Second Generation COSPAS-SARSAT Beacon
General Direction Finding Requirements
C/S G.008 Issue 1 Rev. 2 Section 3.14

RHOTHETA Proposal

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1 Introduction

This document proposes a homing transmission component for 2nd Generation COSPAS-SARSAT beacons. For any comments or questions arising, please contact:

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2 Motivation and Purpose

This document provides a more general, not solution-based, set of requirements how a beacon signal should be specified in order to be suitable for homing and locating purposes, under inclusion of the aspect of downward compatibility to existing direction finding equipment.

Homing, in the sense of this document, is the capability of finding a beacon independently from infrastructures outside the on-scene SAR forces and independent of the correctness of eventually received data within the SAR beacon transmission. **Direction Finding** is the most common homing principle.

Locating, in the sense of this document and as used in the sense of COSPAS-SARSAT document C/S G.008, is any kind of use of the beacon signal to help SAR forces to reach the beacon location, including data content of beacon transmissions.

Detection, in the sense of this document, is the capability to clearly identify a beacon transmission, without necessarily being able to reach the location of the beacon.

3 Homing and Direction Finding Requirements

COSPAS-SARSAT requirements are according to C/S G.008 Issue 1 Rev. 2 Section 3.14:

> ***3.14 Homing and on-Scene Locating***
> ***3.14.1 Requirement***
> *Beacon design shall provide for homing and on scene locating. Compliance with other Cospas-Sarsat requirements shall not prevent compliance of the beacon with international and/or national requirements for on-scene locating, homing, or signal transmission(s) for direction finding (i.e., 406/121.5/243.0 MHz, AIS, etc.).*
> ***3.14.1.1 Altitude and distance performance***
> *Beacon design shall be inherently suitable for detection and homing on 406 MHz line-of-sight from an altitude of 10,000 feet (3048 metres) at a distance of 125 nautical miles (231 kilometres).*
> ***3.14.1.2 Local location performance***
> *Beacon design shall allow suitably equipped SAR units, airports and certain other fixed and mobile facilities to receive and decode beacon identities and GNSS data sent via 406 MHz.*
> ***3.14.1.3 Accuracy Performance***
> *Beacon design shall allow SAR Units travelling at speeds between 90 kts (166 kilometres/hour) and 270 kts (500 kilometres/hour), (inclusive), to be able to locate beacon to within 500 feet (152 metres).*

3.1 Altitude and distance performance

Requirement 3.14.1 cannot be considered as a stand-alone beacon requirement. The effective distance performance always requires appropriate receiving equipment at the receiver end of the signal path.

Inherent suitability for a line-of sight range of 125 NM does not automatically mean that any type of DF equipment needs to provide the necessary sensitivity level. For example, at surface DF equipment, useful line-of-sight-ranges are much lower than 125 NM.

Experience, such as documented in USCG's *"USCG 406 MHz Beacon Direction Finding in the Modern Age"* contribution to BMW2009, shows that with existing DF equipment, 125 NM usually have been reached only at altitudes much higher than 10.000ft. However, DF equipment usually provides DF capabilities in a large frequency range (e.g. 121.5 MHz / maritime band / 243 MHz / 406 MHz) and is not optimized for 406 MHz.

For this reason, we assume that the requirement shall be understood that a beacon shall be designed in a way which allows its homing together with optimized DF equipment.

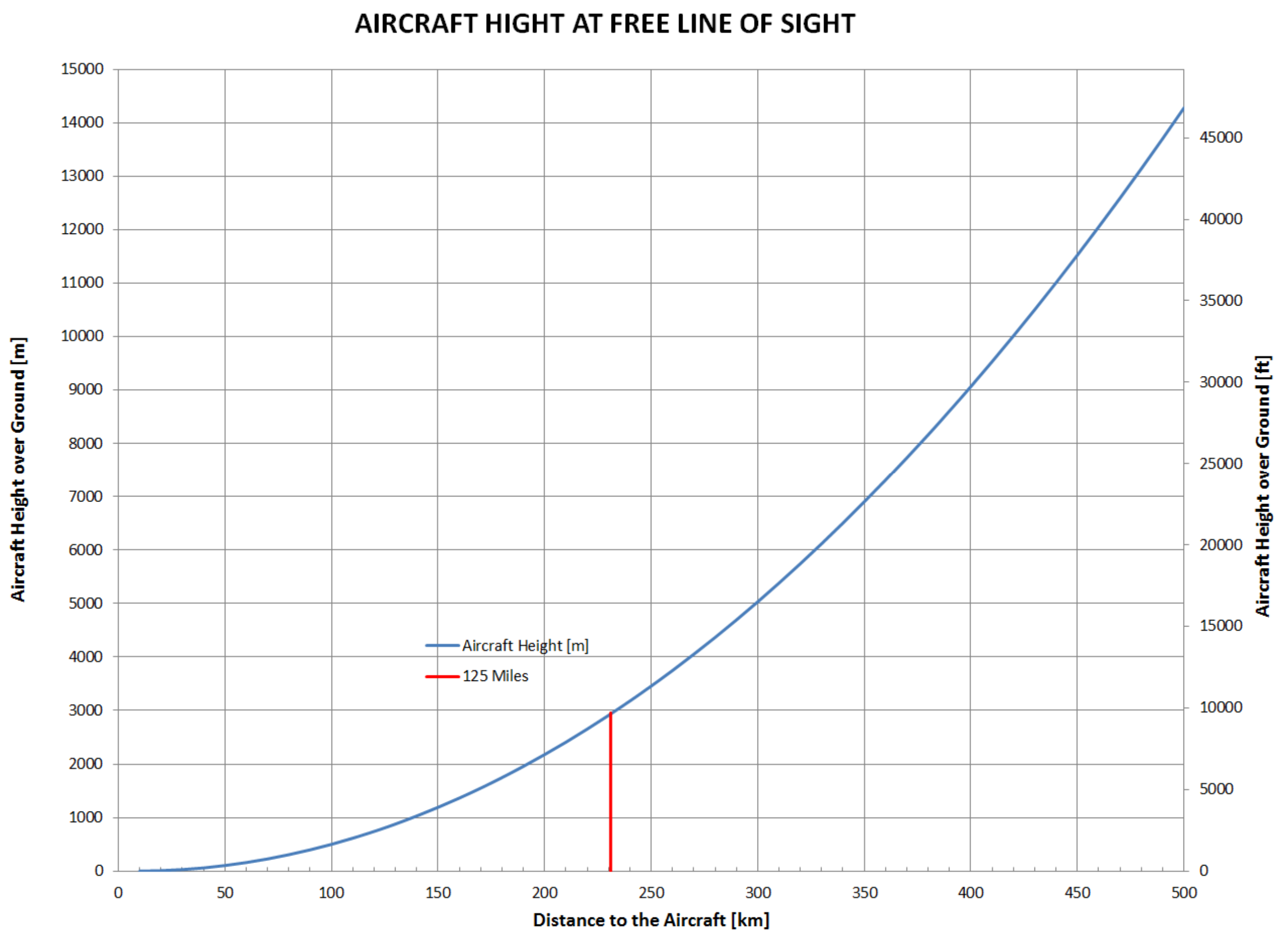
3.2 Relevant factors for homing distance performance

Those factors are relevant for the useable homing range:

- Free Line of Sight or not Line of Sight
- Signal attenuation over the signal path
- Radiated Power
- Receive antenna gain
- Receiver sensitivity
- Signal Characteristics (modulation, duration, …)
- External disturbing factors (co-channel interferences, EMI)

Free line of Sight

As soon as the signal source lay behind the radio horizon, signal attenuation increases significantly. The detection of such signals is out of the scope of this document. High-power transmitters are required for such purpose.



In this diagram, we see the correlation with the requirement. Free Line of Sight at (231km) 125 miles is given at the height of 10000 ft.

Signal attenuation over the signal path L

The Signal Attenuation at free lines of sight depends on a distance and frequency and can be calculated with the following formula:

L [dB] = -147,56 + 20*lg(f[Hz]) + 20*lg(d [m])

For a distance of **125 miles (231km)** and typical frequencies under discussion, the following table gives applicable values:

Application	f [MHz]	Loss [dB]
International Distress Frequency	121,5	121
AIS	162	124
Military Distress Frequency	243	127
COSPAS / SARSAT	406	132

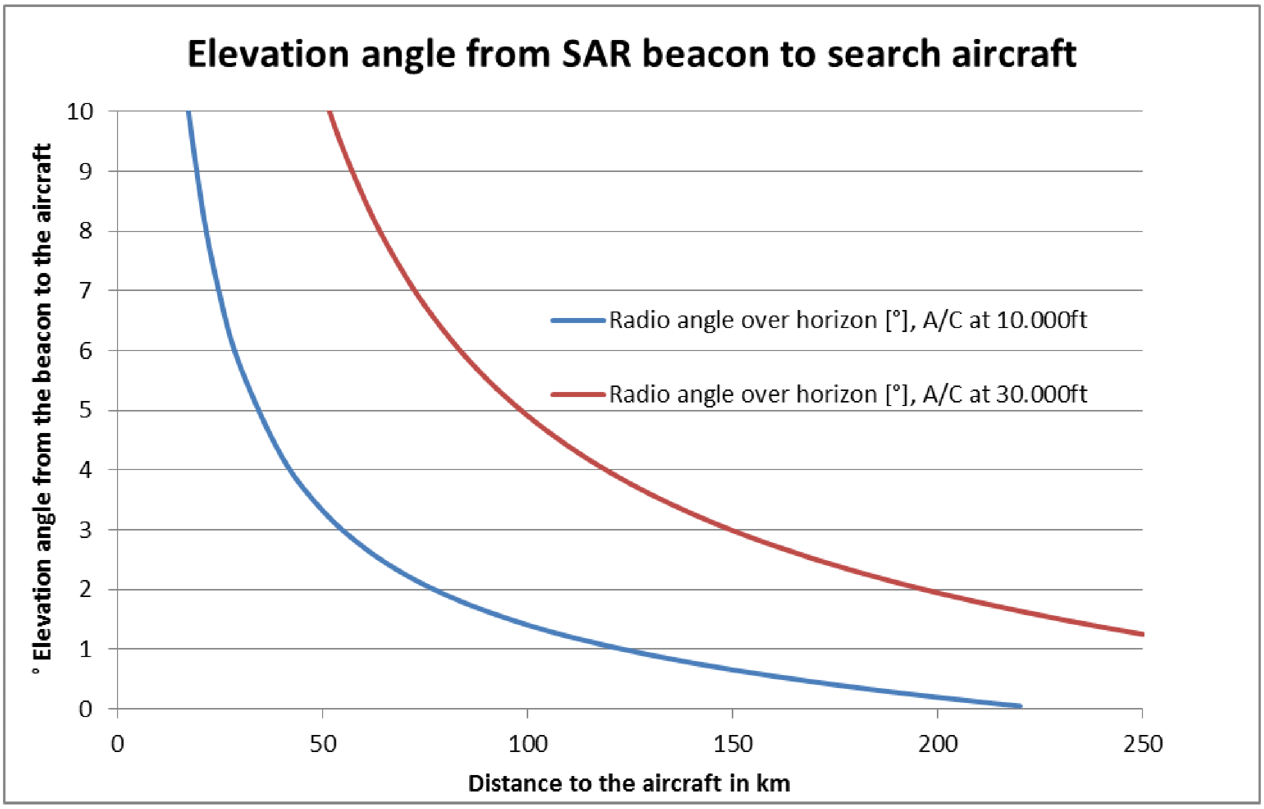
Radiated Power

Radiated power is a function of transmitter power and antenna gain. As wide-range homing takes place with the receiver being placed at extremely low elevation angles (just above horizon), transmit antenna gain at the relevant angle might be much lower than the gain at the antenna's optimum angle.

Typical EIRP at the transmit antenna's main lobe (not necessarily close to the horizon) are:

- 25 mW to 250 mW for 121.5 MHz and 243.0 MHz homing transmitters
- 25 mW to 600 mW for 162 MHz AIS PLBs (source: ETSI EN 303 098-1)
- 5 W for COSPAS-SARSAT-transmitters (not oriented to the horizon but to orbital satellite positions)

The elevation angle at which this power is required is a function of the distance between beacon and aircraft and the aircraft height over ground (assuming a beacon at sea level):



Receiver characteristics

- State of the art receiving systems provide receiver input noise figures of 6 dB or less.
- Wideband antennas and associated wiring plus necessary switching at some DF technologies should allow antenna gains in the range of -7 and -17 dBi. We use -12 dBi for our calculations. Narrowband systems will show better performance at this point.
- A Signal-to-Noise Ratio of 12 dB at the demodulator input should be sufficient to decode any type of beacon message if using optimized decoding, or to recognize a 121.5 MHz SAR beacon, or to clearly detect the presence of a signal.
- Future beacon receivers for standardized homing devices will provide optimized decoding for those signals. We therefor calculated the minimum theoretical receive signal level, independent from actual solutions.
- Detecting, Homing and Locating requires the same signal level, as signal decoding is required for both purposes, and, in general, bearing sensitivity is better than or equal to decoding sensitivity. In a scenario, where multiple beacons are transmitting (e.g. after a midair collision), this allows to pick up one specific beacon among several signals. Depending on the DF technology used, a much lower signal level could be sufficient for bearing (e.g. with some Doppler principle direction finders), however, this is not true for all kind of DF equipment.

Signal characteristics

For downward compatibility reasons, existing modulation schemes and data protocols should be used or modified. For exemplary calculations, we use beacon sweep tone modulation, AIS and COSPAS-SARSAT as examples. For direction finding purposes, a dedicated carrier signal is required, and an un-modulated period of the transmit signal of at least 100 ms is recommended (the longer, the better).

In general, technological backgrounds of signal characteristic requirements are:

- Some DF technology uses the carrier of the received signal to modulate it within the antenna (Doppler principle). A discrete carrier is needed therefor, and, depending on the modulation frequency, modulation on the received signal might degrade the direction finding accuracy:
  - If the DF processing frequency is close to the same or a multiple of the modulation frequency, bearing will not be possible. (random-distributed modulation will disturb much less than constant-frequencie(s) modulation).
  - The higher the modulation degree (AM) or modulation or phase deviation (FM, PM), the higher the influence
  - The complete disappearance of a dedicated RF carrier will disable the direction finder from modulating the received signal.
  - Some other types of DF equipment will amplitude modulate the received signal for the same purpose.
- A longer-than-minimum pulse length allows averaging bearing results, thus increasing accuracy and compensating effects of reflections (e.g. in mountainous areas where a lot of reflections occur).
- 100 ms is a CW portion length where, based on experience, bearing results are of acceptable quality.
- With receive signals just above the noise level, the pulse length directly translates into sensitivity for some types of direction finders. This is NOT true for cases where the received signal is strong compared to the noise level.
- For synchronization purposes (or, in case of large frequency tolerances of the received beacon signals, for frequency correction purposes), the data message should not start at the very beginning of a transmission. The CW portion dedicated for direction finding should be sent AFTER the data message (this allows to selectively home a specific beacon if several beacons are active).

Repetition Rate and Signal Duration

The influence of repetition rate and signal duration largely depends on the selected DF technology.

For direction finding from large distances, transmissions are not required to be continuous. Periodic transmissions at high power are sufficient. For good bearing accuracy at lower distances, the signal should be present as often as possible, but the required transmit power is reduced by 6 dB for each distance division by two. A high signal repetition rate allows more accurate and fast homing (lower waiting time between pulses).

In more sophisticated direction finding solutions, bearing values are averaged over a fixed or flexible time, and some solutions allow to average over consecutive transmission periods.

The transmission length has a direct influence of the accuracy of the averaging algorithms, especially at low signal levels and if reflection effects may be compensated due to averaging.

The repetition rate is only relevant if it is short enough to allow the use of several transmissions, i.e. below ca. 5-10 seconds for practical implementations.

3.3 Resulting EIRP requirements for several exemplary solutions

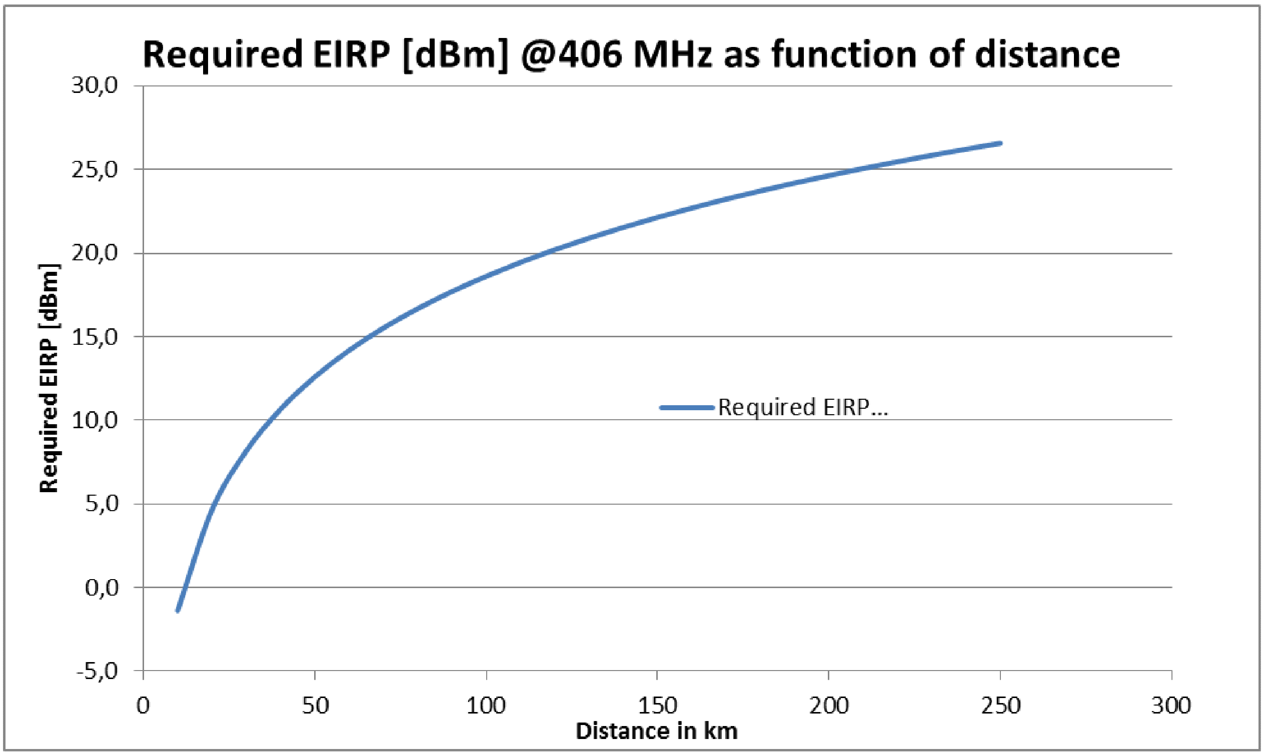
The calculations below are based on the assumptions above, i.e. assuming optimized receiving technology for wide band direction finder systems (which must not be automatically the current performance of in-service systems). Wide band means that the receive antenna is not optimized for 406 MHz reception. Significant improvement (more than 6 dB) over the calculations below could be achieved by using optimized receive antennas for narrowband systems. The last line represents this scenario. Such a DF system very likely will not be able to process 121.5 MHz or 243 MHz beacons.

Application	Data Rate / Modulation / Bandwidth	Required signal level for decoding and homing	Path loss plus antenna losses 125 NM	Required EIRP towards aircraft, 125 NM	Required EIRP towards aircraft, 60 NM	Signal duration
121.5 MHz beacon	Sweep tone AM, B = 10 kHz	-116 dBm	133 dB	17 dBm	11 dBm	∞
162 MHz AIS beacon	9600 bit/s GMSK,B = 20 kHz	-113 dBm	136 dB	23 dBm	17 dBm	26,6 ms
406 MHz beacon Wideband DF	400 bit/s BPSK B = 6 kHz	-118 dBm	144 dB	26 dBm	20 dBm	440 ms 520 ms
406 MHz beacon *Possible future Narrowband DF*	*400 bit/s BPSK B = 6 kHz*	*-118 dBm*	*138 dB*	*20 dBm*	*14 dBm*	440 ms 520 ms

Theoretically, 406 MHz requires the highest transmit signal level of all solutions. On the other hand, due to its longer signal duration, it provides a virtual signal gain over an AIS signal due to the possible longer averaging time (26.6 ms might be too short to be correctly processed in some type of DFs).

121.5 MHz homing requires the lowest amount of transmit power, but provides no standardized means of transmitting identity or position data.

The curve below shows the required minimum EIRP for homing using actual DF systems.



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3.4 Using existing systems not solely dedicated for SAR (AIS etc.)

Dedicated SAR frequencies are used by emergency transmitters only. It should be noted that at frequencies, where the SAR application shares its frequency with other transmitters (e.g. regular AIS transmission), collisions between signals might disable the reception of a beacon transmission. Any same-frequency transmitter in a 125 NM circle will be received at an altitude of 10.000 ft, and regular transmitters might transmit much higher signal levels than an emergency beacon, especially if the PLB / EPRIB / ELT is slightly damaged after an accident.

While the typical PLB-to-ship range of ca. 10 NM covers an area of 340 km², all AIS transmitter in a 53.000 km² area will be possible sources of disturbance to the airborne receiver which, at a height of 10.000 ft, allows an effective receive range of 125 NM.

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4 Summary of requirements for Direction Finding

The following set of requirements should be used to define any homing signal:

- The signal shall be a narrow-band signal with dedicated RF carrier, and for best bearing results, it should be, at least partly, un-modulated
- The minimum signal duration shall be 400 ms or more, with at least 100 ms of continuously un-modulated RF carrier.
- For large-distance homing (125 NM), at least once per minute (as known from COSPAS-SARSAT with its current 50 seconds transmit cycle) transmissions should provide high EIRP values towards the horizon between at least 50 mW (121.5 MHz) and 400 mW (406 MHz). If this is in conflict with system aspects of COSPAS-SARSAT, 100 mW at 406 MHz would allow 60 NM range performance. Using specific narrowband homing equipment dedicated to 406 MHz only, theoretically, 125 NM are possibly achieved with that level of power.
- For accurate direction finding in the final approach phase, the transmit duty cycle shall be as high as possible (< 10, better 5 seconds between to transmissions), but signal levels might be reduced by 10 dB or more relative to the maximum EIRP. It should be kept in mind that under non-line-of-sight-conditions (hills, thick forests, etc.), the signal attenuation increases again.
- Used frequencies shall be reserved for SAR applications, as otherwise, receiver at high-altitude search aircrafts will be blocked by other signals.
- For locating purposes, the data and modulation scheme should be compatible to the existing COSPAS-SARSAT data signal. This allows continued use of systems already in use.