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Sharing of the Band 12.2-12.7 GHz Between the Broadcasting-Satellite and Fixed Services

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LIST OF SYMBOLS AND ABBREVIATIONS

BS	broadcasting service (terrestrial)
BSS	broadcasting-satellite service
CCIR	International Radio Consultative Committee
Comsat	Communications Satellite Corporation
D	diameter of antenna
dB	decibel(s)
dBi	decibel(s) relative to isotropic antenna gain
dBm^2	decibel(s) relative to 1 m^2 (one meter squared)
dBW	decibel(s) relative to 1 W (one watt)
DRS	Digital Radio System
FCC	Federal Communications Commission
FDM	frequency-division multiplex
FM	frequency modulation
FS	fixed service (terrestrial)
FSS	fixed-satellite service
GHz	gigahertz
GWARC	General World Administrative Radio Conference
Hz	hertz
IFRB	International Frequency Registration Board
ITU	International Telecommunication Union
kHz	kilohertz
km	kilometer(s)
m	meter(s)
MHz	megahertz
NF	noise figure
PFD	power flux density
RF	radiofrequency
SBS	Satellite Business System
SNR	signal-to-noise ratio
SPM	Special Preparatory Meeting
TV	television
W	watt(s)
WARC	World Administrative Radio Conference
WARC-BS	World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service

λ	wavelength (of a radio wave)
π	ratio of circumference to diameter of a circle
ϕ	off-axis angle (of an antenna)

SHARING OF THE BAND 12.2-12.7 GHz BETWEEN THE BROADCASTING-SATELLITE AND FIXED SERVICES

Hiroshi Akima*

The United States Administration has proposed for the 1979 WARC (World Administrative Radio Conference) to move the BSS (broadcasting-satellite service) in ITU (International Telecommunication Union) Region 2 from the band 11.7-12.2 GHz to the band 12.2-12.7 GHz, which is also allocated to the terrestrial FS (fixed service). This report discusses the potential of sharing between the BSS and the FS in the band 12.2-12.7 GHz. It is concluded that sharing is feasible under certain conditions.

Key words: 1979 WARC (World Administrative Radio Conference), band sharing, BSS (broadcasting-satellite service), FS (fixed service), interference

1. INTRODUCTION

The U.S. preparatory effort for the 1979 WARC (World Administrative Radio Conference) of the ITU (International Telecommunication Union) has concluded that the existing shared allocation of the band 11.7-12.2 GHz between the BSS (broadcasting-satellite service) and FSS (fixed-satellite service) (space-to-Earth) in ITU Region 2 is insufficient to meet the demands of these services (FCC, 1978). The United States Administration has, therefore, proposed that the allocations for the BSS and FSS (space-to-Earth) in the band 11.7-12.2 GHz in Region 2 be separated in such a way that the FSS (space-to-Earth) is retained in the band 11.7-12.2 GHz and the BSS is moved to the band 12.2-12.7 GHz. This separation of the two space services should provide a greatly increased capacity for each of the services. This and related proposals are shown in Appendix A.

If the band 12.2-12.7 GHz is allocated to the BSS, however, it must be shared between the BSS and the terrestrial FS (fixed service), to which it is also allocated as a primary service. Although various aspects of such sharing have been discussed in several studies (CCIR, 1978 a, b, c; Comsat, 1978; SBS, 1978; Western Union, 1978; Lee et al., 1979), each study is not necessarily complete enough to give a clear picture of sharing between the BSS and the FS. As shown in Appendix B, some conclusions of these studies even contradict each other. In this present study, we try to give a clear and comprehensive picture of the sharing by examining various

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cases of the sharing and by demonstrating in which cases, and how, the sharing between the BSS and FS is feasible.

2. INTERFERENCE FROM BSS TO FS

2.1. Introduction

Interference from BSS to FS (i.e., interference caused by a BSS transmitter on an FS receiver) is considered tolerable, if the interfering BSS signal power is very small compared with the wanted FS signal power. Judgment as to whether the interference is tolerable, therefore, can be made by comparing the interfering BSS signal power with the wanted FS signal power. This way of judgment, however, requires knowledge of both the FS signal power and the signal-to-interference protection ratio. Unless the measured value for the operational FS system or the design value for the planned system is available, the value of the signal power must be estimated from the system noise power and the required SNR (signal-to-noise ratio), or from the wanted-signal transmitter power, the antenna gains, and the propagation loss. The signal-to-interference protection ratio depends on the type of information signal, the type of modulation, the SNR, and the required signal quality. When all of the above items are not known, some of them must be postulated. This may leave unsettled arguments.

The same judgment can be made in a simpler way by comparing the BSS signal power with the noise power of the FS receiver. Regardless of the type of information signal and type of modulation, a communication system is designed in such a way that the wanted signal power is greater than the receiver noise power by a ratio, called signal-to-noise protection ratio, with some system margin. If the interfering signal power is small compared with the noise power, therefore, the interfering signal reduces the system margin only by a small amount, and the performance of the wanted system remains at an acceptable level. This way of judgment will obviate the need for postulating some of the debatable assumptions.

2.2. Interfering BSS Power

To determine the BSS signal power received at an FS receiver, we first examine the PFD (power-flux density) of the BSS signal on the surface of the Earth. The PFD of the BSS signal to be exceeded for 99% of the worst month at the edge of the BSS service area should be equal to -103 dBW/m^2 for service areas in Regions 1 and 3, and -105 dBW/m^2 for service areas in Region 2 (ITU, 1977, p. 82). The PFD at the center of the service area is 3 dB higher than that at the edge. In clear weather, the PFD are higher than the above values by the amount of rain attenuation. Although the rain attenuation largely depends on the rain-climatic zones and the elevation angle of the satellite, the attenuation exceeded for not more than 1% of the worst month is limited to a maximum of 2 dB (ITU, 1977, p. 91). Therefore, the PFD of the BSS signal at the center of the service area should be between -100 dBW/m^2 and -98 dBW/m^2 in Regions 1 and 3, and between -102 dBW/m^2 and -100 dBW/m^2 in Region 2.

The analysis of the 1977 WARC-BS (World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service) plan for Regions 1 and 3 (ITU, 1977, Article 11) indicates that the clear-weather PFD at the center of the service area falls in a range between -100 dBW/m^2 and -97 dBW/m^2 (with a center value of -98.5 dBW/m^2) in nearly 90% of the assignments and that it can be as high as -94.7 dBW/m^2 (see Appendix C). Since the PFD for Region 2 is 2 dB lower than that for Regions 1 and 3, we will take -100.5 dBW/m^2 and -96.7 dBW/m^2 as the typical value and the maximum value, respectively, of the PFD of the BSS signal at the center of the service area.

Next, we convert the PFD to the signal power received with an isotropic antenna. This is done by multiplying the PFD by the effective area of the isotropic antenna, which is represented by $\lambda^2/(4\pi)$, where λ is the wavelength. At the frequency of 12.45 GHz, which is the center frequency of the band 12.2-12.7 GHz, the effective area of an isotropic antenna is calculated to be 0.00004622 m^2, or -43.3 dBm^2. Therefore, the typical value and the maximum value of the BSS signal power received with an isotropic antenna at the center of the service area are -143.8 dBW and -140.0 dBW, respectively.

Finally, we convert the signal power received with an isotropic antenna to the signal power received with an FS receiving antenna by multiplying by the gain of the latter antenna. The reference pattern of a circular-aperture parabolic antenna used in a microwave radio-relay system is given in CCIR (International Radio Consultative Committee) Report 614 (CCIR, 1974). Using the equation given there, we calculate the off-axis gain of the antenna as a function of the antenna diameter and the off-axis angle. The result is shown in Table 1. The typical value and the maximum value of the BSS signal power received by an FS receiver so obtained are given in Tables 2 and 3, respectively.

2.3. Receiver Noise Power

Since we have calculated the interfering BSS signal power at the output of the receiving antenna, we will calculate the receiver noise power at the same reference point. This reference point is before any intervening circuits such as the waveguide and branching circuit if the antenna is used for both reception and transmission.

Table 1. Off-Axis Antenna Gain of a Circular-Aperture Parabolic Antenna (The ϕ denotes the off-axis angle, and D denotes the antenna diameter.)

ϕ (degrees)	Antenna Gain (dB)				
	D=0.6 m	1.0	1.5	2.0	≥2.41
20	5.5	3.3	1.6	0.3	0.0
15	8.6	6.4	4.7	3.4	2.6
10	13.0	10.8	9.1	7.8	7.0

Table 2. Typical Value of the BSS Signal Power Received by an FS Receiver (The ϕ denotes the off-axis angle, and D denotes the antenna diameter.)

ϕ (degrees)	Signal Power (dBW)				
	D=0.6 m	1.0	1.5	2.0	≥2.41
20	-138.3	-140.5	-142.2	-143.5	-143.8
15	-135.2	-137.4	-139.1	-140.4	-141.2
10	-130.8	-133.0	-134.7	-136.0	-136.8

Table 3. Maximum Value of the BSS Signal Power Received by an FS Receiver (The ϕ denotes the off-axis angle, and D denotes the antenna diameter.)

ϕ (degrees)	Signal Power (dBW)				
	D=0.6 m	1.0	1.5	2.0	≥2.41
20	-134.5	-136.7	-138.4	-139.7	-140.0
15	-131.4	-133.6	-135.3	-136.6	-137.4
10	-127.0	-129.2	-130.9	-132.2	-133.0

The NF (noise figure) of the receiver in the 12 GHz range is considered to range between 4 dB and 6 dB with a preamplifier, and between 8 dB and 25 dB without a preamplifier. These NF values are at the input of the receiver excluding the intervening circuits. To convert these values to the values referenced at the receiving antenna output, the loss of the intervening circuits must be added (in decibels) to the NF values at the receiver input. We will take a value of 10 dB as a typical value of the NF at the reference point.

The noise power is proportional to the bandwidth. The spectral density of the noise power is represented by NF - 204 dBW/Hz. With the assumed NF value and with 1 MHz as the unit of the bandwidth, it becomes -134 dBW/MHz. This value will be used as the noise-power spectral density of a typical FS receiver in the following discussions.

2.4. Interference to an FDM-FM Telephony System

Many short-range FDM-FM telephony systems are in operation as FS systems in this band in the United States. Typical receiver bandwidths are 12 MHz and 20 MHz. In an FDM-FM telephony system, degradation of the system performance caused by an interfering signal depends on the power spectral density of the interfering signal as well as the total power of the interfering signal. Even if the total interfering-signal power is so small that the wanted FDM-FM system continues to operate above its threshold, some telephone channels may be degraded severely if the power spectral density of the interfering signal is very high in these channels.

First, we will compare the total power of the interfering BSS signal with that of the noise. The total noise power is -123 dBW in a 12-MHz bandwidth, and -121 dBW in a 20-MHz bandwidth. These values are several decibels higher than -127 dBW, which is the interfering BSS signal power in the worst case given in Table 3. The total power of noise plus interfering signal is only one decibel higher, at most, than the noise power alone in this case. Therefore, the operation of the wanted FDM-FM system should remain above the threshold in all cases if the system is designed with a reasonable margin in SNR.

Next, we will compare the power spectral density of the interfering signal with that of noise. Since the 1977 WARC-BS specifies the power (or energy) dispersal that corresponds to a peak-to-peak deviation of 600 kHz for BSS (ITU, 1977, p. 104), the power of a BSS signal is considered to be uniformly distributed in a 600-kHz bandwidth in the worst case. Therefore, the comparison of the power spectral density can be made equivalently by comparing the total power of the interfering signal with the noise power contained in a 600-kHz bandwidth.

The noise power in a 600-kHz bandwidth is estimated to be -134 + 10 log 0.6 = -136.2 dBW. Since this value is about the same order as the values of the BSS signal power given in Tables 2 and 3, the effect of the interfering BSS signal is not considered negligible. The post-demodulation baseband noise power in a telephone channel is 3 dB higher with the noise plus interference than with the noise alone if the power spectral density of the interfering signal is equal to that of the noise. Tables 4 and 5 show the increases in the baseband noise power caused by the interfering BSS signal, calculated with Tables 2 and 3. These tables show the relation among the off-axis angle of the BSS satellite from the main beam of the FS receiving antenna, the FS receiving antenna diameter, and the required system margin against the interference in the design of the FS system. In the worst case of $\phi = 10^0$ and D = 0.6 m considered in Table 5, a margin of 10 dB is required. The required system margin decreases as the off-axis angle and/or the antenna diameter increases. In the receiving site where the elevation angle of the BSS satellite is 20^0, the required system margin is less than 4 dB regardless of the antenna diameter. When the antenna diameter is equal to or greater than 2.41 m, the required system margin is less than 5 dB even if the elevation angle is 10^0.

2.5. Interference to an FM TV System

An FM TV relay system of a small number of hops (not more than five hops) is considered as an FS system in this band in France (CCIR, 1978c). The channel bandwidth considered in this system is 27 MHz. The FS system considered in the preceding section is used also to transmit an FM TV signal in the United States. Consideration of interference to an FM TV system is essentially the same as that of interference to an FDM-FM telephony system in that both the total power and the power spectral density of the interfering signal must be considered.

Insofar as the total interfering-signal power is concerned, the discussion on the FDM-FM telephony system given in the preceding section also applies. Even with the interfering signal, the system remains operating above its threshold.

Since the power spectrum of the BSS signal is considered to be uniform in a 600-kHz bandwidth for the purpose of interference analysis, the discussion of the interference to the FDM-FM telephone system given in the preceding section also applies to the interference to an FM TV system. The interfering BSS signal causes the baseband noise power spectral density in the victim FM TV system to increase in a part of the baseband by the ratio given in Tables 4 and 5. If the system margin is greater than this ratio, the interference is considered tolerable.

Table 4. Increase in the Baseband Noise Power Due to the Interfering BSS Signal (Typical values of BSS signal power shown in Table 2 are used. The ϕ denotes the off-axis angle, and D denotes the antenna diameter.)

ϕ (degrees)	Increase in Baseband Noise Power (dB)				
	D=0.6 m	1.0	1.5	2.0	≥2.41
20	2.1	1.4	1.0	0.7	0.7
15	3.5	2.4	1.8	1.4	1.2
10	6.5	4.9	3.8	3.1	2.7

Table 5. Increase in the Baseband Noise Power Due to the Interfering BSS Signal (Maximum values of BSS signal power shown in Table 3 are used. The ϕ denotes the off-axis angle, and D denotes the antenna diameter.)

ϕ (degrees)	Increase in Baseband Noise Power (dB)				
	D=0.6 m	1.0	1.5	2.0	≥2.41
20	3.9	2.8	2.0	1.6	1.5
15	5.3	4.5	3.5	2.8	2.5
10	9.3	7.8	6.4	5.5	4.9

2.6. Interference to a Wideband Digital System

A trunking-type coast-to-coast application of a wideband digital system is considered as an FS system in this band in Canada (CCIR, 1978b). The receiver bandwidth considered is 240 MHz. In this FS system, degradation of the system performance caused by interfering signals depends on the ratio of total interfering-signal power to total noise power in the receiver bandwidth.

Since the bandwidth of the FS system is 240 MHz and the minimum spacing between BSS assignments in a BSS service area is 2x19.18 = 38.36 MHz (ITU, 1977, Article 11), up to six BSS signals may interfere with the FS system simultaneously. In the worst case of $\phi = 10^{o}$ and D = 0.6 m considered in Table 3, the total BSS interfering-signal power can be as high as -127.0 + 10 log 6 = -119.2 dBW. On the other hand, the total noise power is -134 + 10 log 240 = -110.2 dBW for the bandwidth of 240 MHz. Therefore, the total interfering-signal power is 9 dB less than the total noise power even for the assumed worst-case conditions. It can be concluded from this result that degradation of the performance of this FS system caused by the BSS interfering signals is negligible.

2.7. Summary

By comparing the interfering BSS signal power with the FS receiver noise power, we have studied interference from the BSS to the FS. The FS systems considered include an FDM-FM telephony system used in the United States, an FM TV system used in France and the United States, and a wideband digital system envisioned in Canada.

The results of the study indicate that interference from the BSS to the FS is, in general, not a serious problem. The signal power from a broadcasting satellite received by an FS receiving antenna is usually smaller than the FS receiver noise power. The total power of noise plus interfering signal is not more than one decibel higher than the noise power alone in most cases. Therefore, the operation of the FS system should remain above the threshold in all cases if the system is designed with a reasonable margin in the SNR.

The interfering BSS signal will increase the baseband noise power in some telephone channels in the FDM-FM telephony system and the noise power spectral density in some part of the baseband in the FM TV system. These increases, however, will be less than 10 dB even in the worst case. These increases can be controlled to an acceptable level by properly designing the FS system.

3. INTERFERENCE FROM FS TO BSS

3.1. Introduction

Interference from FS to BSS (i.e., interference caused by an FS transmitter on a BSS receiver) is not uniform in a service area of the BSS. Severity of the interference largely depends on the location of the BSS receiver relative to the location and the main-beam direction of the FS transmitting antenna. Since a sidelobe envelope pattern better than that of an isotropic antenna (i.e., sidelobe envelope gain of less than 0 dB) cannot be expected for either an FS transmitting antenna or a BSS receiving antenna, there always exists an area around an FS transmitting antenna, where the interfering FS signal power received by a BSS receiver exceeds its maximum permissible limit. If such areas occupy a large portion of the BSS service area, sharing between BSS and FS must be judged impossible because of interference from the FS to the BSS. Therefore, the dimension of such areas must be determined before one can discuss whether or not sharing between the two services is feasible.

3.2. Permissible Limit of Interfering FS Signal Power

The maximum permissible limit of the interfering FS signal power received by a BSS receiver depends on the wanted BSS signal power and the signal-to-interference protection ratio. We will examine each of the last two parameters separately and determine the maximum permissible limit.

We will first determine the wanted BSS signal power received at the BSS receiver. The PFD of a BSS signal to be exceeded for 99% of the worst month at the edge of the service area is specified to be -105 dBW/m^2 in Region 2 (ITU, 1977, p. 82). The received signal power is calculated with this PFD and the effective area of the receiving antenna. For individual reception of a BSS signal in Region 2, the half-power (or 3 dB) beamwidth of a receiving antenna is specified to be 1.8^0 (ITU, 1977, p. 97). This corresponds to an on-axis (main-beam) gain of 39.33 dB (ITU, 1977, p. 101). At a frequency of 12.45 GHz, it corresponds to an effective area of 0.40 m^2, or -4 dBm^2. (If the antenna efficiency is assumed to be 55%, this effective area corresponds to a circular-aperture parabolic antenna diameter of 0.96 m.) Therefore, the wanted BSS signal power received by a BSS receiving antenna at the edge of the BSS service area is -109 dBW.

We will next examine the signal-to-interference protection ratio. The signal-to-interference protection ratio against all types of terrestrial transmissions is 35 dB for carrier frequency differences between the wanted and interfering signals of up to 10 MHz, decreasing linearly from 35 dB to 0 dB for carrier frequency differences between 10 MHz and 35 MHz, and 0 dB for frequency differences in excess of

35 MHz (ITU, 1977, p. 82). Therefore, the protection ratio is 35 dB when the interfering FS signal is situated at the center of the BSS channel in question, 22.1 dB when the interfering FS signal is at the center of the adjacent BSS channel (i.e., 19.18 MHz apart), and 0 dB when the interfering FS signal is two or more BSS channels (i.e., 38.36 MHz or more) apart.

However, it is specified in the Final Acts of the WARC-BS (ITU, 1977, p. 82) that "a signal from a terrestrial station should be considered only if its necessary bandwidth overlaps the necessary bandwidth of the broadcasting-satellite assignment." For this reason, we will consider only the co-channel and adjacent-channel interfering FS signals in this study and exclude the case where the interfering FS signal is two or more BSS channels apart.

The permissible limits of the interfering FS signal power are obtained by subtracting (in decibels) the protection ratio values from the wanted BSS signal power. They are -144 dBW and -131.1 dBW for the co-channel and adjacent-channel interfering FS signals, respectively.

3.3. FS Signal Power Received by a BSS Receiver

The interfering FS signal power received by a BSS receiver is a function of the FS transmitting power, the FS transmitting antenna gain in the direction of the BSS receiver, the propagation loss, and the BSS receiving antenna gain in the direction of the FS transmitter. We will examine these parameters in this section.

The FS transmitter power varies from system to system. It ranges from -20 dBW to 10 dBW. When the FS signal bandwidth is wider than the BSS receiver bandwidth, only the power in the latter is taken as the FS transmitter power.

The reference radiation patterns for circular antennas used in radio-relay systems are given in CCIR Report 614 (CCIR, 1974). The report gives the on-axis gain as a function of D/λ and the sidelobe envelope pattern as a function of D/λ and ϕ, where D is the diameter of the antenna, λ is the wavelength, and ϕ is the off-axis angle. The report selects a value of 0 dB as the residual gain, which is the gain in the distant sidelobes. The sidelobe envelope pattern given there is applicable between the position of the first sidelobe and the angle at which the sidelobe envelope equals the residual gain. For simplicity we assume that the gain near the main-lobe axis expressed in decibels is parabolic with respect to the off-axis angle in the range where the gain is greater than the sidelobe envelope gain at the location of the first sidelobe and that the gain is constant outside the above range but inside the first sidelobe location. We will use these reference radiation patterns for all FS transmitting antennas considered in this study.

The relation among the propagation loss, path length, and type of path is given in the Final Acts of the 1977 WARC-BS (ITU, 1977, pp. 85-86). With this relation, the propagation loss can be calculated from the path length, and vice versa. In this study we assume all overland paths.

The reference pattern for the BSS receiving antenna in Region 2 is given in the Final Acts (ITU, 1977, p. 84). This pattern is given in the form of off-axis gain relative to the on-axis gain, which is equal to 39.33 dB in Region 2, as calculated in the preceding section. The absolute off-axis gain of the BSS receiving antenna is equal to 12.2 dB, 7.8 dB, 4.7 dB, and 0 dB when the off-axis angle is 10^o, 15^o, 20^o, and 27^o or greater, respectively.

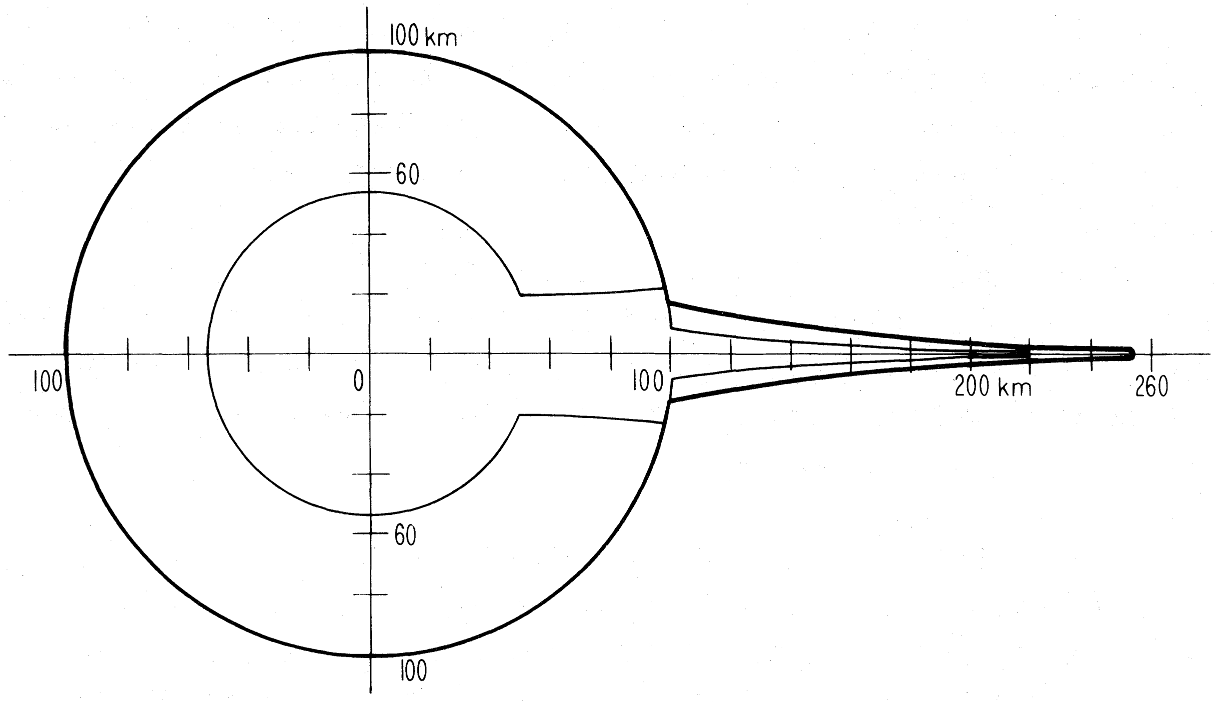
With these relations, we can calculate the FS signal power received by a BSS receiver when the FS transmitter power and the relative locations of the two antennas are known. Conversely, we can calculate the minimum distance between the two antennas necessary to keep the received FS signal power below its maximum permissible limit when all other parameters are known.

3.4. Areas Where Interference is Intolerable

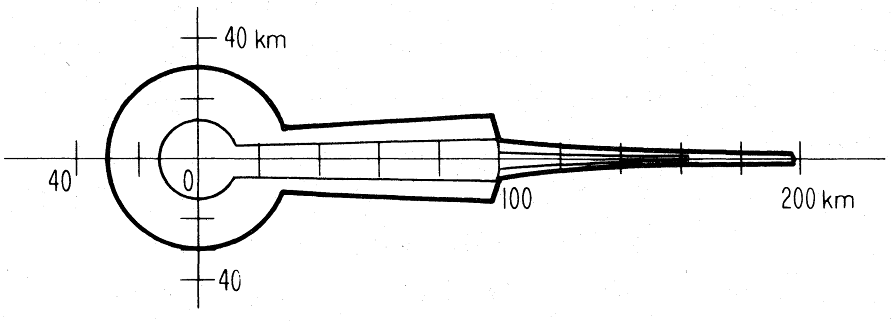
For each FS transmitter, we can plot the minimum distance between the two antennas against the off-axis angle of the FS transmitting antenna on a polar coordinate with the location of the FS transmitter as its origin and with the main-beam direction as the zero-angle direction (i.e., the x-axis direction in the associated Cartesian coordinate). The resulting curve is the contour line on which the received interfering FS signal power is equal to its maximum permissible limit. The area inside the contour represents the area where the interference from the FS to the BSS is intolerable. Figures 1 and 2 show some examples of such contours.

Figure 1 shows contours plotted for the case of a U.S. high-power FS system. The FS transmitter power is 1 W (or 0 dBW), which is typical for such a system. The antenna diameter is 1.8 m. The upper half (A) of the figure is for the co-channel interference, and the lower half (B) is for the adjacent-channel interference. Therefore, the difference between the upper half and the lower half represents the effect of moving the interfering FS signal from the co-channel position to the adjacent-channel position.

Figure 2 shows contours plotted for the case of a wideband FS system envisioned in Canada (CCIR, 1978b). The antenna diameter is 2 m. Only the co-channel interference is considered here. In the upper half (A), the FS transmitter power is -7.8 dBW per 20 MHz of bandwidth, which is the nominal power of the system. In the lower half (B), the power is -0.8 dBW in the same bandwidth, which is the maximum


U.S. High-Power System
Transmitter Power: 0 dBW (Typical)

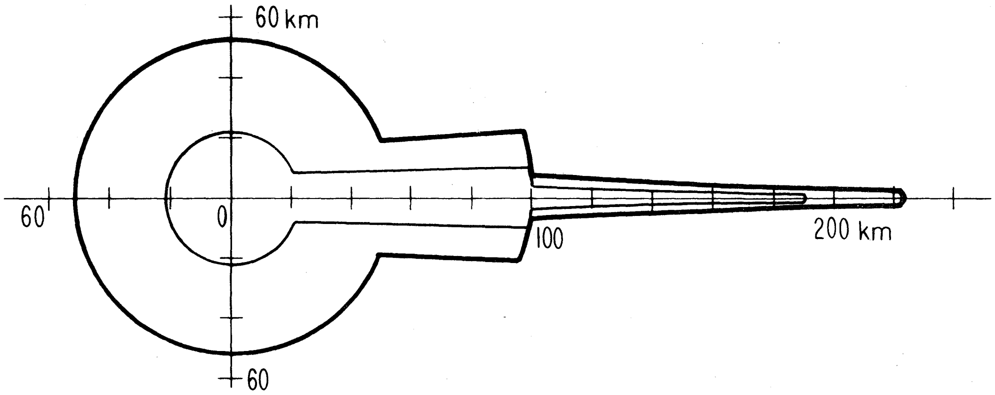
(A) Co-channel Interference



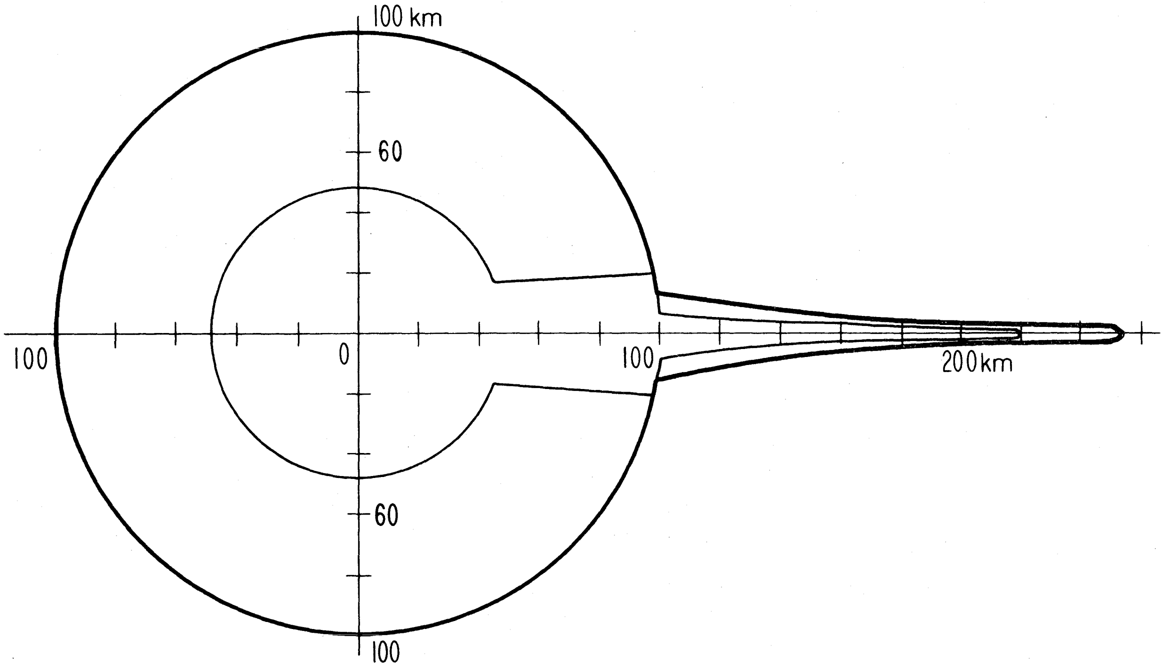
(B) Adjacent-Channel Interference

Figure 1. Contours on which the received interfering FS signal power is equal to its maximum permissible limits for a U.S. high-power FS system. The outer contour is for the worst case, and the inner contour is for the most favorable case.

Canadian FS System
Co-channel Interference



(A) Transmitter Power: -7.8 dBW (Nominal)



(B) Transmitter Power: -0.8 dBW (Maximum)

Figure 2. Contours on which the received interfering FS signal power is equal to its maximum permissible limits for a Canadian FS system. The outer contour is for the worst case, and the inner contour is for the most favorable case.

power of the system. Therefore, the difference between the upper half and the lower half represents the effect of increasing the transmitter power by 7 dB.

In each half of Figures 1 and 2, the outer contour is for the worst case in which the elevation angle of the BSS receiving antenna is 15° and the azimuths of the FS transmitter and the BSS satellite seen from the BSS receiver coincide with each other. The inner contour is for the most favorable case in which the elevation angle of the BSS receiving antenna is so large that the antenna gain in the direction of the FS transmitter is equal to the residual gain regardless of the azimuthal relations. Therefore, the difference between the inner and the outer contours represents the effect of the discrimination of the interfering FS signal by the BSS receiving antenna.

Each contour has a sharp peak in the main-beam direction of the FS transmitting antenna, while it is a circular arc for distant angles. Roughly speaking, therefore, each contour can be represented reasonably well by two distances corresponding to the main-beam direction and to a distant angle. We have calculated the two distances for each of various FS systems and present them in Tables 6 and 7 for the co-channel and adjacent-channel interference, respectively.

So far we have calculated the size of the area where reception of a BSS signal is intolerably interfered with by only one FS transmitter. The next step is to calculate the size of the area interfered with by a number of FS transmitters operating simultaneously and to discuss feasibility of sharing between BSS and FS. This calculation depends on the usage of FS transmitters or the type of applications of the FS systems.

3.5. Sharing With FS of U.S. Applications

In the United States, most FS systems in the band 12.2-12.7 GHz are independent short-hop links. The bandwidth, which is on the order of 10 MHz or 20 MHz, is about the same as the BSS channel spacing, which is equal to 19.18 MHz in Regions 1 and 3. (Long-haul, very wideband, trunking-type applications are not considered in this band in the United States.) There are over 1500 frequency assignments to the FS systems in the United States. Most FS system links are concentrated in or around big cities.

Since most links are mutually independent, there is no general rule or trend in the direction of the link paths. According to the results presented in Tables 6 and 7, therefore, it is safe to consider that, inside the circle with a radius of 100 km and possibly up to 250 km around the center of a big city, reception of a BSS signal would be intolerably interfered with by FS transmitters to which co-channel or adjacent-channel frequencies are assigned. The area of such a circle is in the same order as the area of many western states of the United States.

Table 6. Minimum Separation Distances Required for the Co-channel Interference from FS to BSS

FS System	Antenna Diameter (m)	Transmitter Power (dBW)	Distance (km)			
			Worst Case		Most Favorable Case	
			On-Axis	Distant	On-Axis	Distant
U.S. Low-Power	0.6	Typical -20.0 Max. - 3.0	126.8 200.0	13.0 92.2	100.0 166.4	5.3 37.6
U.S. High-Power	1.8	Typical 0.0 Max. 10.0	254.0 297.0	100.0 104.1	220.4 263.4	53.1 100.0
French	1.5	Min. -41.7 Nominal -35.7	100.0 100.0	1.1 2.1	63.4 100.0	0.4 0.9
Canadian	2.0	Nominal - 7.8 Max. - 0.8	224.3 254.4	53.1 100.0	190.8 220.9	21.6 48.4

Table 7. Minimum Separation Distances Required for the Adjacent-Channel Interference from FS to BSS

FS System	Antenna Diameter (m)	Transmitter Power (dBW)	Distance (km)			
			Worst Case		Most Favorable Case	
			On-Axis	Distant	On-Axis	Distant
U.S. Low-Power	0.6	Typical -20.0 Max. - 3.0	100.0 144.5	3.0 20.9	69.8 110.9	1.2 8.5
U.S. High-Power	1.8	Typical 0.0 Max. 10.0	198.4 241.5	29.5 93.3	164.9 207.9	12.0 38.0
French	1.5	Min. -41.7 Nominal -35.7	35.2 70.3	0.2 0.5	14.3 28.6	0.1 0.2
Canadian	2.0	Nominal - 7.8 Max. - 0.8	168.8 198.9	12.0 26.9	135.3 165.4	4.9 11.0

Since the size of the area intolerably interfered with by the FS transmitters is enormous and since BSS receiving stations are not to be licensed, shared use of FS systems in a BSS service area in the same or adjacent channel is not feasible. In this case, therefore, sharing by frequency division in each BSS service area should be considered. (In this report the phrase "frequency division" is used in conjunction with frequency assignments in a geographical area as opposed to frequency allocations in an ITU Region or in a country.)

As described in Appendix C, only five channels or less each are assigned to most service areas in the 1977 WARC-BS Plan for Regions 1 and 3. We assume that more than five channels will not be assigned to a service area in Region 2. Since the adjacent channels must also be considered to be occupied by the BSS, however, channel occupancy is much greater than the number of channels with assignments. In the 1977 Plan, the channel occupancy is 12 or less in about one-half of the total service areas and from 13 to 18 in most of the remaining half of the total service area (see Appendix C). This large channel occupancy in many service areas arises from the fact that every fourth BSS channel is assigned to a service area. If every other BSS channel is assigned to a service area as in some service areas in Region 3, the BSS channel occupancy is reduced to some extent. For example, the BSS channel occupancy is 14 or 15 when five assignments are made to a service area in every fourth channel, while it is 10 or 11 when the same number of assignments are made in every other channel. If the same channel spacing is used in Region 2 as in Regions 1 and 3 in the 1977 Plan, a total of 24 BSS channels are available in a 500 MHz band. Therefore, we can consider that one-half of this band is available for the FS systems in a service area.

On or near the boundary of two service areas, the BSS channel occupancy depends on the frequency assignments to both service areas. If cross-polarized beams are used for the two areas, the two areas can alternate channels. If the two areas are served from two satellite locations, the two service areas can use the same channels or alternate channels. In these cases the BSS channel occupancy is 11 or 12 channels, and one-half of the band is again available to the FS systems.

If co-polarized beams from the same satellite position must be used for both service areas, on the other hand, the assignments to the two service areas must be separated in frequency without an overlap. In this case, 20 to 22 BSS channels are occupied by the BSS, and only a small portion of the band corresponding to two, three, or four channels remains available to the FS systems.

The study conducted by SBS (Satellite Business Systems) (1978) shows that all the current FS assignments in the band 12.2-12.7 GHz in the United States can be rearranged in one-half of the band. Even if the number of FS assignments is assumed to grow at an annual rate of 10% compounded annually, new FS assignments up to the year 2000 can be accommodated in one-half of the band in most cities of the United States, the only exceptions being New York, NY; Los Angeles, CA; Chicago, IL; St. Louis, MO; and Dallas, TX. Since the boundary of two BSS service areas is not expected to run through big cities, one-half of the band is considered available to FS, and sharing between BSS and FS by frequency division is considered feasible in or around big cities.

As mentioned earlier, only a small portion of the band is available to the FS on or near the boundary of two service areas in some cases. However, as the boundary is expected to run through sparsely populated areas and the FS systems of this type are concentrated in or around big cities, demands for the FS systems on or near the boundary are not considered very intense. It is, therefore, expected that the FS systems can be accommodated in a small portion of the band on or near the boundary of two BSS service areas.

3.6. Sharing With FS of Canadian Applications

A very wideband, trunking-type application is envisioned in Canada (CCIR, 1978b). The long-haul relay system consists of a number of relay stations and can stretch from coast to coast across the continent. The use of the combined 11 and 13 GHz band (10.7-11.7 GHz and 12.2-13.25 GHz) is considered. The RF (radiofrequency) bandwidth is 240 MHz. A high-performance, 2-meter parabolic dish antenna with a maximum gain of 45 dB is considered, and the nominal hop length is 8 km. The transmitter power is equal to -7.8 dBW (nominal) and -0.8 dBW (maximum) per 20 MHz of bandwidth.

Since the hop length of the relay system is smaller than the size of a BSS service area, the FS system uses several frequencies in a BSS service area. If both frequencies that fall in the band 12.2-12.7 GHz are used by the FS relay system in a BSS service area, sharing between BSS and FS by frequency division in the whole service area is impossible. We will first discuss this case.

When n frequencies alternate in every set of n hops, the second station receives from the first station and the (n+2)nd station receives from the (n+1)st station on the same frequency. Therefore, there is a chance for the (n+2)nd station to be interfered with by the signal from the first station. This intrasystem interference can be avoided if the path is zigzagged in such a way that the (n+2)nd station does not lie inside the main beam of the transmitting antenna of the first station and, at the same time, the first station does not lie in the main beam of the receiving antenna of the (n+2)nd station.

This intrasystem interference is most severe when n=2. In this case, the angle between the direction of each hop and the general direction of the relay system is approximately 1.5 times the angle of the first minimum of the antenna pattern. Since the first minimum of the pattern is considered to take place at approximately two-thirds of the position of the first sidelobe, which is given approximately by the equation

$$\phi_1 = 100/(D/\lambda),$$

the angle between the direction of each hop and the general direction of the relay system is approximately given by the above equation for ϕ_1 (CCIR, 1974, Rept. 614). With $D = 2$ m and $\lambda = 0.024$ m (at f=12.45 GHz), the angle is approximately 1.2^o.

We can combine this result with the minimum separation distance given earlier in Figure 2 and Table 6 to determine the size of the area intolerably interfered with by the FS relay system. We rotate each figure in Figure 2 counterclockwise by 1.2^o and take the maximum value of the ordinate values (y values). The distance thus determined represents the width of the belt area where BSS signals are intolerably interfered with by the FS relay system on each side of the general route of the relay system when the route is a straight line. In this FS relay system, the minimum distant-angle separation distance given in Table 6 always dominates and determines the width of the belt area. It is equal to 53.1 km and 21.6 km for the worst case and the most favorable case, respectively, when the nominal transmitter power -7.8 dBW is used, and it is equal to 100 km and 48.4 km when the maximum transmitter power -0.8 dBW is used. When the general direction of the relay system is east-to-west, we can very roughly consider that the area within approximately 50 km on the north side and approximately 20 km on the south side from the general route is intolerably interfered with by the FS system.

When the general route of the FS relay system is deflected, the area intolerably interfered with by the FS system includes spikes of the size and shape shown in Figure 2 in addition to the belt zone described above. When the general route is gradually curved, the area spreads like the pattern of a snowplow turn in skiing. The width of the spread depends on the curvature of the route; the greater the curvature (or the smaller the radius of curvature), the wider the spread.

Assuming that the general routes of the FS relay system are about the same as the existing analog routes and the planned DRS-8 routes (de Witte, 1978), we have drawn a rough sketch of the area intolerably interfered with by the FS relay system. The result is shown in Figure 3. In this sketch, we have assumed the nominal transmitter power throughout the routes and the worst-case condition regardless of the route direction for simplicity; i.e., we have assumed the outer contour of Figure 2(A). We have also assumed that both frequencies that fall in the band 12.2-12.7 GHz

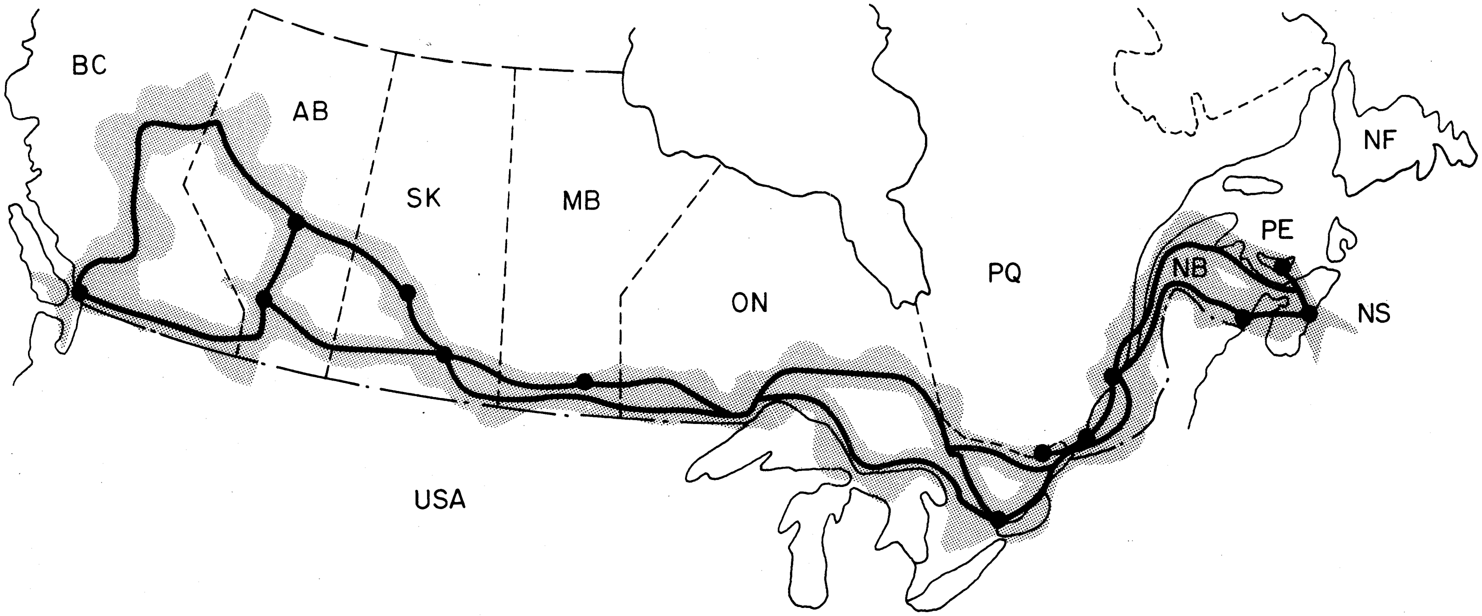


Figure 3. A rough sketch of the area in which BSS receivers would be intolerably interfered with by the Canadian FS relay system.

are used by the FS relay system in every BSS service area. Although the area is not negligibly small, the area is comparably small if the relay system routes are restricted as assumed here. Unfortunately, the area shown in Figure 3 covers much of densely populated areas of Canada. Therefore, it is impossible to replace the BSS for the terrestrial BS (broadcasting service) in such areas, if the wideband trunking-type FS relay system is built across the continent. However, if the BSS is to be used as a supplement to the terrestrial BS in rural areas, there remain many areas where the BSS will be effectively used.

So far in this section, we have assumed that the two FS frequencies that fall in the band 12.2-12.7 GHz are used by the FS relay system in every BSS service area. This assumption, however, might not necessarily be valid. Since the total bandwidth considered for the FS relay system is 2000 MHz and the bandwidth of each FS signal is 240 MHz, there are eight FS frequencies to be assigned to the FS relay system. It is not certain that all eight frequencies are necessary in a geographical area. If one FS frequency can be spared in an area, one-half of the band 12.2-12.7 GHz will become available for the BSS, and sharing between the BSS and the FS by frequency division in the area will become feasible. Sharing will impose a constraint on the design of the FS relay system, but design with such a constraint cannot be considered totally impossible. Sharing will also impose a constraint on the BSS in that all BSS channels in a BSS service area must be in either the upper or the lower half of the band 12.2-12.7 GHz, but the effect of this constraint can be considered minimal.

3.7. Summary

By calculating the minimum separation distance required between the FS transmitting antenna and the BSS receiving antenna from the permissible limit of interfering FS signal power and the FS signal power received by a BSS receiver, we have studied interference from the FS to the BSS. The FS systems considered include a short-hop system for transmission of an FDM-FM telephony signal or an FM TV signal used in the United States and a very wideband, trunking-type digital system envisioned in Canada.

The results of the study indicate that interference from the FS to the BSS is not a negligible problem. For successful sharing between the BSS and the FS, the interference must be controlled by prudent use of both the BSS and FS systems.

To avoid intolerable interference from the FS system currently in use in the United States, the two services must use two different portions of the band in each BSS service area. In other words, sharing must be done by frequency division in each BSS service area. If five BSS channels or less are assigned to a service area in every channel, the BSS will use about one-half of the 500-MHz band and, according to a study by SBS (1978), the FS systems can be accommodated in the rest of the band in most areas.

Since the RF signal bandwidth of the trunking-type FS relay system envisioned in Canada is 240 MHz, interference to the BSS from the FS relay system cannot be controlled by frequency division if both frequencies that fall in the band 12.2-12.7 GHz are used by the FS relay system in a BSS service area. In this case, the interference must be controlled by geographical division. This means that only either BSS or FS, but not both, can be accommodated at a particular geographical location. Since the route of the FS relay system is expected to run through big cities, the BSS is available only in rural areas if no constraint is imposed on the design of the FS relay system.

If this FS relay system can be built under a constraint that at least one FS frequency (with a 240-MHz bandwidth) that falls in the band 12.2-12.7 GHz is spared in each BSS service area, the situation will be completely different. Sharing between the BSS and the FS can be achieved by frequency division in each BSS service area. Although eight FS frequencies (each with a 240-MHz bandwidth) are available for the FS relay system, such a constraint on the design of the FS relay system has investment and economic impact not considered in this report. Sharing will also impose a constraint on the BSS in that all BSS channels in a BSS service area must be in either the upper or the lower half of the band 12.2-12.7 GHz.

4. CONCLUSIONS

In conjunction with the U.S. proposal for the 1979 WARC, we have discussed feasibility of sharing the band 12.2-12.7 GHz between the BSS and FS. As FS systems, we have considered both the short-hop systems currently used in the United States and the very wideband, trunking-type system envisioned in Canada. Interference from BSS to FS is discussed in Section 2, and interference from FS to BSS is discussed in Section 3.

As discussed in Section 2, interference from BSS to FS is in general not a serious problem. A BSS signal power from a broadcasting satellite received by an FS receiving antenna is usually smaller than the FS receiver noise power in the same band. The interfering BSS signal will increase the baseband noise power in some telephone channels in the FDM-FM telephony system and the noise power spectral density in some part of the baseband in the FM TV system, but these increases will be less than 10 dB even in the worst case. These increases can be controlled to an acceptable level by properly designing the FS system.

As discussed in Section 3, on the other hand, interference from FS to BSS is not a negligible problem. For successful sharing between the BSS and FS, the interference of this direction must be controlled by prudent use of both the BSS and FS systems.

To avoid intolerable interference from the FS system currently in use in the United States, the two services must use two different portions of the band in each BSS service area. If five BSS channels or less are assigned to a service area in every other channel, the BSS uses about one-half of the 500-MHz band, and the FS systems can be accommodated in the rest of the band in most areas.

Since the signal bandwidth of the trunking-type FS relay system envisioned in Canada is 240 MHz, interference to the BSS from the FS relay system cannot be controlled by frequency division if both frequencies that fall in the band 12.2-12.7 GHz are used by the FS relay system in a BSS service area. In this case the interference must be controlled by geographical division. Since the route of the FS relay system is expected to run through big cities, the BSS is available only in rural areas if no constraint is imposed on the design of the FS relay system.

If this FS relay system can be built under a constraint that at least one FS frequency (with a 240-MHz bandwidth) that falls in the band 12.2-12.7 GHz is spared in each BSS service area, the situation will be completely different. Sharing between the BSS and the FS can be achieved by frequency division in each BSS service area. Although eight FS frequencies (each with a 240-MHz bandwidth) are available for the FS relay system, designing the FS relay system under such a constraint has investment and economic impact not considered in this report. Sharing will also impose a constraint on the BSS in that all BSS channels in a BSS service area must be in either the upper or the lower half of the band 12.2-12.7 GHz.

5. ACKNOWLEDGMENTS

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APPENDIX A. THE U.S. PROPOSAL OF REVISION OF THE INTERNATIONAL FREQUENCY ALLOCATION TABLE IN THE BAND BETWEEN 11.7 GHz AND 12.75 GHz

As one of the proposals for the 1979 GWARC (General World Administrative Radio Conference) (FCC, 1978), the United States Administration proposes to move the allocation to the BSS (broadcasting-satellite service) from the band 11.7-12.2 GHz to the band 12.2-12.7 GHz for Region 2 in the International Frequency Allocation Table (ITU, 1976). Some changes associated with this move are also proposed. The proposed changes in the band 11.7-12.75 GHz are shown in this appendix.

In the following, underlining indicates new text; hyphens through the text indicate existing text which is being deleted; and "MOD" means a modification of the current provisions. If a service is in all Capitals, then it is a primary service. If a service has a Capital as the first letter and the remainder in lower case, then it is a secondary service.

A.1. References

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ITU (International Telecommunication Union)(1976), Radio Regulations, ITU, Geneva, Switzerland. Article 5 in particular.

Table A.1. 11.7-12.75 GHz

Allocation to Services		
Region 1	Region 2	Region 3
11.7-12.5 FIXED MOBILE except aeronautical mobile BROADCASTING BROADCASTING-SATELLITE 405BA	11.7-12.2 ~~FIXED~~ FIXED-SATELLLITE (Space-to-Earth) ~~MOBILE~~ Mobile except aeronautical mobile ~~BROADCASTING~~ ~~BROADCASTING-SATELLITE~~ ~~405BB~~ MOD 405BC	11.7-12.2 FIXED MOBILE except aeronautical mobile BROADCASTING BROADCASTING-SATELLITE 405BA
	12.2-12.5 FIXED ~~MOBILE except aeronautical-mobile~~ BROADCASTING BROADCASTING-SATELLITE	12.2-12.5 FIXED MOBILE except aeronautical mobile BROADCASTING
12.5-12.75 FIXED-SATELLITE (Space-to-Earth) (Earth-to-space) 405BD 405BE	12.5-~~12.75~~ -12.7 FIXED ~~FIXED-SATELLITE (Earth-to-space)~~ ~~MOBILE except aeronautical-mobile~~ BROADCASTING BROADCASTING-SATELLITE	12.5-12.75 FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE except aeronautical mobile
	12.7-12.75 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE except aeronautical mobile	

405BA Spa2 In the band 11.7-12.2 GHz in Region 3 and in the band 11.7-12.5 GHz in Region 1, existing and future fixed, mobile and broadcasting services shall not cause harmful interference to broadcasting-satellite stations operating in accordance with the decisions of the appropriate broadcasting frequency assignment planning conference (see Resolution No. Spa2-2) and this requirement shall be taken into account in the decisions of that conference.

~~405BB Spa2~~ ~~Terrestrial-radiocommunication-services-in-the-band-11.7-12.2-GHz-in Region-2-shall-be-introduced-only-after-the-elaboration-and-approval-of plans-for-the-space-radiocommunication-services,-so-as-to-ensure compatibility-between-the-uses-that-each-country-decides-for-this-band.~~

405BC
Spa2
The use of the band 11.7-12.2 GHz in Region 2 by the ~~broadcasting-satellite-and~~ fixed-satellite services is limited to domestic systems and is subject to previous agreement between the administrations concerned and those having services, operating in accordance with the Table, which may be affected (see Article 9A ~~and-Resolution-No.-Spa2-3~~).

405BD
Spa2
In Bulgaria, Cameroon, Congo (Brazzaville), the Ivory Coast, Gabon, Ghana, Hungary, Iraq, Israel, Jordon, Kuwait, Libya, Mali, Niger, Poland, Syria, the United Arab Republic, Roumania, Senegal, Czechoslovakia, Togo and the U.S.S.R., the band 12.5-12.75 GHz is also allocated to the fixed service and the mobile, except aeronautical mobile, service.

405BE
Spa2
In Algeria, Belgium, Denmark, Spain, Ethiopia, Finland, France, Greece, Kenya, Liechtenstein, Luxembourg, Monaco, Norway, Uganda, the Netherlands, Portugal, the F.R. of Germany, Sweden, Switzerland, Tanzania and Tunisia, the band 12.5-12.75 GHz is also allocated, on a secondary basis, to the fixed service and the mobile, except aeronautical mobile, service.

APPENDIX B. EXISTING STUDIES ON SHARING BETWEEN BSS AND FS

Some studies already exist on the sharing problems between the BSS and the FS in the 12 GHz band (CCIR, 1978 a,b,c; Comsat, 1978; SBS, 1978; Western Union, 1978; Lee et al., 1979). This appendix presents summaries of those studies with some comments whenever deemed appropriate.

CCIR SPM Report (CCIR, 1978a)

This report states that "interference caused by broadcasting satellites to typical terrestrial systems sharing the same frequencies and locations is generally acceptable provided that the elevation angles to the satellite from these locations are not too small." Regarding the interference of the other direction, this report states that "co-channel interference caused by transmitting stations of the terrestrial fixed service to broadcasting-satellite receiving stations is generally a very serious problem." These statements seem to be in general agreement with the results of other studies.

This report summarizes two input documents (CCIR, 1978 b,c) regarding this subject. The report states that "the geographical separation required is largest for high-capacity digital radio-relay systems, and smallest for certain short-haul radio-relay systems whose transmission parameters are carefully constrained and whose frequency plans are carefully aligned with those of the interfering system(s) in the broadcasting-satellite service." Since the two input documents will be discussed in more detail, comments on this statement are not given here.

CCIR SPM Document by Canada (CCIR, 1978b)

This document studies the sharing problem between the BSS and an FS system now envisioned in Canada. The FS system is premised on the use of the combined 11 and 13 GHz band (10.7-11.7 GHz and 12.2-13.25 GHz) to form a long-haul high-capacity digital trunking system. The nominal value of the transmitter power is 6 dBW, and its maximum value is 13 dBW. The antenna diameter is 2 m. The nominal hop length is 8 km. The RF (radiofrequency) bandwidth is 240 MHz. The RF spectral power is assumed to be uniformly distributed over the total RF bandwidth and, therefore, the transmitter power is equal to -7.8 dBW (nominal) and -0.8 dBW (maximum) per 20 MHz of bandwidth.

Concerning the interference from the BSS to the FS, this document derives the condition for necessary discrimination by the BSS transmitting antenna and the FS receiving antenna. It concludes that the pointing constraints of the FS antenna to avoid the azimuths of specific BSS transmitters in the geosynchronous orbit will be minimal. This conclusion seems to be consistent with those of other studies.

Concerning the interference from the FS to the BSS, this document calculates the minimum separation distance required between an FS station (transmitter) and a BSS earth station (receiver) which is referred to as the coordination distance. The calculated result indicates that separation distances required to meet the co-channel interference protection allowance for the BSS of individual reception will range from a minimum of 100 km up to approximately 300 km. Based on these relatively large coordination distances coupled with unpredictability of all possible locations of BSS receivers within a given service area, the report concludes that sharing between these two services would only be feasible on a geographical basis, i.e., the two services cannot use the same frequency in the same geographical area.

The analysis presented in this document seems to be well-founded insofar as the calculation of the coordination distance in the direction of the FS transmitting antenna main beam is concerned. Since the FS system is a long-haul relay system, however, the coordination distance in the direction normal (perpendicular) to the main-beam direction is also very important to determining the size of the interference area. Although the coordination distance in the normal direction can be read from the figures given in the document, explicit discussions of this subject are not presented in the document.

The document concludes that sharing between the BSS and the FS will only be feasible on a geographical basis. This conclusion may imply that, where the FS system is constructed, the BSS reception must be given up. This is, however, not necessarily the case. Since the total band considered for the FS system is 2000 MHz and the bandwidth of each FS signal is 240 MHz, there are eight frequencies to be assigned to the FS system. If one frequency out of eight can be spared in a geographical area, the BSS can be accommodated in that area. Discussions of this subject are also not included in the document.

<u>CCIR SPM Document by France</u> (CCIR, 1978c)

This document studies the sharing problem between the BSS and the FS system used in France in the band 11.7-12.5 GHz. This FS system operates on one hop or on a small number of hops (not more than five hops) for the transmission of national television programs. The nominal value of the FS transmitter EIRP (equivalent isotropically radiated power) is 1.5 dBW, and its maximum value is 7.5 dBW. The antenna diameter is 1.5 m. The length of a hop is 15 to 20 km.

Concerning the interference caused by the BSS transmitter to the FS radio relay system receiver, the document shows calculated values of the signal-to-interference ratio for the minimum power flux density and for the nominal power flux density of the FS signal. The calculated values range between 33 dB and 46 dB. The document concludes that this interference is negligible in all channels other than that of the satellite itself. This conclusion seems to be consistent with those of other studies.

Concerning the interference caused by the FS system transmitter to the BSS receiver, the document shows the calculated areas of interference caused to a BSS receiver by an FS transmitter operating in the same channel and in the adjacent channel. The size of the area in the direction of the FS transmitting antenna main beam ranges from about 10 km in the case of adjacent-channel interference and a nominal EIRP of 1.5 dBW to over 100 km in the case of co-channel interference and a maximum EIRP of 7.5 dBW. The document concludes that sharing between the BSS and the FS is possible subject to certain constraints.

The document assumes an antenna envelope sidelobe pattern that continues to decrease until the off-axis angle reaches 180°. The antenna envelope sidelobe pattern, however, usually does not decrease beyond a certain value called the residual response. In many cases, the residual response is assumed to be 0 dBi (ITU, 1977). The areas of interference shown in the document must be modified by taking into account the residual response. This revision will increase the area in the direction of distant angles.

The document gives no reasoning that leads from the calculated size of the area on interference to the possibility of sharing. The calculated area of interference is not necessarily small, particularly in the case of cochannel interference, yet the document concludes that sharing is possible. The document lacks the discussion as to how dense (or sparse) the planned FS system is, whether the same channel, an adjacent channel, or a further distant channel is planned for the FS system, etc.

<u>The Comsat Study</u> (Comsat, 1978)

In Para. 49 of its comments on the Eighth Notice of Inquiry, FCC Docket No. 20271, Comsat states that "the BSS would, in general, use only a small part of the band in any one service area, ... In the 1977 Geneva Plan for Region 1, for example, only 12.5% of the band (5 channels out of 40) was assigned to any particular service area. Even allowing for spillover from adjacent service area, terrestrial service could use most of any band it shared with the BSS." These statements are in good agreement with those by SBS (1978) to be discussed later.

These statements, however, overlook two factors. First, since the BSS band is 500 MHz (instead of 800 MHz) in Region 2, only 24 (instead of 40) BSS channels are available in Region 2 if the 1977 WARC-BS plan for Regions 1 and 3 (ITU, 1977) is followed. Second, BSS channels adjacent to a channel which is actually assigned to the BSS cannot be used by the FS systems and, therefore, adjacent channels on both sides must also be included in the BSS channel occupancy. If five BSS channels are assigned to a BSS service area, we must consider that about 10 to 15 channels are occupied by the BSS and that only about one-half of the 500-MHz band can be utilized by the FS at best.

The SBS Analysis (SBS, 1978)

SBS (Satellite Business Systems) analyzed the sharing problem between the BSS and the FS systems currently used in the United States in the band 12.2-12.7 GHz. The conclusions of the analysis are reproduced as follows:

> 55. If a BSS system were based on community reception, then the FS could utilize the full 500 MHz band virtually across the country, subject only to standard coordination of earth station location. In this case there would be little or no restriction on the operation and growth of either BSS or FS systems.
>
> 56. Only if BSS systems were based on a direct-to-home configuration would any sharing complications arise, and even in this case, if the Region 1 Master Plan (1977 WARC) formula were used, the FS could utilize nearly 7/8 of the bandwidth in any service area. That formula is based on a multi-beam configuration designed to increase significantly the total number of channels available through frequency reuse, a goal apparently shared by United States BSS planners.
>
> 57. An analysis undertaken by SBS, summarized below in the Attachment, indicates that in the United States, BSS community reception systems and FS systems could readily share a 500 MHz band through the end of this century, including foreseeable growth of each service. If a domestic direct-to-home BSS system were established, a sharing plan based on a multi-beam formula comparable to the Region 1 Master Plan would impose no restrictions on the number of present FS systems in the United States. Furthermore, even anticipating a 10% compound annual growth rate for the FS, only the Los Angeles metropolitan area would appear to fall outside such a plan by the year 2000.
>
> 58. Even assuming a worst case situation, namely one in which a BSS direct-to-home system were limited to four beams (time zone division) for the United States, our studies indicate that the BSS and the FS could reasonably share the 12.2-12.7 GHz band. In brief, even in this situation, present FS links need not utilize more than 250 MHz except in two, or possibly three, major metropolitan areas. Even projecting an annual compound growth rate of 10%, the number of restricted metropolitan areas would appear to be between three and six by the year 2000 (see Attachment).
>
> * * * * * * *
>
> 61. Given that the delivery of BSS video services in congested metropolitan areas would be better served by community rather than direct-to-home antennas, the entire 500 MHz band as presently allocated for terrestrial services could be retained in those areas. Our studies indicate that the less interference-sensitive community reception service could be provided anywhere in

> the United States. In crowded metropolitan areas, the only restriction imposed would be on the precise location of the BSS community receiver. For example, even in the most congested area, namely the Los Angeles basin, BSS community receivers could be located in approximately 90% of the metropolitan area without harmful interference from existing terrestrial sites.

The SBS analysis concludes that, if the BSS system were based on community reception, then the FS could utilize the full 500 MHz band, subject only to standard coordination on earth station locations. This conclusion, however, is given without any indication of the required minimum separation distance between an FS transmitting antenna and a BSS receiving antenna. Use of a larger antenna in community reception than in individual reception can reduce the required distance, but not drastically. Also since a BSS receiving station is not to be licensed, standard coordination procedure of earth station locations is not applicable to a BSS receiving station even if the station is intended for community reception.

The analysis assumes that, if the 1977 WARC-BS formula for Region 1 (ITU, 1977) were used, the BSS would utilize only one-eighth of the band and the FS could utilize nearly seven-eighths of the band in any service area. The fraction one-eighth assumed for the BSS seems to be based on the observation that only five channels at most out of 40 are assigned to any service area (Comsat, 1978). As discussed earlier, however, we must consider that, if five BSS channels are assigned to a BSS service area, about 10 to 15 channels are occupied by the BSS and that at best only about one-half of the 500-MHz band can be utilized by the FS.

In its appendix, the analysis considers the following four cases:

(1) BSS uses community reception - Region 1 type plan;
(2) BSS uses community reception - FS uses entire 12.2-12.7 GHz band;
(3) BSS uses direct-to-home reception - Region 1 type plan; and
(4) BSS uses direct-to-home reception - limited frequency reuse.

The analysis assumes that the FS uses seven-eighths of the band 12.2-12.7 GHz in Cases (1) and (3), the entire band in Case (2), and one-half of the band in Case (4). Based on the above observations, we consider that only the result for Case (4) is useful.

The result of the SBS study for Case (4) is summarized in Para. 14 of the appendix. It reads:

> 14. The results of our studies indicate that, as the band restriction imposed on the FS is increased from one-eighth to one-half of the allocated band, the first area in the United States that would be seriously constrained is the Los Angeles basin. Assuming a 10% compound annual growth rate to the year 2000, several additional major metropolitan areas might be constrained, including

> New York and Boston. According to the current FS data base, Cleveland is the next most congested area following Los Angeles, Boston and New York. The frequency assignment program was run for the Cleveland area assuming a 10% annual compound growth rate to the year 2000.

This result is reflected in Para. 58 of the text quoted above. Although this case is treated as a worst case in the SBS analysis, it must be considered to be a typical case in the United States because of the above reasons.

The Western Union Study (Western Union, 1978)

In Para. 13 of its comments on the Eighth Notice of Inquiry, FCC Docket No. 20271, Western Union summarizes the results of its study as follows:

> Sharing of the 12.2-12.75 GHz band by the BSS with Terrestrial services is feasible, but not on a co-frequency basis. (Papers presented to various CCIR study groups and service working groups have demonstrated this.) However, since the BSS will not use the full band in all areas in any case, a frequency division arrangement alternating by time zones across the country (or region) would be a viable alternative. We have investigated the present usage of this band by terrestrial services in the U.S., and have found that only small areas on the east and west coasts (essentially the New York and Los Angeles metropolitan areas) show significantly heavy usage, with lesser concentrations in the Chicago, Cleveland and Dallas areas. Since these heavily populated areas are and will continue to be well served by land-based broadcast transmitters, there appears to be no conflict with a sharing arrangement with the BSS countrywide. The areas likely to require BSS service reception (the more lightly populated areas) will experience minimal interference from terrestrial transmitters.

No quantitative discussions are presented in the comments.

The EDUTEL Report (Lee et al., 1979)

Pointing out that sharing between BSS and FS is limited by the interference from FS transmitter into BSS receiver, the report discusses nine different sharing techniques that would reduce the interference. It calculates improvements in discriminating the interfering FS signal at the BSS receiver. The nine techniques discussed in the report are labelled Schemes A to I. They are

A: Frequency interleaving;
B: Split bands and time zone advantage;
C: Power control for terrestrial systems;
D: Increasing terrestrial transmitter antenna size;
E: Avoiding the terrestrial main beam;
F: Larger azimuthal offset angle;
G: Higher elevation angle;

H: Terrain protection;

I: Increasing the broadcasting receiver antenna size.

The report classifies Schemes A and B as techniques imposing restrictions on both BSS and FS; Schemes C and D, on FS only; and all the remaining schemes, on BSS only. The report summarizes the results of the study as follows:

> Some techniques are more attractive, significant improvement can be bought at reasonable prices (like Schemes B, C, E, and H) and some are relatively less attractive (like Schemes A, D, F, G, and I).

After presenting some examples of combined use of the nine techniques, the report concludes as follows:

> Nine different sharing techniques, called Schemes A through I, are proposed, and their improvements and prices are investigated. Examples indicate that sharing will be possible and even become easy if appropriate combinations of sharing techniques are chosen although tradeoffs must be made by broadcasting or terrestrial services or both. This provides a guideline for the consideration of allocation of broadcasting service to this band.

The report lists Scheme B (split band) as one of more attractive techniques. However, it does not discuss the number of BSS channels and the number of FS systems to be accommodated in a particular geographical area.

The report considers only one FS transmitter at a time. In the United States, however, there are a number of FS systems in this band concentrated in or around a large city. Although the report discusses Scheme E (avoiding the terrestrial main beam) as one of the more attractive techniques, it does not treat these FS systems collectively in its discussion.

The report lists Scheme H (terrain protection) also as one of the more attractive techniques. However, it does not give any figure about the extra costs of achieving terrain protection.

B.1. References

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APPENDIX C. SOME STATISTICS OF THE 1977 WARC-BS PLAN FOR REGIONS 1 AND 3

In the plan (ITU, 1977), there are 984 frequency assignments distributed among 247 service areas in 150 countries. Each assignment is identified by an IFRB Serial Number, which consists of a three-digit number and an alphabetical character. All assignments with a common three-digit number are made to a country and to a service area; they differ only in the channel. In the following analyses the IFRB Serial Number is used to indicate only its numerical part.

Statistics by Country Symbol

Frequency assignments are made to 149 country symbols. These symbols include IFB (for IFRB), which is used to reserve one service area each to the Republic of South Africa and to Rhodesia, with five assignments for each area.

The number of assignments per country ranges from 2 (5 countries; BLR, BRU, MLD, NIU, TKL) to 65 (1 country; URS), with 4 (21 countries) or 5 (96 countries) being typical. Only 8 countries have more than 10 assignments. They are ARS (11 assignments), AUS (36), CHN (55), IND (48), INS (21), PAK (11), SDN (15), and URS (65).

The number of IFRB serial numbers per country ranges from 1 (121 countries) to 35 (1 country; CHN). Only six countries have more than three IFRB serial numbers. They are AUS (6 numbers), CHN (35), IND (12), INS (5), PAK (5), and URS (21).

The number of satellite locations per country ranges from 1 (140 countries) to 5 (URS). Only two countries use more than 2 satellite locations. They are CHN (3 locations) and URS (5).

The number of service areas per country ranges from 1 (122 countries) to 35 (1 country; CHN). Only six countries have more than three service areas. They are AUS (6 areas), CHN (35), IND (12), INS (5), PAK (5), URS (21).

Statistics by IFRB Serial Number

The plan uses 252 IFRB serial numbers. These numbers range from 003 to 341.

The number of frequency assignments per IFRB serial number ranges from 1 (37 numbers including 26 numbers assigned to CHN) to 8 (1 number assigned to J), with 4 (53 numbers) or 5 (113 numbers) being typical. Each of 239 IFRB numbers has five assignments or less, each of other 12 IFRB numbers has six assignments, and the remaining one IFRB number has more than six assignments. The 13 IFRB numbers that have more than five assignments each are six numbers for AUS (6 assignments each), one for J (8), one for KOR (6), and five for URS (6 each).

The number of countries per IFRB serial number is always 1. No IFRB serial number is shared by two countries or more.

The number of satellite locations per IFRB serial number is also 1. No IFRB serial number is associated with two satellite locations or more.

The number of service areas per IFRB serial number is also 1. No IFRB serial number is assigned to two service areas or more.

Statistics by Satellite Location

The plan uses 35 satellite locations. Except for the orbit segment between 29^{o}E and 38^{o}E where satellites are 4^{o} and 5^{o} apart, satellites are spaced 6^{o} apart in the geostationary orbit. There are two potential locations not used in the plan; i.e., 116^{o}E and 164^{o}E. (The latter might be used for Region 2, depending on the inter-regional agreement.)

The number of assignments per satellite location ranges from 3 (152^{o}E) to 69 (19^{o}W). Each of 13 satellite locations has 20 assignments or less, each of other 13 locations has 21 to 40 assignments, and each of the remaining nine locations has more than 40 assignments.

The number of countries per satellite location ranges from 1 (10 locations; 160^{o}W, 34^{o}E, etc.) to 13 (31^{o}W, 19^{o}W). Each of 23 satellite locations serves five countries or less, each of other eight locations serves from six to ten countries, and each of the remaining four locations serves more than ten countries.

The number of IFRB serial numbers per satellite location ranges from 1 (5 locations; 160^{o}W, 34^{o}E, etc.) to 15 (92^{o}E). Each of 13 satellite locations has five IFRB numbers or less, each of other 14 locations has from six to ten IFRB numbers, and each of the remaining eight locations has more than ten IFRB numbers.

The number of service areas per satellite location ranges from 1 (5 locations; 160^{o}W, 34^{o}E, etc.) to 15 (92^{o}E). Each of 13 satellite locations serves five service areas or less, each of other 14 locations serves from six to ten service areas, and each of the remaining eight locations serves more than ten service areas.

Statistics by Service Area

The plan identifies 247 service areas. Each service area has a one-to-one correspondence to an IFRB serial number, with the following three exceptions:

- Service area centered at 19.5^{o}W and 61.0^{o}N that corresponds to two IFRB serial numbers 50 (ISL) and 91 (DNK);
- Service area centered at 17.0^{o}E and 61.5^{o}N that corresponds to four IFRB serial numbers 90 (DNK), 104 (FNL), 121 (NOR), and 139 (S);
- Service area centered at 18.4^{o}E and 43.7^{o}N that corresponds to two IFRB serial numbers 148 (YUG) and 149 (YUG).

The number of frequency assignments per service area ranges from 1 (37 areas including 26 areas in CHN) to 10 (1 area in YUG), with 4 (53 areas) or 5 (112 areas) being typical. Each of 232 service areas has five assignments or less, each of other 12 areas has six assignments, and each of the remaining three areas has more than six assignments. The 15 service areas that have more than five assignments each are six areas for AUS (6 assignments each), one area for J (8), one area for KOR (6), one area shared by DNK, FNL, NOR, and S (8), five areas for URS (6 each), and one area for YUG (10).

In 210 service areas where two or more frequency assignments are made, no assignments are made in consecutive channels in an area. In 24 areas out of such areas, assignments are made in every other channel. In the remaining 186 areas, assignments are made in every fourth channel or with wider spacings.

The number of countries per service area ranges from 1 (245 areas) to 4 (1). Each of 245 areas is designated to a single country, one area is shared by two countries (DNK and ISL), and the remaining one area is shared by four countries (DNK, FNL, NOR, and S).

The number of IFRB serial numbers per service area ranges from 1 (244 areas) to 4 (1). Each of 244 areas has one IFRB number, each of other two areas has two IFRB numbers, and the remaining one area has four numbers.

The number of satellite locations per service area is always 1. There is no service area served from two satellite locations or more.

Channel Occupancy in a Service Area

If only the channel with a frequency assignment in a service area is considered to be occupied by the BSS, the channel occupancy is the same as the number of assignments in the service area. The channel occupancy in a service area ranges from 1 (37 areas) to 10 (1), with 4 (53) or 5 (112) being typical. The channel occupancy is 5 or less in 232 service areas, 6 in other 12 areas, and greater than 6 in the remaining three areas.

If adjacent channels are also considered to be occupied by the BSS, the channel occupancy is much greater than the number of channels with assignments. The channel occupancy in a service area in this case ranges from 2 (1 area) to 21 (1), with 9 (21), 12 (36), 14 (26), and 15 (81) being typical. The channel occupancy is 6 or less in 50 service areas, from 7 to 12 in other 75 areas, from 13 to 18 in other 121 areas, and greater than 18 in the remaining one area.

PFD (Power-Flux Density)

The clear-weather PFD at the boresight location of the service area ranges from -101.7 dBW/m^2 to -94.7 dBW/m^2. There are 49 assignments with PFD's -100 dBW/m^2 or below; 220 assignments, over -100 dBW/m^2 up to -99 dBW/m^2; 543 assignments, over -99 dBW/m^2 up to -98 dBW/m^2; 119 assignments, over -98 dBW/m^2 up to -97 dBW/m^2; and 53 assignments over -97 dBW/m^2.

C.1. References

ITU (International Telecommunication Union)(1977), Final Acts of the World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service in Frequency Band 11.7-12.2 GHz (in Regions 2 and 3) and 11.7-12.5 GHz (in Region 1), ITU, Geneva, Switzerland. Article 11 in particular.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The United States Administration has proposed for the 1979 WARC (World Administrative Radio Conference) to move the BSS (broadcasting-satellite service) in ITU (International Telecommunication Union) Region 2 from the band 11.7-12.2 GHz to the band 12.2-12.7 GHz, which is also allocated to the terrestrial FS (fixed service). This report discusses the potential of sharing between the BSS and the FS in the band 12.2-12.7 GHz. It is concluded that sharing is feasible under certain conditions.

16. Key Words *(Alphabetical order, separated by semicolons)*

1979 WARC (World Administrative Radio Conference); band sharing; BSS (broadcasting-satellite service); FS (fixed service); interference.

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