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Broadcasting Satellites at 12 GHz for Region 2—Technical Characteristics

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ABS: Technical parameters such as satellite antenna characteristics, Earth station requirements, bandwidths, channelization, and allowable carrier-to-interference ratios are discussed. An overview of the downlink plan is given, including a histogram of the transmitter power requirements. The plan includes satellite orbit positions, spacecraft transmitted powers, antennas beam sizes, channel assignments, and polarizations.

BROADCASTING SATELLITES AT 12 GHz FOR REGION 2 - TECHNICAL CHARACTERISTICS*

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E-1834

SUMMARY

In June and July of 1983, delegates from International Telecommunications Union Region 2 (the Western Hemisphere) met at the Regional Administrative Radio Conference (RARC) to plan broadcasting satellites at 12 GHz and the associated feederlinks at 17 GHz. This paper presents the technical characteristics of those formal plans. The applicable technical parameters, such as, satellite antenna characteristics, earth station requirements, bandwidths, channelization, and allowable carrier-to-interference ratios are discussed, and insights are given into the rationale for the decisions made at the RARC. An overview of the downlink plan is given, including a histogram of the transmitter power requirements. For the seventy-plus service areas in Region 2 the plan includes satellite orbit positions, spacecraft transmitted powers, antenna beam sizes, channel assignments, and polarizations.

INTRODUCTION

The downlink and feederlink plans developed at the RARC-83 required agreement on a set of technical characteristics to serve as the basis for planning. More than 160 delegates, and advisors, representing 24 administrations, considered, discussed, and evaluated competing technical proposals. Different administrations had different points of view on, for example, power flux density levels, antenna sizes, and allowable interference levels. These differing viewpoints had been brought about by differing assumptions concerning implementation approaches, market size, and schedule for implementation. So there was room for technical discussion and compromise. Of course, political overtones were also present at the Conference, and not every decision reached was based solely on technical issues.

This paper presents the results of those decisions, and gives the technical characteristics of the broadcasting satellite plans at 12 GHz (downlink) and 17 GHz (feederlink) for ITU Region 2. In the concluding section of the paper, a brief overview of the downlink plan is given.

TECHNICAL CHARACTERISTICS OF THE DOWNLINK PLAN AT 12 GHz

The technical agreements reached at RARC-83 are summarized in table I for the downlink. Full details are contained in the Final Acts of the Conference (ref. 1).

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*Portions of this report have been included in "Technical Characteristics of the Broadcasting Satellite Plan at 12 GHz for the Western Hemisphere" by Edward F. Miller presented at IEEE's GLOBECOM '83, San Diego, California, November 29-December 1, 1983.

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System Characteristics

The Conference decided quite early that the frequency band 12.1 to 12.3 GHz would be evenly apportioned between the broadcasting satellite service (BSS) and the fixed satellite service. The BSS band, 12.2 to 12.7 GHz, was divided into 32 channels, with 14.58 MHz spacing, principally to provide a sufficiently low adjacent channel protection ratio which allowed closer satellite spacings. Note that with a 24 MHz bandwidth and only 14.58 MHz channel spacing, adjacent channels have overlapping spectrums. This requires that adjacent channels directed to the same service area from closely spaced orbital positions must have opposite senses of polarization.

The Region 2 plan was based upon frequency-modulated composite-coded color television signals with two sound subcarriers. The use of other formats such as, high definition television, and digitally coded sound signals, was not precluded. Values of the important technical characteristics were chosen to take into consideration the implementation of these new formats within the provisions of the plan.

In the plan, no distinction was made between technical characteristics for individual and community reception. The plan was designed to provide for individual (direct-to-the-home) reception.

The decision on received power flux density level, -107 dB (W/m^2), was the subject of considerable discussion. Proposed values ranged from -105 to -109. The lesser values required less spacecraft transmitter power but increased home receiver performance, for a given signal quality. The greater values required greater spacecraft transmitter power and a lower home receiver performance. The Conference decisions on power flux density, carrier-to-noise ratio (C/N) and G/T are a compromise among the different viewpoints expressed at the Conference.

The protection ratio template (fig. 1) is a symmetric template. Measurements of protection ratios using conventional television formats showed asymmetries which were initially thought to be useful in achieving a greater orbit/spectrum capacity in the plan. However, it was realized that measured protection ratios for new television formats might not have the same asymmetric properties. Thus, to be conservative, the protection ratio template was made symmetric, with the higher values chosen.

The co-channel and adjacent channel protection ratios selected, combined with the overall system noise performance (about 46 dB weighted signal-to-noise ratio at the receiver output) produce systems which are noise limited rather than interference limited. Thus, those who would desire increased signal quality could improve their receiving system performance, e.g., increased antenna size or lower noise temperature, to achieve higher signal quality. This feature of the plan also provides latitude for accommodating new television formats.

The protection ratio values are required to be met for 99 percent of the worst month at beam edge. The protection ratio values used are based upon a signal impairment rating of better than 4.0 on a five point impairment scale. For nonrain conditions, and for receivers located away from beam edge, both the C/N and the C/I (carrier-to-interference ratio) would be improved and a subjectively higher impairment grade would result.

Satellite Characteristics

Satellite positions were established by the downlink plan. General requirements were: (1) acceptable C/I, (2) satellite eclipse 1:00 a.m. local time or later, and (3) elevation angle (to the satellite from receivers in the service area) greater than 20°.

Direct broadcast satellites are planned to transmit circularly polarized signals from antennas having circular or elliptical beams with half-power beam-widths of no less than 0.8°. Two options existed for satellite transmit antenna reference patterns (figs. 2 and 3). Most satellite antennas in the plan conform to figure 2. In several cases, the characteristics of figure 3 were required to solve particularly difficult sharing problems.

Propagation

Several inputs to the Conference indicated that the propagation model listed in the Conference Preparatory Meeting Report (ref. 2) resulted in estimates of rain attenuation that were too high. Consequently, the Conference decided to use, for planning purposes, the adjusted model in table II, with rain attenuation values reduced 12 percent from those given by the model in reference 2. The plan was based on applying the propagation model for 99 percent of the worst month. Figure 5 shows rain attenuation values exceeded for one percent of the worst month for several of the rain climatic zones shown in figure 4. The maximum rain attenuation value of 9 dB was used for satellite power calculations only. In calculations of C/I, both the desired and interfering signals experienced the full fade and depolarization as predicted by the propagation model.

Receive Station Characteristics

Receiving earth station antennas were planned for 1.7° half-power beamwidth (approx 1 m diam). The antenna reference pattern is given in figure 6. Conference input papers described offset-fed parabolic antennas with greater rejection to unwanted, off-axis signals. However, the Conference again took a conservative course and decided upon performance obtainable from more conventional techniques.

TECHNICAL CHARACTERISTICS OF THE FEEDERLINK PLAN AT 17 GHz

The agenda of the RARC-83 included the planning of feederlinks in the frequency range 17.3 to 18.1 GHz. The technical agreements reached at the Conference are summarized in table III, for the feederlinks. Reference 1 gives complete details.

System Characteristics

A simple frequency translation of 5.1 GHz was set between the feederlink frequency band and the downlink frequency band. Consequently, the frequencies from 17.8 to 18.1 GHz, although allocated for BSS feederlinks, were not needed for the Region 2 plan.

The feederlink carrier-to-noise ratio was set to provide a degradation (as a guideline) of no more than 0.5 dB to the downlink C/N. However, the C/N was required to meet only the overall performance specification of 14 dB, which included both downlink and feederlink contributions. The feederlink cochannel protection ratio was treated in the same way. This approach gave flexibility to the plan development, i.e., in situations where the downlink greatly exceeded the requirement, the feederlink was allowed to make a greater contribution to the system degradation.

Because of the narrow beamwidth and rapid off-axis gain fall-off of the earth station transmit antenna, adjacent channel interference was kept to acceptably low values by providing the 0.4° orbital spacing as indicated in table III. The second adjacent channel protection ratio for the feederlink was set to -19.9 dB because of an anticipated 10 dB better filtering in the spacecraft receiver than in the terrestrial, direct broadcast satellite receiver.

Feederlink Transmitter Characteristics

For planning purposes, all feederlink transmitters were assumed to have 1000 W delivered to 5 m diameter antennas, which resulted in 87.4 dBW EIRP. Deviations from these values are permitted under conditions given in reference 1.

Propagation

The propagation model used for the feederlinks at 17 GHz is the same as used for the downlinks at 12 GHz, except with adjustments made to compensate for the frequency difference (see table III, and then ref. 1 for full details). Figure 8 shows rain attenutation values exceeded for one percent of the worst month for several of the rain climatic zones shown in figure 4. For the feederlinks, the maximum rain attenuation of 13 dB and the depolarization given by the model were used for the desired signal only. All interferers were assumed to operate in clear weather.

Satellite Characteristics

The satellite receive systems used for planning purposes had circularly polarized antennas with 0.6° minimum half-power beamwidth. It was assumed that the satellite receive antenna and the satellite transmit antenna might, in many cases, use the same reflector. As for the downlinks, two options were provided for satellite antenna reference patterns. Most satellite receive antennas in the plan conform to figure 9. The characteristics of figure 10 were available to solve particularly difficult feederlink sharing problems.

DOWNLINK PLAN OVERVIEW

The downlink plan developed at RARC-83 provides nearly full satisfaction of the broadcasting satellite channel requirements as submitted by the administrations in Region 2. Additionally, provisions were made for a minimum of four channels for those administrations that did not submit requirements. Compromises were required on the desired orbital positions, the minimum elevation angle, the time of the earliest onset of eclipse, and on meeting the agreed upon protection ratios.

In the downlink plan, forty-eight nominal orbit positions are used ranging from 31° west for service to Bermuda and the Falklands to 175° west for service to Alaska, Hawaii, and the Pacific time zone of the United States. Most of the orbital positions are concentrated between 69° and 110° west longitude. The orbital positions assigned to North America by the Region 2 plan are given in table IV. The United States has eight orbital positions with full spectrum use at each, Canada has six, and Mexico has three with full spectrum use and one with sixteen channels. Satellites serving adjacent service areas are separated by a minimum of 9°, longitude.

The satellite antenna beamwidths in the plan range from the minimum of 0.8° to 5.7° (for coverage of the eastern half of the United States). Most satellite antenna beamwidths are in the range of 1° to 4°.

There are 2114 satellite transponders in the downlink plan. Under the assumption of 1.5 dB loss from the spacecraft transmitter to the antenna input port, the distribution of RF power required for transmitters is as shown in figure 11. More than 75 percent of the amplifiers required are greater than 100 W, and more than 50 percent of the amplifiers are greater than 200 W in output power. Based upon the RARC-83 downlink plan, high power in space has a promising future.

REFERENCES

1. Final Acts of the Regional Administrative Conference for the Planning of the Broadcasting-Satellite Service in Region 2 (SAT-83). International Telecommunications Union, 1983.

2. Technical Bases for the Regional Administrative Radio Conference 1983 for the Planning of the Broadcasting-Satellite Service in Region 2, Report of the CCIR Conference Preparatory Meeting, Joint Meeting, Study Groups 4,5,9,10 and 11, Geneva, 28 June - 9 July 1982. International Telecommunications Union, 1982.

TABLE I. - TECHNICAL CHARACTERISTICS OF THE PLAN FOR THE BROADCASTING SATELLITE SERVICE AT 12 GHz IN REGION 2

TECHNICAL PARAMETER	RARC '83 PLAN VALUE
System Characteristics:	
Type of Modulation	Frequency modulation, composite-coded color video, with 2 audio subcarriers
Frequency Band	12.2 to 12.7 GHz
Number of Channels	32
Necessary Bandwidth	24 MHz
Channel Spacing	14.58 MHz
Guard Bands	24 MHz (total)
Lower Band Edge	12 MHz
Upper Band Edge	12 MHz
Carrier to Noise Ratio (99 percent of worst month)	14 dB overall
Power Flux Density (Edge of coverage area, for 99 percent of worst month)	-107 dB(W/m^2)
Protection Ratio (Required overall carrier-to-interference ratio for 99 percent of worst month)	See figure 1
Co-Channel	28 dB
Adjacent Channel	13.6 dB
Second Adjacent Channel	-9.9 dB
Use of Energy Dispersal	Not required unless necessary for sharing between services For PFD ≥ -138 dB(W/m^2/24 MHz), dispersal required to reduce emissions to 12 dB below unmodulated carrier power in any 40 kHz band For PFD < -138 dB (W/m^2/24 MHz), dispersal required to provide PFD ≤ -150 dB (W/m^2/40 kHz)
Satellite Characteristics:	
Satellite Orbital Position	Established by plan
Earliest Onset of Solar Eclipse	Guideline: 1:00 a.m. local time
Transponder RF Power (Delivered to antenna input)	Calculated from other characteristics
EIRP Difference Between Beam Axis and Edge-of-Coverage	3 dB (nominal)
Variation of Output Power in Satellite Transmitter	≤ 0.25 dB increase during satellite lifetime
Minimum Half-Power Beamwidth of Satellite Transmitting Antenna	0.8°
Cross-Section of Transmitted Beam	Circular or elliptical
Polarization	Circular
Transmitting Antenna Reference Pattern	Figures 2 and 3
Transmitting Antenna Efficiency	55 percent
Pointing Accuracy of Satellite Antenna	± 0.1° from beam axis ± 1° rotation about beam axis
Satellite Station-Keeping	± 0.1° E-W No restrictions N-S

Propagation:	
Atmospheric Absorption	Not used in analysis of plan
Rain Attenuation (1 percent of worst month)	12 percent reduction from CPM model (See table II and figures 4 and 5)
Depolarization	Modelled (See table II)
Maximum Rain Attenuation (used only for power calculation)	9 dB
Receive Station Characteristics:	
Receiving Antenna Half-Power-Beamwidth	1.7° (~ 1 meter diameter)
Receiving Antenna Polarization	Circular
Receiving Antenna Reference Pattern	Figure 6
G/T (Gain/System Noise Temperature)	10 dB/K
Minimum Elevation Angle of Receiving Antenna	Guidelines: 20° in general < 20° for latitudes greater than 60° 30° for mountainous areas where possible 40° for high precipitation areas, (zones M, N, and P), but exceptions were taken in some cases.

TABLE II - RAIN ATTENUATION AND DEPOLARIZATION AT DOWNLINK FREQUENCIES

RAIN ATTENUATION

The rain attenuation A_p of circularly polarized signals exceeded for 1 percent of the worst month at 12.5 GHz is given by

$$A_p = 0.21\ \gamma\ L\ r \qquad (\mathrm{dB}) \tag{1}$$

where

L is the slant path length through rain

$$= \frac{2(h_R - h_0)}{\left[\sin^2\theta + 2\frac{(h_R - h_0)}{8500}\right]^{1/2} + \sin\theta} \quad (\mathrm{km})$$

r is the rain path length reduction factor

$$= \frac{90}{90 + 4L\cos\theta}$$

h_R is the rain height

$$= c\left\{5.1 - 2.15\log\left[1 + 10^{\left(\frac{\phi - 27}{25}\right)}\right]\right\} \quad (\mathrm{km})$$

$c = 0.6$ for $\phi \leq 20^\circ$

$c = 0.6 + 0.02(\phi - 20)$ for $20^\circ < \phi \leq 40^\circ$

$c = 1.0$ for $\phi > 40^\circ$

h_0 = height (km) above mean sea level of the earth station

ϕ = earth station latitude (degrees)

θ = elevation angle (degrees)

γ = specific rain attenuation = $0.0202\ R^{1.198}$ (dB/km)

R = rain intensity (mm/h) for the rain climatic zones identified in figure 4.

(Note: The method is based on R exceeded for 0.01 percent of an average year.)

TABLE II. - CONTINUED

DEPOLARIZATION

For circularly polarized emissions, the XPD ratio not exceeded for 1 percent of the worst month is obtained from:

$$XPD = 30 \log f - 40 \log (\cos \theta) - 20 \log A_p \qquad (dB) \text{ for } 5^\circ < \theta < 60^\circ \qquad (2)$$

where:

XPD = cross-polarization discrimination ratio, the level of the co-polar component relative to the depolarized component

f = frequency in GHz

θ = elevation angle, (for angles of θ greater than 60° use $\theta = 60^\circ$ in equation (2).)

A_p = co-polar rain attenuation exceeded for 1 percent of the worst month (dB)

TABLE III - TECHNICAL CHARACTERISTICS OF THE PLAN FOR THE FEEDERLINKS AT 17 GHz IN REGION 2

TECHNICAL PARAMETER	RARC '83 PLAN VALUE
System Characteristics:	
Frequency Band	17.3 to 17.8 GHz
Frequency Translation	5.1 GHz (Simple translation with channelizations and guardbands preserved)
Carrier to Noise Ratio	Guideline: ≈ 24 dB (0.5 dB degradation of downlink C/N)
Protection Ratio (Required overall carrier-to-interference ratio for 99 percent of worst month)	
Co-Channel	Guideline: ≈ 38 dB (0.5 dB degradation of downlink C/I)
Adjacent Channel	0.4 degrees orbital separation required between satellites having cross-polarized adjacent channels
Second Adjacent Channel	-19.9 dB
Feederlink Transmitter Characteristics:	
Transmit Power, Delivered to Antenna Input	1000 W (maximum)
Transmit Antenna Diameter	5 meters
Transmit Antenna Polarization	Circular, other allowed after agreement
Transmit Antenna Reference Pattern	Figure 7
Transmit Antenna Efficiency/Gain	65 percent/57.4 dBi at 17.55 GHz
Feederlink EIRP	87.4 dBW
Transmit Antenna Pointing Accuracy	1 dB loss in gain, but no greater mispointing than 0.1°
Feederlink Power Control	Not used in development of plan. +5 dB power allowed under certain conditions
Propagation:	
Atmospheric Absorption	Not used in analysis of plan
Rain Attenuation (1 percent of worst month)	12 percent reduction from CPM model. (Same as in table II, but for 17.5 GHz substitute $\gamma = 0.0521\ R^{1.114}$ (dB/km), see fig. 8.)
Depolarization	Modelled (same as in table II, but use 23 log A_p in place of 20 log A_p)
Maximum Rain Attenuation	13 dB
Satellite Characteristics:	
Receive Antenna Half-Power Beamwidth	0.6° minimum
Receive Antenna Polarization	Circular, generally
Receive Antenna Reference Pattern	Figures 9 and 10 (See ref. 1)
Receive Antenna Efficiency	55 percent
Receive Antenna Pointing Accuracy	± 0.1° from beam axis ± 1° rotation about beam axis
Satellite Receive Noise Temperature	1500 K

TABLE IV - SATELLITE POSITIONS IN THE BROADCAST SATELLITE PLAN FOR NORTH AMERICA

Administration or Service Area	Nominal Satellite Longitude (Degrees West)
Canada	138 129 91 82 72.5 70.5
United States	175 166 157 148 119 110 101 61.5
Mexico	136 127 78 69
St. Pierre and Miquelon	53

Note: All positions are permitted to use 32 channels except for Mexico (69) - 16 channels and SPM (53) - 8 channels.

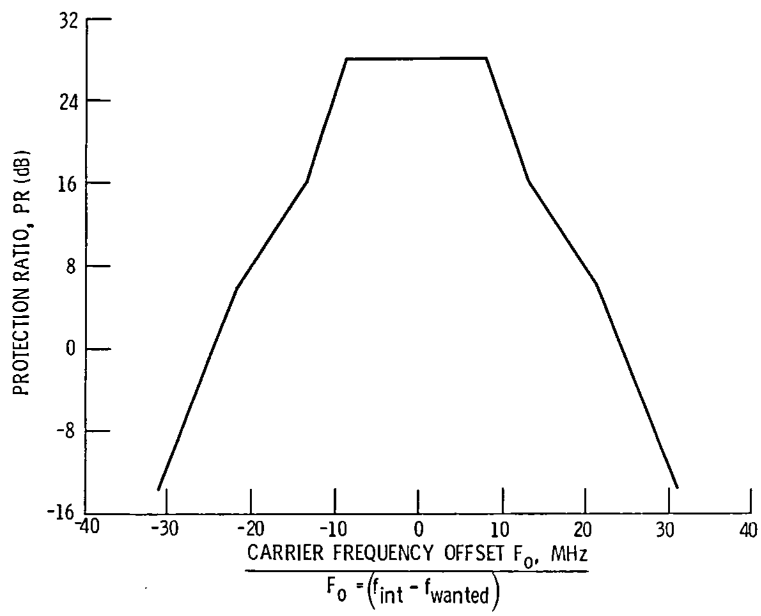

Figure 1. - Protection ratio template (FMTV/FMTV) for planning between broad-casting-satellite systems in region 2.

$$
PR = \begin{cases} 28 \text{ dB} & \text{FOR } |F_0| \leqslant 8.36 \text{ MHz} \\ -2.762\,|F_0| + 51.09 \text{ dB} & \text{FOR } 8.36 < |F_0| \leqslant 12.87 \text{ MHz} \\ -1.154\,|F_0| + 30.4 \text{ dB} & \text{FOR } 12.87 < |F_0| \leqslant 21.25 \text{ MHz} \\ -2.00\,|F_0| + 48.38 \text{ dB} & \text{FOR } |F_0| > 21.25 \text{ MHz} \end{cases}
$$

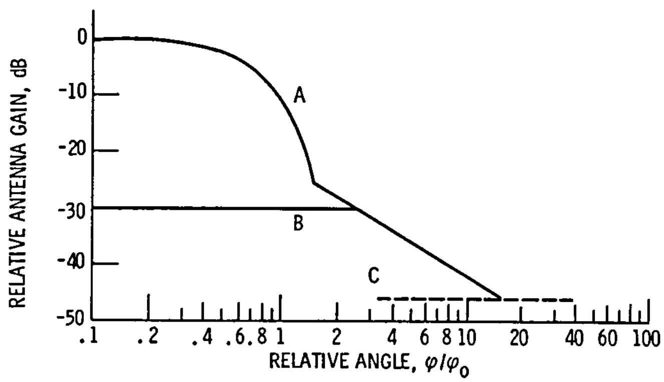

Figure 2. - Reference patterns for co-polar and cross-polar components for satellite transmitting antenna in region 2.

CURVE A: CO-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

$-12(\varphi/\varphi_0)^2$ FOR $0 \leq (\varphi/\varphi_0) \leq 1.45$

$-(22 + 20 \log_{10}(\varphi/\varphi_0))$ FOR $1.45 < (\varphi/\varphi_0)$

AFTER INTERSECTION WITH CURVE C: AS CURVE C

CURVE B: CROSS-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

-30 FOR $0 \leq (\varphi/\varphi_0) \leq 2.51$

AFTER INTERSECTION WITH CO-POLAR PATTERN: AS CO-POLAR PATTERN

CURVE C: MINUS THE ON-AXIS GAIN

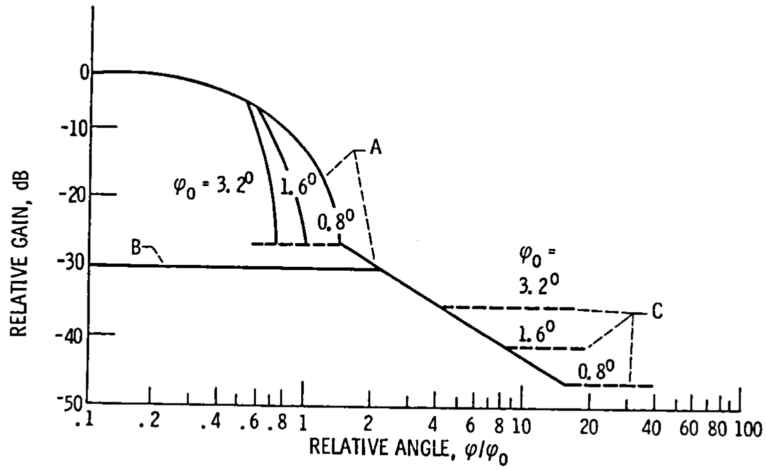

Figure 3. - Reference patterns for co-polar and cross-polar components for satellite transmitting antenna with fast roll-off in the main beam for region 2

CURVE A: CO-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

$-12(\varphi/\varphi_0)^2$	FOR $0 \leqslant \varphi/\varphi_0 \leqslant 0.5$
$-18.75\,\varphi_0^2\,(\varphi/\varphi_0 - x)^2$	FOR $0.5 < \varphi/\varphi_0 \leqslant \frac{1.16}{\varphi_0} + x$
-25.23	FOR $\frac{1.16}{\varphi_0} + x < \varphi/\varphi_0 \leqslant 1.45$
$-(22 + 20\log_{10}(\varphi/\varphi_0))$	FOR $1.45 < \varphi/\varphi_0$

AFTER INTERSECTION WITH CURVE C : AS CURVE C

CURVE B: CROSS-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN

-30	FOR $0 \leqslant \varphi/\varphi_0 < 2.51$

AFTER INTERSECTION WITH CO-POLAR PATTERN : AS CO-POLAR PATTERN

CURVE C: MINUS THE ON-AXIS GAIN

WHERE

φ = OFF-AXIS ANGLE (degree)

φ_0 = DIMENSION OF THE MINIMUM ELLIPSE FITTED AROUND THE DOWN-LINK SERVICE AREA IN THE DIRECTION OF INTEREST (degree)

$x = 0.5\left(1 - \frac{0.8}{\varphi_0}\right)$

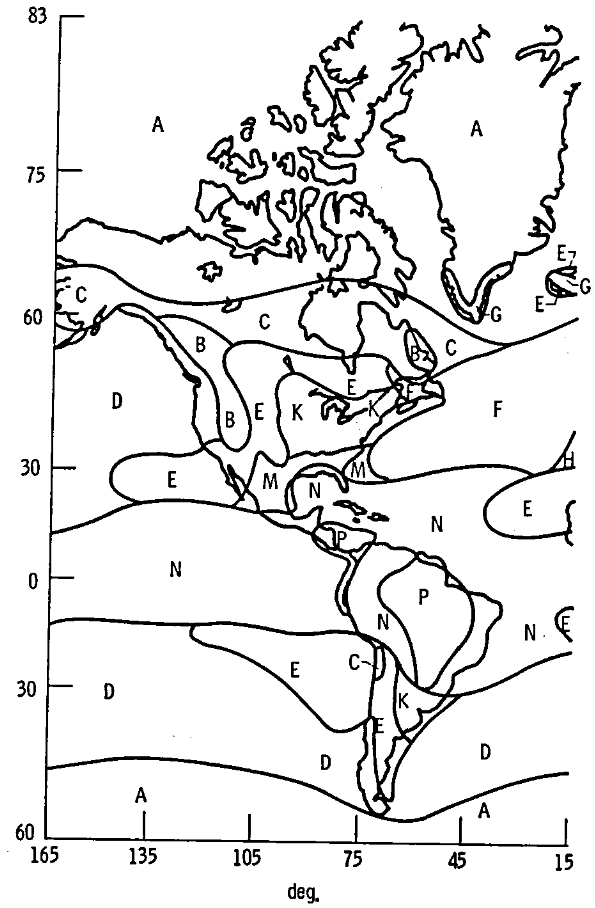

Figure 4. - Rain climatic zones (region 2).

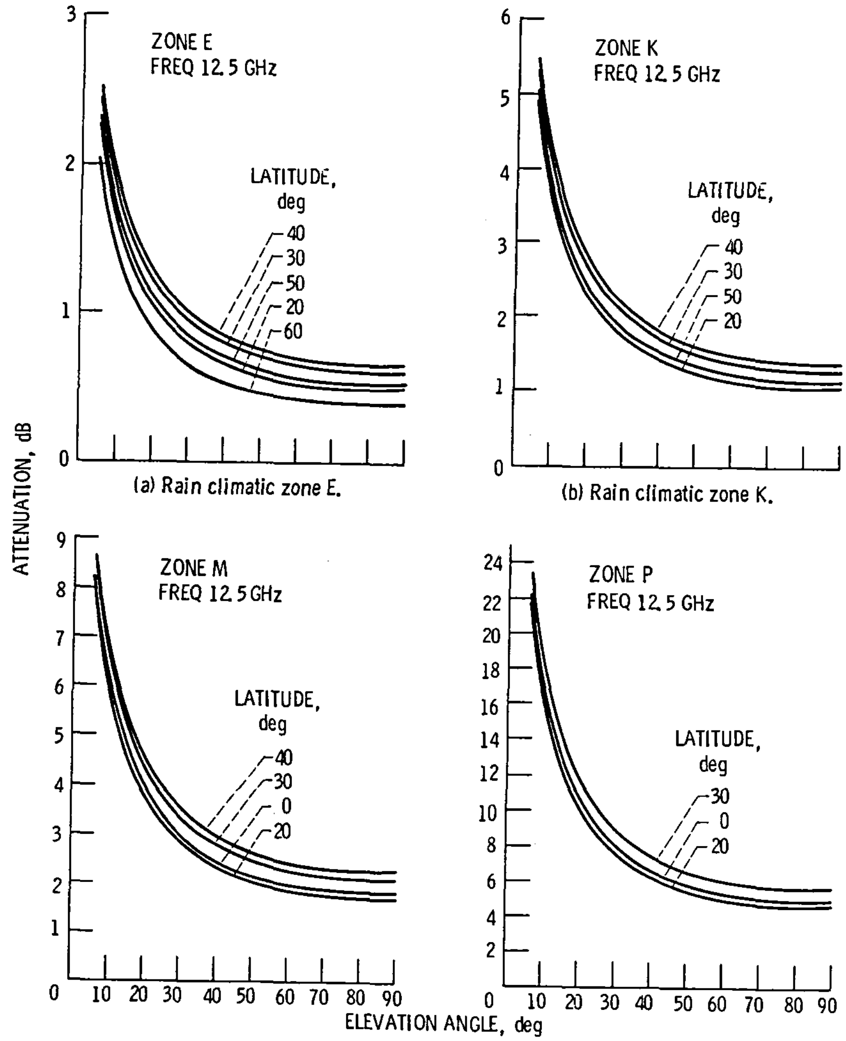

Figure 5. - Rain attenuation values exceeded for 1% of the worst month (sea level) for region 2 rain climatic zones.

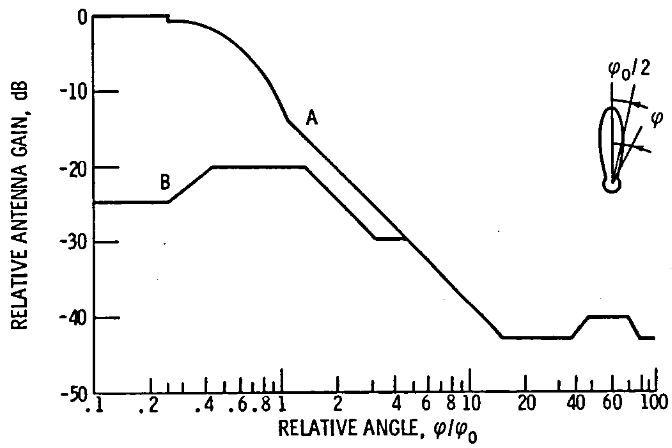

Figure 6. - Reference patterns for co-polar and cross-polar components for receiving earth station antennae in Region 2

<u>CURVE A</u>: CO-POLAR COMPONENT WITHOUT SIDE-LOBE SUPPRESSION
(dB RELATIVE TO MAIN BEAM GAIN)

0	FOR $0 \leqslant \varphi \leqslant 0.25\varphi_0$
$-12(\varphi/\varphi_0)^2$	FOR $0.25\varphi_0 < \varphi \leqslant 1.13\varphi_0$
$-\{14 + 25 \log_{10}(\varphi/\varphi_0)\}$	FOR $1.13\varphi_0 < \varphi \leqslant 14.7\varphi_0$
-43.2	FOR $14.7\varphi_0 < \varphi \leqslant 35\varphi_0$
$-\{85.2 - 27.2 \log_{10}(\varphi/\varphi_0)\}$	FOR $35\varphi_0 < \varphi \leqslant 45.1\varphi_0$
-40.2	FOR $45.1\varphi_0 < \varphi \leqslant 70\varphi_0$
$-\{-55.2 + 51.7 \log_{10}(\varphi/\varphi_0)\}$	FOR $70\varphi_0 < \varphi \leqslant 80\varphi_0$
-43.2	FOR $80\varphi_0 < \varphi \leqslant 180^\circ$

<u>CURVE B</u>: CROSS-POLAR COMPONENT
(dB RELATIVE TO MAIN BEAM GAIN)

-25	FOR $0 \leqslant \varphi \leqslant 0.25\varphi_0$
$-\left(30 + 40 \log_{10}\left\lvert \frac{\varphi}{\varphi_0} - 1 \right\rvert\right)$	FOR $0.25\varphi_0 < \varphi < 0.44\varphi_0$
-20	FOR $0.44\varphi_0 < \varphi \leqslant 1.28\varphi_0$
$-\left(17.3 + 25 \log_{10}\left\lvert \frac{\varphi}{\varphi_0} \right\rvert\right)$	FOR $1.28\varphi_0 < \varphi \leqslant 3.22\varphi_0$

-30 UNTIL INTERSECTION WITH CO-POLAR COMPONENT CURVE;
THEN AS FOR CO-POLAR COMPONENT

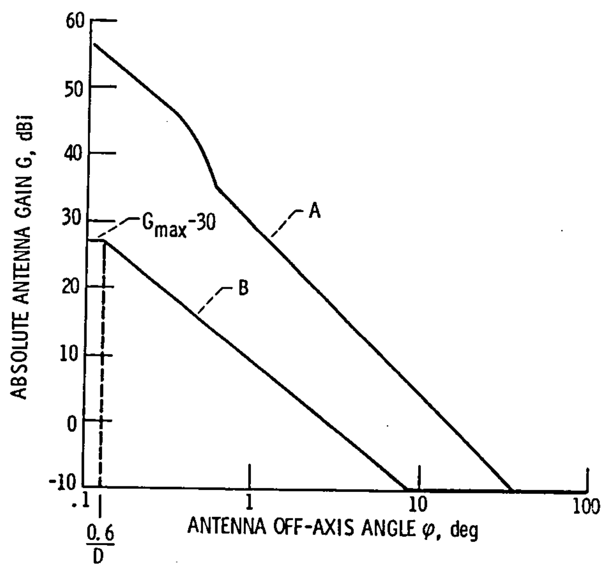

Figure 7. - Reference patterns for co-polar and cross-polar components for earth station transmitting antennae for region 2.

CURVE A: CO-POLAR COMPONENT, dBi

$36 - 20 \log_{10} \varphi$	FOR $0.1^\circ \leqslant \varphi < 0.32^\circ$
$51.3 - 53.2 \varphi^2$	FOR $0.32^\circ \leqslant \varphi < 0.54^\circ$
$29 - 25 \log_{10} \varphi$	FOR $0.54^\circ \leqslant \varphi < 36^\circ$
-10	FOR $\varphi \geqslant 36^\circ$

CURVE B: CROSS-POLAR COMPONENT, dBi

$G_{max}-30$	FOR $\varphi < \left(\frac{0.6}{D}\right)^\circ$
$9 - 20 \log_{10} \varphi$	FOR $\left(\frac{0.6}{D}\right)^\circ \leqslant \varphi < 8.7^\circ$
-10	FOR $\varphi \geqslant 8.7^\circ$

WHERE

φ = OFF-AXIS ANGLE REFERRED TO THE MAIN-LOBE AXIS
G_{max} = ON AXIS CO-POLAR GAIN OF THE ANTENNA
D = DIAMETER OF THE ANTENNA IN METERS ($D \geq 2.5$)

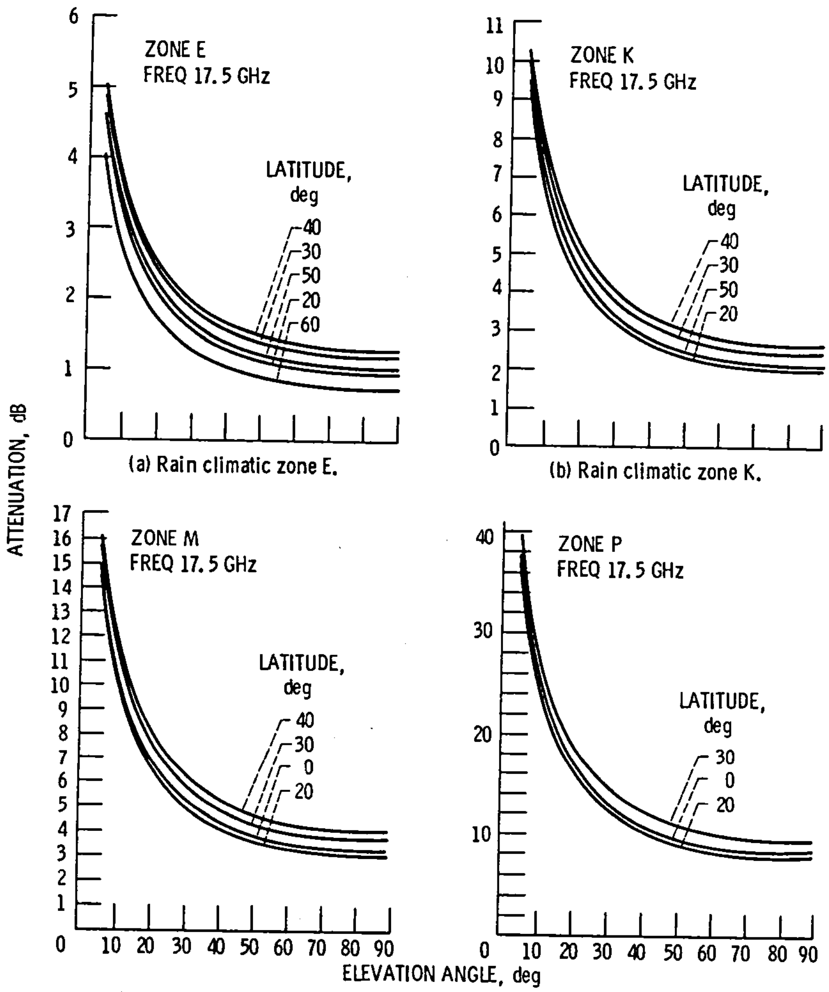

Figure 8. - Rain attenuation values exceeded for 1% of the worst month (sea level) for region 2 rain climatic zones.

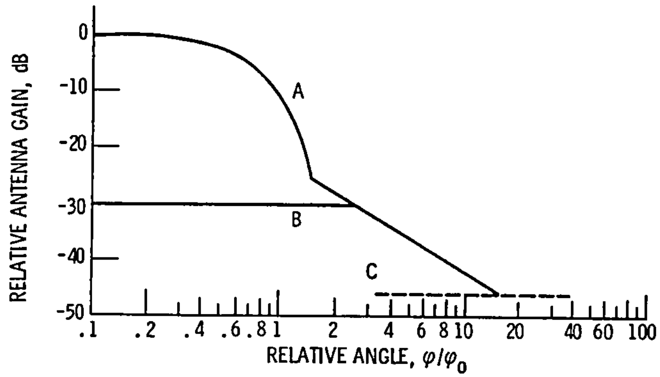

Figure 9. - Reference patterns for co-polar and cross-polar components for satellite receiving antenna in region 2.

CURVE A: CO-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

$-12(\varphi/\varphi_0)^2$ FOR $0 \leq (\varphi/\varphi_0) \leq 1.45$

$-(22 + 20 \log_{10}(\varphi/\varphi_0))$ FOR $1.45 < (\varphi/\varphi_0)$

AFTER INTERSECTION WITH CURVE C: AS CURVE C

CURVE B: CROSS-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

-30 FOR $0 \leq (\varphi/\varphi_0) \leq 2.51$

AFTER INTERSECTION WITH CO-POLAR PATTERN: AS CO-POLAR PATTERN

CURVE C: MINUS THE ON-AXIS GAIN

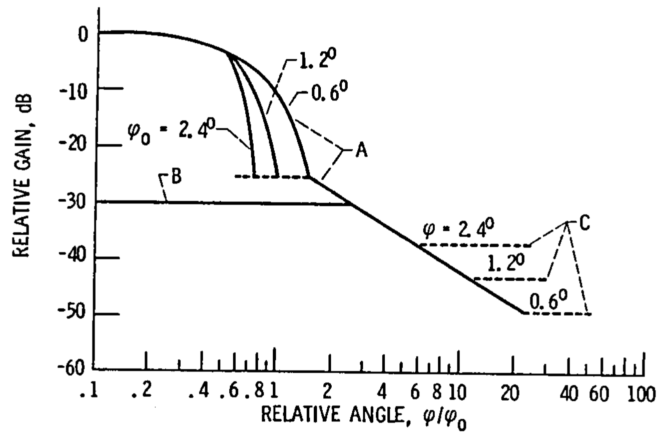

Figure 10. - Reference patterns for co-polar and cross-polar components for satellite receiving antennas with fast roll-off in the main beam for region 2.

CURVE A: CO-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

$-12(\varphi/\varphi_0)^2$ FOR $0 \leq \varphi/\varphi_0 \leq 0.5$

$-33.33\varphi_0^2(\varphi/\varphi_0 - x)^2$ FOR $0.5 < \varphi/\varphi_0 \leq \frac{0.87}{\varphi_0} + x$

-25.23 FOR $\frac{0.87}{\varphi_0} + x < \varphi/\varphi_0 \leq 1.413$

$-(22 + 20 \log_{10}(\varphi/\varphi_0))$ FOR $1.413 < \varphi/\varphi_0$

AFTER INTERSECTION WITH CURVE C: AS CURVE C

CURVE B: CROSS-POLAR COMPONENT (dB RELATIVE TO MAIN BEAM GAIN)

-30 FOR $0 \leq \varphi/\varphi_0 < 2.51$

AFTER INTERSECTION WITH CURVE A: AS CURVE A

CURVE C: MINUS THE ON-AXIS GAIN

WHERE

φ = OFF-AXIS ANGLE (degrees)

φ_0 = DIMENSION OF THE MINIMUM ELLIPSE FITTED AROUND THE FEEDER LINK SERVICE AREA IN THE DIRECTION OF INTEREST (degree)

$x = 0.5\left(1 - \frac{0.6}{\varphi_0}\right)$

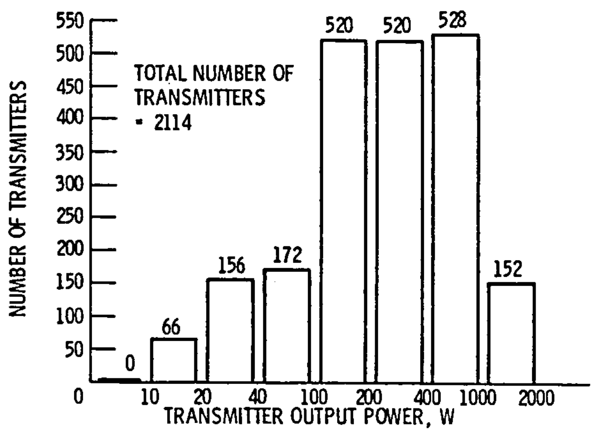

Figure 11. - Histogram of transmitter output powers for spacecraft transponders in the RARC-83 down-link plan.

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15. Supplementary Notes

Portions of this report have been included in "Technical Characteristics of the Broadcasting Satellite Plan at 12 GHz for the Western Hemisphere" by Edward F. Miller presented at IEEE's GLOBECOM '83, San Diego, California, November 29-December 1, 1983.

16. Abstract

In June and July of 1983, delegates from International Telecommunications Union Region 2 (the Western Hemisphere) met at the Regional Administrative Radio Conference (RARC) to plan broadcasting satellites at 12 GHz and the associated feeder-links at 17 GHz. This paper presents the technical characteristics of those formal plans. The applicable technical parameters, such as, satellite antenna characteristics, earth station requirements, bandwidths, channelization, and allowable carrier-to-interference ratios are discussed, and insights are given into the rationale for the decisions made at the RARC. An overview of the downlink plan is given, including a histogram of the transmitter power requirements. For the seventy-plus service areas in Region 2 the plan includes satellite orbit positions, spacecraft transmitted powers, antenna beam sizes, channel assignments, and polarizations.

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