RADIO ENGINEERING
MICROWAVE RADIO
11-GHz SYSTEMS
ENGINEERING GUIDELINES

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1. INTRODUCTION

A. General

1.01 This section provides guidelines essential to the engineering of 11-GHz microwave radio routes. Coverage includes both analog radio systems using a single polarization per frequency (otherwise known as SPF operation) as well as digital radios employing cochannel or dual polarization per frequency (DPF) operation. Channel widths of both 20 and 40 MHz are covered. While analog systems are always SPF, digital systems can be operated either SPF or DPF. Digital radio systems with SPF characteristics have bit rates of 80 to 90 megabits when applied to 40-MHz wide 11-GHz channels. Digital radio systems with DPF characteristics have bit rates of 40 to 45 megabits on each of two polarizations available in a 40-MHz wide channel. The total capacity per frequency is the same in both cases, being equal to or slightly less than two DS-3 signals or 1344 voice frequency circuits.

1.02 Whenever this section is reissued, the reason for reissue will be indicated in this paragraph.

1.03 These guidelines are independent of specific systems and are applicable to any equipment capable of satisfying the performance criteria herein established. In addition to related and necessary facts, concepts, and methodology, major topics include:

1. Frequency and channel growth plans

2. Rain and multipath outage

3. Overall system reliability calculations

4. Interference considerations.

B. FCC Rules

1.04 This section accords with FCC Rules and Regulations Part 21, covering Point-to-Point Microwave and Local Television Transmission Radio Services.

C. 11-GHz Propagation

1.05 In terms of its application to microwave transmission systems, the 11-GHz band occupies a transitional area between frequencies primarily affected by multipath outage, and frequencies at which outages contributed by rain and fog become the overriding concern. At frequencies of 4 and 6 GHz, rain attenuation is negligible, and outage caused by selective fading over the relatively long hop lengths can be effectively offset by space or frequency diversity techniques. On the other hand, at frequencies of 18, 29, and 40 GHz, the short hops dictated by rain attenuation preclude selective fading. In the 11-GHz band, rain can be a significant cause of propagation outage. Here, however, hops can be sufficiently long to experience multipath phenomena, thus 11-GHz design must take both sources of outage into consideration. In contrast to selective fading, there is no compensatory technique applicable to the blanket attenuation caused by rain—the only recourse is to restrict hop length. Thus hop lengths in 11 GHz will frequently be rain limited.

1.06 Under DPF operation, the effects of both rain and multipath go beyond simple selective or nonselective attenuation, as each can cause depolarization of the transmitted wave. The resultant loss of cross-polarization (XPD) discrimination can result in serious cochannel interference in DPF digital installations. Here, a 2-dB penalty (reduction of the fade margin) is allowed for rain caused depolarization, while the DPF multipath fade margin must be limited to approximately 30 dB, as fade depths beyond this level can be expected to cause the bit error rate to exceed the error threshold of 10^{-3}. The multipath fade margin in SPF digital installations must also be restricted to 30 dB. With SPF, the offending mechanism is not depolarization, but results from increased sensitivity to the dispersive effects of multipath fades. This arises from the increased vulnerability of the SPF 8-level PSK signal to multipath effects as compared to the 4-level signal used in DPF operation.

D. Synopsis

1.07 The emphasis of this section is directed to factors which determine system reliability, i.e., the determination of anticipated outage resulting from rain, multipath, and possible equipment failure. Following the topic of frequency allocations and channel growth plans which follows this introduction in Part 2 of this section, Part 3 discusses system parameters and characteristics which are of pertinent significance in determination of system performance. Included here are definitions of system gain and section loss which are necessary in the initial calculation of the hop fade margin. The fade margin, which will vary according to equipment parameters and path length, is necessary to determination of propagation outages. This fade margin, as initially calculated from system parameters, is unrealistically high in not as yet having been adjusted (truncated) to account for the degradations contributed by rain, multipath, and interference. Hence, prior to the calculation of outage, reduced or "practical" fade margins for rain and multipath will be separately evolved (in Parts 6 and 7), permitting the outage contributed by each to be realistically evaluated.

1.08 In Part 4, the topic of outage calculation is begun with an overview which deals in large measure with differences between analog and digital systems. Part 5, which follows, defines and establishes the system outage objectives. Since, in addition to multipath and equipment failure, rain outage is significant at 11 GHz, previous apportionments between multipath and equipment failure are abandoned in favor of a more flexible approach. The topic of rain outage is the subject of Part 6. The factors necessary to the rendition of practical rain fade margins for SPF and DPF systems are covered. The adjusted margins, together with hop length, are applied to a rain outage chart which yields outage time in minutes per year for horizontal and vertical polarizations. A 4-hop system is then used to demonstrate overall rain outage determination.

1.09 Following in logical order, Part 7 covers multipath outage. Differences between SPF and DPF systems are again emphasized, and appropriate fade margins are described. Since XPD degradation and resultant cochannel interference will affect DPF outage, conventional equations are inadequate, and DPF outage is determined via an outage chart. Part 7 concludes with calculations necessary to determination of improvements in outage time available from the application of space and frequency diversity.

1.10 The final source of outage, equipment failure, is treated in Part 8, while Part 9 provides a summary demonstration serving to integrate and solidify the previous concepts and methodology. The same 4-hop system which appeared in Part 6 is again applied to a summation of outage from all causes. Outage times prior to and following space diversity improvement are calculated.

1.11 The final major topic to be considered, in Part 10 of this section, deals with the development of interference budgets and the computation of the fade margin interference penalty for SPF and DPF light and heavy route digital systems. The effect of interference on a regenerative digital system will differ from previously documented analog systems. Tentative budgets are evolved for both rain and multipath fades, following which interference penalties are calculated.

1.12 As improved knowledge and additional information regarding 11-GHz operation is gained, additions and refinements to this section can be anticipated.

2. FREQUENCY AND CHANNEL GROWTH PLANS

A. Frequency Plans

2.01 11-GHz radio systems use the frequency assignments that originated with TJ and TL microwave radio. These assignments are the same as recommended by the CCIR (Consultative Committee, International Radio), although the numbering and channel pairing differ. Table A gives the frequencies and the corresponding TL and CCIR channel numbers. The channels designated P and J make up the so called "regular" plan, while those designated D and E comprise the "alternate" plan.

2.02 At a given radio station, transmitters are in one half of the band, and receivers are in the other half. A high-low station is one in which the receivers are in the upper half-band, and the transmitters are in the lower half-band. In a low-high station, the situation is reversed. Figures 1 and 2 respectively illustrate the 40-MHz regular and alternate frequency plans. The transmitter and receiver associated with the same 2-way channel in the same hop always use the same polarization and make up a channel pair. (For example, transmitter 11J and receiver 12P serving the hop accessed from the left of Fig. 1 both use P_2.) It should be noted that P_1 and P_2 are opposite (orthogonal) polarizations, as are P_3 and P_4. So long as this criterion is met, the assignment of vertical or horizontal polarization is arbitrary, hence actual H and V designations are not specified. Beyond this, the need for adjacent channels serving a common hop to be on opposite polarizations is specified by the channel groupings as in Tables C, D, and E. Examination of Fig. 1 and 2 reveals that the same frequency is used to transmit in both directions, i.e., the same channel pair is used in both directions, comprising what is known as the 2-frequency plan. In older systems, where frequency stability was not very high, the same frequency could not be transmitted in both directions from a given station, necessitating the previous 4-frequency plan. In this plan, separate channel pairs were used in each direction. Strict separation of transmitted frequency was required due to the possibility of slight deviations from nominal transmitter frequency giving rise to "single frequency" interference. This interference, resulting from heterodyne tones as high as several megahertz, was capable of appearing in the active part of the disturbed channel baseband. With modern high stability systems, the same frequency can be transmitted in both directions at any station. Since this type of operation uses less frequency spectrum on a given route, 2-frequency operation is preferred.

2.03 The channel pairings recommended for analog or digital systems which operate on a 2-frequency plan are shown in Table B for both regular and alternate plans. These pairings have been selected to minimize interference between transmitters and receivers in the same antenna waveguide. This interference is the result of third order intermodulation products (A+B-C) and (2A-B) which are generated in the nonlinearities of metallic contacts and surfaces of the common waveguide run by the strong transmitter signals. Product powers ranging from -60 dBm to less than -120 dBm have been measured at receiver inputs. The alternate plan of Table B contains one less channel pair than the regular plan. The deleted channels are 9D and 5E which, as shown in Table A, are located at the interface of the high and low half-bands and are separated by only 50 MHz. For this reason, they cannot be used on the same antenna. If separate transmitting and receiving (simplex) antennas are used however, both of these channels can be used. Regular plan channels 4P and 2J cannot be used for any signals having a bandwidth greater than 30 MHz, as these channels are only 15 MHz from the edges of the 11-GHz common carrier band. Thus, for digital systems using duplexed antennas, both regular as well as alternate plans provide only eleven 2-way channels.

B. Channel Growth Plans for Analog Systems

2.04 Table C shows the recommended growth plan for 40-MHz 12-channel analog systems using the regular or alternate frequency plans. Again, as in Table B and as explained above, channels 9D and 5E are excluded from the alternate plan configuration. The chosen channel pairing is such that the intermodulation tones are 30 MHz away from the received channel carriers, and are therefore well suppressed by the channel filtering. The channels are segregated into two groups which are assigned opposite polarization. In this manner, adjacent channel frequencies are cross-polarized reducing adjacent channel interference.

TABLE A

11-GHz FREQUENCY PLAN

FREQUENCY MHz REG	FREQUENCY MHz ALT	TL CHANNEL DESIGNATOR REG	TL CHANNEL DESIGNATOR ALT	CCIR CHANNEL DESIGNATOR REG	CCIR CHANNEL DESIGNATOR ALT
11,685*		2J*		12'*	
	11,665		2D		12'
11,645		3J		11'	
	11,625		3D		11'
11,605		6J		10'	
	11,585		6D		10'
11,565		7J		9'	
	11,545		7D		9'
11,525		10J		8'	
	11,505		10D		8'
11,485		11J		7'	
	11,465		11D		7'
11,445		4J		6'	
	11,425		4D		6'
11,405		1J		5'	
	11,385		1D		5'
11,365		8J		4'	
	11,345		8D		4'
11,325		5J		3'	
	11,305		5D		3'
11,285		12J		2'	
	11,265		12D		2'
11,245		9J		1'	
	11,225		9D		1'
	11,175		5E		**
11,155		5P		12	
	11,135		8E		12
11,115		8P		11	
	11,095		9E		11
11,075		9P		10	
	11,055		12E		10
11,035		12P		9	
	11,015		3E		9
10,995		3P		8	
	10,975		2E		8
10,955		2P		7	
	10,935		7E		7
10,915		7P		6	
	10,895		6E		6
10,875		6P		5	
	10,855		11E		5
10,835		11P		4	
	10,815		10E		4
10,795		10P		3	
	10,775		1E		3
10,755		1P		2	
	10,735		4E		2
10,715*		4P*		1*	

* These channels may not have an emission designator greater than 30,000F.
**Not defined by CCIR.

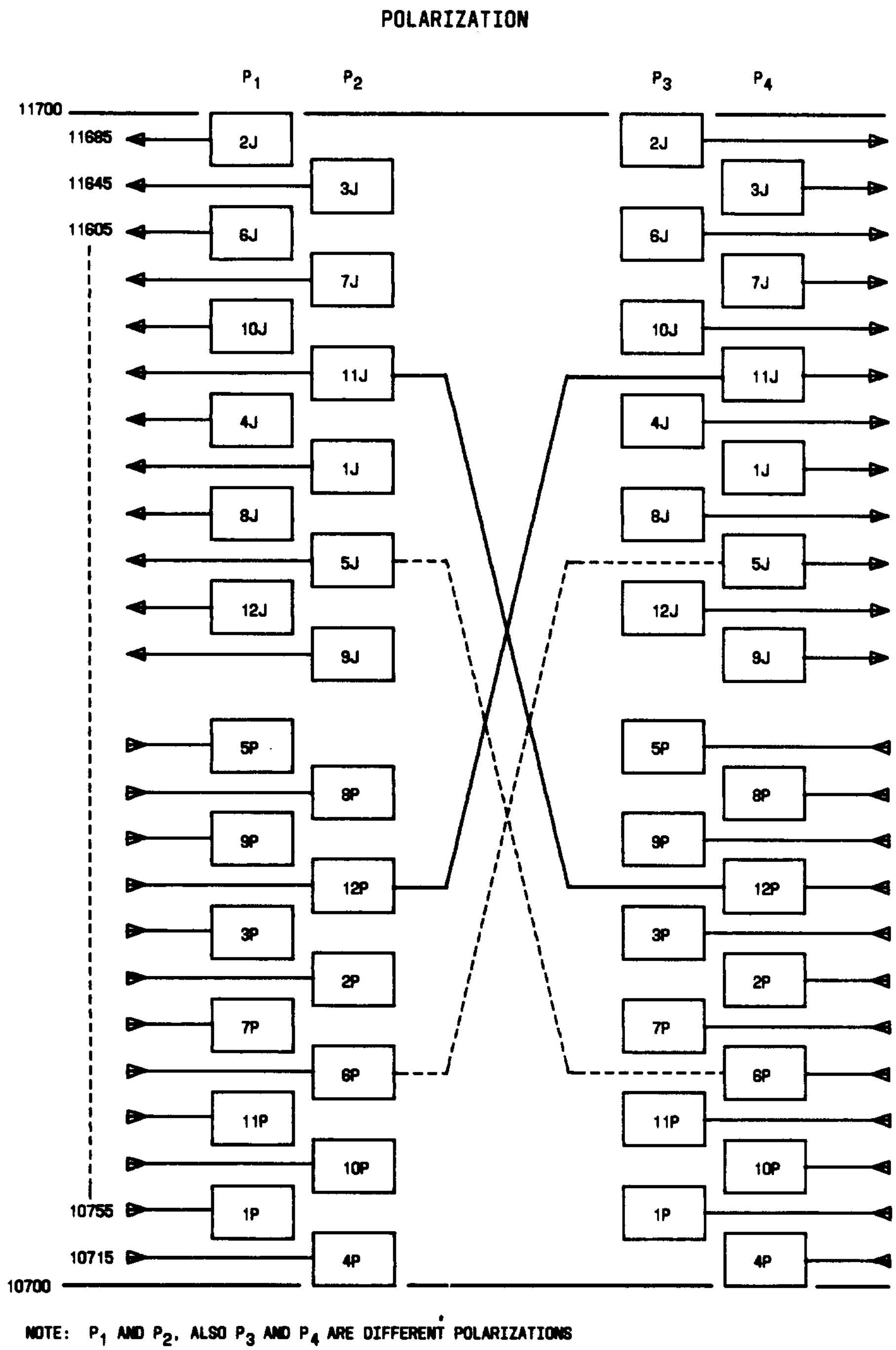
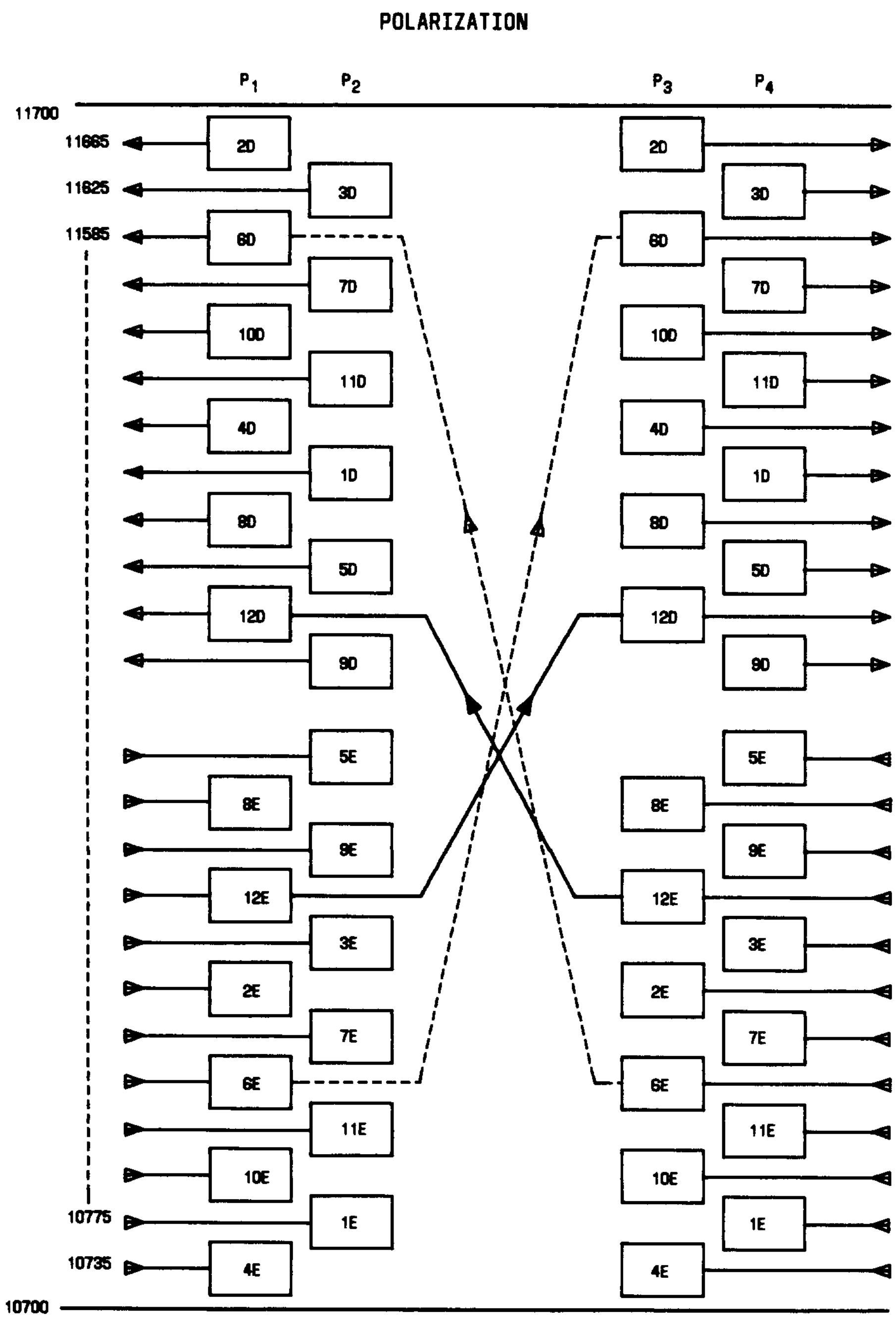


Fig. 1—Two-Frequency, 40-MHz, 11-GHz Regular Frequency Plan (Low-High Repeater Shown)



NOTE: P_1 AND P_2, ALSO P_3 AND P_4 ARE DIFFERENT POLARIZATION

Fig. 2—Two-Frequency, 40-MHz, 11-GHz Alternate Frequency Plan (Low-High Repeater Shown)

TABLE B

CHANNEL PAIRINGS

REGULAR PLAN		ALTERNATE PLAN	
LOWER BAND HALF	UPPER BAND HALF	LOWER BAND HALF	UPPER BAND HALF
1P	2J	1E	1D
2P	1J	2E	2D
3P	4J	3E	3D
4P	3J	4E	4D
5P	6J		
6P	5J	6E	6D
7P	8J	7E	7D
8P	7J	8E	8D
9P	10J	9E	5D
10P	9J	10E	10D
11P	12J	11E	11D
12P	11J	12E	12D

2.05 Table D provides the growth plan for systems using 23 channels available from the combined regular and alternate frequency plans. The recommended procedure is to install the first six regular channels on one polarization and the first six alternate channels on the opposite polarization. Then, a second antenna is used for the remaining channels with regular channels using the same polarization as on the first antenna, and alternate channels using the other polarization. A second antenna is necessary to avoid the intermodulation products which can be generated in the common waveguide run by the transmitters. For proper operation of a 23-channel 20-MHz system, the adjacent regular and alternate channels must be on opposite polarization. Again, as with the 12-channel system, the assignment of the alternate channels to group 2 serves this purpose. The recommended protection channel selection is growth stage 2 (channels 6P and 5J, or 6E and 6D) for 1×N systems, and stage 2 and stage 5 (channels 8P and 7J, or 8E and 8D) for 2×N systems. Other selections of protection channels may be used, but for 2×N systems, the protection channels should be separated by at least 160 MHz to maximize the effect of frequency diversity.

TABLE C

GROWTH PLAN FOR ANALOG 40-MHz CHANNELS

		CHANNEL GROUP 1 *						CHANNEL GROUP 2 *					
	GROWTH STAGE	1	2	3	4	5	6	7	8	9	10	11	12
REGULAR PLAN	LOWER BAND HALF	12P	6P	4P	10P	8P	2P	11P	5P	3P	9P	7P	1P
	UPPER BAND HALF	11J	5J	3J	9J	7J	1J	12J	6J	4J	10J	8J	2J
ALTERNATE PLAN	LOWER BAND HALF	12E	6E	4E	10E	8E	2E	11E	3E	9E	7E	1E	
	UPPER BAND HALF	12D	6D	4D	10D	8D	2D	11D	3D	5D	7D	1D	

* The two channel groups must be on opposite polarizations.

C. Channel Growth Plans for Digital Systems

2.06 The recommended frequency growth plan for digital systems is shown in Table E. This plan is virtually the same as the 40-MHz analog plan shown in Table C. An exception, however, will be noted in the fact that channels 2J and 4P have been deleted. These are the channels located at the upper and lower band edges which cannot be used when required bandwidth exceeds 30 MHz. Elimination of these channels leaves two remaining half-pairs (3J and 1P) which, as shown in growth stage 12, can make up a nonstandard channel pair. Since 1P and 3J initially belonged to separate groups, the group assignment is governed by the transmitter (1P) placing the new channel in group 2. On SPF digital systems, the two channel groups must be on opposite polarizations as in analog operation. The channel pairings are again chosen to reduce the interferences caused by intermodulation products from the transmitter signals. These products will consist of a broad, continuous spectrum like the transmitted digital spectrum. This interference has to be well below the error threshold noise level of the receiver (defined as a bit error rate of 10^{-3}) in order to avoid deliberate reduction of the system fade margin. In DPF systems there is normally enough filter selectivity available to make this interference negligible. However, when the second group of channels is added, DPF systems require that this group be operated over a separate antenna to avoid having the intermodulation spectra fall within the passband of the desired receiver carriers. It should be noted that SPF systems may require the use of a second antenna for purposes of transmitter-receiver isolation, since in digital SPF operation, higher bit rates and therefore wider filter bandwidths can make intermodulation interference potentially serious. Unless reliable ways can be found to keep the intermodulation products low, high power SPF systems may require separate antennas for transmitters and receivers on all but very light route systems. While other growth plans have occasionally been suggested, these plans generally run the risk of third order products or use nonstandard channel pairings and thereby risk increased frequency congestion in areas which use standard pairings. Although each case should be considered on its own merits, these plans are not recommended.

D. Channel Growth for Combined Systems

2.07 A 40000F9Y (emission designation for digitally modulated signal having a bandwidth of 40 MHz) digital signal cannot be operated 40 MHz from an analog signal unless the antenna system provides the needed additional discrimination between the two signals. If the analog and digital systems share a common antenna, the only possible source of this discrimination is the cross-polarization (XPD) discrimination of the antenna system. However, if the digital system uses DPF channels, XPD is not available and the analog and digital channels must then be separated by at least 60 MHz. This means that whenever one DPF digital channel is installed, three analog channels are given up—the channel itself and the two adjacent channels. In the worst case, route capacity is, under single antenna conditions, limited to three analog and three DPF digital frequencies.

2.08 To get maximum capacity on a combined route, the DPF digital and the analog channels should be put at the opposite ends of each half-band. By doing this (again under single antenna conditions) only one radio frequency is lost at the interface between the digital and analog channels as opposed to the two adjacent frequencies required when digital DPF and analog channels are intermixed. For this reason, the recommended growth plan for a combined DPF digital-analog system will be different from the previous analog growth plans. On existing routes that will experience digital growth, the growth plan to be followed must be determined on an individual basis. The anticipated digital and analog growth must also be considered before the decision to change to a new growth plan is made.

2.09 Tables F and G illustrate the respective regular and alternate frequency plans for combined systems. The reversed growth stage sequence for digital and analog channels is contained in the two left-hand columns. Growth stage one (Table F) for digital signals is shown to involve channels 11P and 12J at the top of the table, while the first growth stage for analog channels appears at the bottom, using channels 1P and 2J. The subscripts 1 and 2 (see Table F, Note 2) used in conjunction with the analog or digital channel designations are identical in meaning—the use of two subscripts serves merely to emphasize the

TABLE D

GROWTH PLAN FOR ANALOG 20-MHz CHANNELS

		CHANNEL GROUP 1 *						CHANNEL GROUP 2 *					
	GROWTH STAGE	1	2	3	4	5	6	7	8	9	10	11	12
1st ANTENNA	LOWER BAND HALF	12P	6P	4P	10P	8P	2P	12E	6E	4E	10E	8E	2E
	UPPER BAND HALF	11J	5J	3J	9J	7J	1J	12D	6D	4D	10D	8D	2D
2nd ANTENNA	GROWTH STAGE	13	14	15	16	17	18	19	20	21	22	23	
	LOWER BAND HALF	11P	5P	3P	9P	7P	1P	11E	3E	9E	7E	1E	
	UPPER BAND	12J	6J	4J	10J	8J	2J	11D	3D	5D	7D	1D	

* The two channel groups must be on opposite polarizations.

alternating sequence in polarization or antennas as dictated by the nature of the signal. If, for example, the first two signals applied to the system (growth stages 1 and 2) are SPF digital, the subscripts appearing as D_1 and D_2 indicate the need for opposite polarization between channel pairs 11P - 12J and 6P - 5J. If the signals are DPF digital, the subscripts dictate the use of separate antennas in conjunction with the channel pairs. As applied to analog signals, which are always SPF, the subscripts indicate opposite polarization. As indicated in Table F, Note 3, digital growth stage 11 (channel pair 1P - 3J) contains contradictory subscripts in each half-band. The decision as to which subscript to follow, i.e., which antenna or polarization sequence to follow, is determined by the transmitter.

3. SYSTEM CHARACTERISTICS INFLUENCING PERFORMANCE

A. General

3.01 This part defines and discusses the principal system characteristics and related physical phenomena important to the operation of an 11-GHz digital or analog radio system. Figure 3, which is a simplified schematic representation of a radio system, provides a framework for the following discussion and serves to locate or define the boundaries of various parameters or phenomena being described. The expected operating characteristics and performance requirements will be expressed in general terms so as to be applicable to any 11-GHz radio system.

B. System Gain

3.02 Radio system gain is defined as the difference between the nominal power measured at the Transmitter Bay Output (see location in Fig. 3) in dBm and the minimum power at the Receiver Bay Input for acceptable radio system performance. (Note that the phrase "for acceptable radio system performance" includes the receiver as necessary to this evaluation—a point which might not be apparent with strict respect to the two specified measurement locations of Fig. 3.) Minimum receiver power for

TABLE E

GROWTH PLAN FOR 40-MHz DIGITAL CHANNELS

		CHANNEL GROUP 1 *						CHANNEL GROUP 2 *					
	GROWTH STAGE	1	2	3	4	5	6	7	8	9	10	11	12**
REGULAR PLAN	LOWER BAND HALF	12P	6P	X	10P	8P	2P	11P	5P	3P	9P	7P	1P**
	UPPER BAND HALF	11J	5J	X	9J	7J	1J	12J	6J	4J	10J	8J	3J**
ALTERNATE PLAN	LOWER BAND HALF	12E	6E	4E	10E	8E	2E	11E	3E	9E	7E	1E	
	UPPER BAND HALF	12D	6D	4D	10D	8D	2D	11D	3D	5D	7D	1D	

* The two channel groups must be on opposite polarization for SPF channels and on different antennas for DPF channels. See Paragraph 2.06—in some cases SPF channels may require separate antennas for transmitters and receivers.

** Group assignment governed by transmitter; 1P is part of group 2 and 3J is part of group 1.

acceptable performance is defined by the following conditions:

Analog Systems: Maximum noise level (worst message channel) = 55 dBrnc0

Digital Systems: Maximum Bit Error Rate (BER) = 10^{-3} for message service. Other rates may apply for digital data services.

This definition of system gain results in the relation between system gain, section loss (see paragraph 3.04) and fade margin given by:

$$SG = SL + F \qquad (1)$$

where

SG = System Gain

SL = Section Loss

F = Fade Margin

It should be recognized that this definition of system gain gives a performance measure of the radio equipment alone, and does not depend on antenna size, waveguide losses, path length, or include the effect of any active interferences. [Here, as SL becomes larger, the system fade margin (F) must become smaller to maintain acceptable performance. The receiver fade margin is, in turn, dependent on the internal thermal noise of the radio equipment, which reflects its performance quality.] It should also be noted from Fig. 3 that the system gain (SG), as defined in equation (1) will be smaller than the quantity [$P_{nom\ trans} - P_{rec\ min}$], (the difference of transmitter power and minimum received signal as measured at the respective bay output and input) by the amount of the channel combining and separating filter insertion losses. For multichannel systems, the losses of several tandem filters are incurred.

TABLE F

GROWTH PLAN FOR COMBINED 40-MHz DIGITAL AND ANALOG SYSTEMS REGULAR FREQUENCY PLAN

GROWTH STAGE		CHANNEL DESIGNATORS																							
D	A	4P	1P	10P	11P	6P	7P	2P	3P	12P	9P	8P	5P	9J	12J	5J	8J	1J	4J	11J	10J	7J	6J	3J	2J
1	12			A_2	D_1									A_2	D_1										
2	11				A_1	D_2									A_1	D_2									
3	10					A_2	D_1									A_2	D_1								
4	9						A_1	D_2									A_1	D_2							
5	8							A_2	D_1									A_2	D_1						
6	7								A_1	D_2									A_1	D_2					
7	6									A_2	D_1									A_2	D_1				
8	5										A_1	D_2									A_1	D_2			
9	4											A_2	D_1									A_2	D_1		
10	3			D_2									A_1	D_2									A_1		
11	2	A_2	D_1*																					A_2/	D_2*
12	1		A_1																						A_1

Note 1: D = Digital Channels
A = Analog Channels

Note 2: Channels with subscripts 1 and 2 must be on opposite polarizations for SPF channels and on different antennas for DPF channels.

****Note 3:*** The assignment of digital channel pair 1P—3J per Note 2 is governed by the transmitter.

3.03 For practical application in the determination of fade margin, equation (1) above is solved for F, and SG for this purpose can be obtained from equipment design specifications. The fade margin thus obtained must, however, be further reduced to allow for rain, multipath, depolarization, and interference as described in Parts 6 and 7 of this section.

C. Section Loss

3.04 The power loss, due to all causes between the Transmitter Bay Output and the succeeding Receiver Bay Input is defined as the section loss (SL). As shown in Fig. 3, this loss includes the free space or propagation path loss as well as that contributed by network and waveguide components. In the following paragraphs all elements (including antenna gain) which accumulate to permit a quantification of total section loss over one hop are discussed.

3.05 An expression for SL can be written as:

$$SL = L_{FS} + L_{WG_{TOT}} + L_{NW_{TOT}} - G_{TA} - G_{RA} \qquad (2)$$

where

L_{FS} = propagation path loss (free space)

TABLE G

GROWTH PLAN FOR COMBINED 40-MHz DIGITAL AND ANALOG SYSTEMS ALTERNATE FREQUENCY PLAN

GROWTH STAGE		CHANNEL DESIGNATORS																							
D	A	4E	1E	10E	11E	6E	7E	2E	3E	12E	9E	8E	5E	9D	12D	5D	8D	1D	4D	11D	10D	7D	6D	3D	2D
1		D_1																	D_1						
2	11		A_2	D_1														A_2			D_1				
3	10	A_1			D_2														A_1	D_2					
4	9				A_2	D_1														A_2			D_1		
5	8			A_1			D_2														A_1	D_2			
6	7						A_2	D_1														A_2			D_1
7	6					A_1			D_2														A_1	D_2	
8	5								A_2	D_1					D_1									A_2	
9	4							A_1			D_2					D_2									A_1
10	3									A_1		D_1			A_1		D_1								
11	2		D_2								A_2					A_2		D_2							
	1											A_1					A_1								

Note 1: D = Digital Channels
A = Analog Channels

Note 2: Channels with subscripts 1 and 2 must be on opposite polarizations for SPF channels and on different antennas for DPF channels.

$L_{WG_{TOT}}$ = total waveguide losses (transmitting and receiving)

$L_{NW_{TOT}}$ = total network losses (transmitting and receiving)

G_{TA} = gain of transmitting antenna

G_{RA} = gain of receiving antenna

A distinction is made between microwave facilities which handle only 11-GHz radio traffic and those which handle a mixture of 11-GHz, 6-GHz, and 4-GHz traffic over shared waveguide and antenna components. The latter systems are termed "combined systems", and incorporate additional microwave networks the losses of which must be included in $L_{NW_{TOT}}$.

Waveguide Loss

3.06 The waveguide runs required at a radio station can be grouped into two categories:

(a) Predominantly horizontal short runs from the transmitter bay output to the antenna tower base.

(b) Long vertical runs which feed tower mounted antennas.

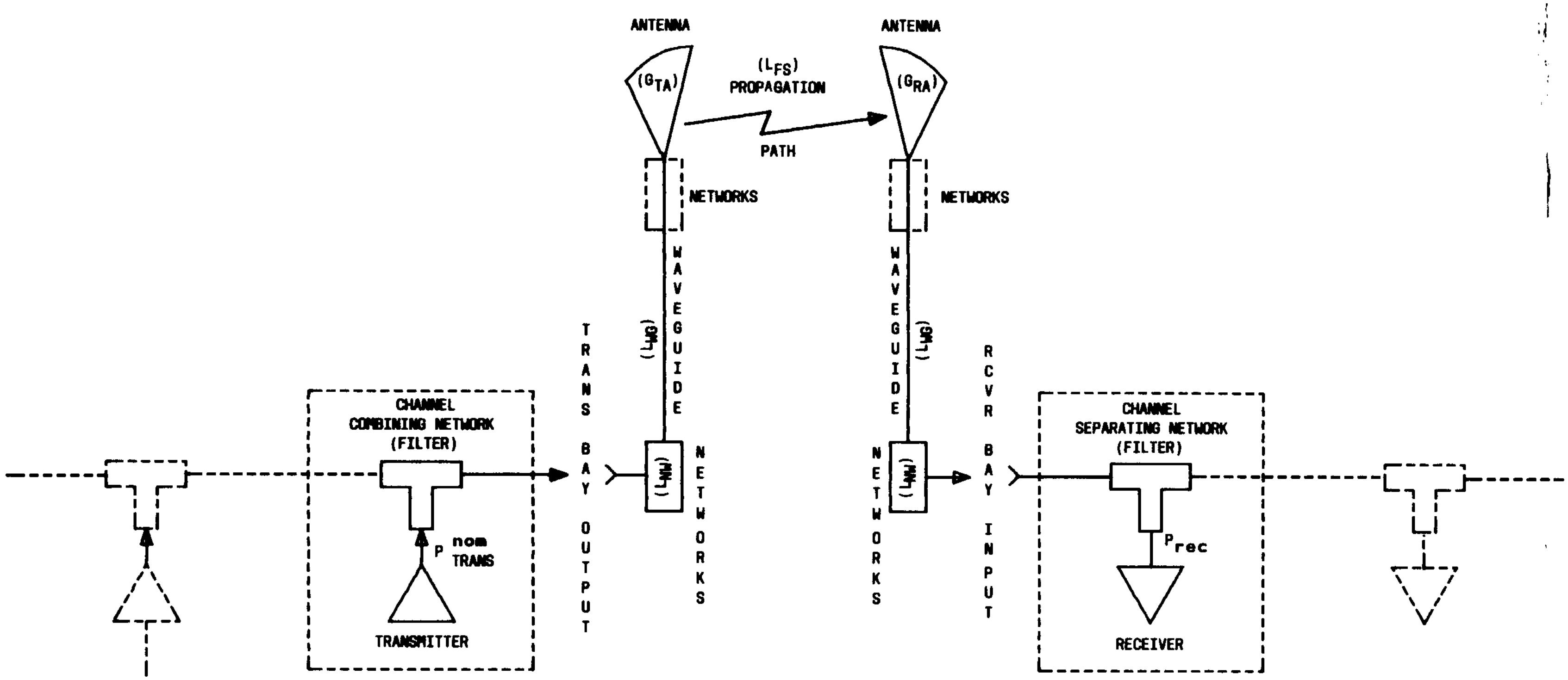


Fig. 3—Radio System Schematic

For category (a), dominant mode operation, single polarization waveguide is typically used, for example WR-90. This type of waveguide does not create objectionable loss, since only short distances are involved and, in addition, provides for convenient bending and handling.

3.07 Since tower mounted antennas [category (b)] usually require on the order of 100 feet or more of vertical waveguide run, guide loss and cost become significant factors in selecting a waveguide type for this purpose. Here, circular waveguide has a substantial advantage over other geometrics by providing both low loss and dual polarization operation via a single guide run. The type of antenna (see paragraphs 3.08 and 3.09) will also influence the selection of waveguide type, since the interfacing of the guide and antenna may require transition networks in some cases. Such networks increase cost and introduce some additional loss. The options in selecting a waveguide for a vertical antenna feed-run will also depend on whether the station is to handle only 11-GHz traffic, or combined 11-GHz, 6-GHz and/or 4-GHz signals. Simultaneous use of lower frequency signals together with 11 GHz with only one vertical waveguide run requires the use of larger size guide, i.e., oversize for the 11-GHz signal. Oversize guide can be used even in the absence of lower frequency bands, but the multimode transmission phenomena which can occur in oversize waveguide may create a variety of problems, such as excessive envelope delay distortion. Table H summarizes loss data for various waveguide options of interest for 11-GHz radio systems.

Networks

3.08 A dual polarized 11-GHz-only radio system which uses a single vertical waveguide run requires polarization combining networks and, if transitions to other waveguide geometrics or sizes occur, transition networks and mode suppressors. In combined systems (4-, 6-, and 11-GHz) using a common vertical antenna feed-run and antenna, combining networks are required to couple the other frequency bands into the waveguide. In some cases, mode suppressor networks may also be required. Each such network contributes to the total section loss through reflection and ohmic losses. Since these networks are usually short, the ohmic loss contributions are very small, and with correct design, reflection losses can also be minimized. Typically, each such network will introduce 0.2- or 0.3-dB loss.

Antenna Gain

3.09 The focusing of radiated energy introduced by the transmitting and receiving antennas reduces the section loss by the sum of the on-axis gains of the two antennas (assuming correct antenna alignment). The on-axis power gains for some antennas which might typically be used with an 11-GHz radio system are given in Table I, together with other antenna parameters of interest.

Radome Losses

3.10 In an open environment, precipitation can accumulate on the reflector and/or feed structure of horn and dish antennas. Such accumulations can introduce losses of 10 dB or more into the section loss. To prevent this condition, radomes are typically used to enclose the reflector aperture and seal out moisture. Radomes may be planar (rigid or flexible) or geometrically molded, for example, parabolic or conical. Accumulation of water, ice, or snow on the radome also results

TABLE H

11-GHz WAVEGUIDE DATA

WAVEGUIDE TYPE	WC281	WC150	WC109	WR90	EW107
Loss per 100 feet (dB)	0.3	0.8	1.35	3.4	3.4—3.7*

* Copper (3.4) versus aluminum (3.7).

TABLE I

ANTENNA RADIATION PARAMETERS AT 11 GHz (MIDBAND)

ANTENNA TYPE	GAIN** (dB)	BEAMWIDTH DEGREES	FRONT-TO-BACK COUPLING (dB)	SIDE-TO-SIDE COUPLING (dB)
KS 15676 Horn Reflector (10′)	48.0 (V_{pol}) 47.4 (H_{pol})	0.81 (V_{plane}) 0.66 (H_{plane})	< 85 (V_{pol}) < 86 (H_{pol})	93 (Same polarization) 100 (Cross-polarization)
Gabriel Minihorn (6′) UHR-10B	43.8	1.2 (V_{plane}) 1.1 (H_{plane})	75 (V_{pol}) 75 (H_{pol})	
PARABOLIC* DISHES 6′ Dia	44	1.1	75	
PARABOLIC* DISHES 8′ Dia	45.9—46.6	0.80-0.78	70—75	
PARABOLIC* DISHES 10′ Dia	47.6—48.5	0.70-0.65	70—75	
PARABOLIC* DISHES 12′ Dia	49.2—49.9	0.60-0.50	70—75	

* Performance varies with manufacturer, the values shown being representative.

** Includes the loss of a dry low-loss radome.

in increased loss in the propagation path, but measures to reduce such losses can be effected.

3.11 Ice and snow accumulation can be minimized through use of resistance heaters distributed through the radome surface. (Prevention of ice buildup may also be desirable to reduce the hazard of falling ice from tower mounted antennas.) The use of flexible planar radomes under tension also minimizes ice and snow buildup through the flexing action which results from normal wind conditions. Special chemical coatings which reduce absorption, adhesion, and friction of the radome surface to precipitation are currently under experimental investigation. These coatings not only reduce precipitation losses, but reduce the recovery time of the radome to normal conditions. It is anticipated that future information on the use of radomes coated with hydrophobic materials will be included in this section as results become available.

3.12 The loss introduced by use of a radome, under dry conditions, can vary from less than a few tenths of a dB to several dB, depending on the specific radome used. It should be noted that the antenna gains given in Table I include the loss contributed by a dry, low-loss radome. A typical value of 4 dB is used as the loss resulting from a wet radome in the various representative calculations throughout the remainder of this section.

Free Space Path Loss

3.13 The geometric spreading of energy radiated from the transmitter location to the receiver results in the free space path loss (L_{FS}). (This topic of propagation path loss is the subject of Section 940-310-101, which may be consulted if additional details are desired.) This contribution to the overall section loss (in dB) at the midband frequency is expressed by the relation:

$$L_{FS} = 117.6 + 20 \log (D) \text{ (miles)}$$

or

$$L_{FS} = 113.5 + 20 \log (D) \text{ (kilometers)}$$

where D is the transmitter-receiver separation in miles or kilometers. It is sufficient to calculate the path loss for midband.

D. Cross-Polarization Discrimination (XPD) Characteristics

3.14 Some 11-GHz digital radio systems have been designed to meet the FCC requirement specifying a voice circuit loading equal to or greater than 1152 voice circuits per 40-MHz channel, to be implemented through cochannel (dual polarization) operation. In this type of operation, otherwise known as dual polarization per frequency (DPF), the same channel frequency is transmitted on two opposite polarizations with unique message information applied to each polarization. (The 3A-Radio Digital System, for instance, uses a voice circuit loading of 672 per polarization, yielding a total of 1344 message channels per frequency.) Signal selectivity is achieved only through the cross-polarization discrimination available at the receiver. Therefore, in order to limit cochannel interference and resultant service outages, systems of this type require that under standard, nonfaded conditions the system cross-polarization discrimination be on the order of 25 dB. The XPD of an 11-GHz radio system is dependent on natural phenomena as well as on design parameters. Thus, due to the variability of environmental phenomena the XPD will fluctuate about its nominal design value, giving rise to time dependent system degradation and outage. Those factors and phenomena which determine the XPD of an 11-GHz radio system are discussed below.

Antenna System

3.15 Several effects can occur within an antenna, its associated waveguide, and other antenna system components all of which may give rise to undesired coupling of cross-polarized energy into a radio channel. The antenna proper responds to a cross-polarized signal, that is, gives rise to a signal at the antenna output signal port, with a polarization sensitivity which depends on the vertical and azimuthal arrival angle of the incoming wave. The cross-polarization response pattern is the measure of such sensitivity.

3.16 Horn reflector and parabolic dish antennas used in 11-GHz radio systems both display a deep null (high discrimination sensitivity) in the cross-polarized antenna response pattern along the axis defined by the center of the main beam of the normal (copolarized) antenna pattern. For the horn reflector, this null persists for all arrival angles in the vertical plane containing the main beam axis, but the null depth decreases somewhat with increasing departure from this axis, i.e., from 0 degrees elevation angle. The desired antenna cross-polarized response decreases very rapidly as the azimuthal arrival departs from the main beam axis. Figures 4, 5, and 6 serve to graphically illustrate those characteristics of a horn antenna as described above. Figure 4 illustrates the degradation in discrimination as a function of azimuthal angle only, for both horizontally and vertically polarized waves. Figures 5 and 6 show the increased azimuthal discrimination degradation to vertically polarized (Fig. 5) and horizontally polarized (Fig. 6) waves resulting from a displacement in the elevation angle of arrival of ±0.5°.

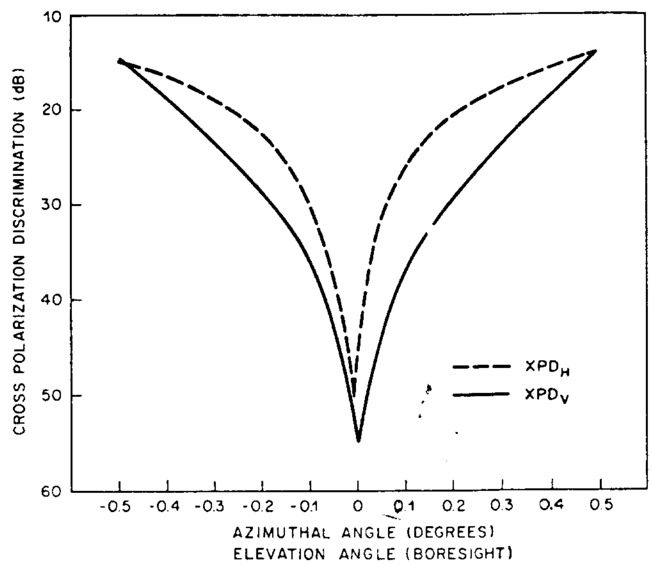


Fig. 4—10.96-GHz Cross-Polarization Discrimination of KS-15676 Pyramidal Horn Reflector Antenna as a Function of Azimuthal Angle

3.17 In the case of a parabolic dish antenna, the deep null in the cross-polarized response pattern along the direction of the main beam axis degrades quickly in both azimuth and elevation planes as the wavefront arrival angle departs from this axis. Figures 7 and 8 respectively reveal this degradation in terms of azimuthal and elevation angles.

3.18 While analysis shows that either the horn reflector or parabolic dish antenna can meet

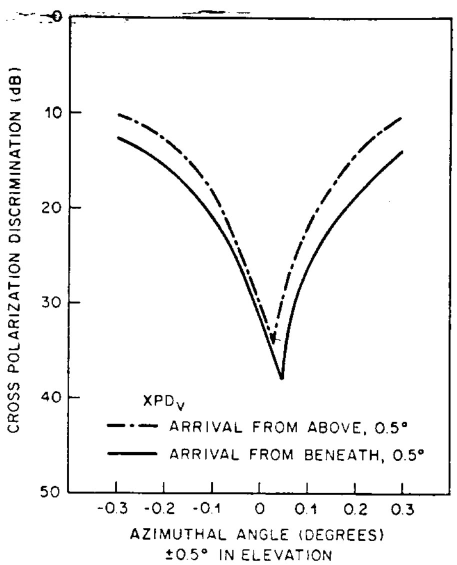


Fig. 5—10.96-GHz Cross-Polarization Discrimination of KS-15676 Pyramidal Horn Reflector Antenna as a Function of Azimuthal Angle for Elevation Angles of ±0.5°, XPDV

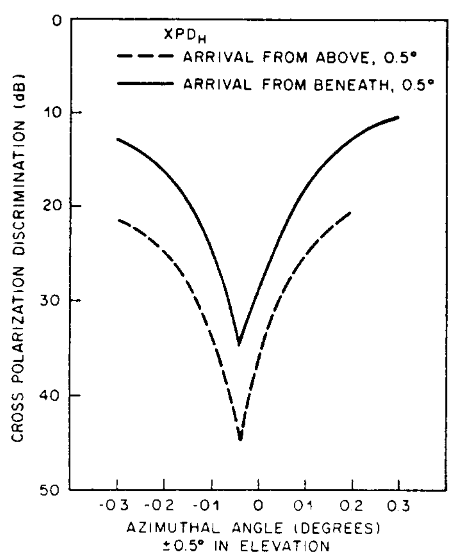


Fig. 6—10.96-GHz Cross-Polarization Discrimination of KS-15676 Pyramidal Horn Reflector Antenna as a Function of Azimuthal Angle for Elevation Angles of ±0.5°, XPDH

a minimum XPD requirement of almost 30 dB under most field conditions, care should be exercised in selecting an antenna and/or antenna tower for use at geographic locations subject to strong wind

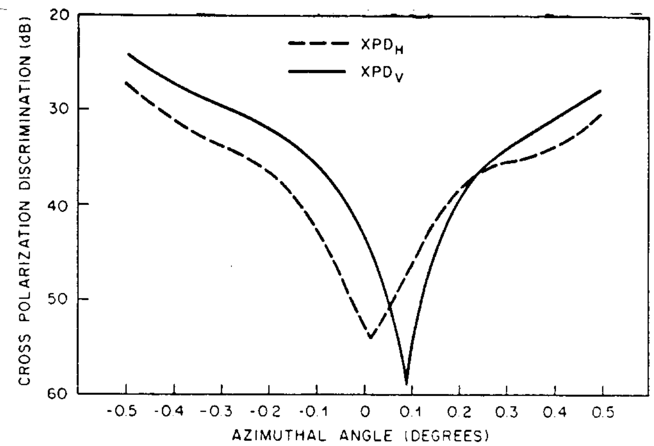


Fig. 7—11.2-GHz Cross-Polarization Discrimination of Scientific-Atlanta UDA10-107 Antenna as a Function of Azimuthal Angle

loading or, for that matter, severe arrival angle fluctuations resulting from multipath phenomena. As can be readily seen from the previous figures, deviations of wavefront arrival angle in azimuth or elevation as a result of tower motion and/or multipath can result in XPD values substantially less than 25 dB.

Antenna Feed Network

3.19 Waveguide phenomena, such as reflections and spurious high-order mode generation and conversion, can result in polarization conversion, that is, coupling of energy from one polarization to the opposite (orthogonal) polarization. The use of dominant mode waveguide and proper installation techniques can minimize such problems. Mode suppressors can also be used to minimize generation and propagation of unwanted modes when such effects are likely. Effects such as these are likely to arise when oversized or closed waveguide systems are used. A closed waveguide system is one in which the waveguide does not end in a natural termination, that is, does not flare into a radiating aperture but terminates in other microwave networks which require mode conversion. A typical network of this type might be a circular waveguide run with polarization couplers providing a transition to WR-90 (rectangular) guide at each end.

3.20 Waveguide transition and polarization coupling networks are other potential sources of cross-polarization degradation. Reflections, mode

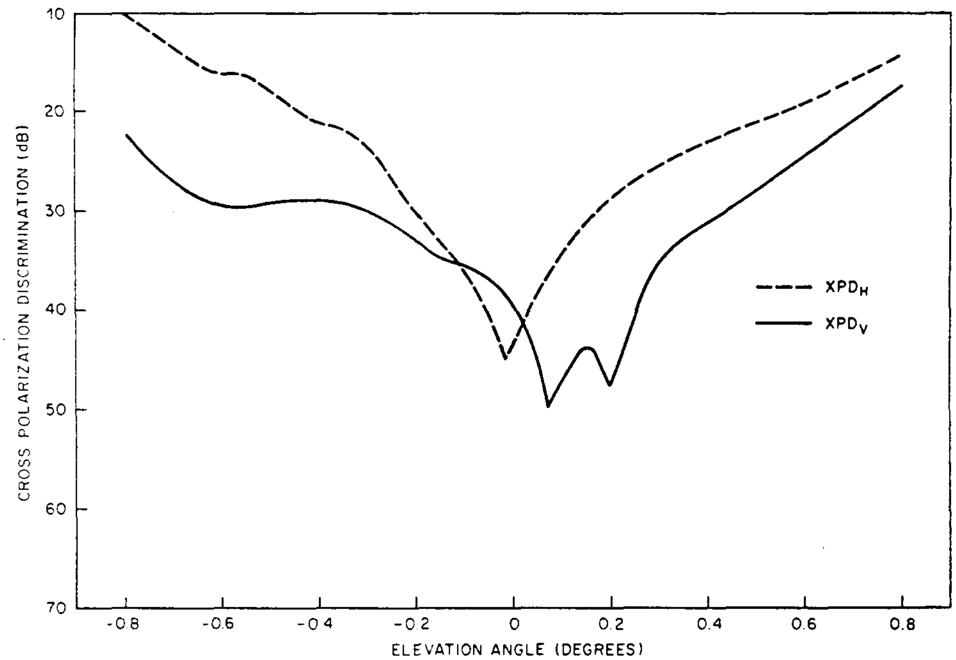


Fig. 8—11.2-GHz Cross-Polarization Discrimination of Scientific-Atlanta UDA10-107 Antenna as a Function of Elevation Angle

generation and conversion, and direct polarization "crosstalk" are all mechanisms which can occur in such networks and lead to degraded XPD. With proper design, however, the XPD characteristics of such networks are usually greater than 30 dB, and are therefore adequate for 11-GHz radio systems. In this regard, a major contributor to poor XPD on 11-GHz systems operating on the same antenna waveguide system with 6-GHz systems has been found to be the 6-GHz 1428A combining network. Tests have shown that XPD can be as low as 12 dB when two 1428A networks are used in tandem, and both 6-GHz polarizations are employed. A new 6-GHz combining network, the 1428B, is now available which should be used in the common waveguide run to replace the second 1428A. The use of the 1428B network can improve the XPD of the 1428A-1428B combination to about 40 dB without affecting the 6-GHz performance. When 11-GHz signals are added to an existing system which has 1406A, 1428A, or 1434A networks, it is recommended that the 6-GHz networks be changed to include a 1428A and 1428B network. For an 11-GHz-only antenna system, measurements indicate that with proper alignment of transmitting and receiving antennas (such as horn reflectors having TM_{01} mode nulls greater than 30 to 35 dB) together with their associated polarization coupling networks, an XPD requirement of better than 25 dB can be met at installation.

Rain

3.21 The attenuation produced by rain is polarization dependent. This results from the fact that a falling drop of rain is not truly spherical, but somewhat elongated (flattened) in the horizontal plane. This physical geometry of a raindrop results in both differental attenuation and phase effects which depend on polarization, and among which is a greater attenuation of horizontally polarized waves. During moderate-to-heavy rain, these polarization dependent effects are capable of substantially reducing the XPD on a given path. (Section 940-310-106 deals with the topic of rain fading. However, at the time of this writing, Issue 1 of the above section had not been augmented to include the more subtle effects of rain attenuation such as depolarization.) Current theory and measurements indicate that for moderate-to-heavy rain conditions, system XPD values of 18 to 22 dB can be expected, with extreme values on the order of 15 dB occurring from very heavy rainfall. Rain related decreases in 11-GHz XPD with respect to clear weather values are correlated with rain fade depth, i.e., the minimum XPD values occur during deep rain fades.

Multipath Fading

3.22 Multipath fading of conventional signals of single polarization in a given radio channel is reasonably well understood and documented. (Section 940-310-102 on the topic of Selective Fading discusses the physics of multipath phenomena and provides experimentally verified statistics relative to fade depth and fade duration.) However, the behavior of cross-polarized energy coupled into a radio channel during fading is not completely characterized at the present time.

3.23 It is known that when multipath fading occurs it will affect the primary vertically and horizontally polarized signals in an identical manner. In contrast to this, however, secondary propagation paths and scattered energy can be independently affected. As a consequence, these secondary sources may continue to contribute to the received cross-polarized energy at a more or less constant level during periods when the primary signal is experiencing a severe fade. Here too, it becomes possible for signals being experienced as external interference to remain at relatively high levels—in contrast to rain fading in which the fading of secondary signals as well as interference will be correlated with primary signal fading. Multipath fading is also capable of shifting the arrival angle of the incoming wave (as previously discussed in paragraph 3.16) and can cause variations of inclination in the plane of polarization both of which result in degraded XPD and increased coupling of cross-polarized signals at the receiving antenna. The net result of all of these effects is an XPD which remains essentially unchanged for small to moderate fades, but degrades rapidly for moderate to deep fades.

4. OVERVIEW OF OUTAGE CALCULATIONS

A. General

4.01 For 11-GHz radio systems, the three major causes of system outage are:

(a) Rain attenuation

(b) Multipath fading

(c) Equipment failure.

With modern solid-state systems, equipment failure should not be a serious contributor on systems with equipment protection, such as 1×N frequency diversity (in which equipment protection is intrinsic) or hot standby (which can be used in conjunction with space diversity). Rain attenuation and selective fading will affect both analog and digital systems; however, the relative effects will differ, depending on the hop in question.

B. Analog Systems

4.02 Rain outage is usually the major factor to be considered in analog systems. This arises from the fact that rain attenuation is nonselective and cannot be compensated by space or frequency diversity techniques. Outage time caused by rain can be held within tolerable limits only by reducing hop length, which assures a high signal level at the receiver and reduces the probability of rain occurrence on a given hop. The short hop lengths dictated by rain outage also reduce the probability of selective fading, the remainder of which can, if necessary, be largely offset by the use of conventional space or frequency diversity.

C. Digital Systems

4.03 Rain outage is, of course, a concern of digital as well as analog systems. Here, however, problems related to multipath propagation can, in spite of diversity protection, become a major source of outage. For digital systems, the multipath fade margin will usually be smaller than the margin necessitated by rain attenuation. As pointed out in paragraph 3.23, the fading of secondary path signals, as well as external interference, is not necessarily correlated with primary path fading. In addition, multipath propagation can shift the arrival angle off the antenna main beam axis and contribute to depolarization as well, which in DPF systems results in degraded XPD and resultant cochannel interference. As a consequence, the DPF fade margin is determined by the cross-polarization discrimination or, in other words, by the carrier to interference (C/I) ratio (which can degrade even to the point of producing negative ratios) rather than by the conventional carrier to thermal noise ratio (C/N). In SPF digital systems, the C/N is also subordinate to the greater consideration of the effect of multipath induced distortion on the 8-level signal. Since, in both cases, conventional thermal noise is not a consideration, and since severely degraded C/I ratios as well as distortion can occur at fade depths corresponding to relatively high C/N ratios, the multipath fade margin cannot be significantly improved by such means as increasing transmitter power, lowering waveguide loss, or increasing antenna gain. These factors improve the already adequate C/N ratio without affecting those mechanisms responsible for digital degradation. The net effect is that in systems employing high performance antennas, the operating fade margin for multipath is in the 30-dB range. This has two significant effects on multipath outages:

(a) As predicted by the Rayleigh distribution, fading time at the 30-dB level is about 10 times that at the 40-dB level.

(b) The effectiveness of frequency diversity at the 30-dB level is also reduced by a factor of 10 from that at the 40-dB level.

(As will be subsequently pointed out in paragraph 7.09, space diversity performance also degrades with a reduced fade margin, but not to the point of impracticality for use with digital systems.) Because of these effects, multipath can be the dominant source of digital system outage, except in those areas where rain severely limits hop lengths and so reduces multipath probability.

5. SYSTEM OUTAGE OBJECTIVES

A. Annual Objectives

5.01 Outage objectives for Bell System microwave transmission systems are stated in terms of an allowed annual outage percentage for a stated route length. For both long-haul and short-haul systems, this 2-way objective is 0.02 percent or 105 minutes per year. The distance over which this objective applies is 4000 miles in the case of long-haul systems, and 250 miles for short haul, and includes outage from all causes, i.e., environmental phenomena as well as equipment failure, of which this latter category includes such things as maintenance and plant errors. Outage objectives for lengths shorter than those specified are scaled down linearly. Thus, a 70 mile short-haul system would have an outage objective of 70/250 × 105 min. = 29.4 minutes per year.

B. 11-GHz Apportionment

5.02 It has been considered conventional practice when calculating outage at lower frequencies (such as 4 and 6 GHz) to further apportion the 0.02 percent 2-way annual objective such that one-half or 0.01 percent was allocated to multipath while the remaining half was assigned to equipment failure. At 11 GHz, rain attenuation becomes an additional source of outage which must be considered, and for which outage time must be allocated. Any time which can therefore be obtained through a reduction in the calculated outage contributed by any given factor or factors can be allocated to rain. For this reason, the approach best suited to 11 GHz is to disregard any strict apportionment in terms of previous convention, and to calculate and sum the specific outages to assure that their total will not exceed the scaled objective for that hop. This method is demonstrated in the extended example presented in Part 9 of this section, and represents the procedure to be followed.

6. OUTAGE DUE TO RAIN

A. General

6.01 Rain outage depends on hop length, the fade margin, and the intensity and duration of the rain. The calculation of expected rain outage time is facilitated by use of a rain outage chart, a typical example of which appears as Fig. 9. The use of this chart requires the application of hop length and the hop rain attenuation margin (M). This rain margin is derived by modification of the basic fade margin (F) which, in turn, is based on system gain and section loss as discussed in Part 3, and can be obtained by resolving equation (1), in which case,

$$F = SG - SL \tag{3}$$

[Given a radio terminal pair of a particular type, the system gain parameter, SG, is fixed, while section loss, SL, is derived as in Part 3, equation (2).] The required modifications to F result in rain fade margins which differ for SPF and DPF systems.

B. Fade Margin for SPF Systems

6.02 The rain fade margins for SPF systems are obtained by first computing F as in equation (3) above, and modifying (reducing) this value in terms of interference and/or radome loss. The correction for interference (the calculation of which is rather involved) takes the form of a penalty which results in a reduction of the fade margin. The calculation of this interference penalty is covered

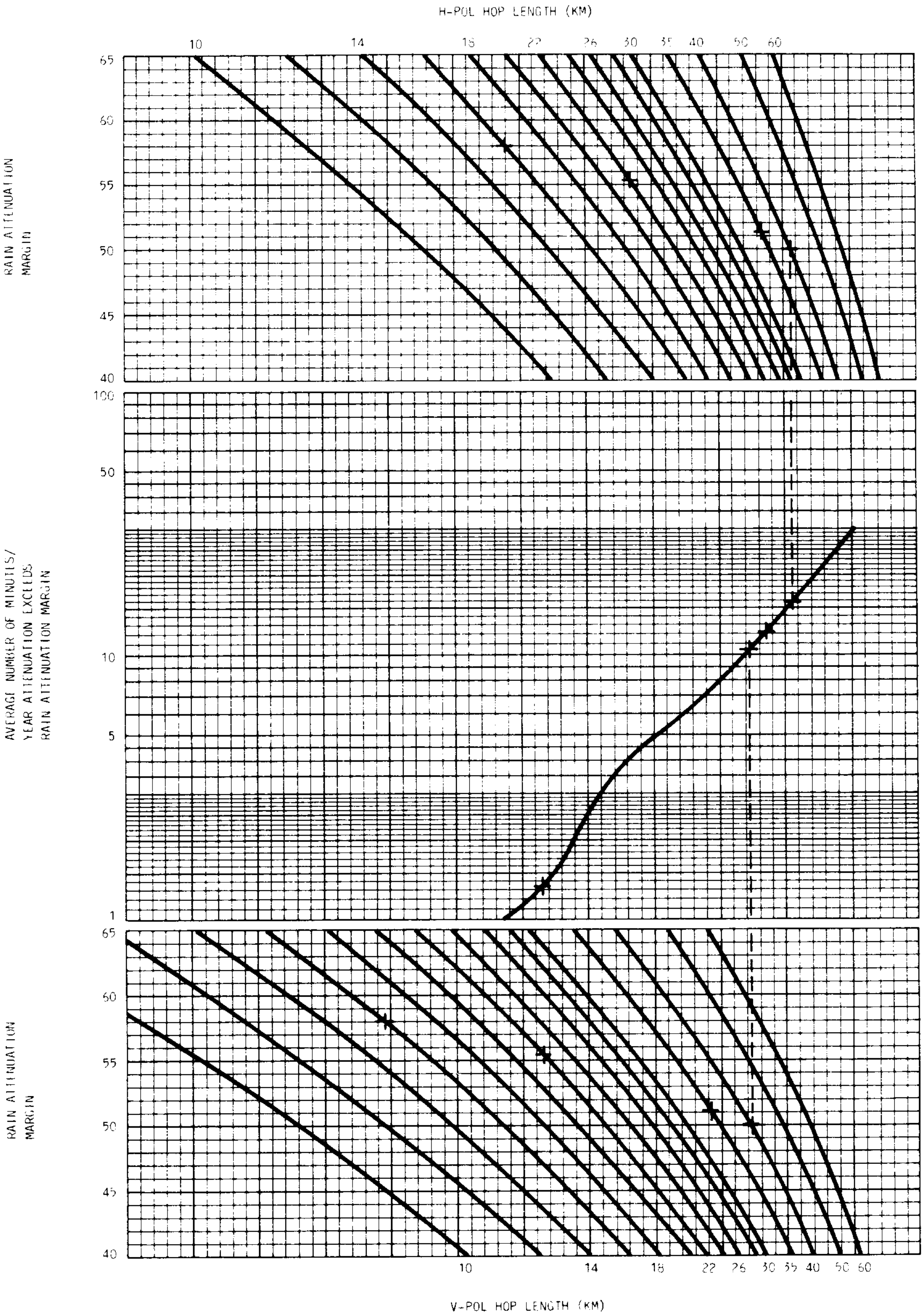


Fig. 9—Rain Attenuation Chart—Typical City

in Part 10 dealing with interference considerations. (See, in particular, paragraphs 10.21 and 10.22.) The best estimate for wet radome loss is 4 dB per section for good quality planar radomes. Conical, hemispherical or corrugated radomes have significantly higher loss. Analog systems require only the 4-dB wet radome allowance, while digital system fade margins are reduced by the wet radome allowance and the calculated interference penalty.

C. Fade Margin for DPF Systems

6.03 The calculated fade margins [equation (3)] for DPF systems must be reduced by three factors: The first is the same 4-dB wet radome allowance as in the SPF case. The second factor is again an interference penalty which, however, will differ from the previous SPF value and the calculation of which is also covered in Part 10. The third factor is unique to DPF systems and, as previously introduced in paragraphs 3.14 and 3.21, involves the degradation of XPD during heavy rain. The resultant cochannel interference results in a reduced carrier-to-interference ratio (C/I) which must be offset by an improved carrier to thermal noise (C/N) ratio if the same BER used to define system gain is to be maintained. Again, reduction of the fade margin is applied to this purpose. For a typical 4-level (modulation via 4-level FSK or PSK) digital signal, this loss of fade margin is approximately 2 dB.

D. Rain Outage Charts

Background

6.04 The frequency and duration of high rainfall rates varies widely with geographical location. Long-term U. S. Weather Service records have been processed for over 200 United States locations. From this data, charts have been derived showing the expected minutes of outage for a range of hop lengths and rain attenuation margins. Separate calculations must be made for vertical and horizontal polarizations since the attenuation due to a specific rain rate is higher for horizontally polarized signals. When calculating outage time, the chart appropriate to the area should be used. Specific rain attenuation charts pertinent to the territorial area of concern to each operating company have been transmitted to the appropriate headquarters radio engineer. If necessary, additional copies of these charts can be requested from the following address:

Engineering Dept. - Intercity Transmission Systems
American Telephone and Telegraph Company
295 North Maple Avenue
Basking Ridge, New Jersey 07920

6.05 The expected rain outage for a hop with a fixed length and fade margin varies widely with geographic location. The southeastern United States tends to have the most frequent and longest duration of high rainfall rates. Moving both north and west from that region improves the outage time by a large factor. The far western regions have the lowest incidence of high rain rates. Repeater spacings required to meet outage objectives thus vary from short in the Southeast to long in the Northwest.

Hop Length Determination

6.06 Formulas are available for the direct calculation of such factors as fade margin and outage time. Since repeater spacings must be adjusted in relation to rainfall, a question might arise as to why no similar, direct method has been applied to the determination of optimum hop length, as well as to the origin of such hop length values as required input to Fig. 9, and as previously required in the calculation of free-space path loss toward the evolution of equations (1) and (3). A chart or nomogram providing hop length as a function of rain rate, outage time, and fade margin could be devised. However, a chart of this type would be useful only under the assumption that the optimum physical locations would be available for station placement. In reality, the possibilities for station location are highly restricted by such things as available real estate, areas en route to be served, and locations of high elevation (mountain tops, for example, which reduce the need for high towers and long waveguide runs). Other variables must also be considered, with the net result that there is usually more than one way to do a job in terms of required route length, service, and outage time. While longer hops could make for economy, multipath would increase along with rain outage, and the added cost of space diversity could offset any gain. Short hops, while reducing rain outage and multipath, would also increase equipment failure. Since hop length (and the related number of hops) will be dictated by practical limitations and considered alternatives, it must be inserted by the design engineer with the calculated fade margin becoming the dependent variable. Again, as with the allocation of outage time, the best method of deciding among alternatives is essentially trial and error, that is, to follow the example in Part 9, using considered practical possibilities and testing the entire route against outage time and economy.

Chart Use

6.07 The sample rain outage chart of Fig. 9 is that of a typical city. Outage time (in minutes) is shown for combinations of rain attenuation margins ranging from 40 to 65 dB and path lengths of 10 to 60 km. Since the path length is shown in kilometers rather than miles, the appropriate conversion factors are:

1 mile = 1.6093 km

1 km = 0.6214 miles

The curves on the upper edge of the chart are for horizontal polarization, while those on the lower portion are for vertical polarization.

6.08 To use this chart—say, for horizontal polarization—the point corresponding to the intersection of the rain attenuation margin and path length is located in the upper portion. This point is then projected vertically downward until it intersects the curve in the center of the chart, and the minutes of outage are read from the scale on the left of the center section. The same process is used for vertical outage time, except that the lower portion of the chart is used. Keep in mind that the rain attenuation margin used with this chart is:

M(Rain Margin) = F - (Wet radome loss)
- (Depolarization correction)
- (Correction for interference)

where

Wet radome loss ≈ 4 dB

Depolarization correction ≈ 2 dB (DPF)
= 0 dB (SPF)

Interference (Digital Systems) = As calculated per Part 10

If the interference penalty is momentarily disregarded, it can be seen that the rain margin for SPF systems will be 4 dB smaller than F, as calculated from system gain minus section loss, while that for DPF systems will be 6 dB smaller.

6.09 The example of Fig. 10 serves to further demonstrate the use of the rain outage chart. This is a light route (2000 VF circuits) DPF system consisting of 4 hops, and is the same exemplary system used in Part 9 as a summary demonstration of outage calculation. The hop lengths and associated rain margins are provided in Fig. 10. Since the interference penalty as calculated in Part 10 for such a light route DPF system is 0.4 dB, the indicated rain margins are reduced by 6.4 dB from the fade margins (F) as otherwise obtained from equation (3). The C-D hop, having a 40-km path length and a 50-dB rain attenuation margin, is fully marked on Fig. 9, while the remaining three hops are shown only as points. The total outage times as derived from the chart are tabulated below:

HOP	D PATH LENGTH KM	M RAIN ATTENUATION MARGIN DB	OUTAGE TIME V MIN.	OUTAGE TIME H MIN.
A-B	16	58.0	—	1.0
B-C	35	51.2	7.6	12.3
C-D	40	50.0	10.5	16.0
D-Z	22	55.2	1.3	4.5
	113		19.4	33.8

7. OUTAGE DUE TO MULTIPATH FADING

A. General

7.01 For many 11-GHz radio paths, system outage will be controlled almost entirely by rain. The short repeater spacings and the use of frequency or space diversity combine to make outages due to multipath fading negligible. For some paths, for example long paths in dry climates, or even moderate paths in coastal areas, multipath effects can be significant. The effects are most likely in hot humid and flat regions and least likely in cool, dry, and mountainous terrain. Over the same terrain, fading on a short path is much less likely than fading on a long path.

B. Fade Margins for SPF Analog Systems

7.02 Fade margins for SPF analog systems are found by the direct application of equation (3):

$$F = SG - SL$$

C. Multipath Fade Margins for SPF and DPF Digital Systems

7.03 Multipath fade margins for digital systems are usually much smaller than the fade margins determined by system gain minus section loss. In DPF, loss of XPD can result in cochannel interference, while in SPF operation selective fading can result in distortion. The best evidence available now suggests that for moderate length hops, a multipath fade of approximately 30 dB results in a high probability of exceeding the 10^{-3} BER. Note that this is a statement of probability, not that of a clear cut cause and effect relationship. Some fades less than 30 dB will cause high error rates, while some deeper fades will not. Longer hops, lower fade margins [from equation (3)], and lower XPDs will make the onset of high error rates occur slightly lower than 30 dB. The usual variations between 11-GHz systems using high quality antennas and with high fade margins for rain are quite small. Thus, the assumption can be made that the fade margin for multipath in digital systems is usually no more than 30 dB.

D. Outage per Hop (Nondiversity)

7.04 Estimates and methods of procedure for determining multipath outage time as a function of path length, frequency, fade margin, and climate and terrain factors are described in Section 940-310-102. This section can be applied to calculations involving SPF analog and digital systems, as well as DPF digital systems which require special considerations.

7.05 The curves and formulas in Section 940-310-102 are applicable to digital systems even though the outage criterion is based on a 10^{-3} bit error rate rather than on thermal noise per se. Since the SPF multipath fade margin will coincide with the 10^{-3} BER, and since the application of this margin to the formulas in Section 940-310-102 yields outage time as "time below level", the time during which the signal level is below this fade margin will also coincide with the 10^{-3} BER. As pointed out in Section 940-310-102, however, 11-GHz installations which are located on mountain tops having midpath clearance hundreds of feet in excess of the radius of the first Fresnel zone can experience less selective fading than predicted by the conventional equations.

E. Outage per Hop, DPF Systems

7.06 An approximation of the DPF outage is shown in Fig. 11. The curve is drawn for typical systems with a thermal noise fade margin greater than 40 dB at 25 miles. A 10^{-3} BER was used to define an outage, thus the Fig. 11 curve reflects a fade margin in the order of 30 dB. The curve provides the outage in minutes per year as a function of repeater spacing. The c factor for these curves is 1.0, corresponding to average humidity and average terrain conditions. A c factor of 1.0 is appropriate for the Middle West. Corrections

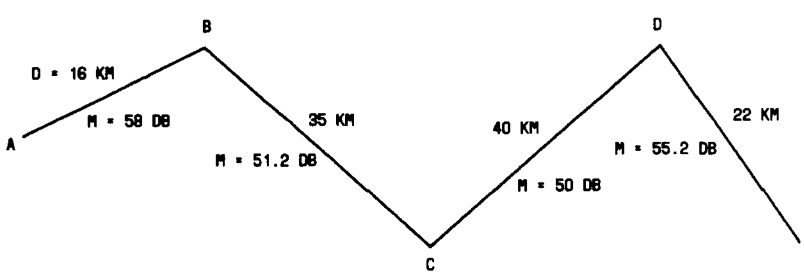


Fig. 10—4-Hop System

for other areas are made by multiplying the outage time obtained from Fig. 11 by different values of c derived as follows:

$$c = x\left[\frac{w}{50}\right]^{-1.3}$$

where x = 2.0 humid regions

= 1.0 average humidity

= 0.5 dry regions

and w = terrain roughness (the standard deviation of the terrain heights measured at 1-mile intervals along the path).

(For w > 140, use 140 as the maximum value. For w < 20 use 20 as the minimum value)

An extended discussion of the c and w factors is available in Section 940-310-102. (Note that a value of w = 50 has been defined as normal, in which case c will remain at 1 for average conditions.) A comparison of the DPF outage time (using the curve of Fig. 11) and the 11-GHz conventional system outage time (inserting similar parameters) as predicted in Section 940-310-102, reveals that the outage for DPF digital systems (due to the existence of XPD degradation) will be much greater than outage time based only on thermal noise with a fade margin of 40 dB or greater.

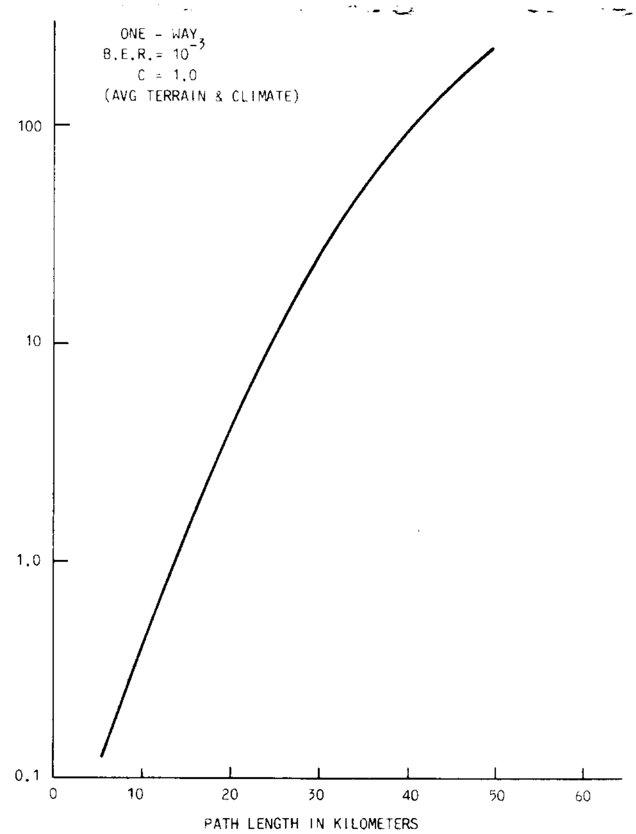


Fig. 11—Multipath Outage Versus Hop Length (DPF)

F. Space and Frequency Diversity Improvements

Space Diversity

7.07 Outage due to multipath can be greatly reduced by switching a receiver to a second antenna which is vertically separated from the main antenna. (Section 940-310-115, as well as EL 3420 on which 940-310-115 was based, provide detailed coverage of this subject.) For the 11-GHz band, with equal gain antennas, the improvement factor, I, is given by:

$$I = 1.3(10)^{-3}\left[\frac{S^2}{D}\right] 10^{\frac{F}{10}}$$

where

S is the separation in feet

D is the hop length in kilometers

F is the fade margin in dB

As an example, assume S = 25 feet, D = 35 kilometers, and F = 30 dB, then:

$$I = 1.3(10)^{-3} \frac{(25)^2}{35} 10^{3.0} = 23.2$$

This means that for the above example, the per-channel outage, T_o, with space diversity is given by:

$$T_o = \frac{\text{Nondiversity Outage}}{23.2} \text{(min/yr)}$$

A nomogram contained in Section 940-310-115 provides a convenient means for determination of the improvement factor, I.

7.08 The above calculation used a fade margin of 30 dB, which is applicable to an SPF or DPF digital system. The improvement factor of 23 is very much less than the improvement obtained with a higher fade margin of, say, 40 dB, which would be 232, but is still large enough to keep the multipath outage time usually well below rain outage time.

7.09 The point at which a space diversity switch should operate is slightly above the receiver fade margin. The SPF and DPF digital fade margins will be in the order of 30 dB as described in paragraph 7.03. As stated in Section 940-310-115, Issue 2, paragraph 5.06, a suitable value of the switching threshold is about 2 dB above the fade margin. This is applicable to both DPF and SPF systems. As mentioned in Section 940-310-115 (paragraph 5.01) the emphasis of that section in being primarily directed to 4- and 6-GHz systems, may require special considerations when applied elsewhere. This arises in the 11-GHz case due to rain vulnerability at this frequency. Since the rain margin is much larger than the 30-dB multipath margin, the diversity system must be inhibited from switching at the relatively low multipath level when the outage is due to rain. Not only would such switching be unnecessary, but the failure of the diversity system to find a suitable signal level would cause prolonged cycling resulting in digital error bursts in some switching systems. As suggested in Section 940-310-115, this can be counteracted through the switching logic used in such circumstances. One possible solution here would make use of logic which sensed the AGC level of all channels. A blanket fade on all channels would be due to rain and switching would be inhibited. A fade on only one channel would be considered selective and switching would be enabled.

Frequency Diversity

7.10 Frequency diversity channels can be provided to reduce outages due to multipath and equipment failure. The frequency diversity improvement for a 1×1 system in the 11-GHz band is given by:

$$I = 6.4(10)^{-4} \frac{\Delta f}{D} 10^{\frac{F}{10}}$$

where

Δf is in MHz,

D is in kilometers

F is in dB

As an example, assume a 1×1 system having 120 MHz between working and protection channels, a 40-dB fade margin, and a distance of 35 kilometers:

$$I = 6.4(10)^{-4} \frac{(120)}{35} 10^{\frac{40}{10}} = 21.9$$

For 1×N systems, an equivalent frequency separation must be defined. For channels equally spaced at X MHz:

$$\Delta f_{eq} = \frac{N}{\frac{N}{X} + \frac{N-1}{2X} + \frac{N-2}{3X} + \cdots + \frac{1}{NX}}$$

For example, a 1×3 system with X = 120 MHz, yields an equivalent separation of 83 MHz:

$$\Delta f_{eq} = \frac{3}{\frac{3}{120} + \frac{2}{240} + \frac{1}{360}} = 83 \text{ MHz}$$

Substitution of 83 MHz in the improvement formula gives:

$$I = 6.4(10)^{-4} \; \frac{83}{35} \; 10^{4.0} = 15.2$$

If the channels should be unequally spaced, Δf_{eq} is found as follows:

$$\Delta f_{eq} = \frac{N}{\frac{n_1}{x_1} + \frac{n_2}{x_2} + \frac{n_3}{x_3}, \text{ etc.}}$$

where n_1 is the number of channels separated by x_1 MHz, n_2 the number separated by x_2 MHz, etc.

Example: 1×3 system with channels spaced 80, 160 and 80 MHz

$$\Delta f_{eq} = \frac{3}{\frac{2}{80} + \frac{2}{240} + \frac{1}{160} + \frac{1}{320}} = 70.2 \text{ MHz}$$

For the usual number of hops in short-haul radio systems, a valid approximation is that the multihop system outage is equal to the sum of that calculated for each hop.

7.11 While frequency diversity can be successfully applied to analog SPF systems, its application to digital systems results in little advantage. When the fade margin is reduced to 30 dB, and applied to the 1×3 system which previously yielded an improvement of 15.2, we find that the improvement drops by an order of magnitude:

$$I = 6.4(10)^{-4} \left[\frac{\Delta f}{D}\right] 10^{\frac{F}{10}} = 1.52$$

for

F = 30 dB

Δf = 83 MHz

D = 35 kilometers

It happens that this value is outside of the range ($I \geq 10$) where the improvement formula is a good approximation. For $I < 10$, the actual improvement will be somewhat larger than given by the formula, but it is clear that a 1×3 frequency diversity system provides only a modest improvement for multipath outages. For digital systems, the combination of higher nondiversity outage and reduced effectiveness of frequency diversity will make the calculated multipath outages significant on all but short hops. Space diversity may be needed on some or all of the medium to long 11-GHz hops.

8. OUTAGE DUE TO EQUIPMENT FAILURE

A. General

8.01 Modern microwave equipment incorporating solid-state devices is characterized by high reliability. If, as will be assumed in this discussion, some form of equipment protection is afforded, either by hot standby or 1×N frequency diversity, outage time due to equipment failure will be small when compared to 11-GHz propagation outages. As will be recalled from the discussion in paragraph 5.02, enhanced reliability can be a contributing factor in the conclusion that previous fixed apportionments of total outage in terms of propagation and equipment failure are not applicable to 11 GHz. If, however, this enhanced reliability cannot be reasonably expected, the apportionment should be reconsidered.

B. Calculation

8.02 The expected value of per-channel outage time (T_E) for a protected system can be approximated by:

$$T_E = \frac{N+1}{2} (P_E)^2$$

where

N = the number of working channels

P_E = probability of outage of one channel

P_E is, in turn, determined from the expected mean time between failure (MTBF) and anticipated mean time to repair for each transmit-receive panel. If we assume that each T/R panel has a mean time between failure of five years, the expected number of channel failures = 1/MTBF or 0.2 failures per year. If the mean time to repair is four hours, the per-panel outage probability is:

$$\frac{0.2 \times 4}{24 \times 365} = 9.1 \times 10^{-5}$$

Based on the above, it can be seen that the T_E for a 1×1 hot standby system is simply $(P_E)^2$ for a single transmitter-receiver unit. For a 1×N frequency diversity system of one or more hops, N is the number of working channels and P_E is the probability of failure in one of the channels.

8.03 As an example, consider a 5-hop system (five T/R panels in a one-way channel) protected by frequency diversity. First for the determination of P_E, we will again assume a five-year MTBF and total time to repair averaging four hours. Here, the expected number of channel failures per year [= 1/MTBF × number of panels] is 5 × 0.2 = 1.0 per year. The outage probability thus becomes:

$$\frac{1.0 \text{ Failure/Yr.} \times 4 \text{ hr. time to repair}}{24 \text{ hr/day} \times 365 \text{ days/yr.}} = 4.6 \times 10^{-4}$$

A 1×3 system will have:

$$T_E = 2(P_E)^2 = 4.2 \times 10^{-7} \text{ or } 0.2 \text{ minutes/yr. (one-way)}$$

A 1×10 system will have:

$$T_E = \frac{11}{2} (P_E)^2 = 1.1 \times 10^{-6} \text{ or } 0.6 \text{ minutes/yr. (one-way)}$$

At 0.6 minutes per year, it takes 200 years to accumulate 120 minutes (2 hours). For 2-way channels:

$$\text{MTBF (2-way)} = \frac{1}{2} \left[\frac{2 \times 60}{0.6}\right] = 100 \text{ years}$$

With ten 2-way working channels, one channel in the route will have an equipment outage once in 10 years.

8.04 It is important to note that this analysis assumes that the MTBF of the protection switch is much larger than the T/R panels, and that all T/R panel equipment failures cause requests to the switching system for protection. Also, local experience should be relied upon to determine the outage time impact of craft errors.

9. SUMMATION AND CALCULATION OF OUTAGE

A. Introduction and System Description

9.01 The dominant outages for 11-GHz radio systems result from rain, multipath, and equipment failure, each of which has now been elaborated upon. It yet remains to summarize these separate outages to arrive at an overall outage figure for the particular system under examination. This final outage value is to be compared with the annual outage objective to determine its acceptability or the need for additional system improvements. In this part, a summary demonstration will be used to arrive at this final value of outage time, thus exemplifying the methodology of Parts 6, 7, and 8 through application to a representative system. Included here will be an analysis of space diversity as will be found necessary in meeting the outage objective.

9.02 The system used in this example will be the same 4-hop system described in Part 6 (see Fig. 10) in conjunction with rain outage. As may be recalled, this was a light route (2000 voice circuits) DPF system having an overall route length of 113 kilometers or 70 miles. The annual 2-way outage objective for a route of this length (as covered in paragraph 5.01) is: 70/250 × 105 min. = 29.4 minutes per year. (Using kilometers, the ratio becomes 113/402 × 105 min.) Equipment protection will be provided by frequency diversity, resulting in a 1×3 configuration for this 4-hop system. (Here, the use of frequency diversity results from the need to provide 1×N equipment protection. Since it will not be switched for multipath outage, it does not enter the selective fading calculations.)

9.03 The resultant outage time as herein calculated will be found to be as follows:

Rain Outage Time:	4 hops	24.2 min
Multipath Outage:	4 hops	3.8 min
Equipment Outage:	4 hops (1×3)	0.3 min
Total:		28.3 min

It is important to note that the outage objective as well as the calculated outage time is stated in terms of a 2-way channel. Since both multipath and equipment outages in the two directions are usually independent events, the calculated outage for a one-way channel must be doubled and then added to the rain outage. Rain outage is directly calculated as a 2-way outage. As can be seen above, the total calculated outage time of 28.3 minutes for the final adjusted system falls just within the 29.4-minute outage objectives.

9.04 In this example, the summation will be made over the four hops. This assumes that the system had no intermediate dropping points. When there are dropping points, the summation of outage times should be done separately for each pair of dropping points, and then combined to find the end-to-end total. (If channels are dropped or added along the route, the value of N as used in the calculation of equipment outage will change, resulting in T_E changes.)

B. Procedure

Rain Attenuation Margin and Outage

9.05 The determination of rain outage is dependent on the value of the hop fade margin (F) from which the rain margin (M) will be derived. In DPF systems, the fade margin (F) will be reduced by three allowances: wet radome, interference, and depolarization. The resultant rain attenuation margin in conjunction with hop length will then yield outage time when applied to the appropriate rain outage chart. To illustrate the use of equations (1) and (2) of Part 3 [as well as equation (3) of Part 6] the rain attenuation margin will be first calculated. For this, the following are given:

(a) Light route DPF system: 4 hops as in Fig. 10

(b) $G_{TA} = G_{RA} = 48.3$ dB

(c) 180 feet waveguide in each section, L_{WG} = 6.1 dB

(d) SG = 112 dB

(e) 11-GHz-only system, $L_{NW_{TOT}} = 0.5$ dB

9.06 Section loss is determined by subtracting antenna gain from total component loss:

HOP	PATH LENGTH D KM	L_{FS} DB		$L_{WG\,TOT}$ DB		$L_{NW\,TOT}$ DB		SUM OF ANT. GAINS DB		SECT LOSS SL DB
A-B	16	137.6	+	6.1	+	0.5	—	96.6	=	47.6
B-C	35	144.4		6.1		0.5		96.6		54.4
C-D	40	145.6		6.1		0.5		96.6		55.6
D-Z	22	140.4		6.1		0.5		96.6		50.4

Subtracting section loss from system gain yields the hop fade margin which is then reduced by the sum of the allowances to provide the rain attenuation margin (M):

HOP	PATH LENGTH D KM	SYS GAIN SG DB		SECT LOSS SL DB		FADE MARGIN F DB
A-B	16	112	—	47.6	=	64.4
B-C	35	112		54.4		57.6
C-D	40	112		55.6		56.4
D-Z	22	112		50.4		61.6

FADE MARGIN F DB		WET RADOME DB		C/I PENALTY DB		DEPOL DB		M DB
64.4		[4		0.4		2]		58.0
57.6	—	4	+	0.4	+	2	=	51.2
56.4		4		0.4		2		50.0
61.6		4		0.4		2		55.2

9.07 The calculated rain attenuation margins and path lengths are applied to the proper rain outage chart. The expected outage times for both horizontal and vertical polarizations are obtained as explained in paragraphs 6.07 and 6.08. Using the typical chart of Fig. 9, the results are:

HOP	RAIN OUTAGE TIME V MIN	RAIN OUTAGE TIME H MIN
A-B	—	1.0
B-C	7.6	12.3
C-D	10.5	16.0
D-Z	1.3	4.5
	19.4	33.8

The digital system is expected to grow to a 1×3 configuration on two frequencies (dual polarized). A good polarization pattern to equalize outage times is:

HOP	CH 1 POL	CH 1 OUTAGE	CH 2 POL	CH 2 OUTAGE	CH 3 POL	CH 3 OUTAGE	PROT POL	PROT OUTAGE
A-B	V	—	V	—	H	1.0	H	1.0
B-C	H	12.3	V	7.6	V	7.6	H	12.3
C-D	V	10.5	H	16.0	V	10.5	H	16.0
D-Z	V	1.3	V	1.3	H	4.5	H	4.5
Total		24.1 min		24.9 min		23.6 min		33.8 min

The average rain outage for the three working channels is 24.2 minutes.

Equipment Outage

9.08 Rain outage is directly calculated as a 2-way outage. Equipment outage, which is computed on a one-way basis, must therefore, be doubled to conform to the 2-way annual objective. We have here a 4-hop system with three working channels. If each T/R panel has a MTBF of five years, and the time to repair is four hours, we have for a one-way channel the following probability:

$$P_E = \frac{(\#\text{ of HOPS})}{\text{MTBF}} \times \frac{\text{Time to Repair}}{\text{Hours/year}}$$

$$= \frac{4.0}{5} \times \frac{4}{24 \times 365} = 3.7(10)^{-4}$$

For a 1×3 system:

$$T_E = \frac{N+1}{2}(P_E)^2 = 2\left[(3.7)(10)^{-4}\right]^2$$

$$= 2.7\,(10)^{-7} \text{ years}$$

This is equivalent to:

0.14 minutes per year (one-way)

or

0.3 minutes per year (2-way)

Multipath Outage

9.09 The nondiversity multipath outage must now be determined for each hop. As with equipment outage, the one-way value must be doubled prior to outage summation for the four hops. Since this is a digital DPF system, outage time must be determined from the curve of Fig. 11 (see paragraph 7.06) which represents the best approximation at the time of this writing.

9.10 The nondiversity, one-way multipath outage obtained from Fig. 11 is that for average terrain and climatic conditions, i.e., $c = 1.0$. For this system, average humidity will be assumed, but the four hops will have terrain roughness factors of 80, 100, 120, and 90. (See tabulation below.) The c factor for each hop is calculated as described in paragraph 7.06, and the $c = 1$ value of outage obtained from the Fig. 11 curve is multiplied by this new value to yield the adjusted one-way outage. The respective values are then doubled to 2-way outage and totaled to yield annual outage in minutes per year. The results of this computation are summarized in the following table:

HOP	D KM	W	c_n	1-WAY c = 1 MIN	2-WAY OUTAGE MIN
A-B	16	80	0.54	1.6	1.7
B-C	35	100	0.41	50.0	41.0
C-D	40	120	0.32	93.0	59.5
D-Z	22	90	0.47	6.0	5.6
				Total	107.8 min/year

Comparison With Objectives

9.11 Having now determined the 2-way annual outage resulting from rain, equipment failure, and multipath, their combined sum must be compared to the scaled outage objective for a system 113 kilometers in length. Using the conversion factor presented in paragraph 6.07 (1 mile = 1.6093 km), the standard 250 mile short-haul route length converts to 402 km. The scaled objective (see paragraph 5.01) thus becomes:

$$\frac{113}{402} \times 105 \text{ minutes} = 29.4 \text{ min/year}$$

9.12 Summing the calculated outages, we find that prior to any diversity improvement we have:

24.2 minutes (rain)
0.3 minutes (equipment)
107.8 minutes (multipath)
132.3 minutes/year

This is 102.9 minutes more than the 29.4 minute objective. The multipath outage must be reduced to 4.9 minutes to meet the objective.

Space Diversity Improvement

9.13 In Part 7 (paragraph 7.11), it was revealed that the improvement, which can be expected when frequency diversity is used in conjunction with the typical 30-dB fade margin of digital systems, is small. For this reason, space diversity will be applied toward reducing the multipath outage time to within the acceptable limit of 4.9 minutes per year. As discussed in paragraph 7.09 and as elaborated upon in Section 940-310-115, a suitable value at which to set the switching threshold is about 2 dB above the fade margin. The switching threshold will therefore be set at 28 dB. Of the four hops in the system, the two longest paths will benefit most from space diversity application; thus, hops B-C and C-D, having respective lengths of 35 and 40 kilometers, will be chosen. Since the 5.6-minute outage of hop D-Z exceeds the 4.9 minute objective, space diversity must be applied here as well. The required improvement can, however, be less than that of the longer hops, and for this reason an antenna separation of 25 feet will be attempted.

9.14 Assuming equal gain antennas, and an antenna separation of 50 feet for the two long hops, the improvement will now be calculated (see paragraphs 7.07 and 7.08) for testing against the overall outage objective. The space diversity improvement is equal to:

$$1.3 \times 10^{-3} \left[\frac{S^2}{D}\right] 10^{\frac{F}{10}}$$

For hop B-C we have:

$$I = 1.3 \times 10^{-3} \frac{(50)^2}{35} \times 10^{2.8} = 58.5$$

$$\text{B-C outage} = \frac{41}{58.5} = 0.7 \text{ minutes}$$

For hop C-D:

$$I = 1.3 \times 10^{-3} \frac{(50)^2}{40} \times 10^{2.8} = 51.2$$

$$\text{C-D outage} = \frac{59.5}{51.2} = 1.16 \text{ minutes}$$

For hop D-Z:

$$I = 1.3 \times 10^{-3} \frac{(25)^2}{22} \times 10^{2.8} = 23.26$$

$$\text{D-Z outage} = \frac{5.6}{23.26} = 0.24 \text{ minutes}$$

Summation and Final Evaluation

9.15 The new multipath outage is:

HOP	
A-B	1.7
B-C	0.7
C-D	1.16
D-Z	0.24
	3.8 minutes

Combining this new value of outage with the previously determined outages for rain and equipment failure results in a total outage from all causes of:

Rain	24.2 minutes
Equipment	0.3 minutes
Multipath	3.8 minutes
	28.3 minutes/year

The objective for this system of 29.4 minutes per year is just met.

10. INTERFERENCE CONSIDERATIONS

A. Overview and Definitions

Rationale

10.01 As noted in the introduction of this section, the determination of outage time is dependent on a knowledge of the hop fade margin. The theoretical fade margin (F) having a thermal noise criterion and predicted from equation (3) of Part 6 is unrealistic in being excessively high. To arrive at a practical and therefore valid fade margin, allowances are made as necessary to account for the deleterious effects of wet radome loss, depolarization, and the existence of interference. The wet radome and depolarization allowances were respectively quantified at 4 and, for DPF systems, 2 dB. The allocation for interference is not so easily disposed of. In this part, the rationale and procedure for determination of interference budgets will be discussed. The purpose of the interference budget is essentially the same as the previous allowances in preserving the integrity of the fade margin.

Analog and Digital Systems

10.02 The interference coordination for digital systems is quite different from that of analog systems. In analog systems, in which noise will be cumulative, the carrier-to-interference (C/I) objectives are set to limit the interference noise to a specific amount per exposure so as to provide the required noise performance under nonfaded conditions. Since in analog systems, only a small portion of the total noise originating in a hop is allocated to interference sources, the interference is always below the normal thermal and cross-modulation noise. The determination and use of analog C/I objectives is discussed in Section 940-330-104, while the C/I objectives for 11-GHz analog systems are contained in Section 940-330-140. In all cases, the most recent objectives as represented in engineering letters or as contained in the available computer program should be used.

10.03 Unlike analog systems, digital systems, which are regenerative, will have essentially error free performance during nonfaded conditions. For deep fades, however, the performance degrades rapidly as the signal-to-noise ratio nears the outage point. Hence, the design of a digital system is dominated by the error performance near and at the outage point. In contrast to analog systems, and depending on the magnitude and degree of correlation between the fading of the carrier and the interference, digital systems will frequently be designed to allow interferences during nonfaded periods to exceed the thermal noise in a hop.

The Interference Budget

10.04 To arrive at an interference budget, the possible interference must be identified as to type (source) and category, i.e., whether the interference fades with the carrier, remains fixed, or is only partially correlated with carrier fading. The interference in these three categories must be itemized, quantified, and an allowance for each assigned to an interference budget. In this part, tentative budgets will be derived for both DPF and SPF digital systems in both light and heavy route configurations. Using values believed to be typical of antenna configurations and equipment types used in 11-GHz systems, the effect on fade margins of such proposed budgets will be shown.

The C/I Ratio

10.05 Prior to any adjustment of the fade margin, it is necessary to determine the carrier-to-interference ratio. As generally defined, the C/I objective or ratio is the minimum (faded carrier) ratio of the desired carrier level to the interfering carrier level. The C/I ratio may thus be considered as the necessary isolation or separation between the two signal levels such that the interference will not excessively degrade the desired signal. As herein applied to the formulation of the actual budget (in accordance with Table J), the C/I values are not the final acceptable minimum ratios, but represent the anticipated interference levels as contributed by the specific interference types and categories. A power summation of these levels then yields a net C/I which, in representing additional noise, must be compensated.

The Fade Margin Adjustment

10.06 Knowing the resultant C/I, i.e., the separation in dB between the faded carrier and the noise arising from the combined interferences, this interference is considered as Gaussian noise added to the previously established C/N—the C/N being the required, practical carrier to thermal noise ratio corresponding to the 10^{-3} BER. Dealing now with N+I, a new C/N must be computed such that the required (increased) separation again defines the 10^{-3} BER. The increase in C/N is obtained by reduction of the fade margin, and represents the interference penalty.

B. Identification and Characteristics of Interference

Identification

10.07 The adverse affect of interference is highly dependent on the degree of correlation which can be expected between the fading of the desired carrier and the simultaneous fading (if any) of the interference. If the interference fades with the carrier, the signal-to-noise ratio will remain constant. Conversely, noise arising from fixed interference will increase dB for dB with the fade, degrading the signal-to-noise ratio. Therefore, to arrive at a meaningful interference budget, the interference must first be properly categorized. For this purpose, the interference can be divided into the three following categories:

(A) Interferences that are not correlated with the fading of the wanted signal.

(B) Interferences which are exactly correlated with the fading of the wanted signal.

(C) Interferences which are somewhat correlated with the fading of the desired signal.

Separation of all interferences into these three categories is not an easy task. In attempting this, it should first be noted that the cochannel cross-polarized signal resulting from degraded XPD, for which a stated 2-dB allowance has already been made (paragraph 6.03), will not be considered here as comprising part of the interference budget. It will, of course, be again considered in arriving at the final value of the adjusted DPF fade margin. Rain can often be the dominant 11-GHz fading mechanism. It is perhaps fortunate that interference paths during many rainstorms result in the higher correlations of categories (B) and (C). This permits relatively low nonfaded C/I ratios—in contrast to multipath where low correlations or complete independence [category (A)] can result in considerable truncation of the fade margin.

10.08 Figure 12 illustrates and lists those interferences which are of importance for 11-GHz systems. It is sufficient to limit the discussion to those correlations which can be expected during rain. Since the interferences in nonfaded hops will have a negligible effect on the BER, only the interference in faded hops need be considered.

10.09 Referring to Fig. 12, interferences (1) and (2) are both same-route interference: (1) is definitely in category (B) and (2) can be in category (A) or category (C). Foreign system interference (5), is also in categories (A) and (C). However, this source tends to be a 2-antenna coupling which implies that under worst conditions when the interference source is in front of the antenna (±90 degrees) the interference is most likely in category (C). Anticipated satellite interference (3) in the future 11.45- through 11.7-MHz downband

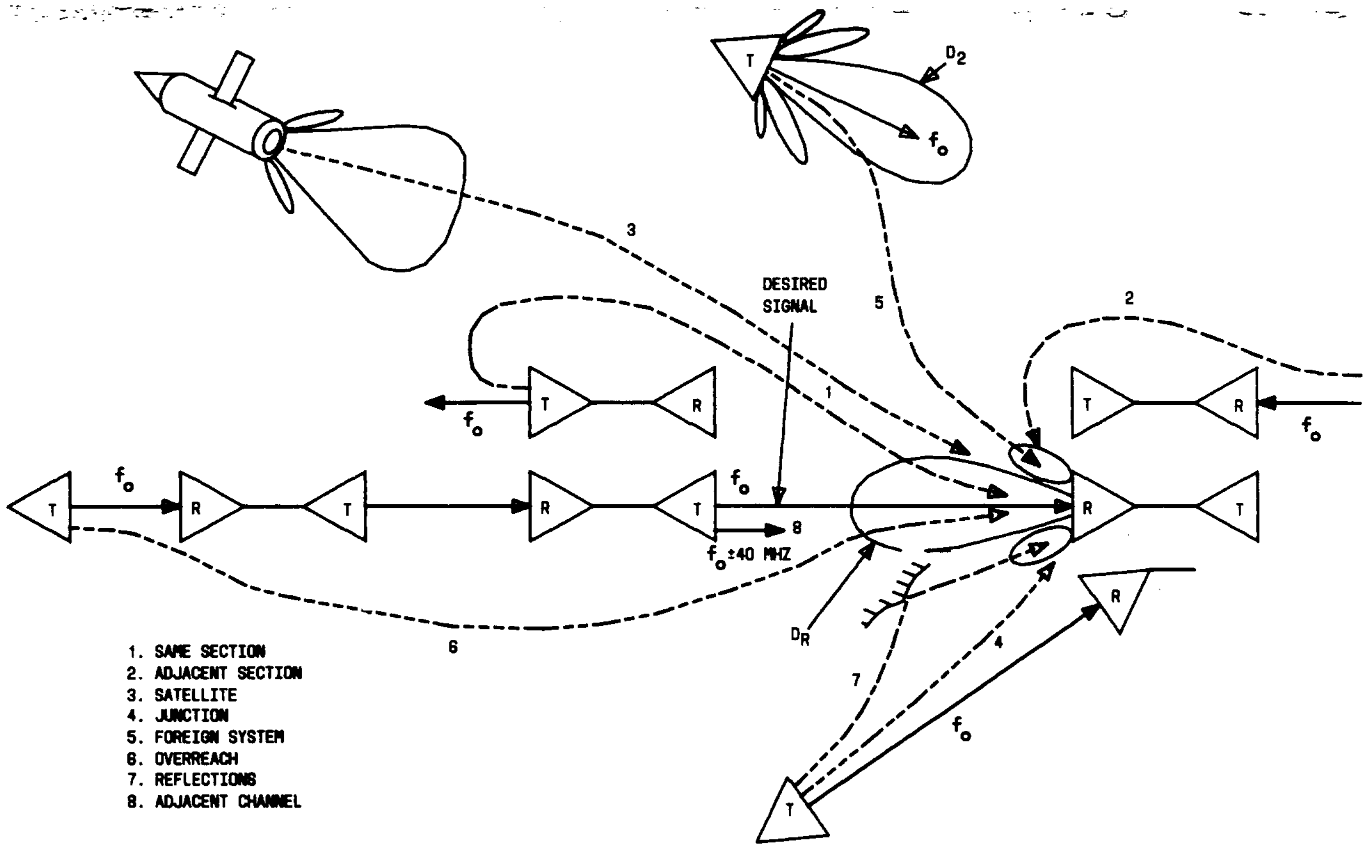


Fig. 12—Interferences in 11-GHz Radio Systems

(satellite to earth link) will tend to be closer to category (B) than to (A). Propagation tests currently in progress should add considerable information to the correlation between space and terrestrial paths. Interferences from overreach (6) and reflections (7) are in category (B) while junction sources are in category (C). Adjacent channel (8) is (B) or (C).

Characteristics and Assumptions

10.10 Before an interference budget for digital systems can be suggested, it is necessary to review certain characteristics and make additional assumptions related to system features and performance. It is known, for example, that in contrast to analog systems, the interference noise arising in a hop can, in certain instances, be allowed to exceed the nominal thermal noise. Here, the AGC action of the receiver, in attempting to restore the nominal level of a faded signal, will act differently on various interference types depending on the category of correlation. Thus, the fade depth at which the hop reaches an unacceptable BER may be equal to the nominal fade margin without interference [as can happen in categories (B) and (C), in which case interference can actually exceed the hop thermal noise]. It may also be slightly less than the nominal fade margin, or can occur at the level of a significantly reduced fade margin in the case of category (A). Regarding this from a converse perspective, insight can be obtained as to the interference objectives with respect to a nonfaded carrier: The nonfaded interference objectives are found by increasing the faded C/Is given in the interference budget by some fraction of the hop fade margin (F), which will be a variable as calculated for each hop. The nonfaded values of the interferences in category (A) will be equal to their faded carrier values plus the full fade margin (since the AGC can, under a deep fade, raise their level by this amount). The nonfaded values of the category (C) interferences will be amplified somewhat less than this amount, and the category (B) interferences will remain fixed under faded or nonfaded conditions.

10.11 There are more assumptions necessary before an interference budget can be suggested. For DPF systems, we will assume that the cochannel, cross-polarized interference will suffer depolarization during rain such that at the error threshold the isolation will be reduced from 30 dB to the range of 15 to 20 dB. The effect of the rest of the interferences we will assume to be equivalent to that of Gaussian noise.

10.12 Since we are considering both SPF and DPF systems, we will have to have two budgets to account for the differences between the systems. DPF systems have the strong cochannel interference between the two cross-polarized signals. For adjacent channels, there are two channels with no cross-polarization isolation. Filter characteristics of DPF systems supply all the adjacent frequency isolation. For SPF systems, there is no cochannel; cross-polarized signal and adjacent channels operate on opposite polarizations. Less filtering is usually provided in SPF systems.

C. Allocation of Interference

10.13 Figure 12 has illustrated the antenna patterns and paths involved in each type of interference. To arrive at an interference budget (actually two major budgets, Tables K and L, to account for the differing effects of rain and multipath), the expected levels of interference must be quantified. Table J contains the formulas serving this purpose, and takes into account the various factors such as sources of isolation, path length corrections, and transmitter power and antenna gain which influence this evaluation. The differences associated with the three interference categories (A), (B), and (C) are accommodated by means of the correlation factor "c" which, by definition, will be equivalent to 0 for category (A), 1 for category (B), and approximately 0.5 for category (C). The expression (1-c) F will thus reduce to 0 for category (B) interference, and represent the fade depth, F, for category (A). The correlation which might be expected during a rainstorm would, for example, depend on the location of the rain with respect to the desired and interfering path. When the rain is relatively close to the receiver, a correlation of 1 might be expected since both signals will be equally attenuated. On long hops, where the rain can be a greater distance away, but still attenuate the desired signal, the values of c would tend to become smaller. The expressions of Table J provide the separation (in dB) which might be expected between the faded carrier and the interference in relation to the fade depth, F, of the carrier. In arriving at the two budgets, the fade depth in the case of rain was assumed to be 50 dB, while that for multipath was assumed to be 30 dB.

10.14 As seen in Table J, many significant interferences are in category (C), partially correlated rain fading. For multipath, most are category (A), uncorrelated, except for the far-end adjacent channel interference. 11-GHz channels separated by only 40 MHz have a high degree of common fading, particularly at low to moderate fade depths (see discussion in paragraph 7.10 for a numerical example). Thus, the term XPD(F) in the expression for far-end adjacent channel interference in a SPF system has a wide statistical variation. With rain, the adjacent channel SPF XPD will degrade just as the DPF cochannel XPD degrades. With multipath, as pointed out in paragraph 4.03, XPD values may go to zero for moderate fades. When adjacent channels fade together, the resulting adjacent channel interference may thus rise sharply in a SPF system.

D. Interference Budgets

10.15 11-GHz digital systems may be used in two distinctly different environments. One is to provide short-haul toll facilities between small and medium size cities. The other is to provide trunks in and around relatively large metropolitan areas. A light route budget is suggested for many systems of the first type, while a heavy route, including additional interference sources is suggested for the second. The omitted light route interferences are junction and far-end adjacent channel. On a light route system, neither interference will be present until the route grows beyond the capacity of one antenna. (See Table E - Growth Plan for Digital Systems and paragraph 2.06.)

10.16 The choice of which budget to apply must be made when the route is first engineered. The governing criteria, however, are the conditions expected to exist over the life of the system. Many of the interference sources listed above may appear to be absent on the initial route layout. Future extensions and new dropping points must be

TABLE J

INTERFERENCE EXPRESSIONS

TYPE OF INTERFERENCE	C/I DURING FADE	FADING CATEGORY RAIN	FADING CATEGORY MULTIPATH
Cochannel			
1. Same Section	$R_{fb}-(1\text{-}c)F$	B	A
2. Adjacent	$R_{fb}+D_{cor}-(1\text{-}c)F$	C	A
3. Satellite	$D_r-(1\text{-}c)F+P_{cor}$	B	A
4. Junction	$D_r+D_{cor}-(1\text{-}c)F+P_{cor}$	C	A
5. Foreign System	$D_r+D_2+D_{cor}-(1\text{-}c)F+P_{cor}$	C	A
6. Overreach	$D_{ov}+D_{cor}-(1\text{-}c)F$	B	A
7. Reflections	$D_r+D_{cor}-(1\text{-}c)F$	C	A
Adjacent Channel (± 40 MHz—two interferers)			
8a. DPF	$L_f-(1\text{-}c)F$	B	B or C
8b. SPF	$L_f-(1\text{-}c)F+XPD(F)$	B	B or C

Definitions of terms (see also Fig. 12)

c = Fade correlation function. By definition, c=0 for category A and c=1 for category B. Correlation of category C interferences vary, being generally close to 0.5.

R_{fb} = Front-to-back ratio of one antenna

F = Fade depth. To include the 4-dB wet radome loss for rain, replace (1-c)F by (1-c)F-4.

D_{cor} = Path length correction = $20 \log \dfrac{D_{interference}}{D_{wanted}}$

D_r = Discrimination receiving antenna to off-axis signals (azimuth or elevation)

P_{cor} = Power correction = $10 \log \dfrac{\text{Signal } P_T G_T}{\text{Interference } P_T G_T}$

= complex factor for satellites

D_2 = Discrimination of transmitting antenna (off-axis)

D_{ov} = Combined discrimination of transmitting and receiving antennas involved in overreach path

L_f = Filter discrimination to ***two*** adjacent channels

XPD(F) = XPD variation as function of fade depth, F.

TABLE K

INTERFERENCE BUDGET[1]—RAIN FADING—50-dB FADE

TYPE OF INTERFERENCE		LIGHT ROUTE SYSTEMS FADED C/I dB	HEAVY ROUTES FADED C/I dB
Cochannel			
1. Same Section		60 (1×10^{-6})	60
2. Adjacent Section		30 (1×10^{-3})	30
3. Satellite		40 (1×10^{-4})	40
4. Junctions		—	25
5. Foreign Systems (two exposures)		30 (1×10^{-3})	30
6. Overreach		45 (3.1×10^{-5})	45
7. Reflections		45 (3.1×10^{-5})	45
Adjacent Channel			
8. Far-End DPF		None[3]	35[2]
SPF		—	40[2]
	Total C/I	26.6 dB	22.5 dB DPF
			22.7 dB SPF

Note 1: The interference may be a DPF digital, a SPF digital or an analog channel.

Note 2. These values may vary with equipment from different manufacturers. The C/I shown assumes 15-dB XPD plus 25-dB filtering for SPF and 35-dB filtering for DPF. One SPF system is known to have about 15 dB of adjacent channel filter rejection.

Note 3: Adjacent Channel Interference at junctions of spur routes will have large C/Is.

TABLE L

INTERFERENCE BUDGET[1]—30-dB MULTIPATH—FADE

	LIGHT ROUTE SYSTEMS FADED C/I dB	HEAVY ROUTE SYSTEMS FADED C/I dB
Cochannel		
1. Same Section	35	35
2. Adjacent Section	35	35
3. Satellite	30	30
4. Junctions	—	25
5. Foreign Systems (two exposures)	30	30
6. Overreach	30	30
7. Reflections	30	30
Adjacent Channel		
8. Far-End DPF	—	35[2]
SPF	—	35[2]
Total C/I	23.4 dB	20.9 dB

Note 1: The interference may be a DPF digital, a SPF digital or an analog channel.

Note 2: These values may vary with equipment from different manufacturers. For DPF systems, 35-dB filtering is assumed. For SPF systems, 25-dB filtering plus XPD(F) = 10 dB at a 30-dB fade is assumed. One SPF system is known to have about 15 dB of adjacent channel filter rejection.

considered. The possibility of future foreign systems cannot be ruled out. The satellite allocation must be considered even though no satellites are currently operating with 11-GHz downlinks, since 11.45 to 11.7 GHz is an authorized satellite band. The one clear criterion is the planned ultimate development of the particular route. If the route will not grow beyond one antenna (5 or 6 frequencies in use with 1200 to 1344 VF per working frequency), light route conditions probably apply. If that condition is not met, the higher interference of the heavy route case should be used in computing fade margins. A specific multihop route may have some hops, light route; and one or more hops, heavy route. This situation might arise near a major city which is the hub of several light routes.

10.17 The proposed interference budgets for both SPF and DPF systems are shown in Tables K and L. Table K applies to rain fading and is based on a 50-dB fade depth, while Table L is appropriate to multipath and assumes a 30-dB fade. It should be noted that for light routes, the SPF and DPF budgets are identical. The values appearing in the budgets are in accordance with Table J, and represent the anticipated interference levels below the faded carrier. The total C/I represents the sum of the specific power ratios which, for the purpose of illustration, have been included with the Table K light route budget. The sum in this case equals 2.16×10^{-3}, and the net C/I is determined by:

$$10 \log \frac{1}{2.16 \times 10^{-3}} = 26.6 \text{ dB}$$

E. Fade Margin Adjustments

C/N Assessment and Preliminary Rain Margin

10.18 To assess the effect of interference on fade margins, assumptions must be made about the performance of typical SPF and DPF digital systems. Prior to any modification of the fade margin, it is first necessary to know the level of isolation corresponding to the 10^{-3} BER error threshold between the faded carrier and any noise. Although theoretical curves are available showing C/N and C/I pairs corresponding to a 10^{-3} BER, significant deviations from the theoretical are found in practical, well designed systems. On the basis of thermal noise, the following final values of 16 dB (DPF) and 20.5 dB (SPF) C/N separation will be used as representative of good practice:

CONDITION FOR 10^{-3} B.E.R.		DPF SYSTEM	SPF SYSTEM
C/N Theoretical	Without Interference	10.5 dB	15.5 dB
C/N Practical		14 dB	20.5 dB
C/N w/15 dB Cochannel XPD		16 dB	not applicable

In either system type, the nonfaded C/N obtained on a typical hop might be as much as 70 dB. Thus, in interference free circumstances, one would estimate the DPF system to have a fade margin of 70 - 14 = 56 dB. In heavy rain, however, the XPD can degrade to 15 dB, thus reducing the fade margin by 2 dB. This is the 2-dB depolarization allowance described in paragraph 6.03 and acknowledged again, here, in paragraph 10.07. This additional 2 dB increases the 14-dB practical C/N above to 16 dB. Thus, our fade margin now becomes 70 - 16 = 54 dB. The allowance of 4 dB for wet radome losses further reduces this margin resulting in a DPF rain margin M, of 70 - 16 - 4 = 50 dB, which is the rain margin prior to the reduction for the interference penalty.

10.19 The SPF system modeled above would have an interference free margin of 70 - 20.5 = 49.5 dB. With the radome allowance, M = 49.5 - 4 = 45.5 dB.

Radome Losses

10.20 Radome losses can occur at either the transmitter or receiver, or at both. When treating interferences in the rain limited case, it is somewhat pessimistic, therefore, to assume carrier radome loss while ignoring a corresponding loss to the interferences. We shall adopt this approach in the following section.

The Interference Penalty and Final Rain Margin

10.21 The C/N separation without interference which corresponds to the 10^{-3} BER was specified in paragraph 10.18 as 16 dB for DPF systems and 20.5 dB for SPF systems. In the interference budgets, a total C/I was determined representing an equivalent level of noise separated from the faded carrier by the amount of this net

C/I. We have, in addition to other rain allowances, already reduced the fade margin by the required 16 dB (DPF), and 20.5 dB (SPF) amounts. Since the net C/Is contributed by interference will represent additional noise added to the previous C/Ns, the new C/N+I values will now exceed the 10^{-3} BER by the amount of noise contributed as interference. To restore the fade margin to the condition where C/N again represents the 10^{-3} BER, we must perform an additional reduction by the amount of noise now contributed by interference. Thus, to determine the effect on the fade margin of all the interference allowed for in the interference budget, we compute a new C/N such that C/N+I (where N and I are power summed) corresponds to the 10^{-3} BER. The increase over the previous C/N is then the interference penalty. Pursuing this for both heavy and light routes for both SPF and DPF systems, yields the following representative results for rain fades:

SYSTEM	ROUTE TYPE	INTERFERENCE BUDGET C/I dB	C/N dB	C/N+I dB	PENALTY dB	M w/o I dB	M w/I dB
SPF	Light	26.6	20.5	21.7	1.2	45.5	44.3
	Heavy	22.7	20.5	24.6	4.1	45.5	41.4
DPF	Light	26.6	16.0	16.4	0.4	50.0	49.6
	Heavy	22.5	16.0	17.1	1.1	50.0	48.9

Using the SPF light route as an example, the new C/N (actually the C/N+I) of 21.7 dB is found by subtracting the power ratio of 26.6 dB from the ratio of 20.5 dB to yield the complement which when added to 26.6 dB will again result in the 10^{-3} BER.

$$\begin{array}{rl} & 0.00892\ (20.5\text{ dB}) \\ - & \underline{0.00216}\ (26.6\text{ dB}) \\ & 0.00676 \end{array}$$

$$10 \log \frac{1}{6.76 \times 10^{-3}} = 21.7\text{ dB}$$

The difference between 20.5 dB and 21.7 dB yields the interference penalty of 1.2 dB, which is the amount by which the preliminary rain margin (45.5 dB) must be reduced to yield the final M of 44.3 dB.

10.22 As seen above, the reduction of the fade margin for the DPF light route system is negligible; that for the DPF heavy route is a modest 1.1 dB. The SPF heavy route penalty calculated above is, however, sufficiently large to require a more detailed analysis. We know that the interference budget for rain assumed a fade depth of approximately 50 dB, and was derived from the relationships of Table J. The actual value of the correlation factor (c) for the category (C) interferences of Table J, was 0.46. This means that each dB less fade will increase the faded C/I for category (C) interferences by 0.54 dB. Applying this correction we have the following improved results for SPF systems:

SYSTEM	ROUTE TYPE	INTERFERENCE C/I dB	C/N dB	C/N+I dB	PENALTY dB	M w/o I dB	M w/I dB
SPF	Light	29.3	20.5	21.1	0.6	45.5	44.9
	Heavy	25.9	20.5	22.0	1.5	45.5	44.0

10.23 In arriving at the above, an iterative process is used: The rain margin without interference is 45.5 dB, which already differs from 50 dB by 4.5 dB. When the further reduction for the interference penalty is included, 45.5 will be reduced again to some smaller number. This final, smaller number will then represent the amount by which the actual rain margin differs from the initial 50-dB fade depth. For the sake of illustration and simplicity, take the SPF light route case above, and assume that a value of 44.9 dB (which happens to be correct) was chosen as a first logical possibility for the final M. This now represents a 5.1-dB difference from the original 50 dB. Since for category (B) the expression (1-c)F reduces to zero, only the category (C) interferences in the budget will be impacted by this change. In the SPF light route budget, there are three such interferences: adjacent section, foreign systems, and reflections. Increasing the C/Is for these three items by 0.54 × 5.1 or 2.75 dB each, a new power summation yields a net C/I of 29.3. Solving for the interference penalty as before, we obtain a value of 0.6 dB, which when subtracted from 45.5 yields 44.9 dB, indicating that this first assumption was correct.

Fade Margin Adjustment for Multipath

10.24 The fade margins for both SPF and DPF digital systems are limited to 30 dB. As will be shown by subsequent calculation, a 30-dB fade margin already falls below the level which would require additional reduction. In the DPF case, the isolation between a 30-dB faded carrier and the N+I will be about 5 dB greater than the required C/N of 16 dB specified in paragraph 10.18. Thus, there is no additional interference penalty required for DPF. In the SPF case, however, the C/N+I (particularly in the heavy route case) is sufficiently close to the required C/N of 20.5 dB that some question remains regarding its adequacy. As opposed to the established DPF fade margin of 30 dB, the need to also reduce the SPF digital fade margin to 30 dB as a result of unforeseen multipath distortion has become known only recently—at the approximate time of this writing. Therefore, the combined effects of multipath-related distortion together with interference might be found to cause signal degradation at fade margins which only slightly exceed interference requirements. Pending additional experience, the conclusion of SPF fade margin adequacy should be considered with some reservation.

10.25 The interference budget for multipath is contained in Table L. Here, both SPF and DPF systems are interference limited rather than thermal noise limited, i.e., the fade margin is almost entirely determined by the interference. At the critical point where the error rate goes to 10^{-3}, the thermal noise which, as stated in paragraph 10.18 can be 70 dB below the level of the nonfaded carrier, will be almost 20 dB below the interference. Since the Table L budget is dominated by category (A) interferences, the C/Is will change dB for dB with increasing multipath fades.

10.26 The following computation serves to illustrate the relationship of the multipath interference budget to a 30-dB fade margin:

SYSTEM	ROUTE TYPE	INTERFERENCE BUDGET 30 DB FADE C/I dB	C/N 30 DB FADE dB	C/(N+I) 30 DB FADE dB	REQUIRED C/N dB	ADDED FADE >30DB dB	MULTIPATH FADE MARGIN dB
SPF	Light	23.4	40	23.3	20.5	2.8	32.8
	Heavy	20.9	40	20.8	20.5	0.3	30.3

Again, taking the SPF light route as an example, the net C/I from Table L is 23.4 dB. If the thermal noise is at -70 dB, the C/N during a 30-dB fade will be 40 dB as recorded above. Power summing 23.4 and 40 results in a C/N+I of 23.3 dB, which is 2.8 dB greater than the required, practical C/N of 20.5 dB. Were it not for the fact that the fade margin is restricted to 30 dB, this 2.8-dB surplus could be added to the fade margin, increasing its level to 32.8 dB as shown here for illustration only. In the same manner, SPF heavy route calculations provide only a fractional surplus of 0.3 dB which, as previously noted, should be accepted as adequate with reservation. In the DPF case, the required C/N (paragraph 10.18) is reduced from the 20.5-dB SPF value to 16 dB. This allows ample separation between a 30-dB faded carrier and the level of the N+I.

F. Digital Into Analog Interference

10.27 The coexistence of digital and analog systems is possible. However, the interference from a digital system into an analog system is usually somewhat higher than that from other analog systems. The interference into an analog system is dependent on the exact characteristics of the digital system. In Table M, an attempt is made, however, to give one set of interference objectives which are typical of the necessary isolation from all 11-GHz digital systems. Since this table was calculated to reflect all digital systems, it is somewhat generalized, but still reasonably accurate (to within about 2 dB). Software is available to compute more accurate numbers from the spectral densities of specific digital systems should more detailed coordination be desired.

TABLE M

DIGITAL INTO ANALOG INTERFERENCE

11-GHz ANALOG SYSTEM	REQUIRED NONFADED C/I (dB) COCHANNEL	20-MHz SEPARATION	40-MHz SEPARATION
TL-2 (L600)	67	47	20
TL-2 (U600)	68	48	20
TL-2 (1200)	77	58	22
TN-1 (1200)	62	64	20
TN-1 (1800)	66	70	30
TN-1 (2400)	67	74	44

11. TRADEOFFS AND ANCILLARY TOPICS

A. Antenna Tradeoffs

11.01 The fade margin for an 11-GHz radio hop is defined by the equation [see Part 3 and equations (1), (2), and (3)]:

$$F = SG - SL = SG + G_{TA} + G_{RA} - L_{FS} - L_{WG_{TOT}} - L_{NW_{TOT}}$$

where LFS is the unfaded path loss for the hop length. Given a radio terminal pair of a particular type, the system gain SG is fixed, while the remaining parameters G_{TA}, G_{RA}, L_{WG}, L_{NW} depend on the specific antenna and antenna feed network chosen for the radio station. Tradeoffs between the several antenna system parameters provides for economy and flexibility in selecting components to achieve a given fade margin. On short hops, smaller antennas may provide adequate margin. Alternately, larger antennas may be used to avoid the expensive (but low loss) circular guide for long waveguide runs to provide the same margin.

B. Received Signal Power Limitations

11.02 Through adjustments of antenna system parameters [see equation (1)], or by shortening the hop length, the fade margin can be increased by raising the unfaded received signal power above the nominal received level. A limit on this procedure is imposed by system specifications for the overload limit on received signal power, i.e., the maximum received signal power level above which distortion effects occur. The possible effect of up-fades should also be considered in the overload limit.

C. Use of Passive Repeaters

General

11.03 Use of passive repeaters in microwave radio systems in the United States is limited, but in instances where terrain problems or the remoteness of the site poses economic or engineering obstacles to use of a conventional repeater station, reflectors are used. In general, the high sidelobes of the reflector radiation pattern make it undesirable for use in congested microwave areas because of the potential for interference problems. Partly because of this infrequent use, not much detailed information is available on electromagnetic radiation properties of passive repeaters for use in microwave radio relay systems.

Use With Space Diversity

11.04 A passive repeater not only changes the direction of propagation of a reflected wave, but acts as an antenna and contributes a gain product arising from the receive and transmit response patterns of the reflector. A reflector with large vertical aperture (large height) creates a response pattern with a very narrow bandwidth in the vertical plane. (Beam-width is inversely proportional to aperture size in the plane in which the beam angle is measured.) If this beam is too narrow, service outages can occur through loss of signal power resulting from "beam wander", i.e., refractive bending effects which cause the beam center to be displaced from what is the nominal beam-center direction. This effect can occur for either the receive or transmit response pattern of the reflector. This phenomena is not an amplitude fade in the usual sense of this term, and space diversity techniques are not applicable, i.e., multipath fading statistics cannot be used to compute outage time reduction with space diversity antenna configurations. To minimize the effect of "beam wander" on radio system outage time, the vertical height of a passive reflector in the 11-GHz band should be limited according to the relation:

$$A \leq \frac{660}{D}$$

where

A = aperture height in feet

D = path length in kilometers

Space and frequency diversity protection switching systems can be applied to hops using passive repeaters. In the typical case where the passive is relatively near one end of the hop, fading will be of concern only on the longer path from the passive to the far-end repeater. A discussion of passive repeaters used in conjunction with space diversity is contained in Section 940-310-115.

Cross-Polarization Effects

11.05 At 11 GHz, the surface tolerance limit available on passive reflectors appears adequate to prevent XPD degradation from surface irregularities. Since the orthogonality of the linear polarized axes are maintained on reflection, shifts in the transmitting and/or receiving antenna or antenna feed orientation can be used to minimize any remaining misalignment.

D. Omission of Radomes

11.06 For most regions of the United States, radomes should always be provided. For drier climates and shorter hops, omission of the radome may be considered. This can be done when the route has a calculated rain outage (with radomes) which results in a total outage time well below the prorated outage objective. Omission of the radome will result in a substantial increase in rain outage time.