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Adjacent Satellite Interference Issues Associated With DSCS III VSAT Links *

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ADJACENT SATELLITE INTERFERENCE ISSUES ASSOCIATED WITH DSCS III VSAT LINKS

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Abstract *Recently, there has been an interest in the development of X-band very small aperture terminals (VSATs) to improve terminal mobility and cost for tactical users. Use of VSATs (in comparison to larger earth terminals), however, increases the levels of interference to and from adjacent satellite systems. This paper addresses adjacent satellite interference issues associated with the use of VSATs and DSCS III space segment. It first describes the role of the ITU in preventing harmful adjacent satellite interference from occurring. It then performs adjacent interference analysis for different DSCS III VSAT (briefcase and manpack terminals) link interference environment scenarios. Finally, it provides conclusions and recommendations on how a DSCS III VSAT link should be designed and operated in compliance with ITU rules and regulations on adjacent satellite interference. Questions on whether spread spectrum should be used and the amount of spectrum spreading required are also answered in the paper.*

1.0 Introduction

Recently, there has been an interest in the development of X-band very small aperture terminals (VSATs) to improve terminal mobility and cost for tactical users. Examples of these X-band VSATs include the NATO manpack terminals, the USAF portable terminal system and the briefcase terminal system currently planned by DISA.

Use of VSATs increases the levels of interference to (and from) adjacent satellite (and terrestrial) systems; because, VSATs, with their lower antenna gains (in comparison to larger earth terminals) require higher satellite EIRPs (for satellite links to VSATs) and higher earth terminal HPA power (for satellite links from VSATs) to support a given data rate. They also have much less off-axis gain isolation against interference to (and from) adjacent satellite systems. Due to the increase in interference by using X-band VSATs, there have been significant discussions within the government community on whether or not (direct sequence) spread spectrum [1] should be imposed as a waveform standard to alleviate the interference. For example, spread spectrum with coding gains of 10, 28, and 437 [2] have been proposed as the NATO STANAG 4485 waveform standard to alleviate adjacent satellite interference.

This paper addresses adjacent satellite interference issues due to the use of VSATs and DSCS III (Defense Satellite Communication System, Third Generation) space segment. Section 2 provides rules and regulations imposed by the International Telecommunication Union (ITU), an organ of the United Nations, to prevent harmful adjacent satellite interference from occurring. Section 3 derives general equations that can be used to estimate the adjacent satellite interference (ASI) effects in the ITU format (i.e., $\Delta T/T$). Section 4 presents simulated ASI results associated with VSATs for different DSCS III interference environment scenarios (e.g., uplink antenna coverage, downlink antenna coverage, transponder gain states, satellite spacing). Finally, Section 5 provides conclusions and recommendations on how a DSCS III VSAT link should be designed and operated in compliance with ITU rules and regulations on ASI. Questions on whether spread spectrum should be used and the amount of spectrum spreading required are also answered in the paper.

2.0 ITU Rules And Regulations

According to ITU-Radio Regulations (RR), Article 8, the military X-band, (7.9 - 8.4) GHz for uplink and (7.25 - 7.75) GHz for downlink, is shared mainly on a co-primary basis among different satellite and terrestrial systems to provide: fixed satellite services (FSS), mobile satellite services (MSS), earth exploration satellite services (EESS), meteorological satellite services (MetSS) fixed (terrestrial) services (FS) and mobile (terrestrial) services (MS). Interference between systems that provide these services occur and is exacerbated by the use of very small aperture terminals (VSATs) to establish satellite links. To limit the amount of interference generated from a satellite link, the ITU have set the following constraints on X-band satellite links:

Earth Terminal EIRP Density Limits at The Horizon

The equivalent isotropically radiated power (EIRP) transmitted in any direction towards the horizon by a terminal shall not exceed the following limits (ITU-RR, Article 28):

- 40 dBW/4 kHz $\delta \leq 0^o$
- $40 + 3\delta$ dBW/4 kHz $0^o < \delta \leq 5^o$
- Any $5^o < \delta$

where δ is the elevation angle of a radiation direction (i.e., angle formed by a radiation direction and the horizontal plane).

Satellite Power Flux Density Limits at Earth Surface

The satellite power flux density at earth surface shall not exceed the following limits (ITU-RR, Article 28):

- -152 dBW/m^2/4 kHz $0° \leq \delta \leq 5°$
- $40 + 0.5(\delta\text{-}5)$ dBW/m^2/4 kHz $5° < \delta \leq 25°$
- -142 dBW/m^2/4 kHz $25° < \delta \leq 90°$

Transmit Earth Terminal Antenna Radiation Pattern Limits

The ITU transmit earth terminal antenna radiation pattern constraints are stated in ITU-R S.580 where the gain G of at least 90 % of the side-lobe peaks does not exceed the envelope

$$G(\theta) = 29 - 25\log(\theta) \quad \text{(dBi)}$$

for $\theta \leq 20^\circ$ and $D/\lambda \geq 50$. The ITU-R S.580 document, however, has not yet set antenna pattern constraints for $D/\lambda < 50$ (e.g., D < 1.8 m for f = 8.4 GHz) which are of interest here.

For frequency coordination and interference assessment purposes, when measured data are not available, the following reference antenna radiation patterns (ITU-R S.391 or ITU-RR, Appendix 29) has been recommended by the ITU :

For $D/\lambda < 100$

$$\begin{array}{lrcccl} G(\theta) = G_{max} - 2.5\times10^{-3}(\theta D/\lambda)^2 & 0^\circ & < & \theta & < & \theta_m \\ G(\theta) = G_1 & \theta_m & \leq & \theta & < & 100\lambda/D \\ G(\theta) = 52 - 10\log(D/\lambda) - 25\log\theta & 100\lambda/D & \leq & \theta & < & 48^\circ \\ G(\theta) = 10 - 10\log(D/\lambda) & 48^\circ & \leq & \theta & \leq & 180^\circ \end{array}$$

For $D/\lambda \geq 100$

$$\begin{array}{lrcccl} G(\theta) = G_{max} - 2.5\times10^{-3}(\theta D/\lambda)^2 & 0^\circ & < & \theta & < & \theta_m \\ G(\theta) = G_1 & \theta_m & \leq & \theta & < & \theta_r \\ G(\theta) = 32 - 25\log(D/\lambda) & \theta_r & \leq & \theta & < & 48^0 \\ G(\theta) = -10 & 48^0 & \leq & \theta & \leq & 180^0 \end{array}$$

where

G_{max} = G(0) = maximum antenna gain, dBi,
D = antenna aperture diameter,
λ = operating wavelength, (in same unit as D),
θ = off-axis angle of the antenna, degrees,
G_1 = gain of first sidelobe = $2 + 15\log(D/\lambda)$, dBi,
θ_m = $(20\lambda/D)(G_{max} - G_1)^{1/2}$, degrees, and
θ_r = $15.85\,(D/\lambda)^{-0.6}$, degrees.

Note that from extensive satellite link calculation results using DSCS III satellite characteristics, it was found that [5] the terminal EIRP density limits at the horizon and the satellite power flux density limits at earth surface can be met (without using spread spectrum) by links using briefcase-sized antennas (with equivalent 0.4 m aperture diameter), BPSK modulation, and 1/2-rate FEC coding for all practical link scenarios (i.e., all practical gain states and antenna configurations).

Note also that the constraints stated above only provide a reasonable interference protection and do not represent the worst possible conditions, i.e., harmful interference may occur, despite conformance to the constraints. Thus, the ITU also set rules that require system operators to coordinate with each other to avoid harmful interference. From the ITU-RR, Appendix 29, coordination between two adjacent satellite systems is required if interference from one system results in an increment of the equivalent overall noise temperature (T) of a link of the other system by more than 6 % {i.e., $\Delta T/T > 6$ %}[1]. $\Delta T/T$ can be calculated from the adjacent satellite interference equations to be derived in the next section.

3.0 Adjacent Satellite Interference Equations

A generalized diagram showing key parameters involving in adjacent satellite interference (ASI) analysis is depicted in Figure 1. In the figure, there are two satellite links:

a) link T'S'R' where a carrier is transmitted from earth terminal T' to earth terminal R' via satellite S', and
b) link TSR where a carrier is transmitted from earth terminal T to earth terminal R via satellite S.

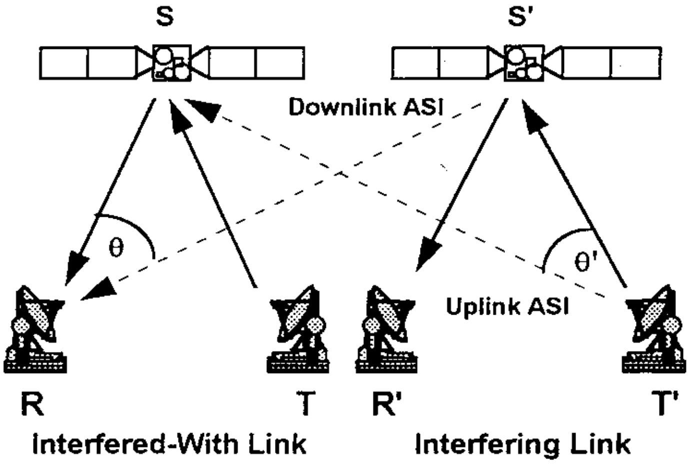

Figure 1. Adjacent Satellite Interference Diagram

Due to the interference symmetry, only the interference from link T'S'R' to link TSR is considered and shown in the block diagram. There are two interference paths through which carrier power spillovers take place and make up the adjacent satellite interference:

i) <u>Uplink interference path T'S</u> through which a fraction of the carrier power radiated from transmit earth terminal T' is received and amplified by the satellite S and then propagated to receive earth terminal R, and
ii) <u>Downlink interference path S'R</u> through which a fraction of carrier power re-radiated by satellite S' is received by earth terminal R.

To derive the ASI equations, these parameters are used:

C: carrier power at input of demodulator of terminal R,
C/I_u (or C/I_d): power ratio between carrier of link TSR and uplink (or downlink) interference component,
E_b: equivalent clear sky energy-per-(uncoded) bit at input of demodulator of terminal R,
E_b/N_o: operating clear sky E_b/N_o of link TSR without influence of ASI from link T'S'R',
I_{ou} (or I_{od}): equivalent clear sky noise density of uplink (or downlink) interference component at input of demodulator of terminal R,
N_o (or N_{ow}): equivalent clear sky overall noise power density of link TSR without (or with) influence of ASI from link T'S'R' at input of demodulator of terminal R,
PD_R: polarization discrimination of receive antenna of terminal R against interfering carrier (of link T'S'R'),

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[1] Note that the ($\Delta T/T$) of 6 % is equivalent to causing a loss of only 0.25 dB in operating E_b/N_o; a very tigh constraint. Yet this constraint was already relaxed from the old limit of 4 % or 0.17 dB set more than a decade ago.

PD_{Sr}: polarization discrimination of receive antenna of satellite S against interfering carrier (of link T'S'R'),

R_b: uncoded bit rate (bit rate before forward error correction (FEC)) of link TSR,

R_s (or R'_s): symbol rate of link TSR (or link T'S'R'),

S_s (or S'_s): spread spectrum coding gain of link TSR (or T'S'R'), when spread spectrum is not used S_s (or S'_s) = 1,

T (or T_w): equivalent clear sky overall noise temperature of link TSR without (or with) influence of ASI from link T'S'R' at input of demodulator of terminal R,

W: effective bandwidth relating power of interferor I_u (or I_d) to corresponding equivalent noise density I_{uo} (or I_{do}),

$\Delta EIRP_{SS'}$: $EIRP_S$ - $EIRP_{S'}$, where $EIRP_S$ (or $EIRP_{S'}$) is carrier EIRP at satellite S (or S') in direction of terminal R (or R'),

$\Delta EIRP_{TT'}$: $EIRP_T$ - $EIRP_{T'}$, where $EIRP_T$ (or $EIRP_{T'}$) is carrier EIRP at terminal T (or T') in direction of satellite S (or S'),

ΔFSL_d: $FSL_d(SR)$ - $FSL_d(S'R)$, where $FSL_d(SR)$ (or $FSL_d(S'R)$) is downlink free space loss for path SR (or S'R),

ΔFSL_u: $FSL_u(TS)$ - $FSL_u(T'S)$, where $FSL_u(TS)$ (or $FSL_u(T'S)$) is uplink free space loss for path TS (or T'S),

$\Delta G_R(\theta)$: $G_R(S)$ - $G_R(S')$, where $G_R(S)$ (or $G_R(S')$) is receive antenna gain at terminal R in direction of satellite S (or S'). ($\Delta G_R(\theta)$ can be treated as receive antenna gain discrimination of terminal R at off-axis angle θ),

ΔG_{Sr}: $G_{Sr}(T)$ - $G_{Sr}(T')$, where $G_{Sr}(T)$ (or $G_{Sr}(T')$) is receive antenna gain at satellite S in direction of terminal T (or T'),

$\Delta G_{S't}$: $G_{S't}(R')$ - $G_{S't}(R)$, where $G_{S't}(R)$ (or $G_{S't}(R')$) is transmit antenna gain at satellite S' in direction of terminal R(or R'),

$\Delta G_T(\theta')$: $G_T(S')$ - $G_T(S)$, where $G_T(S)$ (or $G_T(S')$) is transmit antenna gain at terminal T' in direction of satellite S (or S') ($\Delta G_T(\theta')$ can be treated as transmit antenna gain discrimination of terminal T' at off-axis angle θ'),

ΔT: increment, (T_w-T), of equivalent clear sky overall noise temperature of link TSR due to ASI from link T'S'R' at input of demodulator of terminal R,

ΔT/T: relative increment of equivalent clear sky overall noise temperature of link TSR due to ASI from link T'S'R' at input of demodulator of terminal R,

$(\Delta T/T)_u$ (or $(\Delta T/T)_d$): portion of ΔT/T due to uplink (or downlink) interference component from link T'S'R',

θ (or θ'): (topocentric) angle SRS' (or ST'S'),

By definition,

$$\begin{aligned}(\Delta T/T) &= (T_w - T)/T = (T_w/T) - 1 = (N_{ow}/N_o) - 1\\ &= [(C/N_o)/(C/N_{ow})] - 1\\ &= (C/N_o)\,[(C/N_o)^{-1} + (C/I_{ou})^{-1} + (C/I_{od})^{-1}] - 1\\ &= (C/N_o)\,[(C/I_{ou})^{-1} + (C/I_{od})^{-1}]\\ &= (R_b/W)\,(E_b/N_o)\,[(C/I_u)^{-1} + (C/I_d)^{-1}] \qquad (1)\end{aligned}$$

From ITU-R S.792, the interfering PSK carrier power can be related to the interfering carrier power density by the interfering carrier symbol rate (R'_s). To convert the interfering carrier power density to the equivalent noise density, adjustment must be made to take into consideration the differences in the center frequencies and symbol rates of the carriers and whether the interfered-with carrier (carrier of link TSR) uses (direct sequence) spread spectrum or not. When the two carriers are lined up in center frequencies (worst case), the effective bandwidth W (that relates I_u (or I_d) to I_{ou} (or I_{od}) can be related to the symbol rates R_s and R'_s by Eq. (2a) (when the interfered-with carrier is not spectrum spread) or by Eq. (2b) (when the interfered-with carrier is spectrum spread),

$$W = \mathrm{Max}\{R_s, R'_s\} \quad \text{without spread spectrum} \qquad (2a)$$

$$W = (R_s + R'_s)^{*} \quad \text{with spread spectrum} \qquad (2b)$$

Table 1 displays values of R_b/W when both links TSR and T'S'R' have the same center frequency, same uncoded bit rate, same modulation (both BPSK or QPSK), same FEC coding rate (both 1, 3/4 or 1/2), and same spread spectrum coding gain.

Table 1. (R_b /W) For Links Having Same Waveform, Center Frequency, And Bit Rate.

Modulation	**FEC Rate**	**Spread Spectrum**	**Symbol Rate**	**(R_b /W) (Unitless)**
BPSK	1	No	R_b	1
BPSK	3/4	No	(4/3) R_b	3/4
BPSK	1/2	No	2 R_b	1/2
QPSK	1	No	(1/2) R_b	2
QPSK	3/4	No	(2/3) R_b	3/2
QPSK	1/2	No	R_b	1
BPSK	1	Yes	$R_b S_s$	$1/(2S_s)$
BPSK	3/4	Yes	(4/3) $R_b S_s$	$3/(8S_s)$
BPSK	1/2	Yes	2 $R_b S_s$	$1/(4S_s)$
QPSK	1	Yes	(1/2) $R_b S_s$	$1/S_s$
QPSK	3/4	Yes	(2/3) $R_b S_s$	$3/(4S_s)$
QPSK	1/2	Yes	$R_b S_s$	$1/(2S_s)$

The two terms in the right hand side of Eq. (1) are the portions of ΔT/T due to the uplink and downlink interference components, $(\Delta T/T)_u$ and $(\Delta T/T)_d$, respectively.

By definition, the carrier-to-downlink interference ratio C/I_d in Eq. (1) can be related to the link parameters and the terminal and satellite antenna parameters by Eq. (3),

$$\begin{aligned}C/I_d &= \{EIRP_S - FSL_d(SR) + G_R(S)\}\\ &\quad - \{[EIRP_{S'} - \Delta G_{S't}] - FSL_d(S'R) + G_R(S') - PD_R\}\\ &= \Delta EIRP_{SS'} + \Delta G_{S't} + \Delta G_R(\theta) + PD_R - \Delta FSL_d \ \text{(dB)} \qquad (3)\end{aligned}$$

By assuming the carrier-to-uplink interference ratio at the demodulator input is the same as that at the satellite transponder input[2], C/I_u (in dB) can be related to the link parameters and the terminal and satellite antenna parameters by Eq. (4),

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[*] Note that Eq. (2b) is used because the despreader is assumed to be a mixer (i.e., multiplying process) where the power spectrum of the interfering carrier after despreading is proportional to the convolution of that before despreading with the power spectrum of the pseudo-noise chip sequence.

[2] This assumption is valid for transponder backoff (from saturated power) operation (e.g., transponder is accessed by multiple carriers) [3]

$$
\begin{aligned}
C/I_u &= \{EIRP_T - FSL_u(TS) + G_{Sr}(T)\} \\
&\quad - \{[EIRP_T - \Delta G_T(\theta')] - FSL_u(T'S) + G_{Sr}(T') - PD_{Sr}\} \\
&= \Delta EIRP_{TT} + \Delta G_{Sr} + \Delta G_T(\theta') + PD_{Sr} - \Delta FSL_u \text{ (dB)} \quad (4)
\end{aligned}
$$

4.0 Adjacent Satellite Interference Analysis Results

In this section, a parametric approach is taken to estimate the ASI effects using typical characteristics of DSCS III satellites and their associated links. The following assumptions are made in the parametric study:

- The links use BPSK modulation and 1/2-rate FEC coding[3] and are operated with the same center frequency, information bit rate (so that $R_b/W = -3$ dB), and clear sky E_b/N_o of 9 dB.
- The links have the same polarization type and orientation so that there is no polarization discrimination against the interference (i.e., $PD_{Sr} = PD_R = 0$ dB).
- The topocentric angles θ and θ' are the same as the geocentric angle (i.e., the satellite spacing).
- The distances of the desired paths (TS and SR) are the same as those of interference paths (T'S and S'R) (i.e., $\Delta FSL_u = \Delta FSL_d = 0$ dB).
- The terminals are located on the same satellite antenna gain contours (i.e., $\Delta G_{Sr} = \Delta G_{St} = 0$ dB).
- The terminals considered are:
  - -- Briefcase (B): D = 0.4 m, G/T = 6 dB/K
  - -- Manpack (M): D = 0.6 m, G/T = 8 dB/K
  - -- Point-Point (P): D = 2.4 m, G/T = 18 dB/K
  - -- Hub (H) D = 11 m, G/T = 33 dB/K
- The links considered are:
  - -- Inbound (IB1: B-to-H, IB2: M-to-H)
  - -- Outbound (OB1: H-to-B, OB2: H-to-M)
  - -- Point-To-Point (PP: P-to-P)

Case A: Same Operating Satellite Characteristics

When the two satellites are operated with the same characteristics, the differences in the terminal carrier EIRPs and in the satellite carrier EIRPs are identical (i.e., $\Delta EIRP_{TT} = \Delta EIRP_{SS}$). These differences can be approximated by the differences in G/Ts of the receive terminals of the interfering link and of the interfered-with link [5]. Accordingly, the ASI effects, quantified in terms of $\Delta T/T$, can directly be calculated from Eqs. (1), (3) and (4) and the results are shown in Table 2.

From Table 2, many interference scenarios for Case A exceed the 6 % limit and the worst interference scenario is OB-OB (i.e., interference from an outbound link to an outbound link). At the required operating clear sky E_b/N_o of 9 dB and the satellite spacing of (2, 3, and 4°), the $\Delta T/T$ values corresponding to OB1-OB1 (the outbound links using the briefcase terminals) and OB2-OB2 (the outbound links using the manpack terminals) are (316, 237, and 159 %) and (237, 124, and 50 %) respectively. To avoid coordination, the $\Delta T/T$ values need to be reduced to 6 % or below; and this reduction requires the use of spread spectrum with corresponding coding gains of (53, 40, and 27) and (40, 21, and 9) respectively.

Note that the $\Delta T/T$ values increase/decrease when the required clear sky E_b/N_o increases/decrease. For instance, for the satellite spacing of 2° and the OB1-OB1 scenario, the $\Delta T/T$ values corresponding to the required clear sky E_b/N_o values of (8.0, 9.0, and 10 dB) are (251, 316, and 398).

Table 2. $\Delta T/T$ For Case A: Same Satellite Characteristics.

Scenario	Interfering Link	Interfered-With Link	$\Delta T/T$ (%) for Satellite Spacing of		
			2°	3°	4°
IB1-IB1	B-to-H	B-to-H	303	216	134
IB1-OB1	B-to-H	H-to-B	1	1	1
IB1-PP	B-to-H	P-to-P	10	7	4
OB1-IB1	H-to-B	B-to-H	72	26	13
OB1-OB1	H-to-B	H-to-B	316	237	159
OB1-PP	H-to-B	P-to-P	139	50	25
PP-IB1	P-to-P	B-to-H	217	79	38
PP-OB1	P-to-P	H-to-B	20	15	10
IB2-IB2	M-to-H	M-to-H	216	100	34
IB2-OB2	M-to-H	H-to-M	1	1	0
IB2-PP	M-to-H	P-to-P	7	3	1
OB2-IB2	H-to-M	M-to-H	46	17	9
OB2-OB2	H-to-M	H-to-M	237	124	50
OB2-PP	H-to-M	P-to-P	88	32	16
PP-IB2	P-to-P	M-to-H	217	79	38
PP-OB2	P-to-P	H-to-M	24	13	5

Case B: Different Operating Satellite Characteristics

In general the two satellites are not identical, and therefore their characteristics are not the same. Even if they are identical, they may be operated in different configurations (e.g., different gain states, HPA sizes and backoffs, transmit and receive antenna patterns), and accordingly their operational characteristics are not the same. For Case B, it is assumed that

- The interfering link uses DSCS III Channel 1 operated with transponder gain state 4 (transponder gain of 112.5 dB) and connected to receive antenna MBA-EC (Multiple Beam Antenna - Earth Coverage mode, with antenna gain of 15.7 dBi) and transmit antenna MBA-EC (Multiple Beam Antenna - Earth Coverage mode, with antenna gain of 15.0 dBi), and
- The interfered-with link uses DSCS III Channel 1 operated with transponder gain state 2 (transponder gain of 125.2 dB) and connected to receive antenna MBA-NC (Multiple Beam Antenna - Narrow Coverage mode, with antenna gain of 26.7 dBi) and transmit antenna GDA (Gimbaled Dish Antenna, with antenna gain of 30.2 dBi).

The assumptions made here for Case B are somewhat conservative but still reasonable (i.e., not the worst case), in terms of adjacent satellite interference effects. Results for other assumptions for Case B can be found in [5].

In [5], power budgets for the links with the above space segment assumptions were performed and the terminal and satellite carrier EIRPs required to support the links of all the scenarios considered were calculated. The differences in terminal and satellite carrier EIRPs (i.e., $\Delta EIRP_{TT}$ and

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[3] These are typical modulation and coding used in commercial VSAT links [4]

$\Delta EIRP_{SS'}$) were then obtained and the $\Delta T/T$ values were computed from Eqs. (1), (3) and (4) and are shown in Table 3.

From Table 3, all interference scenarios for Case B exceed the 6 % limit and the worst interference scenario is IB-IB, not OB-OB as in Case A. At the required operating clear sky E_b/N_o of 9 dB and the satellite spacing of (2, 3, and 4°), the $\Delta T/T$ values corresponding to IB1-IB1 and IB2-IB2 are (162181, 115345, and 71779 %) and (115345, 53703, and 18408 %) respectively.

Table 3. ΔT/T For Case B: Different Satellite Characteristics.

Scenario	Interfering Link	Interfered-With Link	ΔT/T (%) for Satellite Spacing of		
			2°	3°	4°
IB1-IB1	B-to-H	B-to-H	162181	115345	71779
IB1-OB1	B-to-H	H-to-B	4467	3177	1977
IB1-PP	B-to-H	P-to-P	51286	36475	22699
OB1-IB1	H-to-B	B-to-H	16637	6041	3304
OB1-OB1	H-to-B	H-to-B	766	398	246
OB1-PP	H-to-B	P-to-P	5358	1945	1062
PP-IB1	P-to-P	B-to-H	112461	40832	19907
PP-OB1	P-to-P	H-to-B	3117	1139	558
IB2-IB2	M-to-H	M-to-H	115345	53703	18408
IB2-OB2	M-to-H	H-to-M	4978	2318	794
IB2-PP	M-to-H	P-to-P	36476	16983	5821
OB2-IB2	H-to-M	M-to-H	10497	3811	2085
OB2-OB2	H-to-M	H-to-M	681	284	138
OB2-PP	H-to-M	P-to-P	3380	1227	670
PP-IB2	P-to-P	M-to-H	112461	40832	19907
PP-OB2	P-to-P	H-to-M	4876	1774	864

5.0 Conclusions And Recommendations

To prevent harmful adjacent satellite interference from occurring, the ITU sets earth terminal EIRP density limits at the horizon and the satellite power flux density limits at earth surface and requires satellite system operators to coordinate with each other if interference from one system results in an increment of the equivalent overall noise temperature (T) of a link of the other system by more than 6 % {i.e., $\Delta T/T > 6$ %}.

DSCS III VSAT links can meet the terminal EIRP density limits at the horizon and the satellite power flux density limits at earth surface with antenna aperture as small as 0.4 m and without using spread spectrum, by using BPSK modulation, and 1/2-rate FEC coding for all practical link scenarios (i.e., all practical gain states and antenna configurations).

The effects of DSCS III VSAT links on adjacent satellite interference vary widely with respect to the characteristics of the two satellites and the characteristics of the links associated with the satellites. The effects can be negligible (through the discrimination in carrier frequencies, polarizations, or satellite antenna coverages) or can be very harmful where the system noise temperature of a link can be increased by hundred or thousand times where frequency coordination is required.

The frequency coordination can be quite simple because there are only two parties (one associated with each adjacent satellite) in the coordination loop, and the bandwidth involved in the coordination may be small (e.g., only tens of kilo-Hertz (per carrier) out of the whole satellite bandwidth of 500 MHz). Use of spread spectrum with a fixed coding gain (e.g., the coding gains of 10, 28, and 437 that had been proposed for the NATO STANAG 4485 standard [2]) reduces ASI, but it does not guarantee ASI to be reduced to below $\Delta T/T$ of 6 % to avoid coordination. Use of spread spectrum with a fixed coding gain is not recommended because it drives up the cost of the VSAT and the transponder bandwidth requirements to support the VSAT link and additionally may make coordination with other satellite operators more difficult since larger coordination bands are required due to the bandspreading. There is also an issue of Equatorial 's patent right on spread spectrum VSATs that must be resolved[4].

Besides the adjacent satellite interference issues that are addressed in this paper, there are also terrestrial interference issues and licensing issues associated with X-band VSATs and use of spread spectrum as an option may be beneficial to resolve these issues [5].

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[4] Equatorial (now absorbed to GE American Communications) was granted its patent right to spread spectrum VSATs by the US Patent Office in 1984 [6].