up to the order of one decibel per statute mile. However, at the higher rain rates, the rain cellsizes are of the order of a few statute miles [15]. Hence, the attenuation rate due to rain is applicable only for that portion of the path over which the high rainrate occurs (a very few miles); the mechanism A5 (attenuation by rainfall) is not expected to be a serious source of additional attenuation.

3.2 Multipath Fading

From the Table I values, items 1 and 3, one determines from the Appendix nomogram for $k=4/3$, that the sea surface reflection will occur at a distance of 11.7 st mi from the Pt. Loma terminal. The path-length-difference phase delay is approximately 162° (Table I item 19 multiplied by 360°) so that the field is near a lobe maximum. A lobe maximum occurs when this phase delay is 180°; the phase shift upon reflection then brings the two components into phase. For this application, the sea electrical constants provide a Fresnel reflection coefficient of approximately unity.



$\frac{\Delta N}{\Delta h}$ *	k
314	0.33
157	0.5
0	1.0
-157	∞
-314	-1.0

* N UNITS/km

Figure 6. Variation of Angle of Arrival with k [1]. The $\Delta N / \Delta h$ is the radio-refractivity gradient and k is the effective earth-radius factor.

However, the divergence factor for the curved sea surface would reduce this to an effective reflection coefficient of $R = 0.41$; see formula 11 given in the appendix. This value would produce a peak field of 2.98 dB and an interference null field of -4.6 dB, relative to the free space field of -22.8 dBm. A sea-surface roughness factor ($e^{-g/2}$, is given by formula 12 in the appendix) can further reduce the reflected component.

For such an M1 mechanism (two-component multipath) the frequency diversity ratio $\Delta f/f=0.05$ is adequate to protect against such reflection fading. See appendix formulas 13 and 14; for $\Delta f/f-0.05$, $\Delta=0.0244$ and $A=16.3$ dB, a protection for fades of 15.3 dB below the free-space field value [16]. The atmospheric (refraction) multipath (mechanism M3) generally involves approximately equal components; for two-component refractive multipath, the $\Delta f/f$ ratio will protect to fades of about 22 dB (figure 7 or appendix formulas 13 and 15) [1,16], as the peaks and null positions shift under the action of the refractivity variations and the tides. That is, examination of figure 7 indicates that for $\Delta f/f=0.05$, the curve for multipath-due-to-refraction yields a value of 22 dB; i.e., the indicated frequency diversity separation will protect against fading to 22 dB. When more than two such components are involved, the time distribution approaches a Rayleigh distribution and other diversity designs are available [5]; the given frequency diversity ratio is then even more favorable. Hence, the frequency diversity design on the SCI/PL path appears adequate, and the space diversity [1,4] is adequate at the Pt. Loma terminal, but inadequate at the SCI terminal. The preferable spacing of antennas for space diversity is half of the null-to-null spacing of the vertical height-gain pattern that would be expected. For the Pt. Loma terminal of the SCI/PL path, that would be an antenna spacing of about 40 to 45 ft; the present spacing is 25 ft and less than optimal, but still adequate. About 210 ft spacing would be required

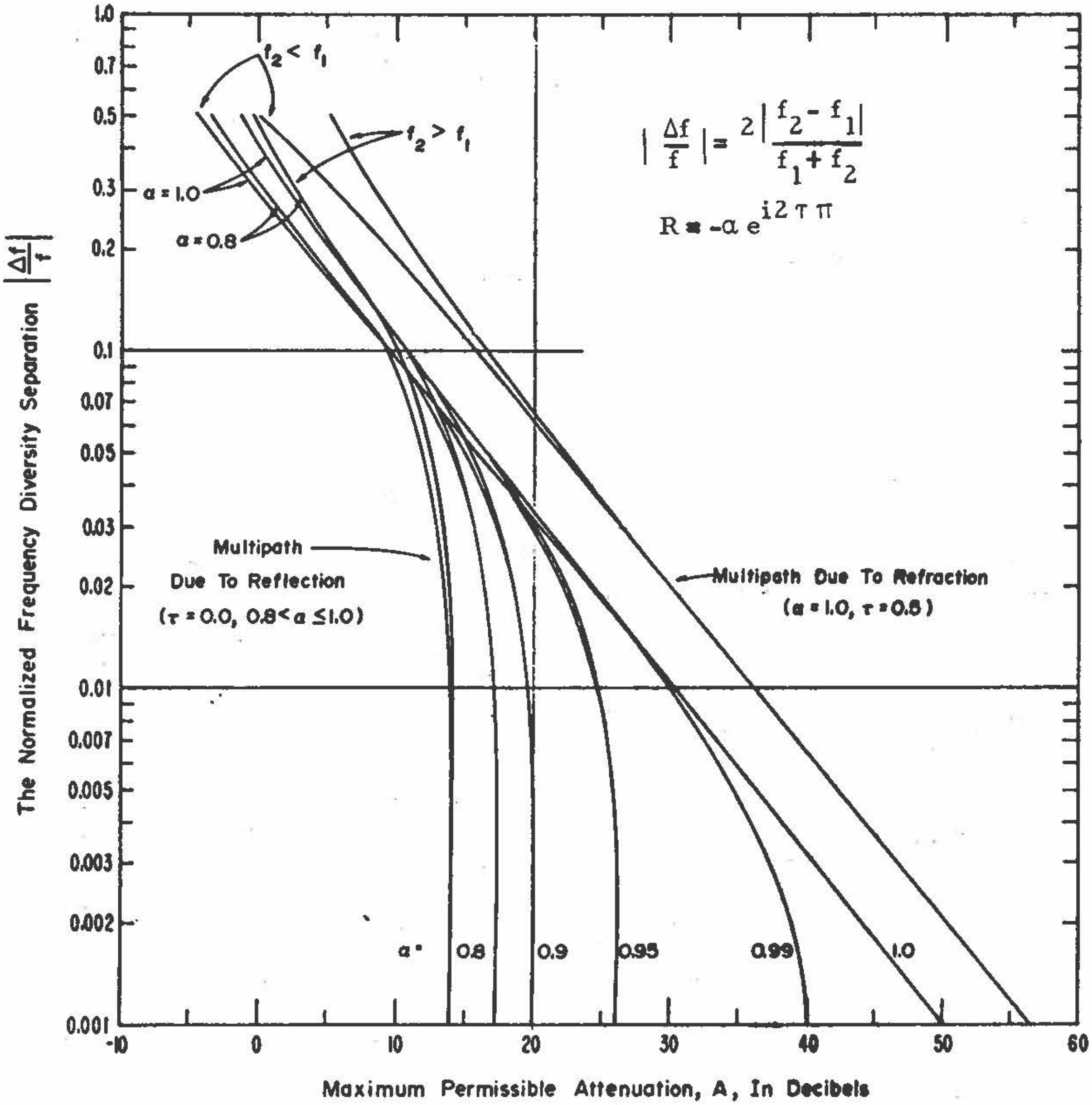


Figure 7. Normalized frequency-diversity separations for maximum permissible attenuation due to two-component multipath [16].

at the SCI terminal to provide a corresponding protection; for the 25 ft spacing at SCI, the protection is marginal at best.

To be effective, these diversity separations require an adequate combiner operation. The FACSFAC equipment employs what used to be called a ratio-squarer or optimal-ratio combiner; the ratio referred to is the signal-to-noise ratio. The FACSFAC employs a pilot signal at 8.5 MHz within the baseband to control the signal-to-noise estimates for effective combiner action on the 7.14 and 7.5 or 7.32 and 7.68 GHz received signals. The combiner operation assumes that estimates of signal, noise, or signal-to-noise ratios derived from the pilot frequency (8.5 MHz) are an adequate description of the corresponding quantity (signal-to-noise, etc.) throughout the baseband. This may not always be true, particularly for a strong reflected-signal component with path delay of many wavelengths. Multipath fading is frequency selective, and selective fading within the microwave bandwidth can introduce distortion within the baseband after demodulation. The 8.5 MHz pilot signal may not then be perfectly correlated with fading throughout the baseband and inappropriate signal-to-noise ratios could result, inhibiting effective combiner action.

3.3 Displacement to the Point Loma Ridge

If we consider raising the Pt. Loma site approximately 344 ft to the Pt. Loma Ridge, the effective reflection coefficient would be increased only to about R=0.565 (assuming the same total path length). The reflection signal nulls would then go to -7.2 dB relative to free space. The effective antenna height would increase to 264 ft (compared to item 21, Table I) and the reflection point would shift to 19.7 st mi from Pt. Loma. The expected null-to-null spacing would be about 39 ft, which suggests a vertical separation of about 20 ft for space diversity operation. Although replacing the Point Loma terminal and its cable link by a terminal on the Point Loma Ridge will dramatically increase the path clearance (to $H_o(K=4/3)=366$ ft at 13.8 st mi with $\theta_{o2}(4/3)=-2.62$ mrad), it should not be attempted until the combiner performance-testing procedure is implemented.

In displacement of the Pt. Loma terminal to the Pt. Loma Ridge, care must be taken to avoid any performance degradation due to the intrusion of structures or vehicles into the immediate foreground of the newly positioned antenna. For such a concern, we may visualize the critical region in the antenna foreground as a cylindrical volume whose axis coincides with the direction of maximum radiation. This imaginary cylinder has a radius D/2 (5 ft from item 6, Table I) and extends to a range of D^2/λ (from items 5 and 6, Table I, approximately 753 ft) from the antenna [17]. At greater ranges, the far-field antenna pattern will identify the critical regions. Therefore, the antenna should be positioned so that over the first 753 ft from the antenna, nothing should intrude to within 5 ft of the antenna boresight.

4.0 NORTH ISLAND/IMPERIAL BEACH PATH

The nominal values of the NORIS/IB path are given in Table 2. Path clearance is sufficient, other than for the known trouble spots [18]. We will return to this point subsequently.

4.1 Multipath Fading

Unlike the SCI/PL path, this NORIS/IB path will experience severe fading due to sea-reflected multipath. The effective reflection coeffient is R=0.9; the reflection point is on the sea surface, 2.6 st mi from the Imperial Beach terminal and 0.25 st mi off the beach of the Silver Strand State Park. The signal peaks can reach 5.6 dB above free-space, the signal nulls can go to 20 dB below free-space. Of course, sea-surface roughness can reduce the effective reflection coefficient by a factor exp(-g/2), given in the Appendix. However, for the values given in Table II (items 5, 13); the departures from a smooth sea (σ in Appendix formula 12) would have to exceed 11 ft (22 ft peak-to-trough) to reduce the effective reflection coefficient by half.

Refering to figure 7, we see that a normalized frequency separation $\Delta f/f=0.05$ will not protect against multipath fading beyond 15 dB. That is, the curve for multipath-due-to-reflection (for $\alpha=0.9$) indicates that the frequency diversity separation will provide protection only against fades of 15 dB or less. The protection (Table II, item 19) is not adequate for the expected fading (Table II, item 21).

There is no space diversity on the NORIS/IB path; however, the null-to-null spacing expected for vertical displacement of the IB antenna would be about 33 ft. Therefore, a vertical separation of about 16 ft would be appropriate for space diversity.

Table II. North Island/ Imperial Beach Path*

No.	Item	North Island		Imperial Beach
1	†path length, d		8.6	
2	†upper antenna height			
3	**lower antenna height	115		45
4	actual transmission frequencies in gigahertz	7.2, 7.56		7.39, 7.74
5	average frequency in gigahertz chosen for computations		7.47	
6	dish antenna diameter in feet, D	4		4
7	antenna half-power beamwidth in milliradians	40		40
8	antenna gain in decibels above isotropic, G	37.6		37.6
9	†transmitter power in dBm, P_t		27	
10	basic transmission loss in decibels, L_{bo}		132.7	
11	direct-path received power in dBm, P_r		-30.5	
12	effective earth-radius factor for a grazing condition, k_g		0.16	
13	grazing angle for reflection in milliradians, ψ		3.1	
14	effective reflection coefficient, R		0.9	
15	reflection point distance from Imperial Beach, d_2		2.6	
16	reflected path phase delay, normalized to 360°, $\varphi/360°$		1.4	
17	antenna effective height H' (k = 4/3)	98		42
18	frequency diversity ratio, $\Delta f/f$		0.05	
19	frequency diversity reflection protection in decibels, A		15	
20	frequency diversity refraction protection in decibels, A		22	
21	maximum fade due to sea-surface reflection, in dB		20	

†Distances are given in statute miles, heights are given in feet, and power is given in decibels above 1.0 mW.

*See Appendix for appropriate formulas.

**The antenna heights above MSL, H_1 and H_2 where $H_1 > H_2$, are used for calculation of path parameters.

4.2 Power Fading

The critical portions of the path, where some degree of obstruction can occur is at the Marginal Wharf Berth L (roughly 0.28 st mi from the North Island terminal) and in the vicinity of the new highrise apartments (approximately 2 st mi from the North Island terminal and 6.6 st mi from the Imperial Beach terminal). On the occassion of the visit of the OT/ITS team there was a dual-stack ship in the berth in question with the tower reflector at the NORIS terminal clearly visible between the stacks from the IB terminal. As long as the ship superstructures do not intrude to within about 14 ft of the microwave path, there should be negligible impact upon path performance. However, during entering or leaving the berth, the superstructure is likely to intrude fully upon the path and cause a serious temporary deterioration of performance.

In the vicinity of the highrise, a lateral first Fresnel Zone clearance is about 32.7 ft. Transit measurements from the IB termianl indicate that the highrise is 20 minutes or 203 ft [$= \frac{0.01745}{3}(6.6)\ 5280$] off the path; that is more than a Fresnel Zone clearance.

From the foregoing, the critical portions are not likely to cause serious degradation of path performance at present (other than during the berthing and deberthing of ships at Berth L). At present, the median received signal level along the path appears to be 20 or more dB below the expected level. This is likely to be attributable to antenna-maintainance problems. The IB terminal feed, antenna, and antenna feed are in need of refurbishing, alignment, and pointing; serious mispositioning of the antenna feed can slew and even split the beam pattern. Similarly, the North Island terminal antenna/tower reflector appears in need of alignment. There, antenna pointing to fully illuminate the reflector on the tower and adjustment of the reflector to maximize the directing of the signal toward the IB terminal are fairly straight-forward adjustments, although requiring appreciable physical agility. Adjustment of the antenna polarization for maximum reception at IB should be carried out. Depolarization (from vertical) of the signal reflected from the tower reflector can contribute to signal loss; the received signal polarization would not match that of the receiving antenna. All of these contribute decibels of loss whose cumulative effect can be significant.

4.3 Passive Relaying

A previous report [9] suggested the possibility of a passive reflector mounted off-path. In such an event, the free-space path loss and passive reflector gain could be adjusted to achieve [19] the same free-space design reference value of -30.5 dBm or better. A promising aspect, however, is the fact that the passive reflector can discriminate against the reflected components and reduce the impact of ground reflections. If the reflected components are sufficiently descriminated against, diversity reception (frequency or space) would not be required.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The present maintainance program is highly effective within the limiations of the original system design; however, this should now be supplemented by expanded monitoring. Additional monitoring should include : (1) calibration of each receiver level periodically (at least monthly); (2) initiation of a testing procedure to evaluate the performance of the diversity combiners, the evaluation to be repeated periodically; (3) weekly use of an on-site RF signal generator to perform receiver quieting measurements; (4) recording of idle-channel noise for a thirty-day period to measure performance and to detect the possibility of interference from ships at sea or nearby microwave systems.

For an immediate effort, check the alignment of the antenna feed horn and passive reflector at the North Island terminal (for the NORIS/IB path) and adjust the polarization (orientation of the feed) for maximum received signal. A similar checkout of the antenna at the Imperial Beach terminal is also recommended. Unless future NORIS/IB traffic requires the present receiver bandwidth, the receiver bandwidths should be narrowed.

The present frequency diversity separation is inadequate for the NORIS/IB path. The frequency separation could be increased (see figure 7); preferably, space diversity should be installed.

The Pt. Loma terminal of the SCI/PL path should be raised; use of the Pt. Loma Ridge should provide an adequate increase of terminal height.

For both the SCI/PL and NORIS/IB paths, a properly functioning combiner is essential to achieving high reliability; test procedure for evaluating combiner performance should be devised and implemented for periodic monitoring.

The radar information is already digitized; an all-digital system could improve overall system performance.

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7.0 APPENDIX

The following formulas, from references 1, 4, and 14, are applicable to the SCI/PL and NORIS/IB paths. All distances and heights within any formula are in the same units, unless otherwise specified. The $r_o \approx 3959$ st mi or 6370 km. The λ is the transmission wavelength; H_1 and H_2 are the lower antenna heights at each terminal. All quantities are as defined in Tables I and II.

1. $L_{bo} = 20 \log (4\pi d/\lambda) = 96.58 + 20\log d_{st\ mi} + 20\log f_{GHz}$ dB.

2. $P_r = P_t + G_T + G_R - L_{bo}$ dBm.

3. $\tan \theta_{o2}(k) = \frac{H_1 - H_2}{d} - \frac{d}{2kr_o}$, $H_1 > H_2$.

4. $d_o(k) = -kr_o \tan \theta_{o2}$.

5. $\tan \theta_{o1}(k) = - \left[\tan \theta_{o2} + \frac{d}{kr_o} \right]$.

6. $H_o(k) = H_2 + \frac{d_o \tan\theta_{o2}}{2}$.

7. $H_{IF} = 72\sqrt{\frac{d_o(d-d_o)}{df_{GHz}}}$ ft; d and d_o are in statute miles.

8. $k_g = \frac{d^2 / 2r_o}{(\sqrt{H_1} + \sqrt{H_2})^2}$.

9. $d_g = -k_g r_o \tan\theta_{o2}(k_g)$; $\tan\theta_{o2}(k_g)$ is from formula 3 for $k = k_g$.

10. $$\tan\psi(k) = \frac{H_2}{d_2} - \frac{d_2}{2kr_o} \quad .$$

11. $$R(k) \approx \left[1 + \frac{2d_1 d_2}{kdr_o \tan\psi}\right]^{-1/2} \quad .$$

12. $$e^{-g/2}, \; g = \left[4\pi \frac{\sigma}{\lambda} \sin\psi\right]^2 \quad .$$

13. $A = -20\log|2 \sin\Delta\pi|$ dB, the deepest fade offset by diversity.

14. $\left(\frac{\Delta f}{f}\right) = \frac{2\Delta}{1-\Delta}$, for reflection multipath.

15. $\left(\frac{\Delta f}{f}\right) = \frac{4\Delta}{1-2\Delta}$, for refraction multipath.

The location of a specular reflection point on the sea or a smooth spherical earth may be determined quickly for an arbitrary earth-radius factor k, with the aid of an electronic calculator (HP-35 or equivalent), by determining a parameter β. Then

$$\frac{d_2}{d_1} = \frac{1-\beta}{1+\beta}, \; d_2 = \frac{d}{2}(1-\beta), \; d_1 = \frac{d}{2}(1+\beta) \quad .$$

An initial estimate, β_e, may be obtained from the nomograph of figure 8 for the quantities

$$\alpha = \frac{H_1 - H_2}{H_1 + H_2} \text{ and } \gamma = \frac{250\, d^2}{6370(H_1 + H_2)} \quad ,$$

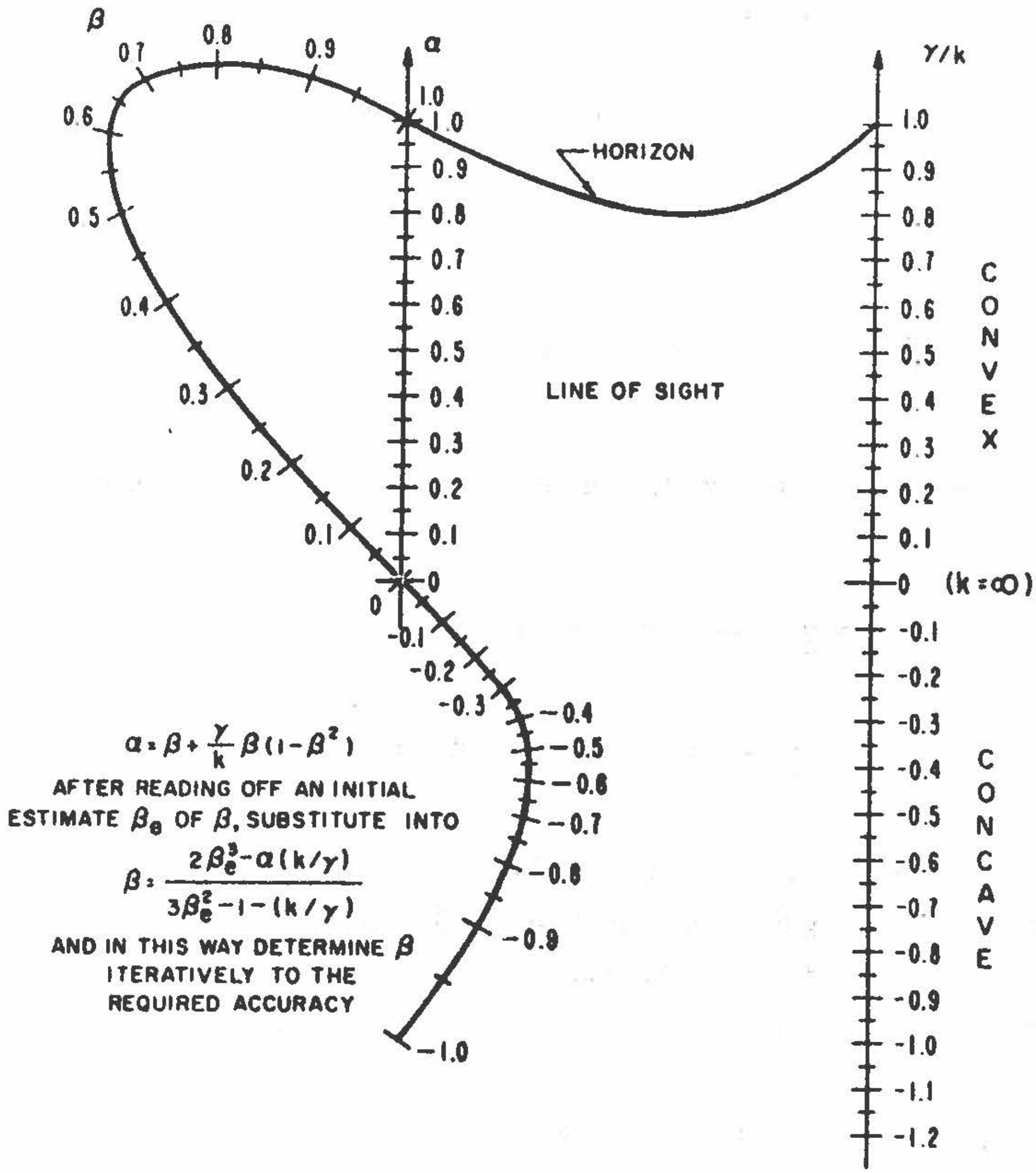

Figure 8. A Nomogram Relating α, β, and γ/k.

where the d, H_1, and H_2 are all in meters [4]. Note that these are not the same α and β are determined from repeated applications of

$$\beta = \frac{2}{3} \frac{\beta_e^3 - \frac{\alpha}{2} [\gamma/k]^{-1}}{\beta_e^2 - \frac{1}{3} [1+(\gamma/k)^{-1}]} \quad .$$

which is the equivalent of the expression for β in figure 8.
Often, only one or two applications of this latter expression will be needed, depending uponthe precision required. Note that when a straight edge joining the α and γ/k values in figure 8 intersects the curve marked "Horizon", the path is beyond-line-of-sight for the chosen value of k.

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This report reviews the available documentation for two links of the FACSFAC microwave system and the findings of on-site inspections. It is recommended that the present maintainance program be supplemented by additional performance monitoring. This should include periodic calibration of received signal levels and the periodic measurement of the combiner performance, receiver-quieting, and idle-channel noise.

At present, one microwave link does not appear to have sufficient clearance for high-reliability performance. Repositioning the lower terminal to a higher elevation will remedy this situation.

(continued)

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A second microwave link does not have sufficient frequency diversity spacing, at present, to offset deep fading due to sea-surface reflection. The frequency diversity separation should be increased or replaced by space diversity. However, this should not preceed a complete check-out and refurbishing of antennas at both terminals. Path obstruction does not appear to be the major cause of outages, with the possible temporary exception of super-structure traversing the path when a ship moves into or out of Marginal-Wharf Berth L. If this latter case occurs often enough to become a problem in the future or if implementing improved diversity is not feasible, then use of an offpath passive reflector (to replace the present path) should be explored further. Proper positioning of a billboard passive reflector could prove a most effective remedy for the multipath due to sea-reflections.