RECOMMENDATION ITU-R SA.1260-1*

Feasibility of sharing between active spaceborne sensors and other services in the range 420-470 MHz

(Question ITU-R 218/7)

(1997-2003)

The ITU Radiocommunication Assembly,

considering

a) that synthetic aperture radars (SARs) can measure soil moisture, forest biomass, can detect buried geologic structures such as faults, fractures, synclines and anticlines, and can map and measure the depth of Antarctic ice, and hydrogeological properties of arid and semiarid regions;

b) that experimental SARs mounted on aircraft have demonstrated the potential for making these measurements;

c) that these spaceborne SARs must operate at frequencies below 500 MHz in order to penetrate dense vegetation and the Earth's surface on a worldwide repetitive basis;

d) that the need for monitoring forests was emphasized at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992;

e) that Resolution 727 (Rev.WRC-2000) seeks provision of up to 6 MHz of frequency spectrum to the Earth exploration-satellite service (active) in the frequency range 420-470 MHz in order to meet the Earth exploration-satellite service (active) requirements;

f) that frequency bands between 420-470 MHz are currently allocated to the radiolocation, fixed, amateur, space operations and mobile services;

g) that within the amateur service weak-signal operations (including Earth-Moon-Earth) are conducted centred around 432 MHz, and amateur-satellite operations (both uplink and downlink) are conducted in the band 435-438 MHz;

* NOTE – The following Administrations – Saudi Arabia, Djibouti, Egypt, United Arab Emirates, Jordan, Kuwait, Morocco, Mauritania, Syrian Arab Republic, Tunisia and Yemen – object to the approval of this Recommendation. For more details, please refer to the appropriate Summary Record of RA-03.

h) that other uses are made of portions of these bands including:

– wind profilers in the range 440-450 MHz, and in case of incompatibility between wind profiler radars and other applications, in the bands 420-435 MHz and 438-440 MHz (Resolution 217 (WRC-97));

– launch vehicle range safety command destruct receivers in the band 449.75-450.25 MHz (No. 5.286 of the Radio Regulations (RR)), as well as around 421.0, 425.0, 427.0, 440.0 and 445.0 MHz in the United States of America and Brazil and, in the French Overseas Departments in Region 2 and India, the band 433.75-434.25 MHz (RR No. 5.281);

j) that certain spaceborne SARs could produce pfd's at the Earth's surface in excess of the pfd levels that may be required to protect the fixed service and the land mobile service allocated in this frequency range;

k) that co-frequency sharing with wind profilers is likely to be unfeasible due to interference to the spaceborne active sensor;

l) that SARs and the amateur service (primary in Region 1 and secondary in Regions 2 and 3, except as in RR No. 5.278) can coexist in the band 430-440 MHz, by taking appropriate technical and operational measures defined in Annex 1 to this Recommendation;

m) that in addition, the provisions of RR Nos. 5.274, 5.275, 5.276, 5.277, 5.278, 5.281 and 5.283 list countries that have defined portions of the band between 430 and 440 MHz as having primary status for the fixed, mobile, space operation and/or the amateur services;

n) that some sharing studies have indicated that co-frequency sharing between the amateur services and some proposed SARs in the Earth exploration-satellite service (EESS) is possible for some amateur modes of transmission such as FM and time division multiple access (TDMA), but would be difficult with continuous wave and single sideband modes of operation;

o) that Recommendation ITU-R M.1462 contains the technical and operational characteristics of, and protection criteria for, radars (airborne, shipborne, and space object tracking) operating in the radiolocation service operating in the band 420-450 MHz;

p) that there is a potential for unacceptable interference from some spaceborne SARs to terrestrial space object tracking radars operating in the band 420-450 MHz if the spaceborne SAR radar is within the view of the terrestrial radars (i.e. above the radars' visible horizon);

q) that some spaceborne SARs will be tracked by terrestrial space object tracking radars, and that the resultant unwanted received power level at a spaceborne SAR can approach its maximum power-handling capability;

r) that there is a potential for unacceptable interference from some spaceborne SARs to airborne and shipborne radars operating in 420-450 MHz, the probability and severity of which is highly dependent upon the characteristics of the SARs;

s) that any harmful interference, even for very short periods, by SARs into launch vehicle command destruct receivers could impede the safety of life and property;

t) that given the complexity of the EESS (active) instruments implementation in these low frequencies, very few such platforms are expected to be in orbit at the same time,

recommends

1 that active spaceborne sensors operating in the bands used by the amateur service, the amateur satellite service, the fixed, radiolocation, space operation, mobile services and the MSS in the range 420-470 MHz, respect the technical and operational constraints provided in Annex 1 to this Recommendation;

2 that spaceborne active sensors operating in the range 420-450 MHz not be put into operation within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, on a case-by-case basis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing have been performed to confirm compatibility with the mutual agreement of the affected administrations;

3 that a spaceborne SAR intended for operation in the 420-450 MHz band be designed to tolerate the unwanted signal power levels that will result from being tracked by terrestrial space object tracking radars;

4 that sufficient frequency and geographical separation between spaceborne SARs and wind profilers operating in the ranges 420-432 MHz and 438-450 MHz may need to be provided;

5 that spaceborne active sensor frequency bands be selected in such a way as not to overlap with launch vehicle range safety command destruct receive frequency bands listed in *considering* h);

6 that in cases where *recommends* 5 becomes difficult to implement, spaceborne active sensors operating in the frequency ranges allocated for launch vehicle range safety command destruct receive frequency bands should not be put into operation within the specific distance of locations where launch vehicle commands are used, in order to avoid interference from spaceborne active sensors into launch vehicle receivers.

Annex 1

Technical and operational constraints for EESS (active) operating in the range 420-470 MHz

For the purposes of protecting stations operating in the existing services, SAR transmissions from stations in the EESS (active) operating in the frequency range 420-470 MHz are subject to the technical and operational constraints specified in this Annex.

The following constraints are based on ITU-R studies. Annex 2 provides information on the feasibility of sharing between active spaceborne sensors and other services in the range of 420-470 MHz.

1 Technical constraints

TABLE 1

Technical constraints for EESS (active) instruments in the range 420-470 MHz

Parameter	Value
Peak pfd on Earth's surface from antenna main lobe	–140 dB(W/(m^2 · Hz))
Maximum mean pfd on Earth's surface from antenna main lobe	–150 dB(W/(m^2 · Hz))
Maximum mean pfd on Earth's surface from 1st antenna side lobe	–170 dB(W/(m^2 · Hz))

2 Operational constraints

EESS (active) operating in the band 420-450 MHz shall not transmit within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing, have been performed to confirm compatibility.

As a consequence of the above constraints, EESS (active) instruments shall be designed in such a way as to allow programmable turning off of all RF emissions over geographical areas or countries where ITU regulations or national regulations do not allow their operations.

The EESS (active) instruments operation profile shall be campaign-oriented, targeted to specific geographical areas and shall limit the instrument active time to the minimum required to achieve the campaign objectives. Thus, the measurements carried out by the instrument do not require continuous operation of the instrument, and intervals of months between successive measurements on the same area can be expected.

The operational duty cycle in campaign-mode will be 15% maximum (typically 10%). While not in campaign-mode, the instrument will be switched off.

FIGURE 1

Example of exclusion zone around space object tracking radars for a SAR in a 550 km orbit

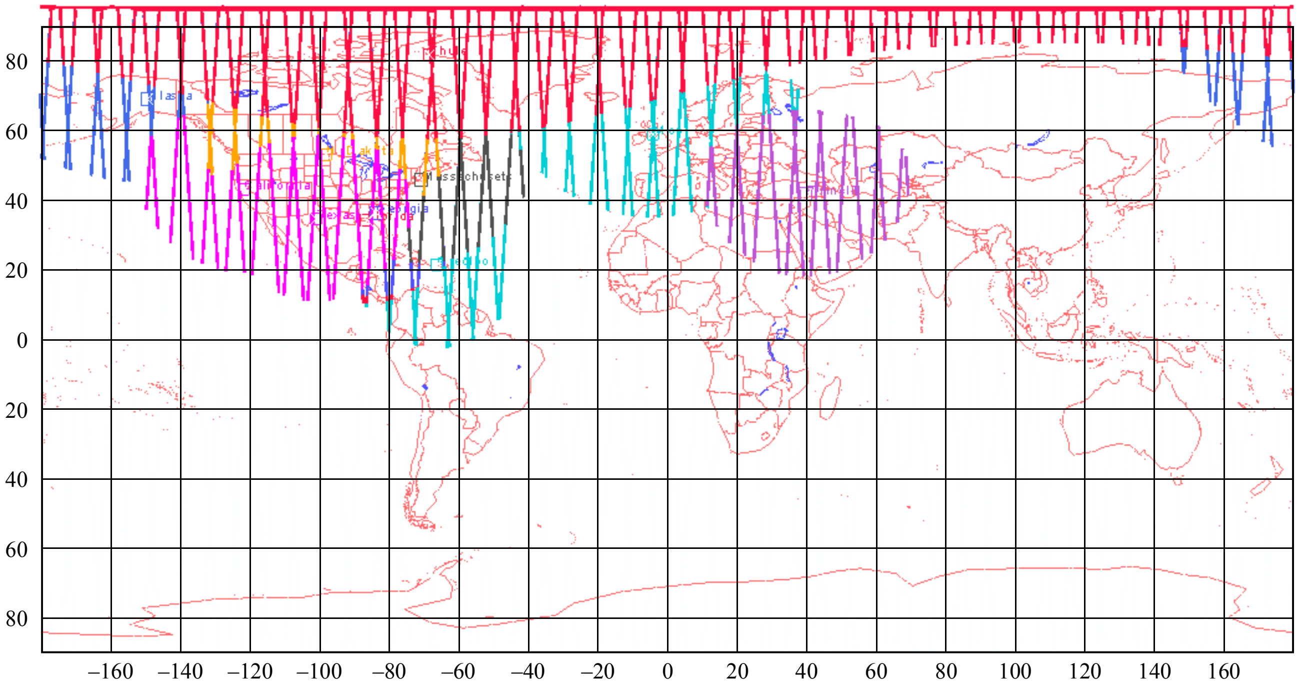

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TABLE 2

Space object tracking radars operating in 430-440 MHz

Radar location	Latitude	Longitude
Massachusetts (United States of America)	41.8° N	70.5° W
Texas (United States of America)	31.0° N	100.6° W
California (United States of America)	39.1° N	121.5° W
Georgia (United States of America)	32.6° N	83.6° W
Florida (United States of America)	30.6° N	86.2° W
North Dakota (United States of America)	48.7° N	97.9° W
Alaska (United States of America)	64.3° N	149.2° W
Thule (Greenland)	76.6° N	68.3° W
Fylingdales Moor (United Kingdom)	54.5° N	0.4° W
Pirinclik (Turkey)	37.9° N	40.0° E

3 Protection criteria for existing services in the frequency range 420-470 MHz

Not all protection criteria mentioned in this section are contained in ITU-R Recommendations. Therefore, some of these protection criteria have been derived from information provided in ITU-R studies. Table 3 reflects the information available at the time of the development of this Recommendation.

It should be noted that any future Recommendation describing the protection criteria for any given service, has preference above the value listed in the table as derived from ITU-R studies.

TABLE 3

Protection criteria for services in the range 420-470 MHz

Frequency range (MHz)	ITU-R services	The time percentages and criteria in columns 4 and 5 are to be applied only in the following geographical areas	Maximum percentage of time that the criteria may be exceeded(1)	Interference criteria at receiving stations	Sources
430-440	Amateur	Within line-of-sight (LoS) of terrestrial amateur stations located in regions defined in *considering* l)	1%	pfd = -204 dB(W/(m^2 · Hz))(2)	ITU-R studies
435-438	Amateur satellite	Within LoS of satellite amateur earth stations located in regions defined in *considering* l)	1%	pfd = -197 dB(W/(m^2 · Hz))	ITU-R studies
435-438	Amateur satellite	Within LoS of receivers of amateur space stations	1%	pfd = -187 dB(W/(m^2 · Hz))	ITU-R studies
420-470(3)	Fixed	Within LoS of stations of the fixed service including stations located in regions defined in *considering* m)	Not applicable	$(I/N)_{MEAN} = -20$ dB (equivalent to 1% fractional degradation in performance)	Recs. ITU-R F.758 and ITU-R F.1108
420-432 and 438-450	Radio-location	Within LoS of wind profiler radars	(4)	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Space operation	Within LoS of launch vehicle command destruct receivers located in regions defined in *considering* m)	Frequency or geographical separation required		ITU-R studies

TABLE 3 (*end*)

Frequency range (MHz)	**ITU-R services**	**The time percentages and criteria in columns 4 and 5 are to be applied only in the following geographical areas**	**Maximum percentage of time that the criteria may be exceeded**[(1)]	**Interference criteria at receiving stations**	**Sources**
420-450	Radio-location	Within LoS of terrestrial space object tracking radars[(5)]	[(4)]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Radio-location	Within LoS of shipborne radars	[(4)]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Radio-location	Within LoS of airborne radars	[(4)]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-470[(3)]	Mobile	Within LoS of mobile stations including stations located in Regions defined in *considering* m)	0.1%	pfd = -204 dB(W/(m^2 · Hz))[(2)]	ITU-R studies

(1) Considering all active SARs in this frequency range.

(2) The maximum aggregate pfd specified for the band 430-440 MHz has been based on the maximum acceptable interference level received by the average side lobe of an amateur receiving antenna.

(3) In the frequency range 430-440 MHz, the fixed and mobile services are allocated only in some countries by footnote.

(4) The criterion given in Recommendation ITU-R M.1462 is based on the protection of radiolocation systems from noise-like interference. Sharing may be possible between radiolocation systems and spaceborne active sensors at interference levels greater than those given in Recommendation ITU-R M.1462 through the use of signal processing techniques to filter out unwanted pulsed emissions. Recommendation ITU-R M.1372 provides a description of some of these interference suppression techniques.

(5) The EESS (active) operating in the band 420-450 MHz shall not transmit within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, on a case-by-case basis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing, have been performed to confirm compatibility with the mutual agreement of the affected administrations.

Annex 2

Methodology for interference assessment and mitigation

1 Introduction

A methodology is presented that allows an estimate to be made as to whether or not the unwanted signal received by other services in the band 420-470 MHz from an active spaceborne sensor may cause difficulties if operated in common frequency bands. Much of the content of this Annex has been extracted from Annex 1 of Recommendation ITU-R SA.1280 – Selection of active spaceborne sensor emission characteristics to mitigate the potential for interference to terrestrial radars operating in frequency bands 1-10 GHz. The calculations highlight a number of parameters of the sensor that can be chosen such that the sharing situation is improved.

2 Calculation of interference to other services

The average interfering signal pfd, I_{pfd} (dB(W/(m^2 · Hz))) and average interfering signal power level, I (dBW), received by the other services from spaceborne active sensors is calculated from the following:

$$I_{pfd} = 10 \log P_t + 10 \log (\tau \, PRF) + G_t - (130.99 + 20 \log R + 10 \log B) + OTR - PG \qquad (1a)$$

and

$$I = 10 \log P_t + 10 \log (\tau \, PRF) + G_t + G_r - (32.44 + 20 \log (f R)) + OTR - PG \qquad (1b)$$

where:

P_t: peak space borne sensor transmitter power (W)

τ: spaceborne sensor pulse width (s)

PRF: spaceborne sensor pulse repetition frequency (Hz)

G_t: spaceborne sensor antenna gain towards other service (dBi)

R: slant range between sensor and radar (km)

B: bandwidth of sensor (MHz)

OTR: receiver on-tune rejection (dB)

PG: processing gain (dB), rejection of unwanted signals due to receiver signal processing (assumed to be zero if not known)

f: frequency (MHz).

Equation (1a) gives the average interference signal pfd level and equation (1b) gives the average interference signal power level. The average interference power level is used when it can be determined that such use is appropriate. For example, a radar that performs a fast Fourier transform (FFT) on the received signal will "smear" the dissimilar pulsed signal across a number of bins, resulting in an averaged interfering signal level. The on-tune rejection term is calculated from:

$$OTR = 10 \log (B_r / B_t) \qquad \text{for } B_r \leq B_t \qquad (2a)$$

$$= 0 \qquad \text{for } B_r > B_t \qquad (2b)$$

where:

B_r: receiver bandwidth

B_t: bandwidth of the transmitted interfering signal.

If the peak interfering signal is of interest, then the second term of equation (1) should be left out, and on-tune rejection is calculated from the following:

Input pulse with no frequency modulation:

$$OTR = 20 \log (B_r \tau) \qquad \text{for } B_r \tau < 1 \qquad (3a)$$

$$= 0 \qquad \text{for } B_r \tau > 1 \qquad (3b)$$

Input pulse with frequency modulation:

$$OTR = 10 \log\left(\frac{B_r^2 \tau}{B_c}\right) \qquad \text{for } \frac{B_r^2 \tau}{B_c} < 1 \tag{4a}$$

$$= 0 \qquad \text{for } \frac{B_r^2 \tau}{B_c} > 1 \tag{4b}$$

where:

B_r: other service receiver IF bandwidth

B_c: chirp bandwidth of spaceborne sensor

τ: sensor pulse width.

3 Interference criteria for other services

Specific criteria for specific systems in the other services are given in Table 1 in terms of the maximum aggregate pfd limits at the receiving stations (dB(W/(m^2 · Hz))) and also the maximum percentage of time that the pfd limits may be exceeded. There are several instances where a different criteria is used as follows.

3.1 Surveillance radars in radiolocation service

It will be assumed that the received *S*/*N* of the surveillance radars may not be degraded by more than 0.5 dB longer than a single scan time, taken to be 10 s. This equates to an *I*/*N* power ratio of –9 dB at the receiver IF stage. The average interfering signal power level is considered to be of interest in the case of the surveillance radars.

3.2 Tracking radars in radiolocation service

Tracking radars often use "range gates" to exclude all returns other than those at specific ranges of interest. An important consideration in determining the susceptibility of a tracking radar to an interfering pulse train is the fraction of interfering pulses that are coincident with the range gate. The coincidence of interfering pulses with the range gate will depend upon whether the desired and undesired PRFs are related by integer multiples (Case I) or not (Case II). The fraction of coinciding pulses, f_c, is found from:

$$f_c = \frac{GCF(PRF_i, PRF_g)}{PRF_g} \qquad \text{for Case I} \tag{5a}$$

$$f_c = PRF_i(\tau_g + \tau_i) \qquad \text{for Case II} \tag{5b}$$

where:

PRF_i: interfering PRF

PRF_g: gate PRF

$GCF\ (PRF_i, PRF)_g$: greatest common factor of PRF_i and PRF_g

τ_i: interfering pulse width

τ_g: gate width.

Note that when $\tau_i > \tau_g$ and the desired and undesired PRFs are not related by integer multiples (Case II), f_c is approximately the duty cycle of the interfering pulses. This situation is considered to be the typical case, and is used in the following determination of degradation threshold for a tracking radar.

To obtain highly accurate position data on objects of interest, tracking radars use high gain antennas with well-defined, narrow mainbeams. A servo mechanism attempts to keep the boresight of the antenna mainbeam on the target; the servo mechanism is driven by an error signal generated by the angle error between the target and the antenna boresight. Undesired signals entering the radar can increase this bias error.

A degradation threshold for a tracking radar, expressed as an allowed fraction of coincident interfering pulses, f_c, as a function of the S/I ratio at the IF output is given as:

$$f_c = \frac{a^2 - 1}{\frac{90 B_r \tau}{(S/I - 1)} - 1} \qquad \text{when } S/I > 1 \qquad (6a)$$

$$f_c = \frac{a^2 - 1}{\frac{90 B_r \tau}{(S/I - 1)} - 1} \qquad \text{when } S/I < 1 \qquad (6b)$$

where:

a: factor associated with total tracking error, with degradation due to interference included (e.g. $a = 1.1$ allows a 0.1%, or 10% increase due to interference)

B_r: 3 dB bandwidth of the radar IF filter

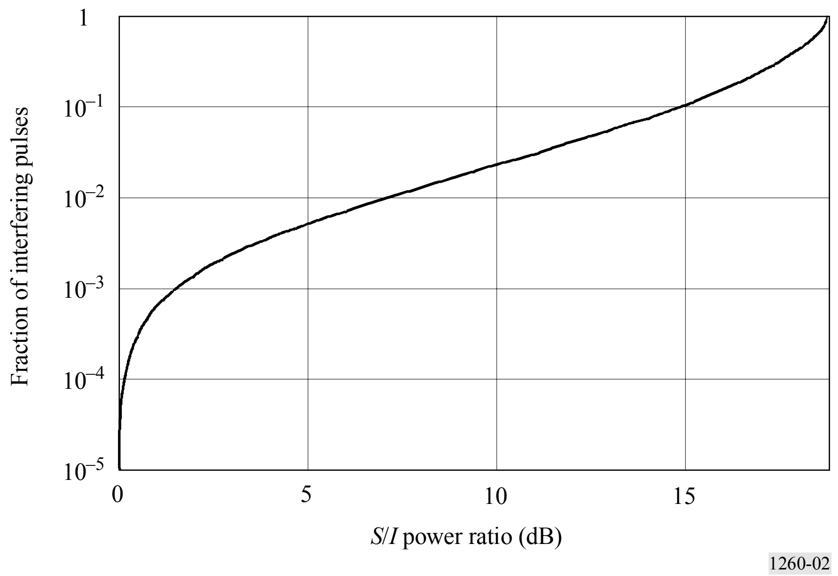
τ: length of the target pulses (note $B_r \tau \cong 1$ for a tracking radar)

S/I: S/I power ratio at the radar IF output (not in dB).

Figure 2 is a plot of the fraction of coincident pulses versus S/I at the radar IF output, allowing a 10% increase in the radar tracking error due to interference. The fraction of coincident pulses is approximately the sensor's duty cycle (6%), so an S/I of 13 dB corresponds to a 10% tracking error. It will be assumed that the S/I must be $\geq$ 13 dB for periods of time longer than 3 s. (Since the interference criterion has been developed based upon an interfering pulse being coincident with the radar's range gate, the peak interfering signal power should be used.)

FIGURE 2

Radar *S*/*I* as a function of fraction of coincident interfering pulses (10% increase in tracking error)



4 Example analysis of the unwanted signal from a spaceborne sensor to other services

4.1 Technical characteristics

4.1.1 Spaceborne sensor

Table 4 gives the technical characteristics of the representative spaceborne sensor used in the following analysis.

TABLE 4

Spaceborne SAR1 characteristics

Parameter	Value
Orbit height (km)	750
Orbit inclination (degrees)	98.4
Peak radiated RF power (W)	400
Average radiated RF power (W)	4.4
Pulse width (μs)	50
PRF (Hz)	2 200
Modulation of pulse	Linear FM
Pulse bandwidth (MHz)	4.8
Antenna peak gain (dB)	27.9
Antenna orientation (degrees)	37 from nadir
Antenna 1st side lobe (dB)	–17.6 from peak
Antenna 5th side lobe (dB)	–34 from peak

4.1.2 Airborne radars

Recommendation ITU-R M.1462 provides the characteristics and protection criteria for radars operating in the frequency band 420-450 MHz. Previous analyses concluded that spaceborne active sensors are not technically compatible with highly sensitive land-based space object tracking radars.

The computer simulation analysis considered the compatibility of spaceborne SARs with airborne radars in this frequency band. Shipboard radar results are similar to those of the airborne radar. The draft revision to the Recommendation lists the airborne receiver bandwidth as 1 MHz, and the radar antenna as a 22 dBi gain planar array. For the purposes of analysis, the antenna was assumed to be scanning in azimuth at a 0º elevation angle. The protection criterion for the radars is an I/N of –6 dB.

4.2 Analysis approach and results

4.2.1 Computer simulations

4.2.1.1 Processing gain

The analysis of the potential interference from spaceborne SARs into the radiolocation service receivers assumed no processing gain (that is, ability to reject the interference due to receiver signal processing). For the radiolocation systems, it may be appropriate to examine the potential response of the receiver to pulsed interfering signals such as from the SARs.

The details of a radar's resistance to interfering pulsed signals are generally not published. However, many modern radar receivers, particularly those which need to perform a surveillance function in the presence of significant clutter, will do digital Doppler processing in order to resolve targets against the clutter background. The effect of the FFT on the incoming pulsed interference will be to "smear" the peak pulse power over the neighbouring range/Doppler bins, and result in an averaged interfering power effect.

4.2.1.2 Radar interference criterion

An I/N equal to −6 dB is given as the protection criterion for the airborne radars in Recommendation ITU-R M.1462. No per cent of time or duration of time is given as permissible for interference to exceed this value. It is not appropriate to apply the concept of an allowed per cent of time that interference can exceed this value to radars, and particularly to surveillance radars such as the airborne radars considered in this analysis. The concept of data loss or permitted "outage" can be applied to a communications link or sensor system, but target detection – a basic and critical radar system function – occurs at an instant in time, and thus long-term outages are not relevant.

An approach used in a number of similar analyses in ITU-R, is to examine the simulation results with the assumption that a surveillance radar cannot be degraded for a period of time exceeding a single antenna scan. This means that a target may go undetected during the first scan period that detection may otherwise have successfully been accomplished. The airborne radars in this analysis have antenna rotation times on the order of 10 s. Thus, interference should not exceed $I/N = -6$ dB for longer than 10 s. (Under this assumption, a target with an 800 km/h velocity approaches another

~2 km after detection should have happened in the absence of interference. This may or may not be acceptable, depending upon the situation.) Upon examination of the results of the simulations (using both peak as well as average interfering power into the radars), it is evident that frequency sharing may be difficult between the spaceborne SARs and the radars.

4.2.1.3 Computer simulation results

Simulations were performed using the SAR1 type (see Table 5). Table 6 provides the results of computer simulations of the expected interference environment from spaceborne SAR1 into radiolocation service systems. All simulations were conducted in 2s time increments over a 60-day period. Note that two results with respect to the per cent of time that interference occurs are also given in Table 6.

The first is the per cent of time that the interference criterion is exceeded during periods when one or more SARs are visible (i.e. above the horizon) to the earth station(s); the second is the per cent of time that the interference criterion is exceeded out of the entire period simulated (i.e. including the times when no SAR is visible on some portions of the Earth).

TABLE 5

Peak/average pfd interference from main lobes and side lobes of P-band SAR1 at Earth's surface

Parameter	Value	dB
Transmitted power (W)	400.00	26.02
Peak main lobe antenna gain (dBi)	27.90	27.90
Antenna side-lobes level (dBi)	–6.10	–6.10
1/(4π)	7.96×10^{-2}	–10.99
1/(distance)^2 (km)	972.80	–119.76
1/Bandwidth (MHz)	1/4.80	–66.81
Pulse width (μs)	50	
PRF (Hz)	2 200	
Peak power density in main lobe (dBW)		–75.86
Peak power density in side lobe (dBW)		–109.86
Peak pfd in main lobe (dB(W/(m^2 · Hz)))		–143.6
Average pfd in main lobe (dB(W/(m^2 · Hz)))		–153.2
Peak pfd in side lobes (dB(W/(m^2 · Hz)))		–177.6
Average pfd in side lobes (dB(W/(m^2 · Hz)))		–187.2

TABLE 6

Computer simulation results

Receiver	Criterion	SAR1
Airborne radar	*I*/*N*, worst (dB)	36.2
	I/*N*, average (dB)	–4.4
	Per cent of time *I*/*N* > –6 dB (SAR visible) (%)	12.0
	Per cent of time *I*/*N* > –6 dB (All times) (%)	0.6
	Maximum time *I*/*N* > –6 dB (min)	4.8
	Average time *I*/*N* > –6 dB (s)	7.3
	Number of times *I*/*N* > –6 dB (events)	3 823

5 Procedure to use methodology

The average pfd of an active spaceborne sensor should be examined during the design stages. Equations (1) to (4) can be examined to determine parameters that can potentially be adjusted during the design of the spaceborne sensor, in order to improve sharing with the other services. Transmitter power, antenna gain (particularly side-lobe levels), pulse width and repetition rate, and chirp bandwidth are all likely candidates for adjustment.

When compatibility between a spaceborne sensor and a particular service system is analysed, the processing gain, if any, of the receiving system should be considered since the analysis assumed that there was none. This assumption is valid for the general case since not all receiving stations have processing gain.

For example, consider two radars operating in 420-450 MHz:

– a tracking radar with a 0.1 MHz IF bandwidth (radar 1)

– an airborne intercept radar with a 1 MHz IF bandwidth (radar 2).

If the spaceborne sensor of Table 4 can be operated with a different pulse width and chirp bandwidth such as in Table 7, then a significant reduction in the unwanted signal power level can be achieved.

TABLE 7

Example of reduction in received unwanted sensor power, via changes in sensor pulse width and chirp bandwidth

	New parameter values for SAR1		ΔOTR (dB)	ΔP_{avg} (dB)	ΔI (dB)
	τ (μs)	B_c (MHz)			
Radar 1	25	6	–4.0	Not available[(1)]	–4.0
Radar 2	25	6	–0.0	–3.0	–3.0

(1) It has been deemed appropriate to use average interference signal power for the airborne radar, and peak interference signal power for the tracking radar.

6 Conclusion

It has been demonstrated that it should be possible to reduce the pfd to improve the emission characteristics of active spaceborne sensor in order to enhance the compatibility with other services. Sensor transmitter power, antenna gain pattern, pulse width, PRF, and chirp bandwidth (if frequency modulation is used) are all possible characteristics that can be adjusted to improve compatibility.