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Prepared by EUMETSAT
Agenda Item: I.1

INTERFERENCE ANALYSIS FROM HIGH ALTITUDE PLATFORM STATIONS (HAPS) TO PASSIVE SENSORS IN THE BAND 31.3 – 31.5 GHz

This document presents the results of a study performed to assess the impact of transmissions from High Altitude Platform Systems (HAPS) to sensors of the Earth Exploration Satellite Service.

CGMS members are invited to support ITU activities related to the protection of EESS in the neighbouring frequency band 31.5 – 31.8 GHz. This band is used as the calibration channel for AMSU measurements. The interference free reception of these sensor data are vital for operations of the instrument.

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1. Introduction

WRC-2000 adopted modifications to Resolution 122 as well as to the Radio Regulations, which require sharing, and compatibility studies between HAPS and systems of other services. This topic has been placed on the agenda of WRC-2003 (agenda item 1.13). Presently there are plans to operate HAPS in the frequency band 31.3 – 31.5 GHz. EESS passive sensors operating in the band 31.5 – 31.8 GHz will be on-board of CGMS Members' spacecraft. The frequency band is vital for calibration of the instruments. Out-of-band emissions into this band could cause the loss of the complete set of measurements.

ITU had selected several candidate bands for HAPS operations. Amongst those there were the bands 18-32 GHz and 46-48GHz. Since the 47 GHz bands are more susceptible to rain attenuation in certain areas of Region 3, the range 18-32 GHz has been proposed for Region 3 for possible identification of additional spectrum, and preliminary ITU-R studies are in progress for these bands.

Radio Regulation S5.5RRR stipulates that the allocation to the fixed service in the band 31.0-31.3 GHz in certain countries may also be used by high altitude platform stations (HAPS) in the ground-to-HAPS direction. The use of the band 31.0-31.3 GHz by systems using HAPS shall not cause harmful interference to, nor claim protection from, other types of fixed-service systems or other co-primary services, taking into account No. S5.545. The use of HAPS in the band 31.0-31.3 GHz shall not cause harmful interference to the passive services having a primary allocation in the band 31.3-31.8 GHz, taking into account the interference criteria given in Recommendations ITU-R SA.1029 and ITU-R RA.769. The administrations of the countries concerned are urged to limit the deployment of HAPS in the band 31.0-31.3 GHz to the lower half of this band (31.0-31.15 GHz) until WRC-2003.

Resolution 122 also recognizes that the 31.3-31.8 GHz band is allocated to the radio astronomy, EESS (passive) and space research (passive) services and the 31.8-32.3 GHz band is allocated to the space research (deep space) service, and that there is a need to appropriately protect these services from unwanted emissions, taking into account No. S5.340 and the interference criteria given in Recommendations ITU-R SA.1029 and ITU-R RA.769

Resolution 122 furthermore requests the ITU-R to conduct studies, as a matter of urgency, and taking into account the requirements of other fixed-service systems and other services, on the feasibility of identifying suitable frequencies, in addition to the 2 x 300 MHz paired band at 47 GHz, for the use of HAPS in the fixed service in the range 18-32 GHz in Region 3, focusing particularly, but not exclusively, on the bands 27.5-28.35 GHz and 31.0-31.3 GHz.

HAPS is an interesting system concept, which can be expected to be deployed worldwide in significant numbers. It is therefore important that HAPS system design and operations is carried out in compliance with protection requirements of other services to arrive at a satisfactory long-term sharing environment.

Figure 1 gives an overview on the geometrical constellation for which interference will occur at a satellite carrying a passive sensor instrument. Between several hundred and several thousand earth stations are expected per system so that many HAPS stations will contribute to the aggregate interference received at the sensor. In view of the large number of HAPS earth stations, there will be a high likelihood for main beam coupling between at least one HAPS earth station antenna and the sensor antenna. If the HAPS antennas are closely spaced, several main beam couplings are likely to occur.

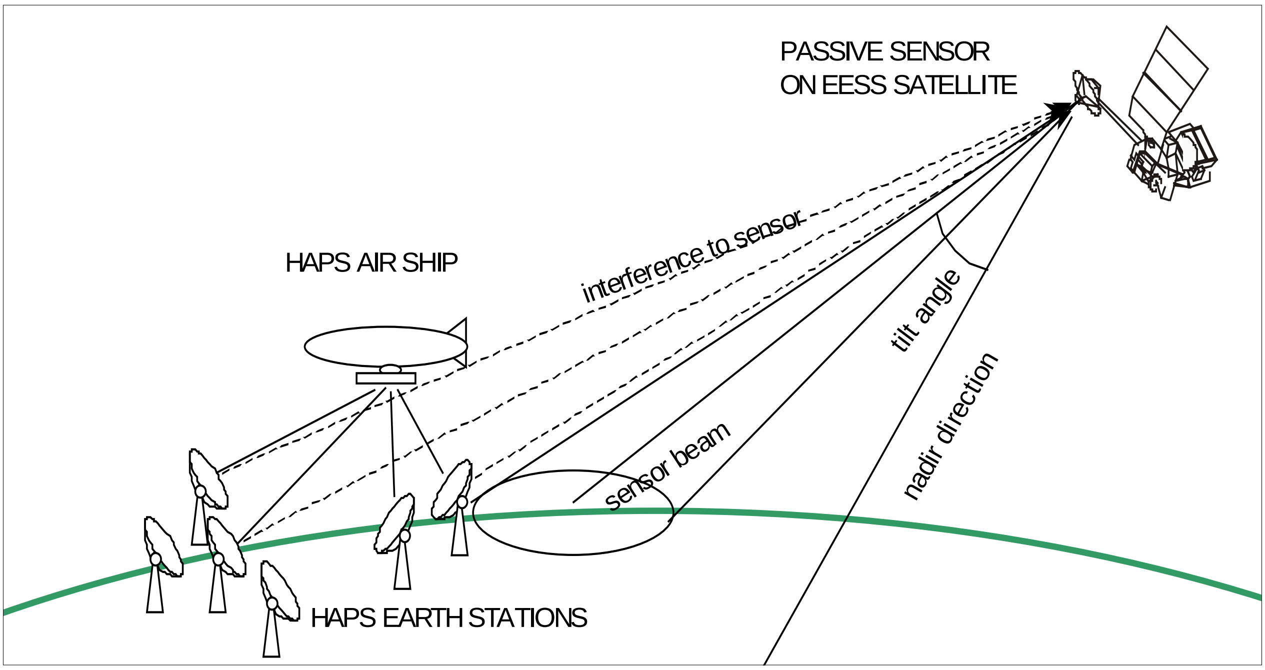

FIGURE 1

GEOMETRICAL INTERFERENCE CONSTELLATION

2. Passive sensor system description and protection requirements

The band 31.3 – 31.8 GHz and, in particular, the sub-band 31.3 – 31.5 GHz are important bands for passive sensor applications. The band 31.3-31.5 GHz is an entirely passive band, which means that no emissions are allowed.

Altitudes of EESS spacecraft carrying passive sensors range typically around 700 km, but can be as low as 250 km and occasionally above 1000 km. It is suggested to consider therefore 2 representative orbital heights, one around 300 km representing a worst case and another one around 800 km representing a typical case.

The passive sensor protection criterion is -183 dBW/MHz not to be exceed for more than 0.01% of time as stipulated by Recommendation ITU-R SA.1029. This is the maximum power to be received by the low noise amplifier. The antenna gain has therefore to be added to obtain the permissible interference level at the antenna input.

The gain of the currently used sensor antennas on EESS satellites is approximately 26 dBi but a new generation based on push-broom sensors is planned. These will have antenna gains of approximately 40 dBi. In view of future use of the band, it is thus recommended to use the higher antenna gain of 40 dBi. For the antenna gain contour, Recommendation ITU-R F.699 can be used. The corresponding equations for the antenna gain for D/λ < 100 are given by:

$$
\begin{aligned}
G_{(\varphi)} &= G_{\max} - 2.5 \times 10^{-3} \left(\tfrac{D}{\lambda}\varphi\right)^2 && \text{for } 0 \le \varphi < \varphi_m \\
G_{(\varphi)} &= 2 + 15 \log \left(\tfrac{D}{\lambda}\right) && \text{for } \varphi_m \le \varphi < 100 \frac{\lambda}{D} \\
G_{(\varphi)} &= 52 - 10 \log \left(\tfrac{D}{\lambda}\right) - 25 \log \varphi && \text{for } 100 \frac{\lambda}{D} \le \varphi < 48^\circ \\
G_{(\varphi)} &= 10 - 10 \log \left(\tfrac{D}{\lambda}\right) && \text{for } 48^\circ \le \varphi < 180^\circ
\end{aligned}
$$

$$\varphi_m = 20 \frac{\lambda}{D} \sqrt{G_{\max} - 2 - 15 \log\left(\tfrac{D}{\lambda}\right)}$$

where: D : antenna diameter

8 : wavelength

ν : off-axis angle of the antenna, in degrees

Figure 2 shows the antenna gain envelope for a sensor antenna with a maximum gain of 40 dBi.

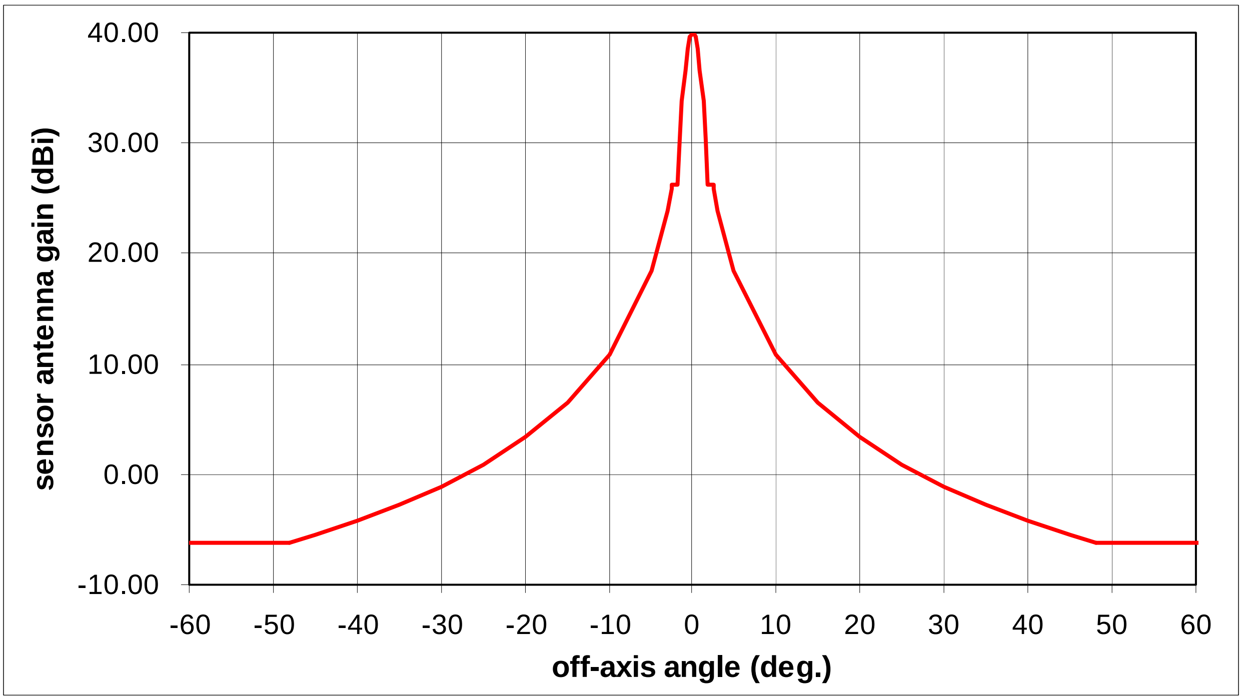

FIGURE 2

ANTENNA GAIN CONTOUR OF PASSIVE SENSOR

3. HAPS system description

HAPS communications will take place between ground-based stations and an airship at an altitude between 20 and 50 km. From preliminary information submitted to the ITU-R, a number of assumptions can be extracted. Transmitter power levels have been specified with –16 dBW for a bandwidth of 20 MHz. This corresponds to a power density of –29 dBW/MHz. The out-of-band noise level has been specified with -100 dBW/MHz.

The number of earth stations per system may range between a few hundred and several thousand. For the purpose of this study, a system with 400 simultaneously transmitting earth stations has been assumed.

The maximum antenna gain of an uplink station is assumed to be 35 dBi. The antenna diameter has been estimated to be approximately 0.22 m by means of the following equation and assuming a $G_{(max)}$ of 35dBi:

$$20 \log\left(\frac{D}{\lambda}\right) \approx G_{(\max)} - 7.7$$

An important aspect is the antenna envelope model for multiple entry interference. The often used Recommendation ITU-R F.699 is more applicable when one or a few interferers or a static interference situation has to be considered. For multiple entry interference from a large number of transmitters, a model has been developed in the ITU-R, which takes into account the actual mean average antenna gain and not the gain given by envelope specifications. This model is contained in Recommendation F.1245. The following equations have therefore been used for the antenna gains of the HAPS stations taking into account that the ratio between the antenna diameter and the wavelength is less than 100:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for} \quad 0 \leq \varphi < \varphi_m$$

$$G(\varphi) = 39 - 5 \log(D/\lambda) - 25 \log \varphi \quad \text{for} \quad \varphi_m \leq \varphi < 48°$$

$$G(\varphi) = -3 - 5 \log(D/\lambda) \quad \text{for} \quad 48° \leq \varphi \leq 180°$$

A key factor in the system design is availability. One system planned to be deployed in the area of Tokyo has been assumed with a rain margin of 10.4 dB based on an availability of 99.14% and a minimum elevation angle of 20 degrees. A number of countries requesting the use of these bands for HAPS are located in tropical regions so that a higher rain margin will be required to obtain an availability above 99%. In addition, HAPS is considered a fixed service systems and will be in competition to existing fixed service deployment. Fixed service systems at higher frequencies have typically system availability specifications above 99.99%. It can therefore be expected that a competitive and practical system will require significantly higher rain margins compatible with existing systems of the same service.

A minimum elevation angle of 20 degrees has been assumed for the HAPS stations in the Tokyo example. For more general applications, this may be rather high and certainly excludes a large range of potential service areas. An operational and competitive system is likely to have a service area limited by elevation angles down to 5 or 10 degrees. For the purpose of this study, 10 degrees has been assumed as the minimum elevation angle. Combining the assumptions of availability requirements between 99.9% and 99.99% and elevation angles down to 10 degrees, and that some areas will have higher rain rates than Tokyo, it appears more appropriate to assume a minimum rain margin of 25 dB for an elevation of 10 degrees and an availability of 99.9%. In fact, even higher rain margins may be required for some systems with high margin dynamics but for these cases it is assumed that automatic power control will be used.

4. Interference analyses

Interference from a single HAPS station can be calculated by means of a spread sheet model. Table 1 shows all assumptions and the results for 4 cases covering the altitude range for the HAPS airship between 20 and 50 km and the orbital height of the sensor between 300 and 800 km.

TABLE 1

HAPS LINK BUDGET ASSUMPTIONS AND SINGLE INTERFERER CALCULATIONS

HAPS air ship altitude	20	50	20	50	km
Carrier frequency	31.3	31.3	31.3	31.3	GHz
Range to air ship for 10 deg. elevation	110	259			km
Range to air ship for 90 deg. elevation			20	50	km
HAPS earth station antenna gain	35.0	35.0	35.0	35.0	dBi
HAPS earth station output power	3.5	10.9	3.5	10.9	dBW
Transmitter feeder losses	0.5	0.5	0.5	0.5	dB
HAPS earth station EIRP	38.0	45.4	38.0	45.4	dBW
HAPS uplink bandwidth	20.0	20.0	20.0	20.0	MHz
HAPS earth station EIRP density	25.0	32.4	25.0	32.4	dBW/MHz
Propagation loss to HAPS receiver	163.2	170.6	148.4	156.4	dB
Rain margin for 99.9% availability	25.0	25.0	10.0	10.0	dB
Attenuation due to atmospheric gases	0.4	0.4	0.0	0.0	dB
HAPS spacecraft antenna gain	32.5	32.5	19.5	19.5	dBi
HAPS system temperature	28.5	28.5	28.5	28.5	dBK
Receiver feeder losses	0.5	0.5	0.5	0.5	dB
Received power at HAPS air ship	-118.6	-118.6	-101.4	-102.0	dBW
HAPS air ship G/T	3.5	3.5	-9.5	-9.5	dB/K
Available signal to noise density	81.6	81.5	98.8	98.2	dBHz
Symbol rate	73.0	73.0	73.0	73.0	dBHz
Technical receiver losses	3.0	3.0	3.0	3.0	dB
Required Es/No for BER = 1E-6	5.5	5.5	5.5	5.5	dB
Required signal to noise density	81.5	81.5	81.5	81.5	dBHz
HAPS system margin	0.0	0.0	17.2	16.7	dB
EESS satellite orbit height	800	800	800	800	km
Range to satellite for 10 deg. elevation	2367	2367			km
Range to satellite for 90 deg. elevation			800	800	km
Propagation loss to EESS satellite	189.9	189.9	180.4	180.4	dB
Spacecraft antenna gain	40.0	40.0	40.0	40.0	dBi
Received interference power density	-124.9	-117.5	-115.4	-108.0	dBW/MHz
Passive sensor protection criterion	-183.0	-183.0	-183.0	-183.0	dBW/MHz
Required out-of-band signal attenuation for a single HAPS station to an EES at 800 km orbit height	58.1	65.5	67.6	75.0	dB
EESS satellite orbit height	300	300	300	300	km
Range to satellite for 10 deg. elevation	1160	1160			km
Range to satellite for 90 deg. elevation			300	300	km
Propagation loss to EESS satellite	64.3	71.7	76.1	83.5	dB
Received interference power density	-118.7	-111.3	-106.9	-99.5	dBW/MHz
Required out-of-band signal attenuation for a single HAPS station to an EES at 800 km orbit height	64.3	71.7	76.1	83.5	dB

It can be seen that in the 8 cases considered, an attenuation in excess of 58 dB and up to 84 dB is required for a single HAPS station. It is, of course, evident, that this is an adjacent band situation and that the HAPS signal will never enter a passive sensor at the above signal levels.

The interference from the number of HAPS stations assumed in this study can be expressed by:

$$I = \sum_{i=1}^{400} P_d + Gt_i - 20\log_{10}(4\pi d_i / \lambda) + Gr_i \quad \text{dB(W/MHz)}$$

where:

P_d : power density of HAPS earth station (dBW/MHz)

Gt_i : transmitting antenna gain of the *i*-th HAPS earth station towards EES (dBi)

d_i : distance between the *i*-th HAPS earth station and EES (m)

λ : wavelength of the carrier signal (9.58mm for 31.3 GHz)

Gr_i : receiving antenna gain of EES toward the *i*-th HAPS earth station (dBi):

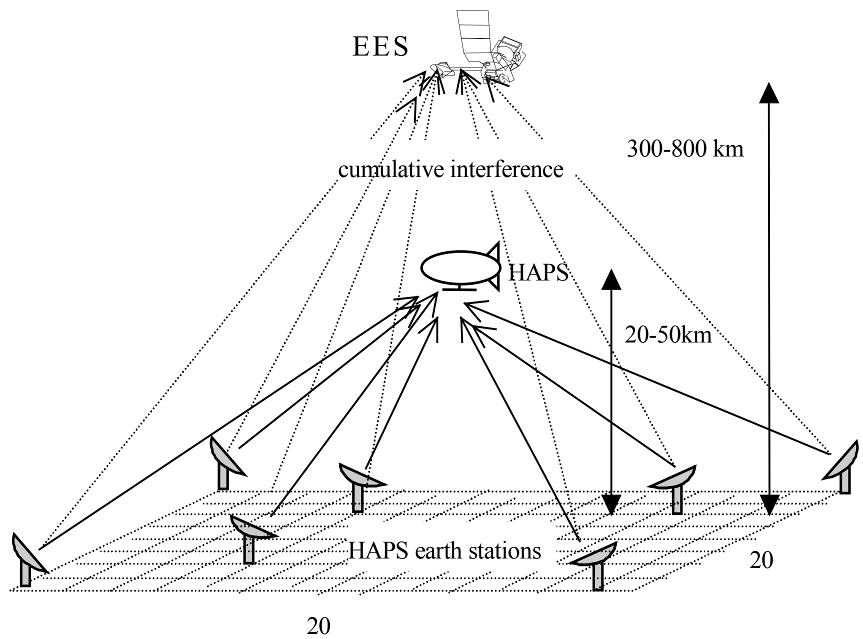

FIGURE 3

HAPS EARTH STATION MULTIPLE INTERFERENCE MODEL

It is evident that the total number of stations and their separation distance determine the aggregate gain of the HAPS network. Figure 4 shows the results for 400 HAPS earth stations as a function of the station separation distance. The gain of a single station is 35 dBi. The closer the stations, the higher the cumulative gain. If all stations were in the centre (d=0), the cumulative gain would be 26 dB (400 times) higher than that of a single station. On the other hand, the interference duration would be rather short.

In the other extreme case of very wide station separation, the cumulative gain approaches that of a single station but whenever a sensor is in line of sight of a HAPS system, it is very likely that one of the stations will have the sensor in its main beam. For a likely separation distance range between 200 and 600 m, it may be assumed that the cumulative antenna gain is approximately 15 dB higher.

Assuming a specific case of 200 m, the cumulative gain increase is around 16 dB for a HAPS altitude of 20 km and 23 dB for an altitude of 50 km.

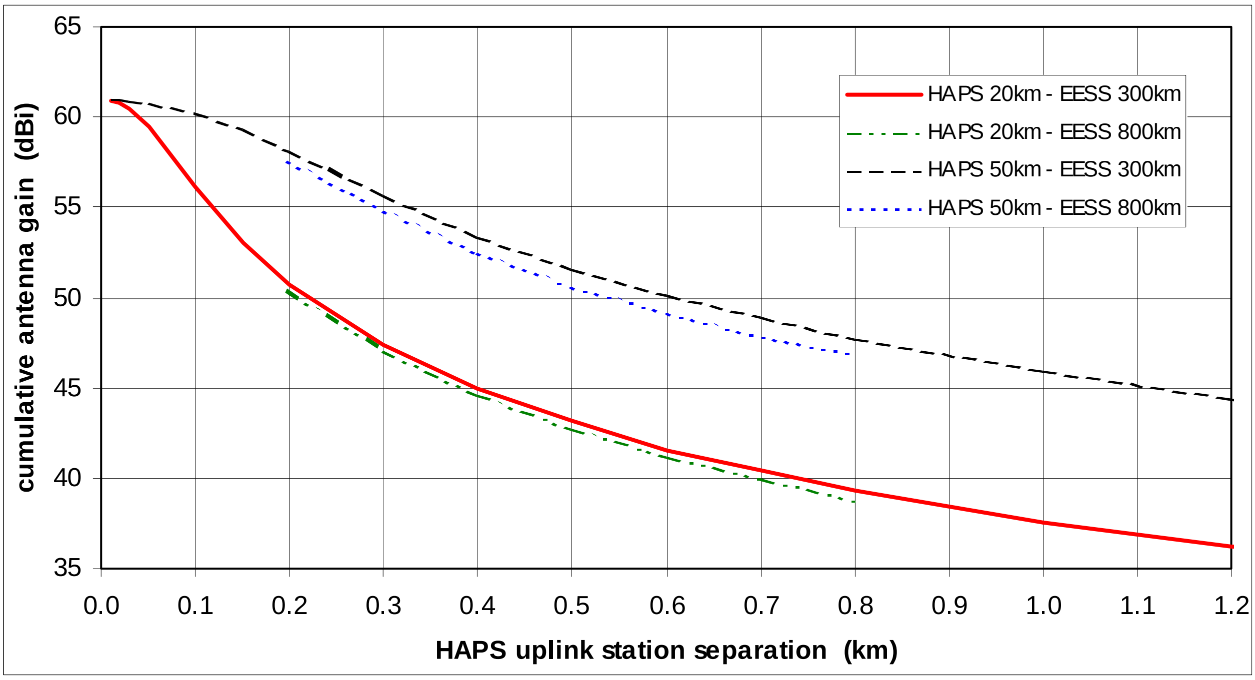

FIGURE 4

CUMULATIVE HAPS EARTH STATION ANTENNA GAIN

In summary, looking at the interference excess from a single HAPS earth station and the impact of the cumulative gain, the total interference excess can be expected somewhere between 83.6 dB and 98 dB for an orbit height of 800 km and between 92.1 dB and 106.5 dB for an orbit height of 300 km. The above applies to a situation where the sensor is approximately above the HAPS air ship. It is evident that the required amount of filtering would be very constraining and could well be prohibitive from a cost and complexity point-of-view.

Another interesting aspect is the impact of a tilt angle for the sensor antenna. This is the angle by which the sensor antenna is pointing away from the nadir direction. Figure 5 shows the relative attenuation as a function of the elevation angle from the HAPS earth station to the sensor satellite. The relative gain is the combined effect of the increasing space loss and the decreasing gain (for a tilt angle of 0) when the sensor satellite is moving away from the overhead direction above the HAPS system. With a tilt angle, the sensor antenna gain will first increase to a maximum and then drop again for low elevation angles. Typical tilt angles are around 20 to 25 degrees. Figure 5 shows the impact of 2 tilt angles of 20 and 40 degrees, respectively in comparison to a nadir pointing sensor (i.e. no tilt angle).

It is interesting to note from figure 5 that antenna decoupling due to tilt angles has little influence on the magnitude of the cumulative interference. There will always be an elevation angle well within the typical deployment range of a HAPS system, where nearly the same maximum interference will be received compared to a nadir looking sensor. The only difference is the slightly increased space loss and the different geometrical constellation when the interference maximum occurs.

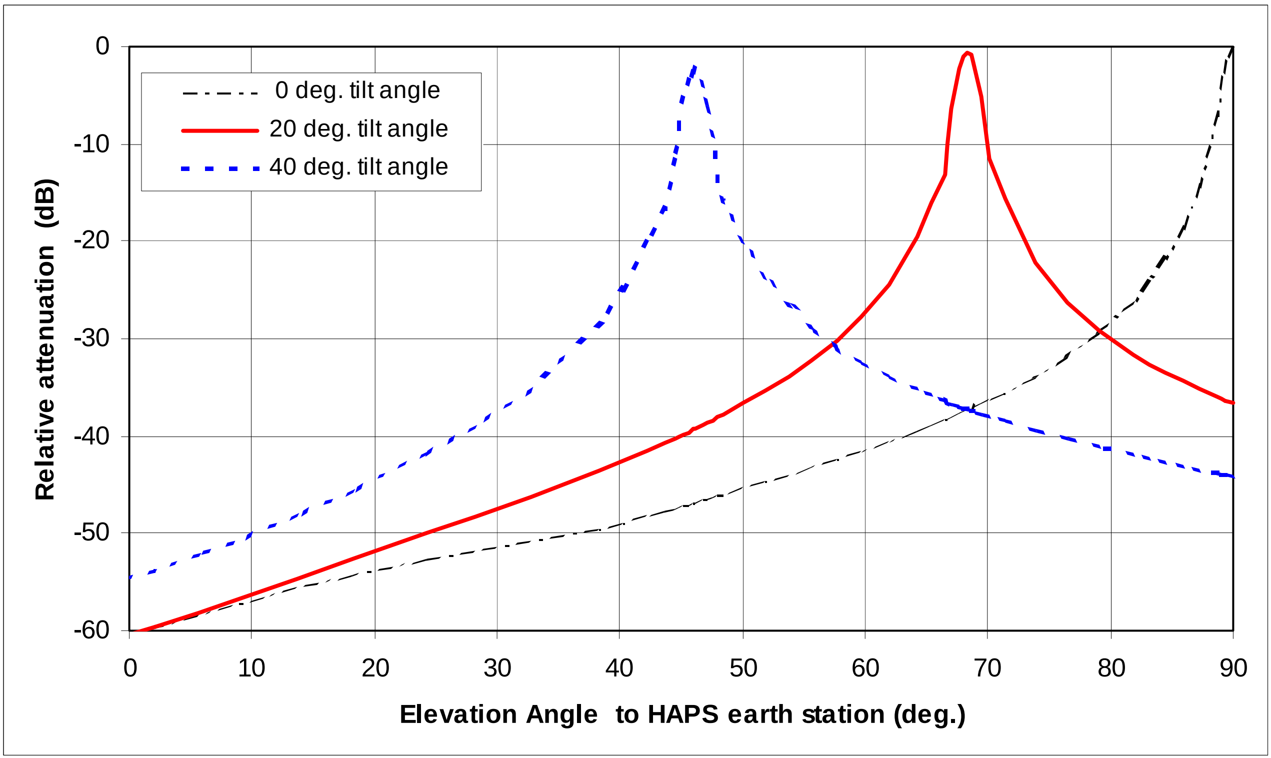

FIGURE 5

IMPACT OF SENSOR ANTENNA TILT ANGLE

5. Conclusions

A worst case HAPS out-of-band signal attenuation of more than 100 dB will be required for typical HAPS systems, which could theoretically only be achieved by a combination of natural signal roll-off, filtering and a guard band.

A draft recommendation is currently in progress within ITU-R Task Group 1/5, which looks at typical out-of-band emissions masks in the range 35 to 50 dB. As an attenuation of around 100 dB is practically nearly impossible to achieve, it can be concluded that HAPS up-links cannot use the band below 31.3 GHz without causing detrimental interference to passive sensors which make any measurements basically useless.

CGMS members are requested to support activities to protect EESS (passive) measurements in the band 31.3 – 31.8 GHz.