Military X-Band Very Small Aperture Terminals (VSATs) - To Spread or Not To Spread ?*

X.T. Vuong, IEEE Senior Member
Science Applications International Corporation (**SAIC**)
1710 Goodridge Drive, MS 1-2-8, McLean, Virginia 22102
Tel: (703) 448-6470, Email: vuong@tieo.saic.com

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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. Because of the increase in the levels of interference to and from neighboring satellite and terrestrial networks by using X-band VSATs, there have been significant discussions within the government community on whether or not spread spectrum should be imposed as a waveform standard to alleviate the interference. This paper discusses the advantages and disadvantages of using spread spectrum with respect to interference reduction, space segment resource utilization, earth terminal cost, compliance with national and international rules and regulations, and blanket licensing. It then provides recommendations on whether or not spread spectrum should be used.

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 USAF PTS (Portable Terminal System) and current DISA planning for a briefcase terminal system. Several waveform standards (e.g., NATO STANAG 4485, US SHF DAMA) are now being revised or developed for use with these VSATs.

Use of VSATs increases the levels of interference to, and from, neighboring satellite and terrestrial networks, because VSATs require higher satellite EIRPs and higher earth terminal HPA power to support a given data rate due to their lower antenna gains (in comparison to larger earth terminals) and have also much less off-axis gain isolation against interference to (and from) neighboring networks. Because of the increase in interference by using X-band VSATs, there have been significant discussions within the government community on whether or not spread spectrum [1] should be imposed as a waveform standard to alleviate the interference.

This paper was developed to help the various standards committees make a decision on whether there is a need to use spread spectrum. The paper discusses the advantages and disadvantages of using spread spectrum with respect to interference reduction, space segment resource (transponder power and bandwidth) utilization, earth terminal cost, compliance with national and international rules and regulations, and blanket licensing. It then provides recommendations on whether or not spread spectrum should be used.

About a decade ago, VSATs were introduced to the commercial satellite (C- and Ku-band) environment and the same issue ("to spread or not to spread") was also discussed and resolved. Accordingly, this paper first addresses spread spectrum and other related issues associated with the design and operation of commercial VSATs and then extends these issues, where appropriate, to military X-band VSATs.

2.0 Design and Operation of Commercial (C- and Ku-Band) VSATs

Commercial satellite (C- and Ku-band) VSATs have been used during the last decade in star networks (VSAT networks) to provide high capability, low cost satellite networks. Three inter-related issues arose during the introduction of VSAT networks: (a) excessive radio frequency interference (RFI) to and from neighboring (satellite and terrestrial) networks, (b) possible violation of power density and antenna radiation pattern constraints set by official regulatory bodies (i.e., the ITU and FCC), and (c) blanket licensing. This section describes these issues and the role of spread spectrum (direct sequence) in resolving these issues at C- and Ku-band.

2.1 Issue (a): Excessive Radio Frequency Interference (RFI)

The first issue (excessive RFI to and from neighboring networks) arose because VSATs (in comparison with larger terminals) require higher HPA power (for inbound links from the VSATs to the hub station) and also require higher satellite downlink EIRP (for outbound from the hub station to the VSATs). This is required to compensate for lower antenna gains of VSATs. VSATs also have much less off-axis gain isolation against interference to (and from) neighboring networks.

To limit the amount of interference from one satellite network to other satellite networks and to terrestrial networks, international and national official regulatory bodies (i.e., the ITU and FCC) have set constraints on power densities and transmit antenna off-axis gain patterns (see Section 2.2). These limits, however, only provide a reasonable interference protection and do not represent the worst possible conditions. That is, harmful interference to (and from) neighboring networks may occur, despite conformance to the constraints. The official regulatory bodies have also set rules that require network operators to coordinate with each other to prevent harmful interference from occurring. (Coordination rules are described in Section 3.1). In addition, before granting a license to operate a C-band[1] earth terminal, the FCC also requires the submission of an RFI analysis that shows that no harmful interference is radiated to neighboring terrestrial networks.

2.2 Issue (b): Possible Violation of ITU and FCC Constraints on Power Densities and Antenna Radiation Pattern

The second issue (possible violation of ITU and FCC constraints on power densities and antenna radiation patterns) arose because a VSAT network requires higher power from the VSATs and also from the satellite compared to ordinary networks with larger earth terminals to compensate for lower antenna gains of the VSATs. VSATs also have higher off-axis and sidelobe gains. At C- and Ku-band, there are three power density constraints and one antenna pattern constraint:

- B1 Earth terminal EIRP density limits at the horizon (ITU-RR, Article 28 and FCC-CFR47, Part 25.204),
- B2 Satellite power flux density limits (ITU-RR, Article 28 and FCC-CFR47, Part 25.208),
- B3 Earth terminal off-axis EIRP density limits (ITU-R S.524), and
- B4 Earth terminal antenna gain pattern limits (ITU-R S.580, FCC-CFR47, Part 25.209).

Constraints B1 and B2, imposed by the ITU (international), are the same as those imposed by the FCC (US - commercial and local government). These two constraints also apply at military X-band (see Section 3.2). Constraint B3 is not imposed by the FCC, and it is not imposed at X-band either. Constraint B4 as imposed by the ITU also applies at X-band (see Section 3.2). Constraint B4, imposed by the FCC, was made tighter than that imposed by the ITU in order to satisfy the two-degree satellite spacing policy adopted by the US. As results,

[1] In the US, while Ku-band is exclusively dedicated to satellite communication networks, C-band is shared with terrestrial microwave networks.

almost all old large antennas (antenna built before 1986) and all small antennas (1.2 m or smaller) do not meet this constraint.

2.3 Issue (c): Blanket Licensing

The blanket licensing issue arose because a VSAT network, in general, has many VSATs scattered over a large geographical area. Therefore, following the traditional licensing practice (of one license per earth terminal per geographical location) would be very time consuming and require a lot of paper work. Thus, there was a need to have one license for all VSATs of the same type to operate anywhere over a large geographical area (e.g., USA).

2.3.1 FCC Blanket Licensing for Ku-Band VSATs

In response to the blanket licensing issue, the FCC on April 9, 1986 issued a *Declaratory Order* that states conditions necessary for blanket licensing qualifications of VSAT networks operated at Ku-band (a band exclusively dedicated to fixed satellite services in the US). These conditions include

- C1 VSAT antenna aperture must be at least 1.2 m in diameter,
- C2 Carrier power entering VSAT antenna must not exceed -14 dBW/ 4 kHz, and
- C3 Satellite carrier EIRP density must not exceed 6 dBW/4 kHz

Note that when Condition C1 is met, it is not required to satisfy Constraint B4[2]; and that when Conditions C1 to C3 are met, Constraints B1 to B3 are automatically met.

Proper selection of modulation and coding can mitigate interference. The selection of BPSK over QPSK modulation and 1/2-rate FEC coding over uncoded links results in a four-time spreading (6 dB density reduction). Since 1/2-rate FEC coding also improves the E_b/N_0 required for a given BER by about 5 to 6 dB, the power density reduction advantage of using BPSK modulation with 1/2 rate FEC coding versus over QPSK without coding is about 11 to 12 dB. For most commercial Ku-band VSAT network applications, this spreading and coding advantage is more than sufficient to meet the FCC Ku-band blanket licensing constraints C2 and C3 with 1.2 m VSATs. For applications where use of BPSK modulation and 1/2-rate FEC coding is insufficient (e.g., Ku-band VSAT networks that operate in high rain zones, at poor satellite EIRP and G/T footprints), an alternative to using larger earth terminal antennas ($\geq$ 1.8 m) is to employ spread spectrum (with an appropriate spreading factor) or a 1/N-rate FEC[3] coding scheme (with an appropriate N for $N > 2$).

2.3.2 FCC Blanket Licensing for C-Band VSATs: Equatorial's Spread Spectrum VSATs

Since C-band is shared equally (on a co-primary basis) among satellite and terrestrial networks, the FCC does not have any similar official blanket licensing requirements for C-band VSAT networks. However, the FCC has granted blanket licensing to Equatorial's [4] C-band VSAT networks [2, 3] that utilize a direct sequence spread spectrum technique [1] and VSATs with antenna diameters of 0.6 m (for data broadcast services) and 1.2 m (for interactive two way data services). For an inbound link (from a VSAT to a hub station), a spreading factor of 1024, 2048 or 4096 has been used by Equatorial to support an information rate of 1.2 or 4.8 kbps (in a 5 MHz band) and for an outbound link (from a hub station to a VSAT) a spreading factor of 32 or 64 has been used to support an information rate of 76.8 or 153.6 kbps (in a 5 MHz band).

Note that a 0.6-m data-receive-only spread-spectrum C-band VSAT [2] and a 1.2-m 1-W interactive two-way spread-spectrum C-band VSAT [3] were sold by Equatorial in 1989 for about $US 3500 and $US 9000 respectively [4]. Note also that Equatorial was probably the first company that introduced VSAT networks into the commercial market. On October 20, 1980, it filed for a US patent for the concept of using very small aperture terminals (VSATs) that "see" multiple satellites in a star network in combination with spread spectrum. The patent filing was granted on June 19, 1984 by the US Patent Office [16]. The patent, however, was rejected by the European Patent Office because a judgment was made that there was "no new invention".

2.4 Spread Spectrum and VSAT Networks

In the early 80's, at conferences, trade shows, and in trade journals, Equatorial engineers and sale representatives had repeatedly claimed that their spread spectrum VSATs were immune (or highly immune) to radio frequency interference (RFI). These claims, coupled with the successful deployment and operation of more than 20,000 C-band spread spectrum VSATs developed by Equatorial [5], prompted a number of engineers to believe that spread spectrum was the answer to the problems of harmful interference that are potentially caused by the use of very small aperture terminals and also to the problem of obtaining VSAT operation licenses from the FCC. Thus, when Ku-band transponders were available for use in the US around 1984, several companies (including GTE Spacenet, Advanced Communications and Telcom General) considered the use of spread spectrum for the design of Ku-band VSAT networks, even though Ku-band was dedicated to fixed satellite services and no terrestrial interference would be encountered. Spread spectrum, however, was not implemented at Ku-band for the following reasons:

- (i) The Equatorial patent right on spread spectrum VSATs that might be infringed,
- (ii) The April 9, 1986 FCC *Declaratory Order* that allowed Ku-band VSAT blanket licenses to be obtained without the use of spread spectrum,
- (iii) The additional cost associated with the use of spread spectrum (i.e., development costs of spreader and despreader plus the relatively high cost of the additional transponder bandwidth required), and
- (iv) Results in the open literature [6, 7] that rejected Equatorial's claim of interference immunity via spread spectrum.

Presently in the US, to the author knowledge, all C-band VSATs in operation (believed to be more than 60,000) use spread spectrum and were built by Equatorial. On the other hand, all Ku-band VSATs in operation (numbered to be more than 63,000 as of December 1992 [15]) do not use spread spectrum[5]. Spread spectrum Ku-band VSATs, however, are available off-the-shelf [8].

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[2] Not really true any more, any VSATs built after May 10, 1993 must comply with Constraint B4 (FCC Part 25.209) for all off-axis angles greater than 1.25° [14]

[3] Forward error correction (FEC) with rate 1/N for N > 2 is not often used because the coding gain improvement over rate 1/2 is insignificant even for very large N. For large N, FEC systems are more costly to implement, and also result in greater time delay (as compared to the combination of 1/2-rate FEC and spread spectrum).

[4] Equatorial (Equatorial Communication Company) was based in California. It was bought by Contel ASC of Rockville, Maryland which in turn was bought by GTE Spacenet of McLean, Virginia. GTE Spacenet was recently acquired by GE American Communications of Princeton, New Jersey.

[5] Qualcomm's Omni-TRACS service uses direct sequence spread spectrum and frequency hopping to provide radio determination and short message store-and-forward communication to trucks (mobile stations) equipped with Ku-band "omni-directional" antennas. This service, however, is not considered as a Ku-band VSAT network service. The reasons why Qualcomm uses both spread spectrum and frequency hopping are probably because of the Equatorial patent right and FCC blanket licensing. Since the OmniTRACS service is a mobile satellite service (MSS), using a fixed satellite service (FSS) band, it was given a license by the FCC on a noninterference only basis (i.e., if OmniTRACS interferes with any fixed satellite services, it must be stopped) [12].

2.5 Spread Spectrum and Radio Frequency Interference

Spread spectrum is a technique that can be used to spread the power of a carrier over a much wider frequency band for transmission. Spread spectrum, therefore, if implemented in a VSAT network, can reduce interference to neighboring (satellite or terrestrial) networks. At the receive site, spread spectrum despreads the spread carrier to its original (unspread) spectrum shape and at the same time spreads any unwanted signals that are received along with the spread carrier, resulting in reduction of interference from neighboring networks. Nevertheless, spread spectrum VSATs are not immune to interference [6, 7]. In [7], it was concluded that spread spectrum is not an answer to the interference problems based on the following rationale:

- For interference from neighboring networks where the interferors are wideband (at least as wide as the spread carrier) or narrowband and packed closely to each other in frequency over the spread carrier bandwidth, spread spectrum is not likely to provide sufficient interference reduction (interference reduction of at most about 3 dB can be achieved with spread spectrum).
- For the other cases {i.e., (i) for interference from neighboring networks with neighboring carriers being narrowband and not stacked closely to each other, and (ii) for interference to neighboring networks}, spread spectrum can provide sufficient interference reduction only if the considered VSAT carriers are sufficiently spread. The amount of spreading that is sufficient cannot, however, be determined in general, unless there is coordination among satellite and terrestrial network operators. One, therefore, may run into either the problem of underspreading where the interference problems are still left unsolved (partially solved), or the problem of overspreading where the transponder bandwidth capacity is utilized even more inefficiently.

As shown in [7], the interference problems can be best resolved through frequency coordination. With frequency coordination, by making use of all known information about the carriers and the networks, optimal carrier frequency plans can be generated resulting in maximum number of carriers that can be transmitted with acceptable interference to all parties.

Because spread spectrum widens carrier bandwidths, it may make the frequency coordination more difficult (e.g., less flexible). Nevertheless, if spread spectrum can be implemented as an option (where the spreader and despreader can be switched in or out), then additional flexibility will be provided for coordination purposes.

With respect to satellite transponder resource utilization, a spread spectrum carrier (as compared to an unspread carrier) requires more transponder power (due to higher implementation loss associated with spread spectrum modem (0.5 to 2 dB)), and much more transponder bandwidth due to spectrum spreading. Code division multiple access (CDMA), however, in some circumstances can be utilized to reuse the required excessive bandwidth. With respect to the intermodulation effects, spread spectrum may either improve or degrade performance[6].

Frequency coordination among neighboring satellite and terrestrial network operators is, however, often difficult to achieve due to the number of operators involved, the long lead times to coordinate, and unknown future traffic requirements and earth terminal locations.

[6] Because spread spectrum increases the bandwidth utilization by each carrier, there will be much less IM-improvement due to selective carrier frequency assignment [9] (i.e., there will be many more intermodulation products that fall into the spread carrier bandwidth). These intermodulation products, however, will be reduced through the despreading and matched filtered receive process. Depending on the number of carriers accessing the transponder and the spreading factor, the overall effects will be either an improvement or a degradation in E_b/IM_0.

3.0 Issues Associated with X-band VSATs

Like their commercial counterparts, military X-band VSATs encounter the same three inter-related issues: (i) excessive radio frequency interference to and from neighboring (satellite and terrestrial) networks, (ii) possible violation of power density and antenna radiation pattern constraints set by official regulatory bodies (i.e., the ITU and NTIA), and (iii) blanket licensing (or permission for VSATs to operate over a large geographical area). This section describes and provides solutions to these issues. The next section will conclude the report by providing recommendations on whether spread spectrum should be used in conjunction with X-band VSATs.

3.1 Radio Frequency Interference (RFI)

Internationally, according to ITU-RR, Article 8, the military X-band, (7.25 - 7.75) GHz downlink and (7.9 - 8.4) GHz uplink, is shared mainly on a co-primary basis among different satellite and terrestrial networks to provide the following services: 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 these networks does occur and is exacerbated by the use of very small aperture terminals (VSATs). To prevent harmful interference from occurring, the ITU has established rules that require network operators to coordinate with each other. According to the ITU-RR, Appendix 28, if a terrestrial station is within an earth terminal's transmit or receive coordination area, coordination between the terrestrial station and earth terminal is required. The coordination radius must be at least 100 km and can be calculated using a procedure given in Appendix 28. Also, according to the ITU-RR, Appendix 29, coordination between two GEO satellite networks is required if interference from one satellite network results in an increment of the equivalent overall noise temperature of a link of the other satellite network by more than 6 % {i.e., $(\Delta T/T) > 6\ \%$}. $(\Delta T/T)$ depends on the characteristics of the satellites (including satellite spacing, satellite G/T and EIRP footprints, and saturation power flux densities) and the characteristics of the links (including clear sky E_b/N_o requirements, receive G/Ts, transmit and receive off-axis antenna gains, modulation and coding, and whether energy dispersal (i.e., scrambling) is used); and these characteristics can vary widely. Thus, use of large antennas does not guarantee that $\{(\Delta T/T) < 6\ \%)\}$ is automatically satisfied; similarly, use of very small antennas does not necessarily mean that $\{(\Delta T/T) < 6\ \%)\}$ is automatically violated. Note that, if $\{(\Delta T/T) < 6\ \%\}$ is violated, it does not mean that spread spectrum is required or very small earth terminals cannot be used; it only means that coordination is required with other satellite network operators.

As mentioned in Section 2.5, spread spectrum reduces interference but does not necessarily reduce interference to acceptable levels. Spread spectrum, due to its bandwidth requirements, can make coordination less flexible. Nevertheless, if spread spectrum is used as an option that can be turned on or off, it will add flexibility to coordination.

3.2 ITU and NTIA Constraints on Power Densities and Antenna Radiation Patterns

At X-band, the ITU (international) constraints and the NTIA (US - federal government) constraints on power densities and antenna radiation patterns are the same and are described below.

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

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

From extensive link calculation results using DSCS III satellite characteristics, it was found that the earth terminal EIRP density limits at the horizon can be met without spread spectrum with 0.6-m earth terminals, BPSK modulation and 1/2-rate FEC coding for all practical link scenarios (i.e., all practical gain states and satellite transmit and receive gains) [13]. These compliances were also independently confirmed [10].

3.2.2 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 $0^o \le \delta \le 5^o$
- $40 + 0.5(\delta-5)$ $dBW/m^2/4$ kHz $5^o < \delta \le 25^o$
- -142 $dBW/m^2/4$ kHz $25^o < \delta \le 90^o$

From extensive link calculation results using DSCS III satellite characteristics, it was found that the satellite power flux density limits earth surface can be met without spread spectrum with 0.6-m earth terminals, BPSK modulation and 1/2-rate FEC coding for all practical link scenarios [13]. These compliances were also independently confirmed [10].

3.2.3 Transmit Antenna Radiation Pattern Limits

The ITU transmit antenna radiation pattern constraints are stated in ITU-R S.580. However, from the ITU-R S.580 paper, the ITU has not yet established antenna pattern constraints for very small antennas ($D/\lambda < 50$, e.g., D < 1.8 m for f = 8.4 GHz) which are of interest in this report. For coordination and assessment purposes, however, 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 where the gains are expressed in dBi:

For $D/\lambda < 100$

$$G(\theta) = G_{max} - 2.5\times10^{-3}(\theta D/\lambda)^2 \qquad 0^o < \theta < \theta_m$$
$$G(\theta) = G_1 \qquad \theta_m \le \theta < 100\lambda/D$$
$$G(\theta) = 52 - 10\log(D/\lambda) - 25\log\theta \qquad 100\lambda/D \le \theta < 48^o$$
$$G(\theta) = 10 - 10\log(D/\lambda) \qquad 48^o \le \theta \le 180^o$$

For $D/\lambda \ge 100$

$$G(\theta) = G_{max} - 2.5\times10^{-3}(\theta D/\lambda)^2 \qquad 0^o < \theta < \theta_m$$
$$G(\theta) = G_1 \qquad \theta_m \le \theta < \theta_r$$
$$G(\theta) = 32 - 10\log(D/\lambda) \qquad \theta_r \le \theta < 48^o$$
$$G(\theta) = -10 \qquad 48^o \le \theta \le 180^o$$

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 for cases where (D/λ) is not given, (D/λ) can be estimated from the following equation:

$$20\log(D/\lambda) = G_{max} - 7.7$$

3.3 Blanket Licensing

X-band is a military frequency band, thus, for operation of an earth terminal at X-band, no license is required. Instead, frequency assignment authorization is obtained through negotiation and coordination with the Federal governments (for operation within the US) and with foreign governments (for operation outside the US). Spread spectrum, again, may make negotiation and coordination more difficult. Nevertheless, if spread spectrum is available as an option, then additional flexibility for negotiation and coordination can be provided.

In the US, the NTIA does not allow the terrestrial mobile services (MS) to be operated at X-band. It also relegates the priority status of the terrestrial fixed services (FS) from primary to secondary over the first 125-MHz of the 500-MHz uplink X-band (i.e., the (7.900, 8.025) MHz subband) and over the first 50 MHz of the 500-MHz downlink subband (i.e., (7.250 - 7.300) MHz subband). These subbands (which correspond to Channel 1 of DSCS III satellite) are dedicated to satellite services (FSS and MSS). Since the remainder of X-band bandwidth is shared on a co-primary basis among terrestrial services (FS) and satellite services (FSS and MSS), at present, frequency assignments to transportable earth terminals in these bands are granted by the NTIA only on a temporary/renewable basis not to exceed five years. These assignments may only be used over a small geographical area, normally not in excess of a 48 km radius. These area assignments may further be restricted if new requirements for authorized services indicate that such restrictions are required in order to provide compatible operations (NTIA Manual, Section 8.2.43). X-band VSATs fall into the category as transportables and therefore the same frequency assignment conditions imposed by the NTIA to transportables apply. Nevertheless, negotiation and coordination can be used to increase the geographical area of operation.

4.0 Conclusions and Recommendations

In the two previous sections, issues associated with the use of very small aperture terminals (VSATs) have been addressed. Advantages and disadvantages of using spread spectrum have also been discussed. This section concludes with recommendations on whether or not to use spread spectrum as a standard waveform for X-band VSATs.

As stated earlier, in the US, C-band is shared equally among terrestrial and satellite networks, and all C-band VSATs in operation utilize spread spectrum (with a spreading factor of 1024, 2048 or 4096 for the inbound links and 32 to 64 for the outbound links). On the other hand, in the US, Ku-band is dedicated to fixed satellite services, and all Ku-band VSATs in operation do not employ spread spectrum.

Since the military X-band is very similar to commercial C-band in the sense that (i) both bands are shared equally {i.e., on a co-primary basis} among different satellite networks and terrestrial networks, and (ii) both bands are subject to the same power density and antenna pattern constraints set by the ITU, it seems logical that spread spectrum should also be used for X-band VSATs. However, **spread spectrum is not recommended for use with X-band VSATs** for the following reasons:

(1) Use of spread spectrum together with VSATs is subject to Equatorial's US patent right which will not expire until the year 2001. The US patent right, however, can be challenged using the fact that the European Patent Office did not approve Equatorial's spread spectrum VSAT patent filing because it was judged not to be a new invention; however, challenging a patent may be costly and require long lead times.

(2) There are no rules or regulations that require X-band VSATs must use spread spectrum (C-band VSATs, however, may be required to use spread spectrum in order to obtain blanket licensing in the US),

(3) Analyses have shown that the ITU constraints on X-band (i.e., VSAT EIRP density and sattellite power flux density) can be met for all practical scenarios without the use of spread spectrum, by utilizing 0.6 m X-band VSATs, BPSK modulation, and 1/2-rate FEC coding (based on DSCS III characteristics and links operated at clear sky E_b/N_o of 9 dB),

(4) Although the cost difference between a spread spectrum VSAT and a VSAT without spread spectrum may be small, the space segment cost

may be high. The transponder power requirement will be about 0.5 to 2 dB higher (for spread spectrum carrier vs. unspread carrier), due to additional implementation losses associated with spread spectrum modem. The transponder bandwidth requirement will be much more (up to 4096 times more as in a case of C-band VSATs). Code division multiple access (CDMA), however, in some circumstances can be utilized to reuse the required excessive bandwidth.

(5) While spread spectrum reduces interference (that is exacerbated by the use of very small antennas), it does not necessarily reduce interference to acceptable levels. For interference from neighboring networks where the interferors are wideband (at least as wide as the spread carrier) or narrowband and packed closely to each other in frequency over the spread carrier bandwidth, spread spectrum will provide interference reduction of at most about 3 dB. For all other cases, spread spectrum can provide sufficient interference reduction only if the considered VSAT carrier is sufficiently spread. The amount of spreading that is sufficient cannot, however, be determined unless there is coordination among satellite/terrestrial network operators. One, therefore, may run into either the problem of underspreading where the interference problems are still left unsolved (partially solved) or the problem of overspreading where the transponder bandwidth capacity is utilized even more inefficiently.

(6) The preceding interference problems can be best resolved through frequency coordination. The use of spread spectrum may make frequency coordination less flexible.

(7) Spread spectrum may increase intermodulation effects because spread spectrum reduces flexibility for carrier frequencies to be assigned within a transponder to improve intermodulation effects. The effects, however, may be small, because at the receive site, the intermodulation products will be spread by the despreader.

Although spread spectrum is not recommended for use with X-band VSATs for the reasons stated above, its availability as an option for X-band VSATs is highly desirable, if the Equatorial patent right issue can be resolved. More precisely, it is desirable to have VSATs that are equipped with spread spectrum modems whose spreading factor is electronically variable and may be set to values from 1 (i.e., unspread) to, say, 4096 (that matches Equatorial's maximum spreading). There are two reasons:

(1) For X-band VSATs to be deployed and used with acceptable interference, coordination among satellite and terrestrial networks and negotiation among governments are required. Situations may be encountered where coordination and negotiation are difficult or nearly impossible when spread spectrum is not used. In this case, the use of spread spectrum with variable spreading factor would provide the additional flexibility in terms of power density reduction (with the reduction of bandwidth flexibility) that may be needed to make coordination and negotiation successful.

(2) There are requirements for certain VSATs to be tri-band operable, i.e., at C-, X- and Ku-band. Spread spectrum VSATs with electronically variable spreading factor will comply with the interoperability requirements. Spread spectrum will be used to meet (US) C-band licensing requirements. For Ku-band and X-band, spread spectrum is probably not needed but it is available to ensure that the most common interference scenarios can be accommodated.

From [11], it was quoted in 1987 that the development cost of a spread spectrum BPSK, 1/2-rate FEC modem with electronically variable spreading factor would be around $US 150,000; and the price of a 1.2 m spread spectrum Ku-band data receive only VSAT (with variable spreading factor), after development, would be about $US 1,500 for a very large quantity order. (Although the quoted dollar values are several years old, their relative values are still adequate)

It is recommended that the Equatorial patent right issue be addressed further to determine whether the use of spread spectrum VSATs at X-band will infringe the Equatorial patent right, and the legal implication for military use.

Another approach to the solution of using X-band VSATs is to convince ITU (at ITU WRCs[7]), to dedicate small portions of the military X-band to satellite services worldwide (like that being allocated in the US). Use of these portions would, therefore, only require frequency coordination among a few satellite network operators. These coordinations, from experience, would be easily achieved and therefore the use of spread spectrum at X-band would not be necessary.

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Reference

[1] R.L. Pickholtz, D.L. Schilling and L.B. Milstein, "Theory of Spread-Spectrum Communication - A Tutorial," *IEEE Transactions on Communications*, May 1982.

[2] "Equatorial Data Broadcast/EDB-1000 for Satellite Data Distribution", Contel ASC Data Sheet, Rockville, Maryland.

[3] "Contel ASC Data Messenger Networks, DMN-2000CF for Interactive Satellite Data Distribution", Contel ASC Data Sheet, Rockville, Maryland.

[4] Private communication with H.J. Detlefs, Managing Director, Contel ASC, Nov. 1989.

[5] B.C Kirk, "Satellite Data Networks Using Micro Earth Stations," *Proceedings of the Canadian Satellite User Conference*, Ottawa, Canada, Nov. 1984.

[6] A.J. Viterbi, "When Not to Spread Spectrum - A Sequel," *IEEE Communications Magazine*, April 1985.

[7] X.T. Vuong, "Does the Use of Spread-Spectrum Reduce Interference?," *Proceedings of the IEEE International Electrical and Electronic Conference*, Toronto, Canada, Oct. 1985.

[8] "Equatorial Data Broadcast / K-100 for Satellite Data Distribution", Contel ASC Data Sheets, Rockville, Maryland.

[9] X.T. Vuong *et al.*, "Some Practical Strategies for Reducing Intermodulation in Satellite Communications," *IEEE Transactions on Aerospace and Electronic Systems*, Nov. 1988.

[10] P. Kullstam, "Review of DGA Proposed STANAG 4485 Manpack Waveform; Presented at the AHWG on 17-21-Jan. 1994," Paircom Memorandum to J. Ozimek, March 3, 1994.

[11] Private communication with S. Black of Comstream Corp. (now part of SPAR Communications), San Diego, California, Aug. 1987.

[12] P.J. Nicholson, "Ku-Band Communications Satellite Follows the Nation's Truckers," *Microwave Journal*, March 1991.

[13] X.T. Vuong and H.I. Paul., *X-Band Briefcase Earth Terminal Feasibility and Interference Study*, Report Prepared by SAIC for DISA/CFE under Contract # DCA 100-90-C-0058, Oct. 1994.

[14] P.L. Spector and J.H. Olson, "Recent Changes in the FCC Earth Station Rules," *Via Satellite*, September 1993.

[15] R. Wigins, "US VSAT Network Guide," *Via Satellite*, March 1993.

[16] P. Baran and Equatorial Communications Company, "Satellite Communications and Apparatus," *US Patent* No. 4455651, June 19, 1984.

[7] WRC (World Radiocommunication Conference) is a new name for WARC (World Administrative Radio Conference).