ETSI TR 103 594 V1.1.1 (2018-08)

System Reference document (SRdoc);
Short Range Devices (SRD) using Ultra Wide Band (UWB);
Technical characteristics and spectrum requirements for High-Definition Ground Based Synthetic Aperture Radars (HD-GBSAR) operating in 1 GHz band within 74 GHz to 81 GHz tuning range

Reference

DTR/ERM-580

Keywords

radio, SRDOC, UWB

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (https://ipr.etsi.org/).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Executive summary

The present document describes the evolutionary motivation, market requirements, technical details and operational scenarios of the next generation of the High Definition Ground Based Synthetic Aperture Radars (HD-GBSAR). It shows the use advantages vis-a-vis addressed technical challenges for this innovation from the previous state of the traditional low resolution GBSAR technology which also had very large size and weight precluding its easy transportation and re-location due to changing measurement circumstances.

HD-GBSAR (with 1 GHz bandwidth) would provide up to 5x improvement of resolution performance compared with GBSAR (with 200 MHz bandwidth), while allowing to achieve 4x reduction of physical size of measurement equipment. This will allow the early detection of displacement trends such as those occurring before a ground collapse, in cases where GBSAR is not applicable.

However, the HD-GBSAR will remain a niche highly-specialized professional application to be used only by trained professionals. Provided market forecasts show that based on extrapolation of GBSAR market trends it may be expected that the total HD-GBSAR market demand would not exceed 500 units over 5 years for the entire European area. Significant proportion of those units would be used in terrain shielded (quarries) and underground (mines and tunnels) scenarios, meaning isolation of EM emissions within confined space of surveyed objects. This means that only small fraction of total deployed HD-GBSAR units will be ever used in open environments where it could possibly impact other radio spectrum users. Thus, it may be concluded that the sharing profile of HD-GBSAR equipment, i.e. its overall deployment density, "visibility" to other radiocommunication systems and resulting possibility to create interference to their operations, is and will remain very low.

The provided initial analysis of various deployment band options in the present document comes to conclusion that the most promising band maybe 74-75 GHz. This is because the higher portions of the considered frequency range are already designated for numerous other radiodetermination applications, most notably the Level Probing Radars in 75-85 GHz, Road Transport and Traffic Telematics in 76-77 GHz and Automotive Short Range Radars in 77-81 GHz.

But it should be noted that the preference for the band 74-75 GHz is not originating from HD-GBSAR vendors or operators but is solely based on the results of the initial regulatory considerations and sharing feasibility analysis presented in the present document in annexes C and D. In case subsequent analysis in CEPT of this proposal would not confirm positive conclusion as regards feasibility of using the band 74-75 GHz, then any other 1 GHz wide portion of the 74-81 GHz range would be equally suitable from the HD-GBSAR system design and operational perspectives.

1 Scope

The present document describes the High-Definition Ground Based Synthetic Aperture Radar (HD-GBSAR) system, which may require a change of the present frequency designation/utilization within the EU and CEPT. A total of 1 GHz bandwidth is required for operation of HD-GBSAR, which could be accommodated in the frequency range between 74 GHz and 81 GHz.

The provided description of HD-GBSAR includes in particular:

- Market information;
- Technical information including expected sharing and compatibility issues;
- Regulatory issues.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 102 522 (12-2006): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detecting Movement; Radio equipment operating in the frequency range 17,1 GHz to 17,3 GHz; System Reference Document for Ground Based Synthetic Aperture Radar (GBSAR)".

[i.2] CEPT ECC Recommendation ERC/REC 70-03: "Relating to the Use of Short Range Devices (SRD)".

NOTE: Available at http://www.ecodocdb.dk/.

[i.3] ETSI EN 300 440-1 (08-2010): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short range devices; Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Part 1: Technical characteristics and test methods".

[i.4] CEPT European Communications Office (ECO) Frequency Information System EFIS.

NOTE: Available at http://www.efis.dk/.

[i.5] CEPT ECC Recommendation ERC/REC 74-01: "Unwanted Emissions in the Spurious Domain".

NOTE: Available at http://www.ecodocdb.dk/.

[i.6] Committee on Radio Astronomy Frequencies, European Science Foundation.

NOTE: Available at www.craf.eu.

[i.7] Andrew Adams, KSL.com Utah News: "Massive landslide damages Kennecott's Bingham Canyon Mine", April 11, 2013.

NOTE: Available at https://www.ksl.com/?nid=148&sid=24748916.

[i.8] ECC/DEC(04)03: "ECC Decision of 19 March 2004 on the frequency band 77-81 GHz to be designated for the use of Automotive Short Range Radars".

NOTE: Available at http://www.ecodocdb.dk/.

[i.9] ECO Frequency Information System.

NOTE: Available at https://efis.dk/.

[i.10] ECC/DEC(11)02: "ECC Decision of 11 March 2011 on industrial Level Probing Radars (LPR) operating in frequency bands 6 - 8.5 GHz, 24.05 - 26.5 GHz, 57 - 64 GHz and 75 - 85 GHz".

[i.11] ITU Recommendation SA.1344-1 (02/2009): "Preferred frequency bands and bandwidths for the transmission of space VLBI data within existing space research service (SRS) allocations".

[i.12] ECC/REC/(05)07: "Radio frequency channel arrangements for Fixed Service Systems operating in the bands 71-76 GHz and 81-86 GHz (2013)".

NOTE: Available at http://www.ecodocdb.dk/.

[i.13] ECC Report 173: "Fixed Service in Europe: Current Use and Trends past 2011 (2012)".

NOTE: Available at http://www.ecodocdb.dk/.

[i.14] ETSI EN 302 217-2 (V3.1.1) (05-2017): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2: Digital systems operating in frequency bands from 1 GHz to 86 GHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.15] ETSI EN 302 217-4: "V2Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4: Antennas".

[i.16] ERC Report 111: "Compatibility Studies between Ground Based Synthetic Aperture Radar (GBSAR) and existing services in the range 17.1 GHz to 17.3 GHz".

NOTE: Available at http://www.ecodocdb.dk/.

[i.17] ERC Report 25: "The European Table of Frequency Allocations and Applications in the frequency range 8.3 kHz to 3000 GHz".

NOTE: Available at http://www.ecodocdb.dk/.

[i.18] Recommendation ITU-R RA.314-10 (06/2003): "Preferred frequency bands for radio astronomical measurements".

[i.19] Recommendation ITU-R RS.515-5 (08/2012): "Frequency bands and bandwidths used for satellite passive remote sensing".

[i.20] Recommendation RS.577-7 (02/2009): "Frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite (active) and space research (active) services".

[i.21] Recommendation ITU-R RS.2064-0 (12/2014): "Typical technical and operating characteristics and frequency bands used by space research service (passive) planetary observation systems".

[i.22] Recommendation ITU-R.M.2057 (02/2014): " M.2057: Systems characteristics of automotive radars operating in the frequency band 76-81 GHz for intelligent transport systems applications".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

GBSAR: Ground Based Synthetic Aperture Radar is a Short Range Device application intended for safety critical deformation monitoring of natural as well as man-made objects and structures

HD-GBSAR: High Definition evolutionary version of GBSAR which allows achieving up to 5x improvement of resolution performance compared with GBSAR, while providing 4x reduction of device size

Target's Surface Point Illumination Time: time interval during which a given point on target surface is being illuminated by the HD-GBSAR transmitting antenna, while it is rotating on the horizontal plane.

NOTE: The illumination time depends on the antenna horizontal half power beam width and the antenna horizontal rotation speed.

3.2 Symbols

dBi	antenna gain in decibels relative to isotropic radiator
dBm	transmit power in decibels relative to mW
C/I	carrier to interference ratio
Gbps	Gigabits per second

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BW	BandWidth
CRAF	Committee on Radio Astrnomy Frequencies
EFIS	ECO's Frequency Information System
EIRP	Effective Isotropically Radiated Power
ERC	European Radio communication Commitee
FS	Fixed Service
GNSS	Global Navigational Satellirte System
IRAM	Institut de Radioastronomie Millemetrique
LFMCW	Linear Frequency Modulated Continuous Wave
LOS	Line Of Sight
MCL	Minimum Coupling Loss
OSO	Onsala Space Observatory
RF	Radio Frequency
RMS	Root Mean Square
RSL	Receiver Signal Level
RX	Receiver
SAR	Synthetic Aperture Radar
SHM	Structural Health Monitoring (of civil structures, such as buildings, bridges, dams, etc.)
SRD	Short Range Device
TX	Transmitter
UWB	Ultra Wide Band
VLBI	Very Large Base Interferometry (a type of space observation)
WGSE	ECC Working Group on Spectrum Engineering

4 Presentation of the HD-GBSAR system

The first-generation of Ground Based Synthetic Aperture Radars (GBSAR) operating in the band 17,1-17,3 GHz [i.1] and [i.2] was introduced in the market more than 10 years ago. It utilized channel bandwidth of 100-200 MHz which allowed it achieving spatial resolution of 0,75 m with displacement measurement accuracy of 1 mm.

Over the past years, GBSAR has been extensively utilized in Europe and all over the world for several safety critical deformation monitoring applications, such as landslide monitoring, dam monitoring and in general in any application requiring real-time deformation monitoring. In particular, the usage of GBSAR has become a standard practice in open pit mine operations, as safety tool capable to provide early warning in case of deformation indicative of impeding slope failure, improving the safety standard of people working in mining environment. A significant example is the case of the world's largest ever open pit mine slope failure at Bingham Canyon Mine in Utah, USA, which occurred on 10th of April 2013 [i.7], see figure 1.

Figure 1: Bingham Canyon Mine slope failure (photo credit: KSL.com [i.7])

The Bingham Canyon Mine operator was using GBSAR and it started to capture the first deformations months before the event. This early warning allowed mine operator to immediately re-route all operations around the risk area and keep monitoring it closely. When the landslide became imminent, the evacuation of the hazardous area was carried out a few days before the failure, saving lives of hundreds of miners.

However, large dimensions and limited range resolution performance of first-generation of GBSAR limited its applicability to more potential applications that require an easily transportable and compact system providing a finer resolution.

The latest technological advances made possible the development of a second generation of GBSAR, named High Definition GBSAR (HD-GBSAR). HD-GBSAR would provide up to 5x improvement of resolution performance compared with GBSAR, while allowing to achieve 4x reduction of physical size of measurement equipment. Moreover, the next generation HD-GBSAR technology enables a higher interferometric accuracy on displacement measurements. It is in fact possible to reach 0,1 mm accuracy on natural targets allowing the early detection of displacement trends such as those occurring before a ground collapse.

The higher resolution and measurement accuracy would however require a much larger operational bandwidth compared with first-generation GBSAR, up to 1 GHz compared with 200 MHz used originally. This requires reconsideration of frequency designation for second generation HD-GBSAR application and it was proposed to look at the range of 74 GHz-81 GHz as potential tuning range that could accommodate the required 1 GHz channel bandwidth.

Proposed frequency range 74 GHz-81 GHz offers a good match between the multiple considerations, such as the required operational bandwidth, the current state of available radar and general RF technological solutions vis-à-vis the requirements of specific HD-GBSAR use scenarios described in the following clause 5. Specific considerations substantiating the choice of the candidate frequency range 74 GHz-81 GHz for second generation HD-GBSAR are provided in clause B.2.

It is also envisaged that some evolving third generation HD-GBSAR applications in the future may require utilizing even higher operational bandwidth of up to 10 GHz. That future requirement would be subject to another work item addressing the possibilities for deploying radiodetermination and other UWB applications in the frequency range above 122 GHz.

5 Market information

The following main use scenarios are envisaged for the HD-GBSAR, enabled by the highly compact portable size and increased measurement precision of second generation equipment. For further details please see clause A.1.

- Structural Health Monitoring (SHM):

  HD-GBSAR can be used to monitor the deformation of civil structures such as various buildings or other man-made structures in order to either assess stability of the structure, or to monitor for any instabilities induced over time by external causes, such as earthquake or underground construction taking place close to or directly under the monitored object.

- Underground Mine and Tunnel Construction Monitoring:

  HD-GBSAR can be used for monitoring of underground mines and tunnels under construction as a geotechnical tool for deformation measurement to provide early warning in case of surface deformation as precursor of an impending collapse.

- Quarry, Cut-slope and Natural Landslide Monitoring:

  This is already a very well-established use scenario for GBSAR equipment, where it is used to monitor the ground superficial deformation of active quarry or natural landslide. For this use case the HD-GBSAR is able to offer a maximum measurement distance of 800 m providing a real-time displacement measure of the monitored scenario every minute or less.

Very importantly for all of the above use case scenarios, the more compact and light-weight portable nature of second-generation HD-GBSAR equipment as well as increased measurement accuracy allows much prominent use of this highly useful and in some scenarios life-saving technology in a wider variety of locations and scenarios. Accordingly, it is forecasted that the market size of the HD-GBSAR will be significantly larger than that of the first-generation GBSAR. It will be not least helped by the reduced price of HD-GBSAR compared with GBSAR thanks to recent advances of commercial mm-wave RF technologies.

Detailed estimates of different segments of HD-GBSAR market are outlined in clause A.2.

6 Technical information

6.1 Detailed technical description

The HD-GBSAR system (figure 2) is a remote sensing radar system able to monitor in real-time deformations of the illuminated surface over wide areas with sub-millimetre accuracy. From a technical point of view, the measurement is performed by a high frequency interferometry radar working as a rotating Synthetic Aperture Radar.

The system can perform an acquisition in less than a minute and provide as output a displacement heat-map of the monitored scenario. The displacement information is in general used to provide early warning in case of deformation having magnitude and rate indicative of hazardous instabilities of the monitored scenario.

Figure 2: HD-GBSAR system composition

The system is divided into two main parts (figure 2):

- Acquisition Unit:

  The Acquisition Unit consists of a Pan/Tilt module which rotates the radar sensor in order to perform the SAR acquisition, while a night vision camera continuously provides visual feedback of the monitored area, even under complete darkness. A laser unit is used to survey the 3D model of the monitored area, on which the heat map produced by the radar is overlaid.

- Supply and Control Unit:

  The Supply and Control Unit provides power to the acquisition unit, processes the radar data and provides the network interfaces to remotely control the system.

Further detailed description of technical principles of HD-GBSAR operation is provided in annex B.

6.2 Technical parameters and implications on spectrum

6.2.0 General

Table 1 contains the summary of main technical parameters of HD-GBSAR system.

Table 1: HD-GBSAR technical specifications

Parameter	Value
Modulation	LFMCW
Central frequency	Tuneable between 74,5 GHz ÷ 80,5 GHz
Emissions Bandwidth	1 GHz
Sweep Duration	1 ms
Power at the antenna connector	24 dBm
Maximum Equivalent Isotropic Radiated Power (EIRP)	48 dBm
Maximum Spectral Power Density	18 dBm/MHz
Antenna Type	Horn
Antenna Gain	17 dBi ÷ 24 dBi
Antenna Half Power Beamwidth	Horizontal/Vertical 15°÷ 30°
Antenna Polarization	Linear Vertical or Horizontal
Antenna Rotation Speed	10 deg/s
Target's Surface Point Illumination Time	1,5-3 s
Weight	24 kg
Size (Height x Depth x Width)	1 000 mm x 300 mm x 600 mm

6.2.1 Status of technical parameters

6.2.1.1 Current ITU and European Common Allocations

Annex C of the present document contains the analysis of current frequency allocations in this target frequency range according to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.17].

Considering the information on current spectrum allocations and its analysis provided in annex C, it is conceived that the most promising candidate band for HD-GBSAR operations may be found in the lower part of the target range, i.e. 74-75 GHz.

Designation of the band 74-75 GHz for HD-GBSAR would logically complement and complete the overall harmonised shared use of the frequency range 74-81 GHz by SRD radio determination applications:

- 74-75 GHz: HD-GBSAR applications (proposed);
- 75-76 GHz (part of tuning range 75-85 GHz): (Tank) Level Probing Radar applications;
- 76-77 GHz: Ground based vehicle and fixed Transport and Traffic Telematics surveillance radar applications;
- 76-77 GHz: Rotorcrafts' proximity radar applications;
- 77-81 GHz: Automotive Short Range Radar applications.

6.2.1.2 Sharing and compatibility studies already available

The original sharing and compatibility study for first-generation GBSAR technology was developed by CEPT and provided in ECC Report 111 (2011) [i.16]. However, that study considered the operation of 200 MHz bandwidth GBSAR application in the band 17,1-17,3 GHz. The current request for second-generation HD-GBSAR technology addresses the proposed use of 1 GHz bandwidth within the 74-81 GHz range, with initial tentative identification of the band 74-75 GHz. This requires a completely new sharing and compatibility study.

The provisional spectrum sharing study to verify the feasibility of deploying HD-GBSAR in the frequency band 74-75 GHz had been carried out within ETSI ERM as part of developing the present document and is provided in annex D of the present document. It considered spectrum sharing of proposed HD-GBSAR application vis-à-vis Space Research and Fixed Service uses of the same spectrum.

6.2.1.3 Sharing and compatibility issues still to be considered

Although the analysis provided in annexes C and D appears to be complete in principle, however it is expected that CEPT (WGSE) will wish to carry out a complementary sharing and compatibility study to verify and possibly expand the used assumptions and scenarios and accordingly review the findings in a more comprehensive light based on consensus of CEPT Administrations and all interested parties.

For instance, it was noted that there are ongoing industry efforts to promote the duplex band 71-76/81-86 GHz as candidate for IMT-2020/5G backhaul applications in ultra-dense and ultra-wideband Gb/s-link configurations. Although such use would essentially represent the same Fixed Service point-to-point use scenario as already considered in annex D, nevertheless this development may affect some of the assumptions made for the study and thus may warrant additional consideration.

6.2.2 Transmitter parameters

6.2.2.1 Transmitter Output Power / Radiated Power

The maximum EIRP value is 48 dBm.

The maximum Power Spectral Density is 18 dBm/MHz across the operating frequency band.

6.2.2.2 Antenna Characteristics

Typical HD-GBSAR antenna radiation patterns are depicted in figures 3 and 4:

- Figure 3 represents Type 1 (low directivity) antenna radiation pattern at 75 GHz, typical antenna gain is 17 dBi. Half Power Beamwidth is approximately 30°.
- Figure 4 represents Type 2 (high directivity) antenna radiation pattern at 75 GHz, typical antenna gain is 24 dBi. Half Power Beamwidth is approximately 15°.

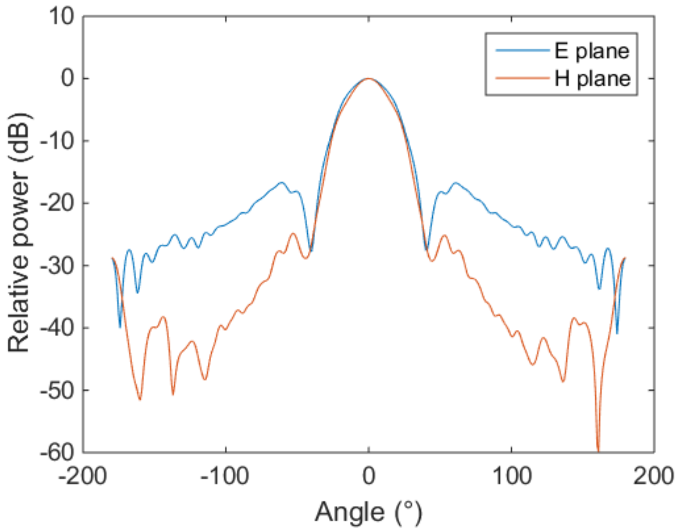


Figure 3: HD-GBSAR antenna Type 1 radiation pattern

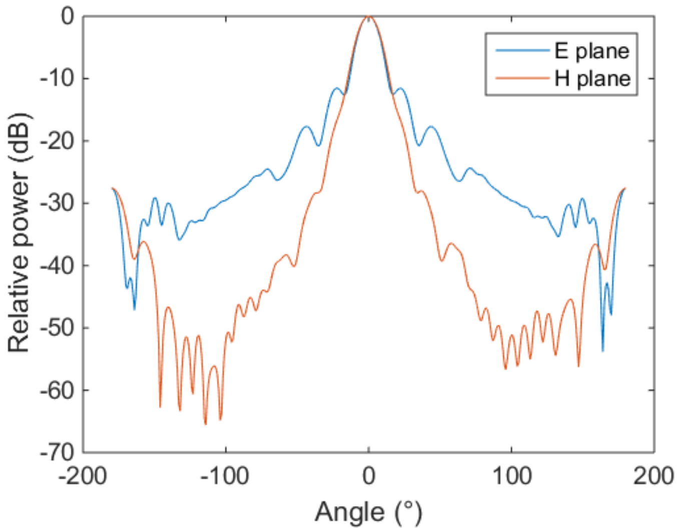


Figure 4: HD-GBSAR antenna Type 2 radiation pattern

6.2.2.3 Operating Frequency

Any 1 GHz wide portion within the range 74-81 GHz. This 1 GHz wide band would be used as a single channel for transmitting Linear Frequency Modulated Continuous Wave signal, as explained in annex B.

6.2.2.4 Bandwidth

Necessary bandwidth is 1 GHz, typical maximum occupied bandwidth is 980 MHz.

6.2.2.5 Unwanted emissions

The limit on RMS Mean Power Spectral density in the out-of-band domain is 0 dBm/MHz.

Maximum emissions in the spurious domain are given as follows:

- -54 dBm, for f within the bands 47-74 MHz, 87,5-118 MHz, 174-230 MHz, 470-862 MHz;
- -36 dBm, for 9 kHz $\leq f \leq$ 1 GHz (except the above frequency bands);
- -30 dBm, for 1 GHz $< f \leq F_{UPPER}$.

Where f is the frequency of the spurious domain emission while F_{UPPER} is defined as the 2nd harmonic of the fundamental frequency (as defined in CEPT/ERC/REC 74-01 [i.5]).

6.2.3 Receiver parameters

The HD-GBSAR radar includes one antenna for signal transmission and one antenna for signal reception. Both antennas are mounted on the radar transceiver module, which includes an active mixer that converts the Radio Frequency signal into an Intermediate Frequency which covers 50 kHz to 10 MHz.

The receiver Noise figure is typically 10 dB at 2 MHz.

6.2.4 Channel access parameters

During the active object scan periods (see clause A.3 for more details on range of activity factors), the HD-GBSAR transceiver is constantly ON. However from the perspective of other devices sharing the same band the HD-GBSAR signal will appear periodical, with equivalent Duty Cycle less than 100 %. This is a result of HD-GBSAR scanning the object with mechanical rotation of antenna beam at 10°/s within the angular limits defined by the user depending on the type of application and size of monitored object. This operation results in maximum target illumination time of 3 seconds with Type 1 antenna (30° beamwidth) or less when using Type 2 (15° beamwidth) antenna.

7 Radio spectrum request and justification

The analysis of the HD-GBSAR system description and its technical parameters and operational scenarios informs the following observations and conclusions that would have implications for categorizing and regulating spectrum access for such systems:

- HD-GBSAR may be characterized as Ultra-Wide Band Short Range Device, belonging within the family of Radiodetermination applications;
- Accordingly, the HD-GBSAR should be considered within the family and framework of SRD regulations contained in annex 6 of the CEPT ERC/REC 70-03 [i.2];
- HD-GBSAR (with 1 GHz bandwidth) would provide up to 5x improvement of resolution performance compared with GBSAR (with 200 MHz bandwidth), while allowing to achieve 4x reduction of physical size of measurement equipment. This will allow the early detection of displacement trends such as those occurring before a ground collapse, in cases where GBSAR is not applicable;
- HD-GBSAR remains a niche highly-specialized professional application to be used only by trained professionals, like was the case for first-generation GBSAR system. The market forecasts provided in annex A.2 show that based on extrapolation of GBSAR market trends it may be expected that the total market demand for next-generation HD-GBSAR would not exceed 500 units over 5 years for the entire European area;

- It should be further noted that a significant proportion of deployed HD-GBSAR units would be used in terrain shielded (quarries) and underground (mines and tunnels) scenarios, meaning isolation of EM emissions within confined space of surveyed objects. This means that only small fraction of the HD-GBSAR will be ever used in open environments where it could possibly impact other radio spectrum users. Thus, it may be concluded that the sharing profile of HD-GBSAR equipment, i.e. its overall deployment density, "visibility" to other radiocommunication systems and resulting possibility to create interference to their operations, is and will remain very low;
- HD-GBSAR spectrum designation should be made for the entire operating band of 1 GHz without specifying channel bandwidth.

Clause 8 provides further details of regulatory analysis and considerations regarding spectrum designation for HD-GBSAR systems and recommends a specific action in that regard.

8 Regulations

8.1 Current regulations

The first-generation of GBSAR [i.1] was recognized as Radio determination SRD application and was designated frequency band 17,1-17,3 GHz in Annex 6 of CEPT ERC Recommendation 70-03 [i.2]. It was specified that GBSAR could operate without restrictions on channel bandwidth, i.e. utilizing up to entire 200 MHz of bandwidth designated to them. The total power was limited to 26 dBm e.i.r.p. and it was mandated that the GBSAR using this band should employ Detect-And-Avoid interference mitigation technique as detailed in annex E of ETSI EN 300 440-1 [i.3]. This mitigation technique was prescribed in order to minimize risk of interference from GBSAR to primary service radiolocation systems utilizing the subject frequency band of 17,1-17,3 GHz.

The current regulations provide a sufficient and satisfactory regulatory conditions for deployment of first-generation GBSAR equipment based on using Stepped Frequency Continued Wave modulation and providing mm-range resolution precision for displacement measurements. However, they are not adequate to allow deployment of next generation HD-GBSAR equipment described in clause 6.1, which would require much wider operating bandwidth than the 200 MHz designated for the first-generation GBSAR.

8.2 Proposed regulation and justification

Matching of HD-GBSAR operational requirements vis-à-vis technological capabilities of suitable RF element base has directed the search of suitable operating band of at least 1 GHz to the range of 74 GHz-81 GHz. Annex C of the present document contains the analysis of current frequency allocations in this target frequency range according to the up-to-date relevant provisions of article 5 of ITU Radio Regulations and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.17].

Specifically, it is proposed that regulatory designation of 1 GHz band in the 74-81 GHz tuning range for HD-GBSAR may be done by making the following addition to annex 6 "Radiodetermination applications" of ERC/REC 70-03 [i.2]:

Table 2: Proposed designation of HD-GBSAR band in Annex 6 of ERC/REC 70-03 [i.2]

#	Frequency Band	Power/Magnetic Field	Spectrum Access and Mitigation Requirements	Modulation/Maximum Occupied Bandwidth	ECC/ERC Deliverable	Notes
n	1 GHz in the 74-81 GHz tuning range	48 dBm e.i.r.p.	Minimum antenna gain 17 dBi	Not specified		For High Definition Ground Based Synthetic Aperture Radar (HD-GBSAR)

Based on the analysis provided in annex C, it is assumed that the band 74-75 GHz might be the most promising band and thus the preferred candidate for locating 1 GHz operational band for HD-GBSAR.

It should be noted that the preference for the band 74-75 GHz is not originating from HD-GBSAR vendors or operators but is solely based on the results of the initial regulatory considerations and sharing feasibility analysis presented in the present document in annexes C and D. In case subsequent analysis in CEPT of this proposal would not confirm positive conclusion as regards feasibility of using the band 74-75 GHz, then any other 1 GHz wide portion of the 74-81 GHz range would be equally suitable from the HD-GBSAR system design and operational perspectives.

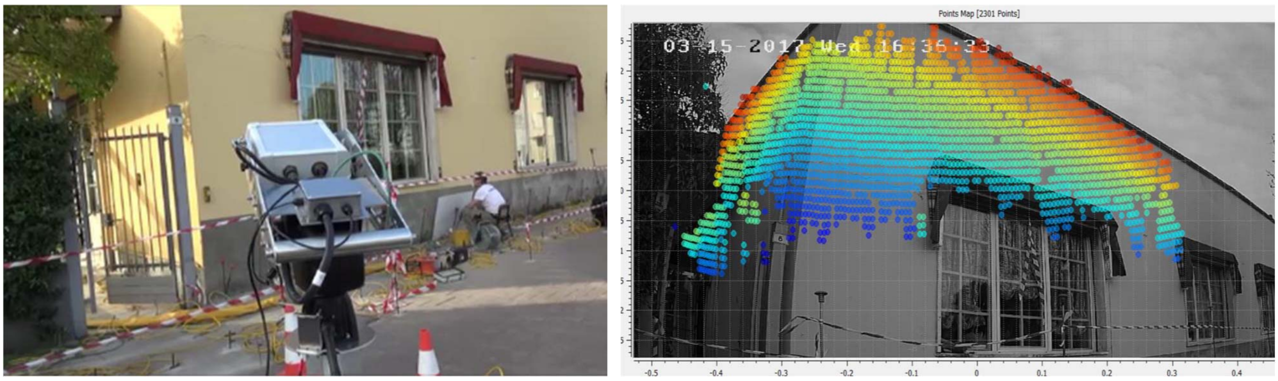
Annex A:
Detailed use case examples and market information

A.1 Use Case Examples

A.1.1 Structural Health Monitoring

HD-GBSAR can be used to monitor the deformation of civil structures either to assess the stability of the structure, or to control instabilities induced by external causes, such as earthquake, structure repair or underground construction that takes place close to or under the monitored structure.

A typical Structural Health Monitoring (SHM) example is building monitoring as illustrated in figure A.1.



(a) **(b)**

NOTE: (a) Deployment, (b) Measured displacement heat map.

Figure A.1: HD-GBSAR used for building monitoring

The illustrated use case example shows the building deformation monitoring during foundation consolidation through resin injection. HD-GBSAR is used to track the building movement due to the injections while they are performed. The system is installed in front of the building to be monitored (see figure. A.1 (a)) and the measurement results can be displayed as a coloured displacement map overlaid on the building picture (see figure A.1 (b)), where the colour represents the displacement value. For each measurement point it is possible to display the time evolution of the deformation and setup certain threshold to trigger alarms alerting of risk of impending building failure.

The same technology can be used for deformation monitoring of many other types of civil structures; important examples are dams (see figure A.2 (a)) and bridges (see figure A.2 (b)).

(a) (b)

NOTE: (a) Dam monitoring, (b) Bridge monitoring.

Figure A.2: Other examples of SHM use cases

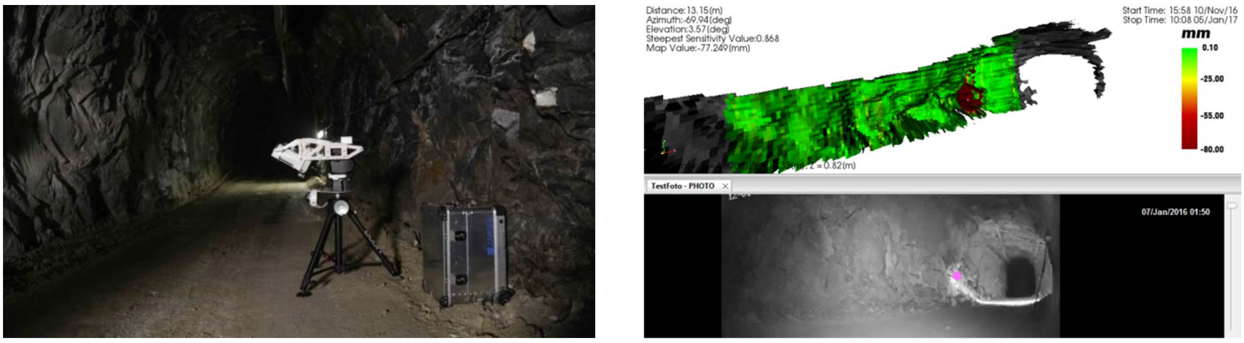
In these contexts, the (4x) reduced size and the consequent high transportability of a HD-GBSAR system enables the deployment of the radar in areas with limited access and space constraints, as often happens in SHM scenarios, where a most typical installation site would be a 1-2 square meters area at the edge of a road.

Moreover, emergency monitoring conditions usually require high speed of deployment and this is again facilitated by compact size and high transportability of a HD-GBSAR system, which can be easily moved and installed even by a single person (thanks to system weight < 25 kg).

HD-GBSAR's spatial resolution (0,15 m) plays also a fundamental role in all SHM applications, as it is possible to retrieve more information about the displacement spatial distribution of the structure under investigation; as a consequence, HD-GBSAR is able to provide a deeper understanding of structural health level, thus improving the safety conditions of people operating in the area.

A.1.2 Underground Mine and Tunnel Construction Monitoring

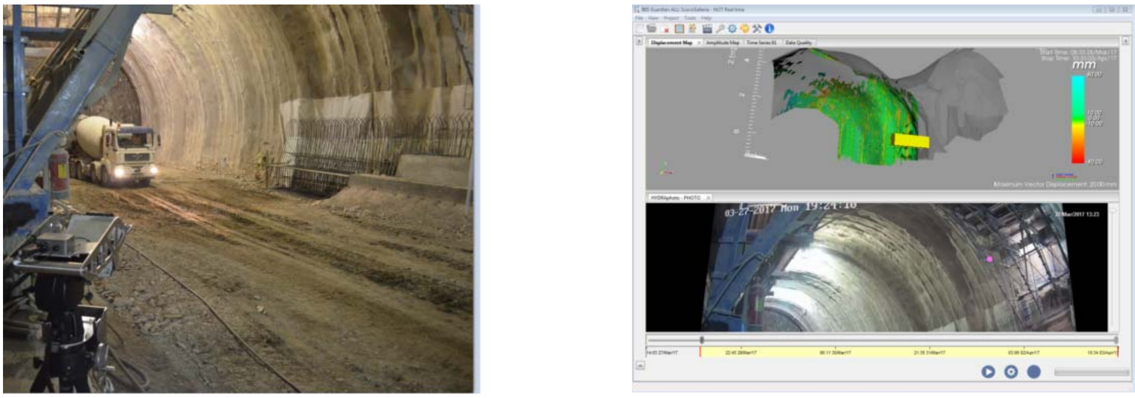
HD-GBSAR can be used for underground mine and tunnel construction monitoring as a geotechnical tool for deformation measurement to provide early warning in case of detecting surface deformation precursor of an impending collapse. This scenario is illustrated in figures A.3 and A.4.



(a) (b)

NOTE: (a) Deployment, (b) Displacement heat map.

Figure A.3: HD-GBSAR used for mine walls monitoring



(a) (b)

NOTE: (a) Deployment, (b) Displacement heat map.

Figure A.4: HD-GBSAR used for tunnel construction monitoring

The information collected by radar can be presented as a displacement heat-map georeferenced on a 3D model of the monitored scenario as illustrated in figure A.3(b) and figure A.4(b). Early warning alert is triggered based on the displacement information allowing the evacuation of people and machinery located in risky area, vastly improving the work safety in underground mining and construction environments.

HD-GBSAR can be used for deformation monitoring during tunnel construction as illustrated in figure A.4 (both (a) and (b)), in order to assess both the stability of the area and to perform convergence measurements before continuing the excavation.

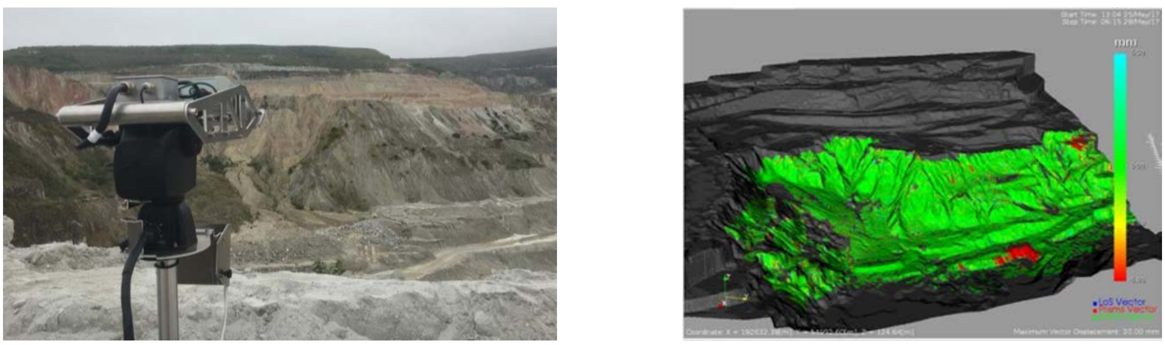
In the context of highly confined underground spaces, the more compact size of second generation HD-GBSAR system allows even wall/ceiling-mounting approach to provide more space for personnel and equipment movements.

In these use cases the spatial resolution becomes a crucial matter: considering a typical tunnel height of 5 meters, a rock detachment from the ceiling represents a serious danger for the workers even if the rock size is around 15-20 cm; moving rocks of this size cannot be detected with conventional GBSAR-based system whose maximum spatial resolution is 75 cm; HD-GBSAR instead offers an appropriate radar technology providing a higher spatial resolution.

Rockfall events are very often anticipated by deformation of only a few millimetres, therefore the higher HD-GBSAR displacement measurement accuracy (0,1 mm compared with 1 mm of GBSAR) enables a more reliable and earlier detection of the rock-fall precursor, providing more time to evacuate the personnel working in the hazardous area.

A.1.3 Quarry, Cut-slope and Natural Landslide Monitoring

HD-GBSAR can be used to monitor the superficial deformation of ground surfaces in active quarry, cut-slope or natural landslide scenarios. The active quarry monitoring scenario is illustrated in figure A.5.



(a) (b)

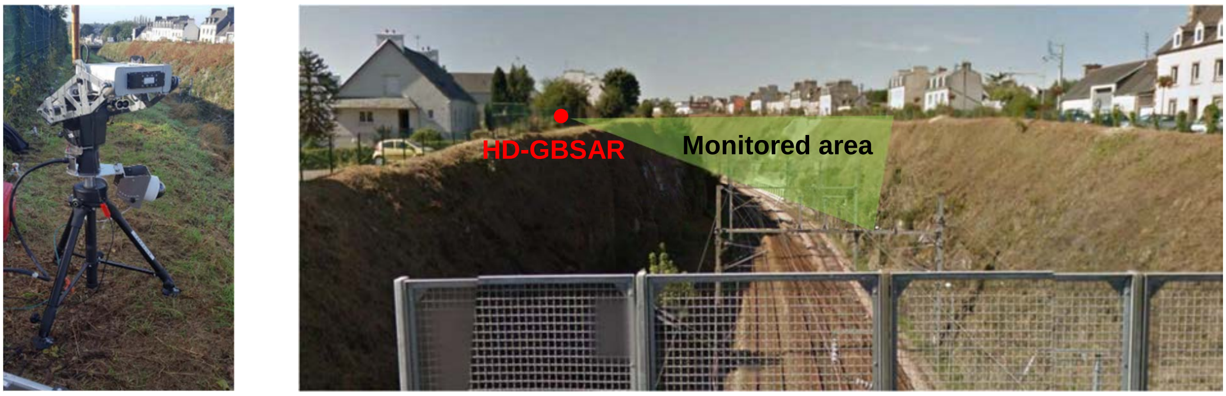
NOTE: (a) Deployment, (b) Displacement heat map.

Figure A.5: HD-GBSAR used for quarry monitoring

For this use case HD-GBSAR is able to cover a maximum distance of 800 m providing a displacement measure of the monitored scenario every minute or less.

The displacement information is georeferenced in a 3D model of the monitored scenario as illustrated in figure A.5(b) and is used to trigger early-warning alerts in case of slope failure precursor, in order to evacuate people and machinery at risk. The high transportability of HD-GBSAR system is fundamental for quarry monitoring, in this mining environment, the monitored scenario is extremely dynamic and it usually evolves very quickly, potentially imposing many changes of the radar installation site over time.

Further use case examples are cut-slope (see figure A.6) and natural landslide (see figure A.7) monitoring, in both these cases the reduced system size and transportability again play a very important role.



(a) **(b)**

NOTE: (a) Installation spot, (b) Monitoring configuration.

Figure A.6: HD-GBSAR used for cut-slope monitoring

Figure A.7: HD-GBSAR used for natural landslide monitoring

The high HD-GBSAR spatial resolution is also very important in these scenarios as it enables the detection of small moving rocks (0,15 m) which nevertheless can represent a serious risk for people operating in the area close by the unstable slope. In addition, the enhanced displacement measurement accuracy (0,1 mm) of HD-GBSAR allows the early detection of rock fall precursors not observable with conventional GBSAR systems.

A.2 Market Information

A.2.0 General

This clause provides a detailed analysis of HD-GBSAR market size and value, divided into three market segments identified by the key use cases described in previous clause A.1. The market survey is based on the actual deployment experiences and market data of first-generation GBSAR application used in similar market segments and offers future forecasts based on publicly available market research data.

Tables A.1 and A.2 summarize the size of accordingly global and European markets for HD-GBSAR, also specifying values of different market segments. The following clauses outline the reasoning and assumptions made as well as calculation methods that were used to arrive at the above quoted estimates of the HD-GBSAR market.

Table A.1: Estimated global HD-GBSAR market size and value

Market segment	Global market estimates for 2019-2023	
	Number of Units	**Value**
Structural Health Monitoring (see clause A.2.1)	200	10 M€
Underground Mine and Tunnel Construction Monitoring (see clause A.2.2)	1 360	68 M€
Quarry, Cut-slope and Landslide Monitoring (see clause A.2.3)	900	45 M€
Totals	**2 460**	**123 M€**

Table A.2: Estimated European HD-GBSAR market size and value

Market segment	European market estimates for 2019-2023	
	Number of Units	**Value**
Structural Health Monitoring (see clause A.2.1)	40	2 M€
Underground Mine and Tunnel Construction Monitoring (see clause A.2.2)	154	7,7 M€
Quarry, Cut-slope and Landslide Monitoring (see clause A.2.3)	280	14 M€
Totals	**474**	**23,7 M€**

A.2.1 Structural Health Monitoring

Global SHM market size was valued at $1,133 billion in 2016, and is expected to reach $3,965 billion by 2023, registering a constant growth rate of 18,9 % from 2017 to 2023.

NOTE 1: Source: Allied Market Research, available from https://www.alliedmarketresearch.com/structural-health-monitoring-market.

In 2016 North America accounted for 27 % share of the global SHM market and the second largest market is the Western Europe with 21 %.

NOTE 2: Source: Future Market Insight from https://www.futuremarketinsights.com/reports/structural-health-monitoring-market.

Over the years, SHM technologies have emerged as a prominent new field within civil engineering. SHM has become an important tool in the design, analysis, and maintenance of civil engineering structures, such as building, bridge, dams, tower, etc. SHM enables to better understand the behaviour of structures under dynamic loads and allows real time monitoring of instability induced by external causes.

The first-generation GBSAR had a limited market penetration in the SHM segment. For instance, IDS GeoRadar is GBSAR market leader and counts around 60 units sold in SHM segment from 2007 to 2017, with the total current global GBSAR's SHM market size estimated at about 100 units. The analysis suggests that the limited dissemination of first-generation GBSAR systems for SHM applications was mainly due to the following factors:

- High unit cost due to the absence of large scale technology (>100 k€), hardly affordable by small SHM service companies;
- Large size of equipment, hindering the nomadic nature of SHM application;
- The range resolution performance of 0,75 m, representing a performance drawback with respect to the competing laser technology.

The second-generation HD-GBSAR is aimed to address the above-mentioned limitations, in order to gain a more significant SHM market share. The forecasted HD-GBSAR market size and volume for SHM application is reported in table A.3 and is based on the following assumptions:

- About 20 HD-GBSAR units sold in 2019 and a constant growth rate of 30 % in the forecasted period (about 10 % above of SHM market growth rate);
- An average cost unit of 50 k€ (achievable by exploiting the mm-wave RF technology advancement pushed by automotive radar industry);
- European market share remaining at approx. 20 % of the global market.

Table A.3: Estimated HD-GBSAR market size and value for SHM segment

	Global market 2019-2023	European market 2019-2023
Value	10 M€	2 M€
Number of units	200	40

A.2.2 Underground Mine and Tunnel Construction Monitoring

The underground mining industry globally counts today about 900 underground operating mine projects for base, precious and ferrous metals, and 1 000 mine projects in the coal industry (see figure A.8). Another 600 projects worldwide are in various preparatory stages between feasibility analysis to construction.

NOTE|: Source: InfoMine, available online at: http://www.infomine.com/.

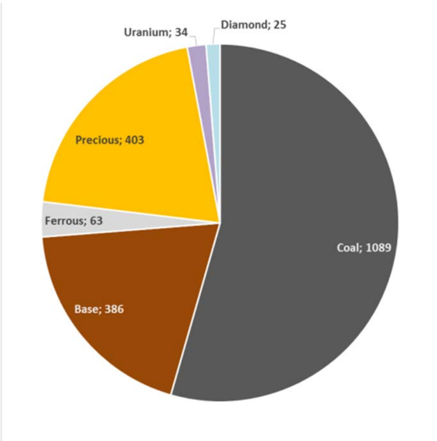


Figure A.8: Globally operating underground mines by commodity

Underground mines represent one of the most difficult, tough and challenging environments to work for human beings. Although safety is considered as one of the key issues, limitations in feasible technological solutions, cost, and the very nature of underground mines as highly constrained, space-limited and fragile structures had long hampered the development of efficient remote monitoring systems to ensure full safety for the miners with respect to monitoring and prediction of rock face collapses.

The US Mine Safety and Health Administration reports that in the years 2010-2014, 24,5 % of fatalities in underground mines in the United States were related to fall of ground accidents, while only 13,7 % of fatalities in surface mining were related to ground instabilities (see figure A.9).

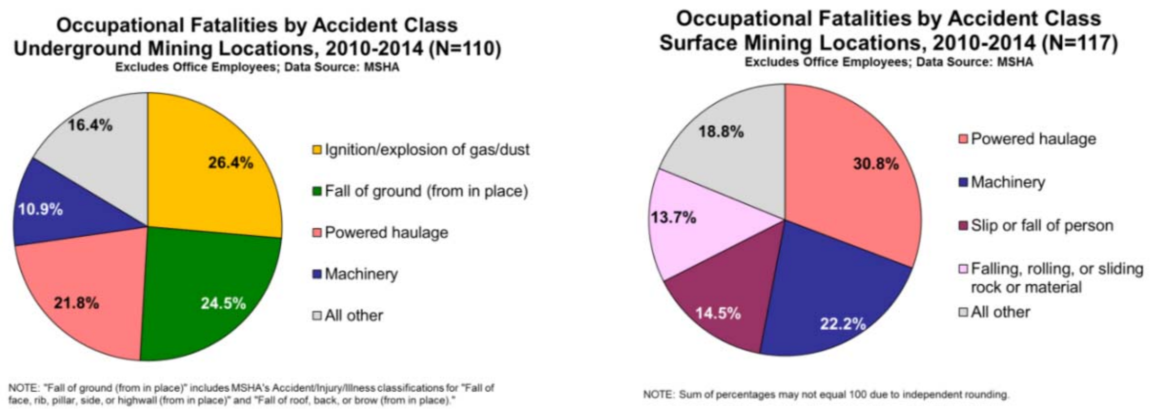


Figure A.9: Comparison of underground and surface mining fatalities by accident class

The use of monitoring systems to detect rock face movements in surface mining has emerged in the last ten years as a standard work and safety practice. The development and optimization of remote monitoring systems like Total Station, GNSS, interferometric radar, and Lidar have greatly contributed to understanding and anticipation of slope movements and thus contributed to the reduction of incidents and fatalities related to slope failures. Particularly interferometric radar technology, such as GBSAR, has become a standard monitoring technique adopted by almost all tier-1 and tier-2 (open) mines. IDS GeoRadar alone has deployed more than 200 GBSAR worldwide between 2010 and 2017 (about 10 % of them in Europe). The IDS GeoRadar is one of the 3 main players in this market and the total global market size in the same period is estimated to be around 1 000 units.

The same has not happened in underground mining operations, where deformation monitoring of rock cavities is in most cases still being done by employing contact sensors like extensometers, micro-seismic gauges, strain gauges, and fibre optic systems. To date technological limitations have not allowed system providers to develop effective remote deformation monitoring systems for the early detection of rock face movements in the underground mining industry.

Underground mine monitoring requires high displacement accuracy (<0,1 mm) and the combination of high spatial resolution (20 x 20 cm) and compact size (maximum dimension <1 m). Therefore, the first-generation GBSAR systems were not adopted in underground mining so far, due to their insufficient spatial resolution and excessive size.

Now HD-GBSAR has the potential to become a new monitoring standard technology for underground mining operations as it happened for GBSAR in surface mining. The estimated HD-GBSAR market size and value in underground mining segment is reported in table A.4 and is based on the following assumptions:

- 10 % of the total number of underground mines (2 000 globally) will adopt HD-GBSAR technology in the forecasted period (10 % in Europe, similarly to GBSAR for open pit mining);
- One underground mine will employ an average of 5 HD-GBSAR units;
- Average unit cost of 50 k€.

Table A.4: Estimated size and value of HD-GBSAR market for underground mining

	Global market 2019-2023	European market 2019-2023
Value	50 M€	5 M€
Number of units	1 000	100

Another use case in underground operational scenarios involves monitoring of the front excavation faces of road and railway tunnels in construction. This use case shares most of the requirements demanded in underground mine monitoring, but it represents a different and separate sub-market.

A market survey performed in 2016 reports that about 5 200 km of tunnels have been constructed annually from 2013 to 2016 with an annual growth of 7 %, and this trend is expected to last for the next 5 to 10 years. For the moment and probably the next decade, China will roughly represent 50 % of the global market (37 billion € per year), whereas the European market remains stable at around 10–12 billion € per year (15 % of global market), with Italy, Russia, Turkey, Germany and Austria being the most active countries.

NOTE: Source: International Tunnelling and Underground Space Association: http://www.tunnel-online.info/en/artikel/tunnel_Tunnel_Market_Survey_2016_3051818.html.

Accordingly, the HD-GBSAR market size and volume forecasts for tunnelling sub-segment are provided in table A.5 and had been estimated on the assumption of one deployed HD-GBSAR unit for every 100 km of tunnels constructed in the 2019-2023 period (36 000 km) and a European share of 15 % of the global market.

Table A.5: Estimated size and value of HD-GBSAR market for underground tunnel construction monitoring

	Global market 2019-2023	European market 2019-2023
Value	18 M€	2,7 M€
Number of units	360	54

A.2.3 Quarry, Cut-slope and Landslide Monitoring

Interferometric radar technology has been extensively used in large and medium open-pit mine operations worldwide and it has played a fundamental role in significant improvement of the safety standards over the past 10 years.

In 2007 IDS GeoRadar introduced GBSAR technology in surface mining market and it is now one of the three major players in this market with more than 200 GBSAR deployed from 2010 to 2017.

Radar technology has not achieved the same level of dissemination in the quarry market, due to the following characteristic factors:

- Complex geometries requiring focus monitoring;
- Monitoring often needs to be done by surveyors (limited staff);
- Low budgets assigned to monitoring.

Therefore, it is considered that first-generation GBSAR achieved limited deployment in this market mainly due to following reasons:

- Lack of high portability/transportability demanded by quarry operations (managed by a single person, frequent relocation of the system);
- High unit cost of >100 k€ is not affordable to quarry companies, who deal with extraction of less precious materials and thus lower operational margins.

HD-GBSAR is expected to satisfy specific and demanding requirements of the quarry market, which has larger number of operations compared with the surface mining market. In 2015 the European market (EU-28 plus the EFTA countries) accounted for over 15 000 producers (mainly SMEs) operating some 26 000 quarries and pits, employing over 200 000 people directly and indirectly and the total direct value of this production is estimated to be in excess of 15 billion €.

NOTE 1: Source: European Aggregates Association, available online at: http://www.uepg.eu/statistics/graphs.

In the forecasted period HD-GBSAR will be more likely adopted by quarry extracting more precious materials like industrial minerals (Bentonite, Kaolin, Clay, Silica, Talc, etc.), which are around 700 throughout Europe.

NOTE 2: Source: Industrial Mineral Association, available online at: https://www.ima-europe.eu/about-industrial-minerals/industry-profile.

It is assumed that around 30 % of industrial mineral quarries will adopt HD-GBSAR in the forecasted period (percentage based on GBSAR market penetration in open pit mines segment).

Based on the above assumptions and number of targeted quarries the European market size in the 2019-2023 is estimated to reach 200 sold units for a value of around 10M€ (table A.6). The European quarry market is around 25 % of the global market, therefore the global number of sold HD-GBSAR units is estimated to be around 800 units.

NOTE 3: Source: Market Research Reports, available online at: https://www.marketresearchreports.com/timetric/global-construction-aggregates-market-%E2%80%93-key-trends-and-opportunities-2018.

Table A.6: Estimated size and value of HD-GBSAR market for quarry monitoring

	Global market 2019-2023	European market 2019-2023
Value	40 M€	10 M€
Number of units	800	200

Much of the world's road and railway network is built on slopes, embankments or in cuttings and thus susceptible to disruption from landslides-particularly in wet weather. Although rapid repair of landslide damage is well within modern civil engineering capabilities, the economic consequences of severing a major transport artery for even a short period can far outweigh the remedial costs. Ideally landslides should be prevented from occurring in the first place, but that requires a sea change in approach (see figure A.10).

Figure A.10: Cut slope failure examples

European regions, with particular regard to large number of mountainous countries such as Italy, Switzerland, Austria, Norway, etc., show a very large incidence of landslides or unstable slopes which need monitoring to forecast hazards and risks. For example, in Italy alone there are about 1 000 areas at risk requiring monitoring.

The estimated market size and value for landslide monitoring is given in table A.7. The estimation is derived based on the current GBSAR market size for landslide monitoring, which counts around 100 units sold in the 2007-2017 period, most of them in Europe (80 %).

Table A.7: Estimated size and value of HD-GBSAR market for cut slope and landslide monitoring

	Global market 2019-2023	European market 2019-2023
Value	5 M€	4 M€
Number of units	100	80

A.3 System deployment and activity factor considerations

The use and deployment of HD-GBSAR equipment shows different characteristics depending on the application field.

For SHM application the use of HD-GBSAR typically consists of short one-two days survey, installing the system nearby the structure to monitor (building, bridge, dam, etc.). During the monitoring survey period the activity factor of the system is around 50 %.

For underground mine monitoring the HD-GBSAR can be used either for continuous monitoring of unstable wall areas for a period from one day to several weeks, or for performing several surveys of various areas in different time-periods, where each survey lasts a few hours. In both cases the system is installed for the survey period close to the monitored area (<200 m) and the maximum activity factor is 50 %.

For tunnelling monitoring application, the HD-GBSAR is installed 20-50 m from the excavation front face and is then constantly re-located along with the tunnel progress. Typically, the system would be moved every 2-3 days and during the monitoring the activity factor is around 50 %.

For quarry, cut-slope and landslide monitoring application, the HD-GBSAR can be exploited for continuous or for time-discreet monitoring surveys: in the first case the system is permanently installed in front of the landslide/unstable slope, while in the second case it will be used as a nomadic system, used for performing several different surveys in different time-period. In the case of a time-discreet nomadic use, one survey would usually last for about 1-2 weeks with a time repetition interval of some months. During the monitoring phase the activity factor is around 25 %.

Annex B:
Technical information on HD-GBSAR signals and operation

B.1 Technical Fundamentals

The HD-GBSAR transceiver (Acquisition Unit) emits a Linear Frequency Modulated Continuous Wave (LFMCW) signal (see figure B.1) through a horn transmitting antenna and receives the signal backscattered from the observed object/landscape with an identical receiving horn antenna. The radar signal is a triangle wave in frequency sweeping a bandwidth of 1 GHz tuneable between 74 GHz and 81 GHz.

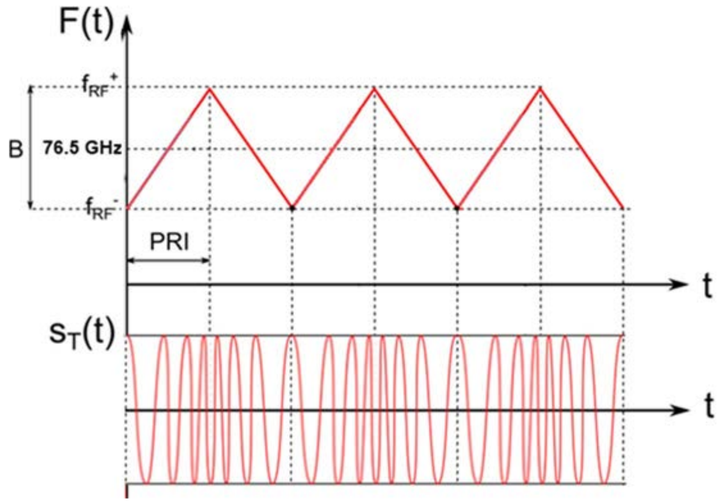


Figure B.1: HD-GBSAR signal in the frequency and time domain

The HD-GBSAR's RF signal is transmitted continuously and received while the entire transceiver with transmit and receive antennas is mechanically rotated by the Pan/Tilt mounting module (see figure B.2), with an angular rotation speed of 10 deg/s.

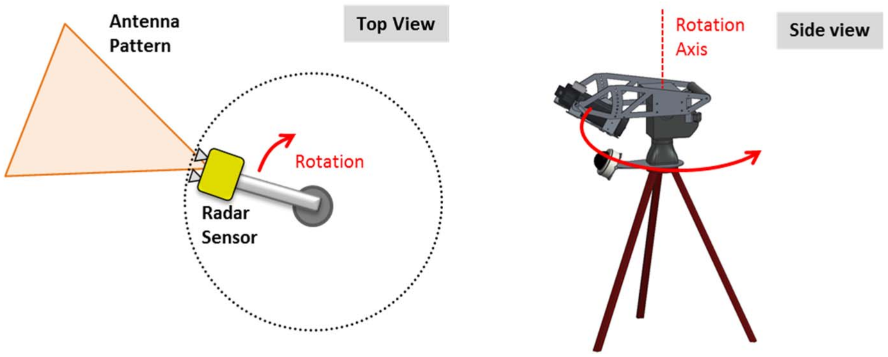


Figure B.2: Arc SAR acquisition

HD-GBSAR provides a bi-dimensional image of the monitored scenario; the two dimensions are determined by the range resolution and the angular resolution capability (see figure B.3).

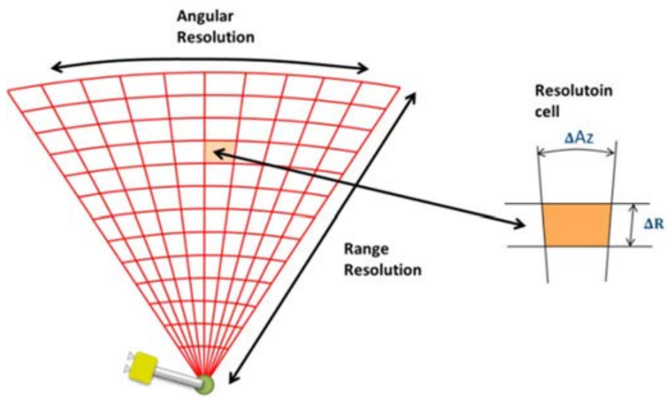


Figure B.3: HD-GBSAR spatial resolution

The range resolution ΔR is determined by the bandwidth of the emitted signal ($\Delta R = c/2B$) and is 0,15 m, whereas the angular resolution ΔAz is around 8 mrad assuming a rotation radius of 0,5 m.

The combination of range and angular resolution allows the creation of a bi-dimensional image (see figure B.3), where each resolution cell is a measurement point providing a real-time displacement information with sub-millimetre accuracy thanks to the interferometric technique.

B.2 Choice of the Frequency Range

This clause will analyse the choice of the frequency range 74 GHz-81 GHz for the second-generation HD-GBSAR application described in the present document as opposed to using higher frequency ranges, e.g. those above 122 GHz.

HD-GBSAR is an interferometric radar which measures radar bin deformations by comparing the phase variation occurred between two acquisitions. The measured phase variation $\Delta\varphi = \varphi_2 - \varphi_1$, where φ_1 and φ_2 are respectively the phase values measured at t_1 and t_2, is translated into the displacement d occurred between t_1 and t_2 through the following formula:

$$\mathrm{d} = \frac{\lambda}{4\pi} \cdot \Delta\varphi$$

where: λ is the wavelength of the transmitted signal corresponding to the center frequency of measuring signal.

Since interferometric radar measures phase difference, the maximum measurable displacement between two acquisitions corresponds to a phase variation of π and is limited at $\frac{\lambda}{4}$, because in case of phase variation greater than π the phase is wrapped.

This inherent limitation is usually referred to as "phase ambiguity", which describes a limit on the maximum measurable displacement between two acquisitions to be proportional to the wavelength of the measuring signal.

In case of HD-GBSAR working in the frequency range 74-81 GHz, the phase ambiguity limits the maximum measurable displacement to around 1 mm between any two acquisitions. Such a limit is particularly relevant in case of discontinuous measurement in some of the addressed use scenarios, where the two acquisitions could be months apart. For comparison, implementing HD-GBSAR at 122 GHz would reduce the maximum measurable displacement between two acquisitions to 0,6 mm, dramatically increasing the impact of phase ambiguity.

The wavelength of the transmitted signal also affects the accuracy required of the mechanics implementing the circular motion of the radar sensor and the knowledge of the location of the LFMCW acquisition along the circular track. The accuracy of the knowledge of the acquisition geometry influences the ArcSAR focusing performance impacting the actual angular resolution performance. The theoretical ArcSAR focusing performance is not impacted if the acquisition geometry is known and repeatable with an accuracy better than $\frac{\lambda}{10}$, which corresponds to 0,4 mm at 77 GHz and 0,25 mm at 122 GHz. Therefore, the usage of higher frequency poses hard requirements on the mechanics that implement the circular motion needed to perform the ArcSAR acquisition.

In conclusion, the proposed operating frequency range 74 GHz-81 GHz appears a good match for the second-generation HD-GBSAR application described in the present document as it offers a good match between the required operational bandwidth (resolution performance) and frequency-related limitations of addressed use scenarios. Frequency ranges above 122 GHz would further improve the compactness of the system, but is not considered optimal for the considered application and use scenarios due to following reasons:

- increased impact of the phase ambiguity limitation;
- over-complicated mechanics needed to perform the ArcSAR acquisition.

The choice of lower frequency range would also offer lower signal attenuation due to absorption by atmosphere gases and other natural phenomena such as fog, rain or dust. However, that improvement is comparatively insignificant at 1 dB or less for the maximum measurement distance of 800 m.

Annex C: Relationship to the existing spectrum regulation

Based on technological requirements and capabilities, it was proposed that the range of 74 GHz-81 GHz may provide a suitable candidate band to accommodate spectrum designation for proposed HD-GBSAR application. This annex reviews the current frequency allocations in this target frequency range with the objective of identifying the band(s) of at least 1 GHz width that could accommodate HD-GBSAR while minimizing potential regulatory and electro-magnetic compatibility impact on existing spectrum users.

The following table lists the existing spectrum allocation s and applications that are in major use in Europe according to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.17].

Table C.1: Spectrum allocations and major European uses in candidate frequency range 74 GHz-81 GHz

Frequency band	Allocations	Applications
74 GHz - 75,5 GHz RR5.561	BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE BROADCASTING Space Research (space-to-Earth)	Space research Radiodetermination applications Fixed
75,5 GHz - 76 GHz RR 5.561 ECA35	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) Amateur Amateur-Satellite	Fixed Radiodetermination applications Amateur Amateur-satellite Space research
76 GHz - 77,5 GHz RR5.149	Amateur-Satellite Amateur RADIO ASTRONOMY RADIOLOCATION Space Research (space-to-Earth)	Amateur-satellite Radio astronomy Amateur Radiolocation (civil) Railway applications Transport and Traffic Telematics (76-77 GHz) Radiodetermination applications Short Range Radars (77-81 GHz)
77,5 GHz - 78 GHz RR5.149	RADIOLOCATION (5.559B) AMATEUR-SATELLITE Space Research (space-to-Earth) AMATEUR	Short Range Radars (77-81 GHz) Radiodetermination applications Radio astronomy Amateur Amateur-satellite
78 GHz - 79 GHz RR5.149 RR5.560	Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) RADIOLOCATION	Radio astronomy Amateur-satellite Amateur Radiolocation (civil) Short Range Radars (77-81 GHz) Radiodetermination applications
79 GHz - 81 GHz RR5.149	RADIO ASTRONOMY RADIOLOCATION Amateur-Satellite Amateur	Radiodetermination applications Short Range Radars (77-81 GHz) Radiolocation (civil) Radio astronomy Amateur Amateur-satellite

Pertinent RR/ECA footnotes quoted verbatim from ERC Report 25 [i.17]:

- ECA 35: In Europe the band 75,5-76 GHz is also allocated to the Amateur and Amateur Satellite services.

- RR5.149: In making assignments to stations of other services to which the bands:…, 76-86 GHz, … are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

- RR5.559B: The use of the frequency band 77,5-78 GHz by the radiolocation service shall be limited to short-range radar for ground-based applications, including automotive radars. The technical characteristics of these radars are provided in the most recent version of Recommendation ITU-R.M.2057 [i.22]. The provisions of No. 4.10 do not apply. (WRC-15)

- RR5.560: In the band 78-79 GHz radars located on space stations may be operated on a primary basis in the earth exploration-satellite service and in the space research service.

- RR5.561: In the band 74-76 GHz, stations in the fixed, mobile and broadcasting services shall not cause harmful interference to stations of the fixed-satellite service or stations of the broadcasting-satellite service operating in accordance with the decisions of the appropriate frequency assignment planning conference for the broadcasting-satellite service. (WRC-2000)

When analysing the information provided in table C.1, the following deductions could be made:

1) The band 77-81 GHz immediately appears as the most problematic one in terms of potential coexistence with existing applications, because it had been designated for harmonised European use by automotive Short Range Radars according to CEPT Decision ECC/DEC(04)03 [i.8] and corresponding EU legislation. These stipulate provisions for deploying Short Range Radar applications on road vehicles as means of collision warning technologies with transmit power of up to 55 dBm/4 GHz or -3 dBm/MHz e.i.r.p. Given already significant and ever-growing proliferation of collision avoidance technologies on road vehicles, and the observation that in most HD-GBSAR use scenarios it would be likely to come in close proximity with road transport movements, it would be logical to infer that HD-GBSAR operation in 77-81 GHz would result in permanent and significant risk of impact from automotive Short Range Radars with no possibility to assume any geographic separation at all.

2) Less extreme but similar coexistence prospects would exist in the band 76-77 GHz which is designated for Transport and Traffic Telematics applications (see annexes 4 and 5 of ERC/REC 70-03 [i.2]), such as long range radars used in automotive scenarios and rail road infrastructure. Along with automotive/road side infrastructure, this band is also designated for proximity alert radars used by rotor crafts. This use by numerous transport systems and roads infrastructure would make achieving any geographical separation of HD-GBSAR operations in many of its intended use scenarios highly risky and unpredictable.

Considering the above, it may be concluded that the primary and most promising candidate band for HD-GBSAR operations should be found in the lower part of the target range, i.e. between 74-76 GHz. Furthermore, it would appear logical to initially focus on the lower half of that band, i.e. 74-75 GHz. This is because the band 75-76 GHz is part of frequency tuning range 75-85 GHz designated by ECC/DEC(11)02 [i.10] for Level Probing Radars, which is another professional radar technology based SRD application intended for use in industrial environments. Level Probing Radars are generally considered to be well suited for sharing with other applications, due to their strictly downwards pointing emissions, and thus significant mitigation of interference thanks to antenna discrimination. Nevertheless, the use of two identical radar technology applications in similar and possibly overlapping industrial environments (dams monitoring being the most obvious example where both Level Probing Radars and HD-GBSAR may need to operate side by side for long periods of time) may give rise to unnecessary concerns due to potential inability to ensure any reasonable spatial separation. By completely avoiding the band 75-75,5 GHz the HD-GBSAR would side step the risk of interference with Level Probing Radars.

In such manner the proposed designation of the band 74-75 GHz for HD-GBSAR would logically complement and complete the overall harmonised shared use of the frequency range 74-81 GHz by SRD radiodetermination applications:

- 74-75 GHz: HD-GBSAR applications (*proposed*);

- 75-76 GHz (part of tuning range 75-85 GHz): (Tank) Level Probing Radar applications;

- 76-77 GHz: Ground based vehicle and fixed Transport and Traffic Telematics surveillance radar applications;

- 76-77 GHz: Rotorcrafts' proximity radar applications; and

- 77-81 GHz: Automotive Short Range Radar applications.

Annex D:
Preliminary spectrum sharing feasibility analysis

D.0 General

As was shown in table C.1, based on available information from the European Frequency Allocation Table and the CEPT's ECO Frequency Information System (EFIS) [i.9], the band 74-75,5 GHz is today intended to be used by the following typical applications:

- Space Research;
- Radiodetermination applications;
- Fixed.

The remainder of this annex will review the details of use and sharing prospects of proposed HD-GBSAR designation vis-à-vis other identified users of this band.

D.1 Sharing feasibility with Space Research

Although there is an indication in EFIS of possible use of the band 74-75,5 GHz by Space Research services, the desk research of relevant regulatory and informational sources did not allow to identify any current or potential usage of this band by Space Research services in terms of any passive or active observation or sensing applications.

More specifically, the frequencies within 74-75,5 GHz band **are not listed** among frequencies of interest to research communities in key reference sources on the subject:

- Recommendation ITU-R RA.314-10 (06/2003) "Preferred frequency bands for radio astronomical measurements" [i.18];
- Recommendation ITU-R RS.515-5 (08/2012) "Frequency bands and bandwidths used for satellite passive remote sensing" [i.19];
- Recommendation RS.577-7 (02/2009) "Frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite (active) and space research (active) services" [i.20];
- Recommendation ITU-R RS.2064-0 (12/2014) "Typical technical and operating characteristics and frequency bands used by space research service (passive) planetary observation systems" [i.21].

The only information on any usage of frequencies in 74-75,5 GHz for science applications is a listing of 74-84 GHz band being possibly used as a secondary service identification in support role for 10 GHz wideband transmission of VLBI-generated telemetry data and time/phase reference signals in the space-to-Earth direction in accordance with provisions of Recommendation ITU-R SA.1344-1 (02/2009) [i.11]. Albeit this represents a radiocommunication application in support of science operations, clearly in terms of type of radiocommunication system, this use would be akin to satellite telecommunication service transmission link from space platform to an Earth Station receiver. Accordingly, any ground-based reception of a strong actively generated telecommunication signal transmissions would be carried out using highly directional antenna by one/few dedicated Earth Stations.

Investigation of data on European radio astronomy stations listed by the Committee on Radio Astronomy Frequencies (CRAF) [i.6] allowed to identify only three space observatories which operational ranges cover the band 74-75,5 GHz:

- France: NOrthern Extended Millimeter Array observatory, located in the French Alpes on the wide and isolated Plateau de Bure at an elevation of 2 550 m (Latitude 44°38'01" N, Longitude 05°54'26" E);
- Spain: Pico Veleta IRAM 30m telescope, located in the Spanish Sierra Nevada, at an altitude of 2 850 m (Latitude 37°03'58" N, Longitude 03°23'34" W);
- Sweden: Onsala radio observatory (OSO), located 45 km south of Göteborg, Sweden (Latitude 57°23'45" N, 11°55'35" E).

It may be therefore reasonably assumed that any possible mutual signal coupling along the surface of the Earth between HD-GBSAR transmitter and space observatory/Earth Station receiver would be sufficiently mitigated thanks to discrimination by two highly directional antennas used on both sides and the location of space observatories in distant non-industrial areas.

D.2 Sharing feasibility with Radiodetermination applications

Analysis of data provided in the EFIS [i.9] database, use of the band 74-75,5 GHz by the Radiodetermination applications entails only the deployment of industrial Level Probing Radars according to provisions established by the ECC/DEC(11)02 [i.10]. In accordance with this ECC Decision, the band 75-85 GHz is designated as a tuning range for industrial Level Probing Radar applications.spec

As was discussed in annex C, by limiting the designated frequency band for HD-GBSAR to 74-75 GHz, this would completely avoid any risk of interference to Level Probing Radars.

D.3 Fixed Service in 71-76 GHz band

The band 71-76 GHz is intended to be used by high bitrate/high bandwidth FS links, normally as one of go-return parts of duplex arrangements with the corresponding band 81-86 GHz. The designation of this band for FS is given in ECC/REC/(05)07 [i.12].

According to the latest available information on band utilization obtained from ECC Report 173 [i.13], the actual uptake in deployment of FS links in this band was very modest with less than 200 links reported across all of 31 CEPT countries that responded to questionnaire at the time. The typical link length was reported to be between 1-2 km.

Based on analysis of information in ETSI EN 302 217-2 [i.14], annex J, it may be suggested that the following average values of key RF parameters may be used to represent a typical FS link in this band, assuming equipment spectral efficiency class 4L, i.e. 2 Gbps capacity link:

- Operational Receive Signal Level threshold for BER<10^{-6}: -52,5 dBm for 1 000 MHz channel;
- Required minimum C/I for co-channel interference @ 3 dB Received Signal Level degradation: 23 dB;
- Minimum antenna gain: 38 dBi.

As regards to the FS antenna's Radiation Pattern Envelope, it may be suggested to use Antenna Class 2 pattern given in ETSI EN 302 217-4 [i.15], figure 38, which is recaptured below in figure D.1 for easy reference.

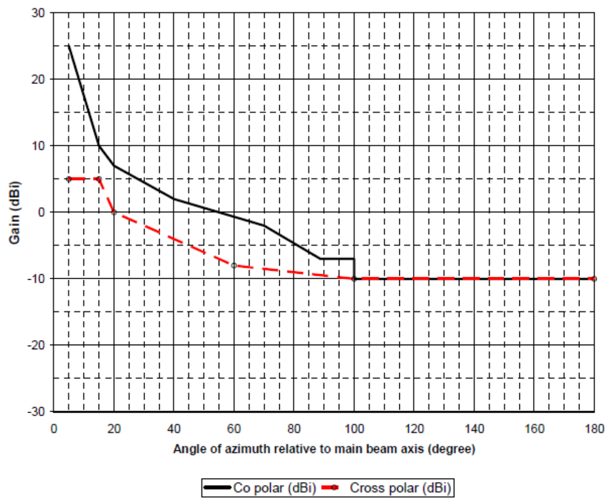


Figure D.1: Representative Radiation Pattern Envelope of FS antenna in 71-76 GHz

When considering typical FS point-to-point link installation scenarios vis-à-vis HD-GBSAR use cases, it may be deduced that a worst-case interference scenario may occur in cases like when an FS terminal is installed on rooftop of a building that is monitored for structural health by a HD-GBSAR, as illustrated in figure D.2.

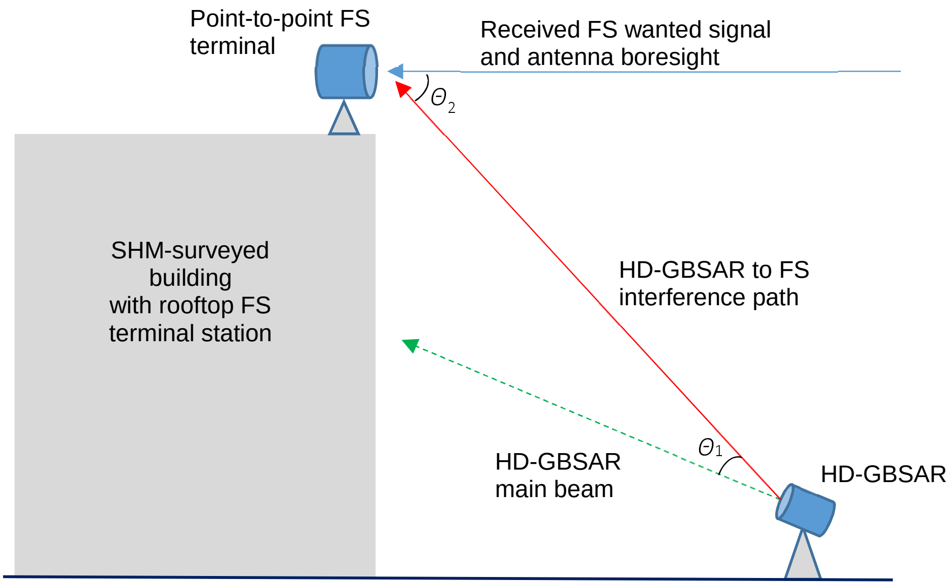


Figure D.2: Representative worst-case scenario of HD-GBSAR to FS interference (V-plane only)

When considering the depicted scenario, it becomes clear that the risk of interference depend on composite of probability of mutual alignment of FS vs. HD-GBSAR antennas as well as separation distance between the two transceivers. These two different aspects could be considered separately by looking at sharing scenario geometry factors in respectively vertical and horizontal planes.

The vertical plane of the HD-GBSAR vs. FS coexistence corresponds exactly to scenario geometry depicted in figure D.1. In order to proceed with this analysis, it is necessary to make some assumptions as to what could be considered a reasonable geometric configuration of such possible real-life placement. It is also important to strive for some balanced representation, i.e. not exaggerating either most unfavourable nor most favourable, coexistence wise, geometric placement. Naturally, any real-life placement situation will be different from whatever is assumed in this hypothetical scenario, however making geometry balanced would suggest a certain averaging of interference risk. It is accordingly proposed to make following assumptions regarding geometric configuration of the above considered scenario:

- Building height (correspondingly FS height above ground) of at least 20 m, as any lower building would not be suggestive to become candidate for installation of point-to-point FS link terminal, which requires direct line-of-sight to corresponding terminal at the other end of the FS link. Even if in some cases the installation height might be lower, then it would likely imply FS terminal antenna installation with upward tilt, which would balance out the overall antenna discrimination geometry;

- In continuation of above logic, the FS terminal antenna tilt is considered 0 degrees, corresponding to geometry of short distance link between terminals mounted at approximately similar height;

- HD-GBSAR positioned at 20 m from the building allowing good frontal coverage of the entire building, accordingly the HD-GBSAR antenna is pointed at the geometric centre of the surveyed building. Closer location of HD-GBSAR to the building may be actually minimizing risk of interference as it might be assumed that closer positioning would minimize the risk of LOS condition to FS terminal as it may be positioned (which is indeed often the case) not directly on the roof edge.

Provided the above assumptions, the corresponding antenna pointing angles in vertical plane would be:

- HD-GBSAR antenna off-set angle towards FS terminal:

$$\theta_1 = \tan^{-1}\left(\frac{10\ m}{20\ m}\right) \cong 27°$$

- FS terminal antenna off-set angle towards HD-GBSAR interference source:

$$\theta_2 = \tan^{-1}\left(\frac{20\ m}{20\ m}\right) = 45°$$

Matching the FS antenna off-set angle with radiation pattern envelope depicted in figure D.1, it is possible to suggest FS antenna gain towards interferer of around 2 dBi, corresponding to antenna gain discrimination of -36 dB for FS antenna with minimum gain of 38 dBi as specified in ETSI EN 302 217-2 [i.14], Annex J.

Assuming similar horn antenna design for the HD-GBSAR antenna and thus referring to the same radiation pattern in figure D.1, the off-set angle on HD-GBSAR antenna would mean around 5 dBi gain in the direction of victim, corresponding to -19 dB antenna discrimination for 24 dBi gain antenna as per table 1 specifications.

Table D.1 provides MCL verification of minimum required separation distance for complete avoidance of interference from HD-GBSAR to FS.

Table D.1: MCL calculation of separation distance between HD-GBSAR and FS in static V-plane scenario

#	Calculation parameter	Calculation formula	Value
A	Frequency, GHz		74
B	Proposed TX max power, EIRP, dBm		48
C	TX antenna max gain, dBi		24
D	TX antenna gain towards victim, dBi		5
E	TX channel BW, MHz		1 000
F	Victim RX channel BW, MHz		1 000
G	Victim RX antenna gain towards interferer, dBi		2
H	Victim operational RSL, dBm		-52,5
I	Victim required C/I, dB		23
J	**RX interference threshold, dBm**	**H-I**	**-75,5**
K	**BW correction factor, dB**	**10xLOG10(F/E)**	**0,0**
L	**Minimum Coupling Loss, dB**	**B-C+D+G+K-J**	**106,5**
M	**Minimum Separation Distance (LOS), m**	**POWER(10, (L-32,5-20*LOG10(A))/20)**	**67,7**

The estimated required minimum separation distance of approximately 70 m is larger than the separation distance that was assumed for this static vertical plane scenario, which means that there would be a risk of interference in such scenario. How big is that risk may be considered by looking at probability of HD-GBSAR vs FS antennas alignment in horizontal plane, as depicted in figure D.3.

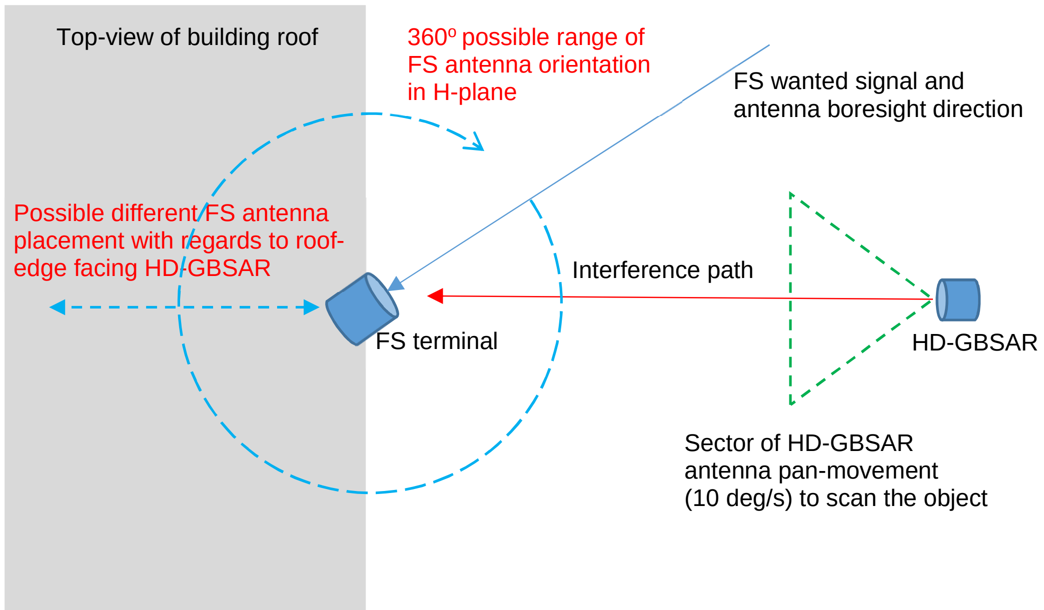


Figure D.3: HD-GBSAR to FS interference scenario in H-plane

Depiction of interference scenario in H-plane make it obvious that even in case of operating HD-GBSAR in close proximity to building/structure with mounted FS antenna, the actual probability of interference occurring will be low due to several mitigating factors:

- The probability of antennas to be in direct alignment in H-plane is very low, i.e. probability of *FS antenna pointing towards HD-GBSAR* would be 1/360;
- The above probability would be further reduced if considering that probability of *HD-GBSAR antenna pointing towards FS* would be much less than 1 even for static scenario. Furthermore, HD-GBSAR would be typically operated in constant panoramic movement scanning the entire defined front of the surveyed object at a speed of 10 deg/s (see annex B);
- Similarly, as for the V-plane scenario, it should be considered that the FS antenna may be mounted further from the edge of the roof, which would mean additional knife-edge attenuation on interference path or even complete avoidance of LOS condition which would fully eliminate any risk of interference.

In summary, it may be concluded from above analysis that although there would exist a certain risk of interference from HD-GBSAR to FS terminals operating in the band 71-76 GHz, the probability of such occurrence would be extremely low.

On operational side it may be also noted that such occurrence would only be possible in case of FS terminal being mounted on the same building/object which is surveyed by the HD-GBSAR. This would mean that the building owner, i.e. the one allowing placement and operation of both devices on their facility, would be aware of reasons in case of interference occurrence and could address/resolve the situation accordingly and instantly, i.e. by requesting HD-GBSAR surveyor to change placement of HD-GBSAR system.

History

Document history		
V1.1.1	August 2018	Publication