The Joint Radio Company Ltd.

Calculation of Wind Turbine Clearance Zones, used by JRC for 460 MHz Telemetry Links, when turbine sizes and locations are accurately known.

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Version Information					
Version	**Issue Date**	**Change**	**Author**	**Editor**	**Authorised**
3.0.0		First Issue	PAS		
3.0.1	30 OCT 2006	Clarification of low-frequency microwave link W/U and maximum link losses for UHF Telemetry. Bibliography updated.	PAS	SJP	AAG
3.0.2	09 JAN 2007	Modification (relaxation) of the criteria for smaller turbines of less than 100m^2 swept area. Minor amendments to clarify text and inclusion of Version Information Table.	PAS	SJP	AAG

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1 Background

(1) The current Government drive to find renewable sources of energy has resulted in the rapid development of wind farms. Wind energy is likely to be the single greatest contributor to the Government's "10% by 2010" renewable energy target and "20% by 2020" renewable aspiration. But there is a downside. Wind turbines reflect radio energy and because of their large moving surfaces the effect is difficult to predict and constantly changing. Although this ability to reflect radio waves means that wind turbines have some sort of effect on all radio communications, the systems most affected are those that rely on a stable propagation environment such as aircraft radars, television and fixed data systems.

(2) Although the turbine blades are not of metallic construction they can nevertheless reflect and diffract radio waves. The lightning protection schemes built into turbine blades can further enhance their reflective radio properties.

(3) The interference effect of wind turbines on radar systems and analogue terrestrial TV systems have been investigated extensively. Ofcom, and its predecessor, the Radiocommunications Agency undertook some theoretical work on the potential for wind turbines to interfere with microwave fixed links but, because of the relatively small size of the market for utility telemetry radio systems, less research has been directed at this service.

(4) In 2002, the Radiocommunications Agency issued a paper that attempted to model the environment with respect to line-of-sight (LOS) microwave links and wind farms. The method described here is a modification of this LOS Microwave method that addresses the added complication offered by the fact that UHF links are often laid over obstructed paths.

(5) JRC has been assessing the potential for wind farms to cause interference to gas and electricity industry Ultra High Frequency (UHF) telemetry links for three years. JRC has co-ordinated over 1500 wind farm applications in the last 18 months. These telemetry links in most cases are an integral part of the Supervisory Control And Data Acquisition (SCADA) systems used by utilities for monitoring and controlling their networks - including the infrastructure connecting the wind farms to the grid. Interruption to the reliable operation of these links compromises the integrity of the UK energy generation, transmission and distribution systems.

(6) UHF telemetry links are normally planned on the basis of approximately 99.9% availability. UHF frequencies are particularly suited to this application as a single hop can provide a reliable link over a 30 km path (up to 50 km under ideal circumstances) and it is not necessary to have a line-of-sight path from transmitter to receiver. This ability of UHF telemetry systems to operate over obstructed paths is the feature that creates the greatest potential for incompatibility with wind turbines.

(7) Because the wind turbines frequently occupy the higher ground and protrude above the landscape they act as massive radio reflectors such that the reflected path via the wind turbine is much superior to the intended path. The reflected signal can thus be strong enough to cause harmful interference.

(8) In order that JRC can assess the potential effect of a wind farm on existing telemetry links it was necessary to develop a methodology that, as accurately as possible, allows us to model the situation. It is desirable that the model is as accurate as possible as there is a lot of investment on both sides and sloppy coordination can cost a lot of money to put right after the fact. A rigorous, practical, science-based approach to the subject is essential.

(9) The latest version of this document is always available at www.jrc.co.uk/windfarms

2 Determination of the Clearance Zone

(10) There are various issues to be examined when considering the potential for wind farms to cause interference to radio links:

Near field effects-
where a transmitting or receiving antenna has a near-field zone where local inductive fields are significant, and within which it is not simple to predict the effect of other objects.

Obstruction –
the physical obstruction to the radio path by a turbine structure that is attenuating the received and/or transmitted signal.

Diffraction –
although not directly obstructing the radio signal, because of the wave-like nature of a radio signal, large structures close to the radio path can cause interference patterns to be generated.

Reflection/Scattering –
where the radio waves are reflected or scattered off a large structure and interfere with the wanted signal.

(11) At UHF frequencies and with the sort of antennas deployed for telemetry links, the near field and blocking clearance zones are always less than the other clearance zones and are therefore not usually used in the determination of the Clearance Zone.

(12) When protecting link availability approaching 99.9%, the wind turbine must be profiled in the worst case scenario, i.e. maximum horizontal profile, maximum radar cross section, maximum Doppler shift, etc. It is accepted that all of these conditions will not be fulfilled at all times, and in practice may only be for a small percentage of time. However, it must be remembered that the total tolerance for loss of service to such a link is no more than 0.1% of the time.

(13) The Clearance Zone is not an amalgam of the Diffraction and Reflection/Scattering Zones but simply the largest of the two zones.

2.1 Determining the Diffraction Clearance Zone

(14) The Diffraction Clearance Zone used by JRC for evaluating wind farms at 460 MHz *when the path is line-of-sight* are:

- For structures with non-moving elements or small turbines having moving elements with less than 100m^2 swept area, the 1st Fresnel zone clearance is used.
- For structures with moving elements above 100m^2, the entire 2nd Fresnel zone clearance is used.

(15) An additional allowance for location uncertainty is added to this clearance:

- Where 8 digit NGRs, or 6 digit Landranger NGRs are used, 150 metres is added;
- where 12 digit NGRs have been supplied, a minimum of 25 metres is added;
- where 12 digit NGRs have been obtained by a JRC survey this distance may be reduced to 15m; and

- an additional allowance is also added for turbine micro-siting; if this is unknown, 100m is assumed.

(16) No part of the turbine shall enter the Diffraction Clearance Zone.

(17) For example, the worst case 2nd Fresnel zone clearance on a 30 km path would be 99 m plus uncertainty; on a 4 km path this would drop to 36 m plus uncertainty.

(18) When a link is 'line of sight' (LOS), turbine height and ground height in relation to the ray path and Fresnel zone are taken into consideration when calculating the clearance required.

2.2 Calculation of the Reflection/Scattering zone.

(19) The David Bacon Method of determining the effects of reflection scattering on LOS microwave links as defined in the Ofcom document *"Fixed-link wind-turbine exclusion zone method" [1],* whilst not appropriate for determining clearance zones for non-line-of-sight UHF paths, can be used as a basis to determine the clearance required (with some modifications, see below).

Extract from the document.

A1.3 Reflection/scattering clearance zone

This zone sets a lateral distance from the radio path D_s to ensure that any multipath effects due to reflection or scattering from the wind turbine 'W' are negligible, as shown in figure A1.2. All distances are in km.

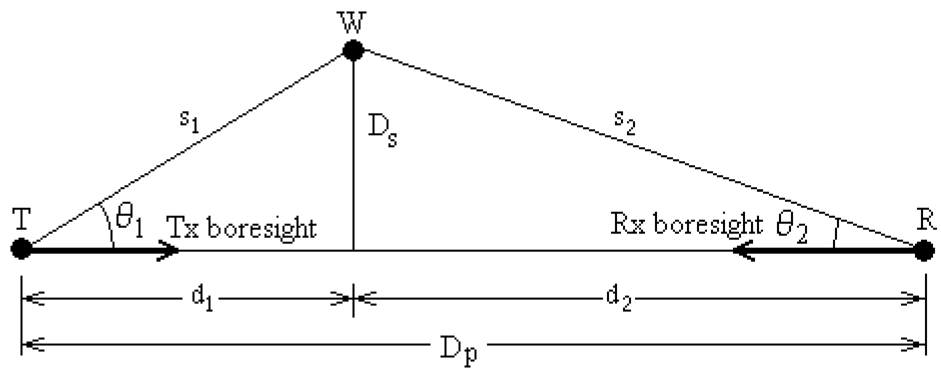

Figure A1.2: Reflection/scattering clearance zone

The ratio, expressed in dB, of the wanted signal level received from the direct T-R path divided by the worst-case signal level received from the indirect T-W-R path, is given by:

R_{ci} =71 - S + 20 log (s_1 s_2) - 20 log (D_p) + $G_1(0)$ + $G_2(0)$ - $G_1(\theta_1)$ - $G_2(\theta_2)$ (dB) (A1.3)

where:

$s_{1,2}$	=	$\sqrt{d_{1,2}^{\ 2} + D_s^{\ 2}}$	(km)	(A1.3a)
S	=	10 log(σ)	(dB)	(A1.3b)
σ	=	Worst-case radar cross section of turbine	(m^2)	
$G_{1,2}(0)$	=	Antenna boresight gains	(dBi)	(A1.3c)
$G_{1,2}(\theta_{1,2})$	=	Antenna gain at off-boresight angles θ	(dBi)	(A1.3d)
$\theta_{1,2}$	=	angle (D_s , $d_{1,2}$)		(A1.3e)

where the function 'angle' represents a generalised form of arctan (D_s / d) with protection against zero-divide for d=0, and returning a result in the range zero to 180 degrees.

End of extract from document.

(20) UHF telemetry links, unlike links that operate at higher frequencies (above 3 GHz), do not always operate over a clear line-of-sight path with no intrusion into the Fresnel Zone. This feature adds further complication to the David Bacon calculation and these additional considerations are discussed below.

(21) Low frequency microwave links (1300 to 1500 MHz) also do not always operate over paths with the first Fresnel zone clear. Consequently, the path loss of these links can also be greater than free space loss.

2.2.1 *Additional considerations required when link path loss is greater than free space loss.*

(22) Result of A1.3 – (PL [Dp]-FS [Dp]) + (PL [s1]-FS [s1]) + (PL [s2]-FS [s2])

FS = Free Space Path Loss: where FSL = 32.4+20logF[MHz]+20logD[km]

PL = Path Loss: derived from radio planning tool using ITU-R. 525/526 propagation model and a k factor of 4/3.

(23) This loss is computed for path loss using antenna heights, and turbine hub height.

(24) The wanted/unwanted (W/U) ratio used by JRC for UHF telemetry links is 38 dB.

(25) JRC acknowledge that these figures taken in isolation are conservative, but:

- The unwanted signal is a delayed image of the wanted signal and has continuously variable Doppler shift; this is a different scenario than normal co-channel interference or noise.
- The path losses used are computer predictions.
- The interaction of multiple turbines is difficult to predict accurately.
- Accurate RCS figures for different types/sizes of turbines at frequencies used by JRC links are not available.

(26) Until meaningful tests are carried out on different turbine types to determine an accurate maximum static and moving Radar Cross Section (RCS) at JRC link frequencies (specifically 460 MHz) and tests are made on individual equipment types under these conditions, then 38 dB is considered a reasonable figure to use in these calculations; this is still substantially less than the 50 to 70 dB suggested for fixed microwave links in the David Bacon method.

(27) Utility telemetry systems generally use an omni-directional antenna with isotropic gain (dBi) between 5 and 8 dB at the scanning site. Yagi antennas with a gain between 9 and 17 dBi are generally used at the outstation.

(28) Owing to the relatively flat response around the bore-sight of a Yagi antenna; the deep nulls in the polar pattern (up to 8 dB per 5°); and distortion of these nulls due to the effect of the mounting structure on their electrical characteristics, the accuracy of the nulls of Yagi-type antennas cannot be guaranteed. Thus a mask is used in preference to the polar pattern for response off bore-sight.

(29) The H-plane mask of two of the most popular outstation antennas in use is indicated in the table below:

Table 1: Two of the most common antenna types used at telemetry outstations with their polar response values at 5° intervals (in dB).

antenna type	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°
J-Beam 7014 12 element yagi	0	-0.5	-1.5	-3.5	-6.5	-11.5	-11.5	-11.5	-11.5	-11.5	-14.5	-16	-16.5
J-Beam 7041 4 element yagi	0	0	0	-0.5	-1	-1.5	-2	-3	-3.5	-5	-6	-8	-10

(30) As these links are already installed, alignment of antennas to better than a few degrees cannot be guaranteed: the unwanted signal is therefore calculated by decrementing the angle used for the reflected signal by five degrees.

(31) Generally, the scanner is on a high site installed on a mast in the region of 25 to 60 m above average ground level (AGL). Outstations normally have the antennas mounted at 5-10 m AGL, usually on the side of a low building or a free-standing pole.

(32) This means that when the turbines are close to the scanner end, the path advantage via the turbine is *generally* less than when the turbines are close to the outstation end.

(33) As the paths are not always line-of-sight with no Fresnel Zone incursions, there are instances where the full turbine profile can be seen from both ends of the link and the link has an obstructed path.

(34) When a turbine is close to an outstation it is not unusual for the additional loss compared to free space loss to be 10 to 20 dB worse on the direct path than via the turbine; in extreme cases this can be in excess of 30 dB.

(35) As the maximum allowed path loss in RA375 is 143 dB, a 10 km link could have as much as 37 dB loss above free space and still be acceptable.

(36) If the path loss of a link exceeds 143 dB and/or the received signal strength is below that specified in RA375 the link W/U will only be protected as if these parameters are met.

Example path profile of a non LOS link with a wind turbine close to the outstation.

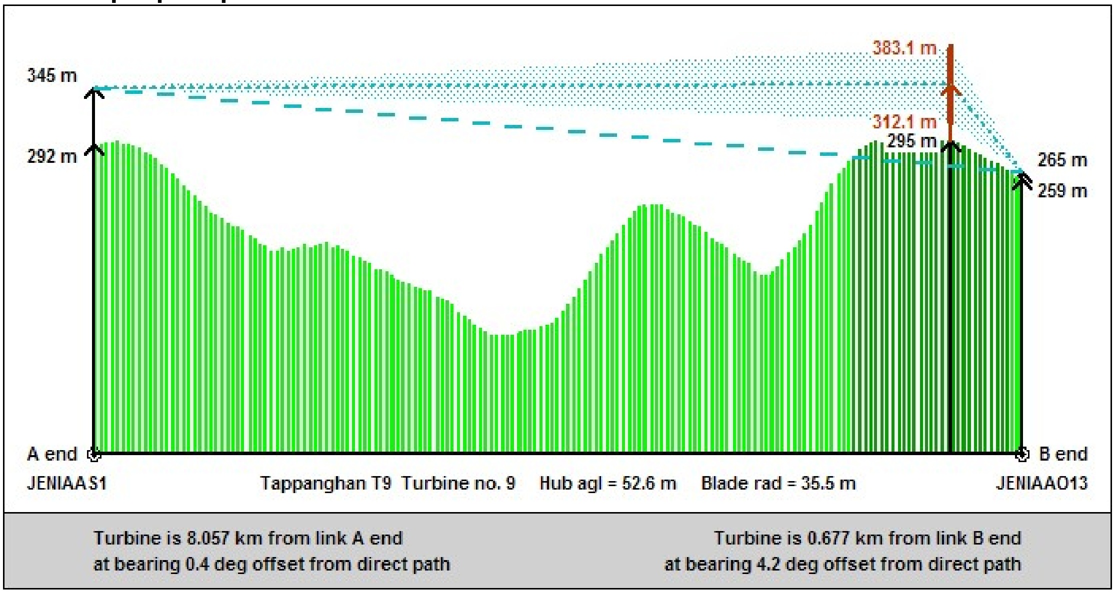

Table 2 - Example of Clearance Zones for links, close to an outstation:

- against a turbine with an 80 m rotor (Peak RCS of +27 dBsm);
- for 38 dB W/U ratio at the outstation end;
- with paths of 20 km and 4 km where all the paths are free space;
- with the main path having 10 and 20 dB more loss with respect to free space loss than the reflected path;
- using the two most popular antenna types; and
- assuming the antennas are in perfect alignment.

Path Length (m)	Angle (degrees) (Note 1)	Distance from link path (m)	Distance down link from the outstation (m)	RCS (dB_{sm})	Path difference (Note 2)
12 Element Yagi					
20000	6.3	55	500	27	0
20000	0.0	0	1000	27	0
20000	0.0	0	2000	27	0
20000	27.5	260	500	27	10
20000	20.8	380	1000	27	10
20000	0.0	0	2000	27	10
20000	56.7	760	500	27	20
20000	44.4	980	1000	27	20
20000	25.4	950	2000	27	20
4000	12.4	110	500	27	0
4000	0.0	0	1000	27	0
4000	0.0	0	2000	27	0
4000	28.8	275	500	27	10
4000	23.7	440	1000	27	10
4000	19.8	720	2000	27	10
4000	58.6	820	500	27	20
4000	51.1	1240	1000	27	20
4000	41.2	1750	2000	27	20
4 Element Yagi					
20000	14.6	130	500	27	0
20000	0.0	0	1000	27	0
20000	0.0	0	2000	27	0
20000	53.7	680	500	27	10
20000	37.2	760	1000	27	10
20000	0.0	0	2000	27	10
20000	68.7	1280	500	27	20
20000	61.6	1850	1000	27	20
20000	50.2	2400	2000	27	20
4000	21.8	200	500	27	0
4000	0.0	0	1000	27	0
4000	0.0	0	2000	27	0
4000	55.8	735	500	27	10
4000	45.0	1000	1000	27	10
4000	35.9	1450	2000	27	10
4000	69.7	1350	500	27	20
4000	63.4	2000	1000	27	20
4000	59.9	3450	2000	27	20

NOTE 1: Arrival angle of interfering signal with respect to wanted signal

NOTE 2: "Difference" is the Main/Reflected path difference with respect to free space loss.

NOTE 3: The increasingly common 92 m rotor turbine will require a larger clearance zone.

(37) When a turbine is close to the scanner, the difference in additional loss compared to free space loss on the two paths is less (generally in the region of 0 to 10 dB). However this is dependant on mast height, hub height and local topography, although it is offset by the omni-directional antennas generally used at the scanner end which have no attenuation of the unwanted signal.

Example path profile of a non LOS link with a wind turbine close to the scanner .

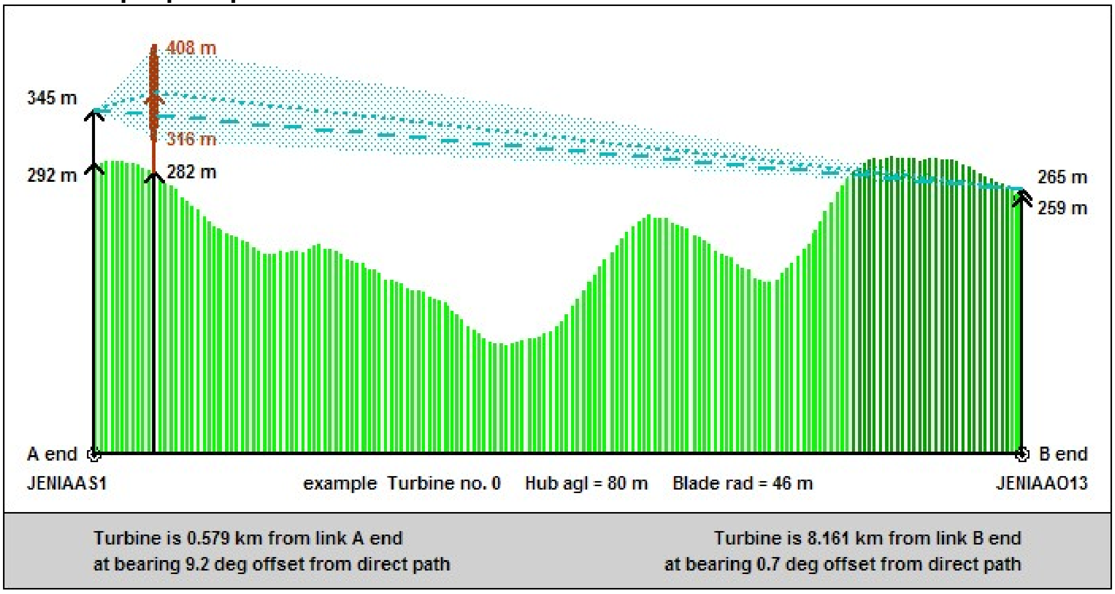

Table 3 - Example of Clearance Zones for links, close to a scanner:

- against a turbine with an 80 m rotor (Peak RCS of +27 dBsm);
- for 38 dB W/U ratio at the outstation end;
- with paths of 20 km and 4 km where all the paths are free space;
- with the main path having 3 and 6 dB more loss with respect to free space loss than the reflected path; and
- using an omni-directional antenna. *(all distances in metres)*

Path Length (m)	**Angle (degrees) (Note 1)**	**Distance from Scanner (m)**	**Distance to O/S (m)**	**RCS (dB_{sm})**	**2nd Fresnel zone (m)**	**FSL W/U (dB)**	**Path Difference (Note 2)**	**W/U (dB)**
Omni								
20000	0.0	515	19485	27	25.5	38.0	0	38.0
20000	0.0	735	19265	27	30.3	41.0	3	38.0
20000	0.0	1050	18950	27	36.0	44.0	6	38.0
4000	0.0	585	3415	27	25.5	38.0	0	38.0
4000	0.0	920	3080	27	30.3	41.0	3	38.0
4000	0.0	1850	2150	27	36.0	44.0	6	38.0

NOTE 1: Arrival angle of interfering signal with respect to wanted signal

NOTE 2: "Difference" is the Main/Reflected path difference with respect to free space loss.

NOTE 3: The increasingly common 92 m rotor turbine will require a larger clearance zone.

(38) The RCS has been estimated using information obtained from various reports that are available in the public domain.

2.3 The Effect of Multiple Turbines.

(39) Two turbines with the same calculated W/U will degrade the resultant W/U by 3 dB IF the interfering signals arrive in phase. Four turbines will degrade the W/U by 6 dB and eight turbines by 9 dB.

(40) There is normally a predominant turbine in relationship to a link. If the next worst turbine has 3 dB less predicted interference than the predominant, the W/U degrade will be approximately 1.8 dB. If the signals are in phase, two turbines with interference 3 dB below the predominant turbine will result in a 3 dB degrade of W/U.

(41) If the next worse turbine has 6 dB less W/U than the predominant then the degrade will be approximately 1 dB. Two turbines 6 dB down will result in a degrade of approximately 1.8 dB. In all instances the signals need to arrive in phase.

(42) The likelihood of RCS peaks coinciding and interfering signals arriving in phase from multiple turbines diminishes as the number of turbines considered increase.

(43) In analysing scenarios, JRC first considers the interference from the worst case turbine. If the projected interference from other turbines is more than 3 dB lower, then they are not considered. If there are turbines that are within 3 dB of the predominant, then the predominant and the second worst only are considered. The resultant W/U is calculated as if the interfering signals were in phase.

2.4 Low Frequency Microwave Links

(44) This document is primarily intended for the evaluation of 460 MHz UHF links. The formulae used are relevant for 1400 MHz links although the W/U required is 49 dB, for a class 4 link and 42 dB for a class 2. The class 4 link requirement figure is close to that suggested for digital links in the "Fixed-link wind-turbine exclusion zone method" [1].

3 References

[1] **Radiocommunications Agency -**
Title: "Fixed-link wind-turbine exclusion zone method"
Author: D F Bacon
Status: released 28 Oct 2002
Version: 1.1 (Current Version)
URI: <http://www.ofcom.org.uk/radiocomms/ifi/licensing/classes/fixed/Windfarms/windfarmdavidbacon.pdf>

[2] **QinetiQ (for DTI)-**
Title: "Wind farms impact on radar aviation interests"
Author: Gavin J Poupart (Prepared by)
Status: Final report, September 2003
Version: DTI PUB URN 03/1294
URI: <http://www.dti.gov.uk/energy/page18050.html>

[3] **RA 375**
Title: Frequency Assignment Criteria, Scanning telemetry radio services operating in the band 457.5 to 458.5 MHz and 463.5 to 464 MHz in which spectrum is managed by the Radiocommunications Agency. The OFCOM version of the document is designated OFW 49.
Version: 1.0

4 Acronyms & Abbreviations

dBsm = decibel square metres, an alternative way of expressing RCS, equivalent to 10LOG(RCS) in m^2 .

Fresnel Zone
(pronounced FRA-nel Zone), named for physicist Augustin-Jean Fresnel, is one of a (theoretically infinite) number of a concentric ellipsoids of revolution which define volumes in the radiation pattern of a (usually) circular aperture. Fresnel zones result from diffraction by the circular aperture.
More: <http://en.wikipedia.org/wiki/Fresnel_zone>

Harmful Interference:
Interference which endangers the functioning of a Radionavigation Service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with the ITU-R Radio Regulations.
(International Telecommunication Union Radio Regulations)

Interference:
The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, or loss of information which could be extracted in the absence of such unwanted energy.
(International Telecommunication Union Radio Regulations)

Microwaves:
Microwaves are electromagnetic waves with wavelengths longer than those of Terahertz (THz) wavelengths, but relatively short for radio waves. Microwaves have wavelengths approximately in the range of 30 cm (1 GHz) to 1 mm (300 GHz). However, the boundaries between far infrared light, Terahertz radiation, microwaves, and UHF radio waves are fairly arbitrary and are used variously between different fields of study. For instance, in the David Bacon Report the term effectively referred to frequencies

above 3 GHz where radio links are increasingly line-of-sight with respect to increasing frequency.
More: <http://en.wikipedia.org/wiki/Microwave>

RCS
: A term that represents the radar "size" of an object, the Radar Cross Section in square metres. Note that it gives an equivalent area that represents how much power is reflected and does not correspond to physical size. Sometimes expressed as dBsm, decibel square metres (10LOG RCS in square metres).
More: <http://en.wikipedia.org/wiki/Radar_cross_section>

UHF
: Ultra High Frequency – officially defined as the range 300 MHz to 3000 MHz and includes part of the region often referred to as “Microwaves”.
More: <http://en.wikipedia.org/wiki/UHF>

W/U
: Wanted to Unwanted (ratio). The ratio of the wanted signal with respect to the unwanted. Usually expressed in decibels.