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OF
THE NINTH INTERNATIONAL SYMPOSIUM
ON
SPACE TECHNOLOGY
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TOKYO

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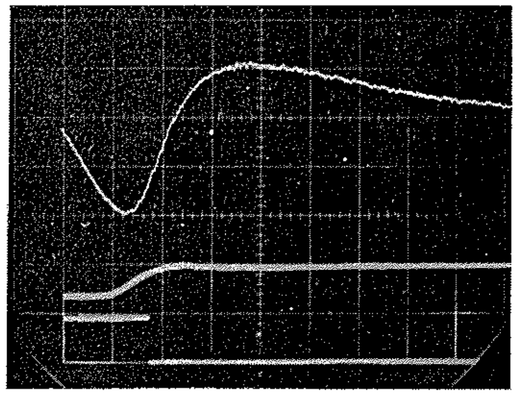
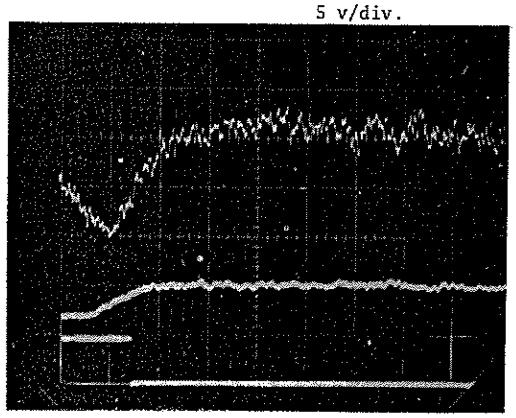
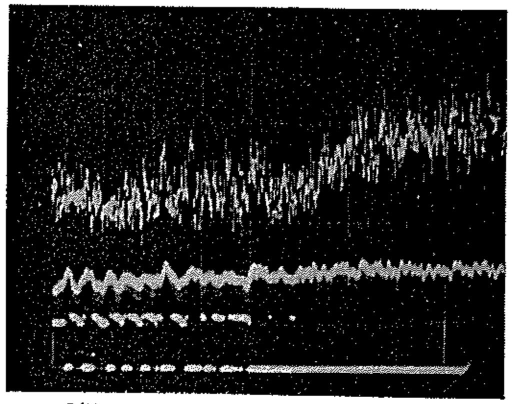


Search ←|→ Tracking 2 ms/div.
C/N = ∞
Upper : Phase detector output 250 mv/div.
Medium: Correlation detector output 1 v/div.
Lower : Search control switching 5 v/div.

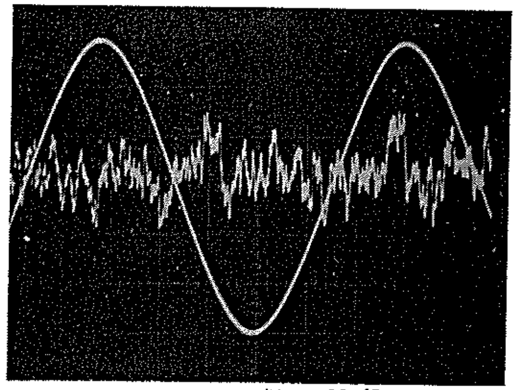


C/N = -10 dB 2 ms/div.

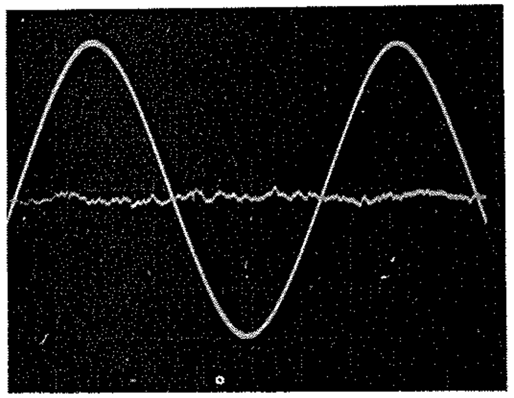


C/N = -17 dB 5 ms/div.

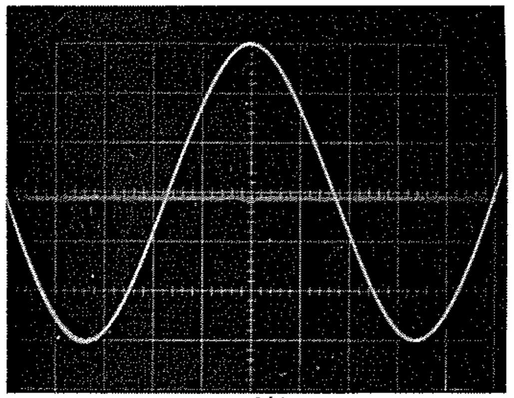
Photo 1. Pull-in Performance of Spread Spectrum Code Synchronization Loop (fscn = 300Hz)



C/N = -20 dB
Sine wave (calibration)
H : 0.5 ms/div.
V : 30 deg/div.
Phase jitter 70 deg p-p
H : 20 ms/div.



C/N = 0 dB
Phase jitter 12 deg p-p
H : 20 ms/div.



C/N = ∞
Phase jitter 3 deg p-p
H : 0.5 ms/div.

Photo 2. Phase jitter in Spread Spectrum Code Synchronization Loop

A STUDY OF FREQUENCY SHARING BETWEEN SATELLITE AND TERRESTRIAL BROADCASTING SYSTEMS

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Yutaka MASUKO

Abstract

This paper describes the conditions for frequency sharing between satellite and terrestrial broadcasting systems.

In VHF·UHF band an interference from broadcasting satellite, emission of which is directed toward some specified area arbitrarily located in the world, may occur over hemisphere of the Earth. The reduction in interference due to geographical separation between satellite and terrestrial service areas is examined and the permissible field strength at the surface of the Earth for satellite broadcasting is shown. In 12 GHz band, since an interference from satellite to terrestrial systems may be restricted within some extent of the local area concerned, the conditions for frequency sharing with overlapping service areas between broadcasting satellite service and the terrestrial services, including television broadcasting and radio relay systems for the studio-transmitter link and the outside-broadcast link, are discussed.

1. Introduction

To assure frequency sharing between broadcasting satellite service and terrestrial services, the two conditions mentioned below must be satisfied simultaneously.

(1) Condition on which terrestrial services can be protected against interferences from satellite emissions.

(2) Condition on which a satellite service can be protected against interferences from terrestrial emissions.

The technical procedure of pursuing such conditions is different from one another among HF, VHF·UHF, and SHF bands, mainly depending on radiation patterns of the antennas used in satellite and terrestrial systems. In this paper VHF·UHF and 12 GHz bands, a study of which has been requested by CCIR on the feasibility of satellite broadcasting, are taken into consideration.

2. Wanted-to-interfering signal ratio

An interference ratio can be expressed by the following equation, when a wanted system is interfered with by "n" interfering systems.

$$\left(\frac{C}{X}\right)_A = \sum_{i=1}^{n} \frac{(P.F.D.)_w}{(P.F.D.)_{ui}} \cdot \frac{A_w}{A_{ui}} \quad \cdots\cdots (1)$$

where $(C/X)_A$ =wanted-to-interfering signal ratio at the input of the receiver at location A,

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$(P.F.D.)_w$, $(P.F.D.)_{ui}$ = power flux density of the wanted signal and of the i-th unwanted signal, respectively, at location A,

A_w, A_{ui} = effective aperture of the receiving antenna to the wanted signal and to the i-th unwanted signal, respectively, at location A.

It is understood that in the case of interference between satellite and terrestrial systems the following factors affect Equation (1).

(1) Radiation pattern of satellite transmitting antenna

(2) Pointing accuracy of satellite transmitting antenna

(3) Radiation pattern of terrestrial transmitting antenna

(4) Radiation pattern of terrestrial receiving antenna

(5) Radiation pattern of earth-station receiving antenna

(6) Station-keeping accuracy of satellites

(7) Type of modulation used

(8) Polarization discrimination.

In calculating interference ratios acceptable values of the above mentioned terms should be decided or assumed, as indicated in the following sections.

3. Interference contour and permissible field strength from broadcasting satellite in VHF and UHF bands

It has already been reported that the geographical separation required for protecting an earth-station receiver against interference from a terrestrial broadcasting transmitter is in the order of several hundred kilometers in VHF and UHF bands.

In this section an attempt is made to clear the effect of interference from a broadcasting satellite to a terrestrial broadcasting receiver on a world wide basis.

Two arbitrarily-selected locations on the earth, located at A (longitude ϕ_A, latitude λ_A) and B (longitude ϕ_B, latitude λ_B) are taken to denote a geographical centre in the terrestrial broadcasting service and in the satellite broadcasting service respectively.

The interference ratio at location A, $(C/X)_A$, can be expressed by Eq. (2) derived from Eq. (1) on the assumption that there is only one satellite concerned. Consequently, the allowable field strength at location B from the satellite is given by Eq. (3).

$$(C/X)_A = E_{T.A} - E_{S.B} + (G_{S(B-A)} + G_{T(O-S)} + \Delta L_{(SB-SA)}) \quad \ldots\ldots\ldots\ldots (2)$$

or $$E_{SB} = E_{TA} - (P.R.)_T + (G_{S(B-A)} + G_{G(O-S)} + \Delta L_{(SB-SA)}) \quad \ldots\ldots\ldots\ldots (3)$$

where

E_{SB} : allowable field strength from the satellite at location B, the centre of the service area (dB rel. 1uV m);

E_{TA} : field strength of the terrestrial broadcasting service to be protected at location A (dB rel. 1uV/m);

$(P.R.)_T$: required protection ratio of terrestrial broadcasting wave to satellite broadcasting wave (dB),

$G_{S(B-A)}$: off-axis gain reduction of the satellite antenna in the direction of location A (dB);

$G_{T(O-S)}$: off-axis gain reduction of the terrestrial receiving antenna in the direction of the satellite (dB);

$\Delta L_{(SB-SA)}$ = difference in path loss between two slant ranges, satellite position to location B and A (dB).

In equations (2) and (3) accurate antenna pointing is assumed and an interference discrimination effect due to cross polarization between the terrestrial and the satellite waves is neglected, because location A may be chosen at any arbitrary place on the Earth. Another interference discrimination effect due to the pattern of the terrestrial receiving antenna is assumed to depend only on angle of elevation of the satellite as seen from location A, since the half-power beamwidth of the antenna may be as much as 55° or more. The third term of equation (2), $(G_{S(B-A)} + G_{T(O-S)} + \Delta L_{(SB-SA)})$, which is defined here as the reduction in interference, can merely be decided by the orbital position of the geostationary satellite, geographical locations of the service area A and B, and antenna radiation patterns relating to $G_{S(B-A)}$ and $G_{T(O-S)}$. It can therefore be projected on the globe viewed from the geostationary satellite as an important parameter in estimating the coexistence of both services.

The expressions of the geometrical relationship with the location of satellite and terrestrial receivers are indicated in Appendix 1, together with the expression of the reduction in interference. The radiation patterns of the satellite transmitting and the terrestrial receiving antennas are assumed by $G(\theta)=1/\{1+(2\theta/\theta_o)^{3.7}\}$ and CCIR Rec. 419 respectively, where θ_o is half-power beamwidth.

Figure 1 snows the contours of the reduction in interference at 800 MHz projected onto the Earth viewed from the satellite, corresponding to various locations of the center of service area for satellite broadcasting, beamwidth of which is assumed to be 4 degrees. Figure 2 shows the similar results in 100 MHz

Substituting into equation (3) the required level of $E_{T.A}$, the required protection ratio and the reduction in interference derived from these figures the allowable field strength from the satellite at location B can be determined.

Table 1 gives some numerical results of this evaluation applied to terrestrial amplitude-modulation television and satellite frequency-modulation television broadcasting in 800 MHz. Table 2 illustrates the evaluation on frequency-modulation sound broadcasting for both terrestrial and satellite services at 100 MHz.

The following conclusion can be derived from the above analysis.

(1) 800 MHz

For protection of a terrestrial amplitude-modulation television broadcasting service at a geographical location (60°E relative longitude, 45°N latitude), as one example, the allowable field strength for satellite frequency-modulation television broadcasting centred at 0° relative longitude, 15°N latitude, as an other example, can be evaluated as 45.5 dB rel. 1uV/m with the illumination of a 4° satellite antenna beamwidth. Under this situation, the interference ratio in other locations of the world can be found such as C/X = 46.8 dB at the location of 50°E relative longitude, 30°N latitude.

(2) 100 MHz

The allowable field strength from a frequency-modulation sound broadcasting satellite centred at sub-satellite point becomes as low as 22 dB rel. 1 uV/m, as an example, with 10° beamwidth illumination from the satellite to protect terrestrial frequency-modulation sound broadcasting assumed at 60°E relative longitude, 45°N latitude.

Special attention should be paid to maintaining the accuracy of satellite antenna pointing with narrow beams to avoid world-wide interference effects from satellites. Although this global evaluation method may also be applied to SHF band in principle, more rigorous considerations on local basis would be suitable especially in 12 GHz band.

4. Conditions for frequency sharing in 12 GHz band

The area of interference between a terrestrial system and a satellite system with overlapping service areas is discussed from the viewpoint of domestic use in 12 GHz band.

The terrestrial systems considered are FM radio-relay systems for television and AM-VSB television broadcasting systems, but not multi-channel telephony systems since it is evident that sharing with multi-channel telephony systems is not practicable. The systems dealt with in this paper are shown as follows.

(1) Broadcasting-satellite system in the 12 GHz band

It is assumed that the broadcasting satellite is to transmit the television signal to the terminal stations in cable distribution systems, whose type of reception is a kind of community reception. Frequency modulation is chosen for the purpose of easy realization. The quality of reception is aimed to be of primary grade which is roughly equivalent to an unweighted signal-to-noise ratio of 39 dB, using a 1 m diameter receiving antenna and a receiver noise figure of 5 dB at the terminal stations. The power flux density at the surface of the Earth is -103.1 dBW/m^2 and the e.i.r.p. from the satellite is 70 dBW (See Table 3).

(2) Terrestrial radio-relay systems for television

The terrestrial radio-relay systems for television considered are the studio-transmitter link (STL) and the outside-broadcast link (OBL) which are operated by the broadcaster.

The required unweighted signal-to-noise ratio is 55 dB, so as not to have a deteriorating effect on the quality of the system as a whole. The output power of an STL or an OBL is usually about 0.3-3 W and the antenna diameter 0.6-3 metres. The required power flux-density of the STL is -74.2 dBW/m^2 and the operating distance is about 22 km. The power flux-density of the OBL is -73.2 dBW/m^2 at an operating distance of 11 km. As the operating time for OBL is shorter than for STL the system margin might be smaller. The 12 GHz band is used only for the short-distance radio link due to the high transmission loss (See Table 3).

(3) Terrestrial television broadcasting systems in the 12 GHz band

The standards of the system are considered to be the same as of the present television broadcasting system and the type of modulation is amplitude-modulation with vestigial sideband for the transmission of many channels. The radius of the service area is assumed to be 15 km. The required e.i.r.p. is 36 dBW and the power flux-density at the fringe of the service area is -73.6 dBW/m^2, using a 1 m diameter receiving antenna and a noise figure of 7 dB for the receiver, to get the unweighted signal-to-noise ratio of 46.5 dB (See Table 3).

4.1 Interference from the satellite to the terrestrial systems

In 12 GHz band it is not necessary to take account of the antenna pattern of the satellite, when the service areas of satellite and terrestrial systems are overlapped. Instead, an entire radiation pattern of the terrestrial receiving antenna could be taken into account for protection of the terrestrial service against interferences from a satellite.

In this case an expression of the interference ratio by Eq.(1) becomes as follows, assuming one interference entry.

$$(C/X)_A = \frac{P_T \cdot G_{TR\cdot TT}}{(P.F.D.)_S \cdot G_{TR\cdot S}} \cdot \left(\frac{4\pi}{\lambda^2} \cdot \frac{1}{L_{TT\cdot TR}}\right) \quad \cdots\cdots (4)$$

where $G_{TR\cdot TT}$: gain of the terrestrial receiving antenna in the direction of the terrestrial transmitter,
$G_{TR\cdot S}$: gain of the terrestrial receiving antenna in the direction of the satellite,
$L_{TT\cdot TR}$: path loss between the terrestrial transmitter and the terrestrial receiver,
other symbols: see Table 3.

Now, $(P.F.D.)_S$ in the FM-TV broadcasting satellite system has the following relation with S/N and other parameters in the satellite down-link path.

$$(P.F.D.)_S = \left(\frac{4k \cdot f_m \cdot T_S \cdot M_S}{3\pi \cdot m_S^2 \cdot \eta_S \cdot D_S}\right) \left(\frac{S}{N}\right)_S \quad \cdots\cdots (5)$$

Replacing $(C/X)_A$ by the required protection ratio $(P.R.)_T$ and substituting Eq.(5) into Eq.(4), then

$$\frac{(P.R.)_T \cdot (\frac{S}{N})_S}{P_T \cdot D_S \cdot G_{TR\cdot TT}} = \left(\frac{3\pi^2 \cdot \eta_S \cdot m_S^2}{k \cdot f_m \cdot T_S \cdot \lambda^2 \cdot M_S}\right) \cdot \left(\frac{1}{L_{TT\cdot TR}}\right) \cdot \left(\frac{1}{G_{TR\cdot S}}\right) \quad \cdots\cdots (6)$$

Denoting the left and right side terms of the above equation as V_{ST}, we have

$$V_{ST} = \frac{(P.R.)_T \cdot (S/N)_S}{P_T \cdot D_S \cdot G_{TR\cdot TT}} \quad \cdots\cdots (7)$$

or $$V_{ST} = \left(\frac{3\pi^2 \cdot \eta_S \cdot m_S^2}{k \cdot f_m \cdot T_S \cdot \lambda^2 \cdot M_S}\right) \cdot \left(\frac{1}{L_{TT\cdot TR}}\right) \cdot \left(\frac{1}{G_{TR\cdot S}}\right) \quad \cdots\cdots (8)$$

The parameter of interference contours (V_{ST}) can be derived from Eq.(8) as functions of the distance between the transmitter and the receiver in a terrestrial system ($L_{TT\cdot TR}$), and of the direction relating to azimuth and elevation angles of the receiving antenna ($G_{TR\cdot S}$).

The geometrical relationship between satellite and terrestrial systems with overlapping service areas is shown in Appendix 2.

By using V_{ST} in Eq.(7), which depends only on primary system parameters that should be decided in the link design, we can apply any value of V_{ST} contours to estimate an effect of interferences.

Fig. 3(a) shows the area in which the broadcasting-satellite system interferes with a terrestrial receiving station, using G = 30-20 log θ (dB) as the expression of the side lobe pattern of the terrestrial antenna. The satellite does not interfere with the terrestrial receiver inside the curve of the required V_{ST} given in the figure.

When applying this figure to the examples of an STL, an OBL and the terrestrial broadcasting system, it is shown that STL receivers within 50 km from the transmitter are not affected for a protection ratio of 30 dB. As the actual operating distance of STL and OBL is 22 km or less, the broadcasting-satellite system provokes no harmful interference to terrestrial television radio-relay systems.

For the terrestrial broadcasting system the protection ratio would be 45 dB and the required e.i.r.p. from the transmitting station would be 36 dBW. Applying Fig. 3(a) to this case, it is shown that the satellite system provokes no harmful interference to terrestrial receivers in the service area.

4.2 Interference from the terrestrial systems to the satellite system

The interference equation in this case includes a term of the radiation pattern of the terrestrial transmitting antenna as follows:

$$(C/X)_A = \frac{(P.F.D.)_S \cdot (\pi (D_S/2)^2 \cdot \eta_S)}{P_T' \cdot G_{TT \cdot SR} \cdot G_{SR \cdot TT} \cdot (1/L_{TT \cdot SR})} \quad \ldots\ldots\ldots\ldots (9)$$

where $G_{TT \cdot SR}$: gain of the terrestrial transmitting antenna in the direction of the satellite earth-station receiver,

$G_{SR \cdot TT}$: gain of the satellite earth-station receiving antenna in the direction of the terrestrial transmitter

$L_{TT \cdot SR}$: path loss between the terrestrial transmitter and the satellite earth-station receiver.

Replacing $(C/X)_A$ by the required protection ratio $(P.R.)_S$ and substituting Eq.(5) into Eq.(9), then

$$\frac{(P.R.)_S \cdot P_T'}{(S/N)_S} = \left(\frac{k \cdot f_m \cdot T_S \cdot M_S}{3\, m_S^2}\right) \cdot \left(\frac{1}{G_{TT \cdot SR}}\right) \cdot \left(\frac{1}{G_{SR \cdot TT}}\right) \cdot (L_{TT \cdot SR}) \quad \ldots (10)$$

Denoting the left and right side terms of the above equation as V_{TS}, we have

$$V_{TS} = \frac{(P.R.)_S \cdot P_T'}{(S/N)_S} \quad \ldots\ldots\ldots\ldots (11)$$

or

$$V_{TS} = \left(\frac{k \cdot f_m \cdot T_S \cdot M_S}{3\, m_S^2}\right) \cdot \left(\frac{1}{G_{TT \cdot SR}}\right) \cdot \left(\frac{1}{G_{SR \cdot TT}}\right) \cdot (L_{TT \cdot SR}) \quad \ldots\ldots\ldots (12)$$

The parameter of interference contours (V_{TS}) can be derived from Eq.(12), as in the case of (V_{ST}) in Eq.(8). By using V_{TS} in Eq.(11), which depends only on primary system parameters that should be decided in the link design, we can apply any value of V_{TS} contours to estimate an effect of interferences.
Figs. 3(b) & 3(c) show examples of an area in which a satellite emission is interfered with by an emission from a terrestrial radio-relay system and a terrestrial broadcasting transmitter respectively. The earth stations outside the curve of the required V_{TS} in the figures are not affected by the terrestrial systems.

When applying these figures to the examples of an STL, and an OBL it is shown that earth-station receivers within 1 to 100 km from the STL or OBL transmitter may be affected for a protection ratio of 30 dB. For the terrestrial broadcasting system, it is also shown that earth-station receivers within 50 km from the transmitter may be affected for a protection ratio of 30 dB.

4.3 Conclusion

The geographical conditions for the frequency sharing are summarized in Table 4.

5. Conclusion

Interference contours by a broadcasting satellite, which illuminates some specific service area selected arbitrarily on the Earth, to terrestrial broadcasting receivers, which locate in any service areas selected on the Earth, are derived from the study for 800 and 100 MHz bands (Figs 1 & 2). The permissible field strength from a broadcasting satellite is also shown (Tables 1 & 2).
As for 12 GHz band the conditions for frequency sharing between the broadcasting satellite and the terrestrial systems for AM-VSB television broadcasting, studio-transmitter link, and outside-broadcast link are made clear for the case of overlapping service areas (Fig. 3). As a conclusion, frequency sharing between the above mentioned systems is only feasible on the condition of geographically shared basis (Table 4).

TABLE 1

Examples of allowable field strength for frequency-modulation television broadcasting from a satellite at 800MHz

Location A		$E_{T.A}$	Protection ratio	Location B		Interference reduction	$E_{S.B}$	$P_{S.B}$
ϕA	λA	$dB_{(rel. 1uV/m)}$	dB	ϕB	λB	dB	$dB_{(rel. 1uV/m)}$	dB W/m²
50°E	30°N	70, (50)	45	0°	0°	25.1	50.1 (30.1)	- 95.7 (-115.7)
				0°	15°N	22.3	47.3 (27.3)	- 98.5 (-118.5)
				0°	30°N	21.3	46.3 (26.3)	- 99.5 (-119.5)
60°E	45°N	70, (50)	45	30°E	0°	19.7	44.7 (24.7)	-101.1 (-121.1)
				30°E	15°N	12.0	37.0 (17.0)	-108.8 (-128.8)

TABLE 2

Examples of allowable field strength for frequency-modulation sound broadcasting from a satellite at 100 MHz

Location A		$E_{T.A}$	Protection ratio	Location B		Interference reduction	$E_{S.B}$	$P_{S.B}$
ϕA	λA	$dB_{(rel. 1uV/m)}$	dB	ϕB	λB	dB	$dB_{(rel. 1uV/m)}$	dB W/m²
20°E	30°N	48, (54)	36, (52)	0°	0°	4.6	16.6, (6.6)	-129.2, (-139.2)
50°E	30°N					8.7	20.7, (10.7)	-125.1, (-135.1)
60°E	45°N					10.1	22.1, (12.1)	-123.7, (-133.7)

Values in brackets correspond to stereophonic sound broadcasting

TABLE 4 Geographical conditions for frequency sharing in 12 GHz

Angle of elevation of satellite: 40°

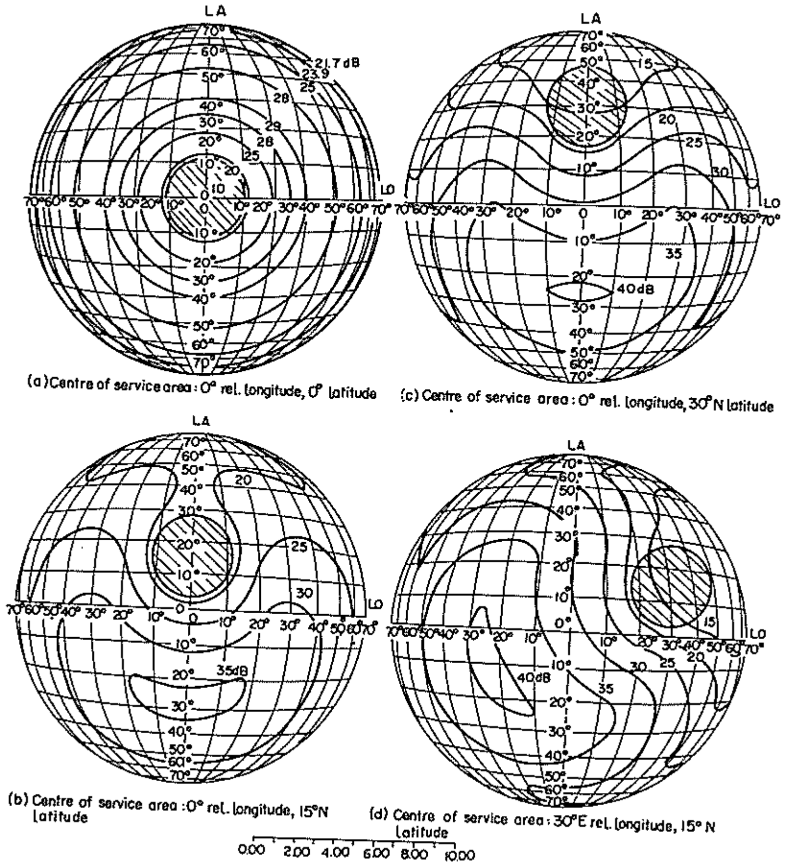
Interfering system	Interfered-with system	Geographical condition
Satellite broadcasting	Terrestrial radio-relay system, for television and broadcasting	Sharing is generally feasible
Terrestrial radio-relay systems for television	Broadcasting-satellite systems	Earth-station receivers should be separated by more than 1 to 100 km from the terrestrial transmitter, depending on the direction of the earth-station receiver
Terrestrial broadcasting	Broadcasting-satellite systems	Earth-station receivers should be separated by more than 50 km from terrestrial transmitting stations

TABLE 3 Examples of 12 GHz systems

Symbol		Studio-transmitter link	OBL	Terrestrial broad-casting	Satellite broad-casting
m_s: FM-modulation index.	Type of modulation	FM	FM	AM-VSB	FM
fm: highest baseband frequency	Radio frequency channel width (MHz)	25	25	6	30
P'_T	Transmitter output power (W)	3	0.3	100	1400
	Diameter of transmitting antenna(m)	2	1	Fan beam	1
P_T	e.i.r.p. from transmitter (dBW)	50	34	36	70
	Noise figure of receiver (dB)	15	15	7	5
D_S	Diameter of receiving antenna (m)	2	1	1	1
$(S/N)_S$	Unweighted signal-to-noise ratio (dB)	55	50	46.5$^{(1)}$	39$^{(1)}$
M_S	Rain margin (dB)	26	15	15	7
	Percentage of time for which rain margin is exceeded	99.95	99.95	99.9	99.99
	Transmission distance (km)	22	11	15	39000
$(P.F.D)_S$	Maximum power flux density at receiving point (dB W/m^2)	-48.2	-58.2	-58.6	-93.1$^{(2)}$
	Minimum power flux$^{(3)}$ density at receiving point (dB W/m^2)	-74.2	-73.2	-73.6	103.1$^{(6)}$
$(P.R.)_T$	Protection ratio$^{(4)}$ against satellite interference (dB)	30	30	45	
$(P.R.)_S$	Protection ratio against terrestrial system interference (dB)				30
k: Boltzman's constant.	Isolation for$^{(5)}$ protecting terrestrial system (dB)	11.1	12.1	25.5	
T_S: System noise temperature.	Off-beam angle of terrestrial antenna required for above isolation (degrees)	1.0	2.0	6.2	
η_S: Antenna efficiency.	Height of terrestrial transmitting antenna(m)	75	75	75	
λ: Wavelength.	Elevation angle of satellite (degrees)				40

(1) the value equivalent to the weighted signal-to-noise ratio of 55 dB.
(2)-(5) the following relation exists, (5) = (2) - (3) + (4).
(6) value at the edge of the service area.

Subscript T or S attached to symbols is the expression for terrestrial or satellite system.



(a) Centre of service area: 0° rel. longitude, 0° latitude
(c) Centre of service area: 0° rel. longitude, 30°N latitude
(b) Centre of service area: 0° rel. longitude, 15°N latitude
(d) Centre of service area: 30°E rel. longitude, 15° N latitude

FIGURE 1 CONTOURS OF REDUCTION IN INTERFERENCE AT 800 MHz PROJECTED ONTO THE EARTH VIEWED FROM THE SATELLITE
Satellite position: 0° relative longitude
Beamwidth of satellite antenna: 4° (service area hatched)

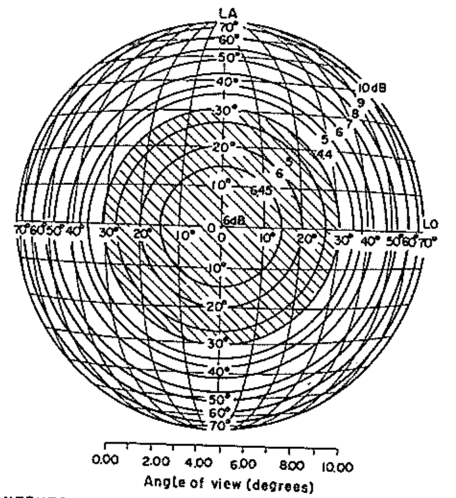
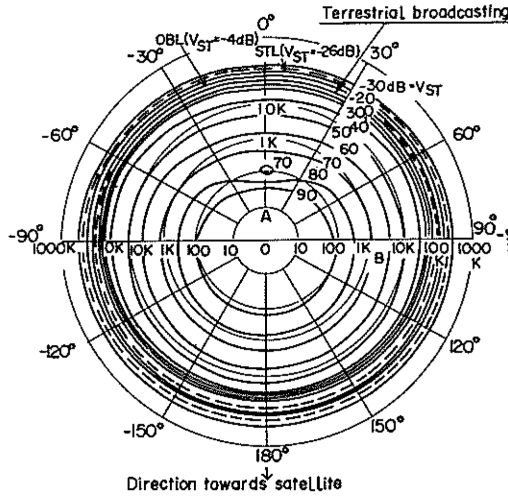
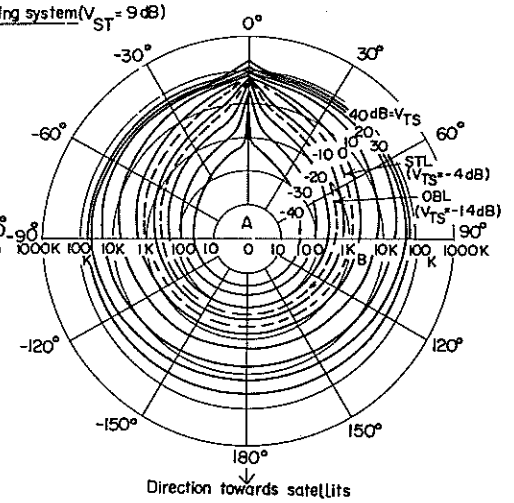


Fig. 2 CONTOURS OF REDUCTION IN INTERFERENCE AT 100 MHz PROJECTED ONTO THE EARTH VIEWED FROM THE SATELLITE
Centre of service area: 0° rel. longitude, 0° latitude
Beamwidth of satellite antenna: 10°



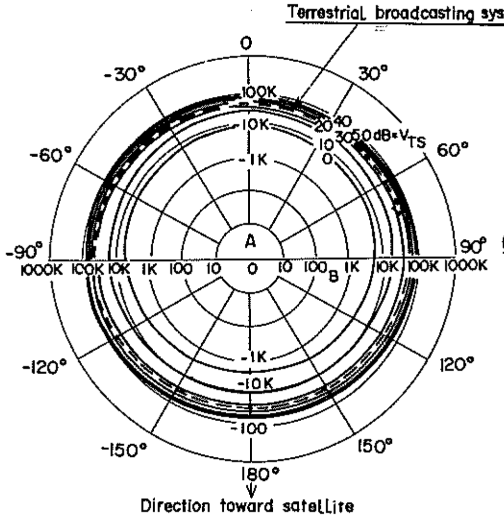
$V_{ST}=(P.R.)_T+(S/N)_S-(E)_T-(G)_{TR}$ (dB)
$(P.R.)_T$: protection ratio for terrestrial system
$(S/N)_S$: unweighted signal-to-noise ratio of satellite system
$(E)_T$: e.i.r.p. of terrestrial transmitter
$(G)_{TR}$: antenna gain of the terrestrial receiver

(a) AREA IN WHICH A SATELLITE SYSTEM INTERFERES WITH A TERRESTRIAL SYSTEM
(The terrestrial receiver inside the curve of required V_{ST} has no harmful interference)



$V_{TS}=(P.R.)_S+(P)_T-(S/N)_S$ (dB)
$(P.R.)_S$: protection ratio for satellite system
$(P)_T$: output power of terrestrial transmitter
Terrestrial receiver is situated on the 0°-line

(b) AREA IN WHICH A TERRESTRIAL SYSTEM INTERFERES WITH A SATELLITE SYSTEM
(The earth receiving station outside the curve of required V_{TS} has no harmful interference)



$V_{TS}=(P.R.)_S+(E)_T-(S/N)_S$ (dB)
$(E)_T$: e.i.r.p. of terrestrial transmitter

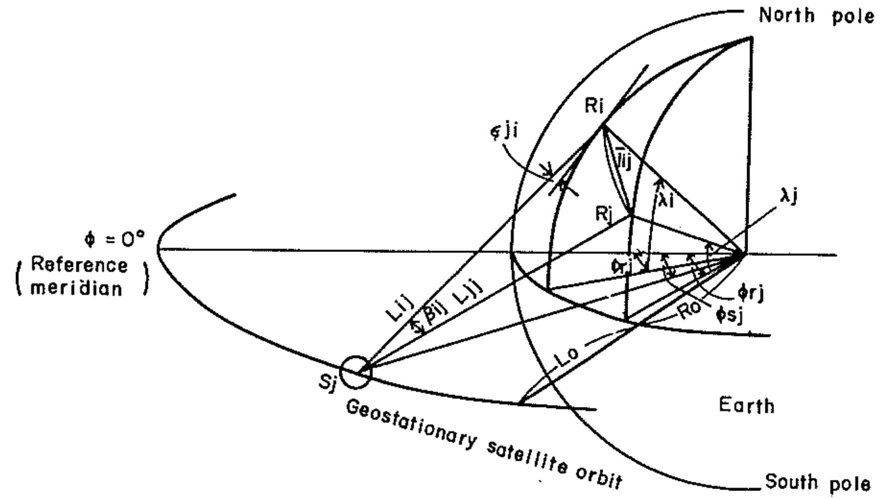
(c) AREA IN WHICH A TERRESTRIAL BROADCASTING SYSTEM INTERFERES WITH A SATELLITE SYSTEM
(The earth receiving station outside the curve of required V_{TS} has no harmful interference)

Frequency: 12 GHz
Angle of elevation: 40°
Diameter of earth-station receiving antenna: 1 m
Height of terrestrial transmitting antenna: 75 m
A: Terrestrial transmitter
B: Distance (m)

FIGURE 3

Appendix 1 Equation for determing geometrical relationship with the locations of satellite and terrestrial receivers

Terms in question	Equation defining the terms in question. (Relative longitude of satellite Sj: ϕsj; Relative longitude and latitude of terrestrial receiving point Ri: ϕri, λi)
Angle subtended from satellite Sj to two receiving points Ri and Rj: βij	$\beta ij = Cos^{-1}(Ljj^2+Lij^2-\overline{lij}^2)/(2 \cdot Ljj \cdot Lij)$
Elevation angle of satellite Sj seen from terrestrial receiving point Ri: ϵji	$\epsilon ji = \pi/2 - Cos^{-1}\left[(Lo/Lij) \cdot \{(1+F) \cdot Cos(\phi rj - \phi si) \cdot Cos\,\lambda i - F\}\right]$
Altitude of geostationary satellite	$Lo = 35761.4$ (km)
Radius of the Earth	$Ro = 6378.4$ (km)
Maximum slant range	$Lmax = Lo. \sqrt{1+2 \cdot F} = 41454.3$ (km)
	$F = Ro/Lo = 0.17836$, $Q = 2F(1+F) = 0.42034$
Slant range between satellite Sj and terrestrial receiving point Ri: Lij	$Lij = Lo \cdot \sqrt{1+Q \cdot \{1-Cos(\phi ri - \phi sj) \cdot Cos\,\lambda i\}}$
Distance between two receiving points Ri and Rj: $\overline{lij}$	$\overline{lij} = F \cdot Lo \cdot \sqrt{2 \cdot \{1 - sin\,\lambda i \cdot sin\,\lambda j - Cos\,\lambda i \cdot Cos\,\lambda j \cdot Cos(\phi rj - \phi ri)\}}$



The reduction in interference (R.I.) can now be given by the following equations, using the notations in Equation 2 and Appendix 2:

$$(R.I.) = G_{S(B-A)} + G_{T(O-S)} + \Delta L_{(SB-SA)}$$

where

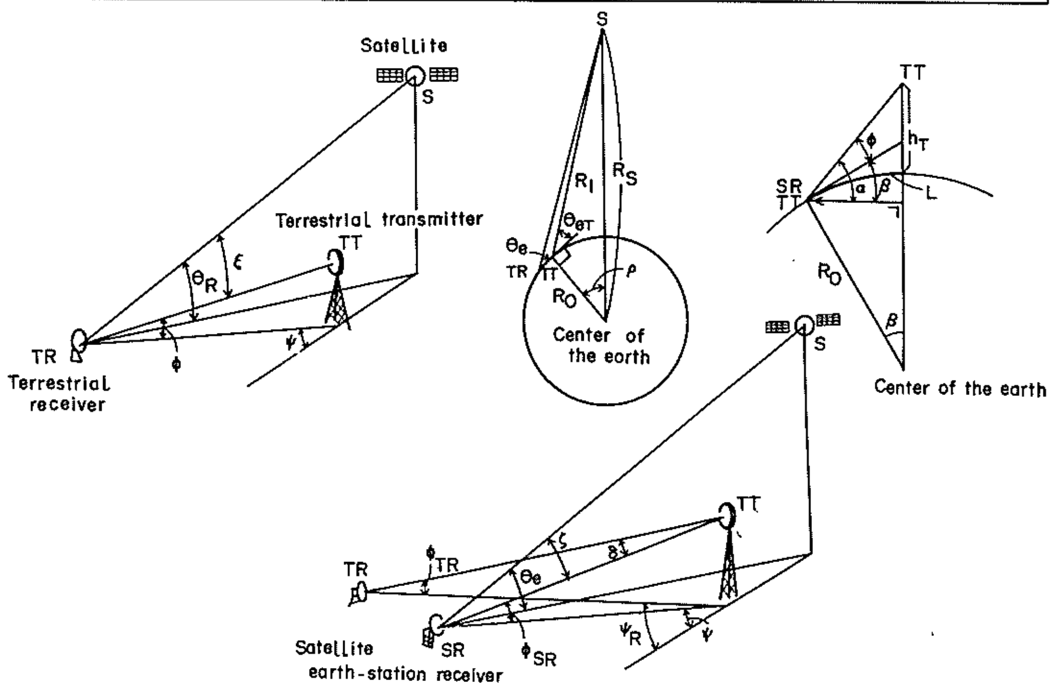
$$G_{S(B-A)} = 10 \log\left[1+\left(\frac{2\beta ij}{\theta_o}\right)^{3.7}\right] \text{(dB)}, \quad (\beta ij \leq 17.3)$$

$$G_{T(O-S)} = 0 \text{ (dB)}, \quad (\text{if } \epsilon ji \leq 20°)$$
$$= 0.4 \cdot \epsilon ji - 8 \text{ (dB)}, \quad (\text{if } 20° \leq \epsilon ji \leq 60°)$$
$$= 16 \text{ (dB)}, \quad (\text{if } \epsilon ji \geq 60°)$$

$$\Delta L_{(SB-SA)} = 2 \cdot Lij(dB) - 2\,Ljj(dB), \quad (0 < \Delta L_{(SB-SA)} < 1.3)$$

Appendix 2 Equation for determining geometrical relationship between satellite and terrestrial systems with overlapping service areas

Terms in question	Equation defining the terms in question
Angle subtended from terrestrial receiver to terrestrial transmitter and satellite: ϵ	$\cos\epsilon = \cos\theta e \cdot \cos\phi \cdot \cos\psi + \sin\theta e \cdot \sin\phi$
Angle subtended from earth-station receiver to terrestrial transmitter and satellite: ζ	$\cos\zeta = \cos\theta e \cdot \cos\phi_{SR} \cdot \cos\psi + \sin\theta e \cdot \sin\phi_{SR}$
Angle subtended from terrestrial transmitter to terrestrial and earth-station receivers: δ	$\cos\delta = \cos\phi_{TR} \cdot \cos\phi_{SR} \cdot \cos(\psi - \psi_R) + \sin\phi_{TR} \cdot \sin\phi_{SR}$
Elevation angle of satellite seen from terrestrial receiver.	$\theta e = \theta eT - \dfrac{(R_I + R_O \sin\theta eT) \cdot R_S \cdot \sin\rho \cdot L \cdot \cos\psi}{R_I^2 \cdot R_O \cdot \cos\theta eT}$
Distance between terrestrial transmitter and satellite.	$R_I = -R_O \cdot \sin\theta eT + \sqrt{R_S^2 - R_O^2 \cdot \cos^2\theta eT}$
Angle subtended from the center of the Earth to satellite and terrestrial transmitter: ρ.	$\cos\rho = (R_S^2 + R_O^2 - R_I^2)/(2R_S \cdot R_O)$
Distance between terrestrial transmitter and receiver.	L
Elevation angle of satellite seen from terrestrial transmitter.	θeT
Distance between the center or the Earth and satellite.	R_S
Elevation angle of terrestrial antenna seen from terrestrial receiver.	ϕ
Azimuth of terrestrial receiver from transmitter.	ψ (Reference azimuth: direction towards terrestrial transmitter from satellite)



OPTIMIZATION STUDY OF THE SATELLITE BROADCASTING SYSTEM FOR TELEVISION

Takehiro IZUMI* and Jun SHIMAOKA*

Abstract

When introducing the broadcasting from space, a careful study of the system optimization should be intensively carried out to make its advantages clear, bearing in mind the present state and development plan of the terrestrial telecommunication and broadcasting networks.

This paper mainly describes economic aspect of a satellite broadcasting system to find optimum combination of a terrestrial rebroadcasting system and a direct community receiving system from satellite.

First, system scale of satellite is optimized in connection with the figure of merit G/T of receivers, then system costs of one country-one satellite system and omnibus satellite system (one satellite to be operated by many countries) have been compared with cost of the terrestrial microwave network system, attaining nationwide full coverage in the country concerned.

A preliminary model for estimating a coverage to be attained by rebroadcasting stations was derived by using the empirical demographic method, and criterion how to combine rebroadcasting and direct community reception in the broadcasting satellite system was described.

1. Introduction

In the developing as well as developed countries, television broadcast has been recognized as one of the useful means for an education and national development. As a huge amount of installation cost is required over a long period for accomplishing the nationwide full coverage by the terrestrial networks, broadcast from space might be effective and economical so far as a country with a large territory is concerned.

Since expenses required for satellite broadcasting are not small, however, it is important to pursue the possibility of introduction of satellite from a long range view and to promote smooth connection between the effective utilization of the satellite and the present and future broadcasting systems.

The following is some of the basic items relating to the condition under which introduction of satellite broadcasting system might be preferable.

(a) Existing terrestrial telecommunication and broadcasting networks and their development plan,

(b) Geographical features such as a territorial area, shape and terrain,

(c) Sociological aspects such as population, population density, racial distribution,

(d) Technical and economic feasibility of satellite system including receivers.

There may be considerable differences in the system requirements for preferable broadcasting satellite among the countries concerned, and the mission objectives and roles of the broadcasting satellite system would depend upon individuality of each country (or each region).

At the beginning of planning the introduction of satellite into broadcasting,

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