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STEERING GROUP ON RADIO FREQUENCY COORDINATION

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ITEM 3.1

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INTERFERENCE PROTECTION CRITERIA FOR METEOROLOGICAL RADARS

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Summary and Purpose of Document

This document discusses work currently in progress within the ITU-R (Working Part 8B) for developing protection criteria for meteorological radars.

Action Proposed

The SG-RFC should consider/debate the appropriate protection criteria to be applied to meteorological radars and develop a WMO position. As an output to the meeting, the SG-RFC should produce a submission to the May 2002 meeting of Working Party 8B that proposes an appropriate protection criteria for meteorological radars.

INTERFERENCE PROTECTION CRITERIA FOR METEOROLOGICAL RADARS

1.0 Introduction.

Increased interest in sharing radar bands with other radio services has prompted the ITU-R to develop protection criteria for radars, including meteorological radars. During the last several meetings of ITU-R Working Party 8B discussions have been held on the appropriate protection criteria for meteorological radars. In the past the ITU-R has taken the approach that radars that perform a safety-of-life function, as defined in the ITU-R Radio Regulations, require a maximum I/N protection value of –6 dB and in some cases a I/N value of –10 dB is justified. The general consensus was that an I/N value of –6 dB was sufficient for protection of meteorological radars. During the October 2001 meeting of Working Party 8B, proposals were made that radars performing safety-of-life functions should be protected with an I/N of –12 dB and meteorological radars should be protected by an I/N of –10 dB. Little written justification was submitted to the meeting for the change from –6 to –10 dB for meteorological radars.

2.0 Discussion.

Annex 1 to this document contains the two ITU-R Recommendations under development by Working Party 8B that contain protection criteria for meteorological radars. The first is a revision of an approved recommendation on radars operated in the 2700-2900 MHz band. The second document is a new recommendation that applies to C-band (5 GHz) radars. As can be seen in the recommendation on C-band radars, an I/N value of –10 dB has tentatively been placed in the document for meteorological radars. The value is in square brackets indicating that agreement has not been reached within Working Party 8B on the final value. In the revision of ITU-R Recommendation M.1464 the I/N value remains at –6 dB for meteorological radars.

Section 2.1 provides a brief analysis of the effect each I/N value will have on the range performance of a meteorological radar. These calculations can form the basis for the appropriate I/N value to be applied to meteorological radars. A range of I/N values were analysed and the results are presented in Table 1. The objective is to provide the WMO SG-RFC some guidance in selecting the appropriate I/N value so that a WMO proposal/recommendation can be made to ITU-R Working Party 8B. The information in the analysis can also provide part of the justification for the value selected.

2.1 Analysis- effect of interference on radar range performance.

One major effect the presence of interference can have on a radar receiver is desensitisation. As interference levels increase, the effective noise (thermal noise + interference) that the receiver must process increases. This leads to a decreased sensitivity and a reduction in maximum range that the radar can detect targets. The radar equation, in one of its basic forms, can be used to estimate the effect of interference on radar range performance. The equation is shown below:

$$R_{max}^4 = \frac{P_t \, A_e^2 \, \sigma}{4\pi \lambda \, S_{min}} \qquad \text{(equation 1)}$$

where,

R_{max} = Maximum radar range

P_t = Radar transmitter power

A_e = Radar antenna effective aperture

σ = Minimum target radar cross section

λ = Radar carrier wavelength

S_{min} = Radar minimum detectable signal.

In the case of this analysis, the objective is to determine the percentage that the maximum radar range is decreased for a given I/N value. In this situation where the only change in environment that the radar is operating in is the introduction of interference signals, the values for P_t, A_e, σ, and λ do not change. Since the minimum detectable signal (S_{min}) is directly related to the radar receiver noise level, an increase in total noise power caused by an introduction of interference will result in a directly proportional increase in the minimum detectable signal level.

Since the values for P_t, A_e, σ, and λ are constant with introduction of interference, the radar equation can be rewritten as:

$$R_{max}^4 = \frac{C}{S_{min}} \qquad \text{(equation 2)}$$

or $$C = (S_{min})(R_{max}^4) \qquad \text{(equation 3)}$$

where C is a constant.

In an environment where interference is present and the radar is operating at a new, higher minimum detectable signal, the value of C remains the same, but the equation can be written as:

$$C = (S'_{min})(R'^4_{max}) \qquad \text{(equation 4)}$$

where,

S'_{min} = New minimum detectable signal with interference present

R'_{max} = New radar maximum range with interference present.

The calculation of the new minimum detectable signal can be written as:

$$S'_{min} = (P_{incr}) \ (S_{min}) \qquad \text{(equation 5)}$$

where P_{incr} is the percentage increase in total noise power (N+I) due to presence of interference relative to simply the receiver thermal noise. Since C is a constant, combining equations 3 and 4, a calculation for the effect of interference on radar maximum range can be performed.

$$(S_{min}) \ (R_{max}^4) = (S'_{min}) \ (R'^4_{max}) \qquad \text{(equation 6)}$$

The percentage of reduction in maximum radar range in the presence of interference can then be calculated.

$$P_{range} = \frac{R'_{max}}{R_{max}} = 1 / (P_{incr})^{-0.25} \qquad \text{(equation 7)}$$

Table 1- Analysis Results for the Effect of Interference on Radar Maximum Range

I/N (dB)	P_{INCR} - Percentage of Total Noise Relative to Radar Thermal Noise Due to Interference (%)	P_{RANGE} - Percentage of Range Reduction (%)
-5	137	7.6
-6	125	5.4
-7	120	4.4
-8	116	3.6
-9	113	3.0
-10	110	2.3
-11	108	1.9
-12	106	1.4

3. Conclusion.

The results in Table 1 show that I/N values of approximately –6 dB can produce significant losses in radar range performance. Meteorological radar networks are designed to so that the radar coverage areas overlap in order to prevent holes in the coverage. However, the overlap distances are minimized as much as possible due to limited funding and spectrum resources. Reduced range will require more radars for equivalent coverage. The WMO SG-RFC should consider the effects shown in Table 1 as well as other effects that interference can have on radar performance. The SG-RFC should develop a WMO submission to ITU-R Working Party 8B making a recommendation for an appropriate I/N value and providing a justification for that value. While it is in the best interest of the meteorological users to set the I/N value as low as possible, caution should also be exercised. The value proposed should be reasonable and defendable.

There are some additional considerations that could be included in the submission to the ITU-R. During the last several ITU-R Working Party 8B meetings at least one administration proposed the ITU-R should not publish protection criteria for radars, including meteorological radars, but should make the protection criteria values that are negotiated on a case-by-case basis. According to ITU-R procedures inference criteria in Recommendations are not binding regulatory values. They are simply recommended values for conducting sharing studies. As such, they are used to determine compatibility. If analysis shows compatibility using the published criteria, then no further work is required. If the analysis using the published criteria shows incompatibility, the option is always available to negotiate more appropriate criteria based on specific system characteristics.

A second consideration that could be included in the submission to the ITU-R is a proposal for the appropriate percentage time that the radar protection criteria may be exceeded. Historically, the argument has been made that the interference criteria may not be exceeded for any percentage of time (0%). The interpretation, by other radio services, of that claim is that the meteorological radar users are not willing to accept any interference. In fact, the users are willing to accept interference up to the I/N threshold, but harmful interference occurring above that threshold cannot be accepted at any time. The SG-RFC should come to agreement on the appropriate percentage of time that should be applied to the proposed I/N value.

Finally, the two recommendations attached in Annex 1 may be approved by the ITU-R before the next meeting of the SG-RFC. Therefore, a thorough review should be conducted at this meeting to ensure the text is in line with WMO objectives.

ANNEX 1-
WP 8B Documents Pertaining
to Protection Criteria for Meteorological Radars

PRELIMINARY DRAFT REVISION OF RECOMMENDATION ITU-R M.1464*

Characteristics of and protection criteria for radionavigation and meteorological radars operating in the frequency band 2 700-2 900 MHz

(Question ITU-R 35/8)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that antenna, signal propagation, target detection, and large necessary bandwidth characteristics of radar to achieve their functions are optimum in certain frequency bands;

b) that the technical characteristics of radionavigation and meteorological radars are determined by the mission of the system and vary widely even within a band;

c) that the radionavigation service is a safety service as specified by RR No. S4.10 and harmful interference to it cannot be accepted;

d) that considerable radiolocation and radionavigation spectrum allocations (amounting to about 1 GHz) have been removed or downgraded since WARC-79;

e) that some ITU-R technical groups are considering the potential for the introduction of new types of systems (e.g. fixed wireless access and high density fixed and mobile systems) or services in bands between 420 MHz and 34 GHz used by radionavigation and meteorological radars;

f) that representative technical and operational characteristics of radionavigation and meteorological radars are required to determine the feasibility of introducing new types of systems into frequency bands in which the latter are operated;

g) that procedures and methodologies are needed to analyse compatibility between radionavigation and meteorological radars and systems in other services;

h) that ground-based radars used for meteorological purposes are authorized to operate in this band on a basis of equality with stations in the aeronautical radionavigation service (see RR No. S5.423);

j) that aeronautical radionavigation and meteorological radars operate in the 2 700-2 900 MHz band,;

[k) that radars in this band are employed for airfield surveillance which is a highly safety critical service at civil airports, providing collision avoidance guidance to aircraft during approach and landing. Aviation regulatory authorities to ensure and preserve safety, impose mandatory standards for performance and service degradation,]

* This Recommendation should be brought to the attention of the International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO).

recommends

1 that the technical and operational characteristics of the aeronautical radionavigation and meteorological radars described in Annex 1 be considered representative of those operating in the frequency band 2 700-2 900 MHz;

2 that Recommendation ITU-R M.1461 be used as a guideline in analysing compatibility between radionavigation and meteorological radars with systems in other services;

3 that the criterion of interfering signal power to radar receiver noise power level (*I*/*N*) of –6 dB be used as the required protection level for the radionavigation and meteorological radars, and that the criterion (*I*/*N*) of –10 dB be used as the required protection level for safety-of-life per S1.59 and S4.10 radionavigation radars. These protection criteria and that this represents the net protection level if multiple interferers are present.

[OR

3 that the criterion of interfering signal power to radar receiver noise power level *(I/N)* of –6 dB be used as the required protection level for the radionavigation and meteorological radars, and that this represents the net protection level if multiple interferers are present. and that the criterion (I/N) for the required protection level for safety-of-life (per S1.59 and S4.10) radionavigation radars should be determined by an analysis taking into account the type of interference signal and the type of radar.

For the safety radionavigation radars, an I/N ratio not greater than –12 dB has been shown necessary. The actual I/N ratio might be more stringent (lower than –12 dB) depending of the result of the analysis.]

NOTE 1 – This Recommendation will be revised as more detailed information becomes available. It should be noted that work is already in progress within ITU-R addressing specifically the compatibility between radars in the band 2 700-2 900 MHz and IMT-2000 systems.

Annex: 1

ANNEX 1

Characteristics of aeronautical radionavigation and meteorological radars

1 Introduction

The band 2 700-2 900 MHz is allocated to the aeronautical radionavigation service on a primary basis and the radiolocation service on a secondary basis. Ground-based radars used for meteorological purposes are authorized to operate in this band on a basis of equality with stations in the aeronautical radionavigation service (see RR No. S5.423).

The aeronautical radionavigation radars are used for air traffic control (ATC) at airports, and perform a safety service (see RR No. S4.10). Indications are that this is the dominant band for terminal approach/airport surveillance radars for civil air traffic worldwide. The meteorological radars are used for detection of severe weather elements such as tornadoes, hurricanes and violent thunderstorms. These weather radars also provide quantitative area precipitation measurements so important in hydrologic forecasting of potential flooding. This information is used to provide warnings to the public and it therefore provides a safety-of-life service.

2 Technical characteristics

The band 2 700-2 900 MHz is used by several different types of radars on land-based fixed and transportable platforms. Functions performed by radar systems in the band include ATC and weather observation. Radar operating frequencies can be assumed to be uniformly spread throughout the band 2 700-2 900 MHz. The majority of systems use more than one frequency to achieve the benefits of frequency diversity. Two frequencies are very common and the use of four is not unknown. Table 1 contains technical characteristics of representative aeronautical radionavigation and meteorological radars deployed in the 2 700-2 900 MHz band. This information is sufficient for general calculation to assess the compatibility between these radars and other systems.

2.1 Transmitters

The radars operating in the band 2 700-2 900 MHz use continuous wave (CW) pulses and frequency modulated (chirped) pulses. Cross-field, linear beam and solid state output devices are used in the final stages of the transmitters. The trend in new radar systems is toward linear beam and solid state output devices due to the requirement of Doppler signal processing. Also, the radars deploying solid state output devices have lower transmitter peak output power and higher pulsed duty cycles approaching 10%. There is also a trend towards radionavigation radar systems that use frequency diversity.

Typical transmitter RF emission bandwidths of radars operating in the band 2 700-2 900 MHz range from 66 kHz to 6 MHz. Transmitter peak output powers range from ~~25~~ 22 kW (~~74~~ 73.4 dBm) for solid state transmitters, 70 kW (78 dBm) for TWT systems, to 1.4 MW (91.5 dBm) for high power radars using klystrons and magnetrons.

In the high peak power systems it is normal to have a single transmitter per frequency and these tend to have narrow-band output stages. The lower peak power systems using TWTs or solid state have single transmitters capable of multi-frequency operation. They thus have wideband output stages capable of multi-frequency use.

TABLE 1

Characteristics of aeronautical radionavigation~~/meteorological~~ radars in the band 2 700-2 900 MHz

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E*	Radar XX
Platform type (airborne, shipborne, ground)	Ground, ATC					Ground, ATC
Tuning range (MHz)	2 700-2 900					2 700-2 900 (4)
Modulation	P0N		P0N, Q3N	P0N	PON, Q3N	PON, Q3N
Tx power into antenna	1.4 MW	1.32 MW	25 kW	450 kW	22 kW	70 kW
Pulse width (µs)	0.6	1.03	1.0, 89	1.0	1.0, 55.0	0.4, 20 0.5, 27 (2)
Pulse rise/fall time (µs)	0.15-0.2		0.5/0.32 (short pulse) 0.7/1 (long pulse)			0.1 Typical
Pulse repetition rate (pps)	973-1 040 (selectable)	1 059-1 172	722-935 (short pulse) 788-1 050 (long pulse)	1 050	8 sets, 1031 to 1080	1100 840 (2)
Duty cycle (%)	0.07 maximum	0.14 maximum	9.34 maximum	0.1 maximum		2% typical
Chirp bandwidth (MHz)	Not applicable		2	Not applicable	1.3 MHz NLFM	2 MHz
Phase-coded sub-pulse width	Not applicable					
Compression ratio	Not applicable		89	Not applicable	55	40:1 55:1
RF emission bandwidth: –20 dB 3 dB	6 MHz	5 MHz 600 kHz	2.6 MHz (short pulse) 5.6 MHz (long pulse) 1.9			3 MHz Typical 2 MHz
Output device	Klystron		Solid state transistors, Class C	Magnetron	Solid state transistors, Class C	TWT
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Cosecant-squared +30°		Cosecant-squared 6° to +30°			Cosecant-Squared Enhanced to +40 degrees
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic reflector					
Antenna polarization	Vertical or LHCP	Vertical or RHCP	Circular or linear	Vertical or LHCP	Vertical or RHCP	LHC
Antenna mainbeam gain (dBi)	33.5		34	32.8	34.3 low beam 33 high beam	33.5

* Note by the Secretariat: The new column E represents a different radar and replaces the previous column E.

TABLE 1 (*continuedend*)

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar XX
Antenna elevation beamwidth (degrees)	4.8			4	4.8	5.0
Antenna azimuthal beamwidth (degrees)	1.35	1.3	1.45	1.6	1.4	1.5
Antenna horizontal scan rate (degrees/s)	75			90	75	90 60 (2)
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	360°					360°
Antenna vertical scan rate (degrees/s)	Not applicable					Not applicable
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	Not applicable		+2.5 to –2.5	Not applicable	Not applicable	Not applicable
Antenna sidelobe (SL) levels (1st SLs and remote SLs)		+7.3 dBi	+9.5 dBi 3.5°			+7.5 dBi 0 to –3 dBi
Antenna height (m)	8					8 to 24m
Receiver IF 3 dB bandwidth	5.0 MHz	653 kHz	15 MHz		1.2 MHz	4.0 MHz
Receiver noise figure (dB)	4.0 maximum		3.3	2.7	2.1	2.0
Minimum discernible signal (dBm)	–110	–108	–110	–112		–110 typical
Receiver front-end 1 dB gain compression point (dBm)		–20				–10
Receiver on-tune saturation level (dBm)		–45				
Receiver RF 3 dB bandwidth	2-2.3 MHz	10 MHz	280.6 MHz			400 MHz (4)
Receiver RF and IF saturation levels and recovery times						
Doppler filtering bandwidth (Hz)		95 per bin				
Interference-rejection features	Feedback enhancer	(1)				
Geographical distribution	Worldwide					
Fraction of time in use (%)	100					

(1) Sensitivity time control (STC), constant false alarm rate (CFAR), selectable pulse repetition frequencies (PRFs), asynchronous pulse rejection, Doppler filtering, saturating pulse removal.

(2) Doppler filtering and saturating pulse removal.

(2) Depends on Range.

(3) Fixed systems operate up to 750 kW or 1 MW.

(4) 2.7 to 3.1 GHz.

TABLE 2

Characteristics of meteorological radars in the band 2 700-2 900 MHz

Characteristics	**Radar F**	**Radar G**
Platform type (airborne, shipborne, ground)	Ground, weather	Ground, weather
Tuning range (MHz)	2 700-3 000	2 700-2 900
Modulation	PON	
Tx power into antenna	500 kW	400 or 556 kW
Pulse width (µs)	1.6 (short pulse) 4.7 (long pulse)	1.0 (short pulse) 4.0 (long pulse)
Pulse rise/fall time (µs)	0.12	
Pulse repetition rate (pps)	318-1 304 (short pulse) 318-452 (long pulse)	539 (short pulse) 162 (long pulse)
Duty cycle (%)	0.21 maximum	
Chirp bandwidth (MHz)	Not applicable	Not applicable
Phase-coded sub-pulse width	Not applicable	Not applicable
Compression ratio	Not applicable	Not Applicable
RF emission bandwidth: –20 dB 3 dB	 4.6 MHz 600 kHz	
Output device	Klystron	Coaxial magnetron
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic reflector	Parabolic reflector
Antenna polarization	Linear: vertical and horizontal	Linear: horizontal
Antenna mainbeam gain (dBi)	45.7	38.0

TABLE 2 (*continued*)

Characteristics	**Radar F**	**Radar G**
Antenna elevation beamwidth (degrees)	0.92	2.0
Antenna azimuthal beamwidth (degrees)	0.92	2.0
Antenna horizontal scan rate (degrees/s)	18	18 and full manual slewing
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	360° and sector	360° and sector
Antenna vertical scan rate (degrees/s)	14 steps in 5 min	
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	Fixed steps: 0.5-20	–2.0 to +60 degrees
Antenna sidelobe (SL) levels (1st SLs and remote SLs)	+20 dBi	+15 dBi (estimated)
Antenna height (m)	30	30
Receiver IF 3 dB bandwidth	630 kHz	0.25 MHz long pulse) 0.5 MHz (short pulse)
Receiver noise figure (dB)	2.1	9.0
Minimum discernible signal (dBm)	–115	–110
Receiver front-end 1 dB gain compression point (dBm)	–17	–32
Receiver on-tune saturation level (dBm)	–10	
Receiver RF 3 dB bandwidth	1.6 MHz	0.5 MHz (long pulse 1.5 MHz (short pulse)
Receiver RF and IF saturation levels and recovery times	–10 dBm, 1 µs	
Doppler filtering bandwidth (Hz)	Estimate 95	
Interference-rejection features	(2)	
Geographical distribution	Worldwide	Worldwide
Fraction of time in use (%)	100	100

(2) Doppler filtering and saturating pulse removal.

2.2 Receivers

The newer generation radar systems use digital signal processing after detection for range, azimuth and Doppler processing. Generally, included in the signal processing are techniques used to enhance the detection of desired targets and to produce target symbols on the display. The signal processing techniques used for the enhancement and identification of desired targets also provides some suppression of low-duty cycle interference, less than 5%, that is asynchronous with the desired signal.

Also, the signal processing in the newer generation of radars use chirped pulses which produce a processing gain for the desired signal and may also provide suppression of undesired signals.

Some of the newer low power solid state transmitters use high-duty cycle, multiple receiver channel signal processing to enhance the desired signal returns. Some radar receivers have the capability to identify RF channels that have low undesired signals and command the transmitter to transmit on those RF channels.

In general high peak power systems tend to use one receiver per frequency and thus have narrow band RF front ends. The lower power systems tend to have wideband RF front ends capable of receiving all frequencies without tuning followed by coherent superset receivers. Systems which use pulse compression have their IF bandwidth matched to the expanded pulse and act as matched filters for minimum signal to noise degradation.

2.3 Antennas

Only parabolic reflector-type antennas are used on radars operating in the 2 700-2 900 MHz band. The ATC radars have a cosecant-squared elevation pattern, while the meteorological radars have a pencil beam antenna pattern. Since the radars in the 2 700-2 900 MHz band perform ATC and weather observation functions the antennas scan 360° in the horizontal plane. Horizontal, vertical and circular polarizations are used. Newer generation radars using reflector-type antennas have multiple horns. Dual horns are used for transmit and receive to improve detection in surface clutter. Also, multiple horns, stack beam, reflector antennas are used for three-dimensional radars. The multiple horn antennas will reduce the level of interference. Typical antenna heights for the aeronautical radionavigation and meteorological radars are 8 m and 30 m above ground level, respectively.

3 Protection criteria

[3.1 Desensitization]

The desensitizing effect on radionavigation and meteorological radars from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power [~~spectral density~~] can simply be added to the power [~~spectral density~~] of the radar receiver thermal noise, to within a reasonable approximation. For example, ~~If~~ if power [~~spectral density~~] of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power [~~spectral density~~] becomes simply $I_0 + N_0$. An increase [in noise power] of about 1 dB for the radiolocation service would constitute significant degradation.~~, equivalent to a detection-range reduction of about 6%.~~ Such an increase corresponds to an $(I + N)/N$ ratio of 1.26, or an I/N ratio of about –6 dB. For the radionavigation service, considering the safety-of-life function, [a noise power] increase of [a fraction of 1 dB constitutes] significant degradation.

[~~This represents the aggregate effects of multiple interferers, when present; the tolerable I/N ratio for an individual interferer depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario.~~]

[For the safety radionavigation service, an I/N ratio not greater than –12 dB has been shown necessary. The actual I/N ratio might be more stringent (lower than –12 dB) depending of the result of compatibility analysis, taking into account the type of interference signal and the type of radar. The maximum tolerable contribution of an individual interferer to the tolerable I/N ratio of a victim receiver depends on the number of interferers their spatial distribution and their signal structure, and needs to be assessed in the course of analysis of a given scenario]. If [~~CW~~] interference were received from [severalmost] azimuth directions, [a lower *I/N* ratio would need to be maintained, an aggregation analysis has to cumulate simultaneous contributions from all these directions, being received via the radar antenna's main and/or side lobes, in order to arrive at the actual overall I/N ratio. The aggregated overall received interference signal level at the input of the victim receiver is to be compared against the tolerable I/N ratio of the specific victim receiver.].

The aggregation factor can be very substantial in the case of certain communication systems, in which a great number of stations can be deployed.

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receivers/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation can be inflicted by such desensitization. Assessing it will be an objective for analyses of interactions between specific radar types. In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low-duty cycle pulsed interference are contained in Recommendation ITU-R M.1372 – Efficient use of the radio spectrum by radar stations in the radionavigation service.

The effect of pulsed interference and its acceptable level, depends heavily on the use of the radar and the level of integrity required. It is difficult to provide a definitive level for acceptable pulsed interference, even for a given class, or type, of radar. The effects of pulsed interference need to be assessed on a case by case basis taking account of the role of the radar.

[3.2 Considerations relating to the choice of a propagation model

Extensive study of available propagation models, such as those in Recommendation ITU-R P.452-9, Recommendation ITU-R P.530 and others have been made. A distinction must be made, and caution observed, between models for radio link planning, and for interference protection planning. The former generally deal with "wanted signal" and are aimed at identification of the probability of high attenuation, whilst those for the latter address "unwanted signal" to provide information on lowest possible attenuation in relation to the percentage of time during which attenuation falls below a certain value. Because of their operational requirement, radar systems used for air traffic purposes in general, and airport surveillance in particular, require to be protected against interference, both for long-term and for short-term periods stated in seconds. Where the interfering signal can originate without location identification over an area and be of short duration, special caution must be observed. In the general case account must therefore be taken of all signal enhancement effects, and of the absence of any shielding offered by terrain or man made obstructions. Models such as that due to Hata, and similar, are not considered suitable for interference assessment in this case. Careful study has led to the conclusion that propagation loss calculation for interference site separation determination has to stay at the basis of conservative and pessimistic. That is, they have to apply line of sight conditions plus atmospheric gas losses (0.0075 dB/Km (one way) at the frequencies in question), plus possible short-term enhancements as described by Recommendation ITU-R P.452 ($E_s(p)$). In individual cases where accurate data is available, a detailed path analysis and loss calculation may be carried out, or where the actual path loss between the interferers site and the victim radar are determined experimentally for all frequencies of interest, may be accepted. Such detailed calculation, as well as experimental assessment of path loss, must take into account possible short- and long-term changes of atmospheric and ground condition parameters.]

4 Operational characteristics

4.1 Meteorological radars

The technical characteristics of a representative weather radars, that predominately operate~~s~~ in the 2 700-2 900 MHz band, are depicted in Table ~~1~~ 2 as radars ~~E~~F and G. However, ~~this r~~Radar F can operate up to 3 000 MHz. ~~This is~~These are the primary weather radar systems used for flight planning activities and is often collocated at airports worldwide, to provide accurate weather conditions for aircraft. Therefore, these radars are also in operation 24 h per day.

~~This r~~Radar F utilizes Doppler radar technology to observe the presence and calculate the speed and direction of motion of severe weather elements such as tornadoes, hurricanes and violent thunderstorms. Radar ~~E~~ F also provides quantitative area precipitation measurements so important in hydrologic forecasting of potential flooding. The severe weather and motion detection capabilities offered by this radar contributes toward an increase in the accuracy and timeliness of warning services. Radar ~~E~~F excels in detecting the severe weather events that threaten life and property, from early detection of damaging winds to estimating rainfall amounts for use in river and flood forecasting. Radar G is a non-Doppler radar used in many countries.

~~These radars~~Radar F is used in ~~are~~ an integrated network spanning the entire United States of America, Guam, Puerto Rico, Japan, South Korea, China and Portugal. The 2 700-2 900 MHz band offers excellent meteorological and propagation characteristics for weather forecast and warning capabilities. Planned enhancements to the radar should extend its service life to the year 2040.

The World Meteorological Organization reports that more than 320 meteorological radars operate in this band in at least 52 countries throughout the world.

4.2 Aeronautical radionavigation radars

Airport surveillance radars operate throughout the world in the band 2 700-2 900 MHz. ~~Four~~ Five representative types of ATC radars are depicted in Table 1, as radars A through radar ~~D~~XX. These radars perform airport surveillance for terminal approach control and normally require surveillance of a full 360° sector use on a round-the-clock schedule. Radars A ~~through~~ C, ~~and~~ E and XX are typically located at airports and every major airport is usually equipped with one or more ~~a~~ similar radar systems. Radars A, ~~and~~ B and XX are the current generation of radars deployed. Radars C and E are~~is~~ representative of the next generation systems, although many have now been deployed and are representative of some currently used technology and these ~~which~~ should augment and/or replace radars A, ~~and~~ B and eventually XX after the year 2010. Radar D is a transportable system used for ATC at airfields where there are no existing facilities. There are also however, still significant numbers of this type of non-coherent magnetron radar on fixed sites around the world. These generally operate with peak powers of approximately 1 MW. When in use, radar D is operated 24 h per day. Some of these radars operate in a frequency diversity mode, which requires two and, in some cases, four frequency assignments per radar.

PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[8B-CHAR]

Characteristics of and protection criteria for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz

Summary

This Recommendation describes the technical and operational characteristics of, and protection criteria for, radars operating in the frequency band 5 250-5 850 MHz. These characteristics are intended for use when assessing the compatibility of these systems with other services.

The ITU Radiocommunication Assembly,

considering

a) that antenna, signal propagation, target detection, and large necessary bandwidth characteristics of radar to achieve their functions are optimum in certain frequency bands;

b) that the technical characteristics of radiolocation, radionavigation and meteorological radars are determined by the mission of the system and vary widely even within a band;

c) that the radionavigation service is a safety service as specified by RR No. S4.10 and requires special measures to ensure its freedom from harmful interference;

d) that considerable radiolocation and radionavigation spectrum allocations (amounting to about 1 GHz) have been removed or downgraded since WARC-79;

e) that some ITU-R technical groups are considering the potential for the introduction of new types of systems (e.g. fixed wireless access and high density fixed and mobile systems) or services in bands between 420 MHz and 34 GHz used by radionavigation, radiolocation and meteorological radars;

f) that representative technical and operational characteristics of radiolocation, radionavigation and meteorological radars are required to determine the feasibility of introducing new types of systems into frequency bands in which the latter are operated;

g) that procedures and methodologies to analyse compatibility between radars and systems in other services are provided in ITU-R M.1461;

h) that radiolocation, radionavigation and meteorological radars operate in the bands between 5 250-5 850 MHz;

j) that ground-based radars used for meteorological purposes are authorized to operate in the band 5 600-5 650 MHz on a basis of equality with stations in the aeronautical radionavigation service (see RR No. S5.452), *recommends*

1 that the technical and operational characteristics of the radiolocation, radionavigation and meteorological radars described in Annex 1 be considered representative of those operating in the frequency bands between 5 250 and 5 850 MHz (see NOTE);

2 that Recommendation ITU-R M.1461 be used as a guideline in analysing compatibility between radiolocation, radionavigation and meteorological radars with systems in other services; that the criterion of interfering signal power to radar receiver noise power level (I/N) of –6 dB be used as the required protection level for the radiolocation [and meteorological radars], and that the criterion (I/N) of [–10 dB] be used as the required protection level for safety-of-life (per S4.10) radionavigation radars [and meteorological radars]. These protection criteria represent the net protection level if multiple interferers are present.

NOTE - Recommendation ITU-R M.1313 should be used with regard to the characteristics of maritime radionavigation radars in the frequency band 5 470-5 650 MHz.

ANNEX 1

Characteristics of radiolocation, aeronautical radionavigation and meteorological radars

1 Introduction

The bands between 5 250 and 5 850 MHz are allocated to the aeronautical radionavigation service and radiolocation service on a primary basis as shown in Table 1. Ground-based radars used for meteorological purposes are authorized to operate in 5 600-5 650 MHz on a basis of equality with stations in the maritime radionavigation service (see RR No. S5.452).

Band (MHz)	Allocation
5 250-5 255	Radiolocation
5 255-5 350	Radiolocation
5 350-5 460	Aeronautical Radionavigation
5 460-5 470	Radionavigation
5 470-5 650	Maritime Radionavigation (NOTE 1)
5 650-5 725	Radiolocation
5 725-5 850	Radiolocation

NOTE 1 - In accordance with S5.452, between 5 600 and 5 650 MHz, ground-based radars for meteorological purposes are authorized to operate on a basis of equality with stations in the maritime radionavigation service.

The radiolocation radars perform a variety of functions, such as:

- tracking space launch vehicles and aeronautical vehicles undergoing developmental and operational testing;
- sea and air surveillance;
- environmental measurements (e.g. study of ocean water cycles and weather phenomena such as hurricanes);
- Earth imaging; and
- national defence and multinational peacekeeping.

The aeronautical radionavigation radars are used primarily for airborne weather avoidance and windshear detection, and perform a safety service (see RR No. S4.10).

The meteorological radars are used for detection of severe weather elements such as tornadoes, hurricanes and violent thunderstorms. These weather radars also provide quantitative area precipitation measurements so important in hydrologic forecasting of potential flooding. This information is used to provide warnings to the public and it therefore provides a safety-of-life service.

Recommendation ITU-R M.1313 should be used with regard to the characteristics of maritime radionavigation radars in the frequency band 5 470-5 650 MHz.

2 Technical characteristics

The bands between 5 250 and 5 850 MHz are used by many different types of radars on land-based fixed, shipborne, airborne, and transportable platforms. Tables 1 and 2 contain technical characteristics of representative systems deployed in these bands. This information is sufficient for general calculation to assess the compatibility between these radars and other systems.

TABLE 1

Characteristics of aeronautical radionavigation and meteorological radar systems

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I
Function	Meteorological	Meteorological	Meteorological	Aeronautical Radionavigation	Meteorological	Meteorological	Meteorological	Meteorological	Meteorological
Platform type (airborne, shipborne, ground)	Ground/Ship	Airborne	Ground	Airborne	Ground	Ground	Ground	Ground	Ground
Tuning range (MHz)	5 300-5 700	5 370	5 600-5 650	5 440	5 600-5 650	5 300-5 700	5 600-5 650	5 600-5 650	5 600-5 650
Modulation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Conventional	With Doppler capability
Tx power into antenna	250 kW Peak 125 kW Avg.	70 kW Peak	250 kW Peak 1500 W Avg.	200 W Peak	250 kW Peak	250 kW Peak	250 kW Peak	250 kW Peak 150 W Avg.	250 kW Peak 150 W Avg.
Pulse width (µs)	2.0	6.0	0.05-18	1-20	1.1	0.8-2.0	3.0	0.8-5	0.8-5
Pulse rise/fall time (µs)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	0.2-2	0.2-2
Pulse repetition rate (pps)	50, 250 and 1 200	200	0-4 000	180-1 440	2 000	250-1 180	259	250-1 200	50-1 200
Output device	TBD	TBD	Klystron	TBD	TBD	TBD	Coaxial Magnetron	Coaxial Magnetron or Klystron	Coaxial Magnetron
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Conical	TBD	Pencil	Pencil	TBD	TBD	Pencil	Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Solid metal parabolic	TBD	Parabolic	Slotted array	TBD	TBD	Solid Parabolic	Solid parabolic	Solid parabolic
Antenna polarization	TBD	Horizontal	TBD	TBD	Horizontal	Horizontal	Horizontal	Horizontal and/or Vertical	Horizontal or Vertical
Antenna mainbeam gain (dBi)	46 dBi	37.5	44	34	50	40	40	40-50	40-50

TABLE 1 (CONTINUED)

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I
Antenna elevation beamwidth (degrees)	4.8	4.1	0.95	3.5	<0.55	<1.0	1.65	0.5-2	0.5-2
Antenna azimuthal beamwidth (degrees)	0.65	1.1	0.95	3.5	<.55	<1.0	1.65	0.5-2	0.5-2
Antenna horizontal scan rate (degrees/s)	0.65	TBD	0-36 (0-6 rpm)	20	TBD	TBD	TBD	6-18 (1-3 rpm)	6-18 (1-3 rpm)
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	360°	TBD	360°	Continuous	TBD	TBD	360°	360°	360°
Antenna vertical scan rate (degrees/s)	Not applicable	TBD	N/A	45	TBD	TBD	TBD	1-10	1-14
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	Not applicable	TBD	N/A	Continuous	TBD	TBD	–1 to +60 Degrees	–1 to +90 Degrees	–5 to +90 Degrees
Antenna sidelobe (SL) levels (1st SLs and remote SLs)	–26	TBD	–35	–31	–27	–25	TBD	–25 to –35	–25 to –35
Antenna height (m)	TBD	N/A	10	Aircraft altitude	TBD	TBD	30	6-30	6-30
Receiver IF 3 dB bandwidth	TBD	TBD	20 MHz	TBD			0.25 to 0.5 MHz	0.7 to 4 MHz	0.1 to 3.0 MHz
Receiver noise figure (dB)	TBD	TBD	4	5	2.3	3.0	TBD	3.5-8 dBm	1.5-8 dBm
Minimum discernible signal (dBm)	–110	TBD	TBD	TBD	TBD	–109 to –112	TBD	–113 to –120	–113 to –120

TABLE 2

Characteristics of radiolocation systems

Characteristics	Radar J	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q
Function	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search	Research and Earth Imaging
Platform type (airborne, shipborne, ground)	Ground	Ground	Ground	Ground	Ground	Ship	Ship	Airborne
Tuning range (MHz)	5 300	5 350-5 850	5 350-5 850	5 400-5 900	5 400-5 900	5 300	5 450-5 825	5 300
Modulation	N/A	None	None	Pulse/chirp pulse	Chirp pulse	Linear FM	None	Non-linear/ Linear FM
Tx power into antenna	250 kW	2.8 MW	1.2 MW	1.0 MW	165 kW	360 kW	285 kW	1 or 16 kW
Pulse width (μs)	1.0	0.25, 1.0, 5.0	0.25, 0.5, 1.0	0.25-1 (plain) 3.1-50 (chirp)	100	20.0	0.1/0.25/1.0	7 or 8
Pulse rise/fall time (μs)	TBD	TBD	TBD	TBD	TBD	TBD	0.03/0.05/0.1	TBD
Pulse repetition rate (pps)	3 000	160, 640	160, 640	20-1 280	320	500	2 400/1 200/ 750	TBD
Chirp bandwidth (MHz)	N/A	N/A	N/A	4.0	8.33	1.5	N/A	TBD
RF emission bandwidth –3 dB –20 dB	TBD	TBD	TBD	TBD	TBD	TBD	5.0/4.0/1.2 16.5/12.5/7.0	TBD
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil	Pencil	TBD	TBD	TBD	Fan	Fan
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic Reflector	Parabolic	Parabolic	Phased Array	Phased Array	TBD	Travelling wave feed horn array	Two dual polarized horns on single pedestal
Antenna polarization	TBD	Vertical/Left-hand circular	Vertical/Left-hand circular	TBD	TBD	TBD	TBD	Horizontal and Vertical
Antenna mainbeam gain (dBi)	38.3	54	47	45.9	42	28.0	30.0	26

TABLE 2 (CONTINUED)

Characteristics	Radar J	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q
Antenna elevation beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	24.8	28.0	28.0
Antenna azimuthal beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	2.6	1.6	3.0
Antenna horizontal scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	TBD	TBD	TBD	TBD	N/A
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	TBD	TBD	TBD	TBD	Fixed to left or right of flight path
Antenna vertical scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	TBD	TBD	TBD	TBD	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	TBD	TBD	TBD	TBD	Fixed in elevation (–20 to –70)
Antenna sidelobe (SL) levels (1st SLs and remote SLs)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Antenna height (m)	TBD	20	8-20	TBD	TBD	TBD	TBD	To 8 km
Receiver IF 3 dB bandwidth	1 MHz	4.8, 2.4, 0.25	4, 2, 1	TBD	TBD	TBD	TBD	TBD
Receiver noise figure (dB)	TBD	5	5	TBD	TBD	TBD	TBD	TBD
Minimum discernable signal (dBm)	TBD	TBD	TBD	TBD	TBD	TBD	–94 (short/medium pulse) –102 (wide pulse)	TBD

3 Operational characteristics

3.1 Meteorological radars

Both airborne and ground-based meteorological radars operate within the frequency range 5 250-5 850 MHz, the technical characteristics of which are given in Table 1.

The ground-based weather radar systems are used for flight planning activities and are often collocated at airports worldwide, to provide accurate weather conditions for aircraft. Therefore, these radars are also in operation continuously 24 hours per day.

Meteorological radars provide quantitative area precipitation measurements and in most cases belong to networks which coordinate such measurements over national or regional areas. Those which use Doppler radar technology also observe precipitation velocity, which indicates the presence and motion of severe weather elements such as tornadoes, hurricanes and violent thunderstorms as well as windshear and turbulence. Quantitative measurements from both kinds of radar are used in real time as a critical and unique data source for hydrological, meteorological and environmental forecasting. Through numerical data assimilation, modelling and forecasting of weather, flooding and pollution, particularly on the occasion of damaging events, the data are used to increase the accuracy and timeliness of forecasts and warnings. The data may be used directly, for example to assess lightning risk. Many applications can be critical to safety and protection of the general public (both life and property) and the safety and security of military operations.

The airborne meteorological radars are used for both hurricane research and reconnaissance. The aircraft penetrate the eyewall repeatedly at altitudes up to 20 000 feet and as low as 1 500 feet. The aircraft collect research-mission data critical for computer models that predict hurricane intensity and landfall. Other aircraft penetrate hurricanes at higher, less turbulent altitudes (30 000-45 000 feet) to determine the position of the hurricane eye.

3.2 Aeronautical radionavigation radars

Radars operating in the aeronautical radionavigation service in the frequency band 5 350-5 460 MHz are primarily airborne systems used for flight safety. Both weather detection and avoidance radars, which operate continuously during flight, as well as windshear detection radars, which operate automatically whenever the aircraft descends below 2 400 feet, are in use. Both radars have similar characteristics and are principally forward-looking radars which scan a volume around the aircrafts flight path. These systems are automatically scanned over a given azimuth and elevation range, and are typically manually (mechanically) adjustable in elevation by the pilot (who may desire various elevation "cuts" for navigational decision-making).

3.3 Radiolocation radars

There are numerous radar types, accomplishing various missions, operating within the radiolocation service throughout the range 5 250-5 850 MHz. Table 2 gives the technical characteristics for several representative types of radars that use these frequencies that can be used to assess the compatibility between radiolocation radars and systems of other services. The operational use of these radars is briefly discussed in the following text.

Test range instrumentation radars are used to provide highly accurate position data on space launch vehicles and aeronautical vehicles undergoing developmental and operational testing. These radars are typified by high transmitter powers and large aperture parabolic reflector antennas with very narrow pencil beams. The radars have autotracking antennas which either skin track or beacon track the object of interest. (Note that radar beacons have not been presented in the Tables; they normally are tuneable over 5 400-5 900 MHz, have transmitter powers in the range 50-200 Watts peak, and serve to rebroadcast the received radar signal.) Periods of operation can last from minutes up to 4-5 hours, depending upon the test program. Operations are conducted at scheduled times 24 hours/day, 7 days/week.

Shipboard sea and air surveillance radars are used for ship protection and operate continuously while the ship is underway as well as entering and leaving port areas. These surveillance radars usually employ moderately high transmitter powers and antennas which scan electronically in elevation and mechanically a full 360 degrees in azimuth. Operations can be such that multiple ships are operating these radars simultaneously in a given geographical area.

Other special-purpose radars are also operated in the band 5 250-5 850 MHz. Radar Q (Table 2) is an airborne synthetic aperture radar which is used in land-mapping and imaging, environmental and land-use studies, and other related research activities. It is operated continuously at various altitudes and with varying look-down angles for periods of time up to hours in duration which depends upon the specific measurement campaign being performed.

4 Protection criteria

The desensitizing effect on radars operated in this band from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can simply be added to the power spectral density of the radar receiver thermal noise, to within a reasonable approximation. If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply $I_0 + N_0$. An increase of about 1 dB for the [meteorological and]radiolocation radar[s] would constitute significant degradation. Such an increase corresponds to an $(I + N)/N$ ratio of 1.26, or an I/N ratio of about –6 dB. For the radionavigation service [and meteorological radars], considering the safety-of-life function, an increase of about 0.5 dB would constitute significant degradation. Such an increase corresponds to an (I+N)/N ratio of about –10 dB. These protection criteria represent the aggregate effects of multiple interferers, when present; the tolerable I/N ratio for an individual interferer depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario.

The aggregation factor can be very substantial in the case of certain communication systems, in which a great number of stations can be deployed.

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation can be inflicted by such desensitization. Assessing it will be an objective for analyses of interactions between specific radar types. In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low-duty cycle pulsed interference are contained in Recommendation ITU-R M.1372 - Efficient use of the radio spectrum by radar stations in the radionavigation service.

5 Interference mitigation techniques

In general, mutual compatibility between radiolocation, aeronautical radionavigation and meteorological radars is fostered by the scanning of the antenna beams, which limits main-beam couplings. Additional mitigation is afforded by differences between the waveforms of the two types of radars and the associated rejection of undesired pulses via receiver filtering and signal processing techniques such as limiting, sensitivity time control and signal integration. Additionally, interference can be mitigated by separation in carrier frequency or discrimination in time. In radar-to-radar interactions, separation in frequency is not always necessary for compatible operation because high degrees of isolation in power coupling and in time either occur naturally or can be achieved by good design. Additional details of interference mitigation techniques employed by radar systems are contained in Recommendation ITU-R M.1372 and PDR [8B/72].