International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R M.1731-1
(12/2010)

Protection criteria for Cospas-Sarsat local user terminals in the band 1 544-1 545 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

ITU
International
Telecommunication
Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

<table>
<tr><td colspan="2" align="center">Series of ITU-R Recommendations
(Also available online at http://www.itu.int/publ/R-REC/en)</td></tr>
<tr><td>Series</td><td align="center">Title</td></tr>
<tr><td>BO</td><td>Satellite delivery</td></tr>
<tr><td>BR</td><td>Recording for production, archival and play-out; film for television</td></tr>
<tr><td>BS</td><td>Broadcasting service (sound)</td></tr>
<tr><td>BT</td><td>Broadcasting service (television)</td></tr>
<tr><td>F</td><td>Fixed service</td></tr>
<tr><td>M</td><td>Mobile, radiodetermination, amateur and related satellite services</td></tr>
<tr><td>P</td><td>Radiowave propagation</td></tr>
<tr><td>RA</td><td>Radio astronomy</td></tr>
<tr><td>RS</td><td>Remote sensing systems</td></tr>
<tr><td>S</td><td>Fixed-satellite service</td></tr>
<tr><td>SA</td><td>Space applications and meteorology</td></tr>
<tr><td>SF</td><td>Frequency sharing and coordination between fixed-satellite and fixed service systems</td></tr>
<tr><td>SM</td><td>Spectrum management</td></tr>
<tr><td>SNG</td><td>Satellite news gathering</td></tr>
<tr><td>TF</td><td>Time signals and frequency standards emissions</td></tr>
<tr><td>V</td><td>Vocabulary and related subjects</td></tr>
</table>

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

RECOMMENDATION ITU-R M.1731-1*

Protection criteria for Cospas-Sarsat local user terminals in the band 1 544-1 545 MHz

(2005-2010)

Scope

This Recommendation provides protection criteria for Cospas-Sarsat local user terminals that receive 1 544-1 545 MHz downlinks from satellites in geostationary and low-Earth orbits. The Cospas-Sarsat program receives and processes signals from emergency position indicating radio beacons (EPIRBs) and other distress beacons operating on 406 MHz. In some cases the signals are delivered to ground stations via a downlink operating in the 1 544-1 545 MHz band.

The ITU Radiocommunication Assembly,

considering

a)   that Recommendation ITU-R SM.1535 calls for the protection of safety services from unwanted emissions;

b)   that the Cospas-Sarsat global search and rescue satellite-aided system operates within the band 1 544-1 545 MHz which is limited by No. 5.356 of the Radio Regulations (RR) to distress and safety, space-to-Earth radiocommunications;

c)   that harmful interference to safety services can cause loss of life and property;

d)   that Cospas-Sarsat geostationary Earth orbit local user terminals (GEOLUTs) receive in the band 1 544-1 545 MHz emergency position indicating radio beacons (EPIRB) signals relayed from geostationary orbiting and environmental satellites (GOES) and Meteo-Sat second generation (MSG) satellites;

e)   that Cospas-Sarsat low-Earth orbit local user terminals (LEOLUTs) receive in the band 1 544-1 545 MHz EPIRB signals relayed from search and rescue repeaters (SARR) on Cospas and Sarsat satellites;

f)   that Cospas-Sarsat LEOLUTs receive in the band 1 544-1 545 MHz a global processed data stream (PDS) of EPIRB data processed by search and rescue processors (SARPs) on Cospas and Sarsat satellites;

g)   that Cospas-Sarsat medium-Earth orbit local user terminals (MEOLUTs) receive in the band 1 544-1 545 MHz EPIRB signals relayed from medium-Earth orbiting navigation satellites (GALILEO);

h)   that Annex 6 contains Cospas-Sarsat link budgets for low-Earth orbit (LEO), medium-Earth orbit (MEO) and geostationary orbit (GEO) operations using near to worst-case values referred to in this Annex as "low-level case",

---

*   This Recommendation should be brought to the attention of Cospas-Sarsat, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO).

recommends

1   that the analysis of interference to Cospas-Sarsat GEOLUTs that operate with GOES satellites should be based on Annex 1;

2   that the analysis of interference to Cospas-Sarsat LEOLUTs receiving global EPIRB PDS data should be based on Annex 2;

3   that the analysis of interference to Cospas-Sarsat LEOLUTs receiving 406 MHz EPIRB signals relayed by Cospas and Sarsat low-Earth orbiting satellites should be based on Annex 3;

4   that the analysis of interference to Cospas-Sarsat GEOLUTs that operate with MSG satellites should be based on Annex 4;

5   that the analysis of interference to Cospas-Sarsat MEOLUTs that operate with GALILEO satellites should be based on Annex 5.

Annex 1

Protection criteria in the 1 544-1 545 MHz band for Cospas-Sarsat GEOLUTS that receive EPIRB signals relayed through GOES satellites

1.1   Introduction

Cospas-Sarsat search and rescue repeaters are onboard GOES. These repeaters receive signals from 406 MHz EPIRBs and relay the signals to Cospas-Sarsat GEOLUTs on downlink frequencies in the 1 544-1 545 MHz band. In accordance with the RR, the 1 544-1 545 MHz band is allocated to the mobile-satellite service (MSS), space-to-Earth, and is specifically limited by RR No. 5.356 to distress and safety communications. The analysis provided in this Annex establishes interference protection criteria for GEOLUTs that receive the GOES 1 544-1 545 MHz downlink.

1.2   Minimum acceptable performance for detection of EPIRB signals relayed through the GOES satellite

To reliably detect 406 MHz distress beacons using GOES 406 MHz satellite repeaters, the bit-error rate (BER) of the channel must not exceed 5×10^{-5}.

1.3   Analysis of interference spectral power flux-density (spfd)

The BER of a communications channel is derived from the ratio of the energy contained in each data bit, E_b, to the noise density. The total noise density is comprised of the noise developed by Cospas-Sarsat equipment, N_0, and noise caused by interference from other systems, I_0. Figure 1 depicts the GOES 406 MHz SARR channel with interference on the downlink.

FIGURE 1

GOES SARR with interference on the downlink
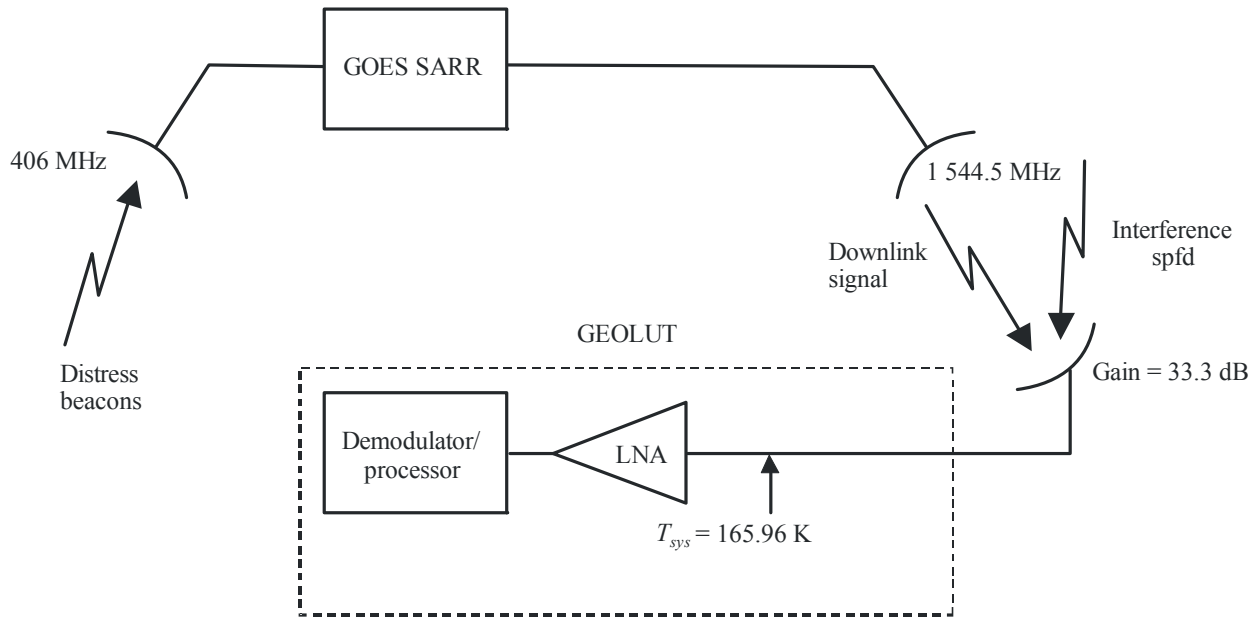
LNA: low noise amplifier

M.1731-01

To achieve a BER of 5×10^{-5}, the ratio of the energy per bit to noise plus interference density $(E_b/(N_0 + I_0))$ at the GEOLUT demodulator must equal or exceed 8.8 dB. This analysis determines the maximum amount of broadband noise-like interference specified as an spfd referenced to the input to the GEOLUT antenna that could be accommodated without degrading the overall link $E_b/(N_0 + I_0)$ below 8.8 dB.

As seen in Fig. 1, 406 MHz distress beacon signals are received by the GOES SARR and phase modulated onto a 1 544.5 MHz downlink carrier for detection and processing by GEOLUTs. The antenna gain and system noise temperature for a GOES GEOLUT are 33.3 dB and 165.96 K, respectively.

The EPIRB signal has an elevation angle of 5° with respect to the spacecraft. When no external sources of interference are present, the overall C/N_0 is 31.1 dB-Hz, which equates to an E_b/N_0 of 5.1 dB. Accounting for implementation and beacon data demodulation losses and processing gains at the GEOLUT, results in an effective ratio of E_b/N_0 of 10.1 dB. Since the channel requires an overall $E_b/(N_0 + I_0)$ of at least 8.8 dB to reliably meet minimum performance, the accumulation of broadband interference on the downlink that reduces the overall carrier-to-noise plus interference density ratio by more than 1.3 dB cannot be accommodated.

Since the overall C/N_0 in the absence of interference equates to 31.1 dB-Hz, broadband noise-like interference on the downlink that degrades it by 1.3 dB, would result in an overall carrier-to-noise plus interference density ratio $(C/(N_0 + I_0))_{overall}$ of:

$$(C/(N_0 + I_0))_{overall} = (C/N_0)_{overall} - 1.3 \text{ dB}$$
$$= 31.1 \text{ dB-Hz} - 1.3 \text{ dB}$$
$$= 29.8 \text{ dB-Hz}$$

The $(C/(N_0 + I_0))_{overall}$ is calculated from the carrier-to-noise plus interference density ratios of the uplink and downlink as indicated below:

$$(C/(N_0 + I_0))_{overall} = ((C/(N_0 + I_0))^{-1}{\uparrow} + (C/(N_0 + I_0))^{-1}{\downarrow})^{-1}$$

Since this analysis only concerns downlink interference, the above equation simplifies to:

$$(C/(N_0 + I_0))_{overall} = ((C/N_0)^{-1}{\uparrow} + (C/(N_0 + I_0))^{-1}{\downarrow})^{-1}$$

Substituting 29.8 dB-Hz for $(C/(N_0 + I_0))_{overall}$ and 31.3 dB-Hz for $(C/N_0){\uparrow}$ results in a $(C/(N_0 + I_0)){\downarrow}$ of 35.1 dB-Hz (see below):

$$C/(N_0 + I_0){\downarrow} = ((C/(N_0 + I_0))_{overall}{}^{-1} - (C/N_0){\uparrow}^{-1})^{-1}$$

or

$$C/(N_0 + I_0){\downarrow} = 10 \log ((10^{-29.8/10} - 10^{-31.3/10})^{-1})$$

then

$$C/(N_0 + I_0){\downarrow} = 35.1 \text{ dB-Hz}$$

The noise power spectral-density of the downlink without interference at the input to the LNA is $N_0 = k\,T$, where k is Boltzmann's constant. Therefore, $N_0 = -228.6 + 22.2 = -206.4$ dB(W/Hz).

The $(C/N_0){\downarrow}$ equals 43.8 dB and $(N_0){\downarrow}$ equals -206.4 dB(W/Hz), so the value of $C{\downarrow}$ is -162.6 dBW.

The maximum permissible interference power spectral-density in the downlink from the aggregate of all interfering emitters, $I_0(\text{max})$, measured at the input to the GEOLUT receiver LNA over the 1 544.5 MHz $\pm$ 100 kHz band is:

$$I_0(\text{max}) = 10 \log (10^{(C{\downarrow} - (C/(N_0 + I_0){\downarrow}))/10} - 10^{(N_0){\downarrow}/10})$$

or

$$I_0(\text{max}) = 10 \log (10^{(-162.6 - 35.1)/10} - 10^{-206.4/10})$$

then

$$I_0(\text{max}) = -198.3 \text{ dB(W/Hz)}$$

It is desirable to characterize the protection criteria in terms of the spfd interference threshold specified in dB(W/(m$^2 \cdot$ Hz)) at the input to the GEOLUT antenna. The effective aperture of an antenna, A_e, having a gain of G is $A_e = G\lambda^2/4\pi$. The GEOLUT antenna has a gain of 33.3 dB, therefore, the effective aperture is 6.42 m^2. The maximum acceptable aggregate interference specified as an spfd is:

$$\text{spfd} = I_0(\text{max}) - L_{Line} - A_e$$

Assuming $L_{Line} = 0$.

$$\text{spfd} = -198.3 - 0 - 10 \log (6.42)$$
$$= -206.4 \text{ dB(W/(m}^2 \cdot \text{Hz))}$$

The maximum level of broadband noise-like interference in the 1 544.5 MHz $\pm$ 100 kHz GEOLUT channel shall not exceed -206.4 dB(W/(m$^2 \cdot$ Hz)).

1.4 Procedure for computing level of interference to the GOES 406 MHz SARR channel downlink

Interference to Cospas-Sarsat is most often a result of out-of-band emissions from services in adjacent or near adjacent bands such as MSS space-to-Earth allocations.

The emission bandwidth must be examined to determine if energy is transmitted in the frequency range 1 544.5 MHz ± 100 kHz. Particular care must be taken when analysing the impact of mobile systems (e.g. non-geostationary satellites and airborne transmitters) to take into account the effects of the Doppler shift generated by their movement.

Compute the level of interference from all sources that transmit energy in the band expressed as an spfd level at the GEOLUT antenna. The aggregate level for all interfering sources must not exceed −206.4 dB(W/(m^2 · Hz)) anywhere in this range.

The above level is based on a GEOLUT antenna on-axis gain of 33.3 dBi. Depending upon the systems, involved antenna discrimination, polarization, and other engineering considerations should be used in establishing the impact of the interference.

Annex 2

Interference protection criteria in the 1 544-1 545 MHz band for LEOLUTs that receive SARP 2.4 kbit/s processed data from Cospas and Sarsat satellites

1 General

The Cospas and Sarsat SARP 2.4 kbit/s channel is located at 1 544.5 MHz ± 5 kHz on the LEOSAR payload downlinks. Because of the frequency spreading caused by the modulation process and the Doppler shift resulting from the movement of the satellite, the 2.4 kbit/s SARP channel is received at LEOLUTs over a frequency range of 1 544.5 MHz ± 50 kHz.

Table 1 provides recommended downlink power budgets for Cospas and Sarsat SARP channels that were developed to assist administrations design LEOLUTs for use in the Cospas-Sarsat system. The link budget shows that the Cospas SARP channel has a more robust communications link than the Sarsat SARP service; therefore, protection requirements suitable for the Sarsat SARP channel would also provide adequate protection for the Cospas SARP service.

2 Minimum acceptable performance for 2.4 kbit/s PDS data in the SARP channel

In order to reliably detect and locate 406 MHz distress beacons, the BER of the SARP channel downlink must not exceed 1×10^{-6} (see Table 1).

3 Analysis of spfd that causes interference

The BER of a communications channel is derived from the ratio of the energy contained in each data bit, E_b, to the noise density. The total noise density is comprised of the noise developed by Cospas-Sarsat equipment, N_0, and noise caused by interference from other systems, I_0.

This analysis will establish the level of interference, expressed as an spfd at the LEOLUT antenna, that would degrade the BER of the SARP channel downlink to one bit error in every million (1×10^{-6}).

TABLE 1

Downlink power budget parameters for the Cospas and Sarsat PDS of the SARP

Parameter	Cospas nominal	Sarsat nominal	Source
Carrier frequency (MHz)	1 544.5		
Polarization (left hand circular)	LHCP		
Elevation angle (degrees)	5		
Satellite altitude (km)	1 000	850	
Satellite e.i.r.p.[1] (dBW)	6.2	7.1	
Slant range @ 5° (km)	3 200	2 900	Calculated from geometry
Free-space path loss (L_p) (dB)	166.3	165.5	Calculated standard formula
Short-term fading loss (L_f) (dB)	10		
Other losses (L_o) (dB)	3.6[2]		LUT-design and site-dependent
Antenna (G/T)[3] (dB/K)	4.3		$G = 26.7$ dB, $T = 22.4$ dB(K)
Boltzmann's constant, k (dB(W/(K · Hz)))	−228.6		Physical constant
Data rate factor @ 2.4 kbit/s, r (dB-Hz)	33.8		
Modulation loss (dB)	−12.1	−14.1	
Desired maximum BER	10^{-6}		
Calculated (E_b/N_0) (dB)	13.3	13.0	Using above parameters
Theoretical (E_b/N_0)-th for BER of 10^{-6} (dB)	10.6		E_b/N_0 for required BER
PDS link margin (dB)	2.7	2.4	

LUT: local user terminal

[1] Equivalent isotropically radiated power.

[2] Polarization mismatch, antenna pointing and demodulator implementation losses.

[3] Antenna gain-to-noise temperature ratio, to include radome, if applicable, and cable losses. United States of America LUTs $G/T = 4.3$ dB.

Table 1 shows the recommended downlink power budget for the SARP channel. The link budget has been completed using typical LEOLUT parameters. The link budget shows that the required BER of 1×10^{-6} is achieved with a 2.4 dB margin for tracking Sarsat satellites. The link must maintain a positive margin in order to sustain the required BER. Therefore, the total of all interference cannot be allowed to degrade the link by more than 2.4 dB. In this case, the cumulative interference power spectral-density, I_0 at the LEOLUT receiver is given by the following equation (numeric quantities):

$$N_0 + I_0 \leq 10^{(2.4/10)} \times N_0$$

or

$$I_0/N_0 \leq (10^{(2.4/10)} - 1) = 0.738 \text{ (numeric)}$$

then

$$I_0/N_0 = -1.3 \text{ dB}$$

The cumulative effect of all interferers, therefore, must not exceed an $I_0/N_0 = -1.3$ dB.

For LEOLUTs with an antenna gain G of 26.7 dB and a system noise temperature, T, of 22.4 dBK at the LEOLUT LNA, the noise power spectral-density without interference, N_0, is the product of Boltzmann's constant, k, and the noise temperature T, or $N_0 = kT$, and is given in dB form as follows:

$$N_0 = -228.6 + 22.4 = -206.2 \text{ dB(W/Hz)}$$

Therefore, the maximum interference power spectral-density from all interfering emitters, $I_0(\text{max})$, at the LEOLUT LNA within the 1 544.5 MHz $\pm$ 50 kHz band must not exceed the following:

$$I_0(\text{max}) = N_0 - 1.3 = -207.5 \text{ dB(W/Hz)}$$

It is desirable to characterize the protection criteria in terms of the spfd interference threshold specified in dB(W/m$^2 \cdot$ Hz) at the input to the LEOLUT antenna. The effective aperture of an antenna having a gain G is $A_e = G\lambda^2/4\pi$. The LEOLUT antenna gain of 26.7 dB results in $A_e = 1.4$ m^2. Therefore, the maximum level of all interference on the downlink is:

$$\text{spfd} = I_0/A_e = -207.5 - 10 \log (1.4)$$
$$= -209.0 \text{ dB(W/(m}^2 \cdot \text{Hz))}$$

The maximum level of broadband noise-like interference in the 1 544.5 MHz $\pm$ 50 kHz band channel should not exceed -209.0 dB(W/(m$^2 \cdot$ Hz)).

4 Procedure for computing level of interference to the LEOSAR SARP channel

Interference to Cospas-Sarsat is most often a result of out-of-band emissions from services in adjacent or near adjacent bands such as MSS space-to-Earth allocations.

The emission bandwidth must be examined to determine if energy is transmitted in the frequency range 1 544.5 MHz $\pm$ 50 kHz. Particular care must be taken when analysing the impact of mobile systems (e.g. non-geostationary satellites and airborne transmitters) to take into account their Doppler effect generated by their movement.

Compute the spfd level at the LEOLUT antenna. The aggregate level of all sources of interference must not exceed -209.0 dB(W/(m$^2 \cdot$ Hz)) in any portion of the 1 544.5 MHz $\pm$ 50 kHz range.

Annex 3

Protection criteria in the 1 544-1 545 MHz band for Sarsat 406 MHz repeater (SARR) services against interference from broadband emissions

1   General

The Sarsat 406 MHz SARR channel occupies approximately 100 kHz of spectrum starting 120 kHz above and below the 1 544.5 MHz carrier. However, due to the allowable frequency drift caused by the ageing of the satellite transmitter, the Doppler shift caused by the movement of the Sarsat satellite, a minimum guardband, and the spreading of the signal caused by the modulation process, LEOLUTs require 220 kHz of spectrum beginning 80 kHz above and below the 1 544.5 MHz carrier to process the 406 MHz SARR channel.

The frequency occupied by the SARR channel is depicted in Fig. 2.

FIGURE 2

Sarsat 1 544.5 MHz downlink signal spectrum
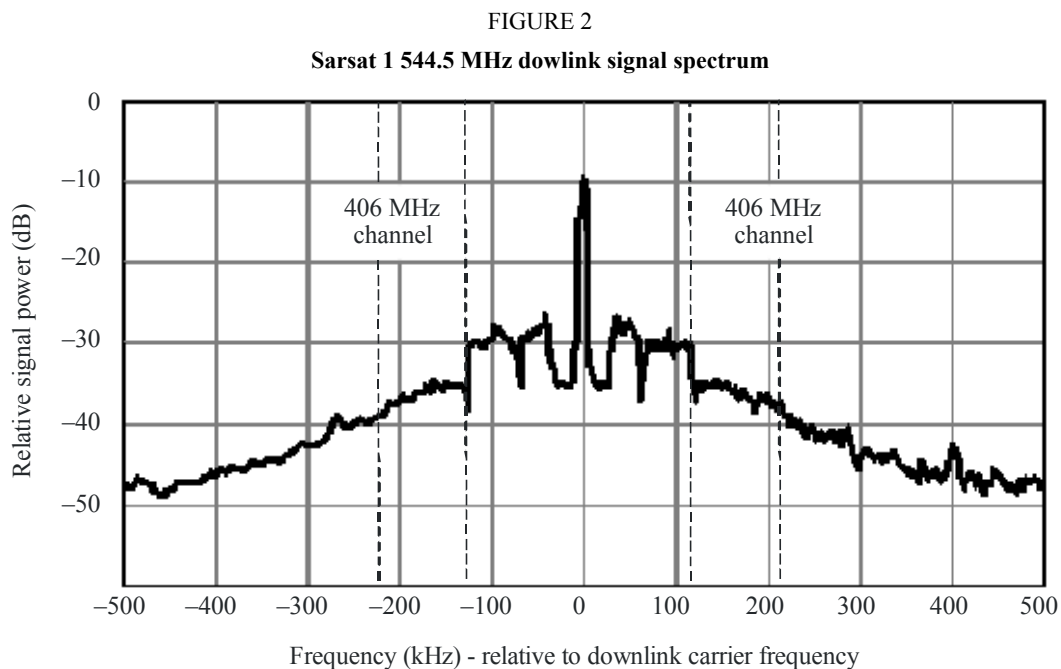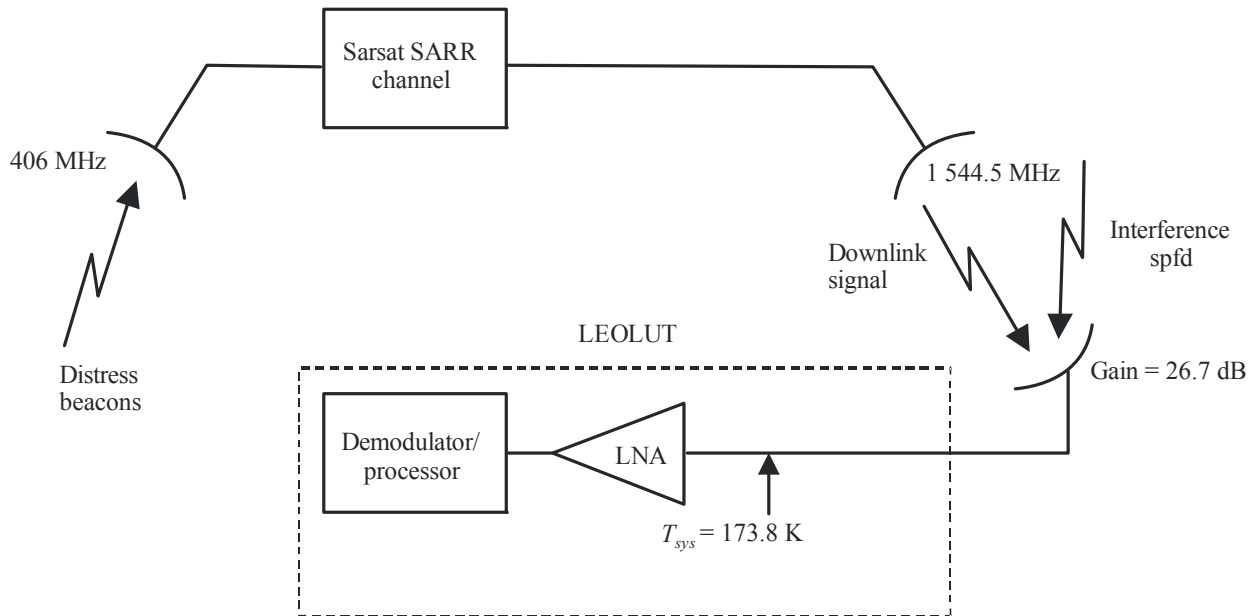

M.1731-02

2   Minimum acceptable performance for detection of EPIRB signals relayed through the SARSAT 406 MHz SARR channel

To reliably detect and locate 406 MHz distress beacons using Sarsat 406 MHz satellite repeaters, the BER of the Sarsat 406 MHz SARR channel must not exceed 5×10^{-5}.

3   Analysis of interference spfd

The BER of a communications channel is derived from the ratio of the energy contained in each data bit, E_b, to the noise density. The total noise density is comprised of the noise developed by Cospas-Sarsat equipment, N_0, and noise caused by interference from other systems, I_0. Figure 3 depicts the 406 MHz SARR channel with interference on the downlink.

FIGURE 3

Sarsat 406 MHz SARR with interference on the downlink

M.1731-03

To achieve a BER of 5×10^{-5}, the ratio of the energy per bit to noise plus interference density $(E_b/(N_0 + I_0))$ at the LEOLUT demodulator must equal or exceed 8.8 dB. This analysis determines the maximum amount of broadband noise-like interference specified as an spfd referenced at the input to the LEOLUT antenna that could be accommodated without degrading the overall link $E_b/(N_0 + I_0)$ below 8.8 dB.

The 406 MHz SARR channel in Fig. 3 is phase modulated onto a 1 544.5 MHz downlink carrier for detection and processing by LEOLUTs. The antenna gain and system noise temperature for a LEOLUT is 26.7 dB and 173.8 K, respectively.

The EPIRB signal has an elevation angle of 5° with respect to the spacecraft. When no external sources of interference are present, the overall C/N_0 is 38.8 dB-Hz, which equates to an E_b/N_0 of 12.8 dB. Accounting for implementation and beacon data demodulation losses and processing gains, the effective ratio of E_b/N_0 is 10.8 dB. Since the channel requires an overall $E_b/(N_0 + I_0)$ of at least 8.8 dB to reliably meet the minimum performance, any broadband interference on the downlink that reduces the overall carrier to noise plus interference density ratio $(C/(N_0 + I_0)_{overall})$ by more than 2.0 dB cannot be accommodated.

The overall C/N_0 in the absence of interference equates to 38.8 dB-Hz, so broadband noise-like interference on the downlink that degrades it by 2.0 dB, would result in a $(C/(N_0 + I_0))_{overall}$ of:

$$(C/(N_0 + I_0))_{overall} = (C/N_0)_{overall} - 2.0 \text{ dB}$$
$$= 38.8 \text{ dB-Hz} - 2.0 \text{ dB}$$
$$= 36.8 \text{ dB-Hz}$$

The $(C/(N_0 + I_0))_{overall}$ can be calculated from the carrier to noise plus interference density ratios of the uplink and downlink as indicated below:

$$(C/(N_0 + I_0))_{overall} = ((C/(N_0 + I_0))^{-1}\uparrow + (C/(N_0 + I_0))^{-1}\downarrow)^{-1}$$

Because this analysis only concerns downlink interference, the above equation simplifies as follows:

$$(C/(N_0 + I_0))_{overall} = ((C/N_0)^{-1}\uparrow + (C/(N_0 + I_0))^{-1}\downarrow)^{-1}$$

Substituting 36.8 dB-Hz for $(C/(N_0 + I_0))_{overall}$ and 41.3 dB-Hz for $(C/N_0)\uparrow$ results in a $(C/(N_0 + I_0))\downarrow$ of 38.7 dB-Hz (see below):

$$C/(N_0 + I_0)\downarrow = ((C/(N_0 + I_0))_{overall}^{-1} - (C/N_0)\uparrow^{-1})^{-1}$$

or

$$C/(N_0 + I_0)\downarrow = 10 \log ((10^{-36.8/10} - 10^{-41.3/10})^{-1})$$

then

$$C/(N_0 + I_0)\downarrow = 38.7 \text{ dB-Hz}$$

The downlink noise power spectral-density in the absence of interference and as referenced at the input to the LNA is $N_0 = kT$, where k is Boltzmann's constant. Therefore, $N_0 = -228.6 + 22.4 = -206.2$ dB(W/Hz).

Since $(C/N_0)\downarrow$ equals 42.5 dB and $(N_0)\downarrow$ equals -206.2 dB(W/Hz), the value of $C\downarrow$ is -163.7 dBW.

The maximum permissible interference power spectral-density in the downlink from the aggregate of all interfering emitters, $I_0(\text{max})$, measured at the input to the LEOLUT receiver LNA in the 1 544-1 545 MHz band used for the downlink of the 406 MHz SARR channel is given as follows:

$$I_0(\text{max}) = 10 \log (10^{(C\downarrow - (C/(N_0 + I_0)\downarrow))/10} - 10^{(N_0)\downarrow/10})$$

or

$$I_0(\text{max}) = 10 \log (10^{(-163.7 - 38.7)/10} - 10^{-206.2/10})$$

then

$$I_0(\text{max}) = -204.7 \text{ dB(W/Hz)}$$

It is desirable to characterize the protection criteria in terms of the spfd interference threshold specified in dB(W/m$^2 \cdot$ Hz) at the LEOLUT antenna input. The effective aperture of an antenna, A_e, having a gain of G is $A_e = G\lambda^2/4\pi$. For LEOLUT antennas with a gain of 26.7 dB, the effective aperture is 1.4 m^2. Therefore, the maximum acceptable aggregate interference specified as an spfd is:

$$\text{spfd} = I_0(\text{max}) - L_{Line} - A_e$$

Assuming $L_{Line} = 0$.

$$\text{spfd} = -204.7 - 0 - 10 \log (1.4) = -206.2 \text{ dB(W/(m}^2 \cdot \text{Hz))}$$

The maximum level of broadband noise-like interference in the bands processed by LEOLUTs for the 406 MHz SARR channel shall not exceed -206.2 dB(W/(m$^2 \cdot$ Hz)).

4 Procedure for computing the level of 1 544-1 545 MHz interference into LEOLUTs receiving the 406 MHz SARR channel

The emission bandwidth must be examined to determine if energy is transmitted in the frequency ranges processed by LEOLUTs for 406 MHz SARR channel (i.e. 1 544.58-1 544.80 MHz and 1 544.42-1 544.20 MHz). Particular care must be taken when analysing the impact of mobile systems (e.g. non-geostationary satellites and airborne transmitters) to take into account effects of the Doppler shift generated by their movement.

Compute the level of interference from all sources that transmit energy in the band expressed as an spfd level at the LEOLUT antenna. The aggregate level for all interfering sources must not exceed -206.2 dB(W/(m^2 · Hz)) anywhere in this range.

The above level was determined using an LHCP LEOLUT antenna with an on-axis gain of 26.7 dBi. Polarization discrimination and other engineering considerations regarding the systems involved should be used in establishing the impact of the interference.

Annex 4

Protection criteria in the 1 544-1 545 MHz band for Cospas-Sarsat GEOLUTS that receive EPIRB signals relayed through MSG satellites

1 Introduction

Cospas-Sarsat search and rescue repeaters are on board MSG satellites. These repeaters receive signals from 406 MHz EPIRBs and relay the signals to Cospas-Sarsat GEOLUTs on downlink frequencies in the 1 544-1 545 MHz band. In accordance with the RR, the 1 544-1 545 MHz band is allocated to the MSS, space-to-Earth, and is specifically limited by RR No. 5.356 to distress and safety communications. The analysis provided in this Annex establishes interference protection criteria for GEOLUTs that receive the MSG 1 544-1 545 MHz downlink.

## 2 Minimum acceptable performance for detection of EPIRB signals relayed through the MSG satellite

To reliably detect 406 MHz distress beacons using MSG 406 MHz satellite repeaters, the BER of the channel must not exceed 5×10^{-5}.

3 Analysis of interference spfd

The BER of a communications channel is derived from the ratio of the energy contained in each data bit, E_b, to the noise density. The total noise density is comprised of the noise developed by Cospas-Sarsat equipment, N_0, and noise caused by interference from other systems, I_0. Figure 4 depicts the MSG 406 MHz SARR channel with interference on the downlink.

To achieve a BER of 5×10^{-5}, the ratio of the energy per bit to noise plus interference density ($E_b/(N_0 + I_0)$) at the GEOLUT demodulator must equal or exceed 8.8 dB. This analysis determines the maximum amount of broadband noise-like interference specified as an spfd referenced to the input to the GEOLUT antenna that could be accommodated without degrading the overall link $E_b/(N_0 + I_0)$ below 8.8 dB.

As seen in Fig. 4, 406 MHz distress beacon signals are received by the MSG SARR and translated to a downlink of 1 544.5 MHz ± 100 kHz for detection and processing by GEOLUTs. The antenna gain and system noise temperature for an MSG GEOLUT are 35.7 dB and 105.0 K, respectively.

FIGURE 4

MSG SARR with interference on the downlink
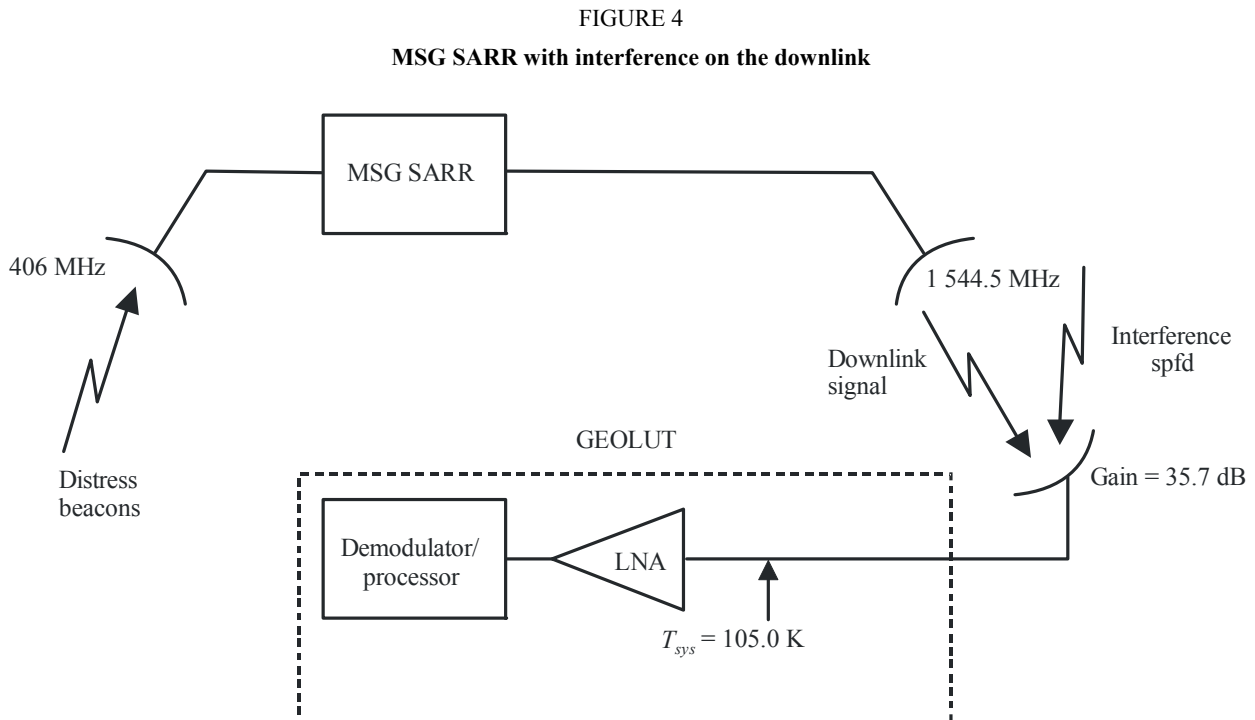
M1731-04

The EPIRB signal has an elevation angle of 5° with respect to the spacecraft. When no external sources of interference are present, the overall C/N_0 is 27.4 dB-Hz, which equates to an E_b/N_0 of 1.4 dB. Accounting for implementation and beacon data demodulation losses and processing gains at the GEOLUT, results in an effective ratio of E_b/N_0 of 8.9 dB. Since the channel requires an overall $E_b/(N_0 + I_0)$ of at least 8.8 dB to reliably meet minimum performance, the accumulation of broadband interference on the downlink that reduces the overall carrier to noise plus interference density ratio by more than 0.1 dB cannot be accommodated.

Since the overall C/N_0 in the absence of interference equates to 27.4 dB-Hz, broadband noise-like interference on the downlink that degrades it by 0.1 dB, would result in an overall carrier to noise plus interference density ratio $(C/(N_0 + I_0))_{overall}$ of:

$$(C/(N_0 + I_0))_{overall} = (C/N_0)_{overall} - 0.1 \text{ dB}$$
$$= 27.4 \text{ dB-Hz} - 0.1 \text{ dB}$$
$$= 27.3 \text{ dB-Hz}$$

The $(C/(N_0 + I_0))_{overall}$ is calculated from the carrier to noise plus interference density ratios of the uplink and downlink as indicated below:

$$(C/(N_0 + I_0))_{overall} = ((C/(N_0 + I_0))^{-1}{\uparrow} + (C/(N_0 + I_0))^{-1}{\downarrow})^{-1}$$

Since this analysis only concerns downlink interference, the above equation simplifies to:

$$(C/(N_0 + I_0))_{overall} = ((C/N_0)^{-1}{\uparrow} + (C/(N_0 + I_0))^{-1}{\downarrow})^{-1}$$

Substituting 27.3 dB-Hz for $(C/(N_0 + I_0))_{overall}$ and 28.1 dB-Hz for $(C/N_0)\uparrow$ results in a $(C/(N_0 + I_0))\downarrow$ of 35.0 dB-Hz (see below):

$$C/(N_0 + I_0)\downarrow = ((C/(N_0 + I_0))_{overall}{}^{-1} - (C/N_0)\uparrow^{-1})^{-1}$$

or

$$C/(N_0 + I_0)\downarrow = 10 \log ((10^{-27.3/10} - 10^{-28.1/10})^{-1})$$

then

$$C/(N_0 + I_0)\downarrow = 35.0 \text{ dB-Hz}$$

The noise power spectral-density of the downlink without interference at the input to the LNA is $N_0 = k\,T$, where k is Boltzmann's constant. Therefore, $N_0 = -228.6 + 20.2 = -208.4$ dB(W/Hz).

The $(C/N_0)\downarrow$ equals 35.5 dB and $(N_0)\downarrow$ equals –208.4 dB(W/Hz), so the value of $C\downarrow$ is –171.0 dBW.

The maximum permissible interference power spectral-density in the downlink from the aggregate of all interfering emitters, $I_0(\text{max})$, measured at the input to the GEOLUT receiver LNA over the 1 544.5 MHz $\pm$ 100 kHz band is:

$$I_0(\text{max}) = 10 \log (10^{(C\downarrow - (C/(N_0 + I_0)\downarrow))/10} - 10^{(N_0)\downarrow/10})$$

or

$$I_0(\text{max}) = 10 \log (10^{(-171.0 - 35.0)/10} - 10^{-208.4/10})$$

then

$$I_0(\text{max}) = -209.7 \text{ dB(W/Hz)}$$

It is desirable to characterize the protection criteria in terms of the spfd interference threshold specified in dB(W/m$^2 \cdot$ Hz) at the input to the GEOLUT antenna. The effective aperture of an antenna, A_e, having a gain of G is $A_e = G\lambda^2/4\pi$. The GEOLUT antenna has a gain of 35.7 dB, therefore, the effective aperture is 12.0 m^2. The maximum acceptable aggregate interference specified as an spfd is:

$$\text{spfd} = I_0(\text{max}) - L_{Line} - A_e$$

Assuming $L_{Line} = 0$:

$$\text{spfd} = -209.7 - 0 - 10 \log (12.0)$$
$$= -220.5 \text{ dB(W/(m}^2 \cdot \text{Hz))}$$

The maximum level of broadband noise-like interference in the 1 544.5 MHz $\pm$ 100 kHz GEOLUT channel shall not exceed –220.5 dB(W/(m$^2 \cdot$ Hz)).

4 Procedure for computing level of interference to the MSG 406 MHz SARR channel downlink

Interference to Cospas-Sarsat is most often a result of out-of-band emissions from services in adjacent or near adjacent bands such as MSS space-to-Earth allocations.

The emission bandwidth must be examined to determine if energy is transmitted in the frequency range 1 544.5 MHz $\pm$ 100 kHz. Particular care must be taken when analysing the impact of mobile systems (e.g. non-geostationary satellites and airborne transmitters) to take into account the effects of the Doppler shift generated by their movement.

Compute the level of interference from all sources that transmit energy in the band expressed as an spfd level at the GEOLUT antenna. The aggregate level for all interfering sources must not exceed -220.5 dB(W/(m$^2 \cdot$ Hz)) anywhere in this range.

The above level is based on a GEOLUT antenna on-axis gain of 35.7 dBi. Depending upon the systems involved antenna discrimination, polarization, and other engineering considerations should be used in establishing the impact of the interference.

Annex 5

Protection criteria in the 1 544-1 545 MHz band for Cospas-Sarsat MEOLUTS that receive signals from distress radio beacons operating at 406 MHz relayed through GALILEO satellites

1   Introduction

Cospas-Sarsat search and rescue repeaters are on board GALILEO satellites. These repeaters receive signals from 406 MHz distress beacons and relay the signals to Cospas-Sarsat MEOLUTs on downlink frequencies in the 1 544-1 545 MHz band. The analysis provided in this Annex establishes interference protection criteria for MEOLUTs that receive the GALILEO 1 544-1 545 MHz downlink.

2   Minimum acceptable performance for detection of 406 MHz distress beacon signals relayed through GALILEO satellites

To reliably detect 406 MHz distress beacons using GALILEO 406 MHz satellite repeaters, the BER of the channel must not exceed 5×10^{-5}.

3   Analysis of interference spfd

The BER of a communication channel is derived from the ratio of the energy contained in each data bit, E_b, to the noise density. The total noise density is composed of the thermal noise, N_0, and noise caused by interference from other systems, I_0. Figure 5 depicts the GALILEO 406 MHz SAR payload channel with interference on the downlink.

To achieve a BER of 5×10^{-5}, the ratio of the energy per bit to noise plus interference density $(E_b/(N_0 + I_0))$ at the MEOLUT demodulator must equal or exceed 8.8 dB. This analysis determines the maximum amount of broadband noise-like interference specified as a spfd referenced to the input to the MEOLUT antenna, that could be accommodated without degrading the overall link $E_b/(N_0 + I_0)$ below 8.8 dB.

The overall required $C/(N_0 + I_0)$ at 400 bit/s (26 dB/s) is:

$$\text{Overall } C/(N_0 + I_0) = 8.8 + 10 \log 10(400) = 34.8 \text{ dB-Hz}$$

As seen in Fig. 5, 406 MHz distress beacon signals are received by the GALILEO SAR payload and translated to a downlink of 1 544.1 MHz $\pm$ 100 kHz for detection and processing by MEOLUTs. The antenna gain and system noise temperature for a SAR/Galileo MEOLUT are 27 dBi and 253 K (24 dB(K)), respectively. The corresponding G/T is 3 dB/K.

FIGURE 5

GALILEO SAR repeater link scenario
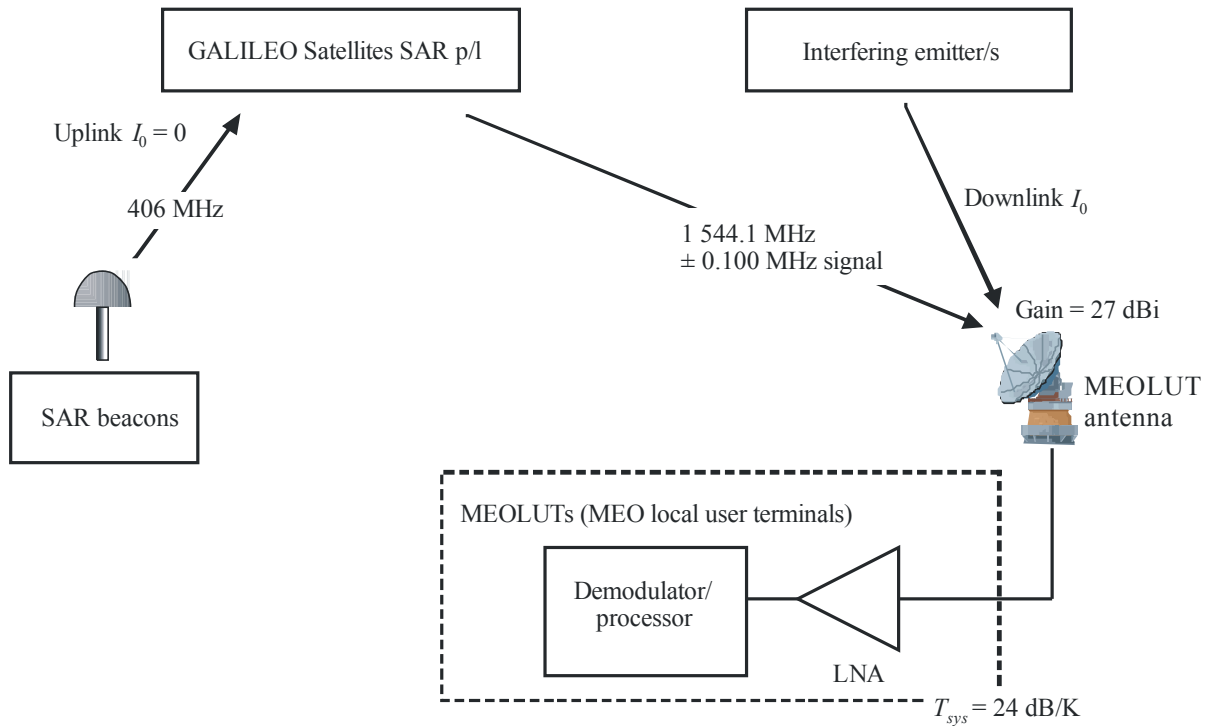
M.1731-05

The beacon signal has an elevation angle of 5° with respect to the spacecraft. When no external sources of interference are present, and according to Annex 6 (calculation of Cospas-Sarsat link budgets), the overall C/N_0 is 35.4 dB-Hz, which for 400 bit/s equates to an E_b/N_0 of 9.4 dB (35.4 dB-Hz − 26 dB/s). Accounting for implementation losses (0.5 dB), beacon data modulation losses (1.0 dB) and processing gain (2.0 dB) at the MEOLUT, results in an effective ratio of E_b/N_0 of 9.9 dB. Since the channel requires an overall $E_b/(N_0 + I_0)$ of at least 8.8 dB to reliably meet minimum performance, the accumulation of broadband interference on the downlink that reduces the overall carrier-to-noise plus interference density ratio by more than 1.1 dB cannot be accommodated.

Since the overall C/N_0 in the absence of interference equates to 35.4 dB-Hz, broadband noise-like interference on the downlink that degrades it by 1.1 dB, would result in an overall carrier-to-noise plus interference density ratio $(C/(N_0 + I_0))_{overall}$ of 34.3 dB-Hz.

The $(C/(N_0 + I_0))_{overall}$ is calculated from the carrier-to-noise plus interference density ratios of the uplink and downlink as indicated below:

$$(C/(N_0 + I_0))_{overall} = ((C/(N_0 + I_0))^{-1}\uparrow + (C/(N_0 + I_0))^{-1}\downarrow)^{-1}$$

Since this analysis only concerns downlink interference, the above equation simplifies to:

$$(C/(N_0 + I_0))_{overall} = ((C/N_0)^{-1}\uparrow + (C/(N_0 + I_0))^{-1}\downarrow)^{-1}$$

Substituting 34.3 dB-Hz for $(C/(N_0 + I_0))_{overall}$ and 35.7 dB-Hz for $(C/N_0)\uparrow$ results in a $(C/(N_0 + I_0))\downarrow$ of 39.9 dB-Hz (see below):

$$C/(N_0 + I_0)\downarrow = ((C/(N_0 + I_0))_{overall}^{-1} - (C/N_0)\uparrow^{-1})^{-1}$$

or

$$C/(N_0 + I_0)\downarrow = 10 \log ((10^{-34.3/10} - 10^{-35.7/10})^{-1})$$

then

$$C/(N_0 + I_0)\downarrow = 39.9 \text{ dB-Hz}$$

The noise power spectral density of the downlink without interference at the input to the LNA is $N_0 = k\,T$, where k is Boltzmann's constant. Therefore, $N_0 = -228.6 + 24 = -204.6$ dB(W/Hz).

The $(C/N_0)\downarrow$ equals 46.7 dB and $(N_0)\downarrow$ equals -204.6 dB(W/Hz), so the value of $C\downarrow$ is -157.9 dBW.

The maximum permissible interference power spectral density in the downlink from the aggregate of all interfering emitters, $I_0(\text{max})$, measured at the input to the MEOLUT receiver LNA over the 1 544.1 MHz ± 100 kHz band is:

$$I_0(\text{max}) = 10 \log (10^{(C\downarrow - (C/(N_0 + I_0)\downarrow))/10} - 10^{(N_0)\downarrow/10})$$

or

$$I_0(\text{max}) = 10 \log (10^{(-157.9 - 39.9)/10} - 10^{-204.6/10})$$

then

$$I_0(\text{max}) = -198.8 \text{ dB(W/Hz)}$$

It is desirable to characterize the protection criteria in terms of the spfd interference threshold specified in dB(W/m^2 · Hz) at the input to the MEOLUT antenna. The effective aperture of an antenna, A_e, having a gain of G is $A_e = G\lambda^2/4\pi$. The MEOLUT antenna has a gain of 27 dBi, therefore, the effective aperture is 1.5 m^2. The maximum acceptable aggregate interference specified as a spfd is:

$$\text{spfd} = I_0(\text{max}) - L_{Line} - A_e$$

Assuming $L_{Line} = 0$:

$$\text{spfd} = -200.6 \text{ dB(W/(m}^2 \cdot \text{Hz))}$$

The maximum level of broadband noise-like interference in the 1 544.1 MHz ± 100 kHz SAR/Galileo MEOLUT channel shall not exceed -200.6 dB(W/(m^2 · Hz)).

4   Procedure for computing level of interference to the GALILEO 406 MHz SAR payload channel downlink

Interference to Cospas-Sarsat is most often a result of out-of-band emissions from services in adjacent or near adjacent bands.

The emission bandwidth must be examined to determine if energy is transmitted in the frequency range 1 544.1 MHz ± 100 kHz. Particular care must be taken when analysing the impact of mobile systems (e.g. non-geostationary satellites and airborne transmitters) to take into account the effects of the Doppler shift generated by their movement.

Compute the level of interference from all sources that transmit energy in the band expressed as an spfd level at the MEOLUT antenna. The aggregate level for all interfering sources must not exceed -200.6 dB(W/(m^2 · Hz)) anywhere in this range.

The above level is based on a MEOLUT antenna on-axis gain of 27 dBi. Depending upon the systems involved antenna discrimination, polarization, and other engineering considerations should be used in establishing the impact of the interference.

Annex 6

TABLE 2

Cospas-Sarsat link budgets

Parameter, unit	See Note	LEOSAR Sarsat PDS Low-level case	LEOSAR Sarsat SARR Low-level case	LEOSAR Cospas SARR Low-level case	GEOSAR GOES SARR Low-level case	GEOSAR MSG SARR Low-level case	MEOSAR GALILEO SARR Low-level case
EPIRB to spacecraft uplink							
SAR frequency bandwidth (kHz)	1		80.0			100.0	80.0
Data rate, R_b (Hz)				400.0			
Frequency (MHz)	2			406.05			
Transmit power (dBW)	3			5.0			
Tx antenna gain (dBi)	4			−2.0			
e.i.r.p. (dBW)				3.0			
Elevation angle (degrees)	5			5.0			
Path distance (km)			2 900.0	3 200.0	41 126.3		28 354.4
Path loss (dB)			153.8	154.7	176.9		173.7
Polarization loss (dB)	6				4.9	4.5	4.0
Fading loss (dB)	6a		2.5				2.5
G/T of satellite Rx antenna (dB/K)	7		−34.0		−18.5	−22.1	−15.7
Boltzmann's constant (dB(J/K))				−228.6			
Uplink C/N_0 (dBHz)			41.3	40.4	31.3	28.1	35.7
Space-to-Earth downlink							
Downlink frequency (MHz)	8	1 544.5	1 544.5 ± 40 kHz			1 544.5± 50 kHz	1 544.1± 40 kHz
Transmit e.i.r.p. (dBW)	9	7.1		6.2	15.0	−18.9	1.6
Power sharing loss (dB)	10		15.3	15.5	18.3		/
Modulation loss (dB)	11	14.1		6.0	3.54		/
Elevation angle (degrees)	12			5.0			
Path distance (km)			2 900.0	3 200.0	41 126.3		28 354.4
Path loss (dB)			165.5	166.4	188.46		185.3
G/T of LUT Rx antenna (dB/K)	13		4.3		11.0	15.5	3.0
Polarization loss (dB)	14				0.35	0.2	0.2
Other losses (dB)			2.6				1.0
Pointing loss (dB)	15				0.20	1.0	0.1
Short term fading loss (dB)	16	10.0					
Downlink C/N_0 (dBHz)		47.8	42.5	48.6	43.8	35.5	46.7
Overall C/N_0 (dBHz)			38.8	39.8	31.1	27.4	35.4
Data rate, R_b (dBHz)	17	33.8		26.0			
E_b/N_0 (dB)			14.0	12.8	13.8	5.1	1.4
Implementation loss (dB)			1.0			0.5	
Bcn data modulation loss, b = 1.1 rad (dB)	18			1.0			
Coding gain (dB)			0.0			2.0	
Processing gain (5 bursts) (dB)	19				7.0		0.0

TABLE 2 (*end*)

Parameter, unit	See Note	LEOSAR			GEOSAR		MEOSAR
		Sarsat PDS	Sarsat SARR	Cospas SARR	GOES SARR	MSG SARR	GALILEO SARR
		Low-level case	Low-level case	Low-level case	Low-level case	Low-level case	Low-level case
Space-to-Earth downlink							
Available E_b/N_0 (dB)		13.0	10.8	11.8	10.1	8.9	9.9
Theoretical E_b/N_0 for 10^{-6} and 5×10^{-5} BERs (dB)	20	10.6	8.8				
Margin (dB)	21	2.4	2.0	3.0	1.3	0.1	1.1

Notes relating to Table 2:

1   Nominal 1 dB bandwidth of satellite receiver, centred at 406.05 MHz.

2   Beacon frequencies are within the range 406.022 to 406.079 MHz.

3   A beacon transmitter can range from 5 to 9 dBW, so this weak beacon (5d BW) beacon is used for the link budget calculation, while two additional nominal 406 MHz beacons are also assumed to be transmitting bursts simultaneously, each at 40 degree elevations to the satellite, with 7 dBW, 0 dB antenna gain, 1 dB emission loss, so 6 dBW e.i.r.p. uplink (this additional beacon loading affects the power sharing value of the satellite transmitter).

4   Transmit antenna is linearly polarized.

5   The 5° elevation from the beacon to the satellite is the nominal edge of coverage, and the nominal altitude of the GEOSAR satellites is 35 786 km, 850 km for Sarsat satellites (ranges from 830 to 870 km) and 1 000 km for Cospas satellites.

6   Polarization loss due to linear polarization of the beacon antenna and fading of the uplink signal. Polarization loss of the LEOSAR link is included in the antenna gain, and is therefore reflected in the *G/T* of the satellite Rx antenna.

6a   Allowance of 2.5 dB for fading of the signal (dominated by scintillation) is provided for the link (see Document C/S R.012, Annex J. A copy of this document can be obtained free of charge from the Cospas-Sarsat secretariat website (E-mail: cospas_sarsat@imso.org http://www.cospas-sarsat.org/)).

7   *G/T* of the satellite 406 MHz receiver referenced to the LNA input, where nominal gain and noise temperatures are:

GOES: G = 7.05 dB and noise temp = 359 K.

MSG: G = 3.0 dB and noise temp = 326 K.

Sarsat: G = –4.0 dB and noise temp = 1 000 K.

Cospas: G = –4.0 dB and noise temp = 1 000 K.

8   Downlink frequency band allocated for distress and safety is 1 544-1 545 MHz.

9   e.i.r.p. is based on satellite transmitter power and transmit antenna gain. In the cases of MSG and Galileo the e.i.r.p. for the observed beacon is given (hence all power sharing with other beacons and thermal noise is included).

10   Power sharing loss is the fraction of the transmit e.i.r.p. allocated for this one distress beacon signal. The "Power sharing loss" has been included in the item "Transmit e.i.r.p." in cases of MSG and GALILEO.

11   Modulation loss is the fraction of the transmit e.i.r.p. allocated to the 406 MHz repeater band on the satellite, as set by the phase modulation index (not applicable for MSG satellite and MEOSAR satellites, which have direct frequency translation).

12   5° elevation angle from the LUT to the satellite is the nominal edge of coverage.

13   *G/T* uses nominal values for each type of LUT.

14   Polarization loss for each type of LUT antenna.

15   Pointing loss due to LUT antenna pointing.

16   Short duration 10 dB drops in the carrier level due to high modulation in other channels before the AGC responds.

17   Data rate is 400 bit/s for the beacon emission and 2 400 bit/s for the PDS.

18   Beacon data modulation loss, since some power is intentionally retained in the carrier, as the modulation index is set to 1.1 ± 0.1 radians.

19   Processing gain due to the integration of several beacon bursts at the LUT. For MEOSAR single burst demodulation is assumed (see Document C/S R.012, Annex J. A copy of this document can be obtained free of charge from the Cospas-Sarsat secretariat website (E-mail: cospas_sarsat@imso.org http://www.cospas-sarsat.org/)).

20   BER for repeater band is 5.0×10^{-5}, as stated in Recommendation ITU-R M.1478, whereas for the PDS channel it is 1.0×10^{-6}.

21   Margin is the extra signal remaining that might be taken when there is interference.