

技術試験事務

「災害・防災情報のための衛星デジタル伝送技術に関する調査検討」のご紹介

ヘリコプター衛星通信システム



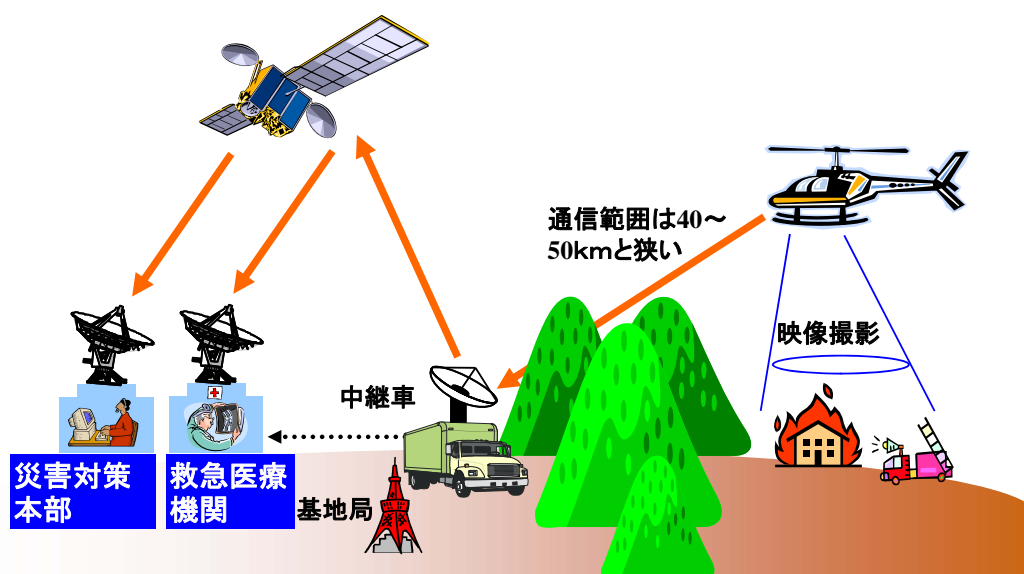
経緯

- 2001年 総務省からNICTへ「災害・防災情報のための衛星デジタル伝送技術に関する調査検討」試験事務が委託される
- 2001年～ ヘリコプター衛星通信(ヘリサット)システムの設計および製作
- 2003年 世界無線通信会議でKu帯における航空移動衛星業務への周波数割り当てが承認される
- 2004年 ヘリコプター衛星通信システム完成、飛行試験を実施
- 2006年 消防庁と共同で、ヘリサットからの映像を霞ヶ関に伝送

目的

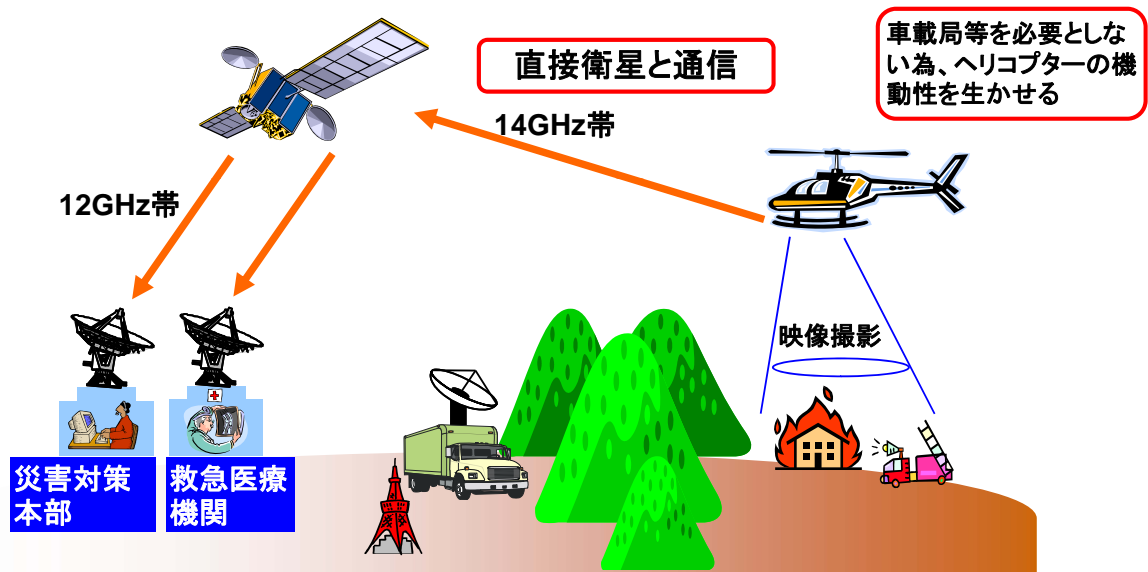
- 現在、ヘリコプター衛星通信に対する無線技術基準が制定されていない。この技術基準案の作成に寄与するデータの取得。
(2003年6月、世界無線通信会議でKu帯における航空移動衛星業務への周波数割り当てが承認される)
- Ku帯を用いる衛星通信用超小型地球局(VSAT)、携帯移動衛星データ通信および航空機衛星通信との周波数共用について技術的検討を行なう。
- ヘリコプター衛星デジタル通信システムを実証し、周波数の不足、周波数逼迫の対策に寄与する。

ヘリコプターからの情報伝送の現状



現在のヘリコプター中継は、ヘリコプターが見える範囲に車載局や中継局が必要な為、例えば災害時に道路が壊れたり、場所が山岳や海上の場合は通信が困難となる。

ヘリコプター衛星通信概念図



通信手段に衛星回線を利用し、衛星と直接通信すれば、障害物が無いのでいつでもどこでもリアルタイムで災害映像を伝送する事が可能。

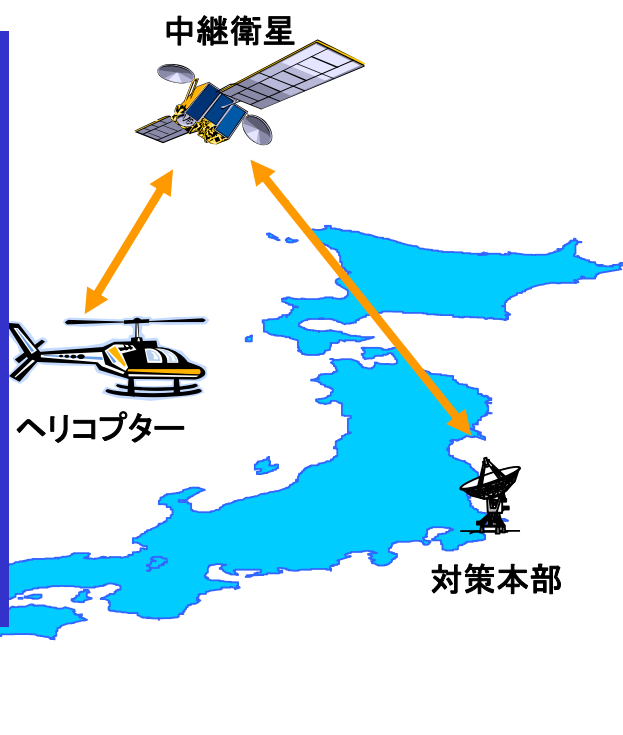
システムへの要求条件

- 機体に搭載するため小型・軽量である事
→ 本システムは機外の機器のみ小型化を配慮
- 機体の姿勢が動揺しても通信を維持する事
→ ヘリコプターは飛行機や自動車より動揺が大きい
- 送信電波が搭乗者(含むパイロット)に影響を与えない事
- 電波法の無線技術基準を遵守



ヘリコプター衛星通信システムの機能

1. 双方向通信(音声・データ)
2. 準動画・静止画伝送
(1.5Mbps, 384kbps)
3. 撮影した位置の特定
4. 衛星捕捉・自動追尾
5. ヘリ局の遠隔制御
6. 電波与干渉防止
(送信インタロック機能)



ブレードによる電波遮断を回避する技術

通信アンテナはプロペラの下側に搭載され、衛星はヘリコプターの上空に位置するため、通信路がプロペラに遮断される。



撮影した被災地の位置をリアルタイムで特定する技術

- ① GPS信号から自機位置を算出
- ② ジャイロにより機体姿勢角、機首方位角を検出
- ③ カメラジンバルからカメラ角を読み取り
- ④ 撮影方向ベクトルを算出
- ⑤ 3次元地図との交点を算出



送信インタロック機能の装備

(隣接衛星への与干渉防止対策)

- ・追尾誤差角が大きくなった時
- ・受信レベルが閾値以下になった時
- ・ヘリコプターの姿勢が予想以上に傾斜した時
- ・機器が異常の場合
- ・その他

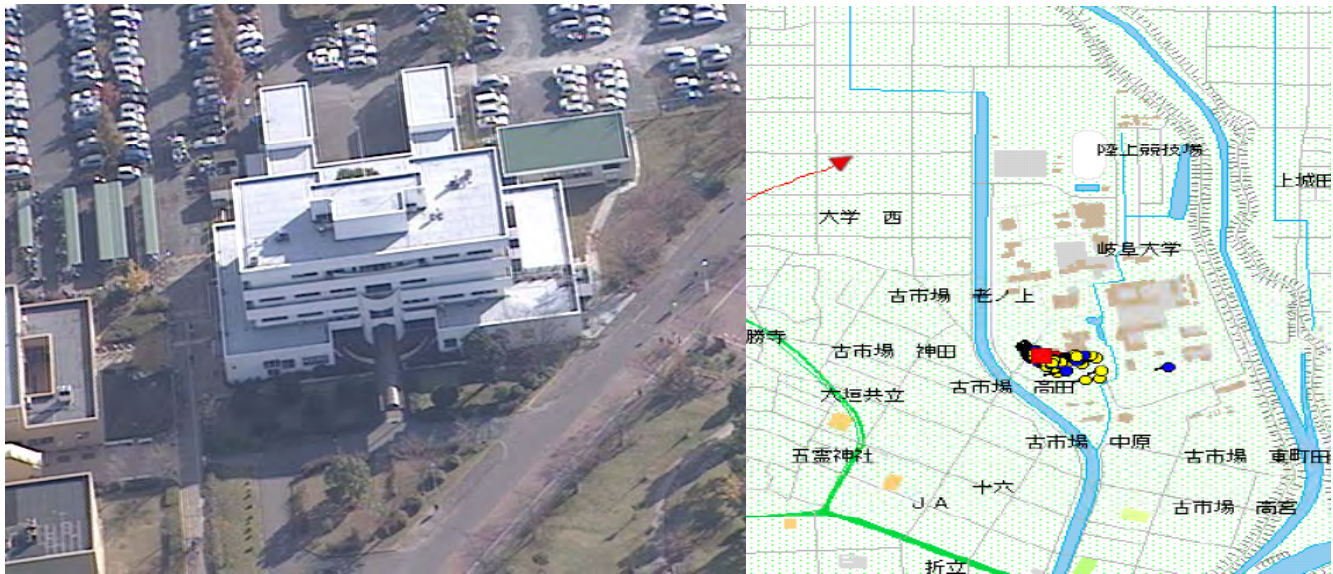
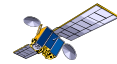
ヘリサットシステムの外観図



飛行実験



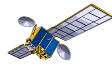
受信した映像とその位置の表示例



主な試験事務の成果

- ・ヘリサットシステムの実証
- ・ヘリサットシステムからの与干渉防止機能の検討
- ・航空移動衛星システムの技術基準とヘリサットシステムとの比較

おわりに



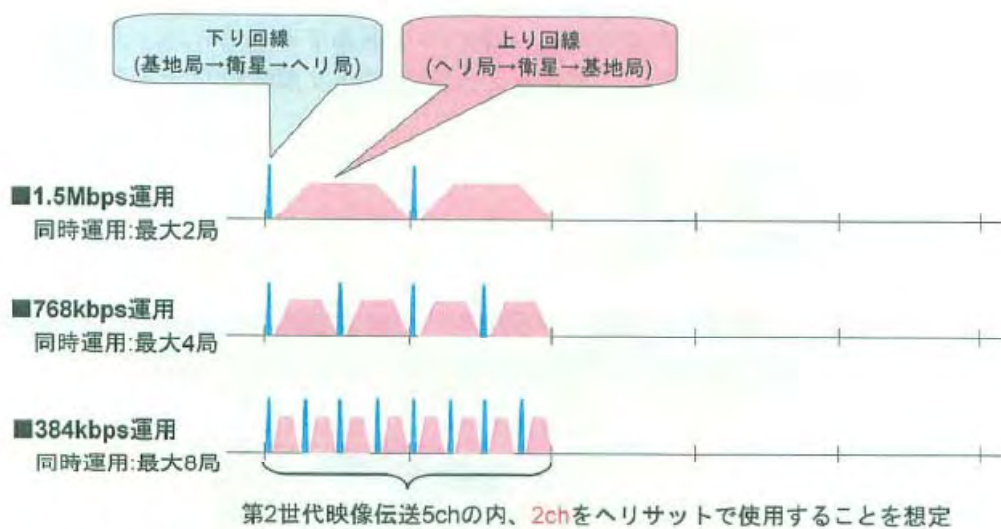
・本プロジェクトの担当を下記に示す。

- 通信 : 三菱電機(株)
- 映像 : (株)NTTデータ
- ヘリ搭載 : 川崎重工業(株)
- 衛星 : 宇宙通信(株)
- システム : (独)情報通信研究機構

参考-1

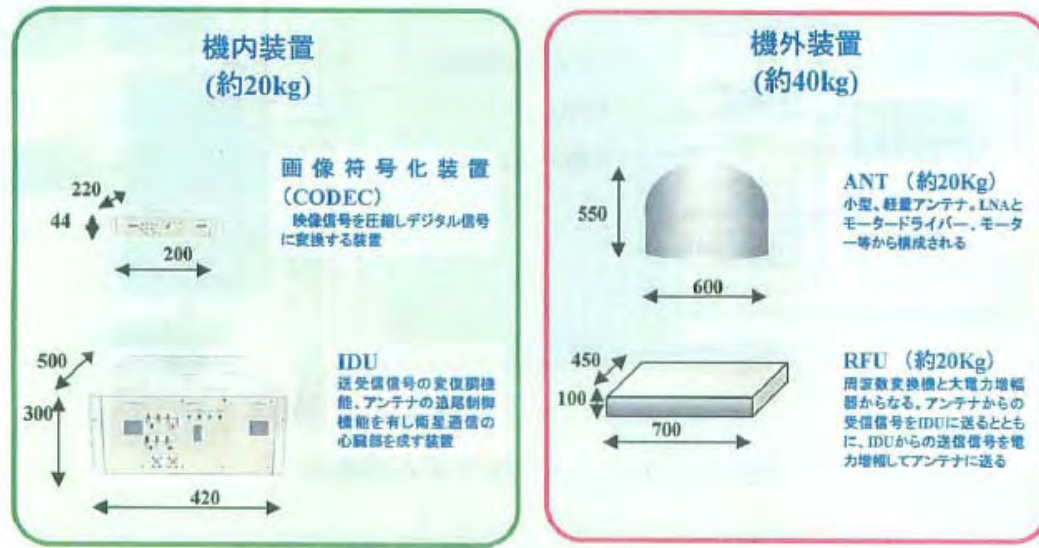
消防防災分野のヘリサット仕様-1(暫定)

(消防庁検討会資料より)



消防防災分野のヘリサット仕様-2(暫定)

(消防庁検討会資料より)



ヘリサットのドップラーシフトによる送信周波数偏差の検討

ヘリコプターのような移動体通信においては、高速移動によるドップラーシフトにより周波数偏差が生じるので、周波数偏差量について検討した。

1. 無線局の条件

- ・周波数 14.0GHz－14.4GHz:
- ・許容偏差 100ppm(電波用による規定値)

2. ヘリコプターの条件

- ・移動速度 180kt (通常利用されるヘリコプターの最大速度)
- ・移動方向 ドップラーシフトが最大となる衛星電波到来方向へ進行

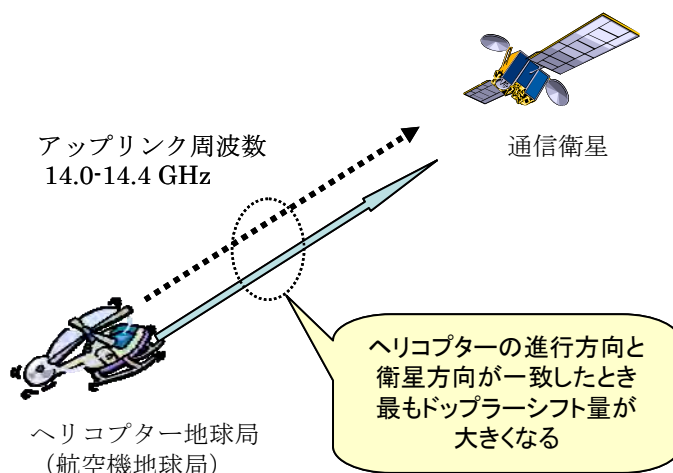


図-1 ヘリサットのドップラーシフト

3. 周波数偏差量の計算

- ・移動速度 180kt: $180 \times 0.514444 \text{ m/s} = 92.59992 \text{ m/s}$
- ・光速度 299,792,458 m/s
- ・偏差は $92.59992 \div 299,792,458 = 3.08 \times 10^{-7} \text{ 乗} = 0.308 \text{ ppm}$

4. 結論

- ・ヘリサットの移動による周波数偏差は約0.31ppmであり、電波法の規定100ppm以下を十分満足する。

ヘリサットのドップラーシフトによる送信周波数偏差の検討

ヘリコプターのような移動体通信においては、高速移動によるドップラーシフトにより周波数偏差が生じるので、周波数偏差量について検討した。

1. 無線局の条件

- ・周波数 14.0GHz－14.4GHz:
- ・許容偏差 100ppm(電波用による規定値)

2. ヘリコプターの条件

- ・移動速度 180kt (通常利用されるヘリコプターの最大速度)
- ・移動方向 ドップラーシフトが最大となる衛星電波到来方向へ進行

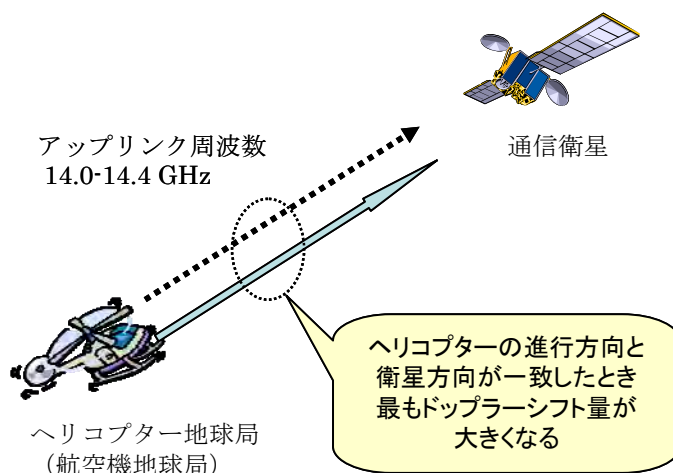


図-1 ヘリサットのドップラーシフト

3. 周波数偏差量の計算

- ・移動速度 180kt: $180 \times 0.514444 \text{ m/s} = 92.59992 \text{ m/s}$
- ・光速度 299,792,458 m/s
- ・偏差は $92.59992 \div 299,792,458 = 3.08 \times 10^{-7} \text{ 乗} = 0.308 \text{ ppm}$

4. 結論

- ・ヘリサットの移動による周波数偏差は約0.31ppmであり、電波法の規定100ppm以下を十分満足する。

ヘリサットの占有帯域の検討

ヘリコプターに搭載可能な小型軽量アンテナで安定な通信を実現するための通信方式を想定し、この時必要となる占有帯域について検討した。

1. 無線局の条件

・周波数	14.0GHz - 14.4GHz
・情報速度	1.5Mbps程度以下
・通信方式	BPSK
・誤り訂正方式	LDPC
・符号化率	1/2
・ロールオフ率	35%
・ブレードによる瞬断率	約50%(日本国内を想定した目安値)

2. 占有帯域の計算

情報速度 1.5Mbpsの場合について、上記条件にて占有帯域の計算を以下に示す。

$$\begin{aligned}
 \text{占有帯域} &= (\text{情報速度} + \text{冗長ビット}) \times 1/\text{LOG}_2(\text{相数}) \times 1/\text{符号化率} \times 1/(1 - \text{瞬断率}) \times \text{BT} \\
 &= 1.56 \times 1/\text{LOG}_2(2) \times 2 \times 1/(1 - 0.5) \times 1.25 \\
 &= 7.8
 \end{aligned}$$

情報速度 + 冗長ビット: 概略設計による目安値

BT: 1.25 (ロールオフ率 35% の場合)

相数: 2 (BPSKの場合)

3. 結論

・ヘリサットで現状想定の情報速度の送信に必要な占有帯域は7.8MHz程度以下となる。

ヘリサットシステムにおける周波数共用に関する検討

(1) 周波数共用検討のための前提条件

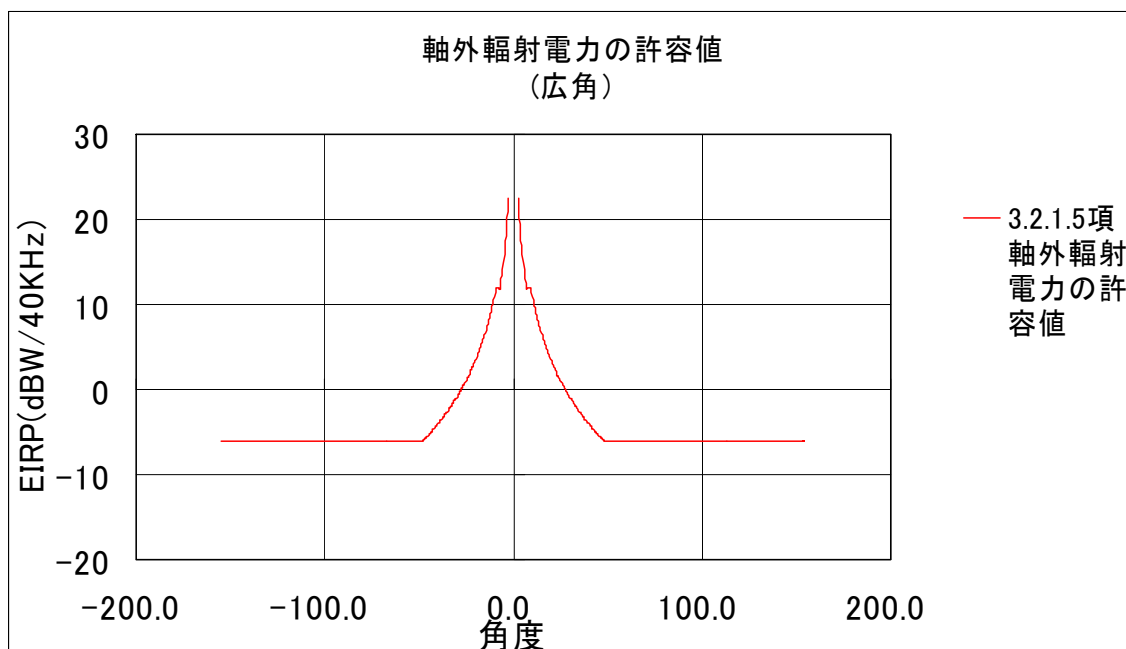
以下の項目について検討の前提とした条件を示す。

- ・ アンテナからの軸外輻射電力の許容値
- ・ 衛星仰角
- ・ ヘリコプター高度
- ・ 電力束密度の求め方

① アンテナからの軸外輻射電力

アンテナからの軸外輻射電力としては、3.2.1.5 項にて規定の値を用いた。

下図に 3.2.1.5 項の軸外輻射電力の広角における許容値を示す。



② 衛星仰角

ヘリコプターから追尾する衛星として下記国内主要衛星を想定し、国内運用における最低仰角を用いた。ただし 110° 衛星は含まない。

SB-A、SB-B2、SB-C、JCSAT-1B、JCSAT-2A、JCSAT-3A、JCSAT-4A、JCSAT-5A

最低仰角は SB-B2 の稚内における角度 34.2° であり、検討に用いる具体的な値としては EL=34° を用いた。

③ ヘリコプター高度

航空施行規則第七十四条 (最低安全高度) の規定において、「人又は家屋の密集している地域の上空にあつては、当該航空機を中心として水平距離六百メートルの範囲内の最も高い障害物の上端から三百メートル以上」「人又は家屋のない地域及び広い水面の上空または、規定する地域以外の地域の上空にあつては、

地表面又は水面から百五十メートル以上」と定められている。これより、本検討においては、地表面への放射電力が一番厳しいヘリコプターの高度として150mを用いた。

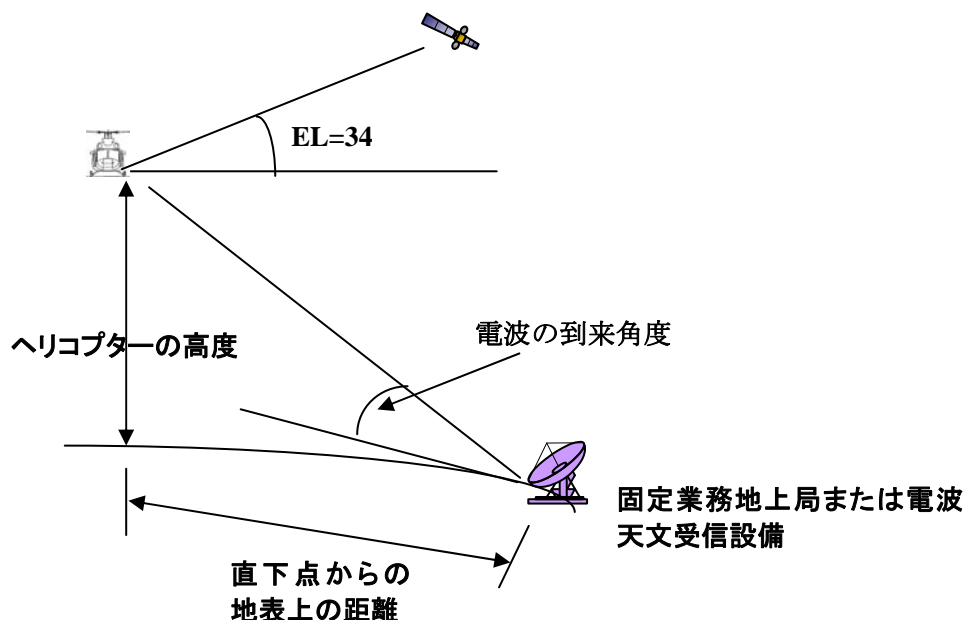
④ 電力束密度の求め方

下図に電力束密度を求める方法を示す。

ヘリコプターの高度150mにおいてEL34°にアンテナが指向している時に、ヘリコプター直下点から地上局または電波天文受信局までの距離をX軸とし、地上局または電波天文受信局での電力束密度をY軸に求めた。(2),(3)項)

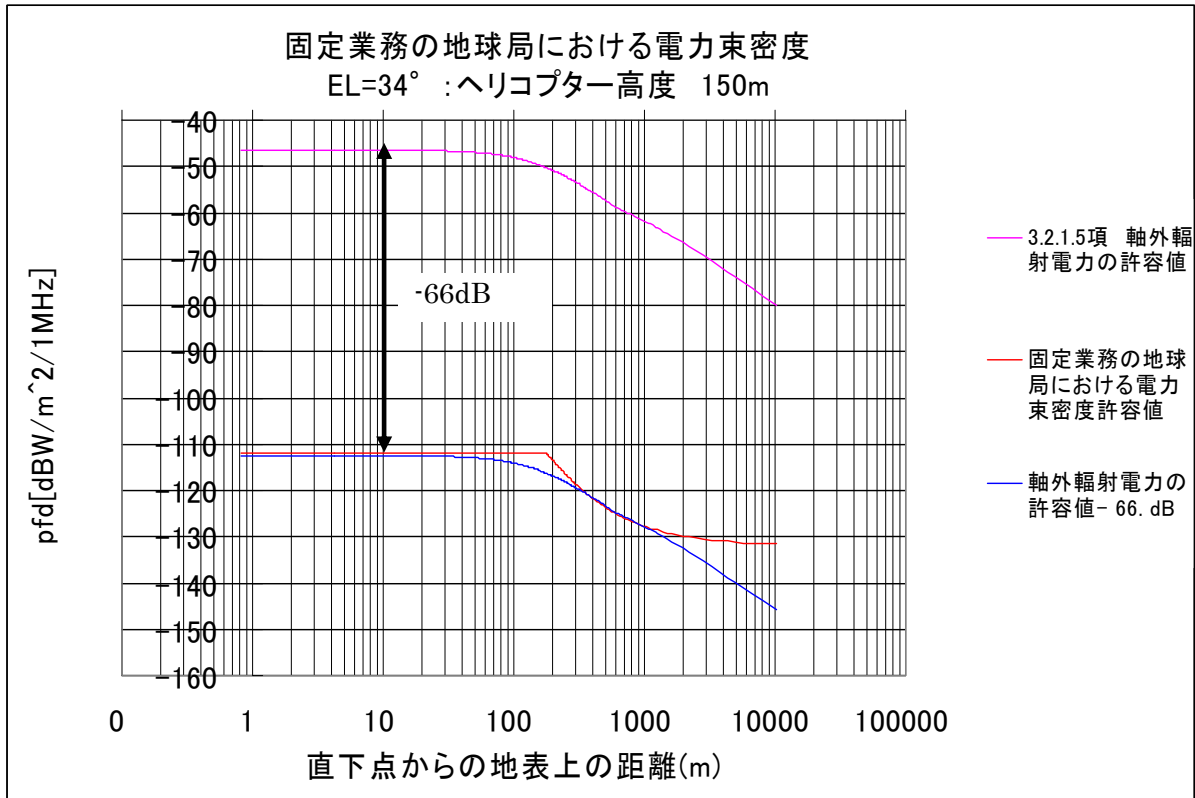
地上局、または電波天文受信局から見たヘリコプター局の角度は、地上局、又は電波天文地球局の位置における水平面からの角度とした。

また、電力束密度についてはヘリコプター局のビーム方向が衛星方向をむいているものとし、ヘリコプターから地表面に対して軸外輻射電力相当の電力密度が放射されているものとして、アンテナから地上局または電波天文受信局間の直線距離でのスパンロスから求めた。



(2) 固定業務との周波数共用に関する検討

軸外輻射電力の許容値で運用した場合の固定業務での電力束密度と本報告書 4.2 項で規定の電力束密度許容値との関係を下図に示す。



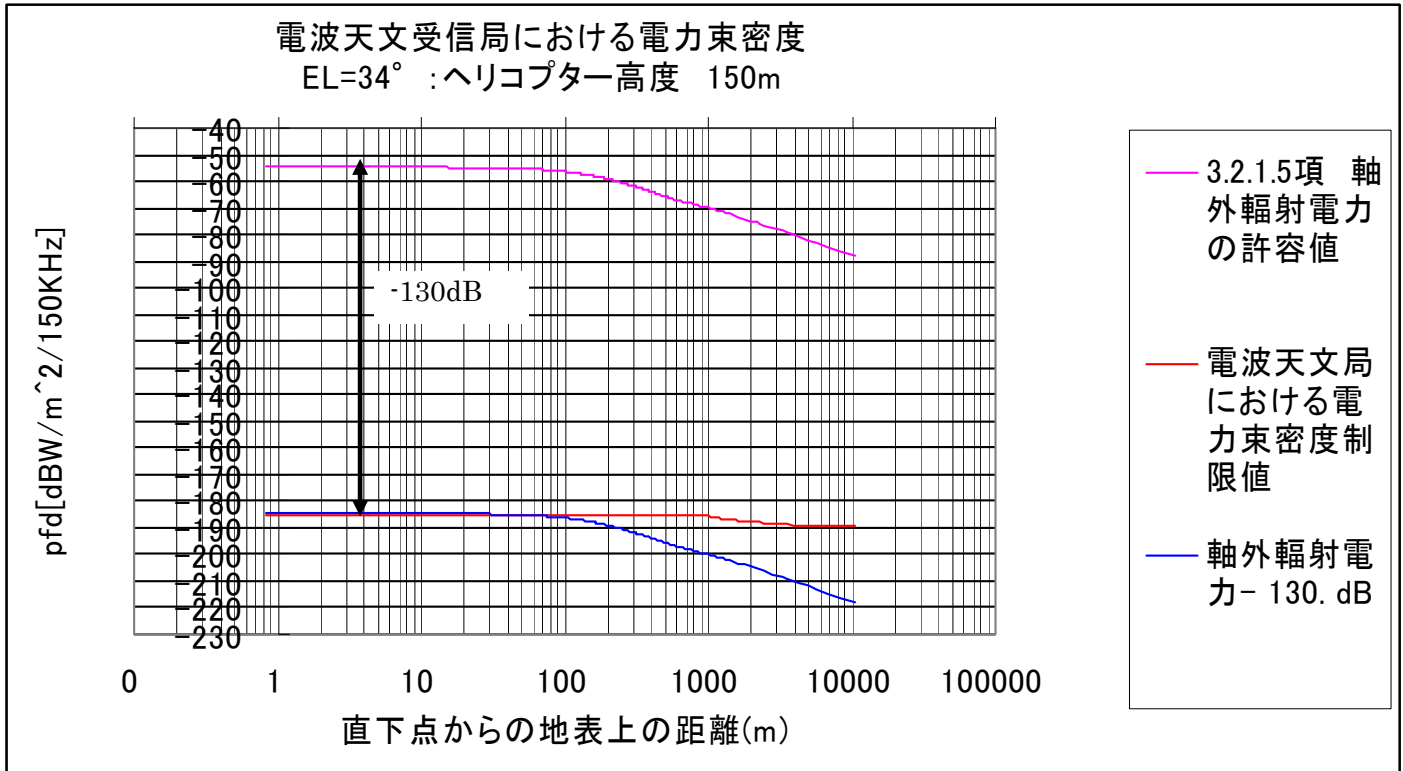
上図から 3.2.1.5 項の軸外輻射電力許容値での運用を行った場合は 66dB 以上の抑圧量が必要となる。

ヘリサットは 14~14.4GHz までの運用としており、固定局は 14.4GHz からの運用である。

送信機の性能としては 60dB 程度の抑圧量が現実的な値であり、不足する場合は、フィルターを追加することにより上記必要量を確保可能であり、技術的に実現可能と考えられる。

(3) 電波天文業務との周波数共用に関する検討

軸外輻射電力の許容値で運用した場合の固定業務での電力束密度と本報告書 4.3 で提案されている電力束密度許容値の関係を下図に示す。



上図から 3.2.1.5 項の軸外輻射電力許容値の特性を持ったアンテナを使用した場合
は 130dB 以上の抑圧量が必要となる。

ヘリサットは 14~14.4GHz までの運用としており、電波天文局は 14.47GHz からの運
用である。

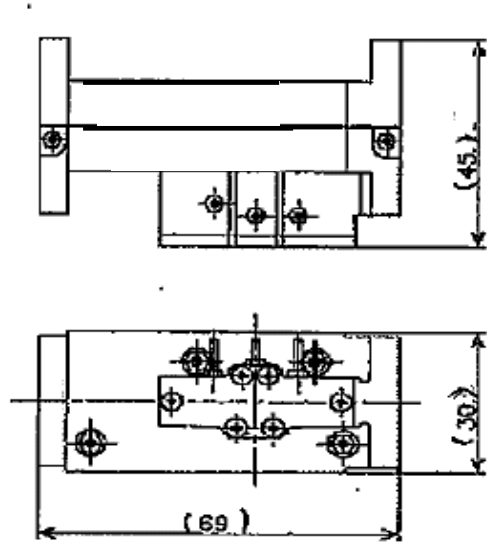
この条件において、送信機の性能としては 60dB 程度の抑圧量が現実的な値であり、
更にフィルターを追加することにより上記必要量を確保可能であり、技術的に実現可
能と考えられる。

上記条件を満足するためのフィルターについて、一例を次ページに示す。

本フィルタを 2 段用いることにより、送信機の特性で 60dB、フィルタ 2 段で 70dB の
抑圧量を確保でき、合計で 130dB 程度の抑圧量の確保が可能と考えられる。

電波天文対応フィルター特性

1. 周波数範囲 14.0-14.4GHz
2. 帯域内挿入損失 0.4dB 以下
3. 帯域内周波数特性 0.15dBpp/36MHz
4. 抑圧量 35dB@14.47GHz-14.5GHz



RECOMMENDATION ITU-R S.728-1*

**Maximum permissible level of off-axis e.i.r.p. density
from very small aperture terminals (VSATs)**

(1992-1995)

The ITU Radiocommunication Assembly,

considering

- a) that geostationary-satellite networks in the fixed-satellite service (FSS) operate in the same frequency bands;
- b) that interference between networks in the FSS contributes to noise in the network;
- c) that it is necessary to protect a geostationary-satellite network in the FSS from interference by other such networks;
- d) that it is necessary to specify the maximum permissible levels of off-axis e.i.r.p. density from VSAT earth stations, to promote harmonization between geostationary-satellite networks;
- e) that networks in the FSS may receive interference into the space station receiver;
- f) that the use of antennas with good off-axis performance will lead to the most efficient use of radio-frequency spectrum and the geostationary-satellite orbit (GSO);
- g) that progress in the development of VSAT antennas indicates that improved side-lobe performance antennas are widely available;
- h) that off-axis e.i.r.p. density levels can be limited through the choice of antenna and/or transmission parameter, e.g. using high gain forward error correction scheme for demodulation or using the spread-spectrum technique;
- j) that in some VSAT systems the code division multiple access (CDMA) scheme is used so that multiple VSATs may transmit simultaneously in the same frequency channel,

recommends

- 1** that VSAT earth stations operating with geostationary satellites in the 14 GHz frequency band used by the FSS be designed in such a manner that at any angle ϕ specified below, off the

* Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

main-lobe axis of an earth-station antenna, the maximum e.i.r.p. in any direction within 3° of the GSO should not exceed the following values:

<i>Angle off-axis</i>	<i>Maximum e.i.r.p. in any 40 kHz band</i>
$2^\circ \leq \varphi \leq 7^\circ$	$33 - 25 \log \varphi$ dBW
$7^\circ < \varphi \leq 9.2^\circ$	12 dBW
$9.2^\circ < \varphi \leq 48^\circ$	$36 - 25 \log \varphi$ dBW
$\varphi > 48^\circ$	-6 dBW

In addition, the cross-polarized component in any direction φ degrees from the antenna main-lobe axis should not exceed the following limits:

<i>Angle off-axis</i>	<i>Maximum e.i.r.p. in any 40 kHz band</i>
$2^\circ \leq \varphi \leq 7^\circ$	$23 - 25 \log \varphi$ dBW
$7^\circ < \varphi \leq 9.2^\circ$	2 dBW

2 that the following Notes should be regarded as part of this Recommendation:

NOTE 1 – Maximum e.i.r.p. density values in § 1 above may need to be decreased up to 8 dB in the systems where the satellite spacing is near 2°.

NOTE 2 – For the systems in which the earth stations are expected to transmit simultaneously in the same 40 kHz band, e.g. for the systems employing CDMA, the maximum e.i.r.p. values in § 1 above should be decreased by $10 \log N$ (dB), where N is the number of earth stations which are expected to transmit simultaneously on the same frequency.

NOTE 3 – Recommendations for VSATs operating in the 6 GHz and other frequency bands are under study. Provisionally Recommendation ITU-R S.524 should be applied for these bands.

NOTE 4 – The values given in § 1 may be exceeded over the range of angles for which the particular feed system may give rise to relatively high levels of spill-over.

NOTE 5 – The limits given in § 1 could be increased up to the limits of Recommendation ITU-R S.524 in case of very large service areas.

NOTE 6 – Annex 1 describes the calculation of permissible off-axis e.i.r.p. density for VSATs.

NOTE 7 – Earth station antennas with D/λ ratios less than 50 are likely to have main beams which extend beyond an off-axis angle of 2° to 3°. Annex 2 shows examples of the main beamwidths of some of these antennas. The off-axis e.i.r.p. limitations at the lower off-axis angles in § 1 can be met by constraining the transmit power spectral flux-density of these antennas.

NOTE 8 – This Recommendation applies to protection between geostationary-satellite networks in the FSS. Potential interference between geostationary-satellite systems and non-geostationary-satellite systems is to be addressed by other Recommendations.

NOTE 9 – The revision in § 1 above to reduce the minimum off-axis angle from 2.5° to 2° applies to earth stations brought into service after the end of 1995 for all geostationary-satellite networks.

ANNEX 1

Calculation of permissible off-axis e.i.r.p. density for VSATs

1 System noise budget

According to Recommendation ITU-R S.523 which deals with permissible interference level in digital satellite transmission, 20% of the total noise power at the demodulator input is allocated to the interference caused by other networks in frequency bands in which the networks practice frequency re-use. Also, 6% of the total noise power is allocated for the single entry interference.

While the off-axis emissions from earth stations cause uplink interference to the adjacent satellites, the emissions from the adjacent satellites cause downlink interference to the receiving earth stations. Therefore, the single entry allocation of 6% should be further divided into uplink and downlink interference. The antenna diameter of the receiving earth station affects the division. If it is larger, the downlink interference becomes less because of its better off-axis isolation, while the uplink interference becomes severer because the total system thermal noise decreases due to increased earth-station G/T .

In considering the off-axis e.i.r.p. limit of VSATs, it may be appropriate to assume that the antenna diameter of the receiving earth station of the interfered network is around 5 m. In this case the budget for the single entry downlink interference can be assumed as less than 1% considering the off-axis gain performance of the antenna. Then the budget for the single entry uplink interference can be assumed as 5%.

Further, the total system noise budget can be assumed as follows:

Thermal noise (uplink + downlink)	50%
Interference from other satellite networks	20% (Recommendation ITU-R S.523)
Interference due to cross-polarization	5%
Intermodulation noise due to transponder	25%

Therefore, the ratio of 5% /50% can be used in comparing the uplink single entry interference power density with the thermal noise density.

2 Derivation of system total thermal noise

In calculating the system total thermal noise, both the uplink and the downlink thermal noise should be considered. The uplink carrier-to-noise density ratio $(C/N_0)_U$, the downlink carrier-to-noise density ratio $(C/N_0)_D$ and the total carrier-to-noise density ratio $(C/N_0)_T$ can be calculated as follows:

$$(C/N_0)_U = e.i.r.p.E - L_U - L_{UA} - L_{UR} + (G/T)_S + 228.6 \quad (1)$$

$$(C/N_0)_D = e.i.r.p.S - OBO - L_D - L_{DA} - L_{DR} + (G/T)_E + 228.6$$

$$= e.i.r.p.E - L_U - L_{UA} - L_{UR} + G_S - L_D - L_{DA} + L_{DR} + (G/T)_E + 228.6 \quad (2)$$

$$(C/N_0)_T = -10 \log (10^{-(C/N_0)_U / 10} + 10^{-(C/N_0)_D / 10}) \quad (3)$$

where:

$e.i.r.p.E$: e.i.r.p. of the transmit earth station of wanted signal

$e.i.r.p.S$: saturation e.i.r.p. of the satellite

L_U : uplink free-space loss

L_D : downlink free-space loss

L_{UA} : uplink clear-air attenuation

L_{DA} : downlink clear-air attenuation

L_{UR} : uplink rain fade

L_{DR} : downlink rain fade

$(G/T)_S$: G/T of the satellite

$(G/T)_E$: G/T of the receiving earth station of wanted signal

OBO : output back-off of the satellite

G_S : small signal gain of the transponder

$$G_S = G_1 + (e.i.r.p.S - SFD) + (IBO - OBO) \quad (4)$$

where:

SFD : saturation flux-density of the satellite

IBO : input back-off of the satellite

G_1 : gain of an ideal antenna area of 1 m²

$$G_1 = 44.4 \text{ dB at 14 GHz}$$

If the effective G/T of the receiving earth station at the satellite input is defined as:

$$(G/T)_{EE} = G_S - L_D - L_{DA} - L_{DR} + (G/T)_E \quad (5)$$

and the total effective G/T of the satellite is defined as:

$$(G/T)_T = -10 \log (10^{-(G/T)_S / 10} + 10^{-(G/T)_{EE} / 10}) \quad (6)$$

then the downlink C/N_0 and the total C/N_0 can be expressed as:

$$(C/N_0)_D = e.i.r.p.E - L_U - L_{UA} - L_{UR} + (G/T)_{EE} + 228.6 \quad (7)$$

$$(C/N_0)_T = e.i.r.p.E - L_U - L_{UA} - L_{UR} + (G/T)_T + 228.6 \quad (8)$$

3 Derivation of permissible off-axis e.i.r.p. density

It is assumed that the off-axis e.i.r.p. density from the interfering VSAT is expressed as $E - 25 \log \phi$ dB(W/40 kHz). Then the uplink carrier-to-interference density ratio in 40 kHz bandwidth can be expressed as follows:

$$C/I_0 = e.i.r.p.E - L_{UR} - (E - 25 \log \phi) \quad (9)$$

Note that it is assumed only the wanted signal suffers the uplink rain fade. Then the interference to thermal noise ratio in 40 kHz bandwidth can be derived as:

$$\begin{aligned} I_0/N_0 &= (C/N_0)_T - C/I_0 - 10 \log B \\ &= (E - 25 \log \phi) - L_U - L_{UA} + (G/T)_T + 228.6 - 10 \log B \end{aligned} \quad (10)$$

where $B = 40$ kHz.

As described in § 1, the value of I_0/N_0 should be less than 5% /50% to satisfy the single entry interference criteria. Then the permissible value of E can be derived as:

$$E = I_0/N_0 + 25 \log \phi + L_U + L_{UA} - (G/T)_T - 228.6 + 10 \log B \quad (11)$$

In the case when the uplink frequency is 14 GHz:

$$E = 25 \log \phi - (G/T)_T + 14.5 + L_{UA} \quad (12)$$

Note that the uplink rain fade does not affect the interference to noise ratio. However, the effect of the downlink rain fade should be taken into account in the calculation of $(G/T)_T$ because the interference budget is defined as a portion of the total noise power which would give rise to a bit error ratio of 1 in 10^6 and usually the system is designed so that the bit error ratio of 1 in 10^6 can be achieved even during the fade condition.

4 Derivation of the required e.i.r.p. from VSATs

The permissible level of E can be derived by the expressions in the previous section. However, it should be checked if VSAT systems can operate with good performance even under that condition.

If it is assumed that the transmit antenna gain of the VSAT earth station is G_T , and that the side-lobe performance of the antenna can be expressed by $29 - 25 \log \phi$, then the e.i.r.p. of the VSAT, $e.i.r.p.E$, in 40 kHz bandwidth can be expressed as:

$$e.i.r.p.E = E - 29 + G_T \quad (13)$$

Then, from expression (8), the carrier power density-to-thermal noise density ratio can be derived as:

$$(C_0/N_0)_T = E - 29 + G_T - L_U - L_{UA} - L_{UR} + (G/T)_T + 228.6 - 10 \log B \quad (14)$$

As explained in § 1 of this Annex, the thermal noise is assumed to be 50% of total noise. Therefore, if required overall energy-per-bit-to-noise density ratio is $(E_b/N_0)_R$ and the conversion factor from C_0/N_0 to E_b/N_0 is K , then the following inequality should be satisfied with an overall system margin of M (dB):

$$(E_b/N_0)_R - K + M \leq (C_0/N_0)_T + 10 \log (50\% / 100\%) \quad (15)$$

The value of K is as follows depending on the type of modulation and forward error correction (FEC):

3 dB for BPSK with rate 1/2 FEC

1.3 dB for BPSK with rate 3/4 FEC

0 dB for QPSK with rate 1/2 FEC

-1.7 dB for QPSK with rate 3/4 FEC.

From the expressions (14) and (15), the required value of E can be calculated. It should be noted that an adequate value of uplink rain fade should be taken into account while the downlink rain fade need not be considered because the effect of the former is usually severer than that of the latter.

5 Numerical results for typical satellite systems

The permissible values and the required values of E are calculated for typical satellite systems as shown in Table 1. The parameter values assumed in the calculation are summarized below:

Antenna diameter of the receive earth station	5 m
G/T of the receive earth station in clear weather	31 dB
G/T of the receive earth station in rainy weather	30 dB
Downlink rain fade	4 dB
Uplink rain fade	3 dB
Downlink clear-air attenuation	0.5 dB
Uplink clear-air attenuation	0.5 dB
Small signal satellite gain increase (IBO-OBO)	4 dB
VSAT antenna diameter	1.2 m
VSAT antenna transmit gain	42.7 dB
Required E_b/N_0 with rate 1/2 FEC	6.4 dB
Required E_b/N_0 with rate 3/4 FEC	7.4 dB
Required overall system margin	1.5 dB

Also the topocentric angle is used for the off-axis angle φ . It is assumed that the topocentric angles are 1.1 times of the geocentric angles and that the satellites are located at their nominal positions. To calculate the downlink free-space loss, the frequencies shown in Table 1 are used.

TABLE 1

Permissible and required values of E

Satellite system	GSTAR	EUTELSAT-II	INTELSAT-VI	AUSSAT
Region	USA	Europe	West-spot	Australia
Downlink frequency (GHz)	11.7	12.5	10.95	12.05
Satellite G/T (dB(K ⁻¹))	1.0	2.0	4.3	-1.0
SFD (dB(W/m ²))	-85.0	-82.8	-81.3	-88.0
Satellite e.i.r.p. (dBW)	42.0	44.0	47.7	42.0
Small signal satellite gain (dB)	175.4	175.2	177.4	178.4
Equivalent total G/T (DL clear)	-2.3	-2.4	0.6	-2.5
Equivalent total G/T (DL rain)	-5.7	-6.1	-3.0	-4.7
Permissible $E - 25 \log \phi$	20.7	21.1	18.0	19.7
Permissible E ($\phi = 2.2$)	29.3	29.7	26.6	28.2
Permissible E ($\phi = 3.3$)	33.7	34.1	31.0	32.6
Permissible E ($\phi = 4.4$)	36.8	37.2	34.1	35.8
Required E (BPSK 3/4 FEC)	27.3	27.4	24.4	27.5
Required E (BPSK 1/2 FEC)	24.6	24.7	21.7	24.8

As shown in the Table, $E = 33$ (dB(W/40 kHz)) may be adequate when the satellite spacing is not less than 3° . When the satellite spacing is 2° less value of E , e.g. 25, may need to be used, although only BPSK transmission with rate 1/2 FEC may be feasible in this case.

ANNEX 2

Ultra small aperture terminal antenna characteristics**1 Introduction**

With the recent introduction of FSS space stations with substantial transmission power capabilities, it has become possible to use “ultra-small aperture terminals (USATs)” for applications formerly relegated to “very small aperture terminals (VSATs)”. However, these USATs have large or wide

main beams which, when transmitting in the Earth-to-space direction, could impinge upon adjacent space stations in the GSO. Likewise, co-frequency, co-coverage transmissions from space stations adjacent to the wanted space station could introduce high levels of interference into these USAT networks. The resultant increase in interference between neighbouring FSS networks will have a negative effect on the communication capacity of the existing GSO/spectrum resources. Thus it is necessary to constrain the interference potential of USAT networks, particularly in the magnitude of uplink off-axis e.i.r.p. densities.

2 USAT antenna beam sizes

Table 2 shows the growth in main beamwidths (MBWs) for antenna sizes with D/λ s below 50. For antennas designed with low side lobe gains and efficiencies around 60% (by incorporating special feed distribution designs), the MBWs shown in Table 2 are likely to be in the higher range.

TABLE 2

Off-axis angular range of antenna half-main beamwidths

Radio frequency (GHz)	D/λ	Antenna diameter (m)	Half-MBW _s ⁽¹⁾ (degrees)
14	50	1.05	1.4-2.3
14	40	0.84	1.7-2.9
14	30	0.63	2.4-3.9

⁽¹⁾ These antennas are paraboloids of revolution or sections of paraboloids. The size of the main beamwidth (MBW) is a function of the antenna feed design. Note that this column shows 1/2 MBW, the angular distance to the first null or zero crossing of antenna gain.

RECOMMENDATION ITU-R M.1643*

**Technical and operational requirements for aircraft earth stations
of aeronautical mobile-satellite service including those
using fixed-satellite service network transponders in
the band 14-14.5 GHz (Earth-to-space)**

(2003)

Summary

This Recommendation provides the technical and operational requirements for aircraft earth stations (AES) of aeronautical mobile-satellite service (AMSS), including those using FSS network transponders operating in the band 14-14.5 GHz (Earth-to-space), that should be used by administrations as a technical guideline for establishing conformance requirements for AES and facilitating their licensing, for worldwide use.

The ITU Radiocommunication Assembly,

considering

- a) that various technically and operationally different aeronautical mobile-satellite service (AMSS) networks have been designed to commence operation in the near future;
- b) that these planned AMSS networks may provide access to a variety of broadband communication applications (Internet, email, internal corporate networks) to and from aircraft on a global basis;
- c) that the aircraft earth station (AES) will operate on national and international airlines around the world;
- d) that circulation of AES is usually a subject of a number of national and international rules and regulations including satisfactory conformance to a mutually agreed technical standard and operational requirements;
- e) that there is a need for identifying the technical and operational requirements for the conformance testing of AES;

* NOTE – The Arab Group represented at RA-03 reserves its position on this Recommendation and is not ready to accept any repercussions with respect to WRC-03 Agenda item 1.11.

f) that the identification of technical and operational requirements for AES would provide a common technical basis for facilitating conformance testing of AES by various national and international authorities and the development of mutual recognition arrangements for conformance of AES;

g) that the technical and operational requirements need to achieve an acceptable balance between radio equipment complexity and the need for effective use of the radio-frequency spectrum,

considering also

a) that in the frequency band 14-14.5 GHz there are allocations to the FSS (Earth-to-space), radionavigation, fixed and mobile (except aeronautical mobile) services on a primary basis; that secondary services allocated in the band 14-14.5 GHz or in parts of the band include mobile-satellite (except aeronautical mobile-satellite) service (Earth-to-space), space research service (SRS), radio astronomy service (RAS), and radionavigation-satellite service;

b) that there is a requirement to fully protect all primary services and pre-existing systems of secondary services in the band 14-14.5 GHz;

c) that results of the studies conducted in accordance with Resolution 216 (Rev.WRC-2000) showed the feasibility of using the band 14-14.5 GHz by AMSS (Earth-to-space) on a secondary basis under certain conditions and arrangements¹;

d) that the identification by ITU-R of technical and operational requirements for AES operating in the band 14-14.5 GHz could assist administrations to prevent harmful and/or unacceptable interference to other services;

e) that technical and operational characteristics should be continuously and accurately measurable and controllable,

recommends

1 that the technical and operational requirements¹ for aircraft earth stations of AMSS networks operating in the band 14-14.5 GHz given in Annexes 1 and 2 be used by administrations as a guideline for:

- establishing conformance requirements for AES;
- facilitating AES operations.

¹ The characteristics of the typical aircraft earth stations need to fulfil the requirements described in this Recommendation and, further, need to be within the envelope of those initially published in the International Frequency Information Circular (BR IFIC) relating to the corresponding FSS network. In the case that the characteristics are outside of the envelope of those in the initial publication, the required coordination of such an aircraft earth station needs to be effected in accordance with the current provisions of the Radio Regulations (RR) and a modified Rule of Procedure as contained in § 2 of the Rules of Procedure relating to RR No. 11.32, as appropriate.

Annex 1

Technical and operational requirements for AES of AMSS networks in the band 14-14.5 GHz (Earth-to-space)

Part A

Essential requirements related to the protection of FSS networks

- 1** AMSS networks should be coordinated and operated in such a manner that the aggregate off-axis e.i.r.p. levels produced by all co-frequency AES within AMSS networks are no greater than the interference levels that have been published and coordinated for the specific and/or typical earth station(s) pertaining to FSS networks where FSS transponders are used.
- 2** The design, coordination and operation of an AES should, at least, account for the following factors which could vary the aggregate off-axis e.i.r.p. levels generated by the AES:

 - 2.1** mispointing of AES antennas. Where applicable, this includes, at least, effects caused by bias and latency of their pointing systems, tracking error of closed loop tracking systems, misalignment between transmit and receive apertures for systems that use separate apertures, and misalignment between transmit and receive feeds for systems that use combined apertures;
 - 2.2** variations in the antenna pattern of AES. Where applicable, this includes, at least, effects caused by manufacturing tolerances, ageing of the antenna and environmental effects. AMSS networks using certain types of AES antennas, such as phased arrays, should account for variation in antenna pattern with scan angles (elevation and azimuth). Networks using phased arrays should also account for element phase error, amplitude error and failure rate;
 - 2.3** variations in the transmit e.i.r.p. from AES. Where applicable, this includes, at least, effects caused by measurement error, control error and latency for closed loop power control systems. Network control and monitoring centres (NCMCs) that calculate the e.i.r.p. of AES based on the received signal need to take into account error sources and latency in this calculation. NCMCs that calculate the e.i.r.p. of AES based on input power must account for measurement error and reporting latency.
- 3** AES that use closed loop tracking of the satellite signal need to employ an algorithm that is resistant to capturing and tracking adjacent satellite signals. AES must immediately inhibit transmission when they detect that unintended satellite tracking has happened or is about to happen.
- 4** AES should be subject to the monitoring and control by an NCMC or equivalent facility. AES must be able to receive at least “enable transmission” and “disable transmission” commands from the NCMC. AES must automatically cease transmissions immediately on receiving any

“parameter change” command, which may cause harmful interference during the change, until it receives an “enable transmission” command from its NCMC. In addition, it should be possible for the NCMC to monitor the operation of an AES to determine if it is malfunctioning.

5 AES need also to be self-monitoring and, should a fault which can cause harmful interference to FSS networks be detected, the AES must automatically mute its transmissions.

Part B

Essential requirements related to the protection of the fixed service

In the 14-14.5 GHz frequency band as used by fixed service networks, within line-of-sight of the territory of an administration where fixed service networks are operating in this band, the maximum pfd produced at the surface of the Earth by emissions from a single AES, of an AMSS network should not exceed:

$$\begin{array}{lll} -132 + 0.5 \cdot \theta & \text{dB(W/(m}^2 \cdot \text{MHz))} & \text{for } \theta \leq 40^\circ \\ -112 & \text{dB(W/(m}^2 \cdot \text{MHz))} & \text{for } 40 < \theta \leq 90^\circ \end{array}$$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

NOTE 1 – The aforementioned limits relate to the pfd and angles of arrival that would be obtained under free-space propagation conditions.

NOTE 2 – An e.i.r.p. mask can be derived from the aforementioned pfd mask by applying the method given in Annex 2 of this Recommendation. Simplification of the resulting e.i.r.p. mask could also be considered.

Part C

Essential requirements related to sharing with the RAS

In order to protect the radio astronomy in the band 14.47-14.5 GHz, AMSS earth stations should comply with both following measures:

AMSS channels in the 14.47-14.5 GHz band

- AMSS stations do not transmit in the 14.47-14.5 GHz band within line-of-sight of radio astronomy stations operating within this band;
- or,
- if an AMSS operator intends to operate co-frequency within the visibility of the radio astronomy station, a specific agreement with the radio astronomy station will be needed to ensure that AMSS AES will meet the requirements of Recommendations ITU-R RA.769 and ITU-R RA.1513 within the 14.47-14.5 GHz band during observations. Where practicable, this may include advance information to AMSS operators regarding observation schedules.

AMSS channels in the 14-14.47 GHz band

All AES transmitters on channels in the 14-14.47 GHz band within line-of-sight of radio astronomy stations during radio astronomy observations have emissions in the band 14.47-14.5 GHz such that they meet the levels and percentage of data loss given in

Recommendations ITU-R RA.769 and ITU-R RA.1513. Results from studies show that the following AES pfd levels (dB(W/(m² · 150 kHz))) in the band 14.47-14.5 GHz are sufficient, with some margin, to meet the radio astronomy pfd levels in Recommendation ITU-R RA.769 and the percentage of data loss given in Recommendation ITU-R RA.1513, i.e.:

$$\begin{array}{lll} -190 + 0.5 \cdot \theta & \text{dB(W/(m}^2 \cdot 150 \text{ kHz))} & \text{for } \theta \leq 10^\circ \\ -185 & \text{dB(W/(m}^2 \cdot 150 \text{ kHz))} & \text{for } 10^\circ < \theta \leq 90^\circ \end{array}$$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

Such AES pfd levels in the band 14.47-14.5 GHz may be achieved by the AMSS operators through a combination of reduced AES signal power, sharp filtering, maintaining adequate frequency separation, or better AES antenna performance.

Part D

Essential requirements related to sharing with the space research service

Coordination agreements should be developed between AMSS and space research systems based on controlling the emissions levels of the AES in the frequency band used by the SRS systems, and, in severe cases, may require cessation of AES emissions on frequencies used by the SRS system when operating in the vicinity of the space research earth station. Specifics of the agreements will vary based on the characteristics of the individual SRS sites and the AMSS networks.

Annex 2

Derivation of a lower hemisphere e.i.r.p. mask from a pfd mask

In testing AMSS equipment to determine if it meets a given pfd mask, such as the one in Annex 1, Part B, it may be useful to determine an equivalent e.i.r.p. mask that can be used for testing purposes.

The pfd mask, $\text{pfd}(\theta)$ where θ is the angle of arrival (elevation angle) at the Earth's surface, can be used to mathematically determine an e.i.r.p. mask, $\text{e.i.r.p.}(\gamma, H)$ where γ is the angle below the local horizontal plane and H is the altitude of the aircraft. This conversion proceeds in two steps. First, γ is converted to an equivalent angle of arrival, θ . Then the length of the propagation path for angle of arrival θ is determined and used to calculate the spreading loss for the path and the resulting e.i.r.p.

Step 1: Calculation of an angle of arrival in degrees, θ , from γ and H :

$$\theta = \arccos((R_e + H) \cos(\gamma)/R_e)$$

where:

- θ : angle of arrival
- R_e : earth radius (6378 km)
- H : altitude of the aircraft (km)
- γ : angle below horizontal.

NOTE 1 – If the argument of the arccos function is greater than 1, the propagation path in the direction of the angle γ does not intersect the Earth. In this case, which occurs for values of γ of about 3.5° or less, a value for θ does not exist and so there is no defined value for the pfd mask.

Step 2: Calculation of the e.i.r.p. value from the defined pfd(θ):

$$d = (R_e^2 + (R_e + H)^2 - 2 R_e (R_e + H) \cos(\gamma - \theta))^{1/2}$$

$$\text{e.i.r.p.}(\gamma, H) = \text{pfd}(\theta) + 10 \log_{10}(4 \pi d^2) + 60$$

where:

- d : distance between the AES and the considered point on the Earth's surface (km)
- pfd(θ): (dB(W/(m² · MHz)))
- e.i.r.p.: (dB(W/MHz)).

The graph in Fig. 1 shows this function for various aircraft altitudes based on the pfd mask provided in Annex 1, Part B of this Recommendation.

