ECC REPORT 111

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY STUDIES BETWEEN GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR) AND EXISTING SERVICES IN THE RANGE 17.1 GHz TO 17.3 GHz

Budapest, September 2007

0 EXECUTIVE SUMMARY

This report considered compatibility between proposed Ground Based Synthetic Aperture Radar (GBSAR) applications operating in the frequency range 17.1 – 17.3 GHz and other services operating in this frequency range:

- Radiolocation Service (RL)
- Earth Exploration Satellite Service (EESS)

Compatibility between GBSAR and RL systems is almost achieved. The GBSAR antenna pattern (as given in Figure 1) ensures such compatibility for high elevation angles. Nevertheless, the calculations show also that some interference may occur in unlikely situations where the GBSAR device main beam crosses the RL main beam. In that case, it is proposed to implement a spectrum access technique such as Detect And Avoid (DAA), as specified in section 4.2.3.

Compatibility is achieved between GBSAR and EESS when GBSAR used the antenna pattern defined in Figure 1.

List of abbreviations

Abbreviation	Explanation
CEPT	European Conference of Postal and Telecommunications Administrations
CW	Continuous Wave
DAA	Detect And Avoid
ECC	Electronic Communications Committee of CEPT
EESS	Earth Exploration Satellite Service
e.i.r.p.	Equivalent isotropically radiated power
ETSI	European Telecommunications Standards Institute
GBSAR	Ground Based Synthetic Aperture Radar
IF	Intermediate Frequency
IQ	In-phase Quadrature
ITU	International Telecommunication Union
ML	Main Lobe
NF	Receiver Noise Figure
NWP	Numerical Weather Prediction
PCPG	Pulse Compression Processing Gain
PL	Propagation Loss
RL	Radiolocation Service
SAR	Synthetic Aperture Radar
SF-CW	Step Frequency Continuous Wave
SL	Side Lobe
SNR	Signal to Noise Ratio
SR	Surveillance Radar
SRD	Short Range Devices

Table of Contents

Compatibility studies between Ground Based Synthetic Aperture Radar (GBSAR) and existing services in the range 17.1 GHz to 17.3 GHz

1 INTRODUCTION

This report deals with the impact of Ground Based Synthetic Aperture Radar (GBSAR), based on Stepped Frequency CW (SF-CW) radar technology, operating in the frequency range 17.1 GHz to 17.3 GHz on the services operating in this frequency range.

GBSAR system is used for detection of movement and its scope is limited to radar equipment operated as a short range device. The GBSAR applications considered in the present document are intended exclusively for detection of movement related to safety of structures potentially affecting the protection of workers and the general public. A few examples of applications are given below:

- static and dynamic load analyses of constructions like bridges and buildings;
- landslide monitoring;
- volcano and earthquake movement detection;
- urban area subsidence detection.

2 CURRENT FREQUENCY ALLOCATION

The current ITU-R allocations [1] for the proposed spectrum for GBSAR applications are shown in the Table 1 below.

Table 1: Current ITU-R allocations

Allocation to services		
Region 1	**Region 2**	**Region 3**
17.1-17.2	RADIOLOCATION 5.512 5.513	
17.2-17.3	EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION SPACE RESEARCH (active) 5.512 5.513 5.513A	

5.512 *Additional allocation:* in Algeria, Angola, Saudi Arabia, Austria, Bahrain, Bangladesh, Bosnia and Herzegovina, Brunei Darussalam, Cameroon, the Congo, Costa Rica, Egypt, El Salvador, the United Arab Emirates, Finland, Guatemala, India, Indonesia, Iran (Islamic Republic of), Jordan, Kuwait, Libya, Malaysia, Morocco, Mozambique, Nepal, Nicaragua, Oman, Pakistan, Qatar, Singapore, Slovenia, Somalia, Sudan, Swaziland, Tanzania, Chad, Yemen and Yugoslavia, the band 15.7-17.3 GHz is also allocated to the fixed and mobile services on a primary basis. (WRC-97)

5.513 *Additional allocation:* in Israel, the band 15.7-17.3 GHz is also allocated to the fixed and mobile services on a primary basis. These services shall not claim protection from or cause harmful interference to services operating in accordance with the Table in countries other than those included in No. **5.512**.

5.513A Spaceborne active sensors operating in the band 17.2-17.3 GHz shall not cause harmful interference to, or constrain the development of, the radiolocation and other services allocated on a primary basis. (WRC-97)

It has to be noted that ERC Rec. 70-03 Annex 3 identifies the band 17.1-17.3 GHz for wideband data transmission. However due to the lack of information, compatibility studies relating to these systems were not developed in this report.

3 DESCRIPTION OF GBSAR SYSTEMS

The GBSAR is using a SF-CW radar technique and is used for a wide range of applications for detection of movement (structure or terrain monitoring).

3.1 Market information

It is forecasted that the deployment density of the GBSAR systems may be up to 0.6-6 units/1 000 km^2 for structure and terrain monitoring respectively. For detailed market information, see annex A.

3.2 GBSAR technical system description

A GBSAR system exploits, as do earth monitoring satellites, interferometric analysis and SAR techniques to provide displacement maps for terrain or structure monitoring applications. In particular:

- the interferometric technique provides data on object displacement by comparing phase information, collected in different time periods, of reflected waves from the object, providing a measure of the displacement with an accuracy of less than 1 mm;

- the SAR technique enables the system to provide high resolution images. High range resolution is obtained using large transmitted bandwidth whereas high cross range resolution is derived, only for the terrain monitoring applications, exploiting the movement of the physical antenna along a straight trajectory.

The GBSAR system is based on a SF-CW coherent radar technology that transmits, step by step, continuous waves at discrete frequency values. By this method, interference mitigation is offered as the transmission is only on for a short time at each discrete frequency.

It is important to observe that the transmitted signal is a sequence of non-modulated CWs, whose total frequency range (bandwidth), is controlled by the equipment management system. The bandwidth can be adjusted between 100 MHz and 200 MHz when required by the measurement.

For detailed technical information on GBSAR, see Annex A.

3.3 Characteristics of GBSAR

The main technical characteristics of GBSAR system are summarized in **Table 2** (see also [2]).

Parameter	**Value**
Signal type	SF-CW
Centre frequency (f_0)	17.200 GHz
Frequency range (Bandwidth)	100/200 MHz
Frequency step increment	30 - 300 kHz
Dwell time duration T_{dw}	3,3 - 33 µs
Radiated power, e.i.r.p.	26 dBm
Antenna height from ground	1 m
Mobility type	Nomadic system

Table 2: GBSAR system technical characteristics

The antenna pattern of the GBSAR antenna is shown in Figure 1.

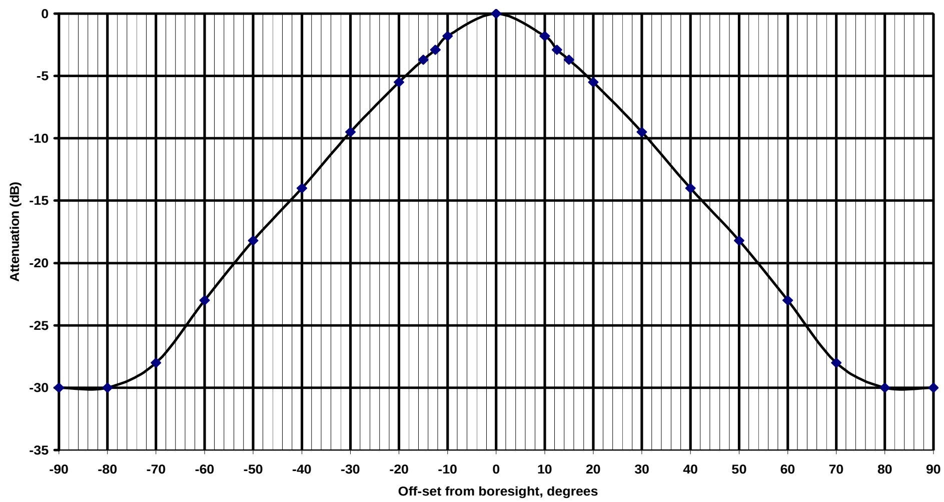

Figure 1: GBSAR Antenna pattern

4 COMPATIBILITY BETWEEN GBSAR AND RADIOLOCATION SYSTEMS

The study used different characteristics of radiolocation systems (RL) for the first three types of systems as provided in the ITU-R Recommendation M.1730 [3]. In addition to the above characteristics, the characteristics of one additional ground radar type used as Surveillance Radar (SR) were considered (System 4 in Table 3).
Where relevant, compatibility analysis in this report between GBSAR and Radiodetermination is based on Recommendation ITU-R M.1461-1 [4].

It has to be noted that no protection is requested by GBSAR from Radiolocation systems.

4.1 Characteristics of the Radiolocation Service

The band 15.7-17.3 GHz is used by many different types of radars including land-based, transportable, shipboard and airborne platforms. Radiolocation functions performed in the band include airborne and surface search, ground-mapping, terrain-following, maritime and target-identification. Radar operating frequencies can be assumed to be uniformly spread throughout each radar’s tuning range.

Table 3 contains technical characteristics of representative radiolocation radars deployed in the 15.7-17.3 GHz band. The major radiolocation radars operating in this band are used for detection of airborne objects and some are used for ground mapping. They are required to measure target altitude, range, bearing and form terrain maps. Some of the airborne and ground targets are small and some are at ranges as great as 300 nautical miles (556 km), so these radiolocation radars must have great sensitivity and must provide a high degree of suppression to all forms of clutter return, including that from sea, land and precipitation.

Recommendation ITU-R M.1730 [3] provides also a protection criterion based on I/N = -6dB.

Characteristics	System 1	System 2	System 3	System 4
Function	Search, track and ground-mapping radar (multi-function)		Air surveillance, landing aid, track while scan	Surveillance Radar
Platform type	Airborne, low power	Airborne, high power	Shipboard, high power	Ground
Tuning range (GHz)	16.2-17.3	16.29-17.21	15.7-17.3	16,8-17,3
Modulation	Variable linear FM	Linear FM pulse	Frequency hopping	Linear FM pulse
Transmit peak power (W)	80	700	20 k	40
Pulse width (µs)	18.2; 49	120-443	0.1	17
Pulse repetition rate (pps)	5 495; 2 041	900-1 600	4 000; 21 600	3140-5630
Antenna gain (dBi)	25.6	38.0	43.0	38
Antenna horizontal scan rate	30 degrees/s	5 degrees/s	1 500 scans/min	24 degrees/s
Antenna horizontal scan type (continuous, random, sector, etc.)	±45º to ±135º (mechanical)	±30º (electronic, conical)	±40º (mechanical)	Continuous or sector
Antenna vertical scan rate	30 degrees/s	5 degrees/s	1 500 scans/min	Automatic elevation tracking
Antenna vertical scan type	–10º to –50º (mechanical)	0º to –90º (electronic, conical)	+30º/–10º (mechanical)	-6.5° (manual tilt)
Antenna height	Aircraft altitude	Aircraft altitude	Mast/deck mount	6m
1st/2nd receiver IF –3 dB bandwidths (MHz)	215/68	26.7 (wideband); 7.2 (narrow-band)	70/40	3
Receiver noise figure (dB)	4	2.7	Not specified	5
Minimum discernible signal (dBm)	–89	–97.4	–80	-95
Chirp bandwidth (MHz)	640	1200	30	3

Table 3: Characteristics of radiolocation radars in the 15.7-17.3 GHz band

4.2 Compatibility studies

The initial step in assessing compatibility is the determination of the signal level at which the receiver performance starts to degrade, I_T.

$$I_T = I/N + N \qquad (1)$$

where:

I/N : interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria (dB)

N :receiver inherent noise level (dBm)

($N = -144$ dBm + 10 log B_{IF} (kHz) + NF

where:

B_{IF} : receiver IF bandwidth (kHz)

NF : receiver noise figure (dB)

The following equation can be used to determine whether interference to radar's transmissions is likely to occur when GBSAR devices operate:

$$I = P_{GBSAR} + G_{GBSAR} + G_{RL} - SL_{GBSAR} - SL_{RL} - PL \qquad (2)$$

where:

I :Interference (peak power of the radar pulses at the receiver) (dBm)

P_{GBSAR} : Conducted power of the GBSAR device (dBm)

G_{GBSAR} : main beam antenna gain of the GBSAR device (dBi)

G_{RL} : receiver antenna gain in the direction of the radar station under analysis (dBi)

PL : propagation path loss between transmitting and receiving antennas (dB)

SL_{GBSAR}: sidelobe attenuation of the GBSAR antenna

SL_{RL}: sidelobe attenuation of the radar station antenna

It should be noted that free-space propagation model is used except for ground propagation where the losses, PL are limited to the extent of the optical visibility since it is unlikely that ground wave ducting will occur for this frequency band. Therefore, for the latter case the propagation losses are limited to $\sqrt{2R_T h}$ (in km) where RT is the radius of the earth (6378 km) and *h* the altitude over the sea level of the interferer, also in km.

Finally, the estimation of PL leads to a needed separation distance that will prevent any radar from suffering interference coming from GBSAR devices.

4.2.1 Single entry case interference

A single entry case is calculated in Table 4. The calculations within the side lobes of the radar are given for a 0 dBi antenna gain.

LINK BUDGET: Impact of GBSAR on radiolocation systems	Value	Units	RL System 1	RL System 2	RL System 3	RL System 4
Emission part: GBSAR						
Bandwidth	100.00	MHz				
Tx out, e.i.r.p.	26.00	dBm				
Tx Out e.i.r.p. per MHz	6.00	dBm/MHz	6	6	6	6.00
Antenna Gain	20.00	dBi	20.00	20.00	20.00	20.00
Frequency (GHz)	17.20	GHz	17.20	17.20	17.20	17.20
Reception part: Radar						
Function			Airborne		Maritime	SR
Radar type			1	2	3 (Note 1)	4 (Note 1)
Tx power into antenna peak		W	80.00	700.00	20000.00	40.00
Receiver IF3dB bandwidth MHz		MHz	215.00	27.00	70.00	3.00
Antenna mainbeam gain		dBi	25.60	38.00	43.00	38.00
Antenna height			Aircraft altitude		Deck mount	Ground
		m	12000	12000	15.00	6.00
Radar feeder loss		dB	0.00	0.00	0.00	0.00
e.i.r.p radar		dBm	74.63	96.45	116.01	84.02
Receiver noise figure		dB	4.00	2.70	3.00	5.00
N=FkTB		dBm	-86.70	-97.00	-92.50	-104.23
N per MHz		dBm/MHz	-110.02	-111.31	-110.95	-109.00
Protection criterion, I/N		dB	-6.00	-6.00	-6.00	-6
MAIN LOBE GBSAR to MAIN LOBE RL						
Sidelobe attenuation (dB)		dB	0	0	0	0
Separation distance GBSAR to Radar		m	**33398**	**161503**	**13833**	**8748**
MAIN LOBE GBSAR to SIDE LOBE RL						
Sidelobe attenuation (dB)		dB	25.60	38.00	43.00	38.00
Separation distance GBSAR to Radar		m	**1747**	**2029**	**1961**	**1557**
SIDE LOBE GBSAR to MAIN LOBE RL						
Sidelobe attenuation (dB)	30	dB	30	30	30	30
Separation distance GBSAR to Radar		m	**1053**	**5098**	**8758**	**3912**
SIDE LOBE GBSAR to SIDE LOBE RL						
Sidelobe attenuation (dB)		dB	55.6	68	73	68
Separation distance GBSAR to Radar		m	**55**	**64**	**62**	**49**

Table 4: Interference analysis

Note 1: Free space propagation model is used for RL types 3 and 4 as an initial indicator. The Propagation model given in Recommendation ITU-R P.452 [5] is useful for all calculations between stations on the surface of the Earth. Nevertheless, at 17 GHz, it is unlikely that any additional propagation phenomena will occur. In that case, only 'Line of sight' PL will remain. Therefore, the propagation model in ITU-R P.452 will be reduced to be the same as free space propagation model. Range will be limited by the optical visibility to 14 km for a radar with antenna height of 15 m (respectively 8.7 km for antenna height of 6 m).

It can be seen that GBSAR device can be compatible with the RL systems 1, 2 and 4 if antenna gain values for high elevation angles are lower than the maximum antenna gain. The high separation distance for the RL system 3 can be explained due to its antenna gain (at least 5 dB higher). The impact created by side lobes is negligible since the altitude of aircraft will be higher than these estimated separation distances.

In addition, Recommendation ITU-R M.1730 [3] stated that for advanced RL systems "frequency hopping mechanism ... should be taken into account in sharing studies".

Advanced signal processing techniques in the newer generation of radars uses chirped and phase coded pulses used for pulse compression which provide a pulse compression processing gain *PCPG* for the desired signal and may also suppress undesired signals:

$$PCPG = 10Log(B.T) \quad (3)$$

where:

PCPG is the processing gain of the pulse compression algorithm
T is the radar pulse width in microseconds
B is the radar chirp bandwidth in MHz

PCPG leads to revised protection distances as provided in
Table 5.

Advanced RL systems						
Pulse width		µs	49	443	0.1	17
Chirp Bandwidth		MHz	640	1200	30	3
Processing gain		dB	**44.96**	**57.26**	**4.77**	**17.08**
MAIN LOBE GBSAR to MAIN LOBE RL						
Required Attenuation (dB)		**dB**	**-103**	**-104**	**-161**	**-142**
Separation distance GBSAR to Radar		**m**	**188**	**221**	**13833**	**8748**
MAIN LOBE GBSAR to SIDE LOBE RL						
Required Attenuation (dB)		**dB**	**-77**	**-66**	**-118**	**-104**
Separation distance GBSAR to Radar		**m**	**10**	**3**	**1132**	**218**
SIDE LOBE GBSAR to MAIN LOBE RL						
Required Attenuation (dB)		**dB**	**-73**	**-74**	**-131**	**-112**
Separation distance GBSAR to Radar		**m**	**6**	**7**	**5056**	**548**
SIDE LOBE GBSAR to SIDE LOBE RL						
Required Attenuation (dB)		**dB**	**-47**	**-36**	**-88**	**-74**
Separation distance GBSAR to Radar		**m**	**0**	**0**	**36**	**7**

Table 5: Interference analysis with advanced RL systems

4.2.2 Impact of the elevation angle of GBSAR

A semi dynamic analysis is provided in this section using the pattern of the GBSAR antenna shown in section 3.3 (Figure 1). It consists in studying the impact of elevation angle of the GBSAR device on the needed separation distance from radar types 1, 2, 3 and 4.
The scenario can be depicted by the following drawing:

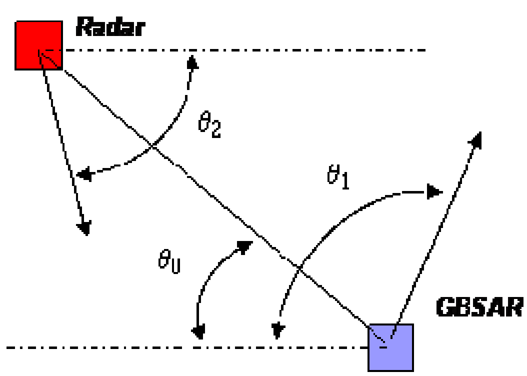

Figure 2: Evaluation of interference by GBSAR

where:

- θ_0: Elevation angle of the radar from the GBSAR view (victim elevation)
- θ_1: Elevation angle of the main beam of the GBSAR device

- θ_2: Elevation angle of the main beam of the radar device

The different scenarios to be investigated are summarized in **Table 6**.

Interferer	Victim	Context	Scenario
ML GBSAR	ML RL	$\theta_2=\theta_1=\theta_0$	*S1*
ML GBSAR	SL RL	$\theta_1=\theta_0$ and $\theta_2\neq\theta_0$	*S2*
SL GBSAR	ML RL	$\theta_1\neq\theta_0$ and $\theta_2=\theta_0$	*S3*
SL GBSAR	SL RL	$\theta_1\neq\theta_0$ and $\theta_2\neq\theta_0$	*S4*

Table 6: Scenarios

The original calculations provided in Table 4 are here expanded to include a stepwise increase of the GBSAR antenna elevation θ_1 for radar type 1. Other results are provided in Annex B for the three other types of radars but lead to the same order of results. These calculations include antenna elevations of 0, 20, 40, 60, 80 and 90 degrees. The calculations are shown in **Table 7** below for different interference assessment.

Reception part: Radar								
Function			**Airborne**					
Radar type			**1**	**1**	**1**	**1**	**1**	**1**
Tx power into antenna peak		W	80	80	80	80	80	80
Receiver IF3dB bandwidth MHz		MHz	215	215	215	215	215	215
Antenna mainbeam gain		dBi	26	26	26	26	26	26
Antenna sidelobe attenuation		dB	16	16	16	16	16	16
Antenna height		m	Aircraft altitude					
Antenna height		m	12000	12000	12000	12000	12000	12000
Radar feeder loss		dB	0.00	0.00	0.00	0.00	0.00	0.00
E.i.r.p radar		dBm	74.63	74.63	74.63	74.63	74.63	74.63
Receiver noise figure		dB	4.00	4.00	4.00	4.00	4.00	4.00
N=FkTB		dBm	-86.68	-86.68	-86.68	-86.68	-86.68	-86.68
N per MHz		dBm/MHz	**-110.00**	**-110.00**	**-110.00**	**-110.00**	**-110.00**	**-110.00**
Protection criterion, I/N		dB	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00
MAIN LOBE GBSAR to MAIN LOBE RL	*Scenario S1*							
Separation distance GBSAR to Radar		**m**	**33295**					
MAIN LOBE GBSAR to SIDE LOBE RL	*Scenario S2*		0					
Separation distance GBSAR to Radar		**m**	**1747**					
SIDE LOBE GBSAR to MAIN LOBE RL	*Scenario S3*	$Theta_0$	0	20	40	60	80	90
Ant elevation (click on + to access details)	*q_1*							
Required attenuation (click on + to access details)	*Att(q_1- q_0)*							
Separation distance GBSAR to Radar	**$Theta_1$=0°**	**(m)**	**33295**	**17676**	**6643**	**2357**	**1053**	**1053**
Separation distance GBSAR to Radar	**$Theta_1$=20°**	**(m)**	**17676**	**33295**	**17676**	**6643**	**2357**	**1326**
Separation distance GBSAR to Radar	**$Theta_1$=40°**	**(m)**	**6643**	**17676**	**33295**	**17676**	**6643**	**4096**
Separation distance GBSAR to Radar	**$Theta_1$=60°**	**(m)**	**2357**	**6643**	**17676**	**33295**	**17676**	**11153**
Separation distance GBSAR to Radar	**$Theta_1$=80°**	**(m)**	**1053**	**2357**	**6643**	**17676**	**33295**	**27063**
SIDE LOBE GBSAR to SIDE LOBE RL	*Sceanrio S4*	$Theta_0$	0	20	40	60	80	90
Required attenuation (click on + to access details)	*Att(q_1- q_0)*							
Separation distance GBSAR to Radar	**$Theta_1$=0°**	**(m)**	**1747**	**928**	**349**	**124**	**55**	**55**
Separation distance GBSAR to Radar	**$Theta_1$=20°**	**(m)**	**928**	**1747**	**928**	**349**	**124**	**70**
Separation distance GBSAR to Radar	**$Theta_1$=40°**	**(m)**	**349**	**928**	**1747**	**928**	**349**	**215**
Separation distance GBSAR to Radar	**$Theta_1$=60°**	**(m)**	**124**	**349**	**928**	**1747**	**928**	**585**
Separation distance GBSAR to Radar	**$Theta_1$=80°**	**(m)**	**55**	**124**	**349**	**928**	**1747**	**1420**

Table 7 : Expanded calculations (for radar 1)

Whatever the elevation angle θ_1 of the GBSAR device, the greatest separation distance is given for a victim elevation angle θ_0 equal to θ_1. Separation distances decrease for all other elevation angles due to the lower antenna gain. The figure below depicts such evolution for a GBSAR antenna elevation of 60°. Some further figures may be found in annex B for other antenna elevation angles, but the shape still remains the same.

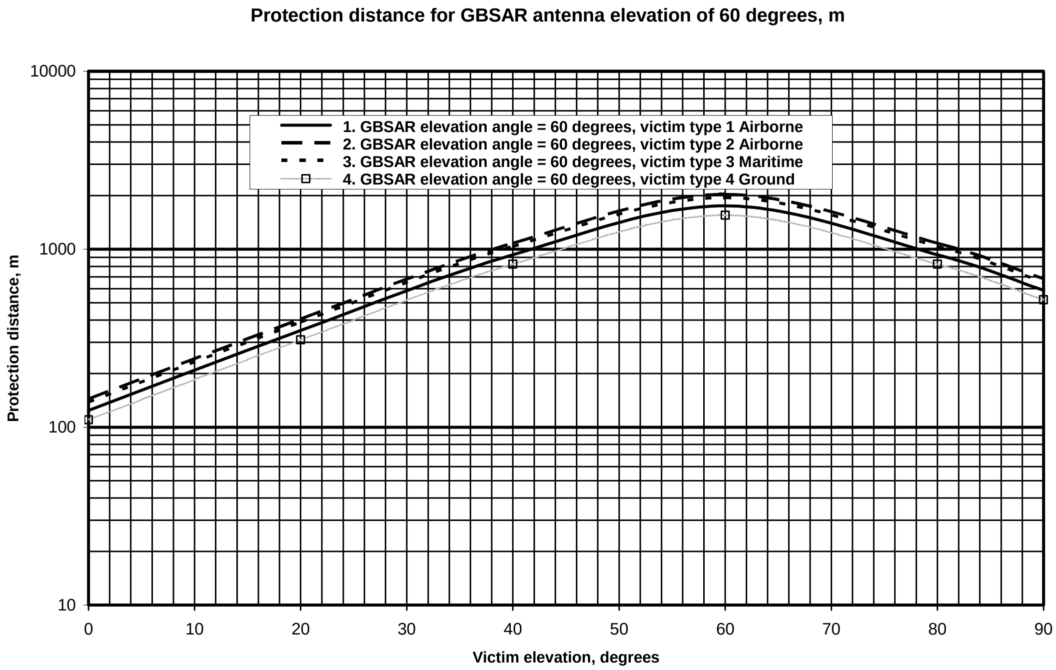

Figure 3: Protection distance for GBSAR antenna elevation of 60 degrees

Therefore, it can be concluded that GBSAR may interfere with RL in some situations.
To avoid any interference to radiolocation, it is necessary to design GBSAR with a spectrum access method e.g. Detect And Avoid (DAA). The following section evaluates this possibility.

4.2.3 GBSAR with DAA

This section considers possible implementation of a DAA function in GBSAR to avoid interference to RL. This mechanism intends to detect if a transmission from RL systems is present and then switch off GBSAR transmissions.

The necessary link budget to protect the RL is calculated as described in Figure 4.

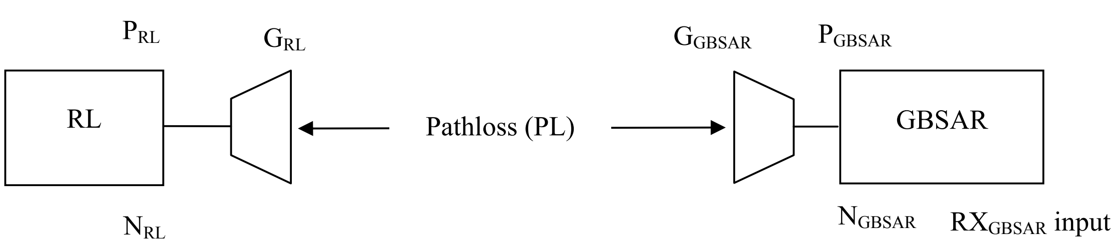

Figure 4: Link budget diagram

where:

GBSAR	= GBSAR equipment
RL	= Radiolocation equipment
N_{RL}	= receiver noise floor for the RL equipment;
$N_{GBSARL0}$	= receiver noise floor for the GBSAR equipment;
P_{GBSAR}	= Conducted power for the GBSAR equipment;
P_{RL}	= Conducted power for the RL equipment;
G_{GBSAR}	= GBSAR antenna gain;
G_{RL}	= RL antenna gain;
$RX_{GBSAR}\ input$	= GBSAR receiver input
PL	= Path loss between GBSAR and radar (in both directions due to reciprocity)

The maximum interference level to the RL equipment is $N_{RL} - 6dB$ as expressed in equation (4) below:

$$I = N_{RL} - 6 = P_{GBSAR} + G_{GBSAR} - PL + G_{RL} \quad (4)$$

Solve equation (4) for PL yields:

$$PL = P_{GBSAR} + G_{GBSAR} + G_{RL} - N_{RL} + 6 \quad (5)$$

The GBSAR received signal from the RL transmitter is the following:

$$RX_{GBSAR}input = P_{RL} + G_{RL} - PL + G_{GBSAR} \quad (6)$$

Eq. (5) into equation (6) yields:

$$RX_{GBSAR}input = P_{RL} + G_{RL} - P_{GBSAR} - G_{GBSAR} - G_{RL} + N_{RL} - 6 + G_{GBSAR} \quad (7)$$

Re-arrangement of equation (7) yields:

$$RX_{GBSAR}input = P_{RL} - P_{GBSAR} + N_{RL} - 6 \quad (8)$$

Assuming interference to an RL equipment of 6 dB below the receiver noise floor, equation (8) shows the received signal from the RL transmitter using the same pathloss. This received level is corresponding to the maximum interference to the RL equipment and can therefore be used as a DAA threshold limit.
As four types of RL equipment with different power are analyzed, the GBSAR received signal from each of RL types is given in Table 8.

DAA threshold, dBm/MHz	**RL Type 1**	**RL Type 2**	**RL Type 3**	**RL Type 4**
GBSAR conducted power, dBm/MHz	-14.00	-14.00	-14.00	-14.00
GBSAR Transmitter RF emission bandwidth (MHz)	640.00	1200.00	30.00	3.00
RL conducted power, dBm/MHz	20.97	27.66	58.24	41.25
N_{RL} -6 dB, dBm/MHz	-116.00	-117.30	-117.00	-115.00
DAA threshold, dBm/MHz	-81.03	-75.64	-44.76	-59.75

Table 8: DAA threshold for radiolocation systems

Table 8 shows that GBSAR shall have DAA with a threshold of -81 dBm/MHz or less.

The DAA time constant, *τ,* which is under the manufacturer's responsibility, shall be considered if the radar pulse is shorter than the detection time. In that case, the pulse width is not sufficient to fully charge the GBSAR detector (capacitor charge behaviour - charging time 1-e-t/RC). For example, if GBSAR is designed with a detection time constant of 1 µs the following applies:

- For radar pulse width $t \geq 5\ \tau = 5$ µs, there is no loss in the DAA detection level mechanism.

- For radar pulse width t < 5 µs, the effective DAA detection level, DAA_{eff}, shall be determined by a correction factor added to the value calculated in equation (8) as the following:

$$DAA_{eff} = DAA_{calc} - 20Log\left(1 - e^{\frac{-t}{5\tau}}\right) \quad (9)$$

where:,
t is the radar pulse width;
τ is the GBSAR detection time constant.

This is comparable with pulse desensitization of a receiver when measuring very narrow pulses. Further explanation can be found in the Application note 150-2 from Hewlett-Packard (Nov 71) [6].

DAA threshold, dBm/MHz	RL Type1	RL Type2	RL Type3	RL Type4
GBSAR conducted power, dBm/MHz	-14.0	-14.0	-14.0	-14.0
Transmitter RF emission bandwidth (MHz)	640.0	1200.0	30.0	3.0
RL conducted power, dBm/MHz	20.97	27.66	58.24	41.25
N_{RL} -6 dB, dBm/MHz	-116.00	-117.30	-117.0	-115.0
Calculated DAA_{calc} threshold, dBm/MHz	-81.03	-75.64	-44.76	-59.75

Used parameters for calculating correction factor	Type1	Type2	Type3	Type4
Pulse width (µs) t	49.0	443.0	0.10	17.0
DAA response time (µsec) τ	1.0	1.0	1.0	1.0
Reaction time (5τ)	5.0	5.0	5.0	5.0
Correction factor (dB)	0.0	0.0	-34.066	-0.295

DAA threshold, dBm/MHz	Type1	Type2	Type3	Type4
DAA threshold correction factor for 1MHz dwell time	0.0	0.0	-34.07	-0.29
Efficient DAA_{eff} threshold, dBm/MHz	-81.03	-75.64	-78.83	-60.05
Margin for DAA threshold, dB	0	5.36	2.17	20.95

Table 9: Examples of Margin for DAA threshold

In this case all RL types are protected against interference from GBSAR.

In addition, this threshold value has to be compared with the received signal level during the whole horizontal scan of the radar. Therefore, a minimum duration of 15 s (scan rate of 24°/s for system 4) has to be observed before starting a transmission for ground radar. It will ensure that a GBSAR device will not be detected by the ground radar main beam.

It is also necessary that a GBSAR device may be able to switch off as fast as possible when an emission from airborne radar is detected. A switch-off time after detection of 2 ms is proposed.

It shall be noted that DAA for GBSAR shall be able to detect radar pulses when illuminated by a scanning radar antenna. The GBSAR illumination time, t_{ill}, can be determined by the radar antenna beamwidth and scan rate as the following:

$$t_{ill} = \frac{b_W}{S_R} \quad (10)$$

where:
sR is the antenna scan rate in degrees/sec
bW is the beamwidth of the antenna in degrees

The effects of scanning antennas are analyzed in Table 10.

Scanning antennas	**RL Type 1**	**RL Type 2**	**RL Type 3**	**RL Type 4**
RL radar, antenna beam width, degrees	6.2	2.2	1	20 mils (Note)
RL radar, antenna horizontal scan rate	30 deg/sec	5 deg/sec	2000 deg/sec	24 deg/sec
RL radar, min pulse repetition rate, pps	2041	900	4000	3140
GBSAR illumination time by RL radar, ms	207	440	0.50	46.9
Number of RL pulses detected by GBSAR	**422**	**396**	**2**	**147**

Table 10: Time margin for DAA detection during scanning antenna

Note: 6400 mils are equal to 360 degrees.

The footprint given by an airborne radar is about 31 km according to the antenna vertical scan type characteristics (0 to -90° for radar 2) and an aircraft altitude of 10 000m. Therefore, a GBSAR device will remain in this area no more than 2 minutes considering an aircraft speed of 270 m/s. This time should be the needed time for ensuring a free access to spectrum once a radar signal is detected by the GBSAR equipment.

Finally, the GBSAR DAA mechanism has to take into account the following factors:
A threshold value of -81 dBm/MHz;
An initial listening time of 15 s before starting any operation;
A switch-off time of 2 ms when a possible victim transmitter is detected;
A listening time of 120 s to ensure a free spectrum access before recommencing the operation.

Equivalent or better techniques than DAA may be used, provided that they meet the above essential requirements.

4.3 Aggregate effect on radiolocation

The first two types of radars are used on board aircraft (Type 1 or 2). It means that a potential aggregate effect may occur from GBSAR devices spread over a wide area.

The SRDoc [2] estimated the density of GBSAR systems at 0.6/1000 km². Therefore it is considered in this section that a GBSAR is located within the main beam of the radar (Type 1 or 2). Over a wide area of 100x100 km, some other GBSAR devices are randomly spread. It is then proposed to look at the additional impact of these other devices to that one located in the main beam of the radar for different tilt angles as well as different altitudes (see figure 5).

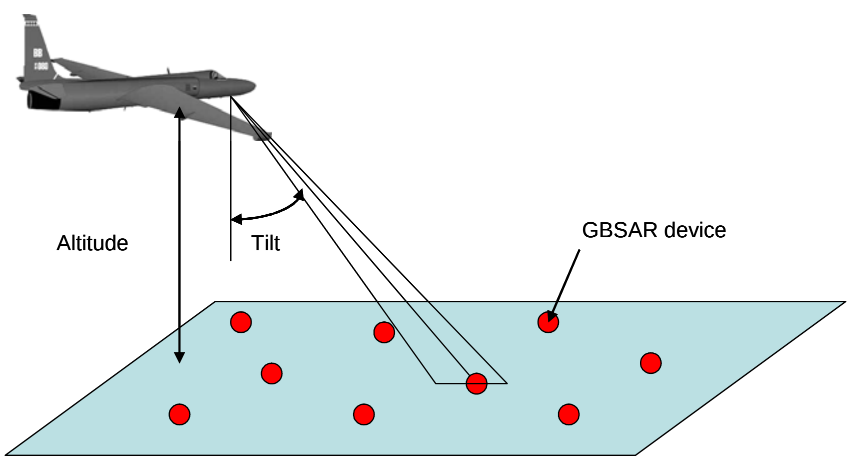

Figure 5: Scenario for aggregated effect

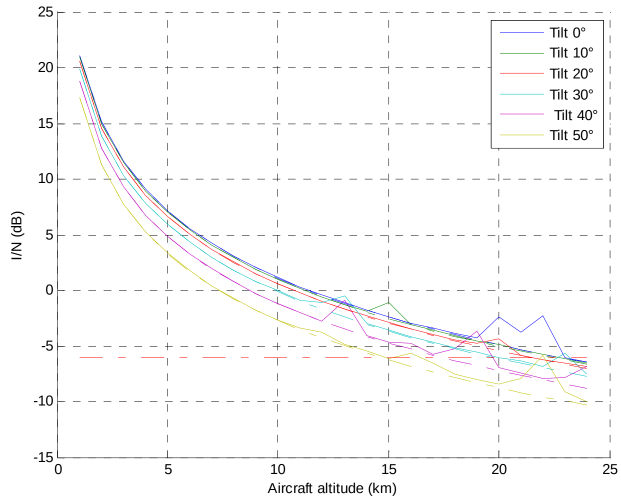

Figure 6: Calculated aggregate effect by GBSAR interference

Figure 6 shows that the aggregate effect can slightly change the amount of interference received by the radar from the main contributor (GBSAR within the main beam) for the highest altitudes. Nevertheless, the GBSAR activity factor will certainly reduce this impact. Therefore, the aggregate effect can be considered negligible compared to the impact of a single GBSAR device within the main beam of the radar.

This section showed that the aggregate effect is negligible and an analysis of a single entry is sufficient.

4.4 Conclusions on Impact of GBSAR on Radiolocation systems

From these calculations, it may be seen that GBSAR devices may create interference to radars on board aircraft when the antenna gain towards the radar is near to the maximum antenna gain. However, typical operation of GBSAR devices may avoid such situations.

To avoid any remaining interference risk to radiolocation systems, GBSAR shall be designed with Detect And Avoid (DAA), or equivalent or better techniques, with a threshold of about -81 dBm/MHz as described in section 4.2.3, Table 9.

5 COMPATIBILITY BETWEEN GBSAR AND EESS (ACTIVE)

5.1 Characteristics of EESS (active)

Recommendation ITU-R RS.1166 [7] describes the performance and interference criteria for active space-borne sensors.

The band 17.2-17.3 GHz is used for scatterometer, SAR imagery and precipitation radar applications, hydrological, permafrost monitoring, Numerical Weather Prediction (NWP) and climate monitoring.

The characteristics of the SAR satellite imager, which is planned, have the following characteristics.

- Altitude = 650 km
- Incidence angle = 30° to 40°
- Antenna gain = 49 dBi
- Antenna beam footprint = 16 km
- Swathe width = 100 km
- Number of SAR beams = 6
- Minimum reflectivity = - 25 dB
- Transmit chirp bandwidth = 10 MHz

In order to develop the technical basis for development of performance and interference criteria for various types of space-borne active sensors that are expected to be in operation in this band, the relevant system parameters are the following. The overall system noise temperature is 900 K. This will yield a noise power of -129 dBW (or -199 dBW/Hz). For SAR studies, the procedure is to have a I/N value of -10 dB which will yield a value of -139 dBW for a bandwidth of 10 MHz or -209 dBW/Hz or -119 dBm/MHz.

5.2 Compatibility studies

5.2.1 Hypothesis for conducting compatibility analysis

According to the description provided by ETSI of a typical GBSAR system, we have the following elements [2]:

- The necessary bandwidth B can be adjusted between 100 MHz and 200 MHz as required by the measurements.
- The maximum e.i.r.p. over B is + 26 dBm (for a bandwidth ranging between 100MHz and 200MHz). Therefore, the corresponding power spectrum density is 6 dBm/MHz or 3 dBm/MHz.

Figure 1 in section 3 described the GBSAR antenna pattern. It can be shown that discrimination factor of antenna pattern can be used to perform the compatibility study. The following table shows the antenna discrimination factors as a function of the GBSAR antenna elevation angle assuming a satellite nadir angle of 30°.

GBSAR antenna elevation angle (degree)	0	20	40	60	80
Off-axis between GBSAR antenna main beam and EESS pointing direction	60°	40°	20°	0°	20°
Antenna discrimination factor in dB	23	14	6	0	6

Table 11: Antenna discrimination factors applicable for compatibility analysis when considering the offset angle between the GBSAR and EESS antenna pointing directions

The estimate of the size and value of the GBSAR system market has to be divided for the two different market segments to which the devices are addressed:
For terrain monitoring applications, the total expected number of GBSAR systems across Europe is 20000 with an activity factor of 30 %.
For structure monitoring applications, the total expected number of GBSAR systems across Europe is 200000 with an activity factor of 15 %.

The initial compatibility analysis gives the result without taking into account any antenna pattern discrimination. This analysis is divided in two parts:
one dealing with the impact of a single active GBSAR device within the field of view of the EESS SAR imaging satellite, and
another part analyzing the impact of the aggregate effect of multiple GBSAR in operation within the field of view of EESS. It is to be noted that the aggregate effect does take into account the above figures concerning the expected densities and activity factors on a long term basis.
After that, gives the resulting margin when the discrimination provided by the antenna pattern of GBSAR is taken into account.

Frequency	17250	MHz	
Wavelength	0.02	m	
Altitude of the satellite	650	km	
Satellite antenna gain	49	dBi	
Antenna beam footprint	16	km	
Satellite nadir angle	30	°	
Maximum interference level	-119.0	dBm/MHz	
Size of Europe	3154000	km^2	
Compatibility analysis		**Value for a 100 MHz GBSAR bandwidth**	**Value for a 200 MHz GBSAR bandwidth**
Compatibility analysis with a single GBSAR			
Maximum e.i.r.p. (power spectral density) of a single SRD GSAR device	dBm/MHz	6	3
Distance GBSAR – Satellite receiver	km	751	751
Space attenuation	dB	175	175
Satellite antenna gain	dBi	49	49
Received power at the EESS sensor	dBm/MHz	-120	-123
Threshold	dBm/MHz	-119.0	-119.0
Margin with a single SRD device in operation	dB	0.6	3.6
GBSAR deployment in Europe: Aggregate effect			
Activity factor for terrain monitoring applications	%	30%	30%
Total number of GSAR for terrain monitoring applications in Europe		20000	20000
Activity factor for structure monitoring applications	%	15%	15%
Total number of GSAR for structure monitoring applications in Europe		200000	200000
Total number of GBSAR devices in operation in Europe		36000	36000
Corresponding density of active SRD devices	SRD/km²	0.011	0.011
Size of the satellite footprint: radius	Km	8.0	8.0
Number of devices in operation within the footprint of the EESS satellite		2.3	2.3
Margin computed with the corresponding density of SRD devices per km2	dB	-3.0	0.0

Table 12: Compatibility analysis assuming no antenna discrimination factor

When GBSAR antenna pointing directions are considered, the margins resulting from the compatibility analysis become:

GBSAR antenna elevation angle, degrees	0	20	40	60	80
Resulting margin, dB	20	11	3	-3	3

Table 13: Results of compatibility analysis according to GBSAR antenna pointing direction

This ta ble shows that except for the case of a GBSAR elevation angle of 60° where the GBSAR is pointing directly in the main beam of the EESS, which is probably unlikely, all the margins are positive.

5.2.2 Scattering effect from structure monitoring

The above analysis considered that the whole interference power sent to the SAR imaging satellite is derived from the GBSAR transmitter itself and not through the reflection of structures made of concrete or steel although GBSAR monitors such structures (bridges, towers, buildings, …). It can be expected that part of the energy transmitted by GBSAR can be reflected by those structures and therefore sent in the direction of the satellite. However, it is considered that such effect will not change the results given in Table 12 and .

5.3 Conclusions on the impact of GBSAR and EESS

The previous calculations show that GBSAR devices can be considered compatible with satellite SAR imaging systems if an appropriate GBSAR antenna pattern is considered (ref. Figure 1).

6 CONCLUSIONS

Compatibility between GBSAR and RL systems is almost achieved. The GBSAR antenna pattern (as given in Figure 1) ensures such compatibility for high elevation angles. Nevertheless, the calculations show also that some interference may occur in unlikely situations where the main beam of GBSAR device crosses the RL main beam. In that case, it is proposed to implement a spectrum access technique such as DAA, as specified in section 4.2.3.

Compatibility is achieved between GBSAR and EESS with GBSAR using the antenna pattern shown in Figure 1.

Under the above conditions GBSAR can be categorized as a licence-free Short Range Device (SRD) falling within Annex 6 of ERC/Rec. 70- 03.

ANNEX A: DETAILED INFORMATION ON GBSAR [2]

A.1 Range of applications

Interferometric analysis and SAR synthesis are two powerful data processing techniques which have nowadays been used for airborne and space-borne remote sensing systems with the objective of detecting ground displacement.
These two techniques, based on processing of data acquired by electromagnetic microwaves reflected by targets, can be exploited by the GBSAR system to perform:

- Structures monitoring;
- Terrain monitoring.

For structure monitoring applications, a GBSAR system can be used for:

- Static monitoring;
- static tests;
- time-dependent displacement or deformation monitoring;
- displacement or deformation detection during building work;
- Dynamic monitoring;
- resonance frequency detection;
- vibration mode detection.

For terrain monitoring applications, a GBSAR system can be used for:

- Landslide monitoring;
- Volcano movement detection;
- Urban area subsidence detection.

Some of the main advantages of the GBSAR system are:

- High measuring accuracy;
- Easy installation;
- High reliability;
- Non-contacting measuring principle (remote sensing);
- Provision of displacement information related to all the illuminated area with high resolution image.

A.2 Market size and value

The estimate of the size and value of the GBSAR market has to be divided for the two different market segments to which the devices are addressed.

A.2.1 Terrain monitoring application

European region, with particular regard to some countries such as Italy, Switzerland, Austria, Norway, etc, shows 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 terrain monitoring GBSAR applications is given in table A.1.

	Total market	**Served market**
Number of units	4 000	2 000
Value	€ 600 million	€ 300 million

Table A.1: Estimated market size and value for terrain monitoring GBSAR in 2011

A.2.2 Structures monitoring application

The estimate of the market size and value of GBSAR systems for the structure monitoring application is based on the assumption that GBSAR systems will be mainly used by structure monitoring service companies, administrators of structures such as dams, towers, or by University Departments that provide design and monitoring services to builders.

The estimated market size and value for structure monitoring GBSAR applications is given in table A.2.

	Total market	Served market
Number of units	40 000	20 000
Value	€ 600 million	€ 300 million

Table A.2: Estimated market size and value for structure monitoring GBSAR in 2011

A.3 Deploy ment and usage activities

The use and deployment of GBSAR systems show different characteristics depending on the two different applications.

A.3.1 Terrain monitoring

For terrain monitoring applications, the GBSAR can be exploited for continuous or for time-discrete monitoring surveys:

- in the first case the system is permanently installed in front of the landslide/unstable slope;
- in the second case it will be used as a nomadic system, used for performing several different surveys in different time-periods.

In the case of a time-discrete use, a survey usually lasts for about 1 or 2 weeks with a time repetition interval of some months.
Assuming deployment of the system in the whole European region, whose area is about 3 154 000 km^2, the mean spatial density of the system will be 0.6 systems per 1 000 km^2 after 5 years.

For the terrain monitoring application, the GBSAR system is provided with a moving module, composed of a 2 m track along which the sensor modules moves, see Figure A.1.

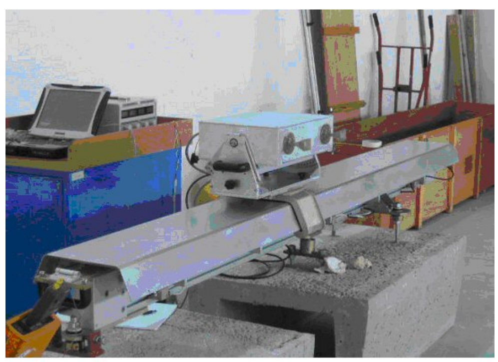

Figure A.1: GBSAR system configuration for terrain monitoring applications

A.3.2 Structural monitoring

For structural monitoring applications the use of the system consists of one/two days survey, installing the system nearby the structure (i.e. under a bridge). Even in this case the mean spatial density of the system is very low, in the order of 4.4 to 6 systems per 1 000 km^2 after 5 years.
Typical usage of GBSAR is as follows:

- For monitoring construction structures: dynamic tests require 10 min/hour with an activity factor of 100%; static tests can last up to 2 days.
- For terrain structures: investigations typically last 1 to 2 weeks with an activity factor of 5 % to 10 %.
- For the structure monitoring application, the sensor module is installed on a tripod that permits tilting and rotation, see Figure A.2.

Figure A.2: GBSAR system configuration for structure monitoring applications

A.4 Detailed technical description

As mentioned above, the GBSAR system exploits, as earth monitoring satellites, interferometric analysis and SAR techniques to provide displacement maps for terrain or structure monitoring applications. In particular:

- the interferometric technique provides data on object displacement by comparing phase information, collected in different time periods, of reflected waves from the object, providing a measure of the displacement with an accuracy of less than 1 mm;
- the SAR technique enables the system to provide high resolution images. High range resolution is obtained using large transmitted bandwidth whereas high cross range resolution is derived, only for the terrain monitoring applications, exploiting the movement of the physical antenna along a straight trajectory.

The GBSAR system is based on a SF-CW coherent radar technology that transmits, step by step, continuous waves at discrete frequency values in a frequency range of bandwidth B. It is important to observe that the transmitted signal is a sequence of non-modulated CWs, whose total frequency bandwidth is controlled by the management system and can be decreased from 200 MHz down to 100 MHz.

The technical characteristics of the GBSAR applications are summarized in Table A.3 below:

Application	Terrain monitoring	Structure monitoring
Frequency band	17.1 to17.3 GHz	17.1 to 17.3 GHz
Radar type	SF CW	SF CW
Use	Ground-based	Ground-based
SAR capability	Yes	Yes
Interferometric capability	Yes	Yes
Operating distance	0.2 to 4 km	10 to 500 m
Spatial resolution	Range = 0.75 m Cross range = 9.0 m	Range = 0.75 m
Image acquisition time	≤ 6 min	20 ms
Installation time	≤ 2 h	15 min
Power supply	12 VDC or mains supply	12 VDC or mains supply
Size	250 x 100 x 100 cm	50 x 100 x 40 cm
Weight	100 kg	15 kg
Power consumption	120 W	30 W
Power [e.i.r.p]	26 dBm	26 dBm

Table A.3: Technical characteristics of GBSAR applications

The displacement accuracy of GBSAR is linked to the received SNR according to the following formula:

$$\sigma_r = \frac{\lambda}{4\pi} \cdot \frac{1}{\sqrt{SNR}}$$

It can be seen that σ_r is decreasing with increased SNR. This function continues until a fixed level which is determined by internal noise of the equipment itself. This level is depending on the stability of the local oscillator, the phase and amplitude unbalance of the IQ demodulator, thermal noise etc. For a good design such level can be around 5 µm. In this case the displacement accuracy is approximately given by the following formulas:

$$\begin{cases} \sigma_r = \dfrac{\lambda}{4\pi} \cdot \dfrac{1}{\sqrt{SNR}} & \text{for SNR} < 55\text{dB} \\ \sigma_r = 5\mu m & \text{for SNR} > 55\text{dB} \end{cases}$$

The overall measurement accuracy depends not only on the sensor module's accuracy but also on noise due to other effects.

The received SNR depends on power of the received signal from a single pixel. The received power depends on the operating conditions:

- pixel - radar distance;
- pixel reflectivity (RCS);and
- pixel dimension.

The SNR for the single pixel at the receiver antenna is increased by the range compression process and, for terrain monitoring application, even by the cross-range SAR integration. These two gains depend on:

- number of frequency steps;
- number of steps for sampling along the 2 m rail.

To obtain a displacement accuracy of 1 mm for terrain monitoring, an SNR of at least 3 dB is needed (this SNR includes both the range and cross range integration gains). To obtain a displacement accuracy of 0.5 mm for structure monitoring, an SNR of at least of 9 dB is needed (this SNR includes the range integration gain).
The overall displacement measure accuracy depends also on other parameters, such as the atmospheric changes or mechanical errors, but, from a radar point of view, it is necessary to start with a good SNR and displacement accuracy.

ANNEX B: DETAILED RESULTS FOR THE COMPATIBILITY BETWEEN GBSAR DEVICES AND RADAR TYPES 2, 3 AND 4

LINK BUDGET:																				
Impact of GBSAR on radiolocation systems	Value	Units																		
Emission part: GBSAR																				
Bandwidth, min	**100.00**	MHz																		
Tx out, eirp	**26.00**	dBm																		
Tx Out eirp per MHz	6.00	dBm/MHz	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Antenna Gain	20.00	dBi	20.00	20.00	20.00	20.00	20.00	20.00	20.00	dBi	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Frequency (GHz)	17.20	GHz																		
Reception part: Radar																				
Function			**Airborne**						**Maritime**						**Ground**					
Radar type			**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**
Tx power into antenna peak		W	700	700	700	700	700	700	20000	20000	20000	20000	20000	20000	40.00	40.00	40.00	40.00	40.00	40.00
Receiver IF3dB bandwidth MHz		MHz	27	27	27	27	27	27	70	70	70	70	70	70	3.00	3.00	3.00	3.00	3.00	3.00
Antenna mainbeam gain		dBi	38	38	38	38	38	38	43	43	43	43	43	43	38.00	38.00	38.00	38.00	38.00	38.00
Antenna sidelobe attenuation		dB	20	20	20	20	20	20	23	23	23	23	23	23	20.00	20.00	20.00	20.00	20.00	20.00
Antenna height		m	Aircraft altitude						Deck mount						Ground					
Antenna height		m	12000	12000	12000	12000	12000	12000	15	15	15	15	15	15	6.00	6.00	6.00	6.00	6.00	6.00
Radar feeder loss		dB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E.i.r.p radar		dBm	96.45	96.45	96.45	96.45	96.45	96.45	116.01	116.01	116.01	116.01	116.01	116.01	84.02	84.02	84.02	84.02	84.02	84.02
Receiver noise figure		dB	2.70	2.70	2.70	2.70	2.70	2.70	3.00	3.00	3.00	3.00	3.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00
N=FkTB		dBm	-96.99	-96.99	-96.99	-96.99	-96.99	-96.99	-92.55	-92.55	-92.55	-92.55	-92.55	-92.55	-104.23	-104.23	-104.23	-104.23	-104.23	-104.23
N per MHz		dBm/MHz	-111.30	-111.30	-111.30	-111.30	-111.30	-111.30	-111.00	-111.00	-111.00	-111.00	-111.00	-111.00	-109.00	-109.00	-109.00	-109.00	-109.00	-109.00
Protection criterion, I/N		dB	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00
MAIN LOBE GBSAR to MAIN LOBE RL	*Scenario S1*																			
Separation distance GBSAR to Radar		**m**	161207						13833						8748					
MAIN LOBE GBSAR to SIDE LOBE RL	*Scenario S2*		0						0						0					
Separation distance GBSAR to Radar		**m**	789						644						606					
SIDE LOBE GBSAR to MAIN LOBE RL	*Scenario S3*	Theta$_0$	0	20	40	60	80	90	0	20	40	60	80	90	0	20	40	60	80	90
Ant elevation (click on + to access details)	*q_1*																			
Required attenuation (click on + to access de	*Att(q_1- q_0)*																			
Separation distance GBSAR to Radar	**Theta$_1$=0°**	**(m)**	161207	85582	32165	11413	5098	5098	13833	13833	13833	13833	8758	8758	8748	8748	8748	8748	3912	3912
Separation distance GBSAR to Radar	**Theta$_1$=20°**	**(m)**	85582	161207	85582	32165	11413	6418	13833	13833	13833	13833	13833	11025	8748	8748	8748	8748	8748	4925
Separation distance GBSAR to Radar	**Theta$_1$=40°**	**(m)**	32165	85582	161207	85582	32165	19833	13833	13833	13833	13833	13833	13833	8748	8748	8748	8748	8748	8748
Separation distance GBSAR to Radar	**Theta$_1$=60°**	**(m)**	11413	32165	85582	161207	85582	53999	13833	13833	13833	13833	13833	13833	8748	8748	8748	8748	8748	8748
Separation distance GBSAR to Radar	**Theta$_1$=80°**	**(m)**	5098	11413	32165	85582	161207	131034	8758	13833	13833	13833	13833	13833	3912	8748	8748	8748	8748	8748
SIDE LOBE GBSAR to SIDE LOBE RL	*Sceanrio S4*	Theta$_0$	0	20	40	60	80	90	0	20	40	60	80	90	0	20	40	60	80	90
Required attenuation (click on + to access de	*Att(q_1- q_0)*																			
Separation distance GBSAR to Radar	**Theta$_1$=0°**	**(m)**	2029	1077	405	144	64	64	1961	1041	391	139	62	62	1557	827	311	110	49	49
Separation distance GBSAR to Radar	**Theta$_1$=20°**	**(m)**	1077	2029	1077	405	144	81	1041	1961	1041	391	139	78	827	1557	827	311	110	62
Separation distance GBSAR to Radar	**Theta$_1$=40°**	**(m)**	405	1077	2029	1077	405	250	391	1041	1961	1041	391	241	311	827	1557	827	311	192
Separation distance GBSAR to Radar	**Theta$_1$=60°**	**(m)**	144	405	1077	2029	1077	680	139	391	1041	1961	1041	657	110	311	827	1557	827	522
Separation distance GBSAR to Radar	**Theta$_1$=80°**	**(m)**	64	144	405	1077	2029	1650	62	139	391	1041	1961	1594	49	110	311	827	1557	1266

Table B.1: Expanded calculations (for radar types 2, 3 and 4)

The results of the extended calculations are shown in the figures below for the case SL GBSAR-SL RL for different elevation angles of the GBSAR.

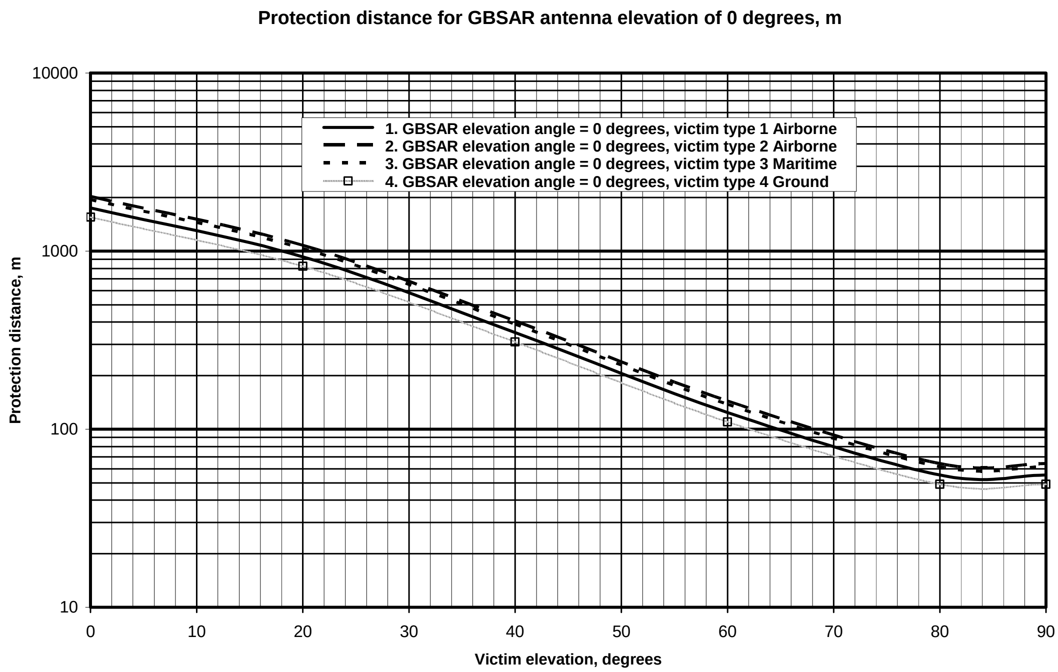

Figure B.1: Protection distance for GBSAR antenna elevation of 0 degrees

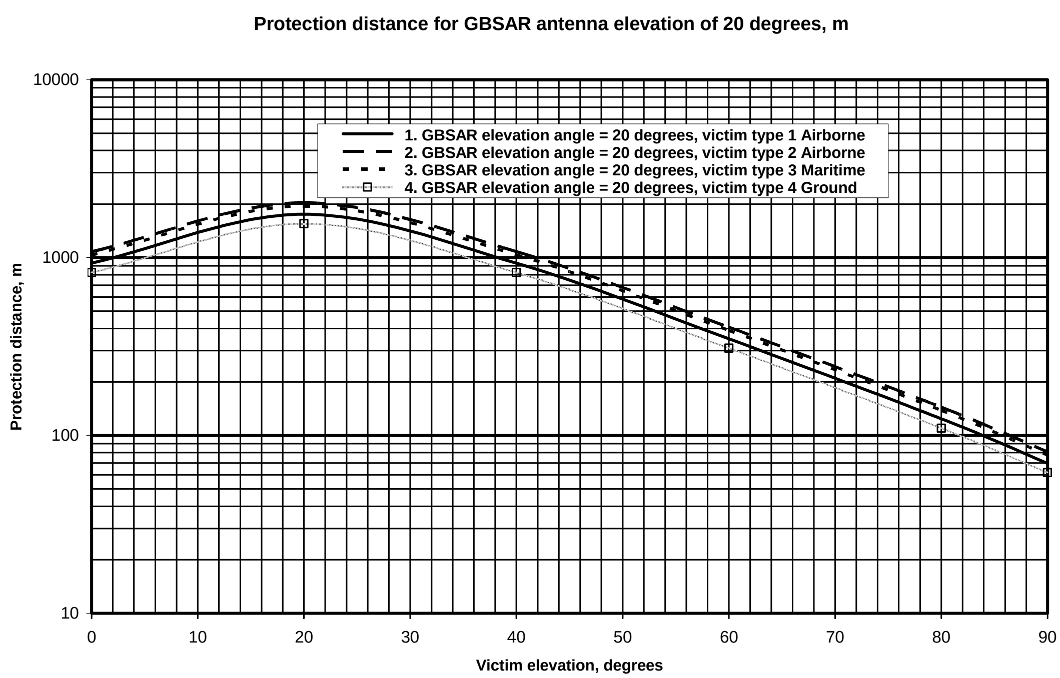

Figure B.2: Protection distance for GBSAR antenna elevation of 20 degrees

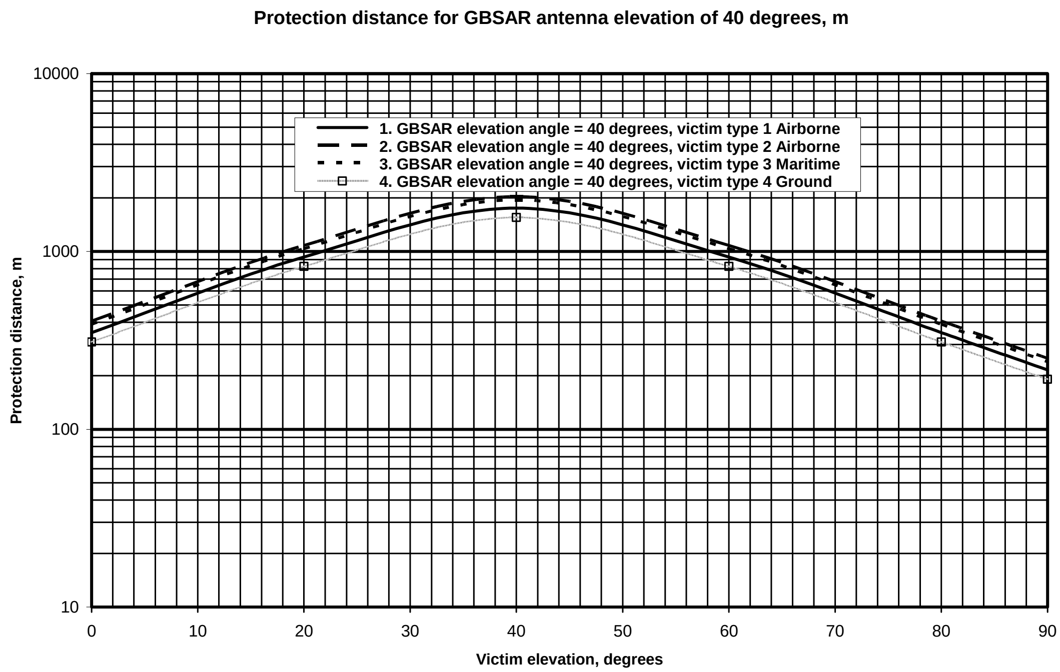

Figure B.3: Protection distance for GBSAR antenna elevation of 40 degrees

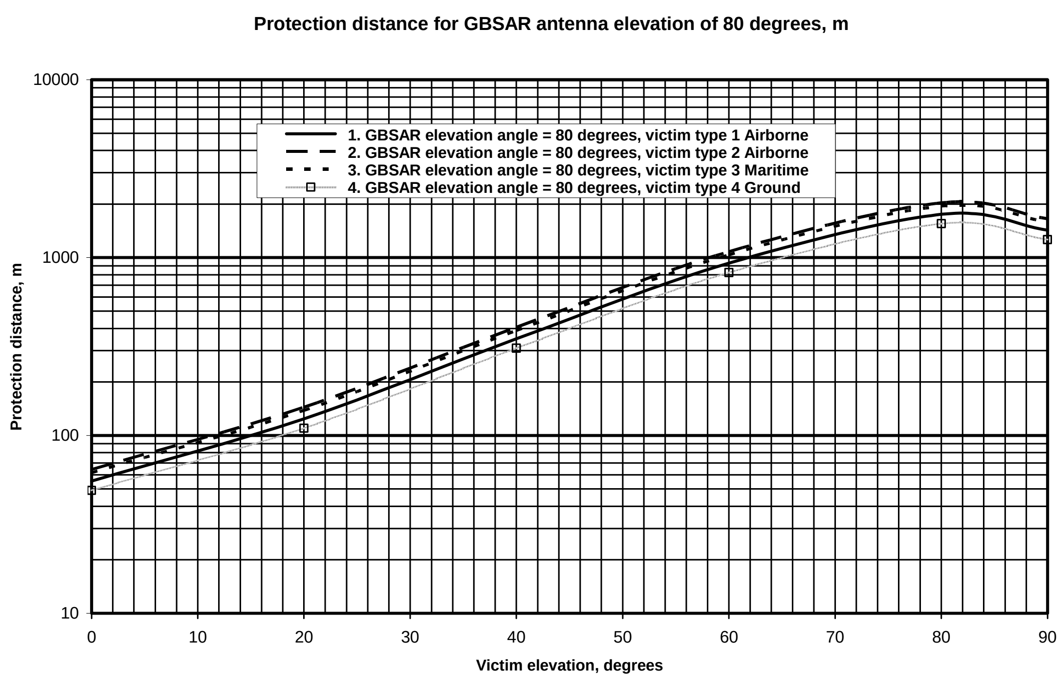

Figure B.4: Protection distance for GBSAR antenna elevation of 80 degrees

ANNEX C: LIST OF REFERENCES

[1] ITU Radio Regulations (www.itu.int)

[2] ETSI TR 102 522: Equipment for Detecting Movement; Radio equipment operating in the frequency range 17.1 GHz to 17.3 GHz (www.etsi.org)

[3] Recommendation ITU-R M.1730: Characteristics of and Protection Criteria for the Radiolocation Service in the Frequency Band 15.7-17.3 GHz (www.itu.int)

[4] Recommendation ITU-R M.1461-1, “Procedures for determining the potential interference between radars operating in the radiodeterminaton service and systems in other services”

[5] Recommendation ITU-R P.452*:* Prediction Procedure for the Evaluation of Microwave Interference between Stations on the Surface of the Earth at Frequencies above about 0.7 GHz

[6] Spectrum analyzer series, Application note 150-2 “Spectrum analysis…pulsed RF”, Hewlett-Packard, Nov 1971.

[7] Recommendation ITU-R RS.1166: Performance and Interference Criteria for active Spaceborne Sensors