

## 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**

(Question ITU-R 213/7)

(1997)

The ITU Radiocommunication Assembly,

*considering,*

- a) that active spaceborne sensors may be operated in common frequency bands with systems in the radiolocation and radionavigation services;
- b) that active spaceborne sensors may have technical characteristics which would cause unacceptable interference to terrestrial radars operating in frequency bands 1-10 GHz;
- c) that the last 20 years of experience in sharing the bands have shown no record of harmful interference occurrences;
- d) that some terrestrial radars are designed to provide an amount of processing gain with respect to certain types of pulsed interference;
- e) that the exact value of the processing gain of a terrestrial radar with respect to a particular type of pulsed interference may not be known;
- f) that some of the technical characteristics of spaceborne sensors can be adapted to enhance the compatibility with terrestrial radars, but this flexibility is limited by the sensor performance requirements,

*recommends*

- 1** that the methodology given in the Annex 1 may be used to improve the emission characteristics of active spaceborne sensors in order to enhance the compatibility with terrestrial radars operating in common frequency bands;
- 2** that when specific interference or sharing criteria have been established for a frequency band, these should be used rather than the generic criteria in the Annex 1.

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\* This Recommendation was developed jointly by Radiocommunication Study Groups 7 and 8, and future revisions should be undertaken jointly.

## 1 Introduction

A methodology is presented that allows an estimate to be made as to whether or not the unwanted signal received by a terrestrial radar from an active spaceborne sensor may cause difficulties if operated in common frequency bands. The calculations highlight a number of parameters of the sensor that can be chosen such that the sharing situation is improved.

The frequency bands below 10 GHz being considered by this methodology are 1 215-1 300 MHz, 3 100-3 300 MHz, 5 250-5 350 MHz, 8 550-8 650 MHz and 9 500-9 800 MHz. These are commonly called L-, S-, C-, and X-band (the latter two) by radar operators. The characteristics of these various bands are such that L- and S-bands are quite often used for search and surveillance radars, while C- and X-bands are often used for tracking radars.

## 2 Calculation of interference to terrestrial radars

The average interfering signal power level,  $I$  (dBW), received by a terrestrial radar from spaceborne is calculated from

$$I = 10 \log P_t + 10 \log (\tau PRF) + G_t + G_r - (32.44 + 20 \log (fR)) + OTR - PG \quad (1)$$

where:

- $P_t$ : peak spaceborne sensor transmitter power (W)
- $\tau$ : spaceborne sensor pulse width (s)
- $PRF$ : spaceborne sensor pulse repetition frequency (Hz)
- $G_t$ : spaceborne sensor antenna gain towards terrestrial radar (dBi)
- $G_r$ : terrestrial radar antenna gain towards spaceborne sensor (dBi)
- $f$ : frequency (MHz)
- $R$ : slant range between sensor and radar (km)
- $OTR$ : radar receiver on-tune rejection (dB)
- $PG$ : processing gain (dB), rejection of unwanted signals due to radar receiver signal processing (assumed to be zero if not known).

Equation (1) 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 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:

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

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

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:*

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

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

Input pulse with frequency modulation:

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

$$= 0 \quad \text{for } \frac{B_r^2 \tau}{B_c} > 1 \quad (4b)$$

where:

$B_r$ : terrestrial radar IF bandwidth

$B_c$ : chirp bandwidth of spaceborne sensor

$\tau$ : sensor pulse width.

### 3 Interference criteria for terrestrial radars

General interference criteria for the terrestrial radars have been postulated based upon preliminary work of JRG 7-8R; if specific criteria exist for specific systems or frequency bands, these should be used.

#### 3.1 Surveillance radars

It will be assumed that the received signal-to-noise 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 interference-to-noise 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

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 pulse repetition frequencies are related by integer multiples (Case I) or not (Case II). The fraction of coinciding pulses,  $f_c$ , is found from

$$f_c = \frac{GCF(PR F_i, PR F_g)}{PR F_g} \quad \text{for Case I} \quad (5a)$$

$$f_c = PR F_i (\tau_g + \tau_i) \quad \text{for Case II} \quad (5b)$$

where:

$PR F_i$ : interfering pulse frequency

$PR F_g$ : gate repetition frequency

$GCF(PR F_i, PR F_g)$ : greatest common factor of  $PR F_i$  and  $PR F_g$

$\tau_i$ : interfering pulse width

$\tau_g$ : 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 signal-to-interference ratio at the IF output is given as:

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

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

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)

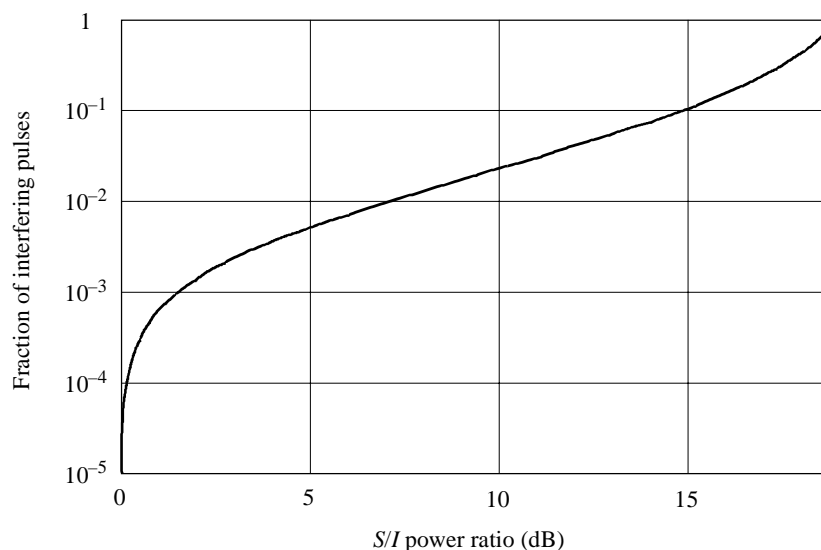
$B_r$ : 3 dB bandwidth of the radar IF filter

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

$S/I$ : signal-to-interference power ratio at the radar IF output (not in dB).

Figure 1 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 1  
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 terrestrial radars

### 4.1 Technical characteristics

#### 4.1.1 Spaceborne sensor

Table 1 gives the technical characteristics of the representative spaceborne sensor used in the following analysis. Tables 2, 3, 4, and 5 give the antenna gain characteristic of the spaceborne sensor.

TABLE 1  
Spaceborne synthetic aperture radars (SAR) characteristics

Parameter	Value
Orbit height (km)	400
Orbit inclination (degrees)	57
Transmit power (W)	1 500
Pulse width (μs)	33.8
PRF (Hz)	1 736
Duty cycle	0.059
Modulation of pulse	Linear FM
RF bandwidth (MHz)	10

TABLE 2  
Spaceborne SAR antenna gain pattern at 1 240 MHz

Pattern	Gain $G(\theta)$ (dBi) as a function of off-axis angle $\theta$ (degrees)	Angle range
Vertical (elevation)	$G_v(\theta_v) = 36.4 - 0.478(\theta_v)^2$ $G_v(\theta_v) = 33.8 - 1.0 \theta_v$ $G_v(\theta_v) = -11$	$0^\circ < \theta_v < 3.6^\circ$ $3.6^\circ < \theta_v < 45^\circ$ $\theta_v > 45^\circ$
Horizontal (azimuth)	$G_h(\theta_h) = 0.0 - 19.6(\theta_h)^2$ $G_h(\theta_h) = -24.5 - 0.47 \theta_h$ $G_h(\theta_h) = -30.5$	$0^\circ < \theta_h < 1.13^\circ$ $1.13^\circ < \theta_h < 12.7^\circ$ $\theta_h > 12.7^\circ$
Beam pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h), -11\} \max$	

TABLE 3  
Spaceborne SAR antenna gain pattern at 3 200 MHz

Pattern	Gain $G(\theta)$ (dBi) as a function of off-nadir angle (degrees)	Angular range
Elevation	$G_{el}(\theta_{el}) = 39.7 - 0.397(\theta_{el})^2$ $G_{el}(\theta_{el}) = 19.7$ $G_{el}(\theta_{el}) = 4.7$ $G_{el}(\theta_{el}) = 17.7$	$0^\circ < \theta_{el} < 7.1^\circ$ $7.1^\circ < \theta_{el} \leq 30^\circ$ $30^\circ < \theta_{el} \leq 60^\circ$ $60^\circ < \theta_{el} \leq 90^\circ$
Azimuth	$G_{az}(\theta_{az}) = 0.0 - 68.0(\theta_{az})^2$ $G_{az}(\theta_{az}) = -12.0$ $G_{az}(\theta_{az}) = 0.0 - 9.0(\theta_{az})$ $G_{az}(\theta_{az}) = -35.0$	$0^\circ < \theta_{az} < 0.42^\circ$ $0.42^\circ < \theta_{az} \leq 1.32^\circ$ $1.32^\circ < \theta_{az} \leq 3.9^\circ$ $\theta_{az} > 3.9^\circ$
Beam pattern	$G(\theta) = \{G_{el}(\theta_{el}) + G_{az}(\theta_{az}), -8\} \max$	

TABLE 4

## Spaceborne SAR antenna gain pattern at 5 300 MHz

Pattern	Gain $G(\theta)$ (dBi) as a function of off-axis angle $\theta$ (degrees)	Angle range
Vertical (elevation)	$G_v(\theta_v) = 42.7 - 0.478(\theta_v)^2$ $G_v(\theta_v) = 40.1 - 1.0 \theta_v$ $G_v(\theta_v) = -5$	$0^\circ < \theta_v < 3.6^\circ$ $3.6^\circ < \theta_v < 45^\circ$ $\theta_v > 45^\circ$
Horizontal (azimuth)	$G_h(\theta_h) = 0.0 - 442(\theta_h)^2$ $G_h(\theta_h) = -25.0 - 2.2 \theta_h$ $G_h(\theta_h) = -31$	$0^\circ < \theta_h < 0.24^\circ$ $0.24^\circ < \theta_h < 2.7^\circ$ $\theta_h > 2.7^\circ$
Beam pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h), -5\} \max$	

TABLE 5

## Spaceborne SAR antenna gain pattern at 8 600 and 9 650 MHz

Pattern	Gain $G(\theta)$ (dBi) as a function of off-axis angle $\theta$ (degrees)	Angular range
Vertical (elevation)	$G_v(\theta_v) = 44.0 - 0.397(\theta_v)^2$ $G_v(\theta_v) = 24.5$ $G_v(\theta_v) = 9.5$ $G_v(\theta_v) = 22.5$	$\theta_v < 7.1^\circ$ $7.1^\circ < \theta_v < 30^\circ$ $30^\circ < \theta_v < 60^\circ$ $\theta_v > 60^\circ$
Horizontal (azimuth)	$G_h(\theta_h) = 0 - 612.2(\theta_h)^2$ $G_h(\theta_h) = -12$ $G_h(\theta_h) = 0 - 27.0 \text{ dB } (\theta_h)$ $G_h(\theta_h) = -35$	$\theta_h < 0.14^\circ$ $0.14^\circ < \theta_h < 0.44^\circ$ $0.44^\circ < \theta_h < 1.3^\circ$ $\theta_h > 1.3^\circ$
Beam Pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h), -3\} \min$	

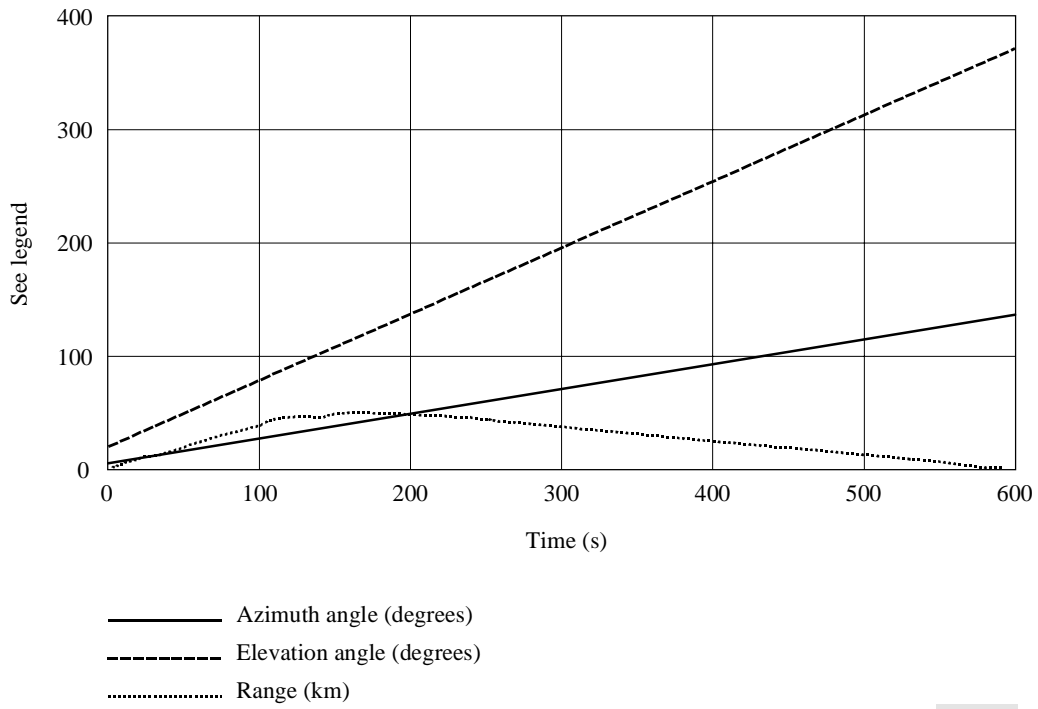
#### 4.1.2 Terrestrial radars

A sidelobe level of  $-5.38$  dBi (corresponding to the minimum gain for a 38 dBi gain antenna pattern) is used in the calculations for the surveillance radars, since mainbeam conjunctions are rare and very brief due to their scanning characteristics. Mainbeam coupling is more likely in the case of the tracking radars, which may point in a specific direction for long periods; a high gain (47 dBi) parabolic antenna gain pattern is used for the tracking radars. For both cases, a 1 MHz IF bandwidth, and a 5 dB noise figure are assumed.

## 4.2 Analysis approach and results

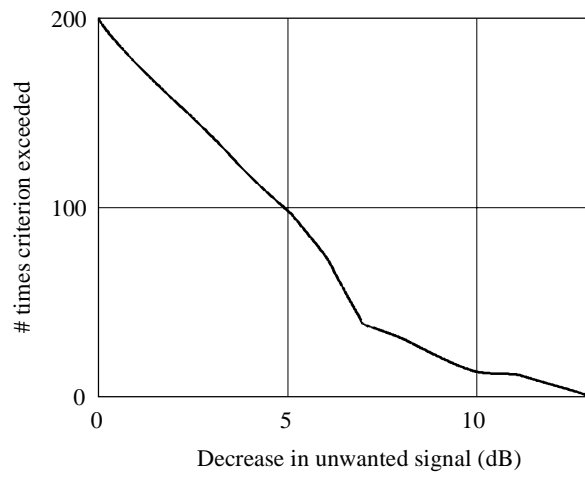
A simulation of 1500 orbits of the spaceborne sensor was performed. The tracking event – repeated throughout the simulation – assumed for the tracking radars (C- and X-band) is shown in Fig. 2. (A target with a 5 dB/m<sup>2</sup> radar cross section is used). The received unwanted signal was calculated throughout the period simulated, and compared to the criteria. The processing gain, as defined in equation (1), was assumed to be equal to zero. If the criteria were exceeded, the simulation was re-run with an incremental reduction in the received unwanted signal power. This was repeated until the criteria were not exceeded. The results for the sensor in Table 1 are shown in Figs. 3 to 6.

FIGURE 2  
Tracking event assumed for terrestrial tracking radar



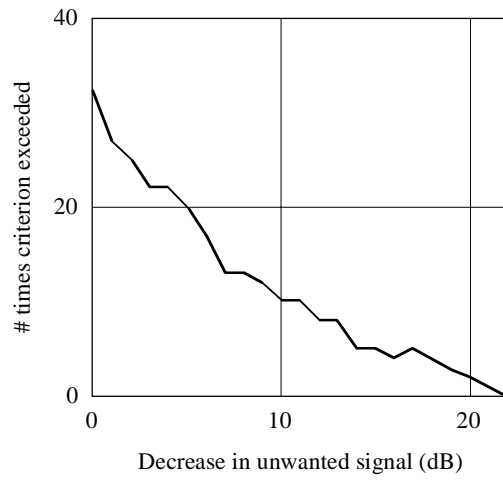
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FIGURE 3  
L-band radar (1 240 MHz)



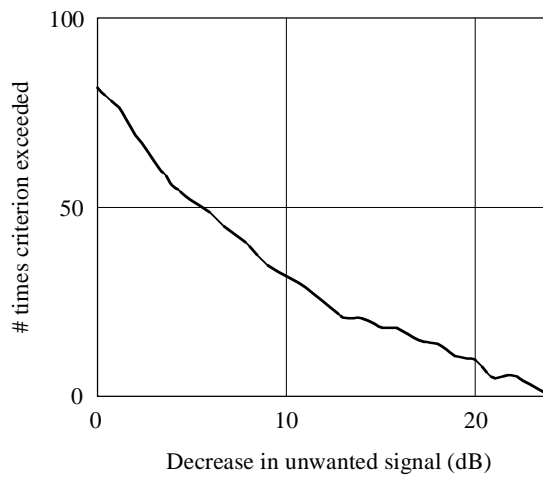
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FIGURE 4  
S-band radar (3 200 MHz)



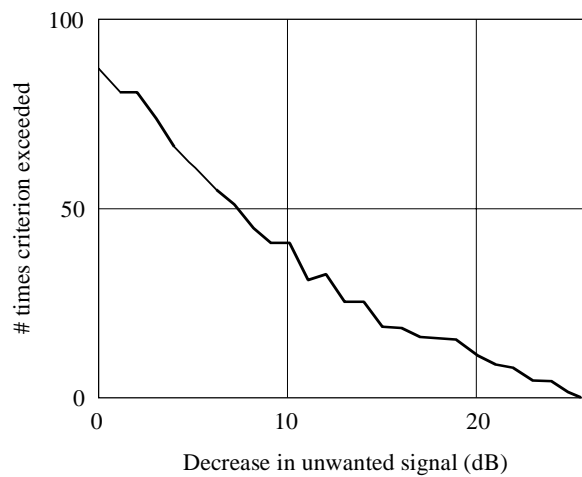
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FIGURE 5  
C-band radar (5 300 MHz)



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FIGURE 6  
X-band radar (8 600 MHz)



1280-06



## 5 Discussion of example analysis results

It can be seen from the Figs. 2 to 6 that regardless of whether tracking radars or surveillance radars are being considered, the sensor of Table 1 can potentially cause a significant number of interference events. However, a decrease in the unwanted signal power level received by the terrestrial radars can improve the situation dramatically. A reduction of around 13 and 20 dB, for the surveillance radars and tracking radars, respectively, can reduce the number of possible interference events to a number small enough that it is likely to be acceptable.

## 6 Procedure to use methodology

The peak or average power of an active spaceborne sensor should be examined during the design stages. If it is not in the range of 13 to 20 dB below that of the example sensor of Table 1, then unacceptable interference into a terrestrial surveillance or tracking radar, respectively, is possible (see Note 1). 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 terrestrial radars. Transmitter power, antenna gain (particularly sidelobe levels), pulse width and repetition rate, and chirp bandwidth are all likely candidates for adjustment.

NOTE 1 – When compatibility between a spaceborne sensor and a particular terrestrial radar is analysed, the processing gain, if any, of the terrestrial radar should be considered since the analysis assumed that there was none. This assumption is valid for the general case since not all radars have processing gain. If all radars within a band have some processing gain a single value will need to be determined.

For example, consider two radars operating in 9 500-9 800 MHz:

- a tracking radar with a 1 MHz IF bandwidth (radar 1)
- an airborne intercept radar with a 5 MHz IF bandwidth (radar 2).

If the spaceborne sensor of Table 1 can be operated with a different pulse width and chirp bandwidth such as in Table 6, then a significant reduction in the unwanted signal power level can be achieved. The reduction in unwanted signal power level obtained in this example is of the order of that needed to reach the improved sharing situation desired.

TABLE 6

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

	New parameter values		$\Delta OTR$ (dB)	$\Delta P_{avg}$ (dB)	$\Delta I$ (dB)
	$\tau$ ( $\mu s$ )	$B_c$ (MHz)			
Radar 1	3	280	-19.7	NA <sup>(1)</sup>	-19.7
Radar 2	3	280	-5.7	-10.5	-16.2

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

## 7 Conclusion

It has been demonstrated that it should be possible to meet the protection criteria for terrestrial radars through selection of active spaceborne sensor parameters with this goal in mind. Sensor transmitter power, antenna gain pattern, pulse width, pulse repetition frequency, and chirp bandwidth (if frequency modulation is used) are all possible characteristics that can be adjusted to improve compatibility.