Radiocommunication Study Groups

Source: Document 4-5-6-7/TEMP/156(edited)

Annex 34 to
Document 4-5-6-7/715-E
25 August 2014
English only

Annex 34 to Joint Task Group 4-5-6-7 Chairman's Report

WORKING DOCUMENT TOWARDS PRELIMINARY DRAFT
NEW REPORT ITU-R M.[RLAN5GHz.SHAR]

Compatibility studies between radio local area network systems and radiodetermination systems in the 5 350-5 470 MHz frequency band[1]

Overall consideration of results of studies

The annexes to this attachment provide compatibility studies between radio local area network (RLAN) and the radiodetermination service (RDS) for the 5 350-5 470 MHz frequency range, and have not been agreed. It should be noted that some of these RDS radars operate across the 5 250-5 850 MHz frequency range.

Members of JTG 4-5-6-7 were unable to reach agreement on the applicability of specific additional RLAN mitigation techniques. The regulatory provisions in the 5 150-5 350 MHz and 5 470-5 725 MHz frequency ranges contained in Resolution **229 (Rev. WRC-12)** are insufficient to ensure protection of certain radar types in the 5 350-5 470 MHz frequency range. Some additional RLAN mitigation techniques to enable sharing are being studied by the expert groups in the ITU-R but no conclusions can be drawn at this time. Further study by the expert groups is required to determine if these additional mitigation techniques can be utilized to mitigate potential interference to these particular radar types.

[1] Some administrations submitted contributions indicating that the study results for the 5 350-5 470 MHz frequency range are applicable to the 5 725-5 850 MHz frequency range to ensure protection of certain radars that operate across or in portions of the 5 250-5 850 MHz frequency range. Some other administrations raised concerns regarding these results because no RLAN characteristics were previously agreed for the 5 725-5 850 MHz frequency range and that the RLAN characteristics utilized for the 5 350-5 470 MHz frequency range cannot be applied similarly to the 5 725-5 850 MHz frequency range. Some administrations also highlighted that the sharing environment is significantly different between the two bands due to the ISM designation of the 5 725-5 875 MHz frequency band. There are current deployments of RLAN in the 5 725-5 850 MHz band in some countries in all three ITU Regions. Therefore, agreement was not reached on the conclusions in these documents.

Annexes A - I follow below:

Annex A: “Studies in compatibility of RLAN with radiodetermination radars in the frequency band 5 350-5 470 MHz”

Annex B: “Compatibility studies between RLAN systems and ground-based radiodetermination systems in the 5 350-5 470 MHz frequency bands”

Annex C: “Sharing between radio local area network systems and radiolocation service systems in the 5 350-5 470 MHz frequency range”

Annex D: “Initial analysis of Dynamic Frequency Selection (DFS) as mitigation measure for the co-existence of RLAN systems and radiolocation service systems in the 5 350-5 470 MHz band”

Annex E: “Bistatic Radars in the 5 GHz band”

Annex F: “Statistical study between WAS-RLAN and frequency hopping radars in the 5 GHz frequency band”

Annex G: “Analysis of the co-existence of RLAN systems and radiolocation service systems in the 5 350-5 470 MHz and 5 725-5 850 MHz band and evaluation of Dynamic Frequency Selection (DFS) as mitigation technique”

Annex H: “Compatibility between RLAN systems and shipborne radiodetermination systems in the 5 350-5 470 MHz frequency range”

Annex I: “Sharing between RLANs and radiolocation systems in the 5 350-5 470 MHz frequency range”

ANNEX A

Studies in compatibility of RLAN with radiodetermination radars in the frequency band 5 350-5 470 MHz

1 Introduction

[At the meetings of JTG 4-5-6-7] this frequency band was proposed for implementing radio local area network (RLAN) systems and studies in sharing between the RLAN systems and radiodetermination radars were commenced. Taking part in the studies Russian Federation estimated separation distances required for ensuring interference-free operation of radiodetermination radars in the frequency band 5 350-5 470 MHz. Results of the estimations are presented below.

2 RLAN technical characteristics

Parameters of RLAN systems operating in the frequency band 5 350-5 470 MHz have not been adopted [by JTG 4-5-6-7 yet]. Nevertheless [previous JTG 4-5-6-7 meeting] discussed contributions which assumed appropriate RLAN technical characteristics were assumed. Table 1 below presents assumed technical characteristics of RLAN systems as used for the sharing studies.

TABLE 1

Assumed RLAN technical characteristics

Parameter	Value
e.i.r.p., mW	200; 25
Antenna type	omnidirectional
Frequency band, MHz	20; 160
Antenna height above the ground level, m	30
Wall propagation losses, dB	25
Deployment	Outdoor, indoor

3 Technical characteristics of radars operating in the band 5 350-5 470 MHz

The frequency band 5 350-5 470 MHz is used for operation of radiolocation, meteorological and aeronautical radionavigation radars. The radiolocation radars are designed for fulfilling multiple functions, such as:

– tracking the space launch vehicles and aircraft in the course of their development and operational tests;
– maritime and aerospace surveillance;
– environment monitoring (e.g. research of oceanic tides and such natural phenomena as hurricanes);
– Earth remote imaging, etc.

Meteorological radars are used for detecting dangerous weather phenomena such as tornado, thunderstorms and hurricanes. They are also useful for measuring amounts of rainfalls in certain areas to provide for hydrological forecasting of potential floods. Such data are important for warning the population on expected threats and hence they are part of safety of life services.

Technical characteristics of radiodetermination radars operating in the frequency band 5 250-5 850 MHz may be found in Recommendation ITU-R M.1638 and are summarized in Table 2 below.

TABLE 2

Technical characteristics of ground-based radars

Radar	**Radar A**	**Radar F**	**Radar J**	**Radar L**	**Radar M**	**Radar N**	**Radar O**	**Radar P**	**Radar Q**
Purpose	**Meteorology**			**Monitoring and measurements**				**Surface/air search**	
3 dB IF receiver pass-band, MHz	0.5	0.91	10	4.8	4	8	8	1.5	10
Noise figure, dB	7	3	3	5	5	11	5	5	10
Antenna gain, dB	39	40	45	54	47	45	42	28	30
Noise temperature, K	-140	-143.2	-131	-132	-133	-124	-130	-137	-124
Protection criteria I/N, dB	-6								
Receiver thermal noise power, dBW	-146	-149.2	-137	-138	-139	-130	-136	-143	-130

4 Sharing study methodology

The studies in compatibility of RLAN systems with air-borne radars estimated effective e.i.r.p. of RLAN transmitter using the following equation:

$$e.i.r.p._{eff} = e.i.r.p._{RLAN} + 10\lg\left(\Delta F_{RLS} / \Delta F_{RLAN}\right) \quad (1)$$

Wall penetration losses were estimated using the following equation:

$$e.i.r.p._{eff} = e.i.r.p._{RLAN} + 10\lg\left(\Delta F_{RLS} / \Delta F_{RLAN}\right) - \sigma \text{, dBW;} \quad (1a)$$

where:

σ - extra attenuation, dB.

Then the receiver thermal noise power was estimated for each of the radars concerned using the following equations:

$$T_N = 290 * \left(10^{\frac{NF}{10}} - 1\right) \text{ K,} \quad (2)$$

$$N = 10 * \lg(k T_N \Delta F_{RLS}) \text{ dBW,} \quad (3)$$

where:

k – Boltzmann constant;

NF – radar receiver noise figure;

ΔF_{RLS} - radar receiver IF pass-band.

Maximum acceptable noise power at radar receiver front end was estimated using he following equation:

$$I_{acc} = N + I/N \text{, dBW.} \quad (4)$$

Estimation of interference caused to airborne radars used a free space propagation model. In that case the separation distance R required for protecting the radiodetermination radar was estimated using the following equation:

$$R = 10^{\frac{e.i.r.p._{eff} + G_{RLS} + 20\lg(\lambda/4\pi) - I_{acc}}{20}}, \quad (5)$$

where:

G_{RLS} - radar antenna gain, dB;

λ – operational wavelength, m.

Compatibility of ground-based radars with RLAN was estimated using method of minimum coupled losses (MCL). The required attenuation in a radio path was estimated such as:

$$L = e.i.r.p._{eff} + G_{RLS} - I_{acc} \text{, dB} \quad (6)$$

Then the separation distance *R* was estimated considering minimum required losses. Estimation used a propagation model described in Recommendation ITU-R P.452.

5 Estimation results for feasibility of sharing between RLAN and ground-based radiodetermination radars

Separation distances for ground-based radars operating in the frequency band 5 350-5 470 MHz were also estimated. Table 3 shows minimal coupled losses requires for protecting the radars concerned. The estimation used equation (6) and covered all considered RLAN operation modes.

TABLE 3

Minimal coupled losses for protecting ground-based radars from a single outdoor RLAN

	Minimal coupled losses, L, dB			
	e.i.r.p. $_{eff}$=-7 dBW		**e.i.r.p. $_{eff}$=-16 dBW**	
ΔF_{RLAN}, MHz	20	160	20	160
Radar A	162	153	153	144
Radar F	167	158	158	149
Radar J	172	163	163	154
Radar L	179	171	171	162
Radar M	172	163	163	154
Radar N	165	156	156	147
Radar O	167	158	158	149
Radar P	153	144	144	135
Radar Q	150	141	141	132

The obtained estimates of minimal coupled losses were used for estimating minimum separation distances. The results are shown in Table 4.

TABLE 4

Minimum separation distances for the protection of ground-based radars from a single outdoor RLAN

	Separation distance R, km			
	e.i.r.p. eff=-7 dBW		**e.i.r.p. eff=-16 dBW**	
ΔF_{RLAN}, MHz	20	160	20	160
Radar A	35	27	27	23
Radar F	39	32	32	24
Radar J	45	36	36	29
Radar L	53	44	44	35
Radar M	45	36	36	29
Radar N	37	30	30	24
Radar O	39	32	32	24
Radar P	27	22	22	16
Radar Q	26	20	20	14

Analysis of Table 4 shows that separate types of ground-based radars would require separation distances exceeding 50 kilometres to ensure their interference-free operation.

Table 5 below shows estimates of minimal coupled losses required for protecting the considered ground-based radars from interference caused by indoor RLAN.

TABLE 5

Minimal coupled losses for protecting ground-based radars from indoor RLAN

	Minimal coupled losses, L, dB			
	e.i.r.p. eff=-7 dBW		**e.i.r.p. eff=-16 dBW**	
ΔF_{RLAN}, MHz	20	160	20	160
Radar A	137	128	128	119
Radar F	142	133	133	124
Radar J	147	138	138	129
Radar L	154	146	146	137
Radar M	147	138	138	129
Radar N	140	131	131	122
Radar O	142	133	133	124
Radar P	127	119	119	110
Radar Q	125	116	116	107

The obtained estimates of minimal coupled losses were used for estimating the minimum separation distances. The results are shown in Table 6.

TABLE 6

Minimum separation distances for the protection of ground-based radars from a single outdoor RLAN

	Separation distance R, km			
	e.i.r.p. $_{eff}$=-7 dBW		**e.i.r.p. $_{eff}$=-16 dBW**	
ΔF_{RLAN}, MHz	20	160	20	160
Radar A	20	12	12	
Radar F	23	18	18	9
Radar J	28	21	21	13
Radar L	34	27	27	20
Radar M	28	14	14	13
Radar N	22	16	16	4.5
Radar O	23	17	17	5
Radar P	10	4	4	1.5
Radar Q	8	3	3	1

The estimation results show that even with RLAN indoor transmitter and favourable propagation conditions (i.e. attenuation due to building wall would be above 25 dB that is not true in majority of cases) minimum separation distances may be as long as 34 kilometres.

It is obvious that in case of aggregate interference from multiple RLAN transmitters the separation distances would multifold increase. The level of increasing would be a function of deployment density related to RLAN transmitters and by their operation modes.

6 Conclusions

The conducted compatibility studies show that to ensure the protection of airborne radar receivers from emissions produced by both indoor and outdoor RLAN transmitters would require separation distances exceeding those of line-of-sight.

Moreover to provide for sharing between RLAN and ground based radars would require separation distances of dozens (and hundreds in some cases) of kilometres. Taking the level of ground-based radar deployment one may arrive at the conclusion that usage of proposed RLANs in the frequency band discussed would be rather difficult.

Based on the above it is proposed:

– to exclude the frequency band 5 350-5 470 MHz from consideration as a candidate band for deployment of the proposed RLAN systems;

ANNEX B

Compatibility studies between RLAN systems and ground-based radiodetermination systems in the 5 350-5 470 MHz frequency bands

1 Introduction

The frequency range 5 350-5 470 MHz is comprised of two frequency bands: 5 350-5 460 MHz and 5 460-5 470 MHz. The 5 350-5 460 MHz band is allocated to the Earth exploration-satellite (active), radiolocation, aeronautical radionavigation, and space research (active) services. The 5 460-5 470 MHz frequency band is allocated to the Earth exploration-satellite (active), radiolocation, radionavigation, and space research (active) services.

This Report provides results of a study on the feasibility of RLAN systems operating in the 5 350-5 470 MHz frequency bands with incumbent primary ground-based radiodetermination systems. It includes an analysis of dynamic frequency selection (DFS) with a threshold of -64 dBm as a potential mitigation technique.

2 Background

This analysis uses the DFS procedures and modelling to determine the operating environment for discussion on DFS suitability in the 5 350-5 470 MHz bands. In particular, this study tested the current DFS threshold (-64 dBm) to detect ground-based radiodetermination systems in the 5 350-5 470 MHz band while not exceeding the ground-based receiver protection threshold based on an I/N = –6 dB (Recommendation ITU-R M.1638-1).

3 Technical characteristics

3.1 Technical characteristics of ground-based radiodetermination systems

The technical characteristics for the ground-based radiodetermination systems considered in this analysis are shown in (info taken from Recommendation ITU-R M.1638).

TABLE 1

Characteristics	**Radar 4**[2]
Function	Instrumentation
Platform type (airborne, shipborne, ground)	Ground
Tuning range (MHz) *	5 400-5 900 (5400)
Modulation	Pulse/chirp pulse
Tx power into antenna (kW)	1 000
Pulse width (us) *	0.25-1 (unmodulated) 3.1-50 (chirp) (3.1)
Pulse repetition rate (pps) *	20-1 280 (20)

Radar characteristics

[2] In this study, Radar 4 will become Radar 4a and Radar 4b corresponding to the 2 and 8 MHz bandwidths, respectively.

Chirp bandwidth (MHz)	**4.0**
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Phased array
Antenna polarization	Vertical/left-hand circular
Antenna main beam gain (dBi)	45.9
Antenna elevation beamwidth (deg)	1.0
Antenna azimuthal beamwidth (deg)	1.0
Antenna horizontal scan rate (deg/sec)	N/A (Tracking)
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (deg)	N/A (Tracking)
Antenna vertical scan rate (deg/sec)	N/A (Tracking)
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (deg)	N/A (Tracking)
Antenna gain pattern	Statgain
Antenna height (m)	20
Receiver IF 3 dB bandwidth (MHz)	2-8
Receiver noise figure (dB)	11

* The values contained in parenthesis are the ones used in this study.

3.1.1 Description of Statgain antenna pattern

Figure 1 illustrates the general form of the antenna gain distribution in the Statgain model. The equations for the angles θ_M (first side-lobe region), θ_R (near side-lobe region), and θ_B (far side-lobe region) are given in **Table 2**. The antenna gain, as a function of off-axis angle, is given in **Table 3**. The angle θ is in degrees and all gain values are given in terms of dBi.

FIGURE 1

General Form of Antenna-Gain Distribution

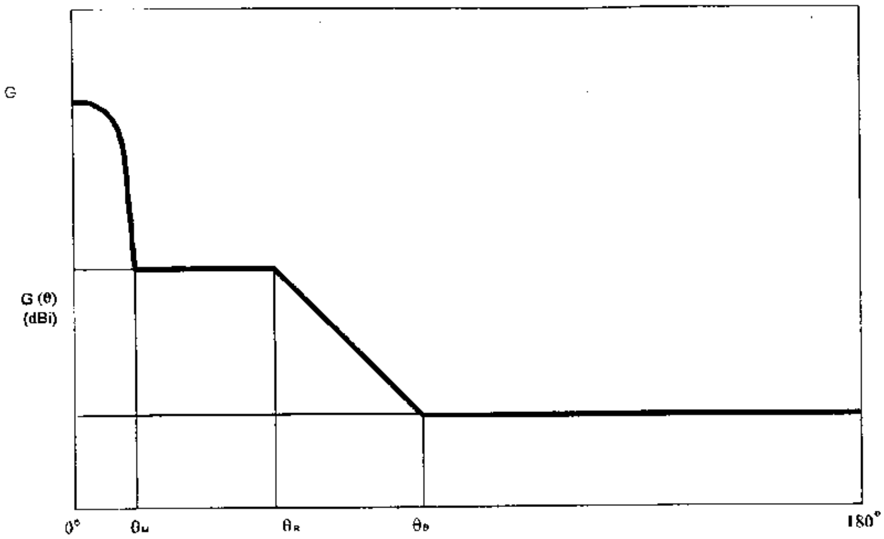


TABLE 2

Angle Definitions

High-gain (22 < G < 48 dBi)
$\theta_M = 50\ (0.25\ G + 7)^{0.5}/10^{G/20}$
$\theta_R = 250/10^{G/20}$
$\theta_B = 48$

TABLE 3

Equations for High-Gain Antennas (22 < G < 48 dBi)

Angular interval (degrees)	**Gain (dBi)**
0 to θ_M	$G - 4 \times 10^{-4}\ (10^{G/10})\ \theta^2$
θ_M to θ_R	0.75 G – 7
θ_R to θ_B	53 – (G/2) – 25 log (θ)
θ_B to 180	11 – G/2

3.2 Mobile system parameters and deployment

The RLAN devices will be randomly distributed over three regions: urban, suburban, and rural. The three regions exist within concentric circles as shown in Figure 2.

FIGURE 2

RLAN device deployment regions

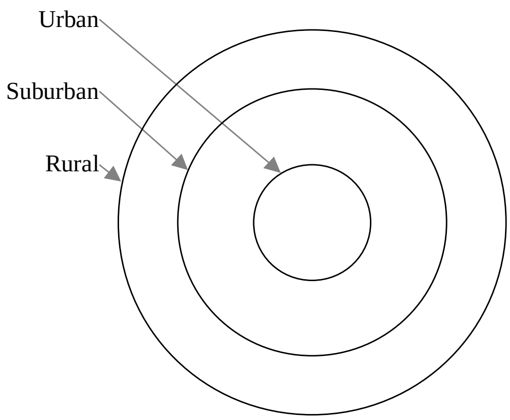


Table provides the radius of each RLAN deployment zone.

TABLE 4

Deployment Zones

RLAN Deployment Region	Radius from the centre (km)
Urban	0 to 5
Suburban	5 to 15
Rural	15 to 30

The population used for the baseline is 5.25 million people. Table provides the population distribution within each zone in the RLAN device environment.

TABLE 5

Population Zones

Total Population	Population split	Percent	Population in Zone
5 250 000	Urban	30%	1 575 000
	Suburban	50%	2 625 000
	Rural	20%	1 050 000

Number of On-tune, Active RLAN devices

The following methodology was used to determine the number of on-tune active RLAN devices:

Step 1: Determine base population size by zone.

Step 2: Apply a Busy Hour factor to determine the base population by zone.

Step 3: Apply Market Factor (percent of users with devices) by zone.

Step 4: Apply System Factor (determine number of cells) by zone.

Step 5: Apply Activity Factor (percent of cells operating) by zone.

Step 6: Apply Bandwidth Factor (percent of devices on-tune based on bandwidth distribution model).

Using the six step methodology, the number on-tune active RLAN devices per 20 MHz are forecasted in Table 6.

TABLE 6

RLAN On-tune, Active Devices

	Population	Step 2 Busy Hour Factor	Busy Hour Population	Step 3 † Market	Step 4 † System	Step 5 † Activity	Step 6 * Bandwidth
Urban	1 575 000	71%	1 118 250	894 600	62 622	15 656	
Suburban	2 625 000	64%	1 680 000	1 344 000	94 080	23 520	
Rural	1 050 000	47%	493 500	246 750	49 350	4 935	
Total						44 111	5 186 Per 20 MHz

TABLE 7

Market/System/Activity Factors

†	Market	System	Activity
Urban	80%	7%	25%
Suburban	80%	7%	25%
Rural	50%	20%	10%

The distribution of channel bandwidths for the number active RLAN devices in a 20 MHz bandwidth is shown in Table 8.

TABLE 8

Distribution of RLAN Channel Bandwidths

Start Channel	*	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
5 150 MHz	Percent	10%	25%	50%	15%
End Channel	Devices	4 411	11 028	22 055	6 617
5 850 MHz	Channels	35	17	8	4
	On-tune	126	649	2 757	1 654

Technical parameters

The baseline will include RLAN devices employing omni-directional antennas. For each time step the RLAN device power, operating bandwidth, and height will be randomly determined.

The RLAN device equivalent isotropically radiated power (e.i.r.p.) level distribution for the baseline is shown in Table 9.

TABLE 9

RLAN Power Distribution[3]

RLAN e.i.r.p. Level	200 mW (Omni-Directional)	80 mW (Omni-Directional)	50 mW (Omni-Directional)	25 mW (Omni-Directional)
RLAN Device Percentage (Indoor operation)	18%	26%	14%	37%
RLAN Device Percentage (Outdoor operation)	0.9%	1.3%	0.8%	2%

This study will consider a limit on the e.i.r.p. of 200 mW to determine sharing feasibility. If higher power levels are submitted, additional studies will be required.

The RLAN device transmitter bandwidth distribution for the baseline is shown in Table 10.

TABLE 10

Bandwidth Distribution

RLAN Transmitter Bandwidth	20 MHz	40 MHz	80 MHz	160 MHz
RLAN Device Percentage	10 %	25 %	50 %	15 %

The RLAN antenna pattern in the azimuth orientations is omni-directional. The RLAN device elevation antenna pattern is described in Table 11. The angle elevation angle is with respect to the horizontal. Positive elevation angles are below the horizontal.

[3] The e.i.r.p. levels and percentages are derived from: 1) predictions of shipped devices for various devices classes; 2) expected e.i.r.p. of the device classes; 3) matching the percentages from the sum of the rows in device distribution and 4) traffic mix in a Basic Service Set between Access Point and client.

TABLE 11

RLAN Device Elevation Antenna Pattern

Elevation Angle θ (Degrees)	Gain (dBi)
45 < θ ≤ 90	–4
35 < θ ≤ 45	0
0 < θ ≤ 35	3
–15 < θ ≤ 0	–1
–30 < θ ≤ –15	–4
–60 < θ ≤ –30	–9
–90 < θ ≤ –60	–8

Table 12 provides the distribution of RLAN device antenna heights for each RLAN deployment zone.

TABLE 12

Distribution of RLAN Device Antenna Heights

RLAN Deployment Zone	Antenna Height (meters)
Urban	1.5 to 28.5 (3 meter increments)
Suburban	1.5, 4.5
Rural	1.5, 4.5

For omni-directional RLANs the antenna heights are randomly selected using a uniform probability distribution from the set of floor heights at 3 meter steps specified in Table 12 for the urban, suburban and rural zones.

This analysis examines a scenario comprised of 95 percent of the RLAN devices operating indoors and 5 percent operating outdoors.

4 Radar deployments

The analysis will consider ground-based radars.

4.1 Ground-based radars

In this study, the radars will be located at set increments from the RLAN distribution centre with distance increments of 0, 10, 20, 50, and 70 km along a line -120° azimuth with respect to the centre.

Radar 4 uses a tracking antenna beam. For the tracking antenna beam, the beam begins at the horizontal (0°) pointed at an azimuth of 60°.[4] The radar elevation angle increases in 0.4° increments until it reaches the zenith, and then begins to decrease in the opposite direction until it reaches the horizontal once more. The beam will then retrace itself until it finishes in the same orientation it started at. Thus, the beam will have moved through 360° of antenna rotation in 0.4° increments.

[4] The antenna beam will be pointed at the centre of the RLAN distribution.

The analysis distributes RLAN device locations randomly within the three zones of concentric circles described in Section 3.[5] The analysis then begins by placing the radar at one of the distance increments from the centre. The model then begins calculating I^{RLAN} for each RLAN device.

The analysis then proceeds to compare each individual value of I^{RLAN} to the DFS detection threshold. For each I^{RLAN} that exceeds the DFS detection threshold, the corresponding RLAN device is eliminated from further consideration during the particular model run. I^{RADAR} is then calculated for each RLAN device remaining in the simulation, and is then used to calculate I^{AGG}. The radar antenna motion is then incremented by one degree and the calculations are repeated. This process is continued through the full motion of the antenna (as previously described). These aggregate values are then used to calculate the I^{AGG}/N ratio as a function of radar rotation angle in degrees.

5 Analysis

5.1 Assumptions

a) RLAN totals, densities and distribution:

The RLAN characteristics used in this study are the latest available or projected characteristics. For example, this study uses a total RLAN population of 44 111.

b) Propagation Modelling:

The propagation model utilized is from Recommendation ITU-R P.452-15 where the RLAN distribution centre will be located near Los Angeles, CA.[6] The percentage of time will be set at 50 percent, and the surface refractivity will be set at 301. For cases where the distance between emitter and receiver is less than 1 km, free space loss will be used.

c) Building loss:

This analysis also includes an additional reduction for indoor RLANs due to building loss. Any values that would fall below 0 dB are set to 0 dB. This additional loss is a Gaussian random variable with mean 17 dB and standard deviation 7 dB. This can be modelled with the following Matlab code:

building_att_dB= 17+7*randn (1)

Note: The Matlab function `randn(n)` returns a pseudorandom value drawn from the standard normal distribution.

d) Clutter loss:

This study also includes the clutter loss of Recommendation ITU-R P.452-15 equations 57 and 57a to account for the effects of ground cover in cases where the obstacles could typically intercede on the interfering signal path. For emitters in the rural area, the “High crop fields” clutter category of Table 4 of that Recommendation is utilized. For the suburban area, “Suburban” is utilized, and for the urban area, “Urban” is utilized. These clutter losses are shown in Table and they are applied only in cases where the elevation angle from the RLAN to the radar is less than the associated maximum elevation angle specified in Table. The latter maximum elevation angles were computed

[5] Since the RLAN devices are distributed uniformly within the three zones defining the urban, suburban, and rural areas, and all RLAN emitters use omni-directional antennas, the actual location of the radar is not believed to be a critical parameter in the analysis.

[6] 33.976753° -118.108672°.

using the clutter heights and distances specified in Table 4 of Recommendation ITU-R P.452, and negative elevation angles were truncated at 0° because they will not occur in this analysis. No clutter loss is assumed when the elevation angle of the interfering signal path exceeds the applicable maximum elevation angle shown in Table 13.

TABLE 13

Clutter losses values used in study

Ht (m)	Clutter loss (dB)		
	High crop fields	**Suburban**	**Urban**
1.5	17.3	19.6	19.7
4.5	0[7]	16.0	19.6
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table)		18.8
10.5			15.1
13.5			6.8
16.5			1.3
19.5			0
22.5			0
25.5			0[23]
28.5			0

TABLE 14

Elevation angles below which clutter losses could typically occur

Ht (m)	Maximum elevation angle (degrees)		
	High crop fields	**Suburban**	**Urban**
1.5	1.4	16.7	42.8
4.5	0.0	10.2	37.8
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table)		32.0
10.5			25.4
13.5			18.0
16.5			9.9
19.5			1.4
22.5			0.0
25.5			0.0
28.5			0.0

7 Any values that would fall below 0 dB are set to 0 dB.

a) RLAN channel bandwidths: This study uses RLAN channel bandwidths of 20, 40, 80 and 160 MHz.

b) RLAN DFS detection threshold and Bandwidths: This study uses a DFS detection threshold of –64 dBm and DFS detection bandwidth of 20 MHz. If the radar power into an RLAN detector exceeds the detection threshold, that device is turned off for the remainder of the simulation.

c) Probability of coincidence (POC) and pulse widths: a range of values was considered for POC given that determination of a value is specific to equipment implementation and a value that can be addressed by operational changes to the RLAN listening periods. The expected POC is highly dependent on the pulse repetition rate (PRR) of the radar system and at the lowest values for radars in this band could be low. Adjustment of the RLAN listening periods can have impact on system throughput and is not addressed in this study.

5.2 Methodology:

5.2.1 DFS detection model description

DFS is a mechanism that dynamically detects signals from other systems and avoids co-channel operation with these systems. When the DFS detection threshold is exceeded for a particular RLAN, the model generates a uniform random number between 0 and 1 and compares it to the probability of a radar pulse overlapping with an RLAN burst rest "listening" period, which in this model is referred to as the POC. The DFS detection occurs when coincidence has been declared and when the received power from the radar in the RLAN detector exceeds the detection threshold. The POC is based on the packet length and the timing of the RLAN transmissions. Recommendation ITU-R M.1652 describes the parameters and methodology for calculating the POC for the DFS RLAN devices.[8] For the purpose of this analysis, a range of POC values was used.

This received signal level from the radar at the input of the RLAN receiver is evaluated by using Equation 2.

$$I^{RLAN} = P_{RADAR} + G_{RADAR} + G_{RLAN} - L_{Radar} - L_P - L_C - L_A - FDR \quad (2)$$

Where:

I^{RLAN} = Received interference power at the output of the RLAN antenna (dBm);

P_{RADAR} = Peak power of the radar (dBm);

G_{RADAR} = Antenna gain of the radar in direction of the RLAN (dBi);

G_{RLAN} = Antenna gain of the RLAN in direction of the radar (dBi);

L_{RADAR} = Radar transmit insertion loss (dB);

L_P = Propagation loss (dB);

L_C = Clutter loss due to ground cover (dB);

L_A = Building loss (dB);

FDR = Frequency dependent rejection (dB).

If the receiver sampling rate is sufficiently high to capture the peak radar pulse power, the FDR in Equation 2 is zero; otherwise the FDR used is the following:

---

[8] Recommendation ITU-R M.1652, *Dynamic Frequency Selection (DFS) in Wireless Access Systems Including Radio Local Area Networks for the Purpose of Protecting the Radiodetermination Service in the 5 GHz Band* (2003), at Annex 4.

$$FDR = \max\left(0, 20\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \tag{3}$$

Where:

B_{tx} = Bandwidth of the radar transmitter;

B_{rx} = Bandwidth of the RLAN DFS receiver.

5.2.2 Analysis model sescription

Equation 2 is calculated for each RLAN in the distribution. The value obtained is then compared to the DFS detection threshold under investigation. Any RLAN for which the threshold has been exceeded will begin to move to another channel, and thus is not considered (for the remainder of the simulation) in the calculation of interference to the radar, as given by Equation 4.

$$I^{RADAR} = P_{RLAN} + G_{RLAN} + G_{RADAR} - L_{RADAR} – L_P – L_C – L_A - FDR \tag{4}$$

Where:

I^{RADAR} = Received interference power at the input of the radar receiver (dBm);

P_{RLAN} = Power of the RLAN (dBm);

G_{RLAN} = Antenna gain of the RLAN in the direction of the radar (dBi);

G_{RADAR} = Antenna gain of the radar in the direction of the RLAN (dBi);

L_{RADAR} = radar receiver insertion loss (dB);

L_P = Radiowave propagation loss (dB);

L_C= Clutter loss due to ground cover (dB);

L_A= Additional building loss (dB);

FDR = Frequency dependent rejection (dB).

Using equation 4, the values are calculated for each RLAN being considered in the simulation that has not detected energy from the radar in excess of the DFS detection threshold. These values are then used in the calculation of the aggregate interference to the radar by the RLANs using equation 5.

$$I^{AGG} = 10\log[\sum_{j=1}^{N} I_j^{Radar}] + 30 \tag{5}$$

Where:

I^{AGG} = Aggregate interference to the radar from the RLAN devices (dBm);

N = Number of RLANs remaining in the simulation;

I^{RADAR} = Interference into the radar from an individual RLAN device (Watts).

It is necessary to convert the interference power calculated in equation 4 from dBm to Watts before calculating the aggregate interference seen by the radar using equation 5.

The propagation model used in the analysis was Recommendation ITU-R P.452 except in cases where distance is less than one kilometre, in which case free space loss was used.

In addition to the propagation loss, this analysis includes an additional reduction due to building losses.

In this analysis the RLAN transmitters will be operating co-frequency with the radar receivers and the FDR is computed using Equation 6.

$$FDR = \max\left(0, 10\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \quad (6)$$

Where:

B_{tx} = Bandwidth of the RLAN transmitter;

B_{rx} = Bandwidth of the radar receiver.

6 Results

For each radar in this section, a series of 5 outputs will be listed corresponding to the distance the radar is from the centre of the RLAN distribution.

6.1 Radar 4 analysis results for a 2 MHz bandwidth using POC of 100 percent

Figure 3 shows the main output of this study for Radar 4a at a distance of 70 kilometres from the distribution centre. The first graph in Figure 3 shows the number of RLANs that are turned off as a result of DFS detection process during the simulation (53 emitters were turned off at the start of the simulation and no more were turned off during the remainder of the simulation). The second and third graphs show the aggregate received power from the RLANs at the output of the radar receiver as a function of simulation time and distance. The red line is the receiver protection threshold.

The fourth graph is a function of distance showing the maximum received power level at the output of any of the RLAN receivers that are not turned off.

The red line is the DFS detection threshold (–64 dBm) utilized in the study. For this simulation, the maximum aggregate interference power at the output of the radar receiver is 27.815 dB below the ground-based receiver protection threshold and it happened 0 seconds into the simulation. In other words, in this scenario, the radar protection threshold is not exceeded. The analysis results in the remainder of this paper are presented as a series of these four graphs. The following table explains the title in each figure.

TABLE 15

Explanation of Header Values

el:0	The antenna elevation angle at the end of the simulation was 0° with respect to the horizontal.
Dir:0	There were no RLANs with directional antennas
Bif:2	The IF radar receiver bandwidth was 2 MHz
Omni:5186	There were 5186 RLANs with omni-directional antennas
DFS(off):-64	DFS turned any RLAN off (that exceeded a detection threshold of -64 dBm) for the remainder of the simulation.
poc:1	The probability of coincidence was 1 (100%).
distctr@70	The radar started 70 km away from the RLAN distribution centre
P452	The propagation model used was Rec. ITU-R P.452-15
#e:0	The number of interference events was 0
le:	The longest event in seconds
RLAN transmit bandwidths were 20, 40, 80, and 160 MHz occurring in exactly the percentages of total RLANs listed, respectively	
The detection bandwidth was 20 MHz for 100% of the RLANs.	
Max overage:-30.8501 dB@0sec	The maximum over threshold was -30.8501, which occurred when the radar was 0 seconds in the 2nd graph.
outdoor:0.050039	Exactly 5.0039% of the RLANs were outdoor

FIGURE 3

Radar 4 with 2 MHz bandwidth at 70 km

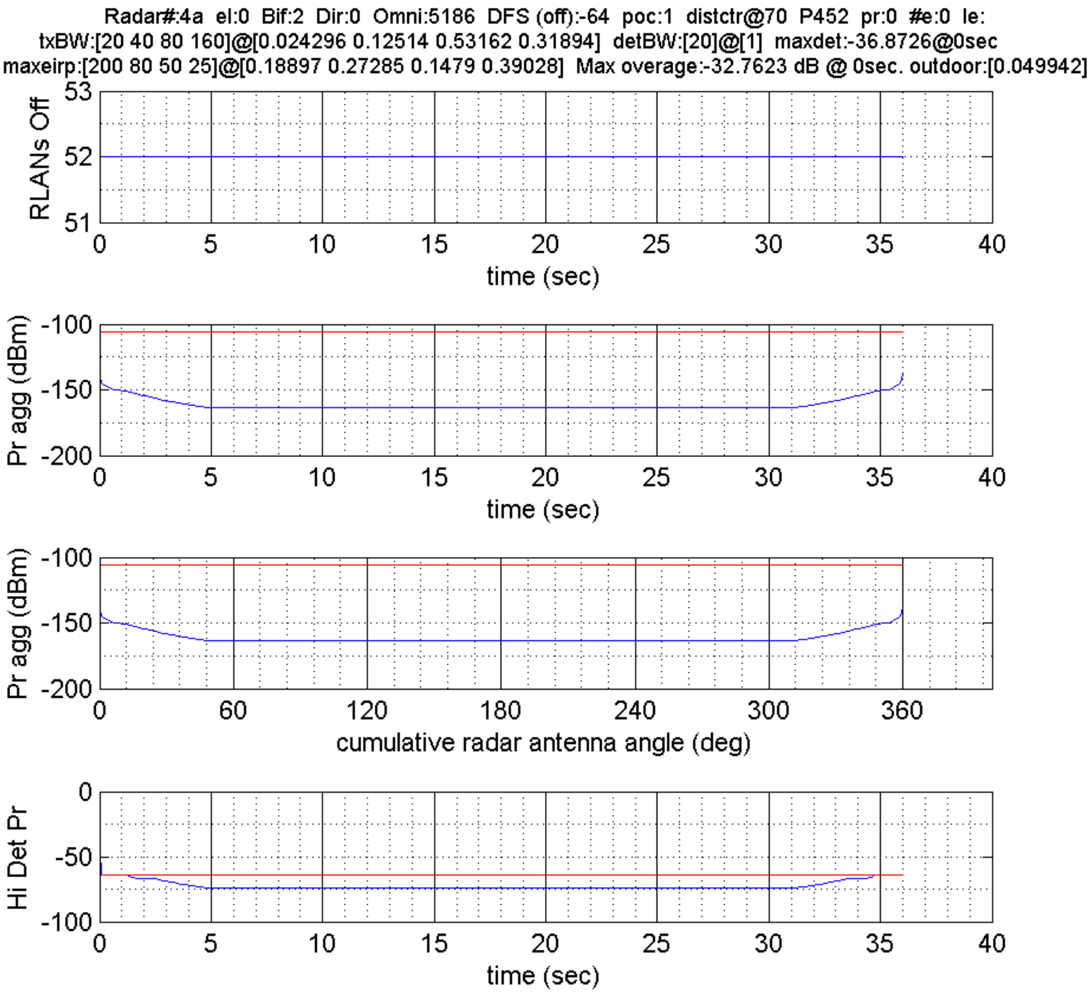


Figure 4 is another output showing the normalized histograms of additional loss, emitter maximum e.i.r.p. and antenna heights used. The additional loss shows more than 5% of emitters at 0 dB because it includes not only the 5% of devices which are outdoors but also the indoor devices which fell below 0 dB when the Gaussian random variable was cast. Figure 4 will apply to all histograms of RLAN variables used in this study.

FIGURE 4

Randomized RLAN Variables used throughout this study

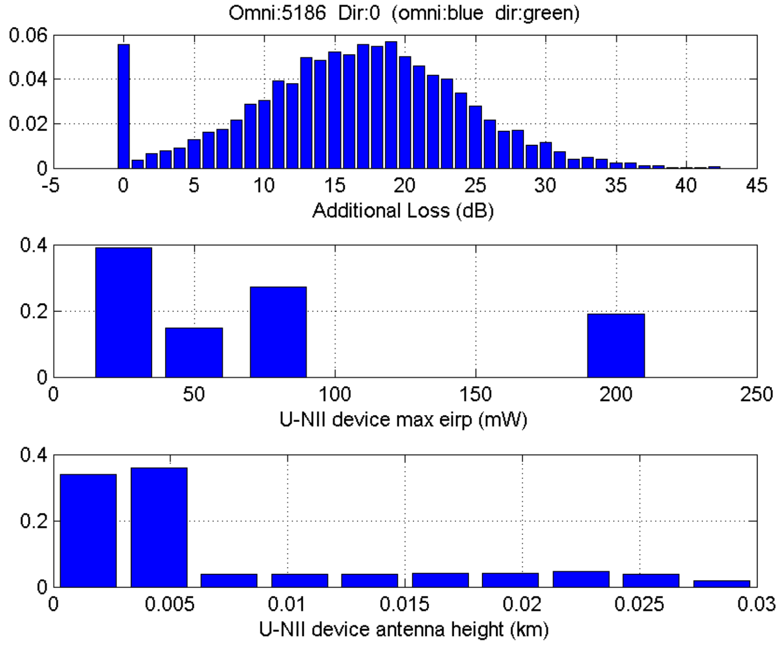


FIGURE 5

Radar 4 with 2 MHz bandwidth at 50 km

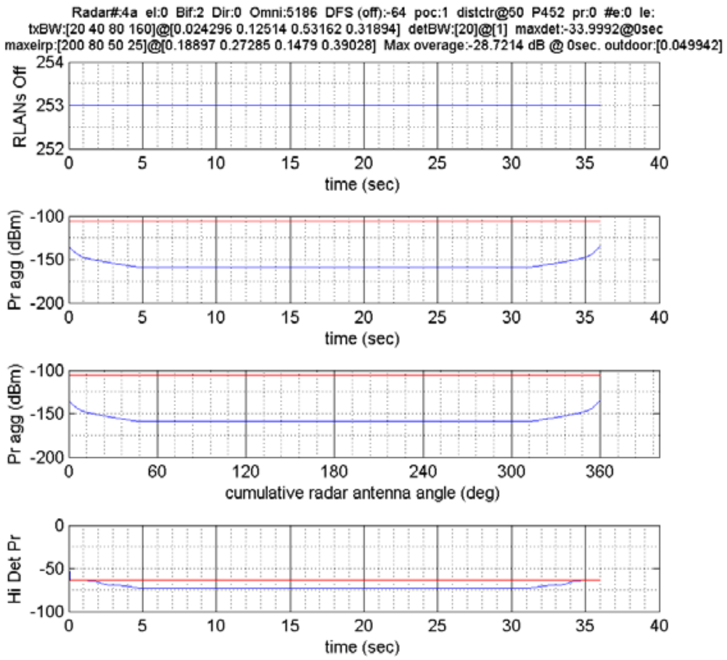


FIGURE 6

Radar 4 with 2 MHz bandwidth at 20 km

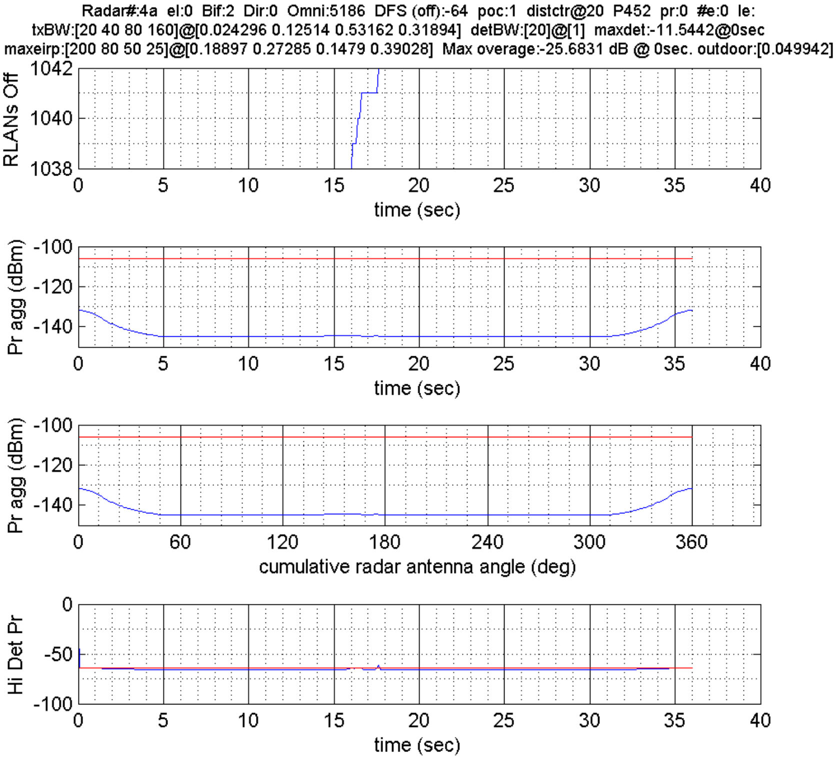


FIGURE 7

Radar 4 with 2 MHz bandwidth at 10 km

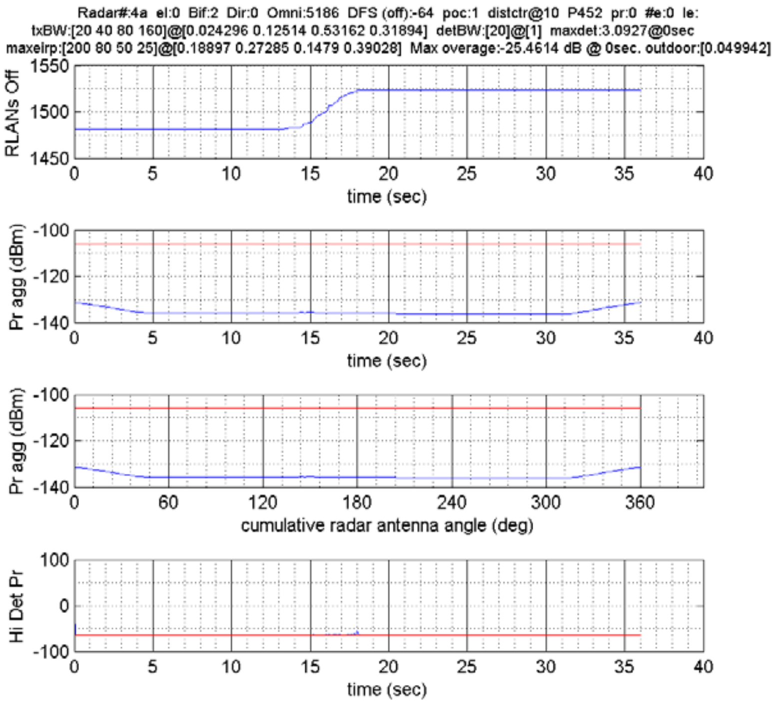
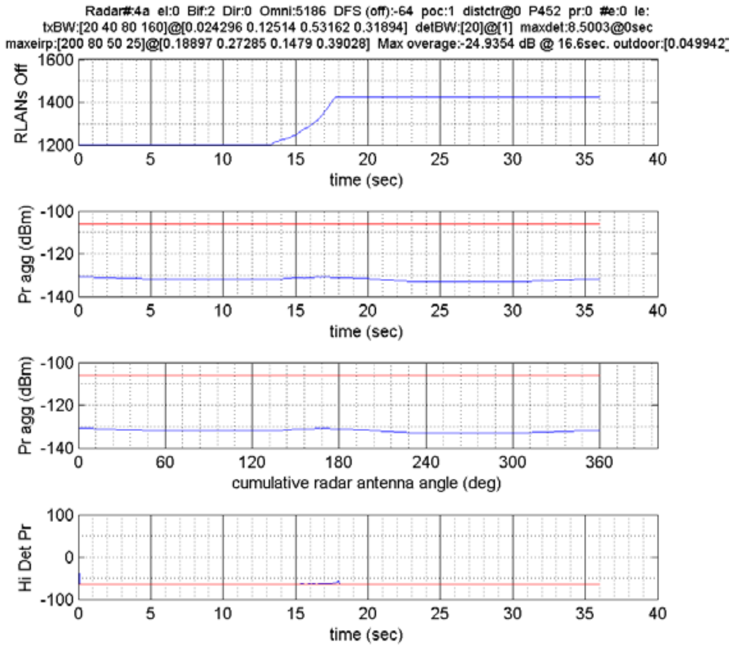


FIGURE 8

Radar 4 with 2 MHz bandwidth at 0 km



6.2 Radar 4 analysis results for a 8 MHz bandwidth using POC of 100 percent

FIGURE 9

Radar 4 with 8 MHz bandwidth at 70 km

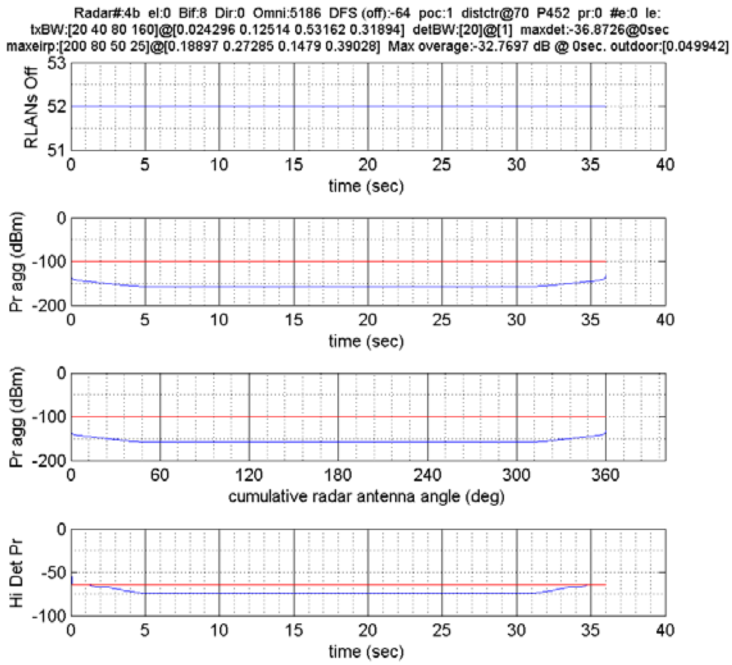


FIGURE 10

Radar 4 with 8 MHz bandwidth at 50 km

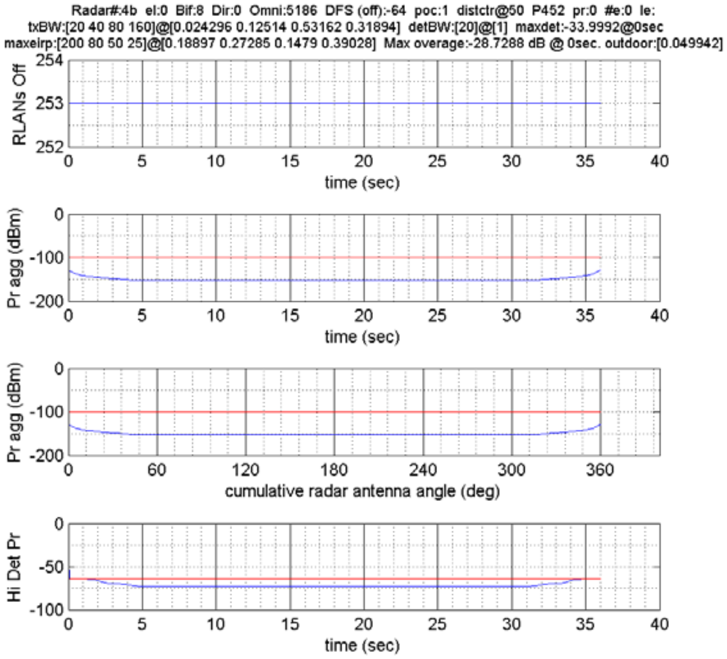


FIGURE 11

Radar 4 with 8 MHz bandwidth at 20 km

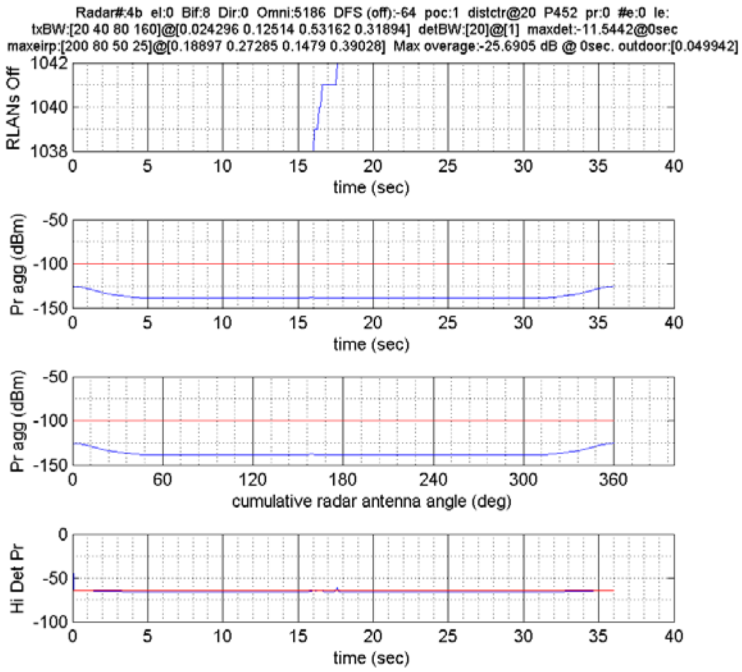


FIGURE 12

Radar 4 with 8 MHz bandwidth at 10 km

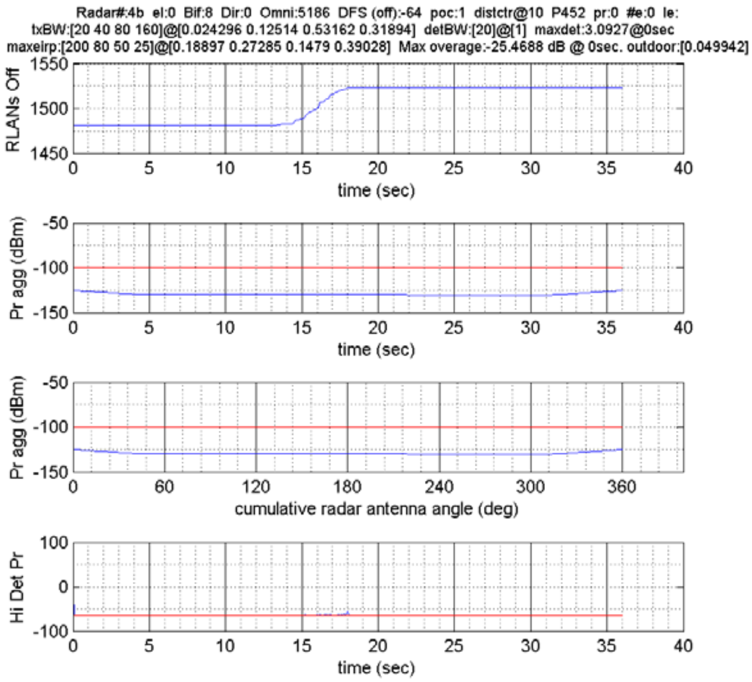
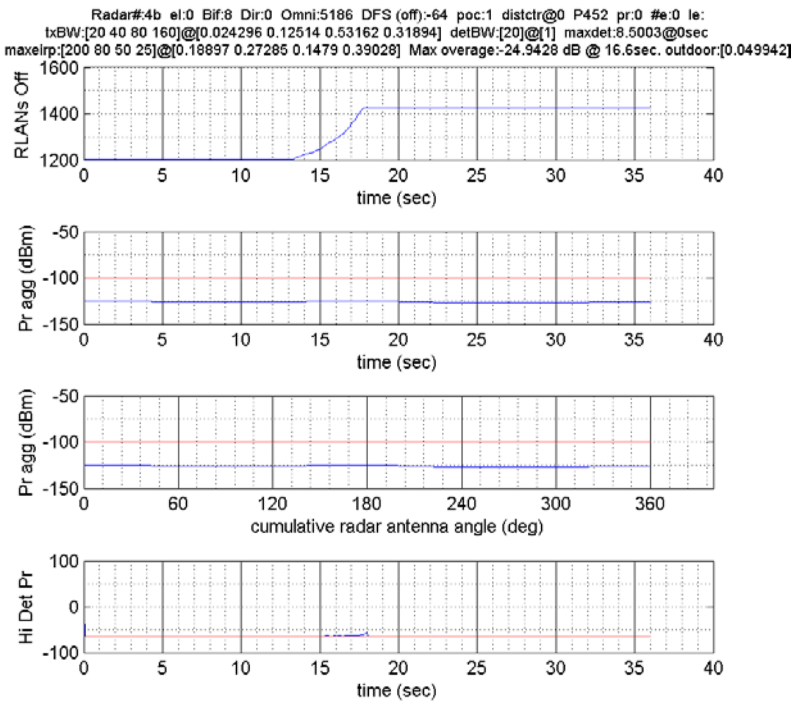


FIGURE 13

Radar 4 with 8 MHz bandwidth at 0 km



6.3 Results using POC of less than 100%

Since the pulse repetition frequency for Radar 4 was very low (20 pps) the average POC was determined to be less than 100% for Radar 4.[9]

The results of a parametric study are shown below.

TABLE 16

POC parametric study

Radar	POC	Maximum over radar detection threshold (dB)for a radar distance from city Centre				
		70 km	50 km	20 km	10 km	0 km
Radar 4b	1	–32.8	–28.7	–25.7	–25.5	–24.9
Radar 4b	0.9	–32.0	–21.5	3.1	9.6	0.4
Radar 4b	0.8	–30.8	–19.1	4.9	13.2	6.3
Radar 4b	0.7	–25.0	–14.8	8.2	18.4	9.1
Radar 4b	0.6	–25.0	–14.3	8.9	20.4	11.0
Radar 4b	0.5	–24.8	–13.5	10.0	21.6	13.4
Radar 4b	0.4	–22.8	–12.8	10.3	22.1	14.2
Radar 4b	0.3	–22.6	–12.1	11.2	22.3	14.3
Radar 4b	0.2	–22.4	–12.0	11.3	22.5	15.1
Radar 4b	0.1	–20.4	–11.7	11.6	23.2	15.3
Radar 4a	1	–32.8	–28.7	–25.7	–25.5	–24.9
Radar 4a	0.9	–32.0	–21.5	3.1	9.6	0.4
Radar 4a	0.8	–30.8	–19.1	4.9	13.2	6.3
Radar 4a	0.7	–25.0	–14.7	8.2	18.4	9.1
Radar 4a	0.6	–25.0	–14.3	8.9	20.4	11.0
Radar 4a	0.5	–24.8	–13.5	10.1	21.6	13.4
Radar 4a	0.4	–22.8	–12.8	10.3	22.1	14.2
Radar 4a	0.3	–22.6	–12.1	11.2	22.3	14.3
Radar 4a	0.2	–22.4	–12.0	11.3	22.6	15.1
Radar 4a	0.1	–20.4	–11.7	11.6	23.2	15.3

[9] An example POC of 46.2% for Radar 4 is shown in the figures below. A range of values was considered given the difficulty in determining a single value.

7 Conclusion

This study investigated the feasibility of RLAN systems operating in the 5 350-5 470 MHz frequency bands with incumbent primary ground-based radiodetermination systems. This study incorporated the following mitigation techniques: DFS (threshold of –64 dBm), predominately indoors (95%) and low power (maximum e.i.r.p. of 200 mW). Sharing between RLANs and ground-based radiodetermination systems in the 5 350-5 470 MHz frequency bands is not feasible when mitigation is limited to these techniques.

The results of the study are summarized in Table 16 above. Based on the technical and deployment characteristics and assumptions considered in this study, the aggregate interference levels from the RLAN emitters exceed the protection threshold for a POC of 90%. One potential remedy that Administrations could investigate is whether POC could be maintained above that level taking into account, for example the features discussed in Section 5.1 g) above.

If different transmit powers or detection levels are applied, or if additional mitigation techniques are developed, the results may be different. Additional studies would be required to evaluate any other mitigation measures to determine their efficacy for RLAN sharing with ground-based radiodetermination systems.

ANNEX C

Sharing between radio local area network systems and radiolocation service systems in the 5 350-5 470 MHz frequency range

1 Introduction

This initial study examines the potential for sharing between proposed RLAN systems and radiolocation systems operating in the 5 350-5 470 MHz frequency range.
The analysis considers example ground-based and ship-based radar systems operating in the radiolocation service (RLS). The analysis utilizes information provided by the United States of America [to the JTG 4-5-6-7 Correspondence Group (CG)] on RLAN parameters in the 5 GHz frequency range.

2 Methodology

The interference situation between RLAN devices and radars is determined using a model suggested [to the CG] on RLAN parameters in the 5 GHz frequency range by the United States. The [CG] input document is reproduced here as Appendix 1.

The RLAN positions, pointing vectors, and RF characteristics are distributed based on the model described in Appendix 1. The radar is initially located some distance from the city centre.
At each time step in the simulation, the radar location and pointing vector is determined based on the position and scanning characteristics of the radar. Then the power received by the RLAN devices is computed based on the RLAN and radar positions, pointing vectors, and RF characteristics. Any RLAN devices with a receive power that is above the DFS threshold are turned off, and remain off for the duration of the simulation.

The aggregate interference into the radar from any RLANs that remain active is computed. Results are presented in a graph of the aggregate interference into the radar as a function of time.

The RLAN receive power is calculated as follows:

$$I_{RLAN} = P_{Radar} + G_{Radar}(\theta_{Radar}) - FL_{Radar} + G_{RLAN}(\theta_{RLAN}) - PL - CL - BL - FDR_{RLAN}$$

where:

I_{RLAN} = Interference power into RLAN, dBm;
P_{Radar} = Radar signal power, dBm;
$G_{Radar}(\theta_{Radar})$ = Radar antenna gain in direction of RLAN, dBi;
FL_{Radar} = Radar insertion loss, dB;
$G_{RLAN}(\theta_{RLAN})$ = RLAN antenna gain in direction of radar, dBi;
PL = Propagation loss including clutter losses, dB;
CL = Clutter losses, dB;
BL = Building penetration loss, dB;
FDR_{RLAN} = Frequency dependent rejection into RLAN, dB.

The FDR applicable to the RLAN receiver is approximated as follows:

$$FDR_{RLAN} = \max(0,10 \times \log_{10}(BW_{Radar} / BW_{RLAN})$$

where:

BW_{Radar} = Bandwidth of radar signal, Hz;

BW_{RLAN} = Detection bandwidth of RLAN device, Hz.

The interference power into the RLAN is compared with the DFS threshold to determine which RLANs remains active.

The interference into the radar from each active RLAN is calculated as follows:

$$I_{Radar} = PD_{RLAN} + G_{RLAN}(\theta_{RLAN}) + G_{Radar}(\theta_{Radar}) - FL_{Radar} - PL - CL - BL + 10 \times \log 10(BW_{Radar})$$

where:

I_{Radar} = Interference power into radar from individual RLAN, dBm;

PD_{RLAN} = RLAN signal power density, dBm/Hz.

The radar signal bandwidth is assumed to be fully occupied by RLAN emissions.

The aggregate interference into the radar from all active RLANs in the 20 MHz channel (N_{RLAN}) is computed as follows:

$$I_{Total,Radar} = 10 \times \log_{10}\left(\sum_{i=1}^{N_{RLAN}} 10^{(I_{Radar,i}/10)} \right)$$

where:

$I_{Total,Radar}$ = Aggregate interference power into radar, dBm.

The calculations presented here are preliminary and the software tool used needs to be validated.

3 System characteristics

The following tables summarize the RLAN and radar characteristics considered for this analysis. The RLAN characteristics are taken from the CG input included as Attachment 1. Radiolocation system characteristics are taken from Recommendation ITU-R M.1638.

TABLE 1

RLAN characteristics

Parameter	RLAN
RLAN deployment	
Radius (km)	(5, 15, 30)
Percent users (%)	(30, 50, 20)
Maximum height (m)	(28.5, 4.5, 4.5)
Minimum height (m)	(1.5, 1.5, 1.5)
Height increment (m)	3.0
Number	5186
RLAN pointing	
Azimuth range (deg)	(-180, 180)
Elevation range (deg)	(0, 0)
RLAN RF	
EIRP (mW)	(200, 80, 50, 25)
EIRP percent indoor (%)	(18, 26, 14, 37)
EIRP percent outdoor (%)	(0.9, 1.3, 0.8, 2)
Antenna peak gain (dBi)	3.0
Antenna pattern	Appendix 1
Bandwidth (MHz)	(20, 40, 80, 160)
Percent bandwidth (%)	(10, 25, 50, 15)
DFS threshold (dBm)	-64.0

TABLE 2

Radar characteristics

Parameter	Ground	Maritime
Radar deployment		
Name	Radar A	Radar Q
Initial distance from city center (km)	25	35
Height (m)	30	40
Speed (km/hr)	0	0
Radar pointing		
Azimuth scan type	Continuous	Sector
Azimuth scan rate (deg/s)	0.65	90
Azimuth scan range (deg)	[0, 360]	[-120, 120]
Elevation scan type	Fixed	Fixed
Elevation scan rate (deg/s)	-	-
Elevation scan range (deg)	0	0
Radar RF		
Power (dBm)	84.0	84.5
Pulse width (µs)	2.0	1.0
Pulse repetition rate (pps)	1200	750
Antenna gain (dBi)	46.0	30.0
Antenna gain pattern	Rec. ITU-R M.1652	Rec. ITU-R M.1652
Feeder loss (dB)	2	2
Bandwidth (MHz)	0.5	1.2
Noise figure (dB)	7.0	10.0
Protection requirement (dBm)	-116.0	-109.2

4 Propagation characteristics

Free space loss (FSL) is assumed in this analysis. The [CG] input by the United States did not propose a propagation model for the RLS case. Although FSL may not be the most appropriate model to use, it is chosen as a starting point while further investigation on propagation models is progressed[within JTG 4-5-6-7].

Building losses for indoor RLAN devices are determined from a normal distribution with a mean of 17 dB and a standard deviation of 7 dB, with the restriction that the building loss cannot be less than zero.

Clutter losses at the radar and RLAN locations are determined using the elevation angle dependent model adapted from Recommendation ITU-R P.452-14 as described in Appendix 1.

5 Results

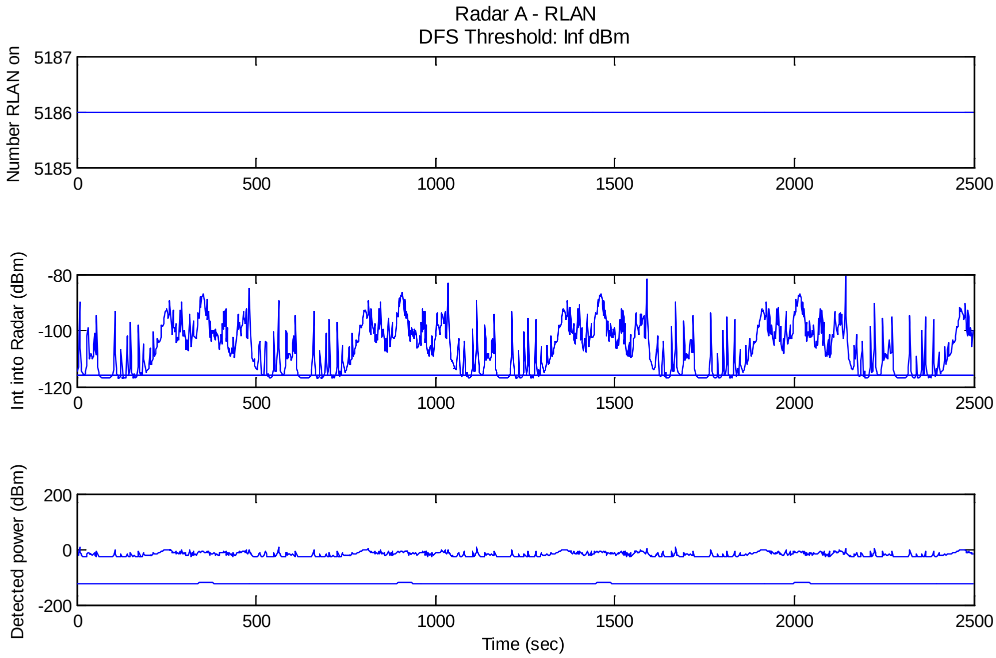
The following figures show the time-dependent interference into the radar systems from the assumed distribution of RLAN devices. Two figures are provided for the radar system: the first shows the interference situation without applying the DFS mechanism; the second figure shows the impact of applying DFS with a threshold value of –64 dBm.

Each figure consists of three plots. The first plot shows the number of RLAN devices remaining on as a function of time. The second plot shows the aggregate interference into the radar as a function of time. The last plot shows the range of detected power levels at the RLAN devices as a function of time.

This analysis utilized conservative assumptions (e.g. free space loss propagation model) that overestimate interference into RLS. It is also important to note that the results shown below are the output of only a single run for each case. Due to the statistical nature of the analysis, multiple runs should be made to more accurately determine interference levels. These results should therefore be treated as preliminary. Further study is required.

FIGURE 1A - RADAR A

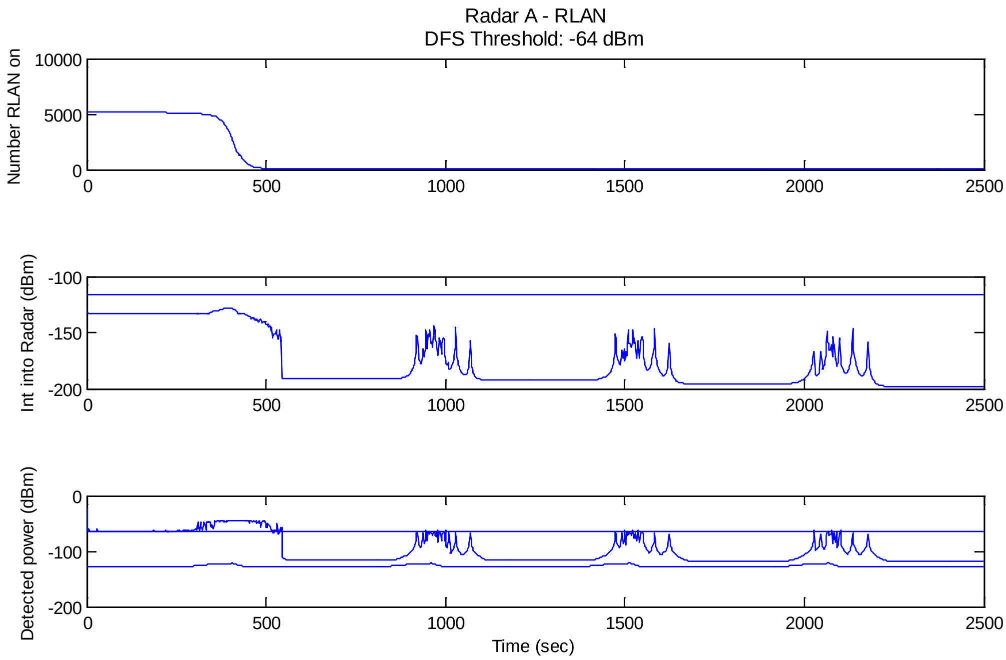
No DFS Applied



Max Int radar: -80.7 dBm; Max exceedance: 35.3 dB; Max Det RLAN: 5.5 dBm

FIGURE 1B – RADAR A

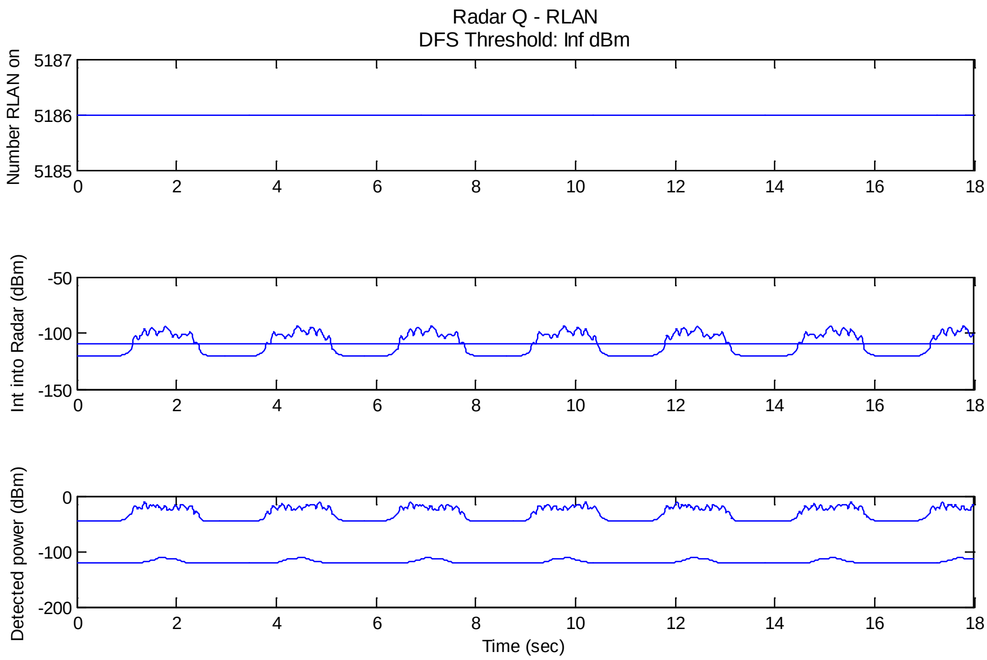
DFS Threshold = –64 dBm



Max Int radar: -127.8 dBm; Max exceedance: -11.8 dB; Max Det RLAN: -23.8 dBm

FIGURE 2A – RADAR Q

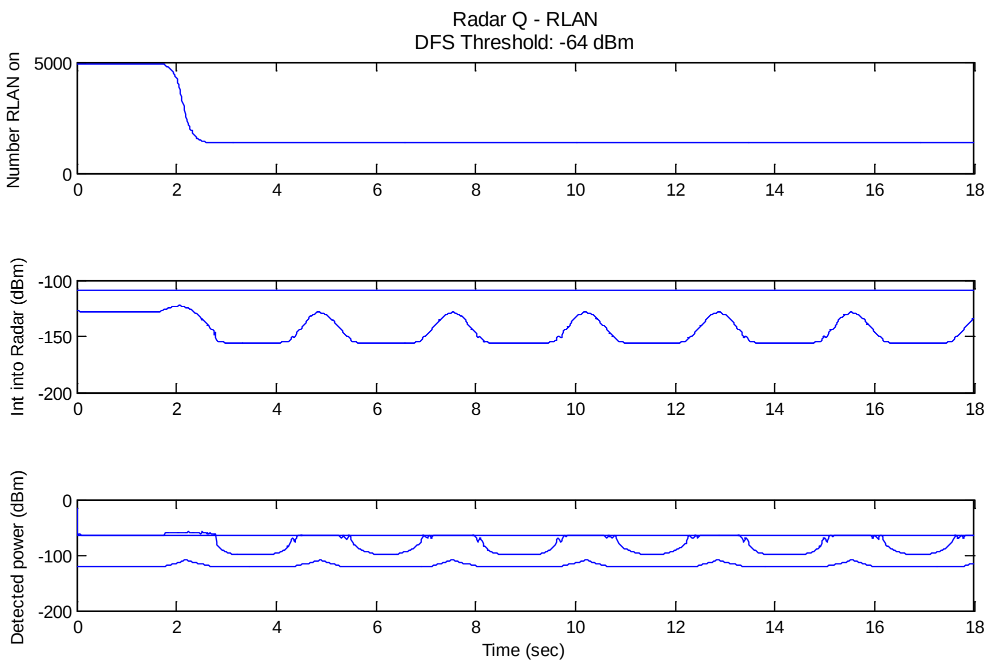
No DFS Applied



Max Int radar: -93.8 dBm; Max exceedance: 15.4 dB; Max Det RLAN: -11.5 dBm

FIGURE 2B – RADAR Q

DFS Threshold = –64 dBm



Max Int radar: -122.5 dBm; Max exceedance: -13.3 dB; Max Det RLAN: -15.7 dBm

The results shown in the figures above can be summarized as shown in Table 3.

TABLE 3

Summary of results

Parameter	Value	Value
Radar name	Radar A	Radar Q
No DFS		
Maximum interference level into radar (dBm)	-80.7	-93.8
Maximum exceedance of protection requirement (dB)	35.3	15.4
Maximum detected signal into RLAN (dBm)	5.5	-11.5
With DFS		
Maximum interference level into radar (dBm)	-127.8	-122.5
Maximum exceedance of protection requirement (dB)	-11.8	-13.3
Maximum detected signal into RLAN (dBm)	-23.8	-15.7

These results show that in general, without the application of any mitigation technique, the interference into the radar system can be expected to exceed the protection requirement for some periods of time. The results also show that the DFS mechanism may be able to mitigate this interference. Further study is needed to determine the interference between proposed RLAN devices and systems operating in the 5 GHz frequency range.

6 Conclusions

This analysis examined the potential for sharing between RLAN and radiolocation systems operating in the 5 350-5 470 MHz frequency range. The analysis utilized information provided by the United States of America [to the Correspondence Group] on RLAN parameters in the 5 GHz frequency range. The interference situation was determined for example radar systems in the RLS. The impact of the DFS mechanism on the interference situation was also analysed.

These results show that in general, without the application of any mitigation technique, the interference into the radar system can be expected to exceed the protection requirement for some periods of time. The results also show that the DFS mechanism may be able to mitigate this interference. It is premature to draw any definitive conclusions as these results obtained here are preliminary.

Furthermore, the analysis utilized free space loss propagation model which overestimates interference. The analysis also only considered a single example radar system of each type and it may be appropriate to examine additional radar systems. Also, multiple runs should be made for each case to produce more accurate results. Finally, the software tool used needs to be validated. Further study is needed determine the interference between proposed RLAN devices and systems operating in the 5 GHz frequency range.

APPENDIX 1 TO ANNEX C

REPRODUCED FROM INPUT TO 5 GHz CORRESPONDENCE GROUP

Baseline RLAN Deployment and Technical Parameters

This document develops baseline RLAN deployment and technical parameters to be used in compatibility analyses.

Deployment Parameters

The RLAN devices will be randomly distributed over three regions: urban, suburban, and rural. The three regions exist within concentric circles as shown in Figure 1.

FIGURE 1

RLAN Device Deployment Regions

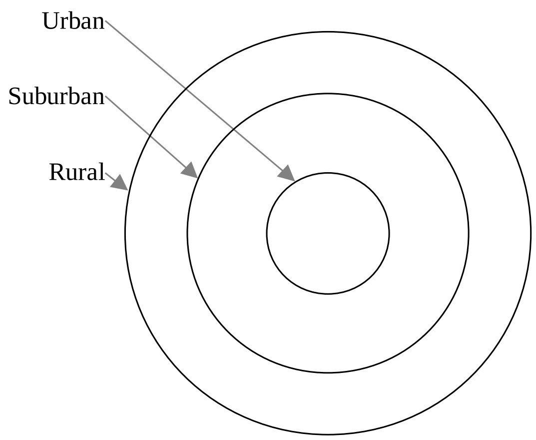


Table 1 provides the radius of each RLAN deployment region.

TABLE 1

RLAN Deployment Region	Radius from the Center (km)
Urban	0 to 5
Suburban	5 to 15
Rural	15 to 30

The population used for the baseline is 5.25 million people. Table 2 provides the population distribution within each region for each RLAN device environment.

TABLE 2

Population Zones

Total Pop.	Population split	Percent	Pop. In Zone
5 250 000	Urban	30%	1 575 000
	Suburban	50%	2 625 000
	Rural	20%	1 050 000

The number of active users in each region is computed based on factors such as the population, and estimates of market penetration, system factor, and activity rate as shown in Table 3 based on the corporate busy hour, which represents the peak traffic and activity for RLAN devices. Market penetration indicates the percentage of the population that uses 5 GHz RLAN devices. The system factor determines the ratio of user devices associated with an access point. Activity rate is the percentage of over-the-air activity time for an RLAN device and represents the percentage of devices actively associating with an access point.

Number of On-tune, Active RLAN devices

Step 1: Determine base population size by zone.

Step 2: Apply a Busy Hour factor to determine the base population by zone.

Step 3: Apply Market Factor (% of users with devices) by zone.

Step 4: Apply System Factor (% of devices actively transmitting <AP/Users>) by zone.

Step 5: Apply Activity Factor (% of devices operating) by zone.

Step 6: Apply Bandwidth Factor (% of devices on-tune based on bandwidth distribution model).

Calculations:

TABLE 3

RLAN On-tune, Active Devices

	Population	Step 2 Busy Hour Factor	Busy Hour Population	Step 3 † Market	Step 4 † System	Step 5 † Activity	Step 6 * Bandwidth	
Urban	1 575 000	71%	1 118 250	894 600	62 622	15 656		
Suburban	2 625 000	64%	1 680 000	1 344 000	94 080	23 520		
Rural	1 050 000	47%	493 500	246 750	49 350	4 935		
Total						44 111	5 186	per 20 MHz

Factors

†	Market	System	Activity
Urban	80%	7%	25%
Suburban	80%	7%	25%
Rural	50%	20%	10%

Bandwidth

Start Channel	*	20 MHz	40 MHz	80 MHz	160 MHz
5150	Percent	10%	25%	50%	15%
End Channel	Devices	4 411	11 028	22 055	6 617
5 850	Channels	35	17	8	4
	On-tune	126	649	2 757	1 654

Note: The U.S. Federal Communications Commission initiated a notice of proposed rulemaking (NPRM) on February 20, 2013. Although no final decision has been made in the U.S. regarding this proceeding, this NPRM is examining the proposed operation of RLANs in the 5 350-5 470 MHz and 5 850-5 925 MHz bands while ensuring protection of incumbent users. Considering the international mobile allocation at 5 850-5 925 MHz, spreading the devices over the 75 MHz of additional spectrum from 5 850-5 925 MHz would reduce RLAN density.

Technical parameters

The baseline will include RLAN devices employing omni-directional antennas. For each time step the RLAN device power, operating bandwidth, and height will be randomly determined.

For EESS studies:

In the U.S. power will be parametrically modified to determine the maximum allowable power level that does not exceed the required protection criteria of I/N –6 dB.

For aeronautical radar studies:

In the U.S. power will be parametrically modified to determine the Maximum allowable power level that does not exceed the required protection criteria of I/N –6 dB.

For ground based/Shipborne radar studies:

The RLAN device equivalent isotropically radiated power (e.i.r.p.) level distribution for the baseline is shown in Table 4.

TABLE 4

RLAN power distribution

RLAN e.i.r.p. Level	200 mW (Omni-Directional)	80 mW (Omni-Directional)	50 mW (Omni-Directional)	25 mW (Omni-Directional)
RLAN Device Percentage (Indoor operation)	18%	26%	14%	37%
RLAN Device Percentage (Outdoor operation)	0.9%	1.3%	0.8%	2%

The e.i.r.p. in this table reflects what the actual transmit powers are likely to be, and that these in many cases will be below maximum power allowed based on adjusting the transmit power for capacity versus coverage. TPC therefore does not need to be separately modelled for the purposes of the analysis.

The e.i.r.p. levels and percentages in Table 4 are derived from: 1) predictions of shipped devices for various devices classes; 2) expected e.i.r.p. of the device classes; 3) matching the percentages from the sum of the rows in device distribution and 4) traffic mix in a Basic Service Set between Access Point and client.

Studies will consider a limit on the e.i.r.p. of 200 mW to determine sharing feasibility. If higher powers are submitted, additional studies will be required.

The RLAN device transmitter bandwidth distribution for the baseline is shown in Table 5.

TABLE 5

Bandwidth distribution

RLAN Transmitter Bandwidth	20 MHz	40 MHz	80 MHz	160 MHz
RLAN Device Percentage	10%	25%	50%	15%

For EESS studies, the bandwidth distribution found in the Annex will determine the number of on-tune active devices.

For all other studies, the worst-case the sum of devices overlapping a 20 MHz channel was determined in Table 3 above.

The RLAN antenna pattern in the azimuth orientations is omni-directional. The RLAN device elevation antenna pattern is described in Table 6.

TABLE 6

RLAN elevation antenna pattern

Elevation angle θ (Degrees)	Gain (dBi)
45 < θ ≤ 90	–4
35 < θ ≤ 45	0
0 < θ ≤ 35	3
–15 < θ ≤ 0	–1
–30 < θ ≤ –15	–4
–60 < θ ≤ –30	–9
–90 < θ ≤ –60	–8

Table 7 provides the distribution of RLAN device antenna heights for each RLAN deployment region. Distribution of antenna height is important for ground/shipborne radar interference cases and will have less impact on EESS and aeronautical case studies.

TABLE 7

RLAN antenna height distribution

RLAN Deployment Region	Antenna Height (meters)
Urban	1.5 to 28.5
Suburban	1.5, 4.5
Rural	1.5, 4.5

For omni-directional RLANs the antenna heights are randomly selected using a uniform probability distribution from the set of floor heights at 3 meter steps specified in Table 7 for the urban, suburban and rural zones.

Propagation models:

Aeronautical radar case:

Recommendation ITU-R P.528 + angular clutter loss model from Recommendation ITU-R P.452 + building attention with a Gaussian distribution utilizing a mean of 17 dB and a standard deviation of 7 dB.

EESS radar case:

Recommendation ITU-R P.619 + angular clutter loss model from Recommendation ITU-R P.452 + building attention with a Gaussian distribution utilizing a mean of 17 dB and a standard deviation of 7 dB.

Angular clutter loss model

The angular clutter loss model provided by the "RLAN User Defined Height" column of the attached worksheet should be used in conjunction with the Table 8 antenna heights. The clutter loss values calculated for the "sparse houses", "suburban" and "urban" clutter (ground-cover) categories should be applied in the rural, suburban and urban zones of the RLAN deployment model, respectively.

Theta max (°) provides the angle from the RLAN transmitter to the top of the clutter height. Therefore, if the aircraft/spacecraft is at an elevation angle at or below theta max (°), clutter loss should be added. If the aircraft/spacecraft is above theta max (°), there is no clutter loss.

Clutter calcs Rev 4.xlsx

APPENDIX 2 TO ANNEX C

Proposal for distributing active U-NII devices over 5 GHz channels

The U.S. uniformly distributed active U-NII devices across all of the currently available channels and new channels 68-96 and 169-181. For each active U-NII device, the channel bandwidth would be based on the distribution in Table 1 and a channel number would be selected with a uniform distribution from the available channel bandwidths.

TABLE 1

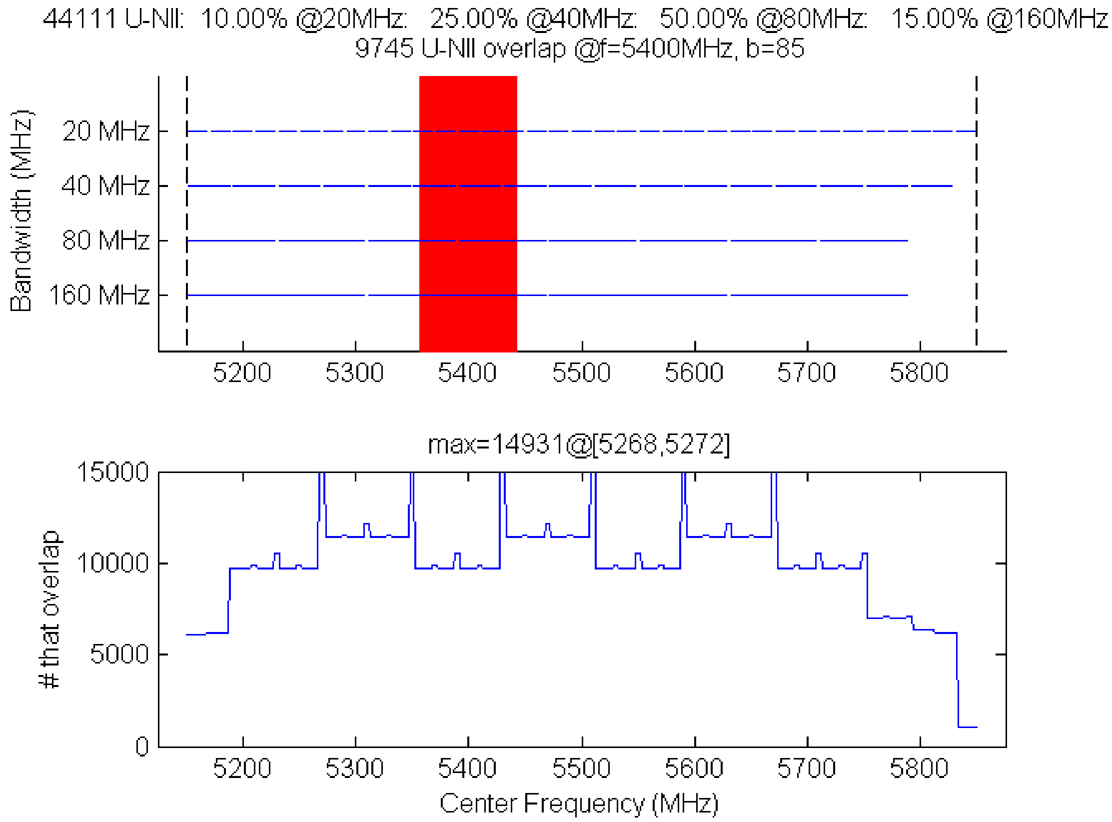
U-NII Device Channel Bandwidth Distribution

U-NII Device Channel Bandwidth	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz** **80 MHz and 80 MHz (non-contiguous)**
Percentage of U-NII Devices	10%	25%	50%	15%

The overall band is 5 150-5 850 MHz (indicated by dashed lines) as shown in the first graph of Figure 2. The first graph of the figure shows the U-NII device channels with a gap between them, the overlap algorithm considers that channel edges touch each other. This means that a receiver centred between channels will always overlap with both channels (because the radar bandwidth is always greater than 0 MHz). The gap is provided in the figures only as a visual aid to distinguish between channels.[10] In the example shown in Figure 2 there is a receiver centred on 5 400 MHz with an 85 MHz bandwidth. A current proposal that is under consideration would deploy 4 4111 active U-NII devices in the 5 GHz frequency range (5 150-5 850 MHz). The second graph shows the number of U-NII devices that overlap when the receiver centre frequency is shifted throughout the band.

[10] The gap is created by clipping 2 MHz off each of the ends of a channel.

FIGURE 1



Of 44 111 active users based on the channel bandwidth distribution shown in Table 1, 10 percent are evenly spread in 20 MHz channels, 25 percent in 40 MHz channels, 50 percent in 80 MHz, and 15 percent in 160 MHz channels. There are 4 411 U-NII devices spread across the thirty five 20 MHz channels. There are 11 028 U-NII devices spread across the seventeen 40 MHz channels. There are 22 056 U-NII devices spread across the eight 80 MHz channels. There are 6 616 U-NII devices spread across the four 160 MHz channels. The first 20 MHz channel has 127 U-NII devices and the remaining thirty four channels have 126 U-NII devices each. The first twelve 40 MHz channels have 649 U-NII devices each and the remaining five channels have 648 emitters each.

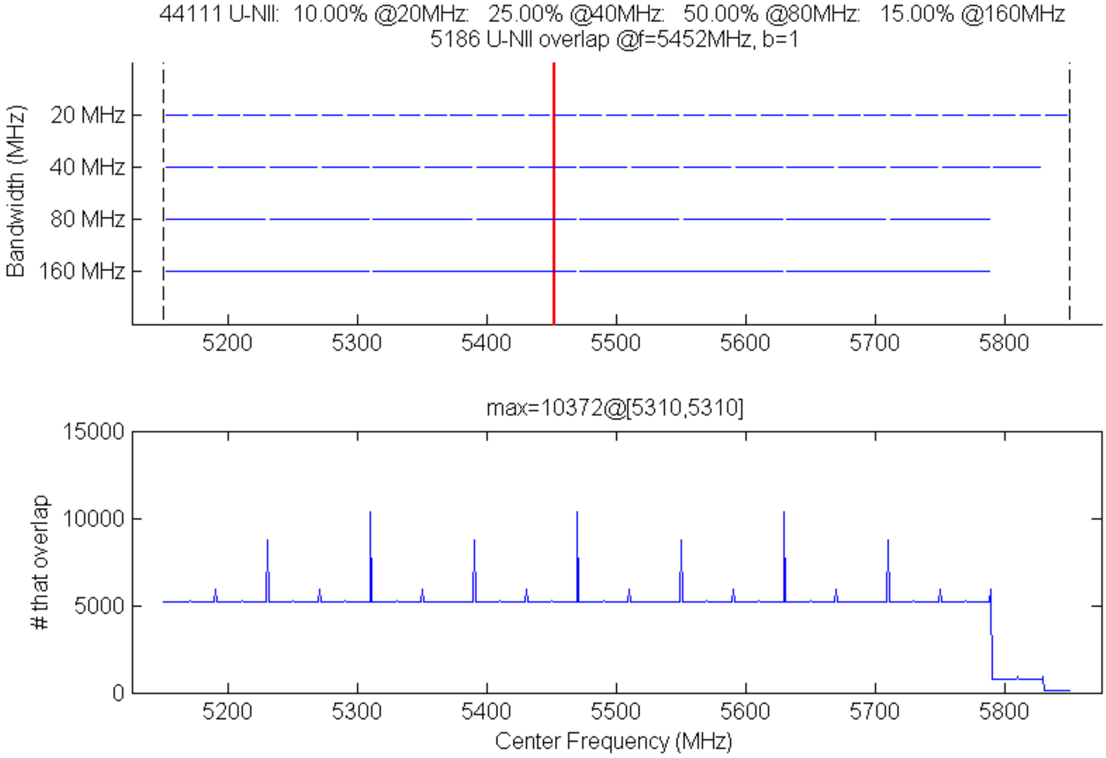
All eight 80 MHz channels have 2 757 U-NII devices each. All four 160 MHz channels have 1 654 U-NII devices each.

The radar in the example shown in Figure 1 with an 85 MHz receiver bandwidth overlaps the eleventh through fifteenth 20 MHz channels, resulting in 5*126 =630 active co-channel U-NII devices. The 85 MHz radar receiver bandwidth overlaps with the sixth through eighth 40 MHz channels, resulting in 3*649=1947 active co-channel U-NII devices. The 85 MHz radar receiver bandwidth overlaps the third and fourth 80 MHz channel, resulting in 2*2757=5 514 active co-channel U-NII devices. The 85 MHz radar receiver bandwidth overlaps the second 160 MHz channels, resulting in 1 654 active co-channel U-NII devices. This results in a total of 630 + 1 947 + 5 514 + 1 654 = 9 745 active co-channel U-NII devices falling within the 85 MHz receiver bandwidth.

Using this methodology with 44 111 U-NII devices for 1, 20, and 100 MHz receiver bandwidths centred at an arbitrarily chosen 5 452 MHz gives the following. The second subplot in each figure shows the number of U-NII devices that overlap when the receiver centre frequency is shifted throughout the band.

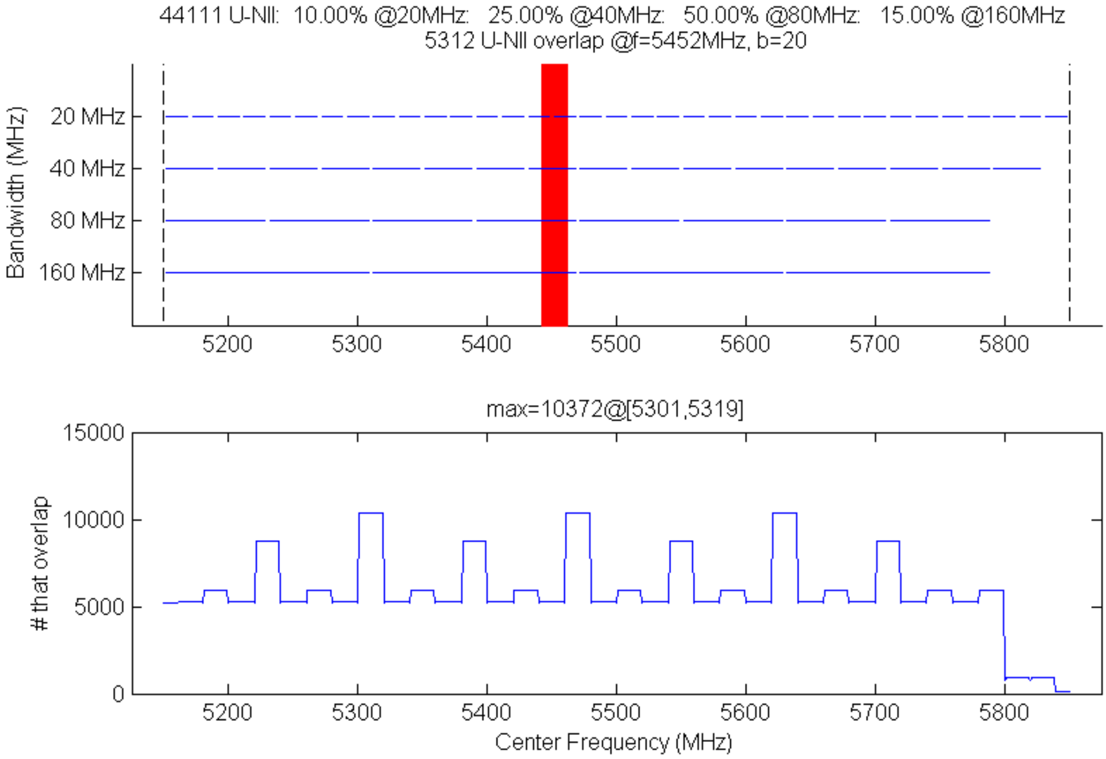
The results for the 1 MHz receiver bandwidth are shown in Figure 2.

FIGURE 2



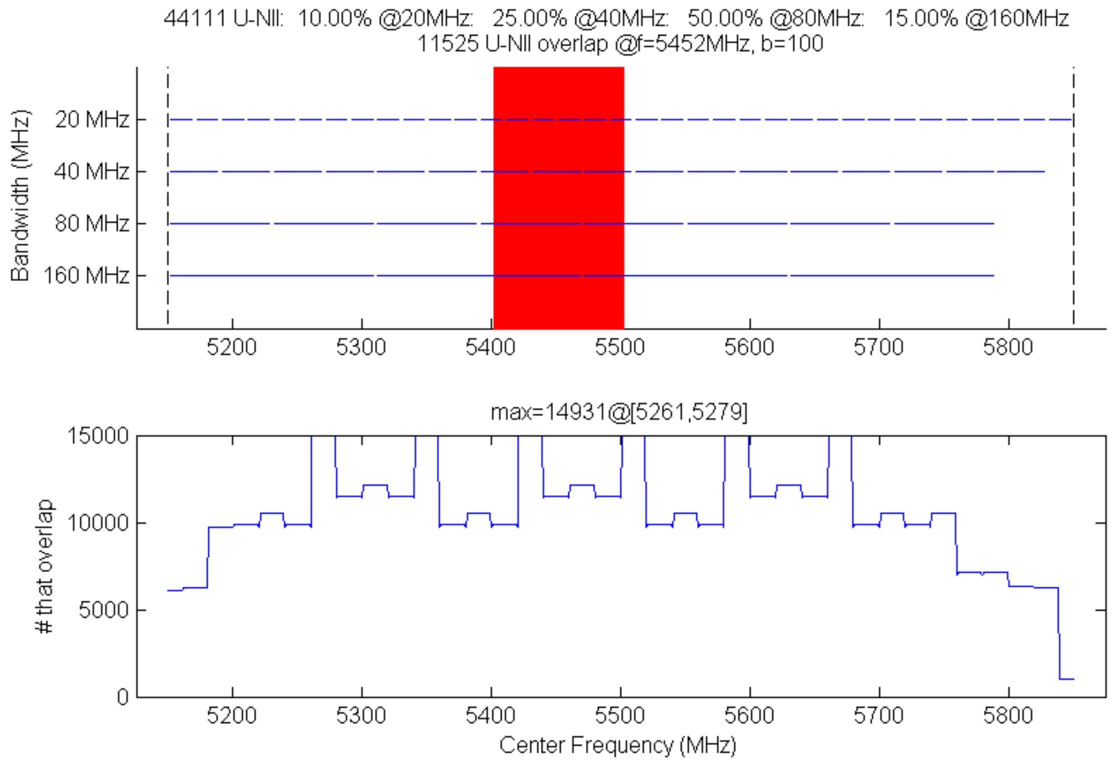
The results for the 20 MHz receiver bandwidth are shown in Figure 3.

FIGURE 3



The results for the 100 MHz receiver bandwidth are shown in Figure 4.

FIGURE 4



A summary of the maximum number of active co-channel U-NII devices for each receiver bandwidth is provided in Table 2.

TABLE 2

Summary of maximum number of active co-channel U-NII devices

Receiver bandwidth (MHz)	Maximum number of active co-channel U-NII Devices
1	10 372
20	10 372
100	14 931

ANNEX D

Initial analysis of DFS as mitigation measure for the co-existence of RLAN systems and radiolocation service systems in the 5 350-5 470 MHz frequency band

1 Introduction

This initial analysis addresses the DFS, as is currently described in the Recommendation ITU-R M.1652-1, and the ability of this mechanism to adequately detect signals of frequency hopping radars.

The DFS mechanism was originally introduced in Resolution **229 (WRC-03)** as mitigation method to avoid interference from RLAN systems in the bands 5 250-5 350 MHz and 5 470-5 725 MHz to other systems in these bands including radars. In this Resolution **229 (Rev.WRC-12),** ITU-R is invited to “continue studies on suitable test methods and procedures for the implementation of dynamic frequency selection, taking into account practical experience”. Information on the practical implementation and the experience with DFS can be found in documents within various organisations including ETSI, IEEE and CEPT.

Currently under WRC-15 agenda item 1.1 the band 5 350-5 470 MHz is considered as potential candidate band for International Mobile Telecommunications (IMT) and other terrestrial mobile broadband applications. In both frequency bands an primary allocation to the radiolocation service exists. The existing radar systems, that are operating under this allocation, need to be considered in the sharing and compatibility studies that are undertaken within the scope of Resolution **233 (WRC-12)**.

2 Radiolocation service

Under the radiolocation service in the band 5 350-5 470 MHz, several radar systems and applications are in operation. One of the radar applications is to monitor a certain part of the airspace. These radar systems are employed to detect, localise, classify and track all flying objects in the airspace; nearby as well as at large distances (well over 100 kilometres) and from high altitude to low flying airborne vehicles. In fact the purpose of these radar systems is to obtain as much information as possible from all objects in the air space: range, height, velocity, direction of movement, size, etc. In order to be able to adequately perform different functions (searching, surveillance, tracking) and retrieve all required information in real-time, also under adverse conditions, radar systems are using sophisticated signal forms and schemes such as frequency hopping. Modern radars also apply phased array antenna technology which enables the fast steering of a pencil beam in any wanted direction to scan a sector of the air space in azimuth and elevation.

Radar systems have to cope with a variety of objects and conditions. Large objects can be at close distance (giving strong echoes), small objects at large distances (that result in very weak echoes) and all have to be detected effectively and accurately. Also it is unknown where new objects may appear, and what characteristics these will have.

The radar systems have to adapt to all these situations. In addition, radar operation is hampered by adverse weather conditions (variations in atmospheric diffraction, rain clutter), unintended reflections from nearby large objects (buildings), the reception of reflections to all fixed objects (land clutter) and the reception of echoes of moving reflection points of the sea surface (sea clutter). Also discernibility of the object under observation might be poor (for example an aircraft at maximum range just above the horizon). Almost all radar systems apply techniques to be as effective and accurate as possible even under adverse conditions. The more advanced the radar system and the higher the required performance, the more sophisticated these techniques will be.

Most commonly applied techniques to enhance the radar system performance require versatility in operating frequency (frequency hopping), and variability in signal form (i.e. the applied pulse widths and pulse repetition frequency (PRF)). In particular these techniques that imply variability in the transmitted signals and frequencies are prone to impede the detection by DFS.

Recommendation ITU-R M.1638 lists the characteristics and protection criteria for a number of different radar systems. Recently, a proposal is done to add two additional types of radars for which it is explicitly stated that these apply frequency hopping. These are Radar 22 and Radar 23 [included in Document 5B/475, Annex 12[11]]for which the characteristics are shown in Table 1.

[11] [Annex 12 to Working Party 5B Chairman's Report, 'preliminary draft revision of Recommendation ITU-R M.1638-1', 'Characteristics of and protection criteria for sharing studies for radiolocation (except ground based meteorological radars) and, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz', 9 January 2014.]

TABLE 1

Characteristics	**Unit**	**Radar 22**	**Radar 23**
Function		Multi-function	Multi-function
Platform type (airborne, shipborne, ground)		Surface and air search, ground-based on vehicle	Search, ground-based on vehicle
Tuning range	MHz	5 400-5 850	5 250-5 850
Modulation		Coded pulse/barker code and Frequency hopping	Coded pulse/barker code and Frequency hopping
Tx power into antenna	kW	12 peak	70
Pulse width	us	4.0-20.0	3.5/6.0/1.0
Pulse rise/fall time	us	0.2	0.3
Pulse repetition rate	pps	1 000-7 800	2 500-3 750
Chirp bandwidth (MHz)	MHz	NA	NA
RF emission bandwidth - 3 dB - 20 dB	MHz	5 Not available	5 Not available
Antenna pattern type (pencil, fan, cosecant-squared, etc.)		Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)		Phased array	Phased array
Antenna polarization		Vertical	Horizontal
Antenna main beam gain	dBi	35	31.5
Antenna elevation beamwidth	degrees	30	30
Antenna azimuthal beamwidth	degrees	2	2
Antenna horizontal scan rate	degrees/s	Variable	Variable
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	degrees	360	360 sector
Antenna vertical scan rate	degrees	NA	NA
Antenna vertical scan type (continuous, random, 360°, sector, etc.)	degrees	Sector	Sector
Antenna side-lobe (SL) levels (1st SLs and remote SLs)	dB	-40	–30
Antenna height	m	10	6-13
Receiver IF 3 dB bandwidth	MHz	4	5
Receiver noise figure	dB	5	13
Minimum discernable signal	dBm	–103	–108

The radars are hopping randomly with a hopping rate of 300 to 1 500 hops/s (in accordance with ECC Report 68).

In practice modern radars show little regularity in signal composition. A small number of pulses (typically 3 to 16, and in some cases even fewer) is transmitted per burst for which the pulse width as well as the pulse spacing differs from pulse to pulse. The number of pulses per burst (hop) can be retrieved from the characteristics of Radar 22 and Radar 23 and results in the values shown in Table 2.

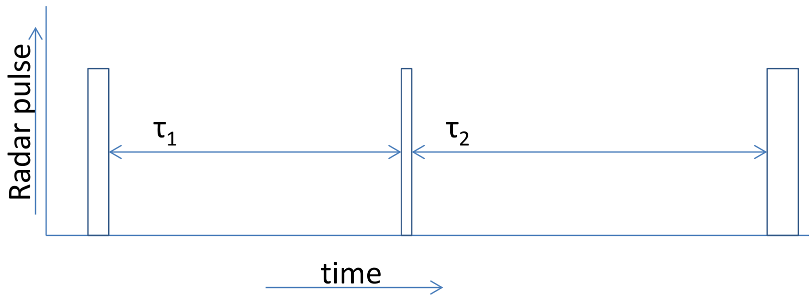
TABLE 2

Pulse repetition rate (pulses/s)	**Frequency hopping rate (hops/s)**	**Number of pulses per hop**
1000	300	3
1000	1500	1
7800	300	26
7800	1500	5
2500	300	8
2500	1500	1
3750	300	12
3750	1500	2

An example of a radar burst of 3 pulses (3 pulses per hop) is shown in Figure as illustration of the variability that can be expected in the signals transmitted by modern radars. Commonly, the pulse repletion interval (PRI) is staggered (irregular) in a random order, not only within a hop but also over multiple hops and also the pulse length may differ from pulse to pulse.

FIGURE 1

Radar pulse burst on a single channel



In order to be effective the DFS mechanism must be capable to detect these types of radar signals and react accordingly.

3 Dynamic frequency selection

The effectiveness of the DFS mechanism to detect frequency hopping radars has been an issue of discussion since the adoption of Resolution **229 (Rev.WRC-12)**.

3.1 DFS requirements in ITU recommendations

As stated in Recommendation ITU-R M.1652-1, interference mitigation techniques are required to enable sharing of WAS (including RLAN) with other services such as radar systems. This conclusion has been confirmed in a recent study [(Document 4-5-6-7/364)] dealing with sharing between RLAN systems and radiolocation service systems in the 5 350-5 470 MHz frequency range.

DFS is seen as a mechanism which is intended to provide adequate protection to radars in the 5 GHz band. Recommendation ITU-R M.1652-1describes the functional performance criteria for the DFS mechanism and leaves the implementation to equipment manufacturers. The remark is made that the effectiveness of the DFS mechanism to detect frequency hopping radars will depend on the pulse characteristics and the time for which the radar occupies the WAS channel; the *dwell time*.

For the probability of detection Recommendation ITU-R M.1652-1 distinguishes between channel availability and in-service monitoring. For in-service monitoring, the functional requirement is based on 'quiet periods' in which the WAS (RLAN) checks for the presence of radar signals. The concept is detailed out in Annex 4 of Recommendation ITU-R M.1652-1. In this annex the need for quiet periods is described as well as a method to calculate the probability of detection. A requirement for the probability of detection is not stated, however Recommendation ITU-R M.2034[12] mentions a detection fail rate of 1%.

The probability of detection of radar pulses is depending both on physics and implementation. Here the achievable probability of detection is elaborated from physical point of view. Given frequency hopping radars can transmit in burst as short as 1 pulse, the single pulse detection probability is initially calculated. In a second stage the detection probability for multiple pulses is also calculated.

The probability of detection is governed by four aspects:

Main beam probability:

Probability of the radar transmitting in the direction of the WAS, the WAS is in the main beam of the radar. For Radars 22 and 23, this probability is 2/360 = 0.0055. This is detailed out in Recommendation ITU-R M.1652-1 Annex 4 step 1.

The scan rate is variable, so the analysis time cannot be determined. A value of 25-100 ms is assumed to be realistic.

Channel probability:

Probability of the radar transmitting in a given channel. This aspect is not yet addressed in the ITU Recommendation. ITU input Document 4-5-6-7/319 which makes the assumption that the frequency band (5 250-5 850 MHz) is divided in 50 sub-bands of 10 MHz between which the radar transmissions hop randomly. In this case the probability for the radar to transmit on a certain channel is 0.02. Assuming that the WAS performs the radar detection in a 20 MHz band, the detection probability per 20 MHz band is 0.04.

Listening probability:

The probability of the pulses being received while the WAS is listening, thus during the 'quiet periods'. (Pulses received while the WAS is communicating[13] cannot be detected). This is covered by Recommendation ITU-R M.1652-1 Annex 4 Step 3. The listening time stated here is $(x)\times 9+50$ ms, x being an integer 2….32. This listening time is at least 2×9 + 50 = *68* ms, whereas the maximum transmission is 2 ms (largest packet at lowest data rate). The listening probability is at least 68/(68+2) = 0.97.

This listening time is however exceptional and is only achieved when the WAS is only transmitting Short Control Signalling, which is far from realistic for an operational system. ETSI (EN 301 893 V1.7.1, par 4.9) states that:

[12] Impact of radar detection requirements of dynamic frequency selection on 5 GHz wireless access system receivers.

[13] Communicating implies both transmitting and receiving (receiving=another nearby WAS is active).

– during in service monitoring, there shall be an idle period of at least 5%[14], the occupancy period being between 1 and 10 ms. So a listening probability of 0.05 seems to be more appropriate;

– during channel availability check, short control signalling is allowed up to 5% duty cycle. In this case a listening probability of 0.95 seems to be more appropriate.

Excess threshold probability.

Probability of the radar pulse exceeding the threshold. The threshold needs to be exceeded by a given amount, to actually achieve the required detection probability. This is dealt with in Report ITU-R M.2034. Considering that frequency hopping radars only transmit one to a few pulses per hop, the single radar pulse scenario of Report ITU-R M.2034 is assumed to be relevant.

Following these steps the probability of detection can be calculated, according to the methodology recorded in the ITU recommendations. From an WAS (RLAN) point of view the need to detect radar pulses adequately and in particular the level of the detection threshold is competing might imply that DFS is triggered unnecessary, due to detected disturbances on the channel other than radar pulses, in which case there is a so-called 'False Alarm'. In order to maintain a high level of service for the WAS an objective is to keep the False Alarm (FA) rate as low as possible.

Same as for the detection probability there is no requirement for the False Alarm Rate provided in the ITU recommendations either. However Report ITU-R M.2034 par 3.2 mentions
"it is sufficient to be sure that the channel is not measured as occupied for some small percentage of the time". Assuming a small percentage being 5%, it implies a FA of:

$$FA \ = \frac{Non\ occupancy\ period}{RSS\ measurement\ duration} \times 5\% = 2.8 \times 10^{-11}$$

This false alarm rate is needed to achieve only one in 20 periods of 30 minutes to be erroneously marked as occupied.

Figure 4 in Report ITU-R M.2034 shows the False Alarm rate and the Detection Failure probability, and can be extrapolated, indicating a required power comparison threshold[15] of -76 dBm (or higher) is required to achieve the FA target. The particular graph is reproduced from the ITU recommendation and shown in FIGURE 1 of this document.

The calculation of FA in Report ITU-R M.2034 is not elaborated and cannot be checked. Concurrent calculations indicate that a FA of 2.8×10^{-11} is achieved at a power comparison threshold of approximately 16.5 dB above the interference/noise floor[16] of –84 dBm, which is -67.5 dBm.

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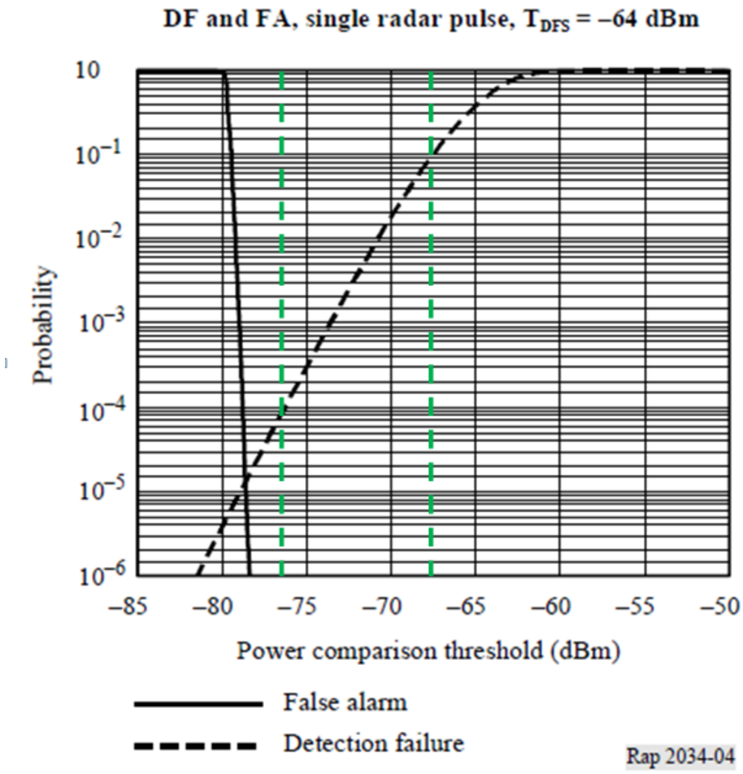
[14] According to ETSI (EN 301 893 V1.7.1, par 4.7 & 4.9), idling occurs only to check for radars and other WAS (5%) and (for longer periods) to allow other WAS to communicate.

[15] Report ITU-R M.2034 defines "power comparison threshold" (or rrs_threshold) is as the power level set at the detector. The input signal, containing noise, interference & radar signals is fed to the detector. Any excess of this power is discriminated as "signal", anything lower than the level is considered noise.

[16] Report ITU-R M.2034 defines "interference/noise floor" as the equivalent input power resulting from noise+interference.

FIGURE 1 (COPY OF REPORT ITU-R M.2034, FIGURE 4)

The two discussed power comparison thresholds are shown in green



The resulting detection probability values for the different parameter settings of Radar 22 and Radar 23 are given in Table 3. Three variants are shown for each radar:

– listening probability of 97% and a power comparison threshold of –76 dBm. As discussed, this variant is highly unrealistic, especially the listening probability;

– listening probability of 0.05% and a power comparison threshold of –76 dBm. As discussed, this variant is still debatable, due to the method of calculating FA;

– listening probability of 5% and a power comparison threshold of –67.5 dBm.

TABEL 3

Detection probability for Radar 22 and Radar 23

Radar	Units	22	22	22	23	23	23
Prf	pulses/s	1000	1000	1000	2500	2500	2500
Az. Beam width	degree	2	2	2	2	2	2
Main beam probability	%	0.56%	0.56%	0.56%	0.56%	0.56%	0.56%
Freq. Range	MHz	450	451	452	600	600	600
Channel probability	%	4,44%	4,43%	4,42%	3,33%	3,33%	3,33%
Listening probability[17]	%	97%	5%	5%	97%	5%	5%
Power comparison threshold	dBm	–76	–76	–67,5	–76	–76	–67,5
Detection Failure probability	%	0.01	0.01	10	0.01	0.01	10
Excess threshold probability	%	99.99	99.99	90	99.99	99.99	90
Single pulse detection probability		2,39E-04	1,23E-05	1,11E-05	1,80E-04	9,26E-06	8,33E-06
In service monitoring (ISM)							
Pulses in 10 sec channel move time		10000	10000	10000	25000	25000	25000
ISM detection probability	%	91	12	10	99	21	19
Channel Availability Check (CAC)							
Pulses in 60 sec CAC time		60000	60000	60000	150000	150000	150000
CAC detection probability	%	100	100	100	100	100	100

From Table 3, it is clear that, applying the ITU methodology for assessment of the DFS effectiveness, for the frequency hopping radars:

– the suggested fail rate of 1% (Report ITU-R M.2034), equalling a detection probability of 99%, is not met for in-service monitoring, even not with the unrealistic propositions;

– apparently, the DFS detection probabilities do not meet the requirements;

– the detection probability is the maximum achievable and cannot be improved without elaboration of current ITU regulations.

The values given here are first approximations. They should however be considered as a clear indication that the requirements for DFS specified in Recommendation ITU-R M.1652-1 are insufficient to guarantee effective protection of frequency hopping radars. Elaboration and concrete unambiguous specification of the requirements for DFS are needed.

It should also be noted that in Recommendation ITU-R M.1652-1 the issue concerning the effective detection of frequency hopping radars is already raised, without providing guidance as to how to resolve this.

3.2 DFS requirements in regulations and standards

Currently several administrations and standards organizations have developed DFS test methodology. For instance ETSI and FCC have developed test methods which are used to evaluate if the DFS mechanisms implemented in RLAN systems complies with the requirements.

These test methods are based on the approach that a Unit Under Test is tested with a specified set of radar pulse patterns. It is verified if the unit's DFS mechanism is capable of detecting the radar and react correctly by timely vacating the specific channel.

With respect to the DFS compliance testing 6 different radar test patterns are defined in Table 4 of ETSI EN 301 893 V1.7.1. This particular table from the ETSI is copied and shown below.

17 For CAC, a listening time of at least 95% is used.

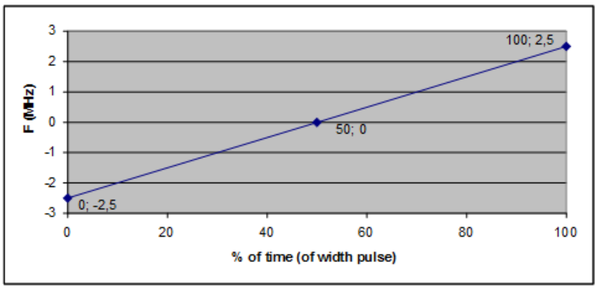
TABLE 4

Reproduction of ETSI EN301893 V1.7.1

Radar test signal # (see notes 1 to 3)	Pulse width W [µs]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,5	5	200	1 000	1	10 (see note 6)
2	0,5	15	200	1 600	1	15 (see note 6)
3	0,5	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,5	2	300	400	2/3	10 (see note 6)
6	0,5	2	400	1 200	2/3	15 (see note 6)

NOTE 1: Radar test signals 1 to 4 are constant PRF based signals. See figure D.1. These radar test signals are intended to simulate also radars using a packet based Staggered PRF. See figure D.2.

NOTE 2: Radar test signal 4 is a modulated radar test signal. The modulation to be used is a chirp modulation with a ±2,5 MHz frequency deviation which is described below.



NOTE 3: Radar test signals 5 and 6 are single pulse based Staggered PRF radar test signals using 2 or 3 different PRF values. For radar test signal 5, the difference between the PRF values chosen shall be between 20 PPS and 50 PPS. For radar test signal 6, the difference between the PRF values chosen shall be between 80 PPS and 400 PPS. See figure D.3.

NOTE 4: Apart for the Off-Channel CAC testing, the radar test signals above shall only contain a single burst of pulses. See figures D.1, D.3 and D.4.
For the Off-Channel CAC testing, repetitive bursts shall be used for the total duration of the test. See figures D.2 and D.5. See also clauses 4.7.2.2, 5.3.8.2.1.3.1 and 5.3.8.2.1.3.2.

NOTE 5: The total number of pulses in a burst is equal to the number of pulses for a single PRF multiplied by the number of different PRFs used.

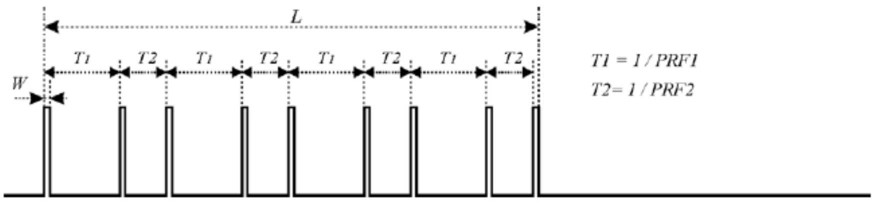
NOTE 6: For the CAC and Off-Channel CAC requirements, the minimum number of pulses (for each PRF) for any of the radar test signals to be detected in the band 5 600 MHz to 5 650 MHz shall be 18.

As can be seen from the Table 4 the number of pulses per bursts for the specified radar test signals is between 10 and 25. This is significantly higher than the number of pulses that can be expected from the frequency hopping radars which in many cases is less than 10 as was shown on the basis of Table 1 and Table 2 of this document. This implies that the effectiveness of the DFS mechanism to detect burst with less pulse, which are operational in current practice, is not tested.

Another aspect is the variability of the burst composition. The ETSI EN301893 v1.7.1 specifies different radar test signals from which test signals 5 and 6 have a staggered PRF. The general structure of a single burst/single pulse based staggered PRF radar test signal is shown in Figure 3. As can be seen this radar pulse pattern shows regularity in pulse width and pulse repetition intervals. This does not correspond to the variability that can be expected in signals from modern radar systems of which an illustration is shown in Figure 1.

FIGURE 3

Copied from ETSI EN301893 V1.7.1



Probability of detection is specified in terms of the ability of DFS to detect the radar burst (pulse train) successfully. According to ETSI EN301893 v1.7.1 methodology each radar test signal is repeated 20 times and the radar test signal shall be detected at least 12 times out of the 20 trials in order to comply with the detection probability specified. This approach is significantly different from the methodology described in the ITU recommendations. Radars with a smaller number of pulses (less than 10) are not tested, so that according to the ETSI requirements the Unit Under Test may be compliant while radars applying shorter bursts are not detected.

Both theoretical analysis as well as laboratory and field testing (e.g. CEPT JPTBWA(04)36) have shown that DFS is not in all cases sufficient to protect frequency hopping radars adequately and RLAN effects on the radar performance are reported. Various documents (e.g. ECC Report 68, ECC Report 140) address the DFS mechanism in different scenarios. The overall observation it that suitable protection of frequency hopping radars is not ensured with DFS. In this context ETSI EN301 893 v1.7.1 states: “The DFS function as described in the present document is not tested for its ability to detect frequency hopping radar signals”.

4 Conclusions

Mitigation measures are required to enable the coexistence of the RLAN systems to be introduced in the band 5 350-5 470 MHz with the existing radar systems. The DFS mechanism that is already applicable for RLAN systems in other parts of the 5 GHz band (5 250-5 350 MHz and 5 470-5 725 MHz) to provide suitable protection to radar systems is also considered as mitigation measure to enable co-existence in the potential candidate bands in the 5 GHz that are currently studied under agenda item 1.1 (WRC-15).

This analysis shows that the DFS mechanism as currently specified is not sufficient to provide adequate protection. Frequency hopping radars, which transmit only one to few pulses per burst and/or apply variability in the PRF and pulse width on a per pulse basis, are insufficiently protected.

The experience with the current DFS framework is that although the ITU resolution states that DFS shall be implemented to ensure compatible operation with radiodetermination systems, in practice it turns out that DFS is not sufficient to provide the suitable protection for various radars that are currently in operation. The reasons partly originate from the functional specification of the DFS mechanism in ITU that is not sufficiently specific and actual requirements are not always specified. This is for instance the case for the detection probability level that shall be achieved.

With regard to the regulations for DFS specified by administrations and standardisation organisations the requirements for DFS do not comply with the intended functionality as foreseen in the ITU resolution and are not consistent with the relevant recommendations (in particular with regard to detection probability). It seems that developing a DFS implementation that is also effective for all types of radars operating in the 5 GHz band, including the frequency hopping radars is a great challenge. The implementation of DFS is a burden for the WAS and implies a compromise between RLAN transmission performance and radar detection probability. The protection of frequency hopping radars turns out to get the lower priority. DFS under current regulations is shown to be insufficient for the protection of certain frequency hopping radar systems

Overall we would like to come to the proposal that within ITU a sound basis for DFS is recorded, including the concrete functional requirements. Hence elaboration and concrete unambiguous specification of the requirements for DFS are needed. It might be that in order to achieve this objective some implementation issues have to be contained in the relevant recommendations and/or regulations.

ANNEX E

Bistatic radars in the 5 GHz band

1 Introduction

[Joint Task Group 4-5-6-7] was tasked to study issues related to WRC-15 agenda item 1.1, in particular to consider possible additional spectrum allocations to the mobile service (MS) on a primary basis and subsequent identification of these frequency bands for IMT. The frequency band 5 350-5 470 MHz is under consideration for an allocation to MS and/or use by RLAN applications at WRC-15, respectively.

The bands between 5 250-5 850 MHz are in use for radiolocation on a primary basis. Mitigation techniques, such as DFS, have been defined in Resolution **229 (WRC-03)** to protect radars against WAS/RLAN in the band 5 470-5 725 MHz. The corresponding Recommendation ITU-R M.1638 for the radar characteristics is under revision[in ITU-R WP 5B]. The revision will contain some new radars types, e.g. bistatic radars.

This document provides an evaluation of the impact of potential new RLANs on bistatic radars operating in the 5 GHz band.

2 Bistatic radars

2.1 Characteristics

To describe bistatic radars the following passage is taken from the preliminary draft revision of Recommendation ITU-R M.1638.

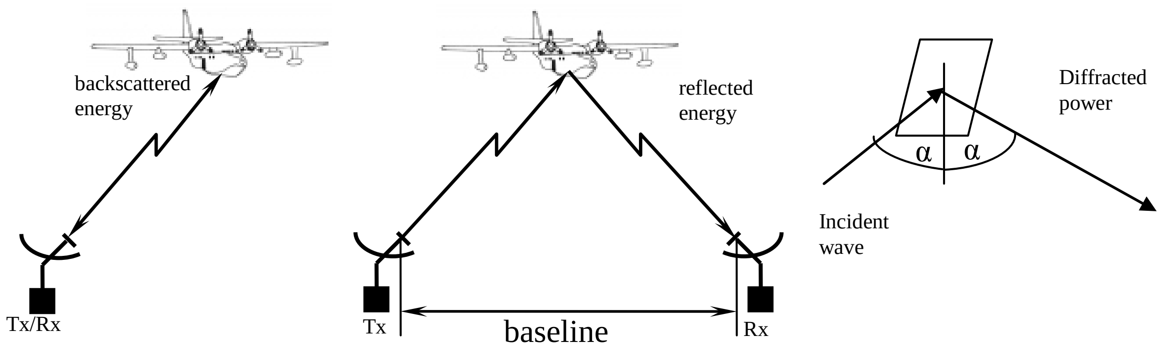
"… radars are conventionally operated as monostatic radar with transmitter and receiver at the same location (Figure 1a). However, Radars 10A and 14A of Table 2 are additionally operated as bistatic radar where the transmitter and receiver are spatially separated (Figure 1b).

The advantage of the separation of transmitter and receiver is the possible enhancement of the radar cross section of an object. The effect is exemplarily shown in Figure 1c for a square plane. This is especially important if the object to be detected does not reflect much energy in the direction of the incident radar signal.

The distance between transmitter and receiver (baseline) is typically in the range of 30-50 kilometres. Synchronisation of transmitter and receiver can be achieved by a radio link or global navigation satellite service or by time standards. This operation mode with passive receiver at a different location than the transmitter should be taken into account in compatibility studies. Since the receivers are not changed the protection criteria of the mono-static and bi-static radar receiver are equal. …"

FIGURE 1

1a: Monostatic radar; 1b: bistatic radar; 1c: diffracted power of a simple square plane



The technical characteristics of the bistatic radar types 10A and 14A are given in Table 1 below for illustration (Source: draft revision of Recommendation ITU-R M.1638 Document 5/106).

TABLE 1

Characteristics of radiolocation (except ground based meteorological radars) and aeronautical radionavigation radars

Characteristics	Unit	Radar 10A	Radar 14A
Function		Radionavigation, Surface and Air Search	Radiolocation
Platform type (airborne, shipborne, ground)		Ground bistatic	Ground bistatic
Tuning range	MHz	5 250–5 875	5 300-5 800
Modulation		Bi-phase Barker Code	NA
Tx power into antenna	kW	90	50
Pulse width	us	0.30-14.0	NA
Pulse rise/fall time	us	0.04-0.1	.100/.100
Pulse repetition rate	pps	4 000-5 000	NA
Chirp bandwidth	MHz	1.5	NA
RF emission bandwidth –3 dB –20 dB	MHz	4 12 20 at –40dB	470 490
Antenna pattern type (pencil, fan, cosecant-squared, etc.)		Fan	Pencil
Antenna type (reflector, phased array, slotted array, etc.)		Passive Phased Array	Phased array

Characteristics	Unit	Radar 10A	Radar 14A
Antenna polarization		Horizontal	NA
Antenna main beam gain	dBi	33 (<55)	40

Antenna elevation beamwidth	degrees	7	2.5
Antenna azimuthal beamwidth	degrees	1.8	2.5
Antenna horizontal scan rate	degrees/s	6 - 60	30
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	degrees	360	360
Antenna vertical scan rate	degrees/s	N/A	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.)	degrees	N/A	Electronically Steered
Antenna side-lobe (SL) levels (1st SLs and remote SLs)	dB	-29	–40
Antenna height	m	30	NA
Receiver IF 3 dB bandwidth	MHz	11	NA
Receiver noise figure	dB	3	4
Minimum discernible signal	dBm	–115	–100

For Radar 14A the receiver bandwidth is not given. This bandwidth and the receiver noise threshold are derived from the minimum discernible signal as described in section 6. The heights for the receiver antennas of the ground based radars are assumed to be below 30 metres. They are set to a lower value for this study, typically 20 metres.

2.2 Assessment of the maximum baseline of Radar 14A:

The received power of a bistatic radar receiver (see Figure 2) can be estimated using the radar equation (free space propagation):

$$P_E = \frac{P_S \cdot G_S \cdot G_E \cdot \lambda^2 \cdot \sigma_{Bi}}{(4\pi)^3 \cdot R_1^2 \cdot R_2^2}$$

And slightly rewritten

$$R_1^2 \cdot R_2^2 = \frac{P_S \cdot G_S \cdot G_E \cdot \lambda^2 \cdot \sigma_{Bi}}{P_E \cdot (4\pi)^3}$$

Assuming further that the distance between the radar transmitter and flying object, R_1, is equal to the distance between the flying object and the radar receiver, R_2, i.e. $R_1=R_2=R$, the equation can be simplified to

$$R = \sqrt[4]{\frac{P_S \cdot G_S \cdot G_E \cdot \lambda^2 \cdot \sigma_{Bi}}{P_E \cdot (4\pi)^3}}$$

The maximum baseline (Tx-Object to Rx) is 2-times R, if the Object is on the (base-) line between the transmitter and receiver.

Where

P_E is the received signal level (details on the minimum discernible signal level for Radar 14A see section 6: -100 dBm),

P_S is the transmitted signal level (radar 14A: 50 kW),

G_S, G_E are the antenna gains of the radar transmitter and receiver (Radar 14A: G_S=G_E=40 dBi),

λ wave length (f=5.4 GHz, λ=300/f= 0.055 m)

It is further noted that radar cross section for bistatic radars differs from the one for mono-static radar: $\sigma_{Bi} \neq \sigma_{Mono}$!

Assuming a radar cross section of 1 m², the maximum baseline results in about 200 kilometres, and for a cross section of 0.01 m² the maximum baseline results in about 60 kilometres. (Note: a rectangular metal plate with a surface of 1 m^2 has a maximum radar cross section of around 4000 m^2 at 5.4 GHz.).

3 RLAN Parameters

For the interference calculation the following parameters are used, that are in line with the discussed parameters[in fifth meeting of JTG 4-5-6-7]:

e.i.r.p.$_{\text{RLAN}}$ 23 dBm (200 mW)

Bandwidth (B_{RLAN}): 20 MHz

$h_{\text{RLAN,rural}}$: 4.5 m access-point or user-equipment

$h_{\text{RLAN,urban}}$: 28.5 m

Antenna: 0 dBi (omnidirectional)

4 Propagation Model

For the calculations the propagation model described in Recommendation ITU-R P.452 for 50% time probability was used. The frequency was chosen to be 5.4 GHz. This Recommendation contains also additional clutter loss for the radio sites. The computed clutter losses for the different environments (urban, suburban and rural) are based on the parameters for RLAN[defined in the JTG 4-5-6-7 (see also Annex 2 of Document 4-5-6-7/584).

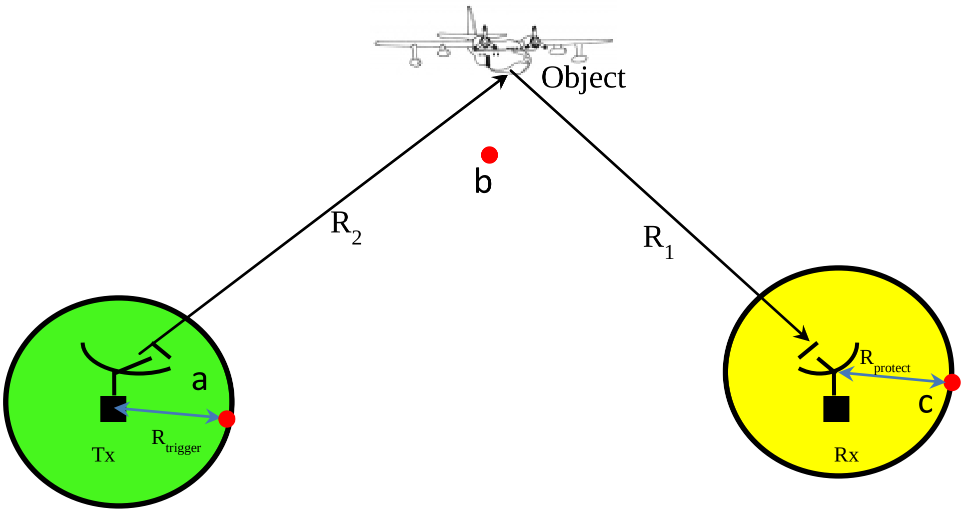
The mean penetration loss used to describe the attenuation between indoor and outdoor of the building wall was assumed by 17 dB.

5 Scenarios to be considered

Figure 2 below shows the principle three cases a, b, c where a RLAN with its detection radius / trigger distance R_{trigger} can be positioned to a bistatic radar.

FIGURE 2

Principle cases a RLAN a, b, c can be positioned in relation to radar transmitter (Tx) and the passive radar receiver



(Rx)

Scenario Case (a):
If the RLAN (a) detects a radar transmission within the green area around the radar transmitter trigger distance $R_{trigger}$ the DFS or DAA algorithm will change the frequency of the RLAN. In this case, the passive radar receiver (Rx) is protected.

Scenario Case (b):
If the radar transmitter (Tx) is outside of the trigger distance of the RLAN (b) receiver, the RLAN (b) will not stop its transmission. In case the passive radar receiver (Rx) is sufficiently far away the protection is given by the geographical separation.

Scenario Case (c):
If the radar transmitter is outside of the trigger distance of the RLAN receiver, sensing on its own has the risk of "false-vacancy-detection" where a channel is detected as not being used when in fact it is occupied. In case the distance between RLAN transmitter (c) and the passive radar receiver (Rx) is smaller or equal to a necessary separation distance ($R_{protect}$ is not identical with $R_{trigger}$) the passive receiver will be interfered by the RLAN because DFS is not activated and the RLAN will not stop its transmission.

This scenario is also known as hidden node problem for other radio application, e.g. for cognitive radio systems.

6 Necessary separation distance between RLAN (c) transmitter and passive radar receiver (Rx)

6.1 RLAN (c) is in the main lobe of the radar

For the calculation it is assumed, that there is only one interfering RLAN. The aggregation effect of multiple RLAN devices should be considered in further studies.

The maximum interfering power I_{max} at the radar receiver can easily be calculated as follows by consideration of the receiver performance (1) and allowed interfering signal at the receiver input (2):

$$I_{max} = N + I/N \quad (1)$$

$$I_{max} = \mathrm{EIRP}_{RLAN} + G_{Receiver} - MCL + C. \quad (2)$$

Where MCL is the minimum coupling loss, C is the bandwidth correction factor and $G_{Receiver}$ is the gain of the receiving antenna of the radar taken from the table above The used protection criterion is $I/N = –6$ dB and is given in Recommendation ITU-R M.1638 (noting that in some cases $I/N = –10$ dB might be necessary).

The thermal noise threshold N of radar receiver type 10 A can be calculated as follows:

$$N = 10 \log kT + NF_{dB} + 10 \log B_{Hz} \quad (3)$$
$$= -174 \text{ dBm} + NF_{dB} + 10 \log B_{Hz}$$

where:

k	–	Boltzmann's constant (1.3806488×10-23 J K-1);
T	–	temperature (290 K);
B	–	noise equivalent bandwidth of receiver (Hz);
NF	–	receiver noise figure (dB).

The noise power for the receiver (radar 10A) of 11 MHz bandwidth and NF of 3 dB

$$N_{radar\ 10A} = -174 \text{ dBm} + 3 + 10 \log 11 \times 10^6 \approx -101 \text{ dBm}$$

The thermal noise threshold N of Radar receiver type 14 A can approximately be derived from the minimum discernible signal (*MDS*). *MDS* means the smallest recognizable signal at a radar receiver which is slightly above N according to equation (3) (remark: if it is not a correlation radar). By using the "engineers equation" $N \approx MDS$, the noise threshold can be estimated by $N_{radar\ 14}$ = - 100 dBm for Radar 14A. Additionally with the noise figure of Radar 14, the receiver bandwidth of Radar 14 can be estimated from equation (3):

$$B_{radar\ 14A} \approx 10^{\left(\frac{MDS + 174 \text{ dBm} - NF_{dB}}{10}\right)} = 10^{\left(\frac{-100 \text{ dBm} + 174 \text{ dBm} - 4 \text{ dB}}{10}\right)} = 10 \text{ MHz}. \quad (4)$$

To account for the different bandwidth of victim and interferer the bandwidth correction factor C = 10 $\log_{10}(B_{Radar}/B_{RLAN})$ was used in equation (2). With the bandwidth of Radar type 10A from the table above:

$$C_{\text{radar } 10\,A} = 10 \log_{10}(B_{\text{radar 10A}}/B_{\text{RLAN}}) = -2.6 \text{ dB}$$

and with the bandwidth from equation (2)

$$C_{\text{radar } 14A} = 10 \log_{10}(B_{\text{radar 14A}}/B_{\text{RLAN}}) = -3 \text{ dB.}$$

Combining (1) and (2), the MCL (Minimum Coupling Loss) results in:

$$\text{MCL} = P_{\text{RLAN}} + G_{\text{Receiver}} + C - N - \text{I/N} \qquad (5)$$

$MCL_{\text{Radar 10A}}$ = 23 dBm + 33dBi - 2.6 dB+ 101 dBm + 6 dB ≈ 160 dB for Radar type 10A and

$MCL_{\text{Radar 14A}}$ = 23 dBm + 40 dBi - 3 dB + 100 dBm + 6dB≈ 166 dB for Radar type 14A.

The required separation distance between the RLAN and the radar receiver (protection radius) can be determined by applying the propagation model Recommendation ITU-R P.452 with diffraction and 50% - time probability. The separation distances were estimated with and without clutter loss.

It can be assumed that the antenna of the radar receiver is always above the clutters in the environment. Hence, no additional loss is to be considered.

The antennas of the RLAN systems are typically below the clutter heights in suburban and urban environment. The additional loss is given in Table 2. The values in the table are calculated based on the parameters [defined by JTG 4-5-6-7]for different environments and RLAN-antenna heights. This could reduce the required separation distance between RLAN and radar receiver.

It has to be noted, that the clutter loss will also influence the detection distance, but this topic is not addressed in this document.

TABLE 2

Clutter loss in dependence of antenna and clutter heights

	RLAN antenna 1.5 m	RLAN antenna 4.5 m	RLAN antenna 10 m	RLAN antenna 28.5 m
Clutter height Rural: 4 m	17.3 dB	0	0	0
Clutter height suburban: 9 m	19.6 dB	16 dB	0	0
Clutter height urban: 20 m	19.7 dB	19.7 dB	19.4 dB	0

For the antenna heights of 4.5 metres the required separation distances in the Tables 3A and 3B were computed for illustration. Other antenna heights will lead to a comparable range.

TABLE 3A

Separation distances in km for Radar 10A

Radar 10A	without clutter	Rural	sub urban	urban
MCL outdoor: 160 dB	30	30	20	18
MCL indoor: 160-17 = 143 dB	20	20	10	6.4

TABLE 3B

Separation distances in km for Radar 14A

Radar 14A	without Clutter	Rural	sub urban	urban
MCL outdoor: 166 dB	34	34	23	21
MCL indoor: 166-17 = 149 dB	23	23	15	13

6.2 RLAN (c) is in the side lobe

Without loss of generalization, the further calculations were done for Radar 14A, only.

The separation distances in the main beam region of the radar receiver were calculated above in detail. They are given in Table 3B.

A comparable MCL calculation to section 6.1 taking into account the antenna side lobe levels (side lobe suppression SL = 40 dB for Radar14 A) as give in Table 1 leads to the separation distances in Table 4 for the side lobe area of the Radar 14A.

TABLE 4

Separation distances in km for Radar 14A in the side lobe (SL= 40 dB)

Radar 14A	without clutter	Rural	Suburban	urban
$R_{\text{protect, outdoor}}$ MCL=126 dB	8.8 km	8.8 km	1.4 km	0.8 km
$R_{\text{protect, indoor}}$ MCL=109 dB	1.3 km	1.3 km	0.3 km	0.1 km

7 Trigger distances between RLAN (c) transmitter and radar receiver (Rx)

Within the trigger distance (between radar transmitter and RLAN receiver) the detection threshold is exceeded and the DFS-algorithm will change the frequency. According to the detection requirements give in the Recommendation ITU-R M.1652 the DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold of –62 dBm for devices with a maximum e.i.r.p. of < 200 mW.

7.1 RLAN (c) is in the main lobe of the Radar 14A

Analog to the calculation of the separation distance the trigger distance was determined by a MCL calculation and applying the propagation model Recommendation ITU-R P.452 with diffraction and 50% - time probability, 20 metres antenna height of the radar and 4.5 metres for RLAN.
The separation distances were again estimated with and without clutter loss.

The MCL for the Trigger distance in the main beam is:

$$\text{MCL} = P_{\text{SRadar 14A}} + G_{\text{S}} - P_{\text{trigger}} = 77+40-(-62) = 179$$

TABLE 5

Main beam trigger distances in km for Radar 14A

Radar 14A	without clutter	Rural	Suburban	urban
$R_{\text{trigger, outdoor}}$ MCL=179 dB	44 km	44 km	32 km	29 km
$R_{\text{trigger, indoor}}$ MCL=162 dB	31 km	31 km	21km	19 km

7.2 RLAN (c) is in the side lobe of Radar 14A

Taking into account the antenna side lobe levels (side lobe suppression SL = 40 dB for Radar14 A) the MCL-calculation

$$\text{MCL} = P_{\text{SRadar 14A}} + G_{\text{S}} - P_{\text{trigger}} - \text{SL} = 139 \text{ dB.}$$

The trigger distance for the side lobe area summed up in Table 6. Noting, compared with Table 5, the required separation distances are considerably smaller.

TABLE 6

Trigger distances in km for Radar 14A in the side lobe

Radar 14A	without clutter	Rural	Suburban	urban
$R_{\text{trigger, outdoor}}$ MCL=139 dB	17 km	17 km	6.2 km	4.0 km
$R_{\text{trigger, indoor}}$ MCL=122 dB	5.5 km	5.5 km	<1 km	<1 km

8 Discussion of the results

In contrast to a monostatic radar for a bistatic radar, the main beams of the transmitter and receiver are pointing into different directions towards a reflecting object, if the transmitter and receiver are not co-located.

The necessary condition to trigger DFS for a RLAN is illustrated in the following Figure 3A.
The protection zone around Rx is marked yellow and the area around Tx where a RLAN is triggered by DFS is marked green. If both areas overlap (shaded area), the RLAN in the protection zone will not interfere because it is triggered by DFS.

FIGURE 3 A

Principle visualization of condition for principle trigger and protection area for a bistatic radar (illustration not to scale)

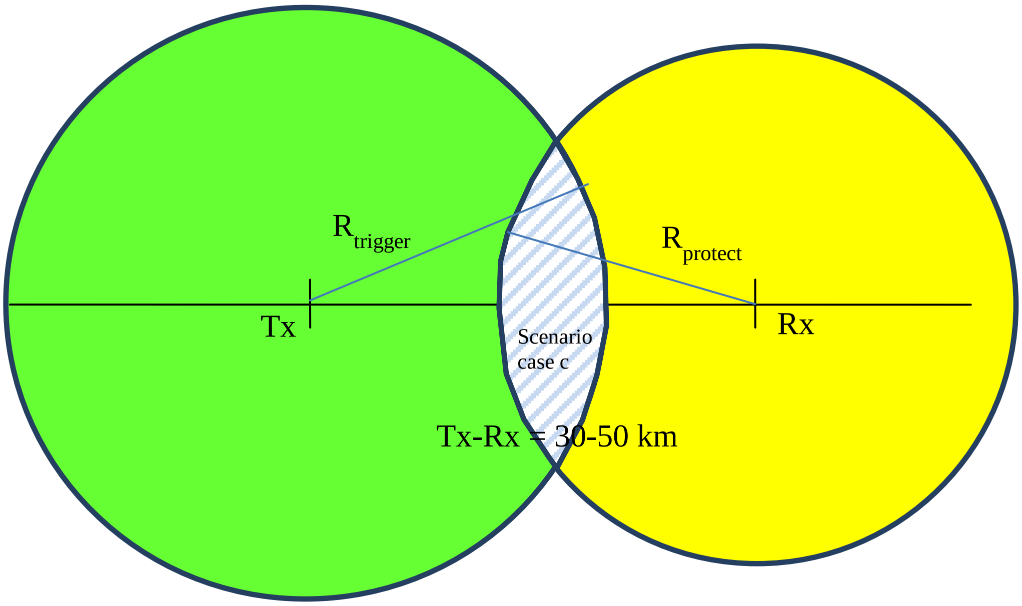
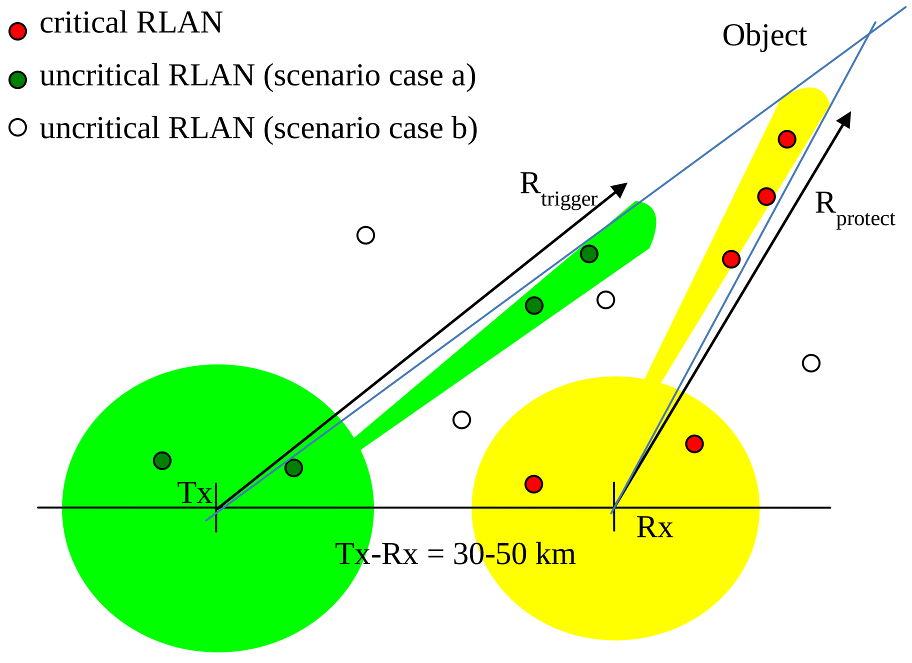


FIGURE 3B

Typical case of critical areas for a bistatic radar (illustration not to scale)



In Figure 3B the typical situation is illustrated for the main beam and side lobe regions. The reception of the radar is interfered, if the RLAN is located in the yellow protection area (red dots), whereas in all other cases the distance (for white and green dots) and DFS (green dots) protects the radar reception.

For shorter baselines (e.g. <30-50 km) and depending on the region (e.g. rural), the trigger (green) area can partly overlap the protection (yellow) area and thus provide partly protection by DFS (see Figure 3A additionally). But the trigger-area never overlaps fully the protection-area. Hence, DFS cannot protect the bistatic radar, if the RLAN is located in the side lobe region.

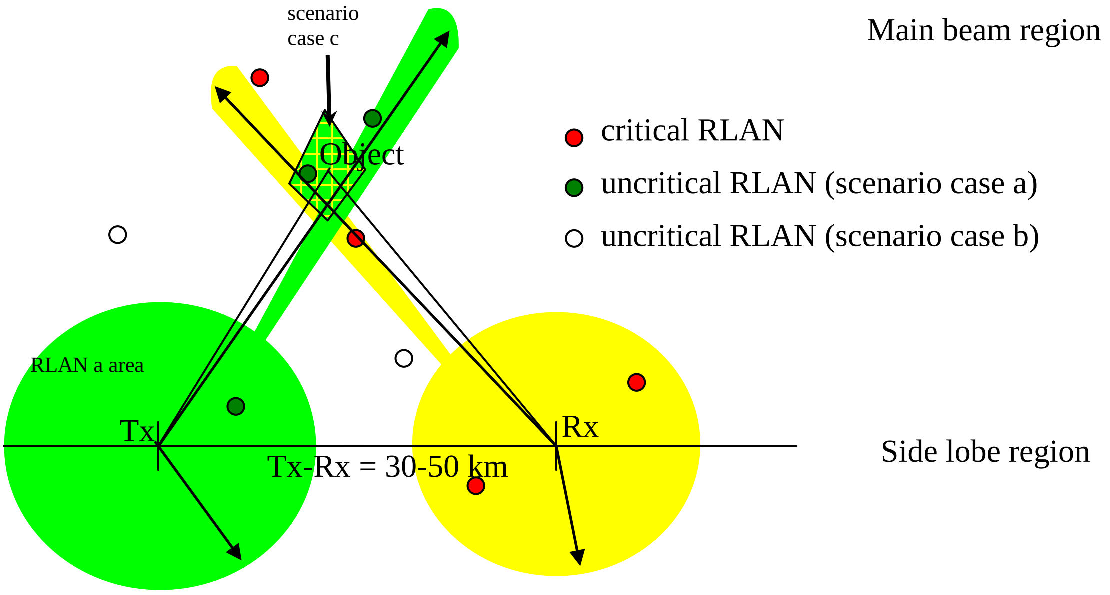
Due to the different directions of the main beams of the radar transmitter and receiver towards an object and due to the large operational distance an overlapping area is in general not given as shown in Figure 3B. Thus, no RLAN in the main beam within the protection zone around the radar receiver will stop its transmission and the bistatic radar will not be protected by DFS.

In the special case if the main beams cross (Figure 3C) and an overlapping area (shadowed yellow green) is given around the observed target (object), DFS would trigger correctly the RLAN. However, all other RLANs within the receiving beam (yellow) will not be triggered and, therefore, these RLANs will interfere the bistatic radar.

As conclusion it could be stated, that DFS cannot protect the bistatic radar.

FIGURE 3C

Special case of critical areas for a bistatic radar (illustration not to scale)



Conclusions

The protection of bistatic radars in the cases (a) scenarios can be ensured by applying of proper DFS detection algorithm. The bistatic radar in scenario (b) is only protected by sufficient spatial separation between the RLAN and the passive receiver of the bistatic radar.

However, DFS cannot be applied for the bistatic radar in case (c). In the side lobe and in the main beam region DFS is not able to protect the bistatic radar if the “trigger area” is not overlapping that part of the “protection area” where the RLAN is located (known as hidden node problem).

The bistatic radars will only be protected for separation distances larger than 20 - 34 kilometres between a RLAN located in the radar main beam and the radar receiver. Even in the side lobe region up to ~9 kilometres of separation distances are necessary to protect the bistatic radar.
The impact of the clutter types (e.g. buildings) in the environment of the RLAN may reduce these distances. For smaller separation distances, other mitigation techniques as DFS have to be applied.

Further studies should address other mitigation techniques and as well as aggregation effects due to multiple RLAN transmitters.

ANNEX F

Statistical study between WAS-RLAN and frequency hopping radars in the 5 GHz frequency band

1 Introduction

Frequency hopping radars, depending on their types, conditions of use, missions, nature of the objects to detect, spectrum environment, use different frequency hopping patterns (hopping rates, pulse width, number of pulses per burst, etc.). This significantly increases the difficulty to develop a DFS that could be able to detect the radar signals.

However, prior detecting a radar signal, the RLAN must receive it. This preliminary condition is not verified so easily because of 3 main factors:

The frequency hopping rate: The radar uses the listened frequency for a short period (and hops to another frequency);

The radar rotation that implies the radar emission is not always directed toward the RLAN;

The number of pulses per burst that can be lower than the number “expected” by the DFS (at maximum 9, in the case of some current standards).

Thus, a statistical study has been conducted in order to assess how far different types of DFS (real and fictive) could meet the conditions of receiving the radar signals and then, to be in a position to conduct the tests of the signals without presuming of the ability of the DFS itself to properly “understands” that the received signal is coming from a radar or not.

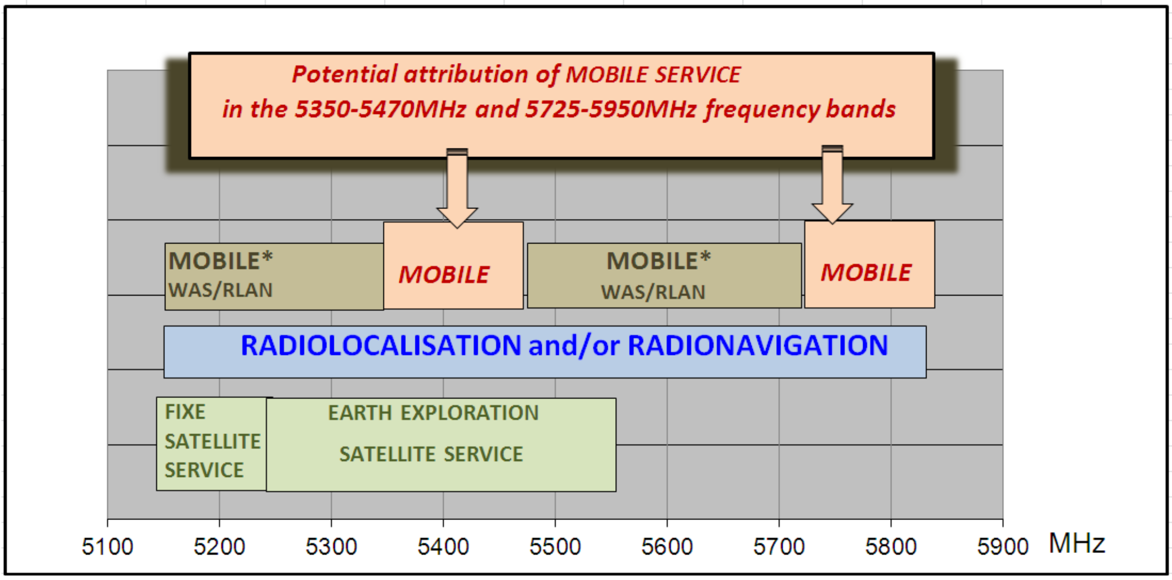
The results of this study, detailed hereafter, demonstrate, in most cases, the real difficulties for the DFS to meet the conditions to detect frequency hopping radar signal. Additionally, these difficulties are not only due to radar signals using short pulse widths (<=1µs) and/or radar transmission of only one pulse per frequency. The pulse repetition interval (PRI) or the rotation speed of the radar antenna can also seriously degrade the probabilities.

2 Configuration

2.1 Background

The possible introduction of mobile service in the 5 350-5 470 MHz and 5 725-5 925 MHz would conduct to a coexistence of radars and WAS/RLAN in the same whole frequency band. Furthermore, it can be noted that these additional bands for RLAN should enforce radiolocation to share the entire radiolocation frequency range 5 250-5 850 MHz. This situation is illustrated in the following figure:

FIGURE 1



*MOBILE : mobile service mobile except aeronautical mobile. DFS is required for 5 250-5 350 MHz and 5 470-5 725 MHz frequency band (Resolution **229(WRC-03)**).
Recommendation ITU-R M.1652 defines DFS system.

2.2 Synoptic

To insure radar signal detection by DFS, three conditions must be satisfied:

– spatial impact: DFS “sees” the radar only when radar antenna is pointed towards WAS/RLAN;

– co-frequency: The radar signal frequency are included in the listened channel by the DFS;

– synchronization time: DFS received radar pulses only during its listen time.

(See Figure 2 and 3 below)

FIGURE 2

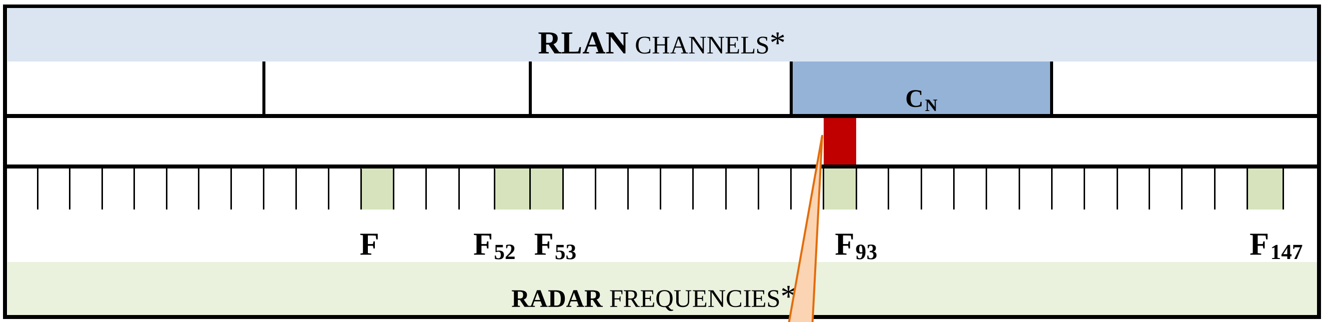
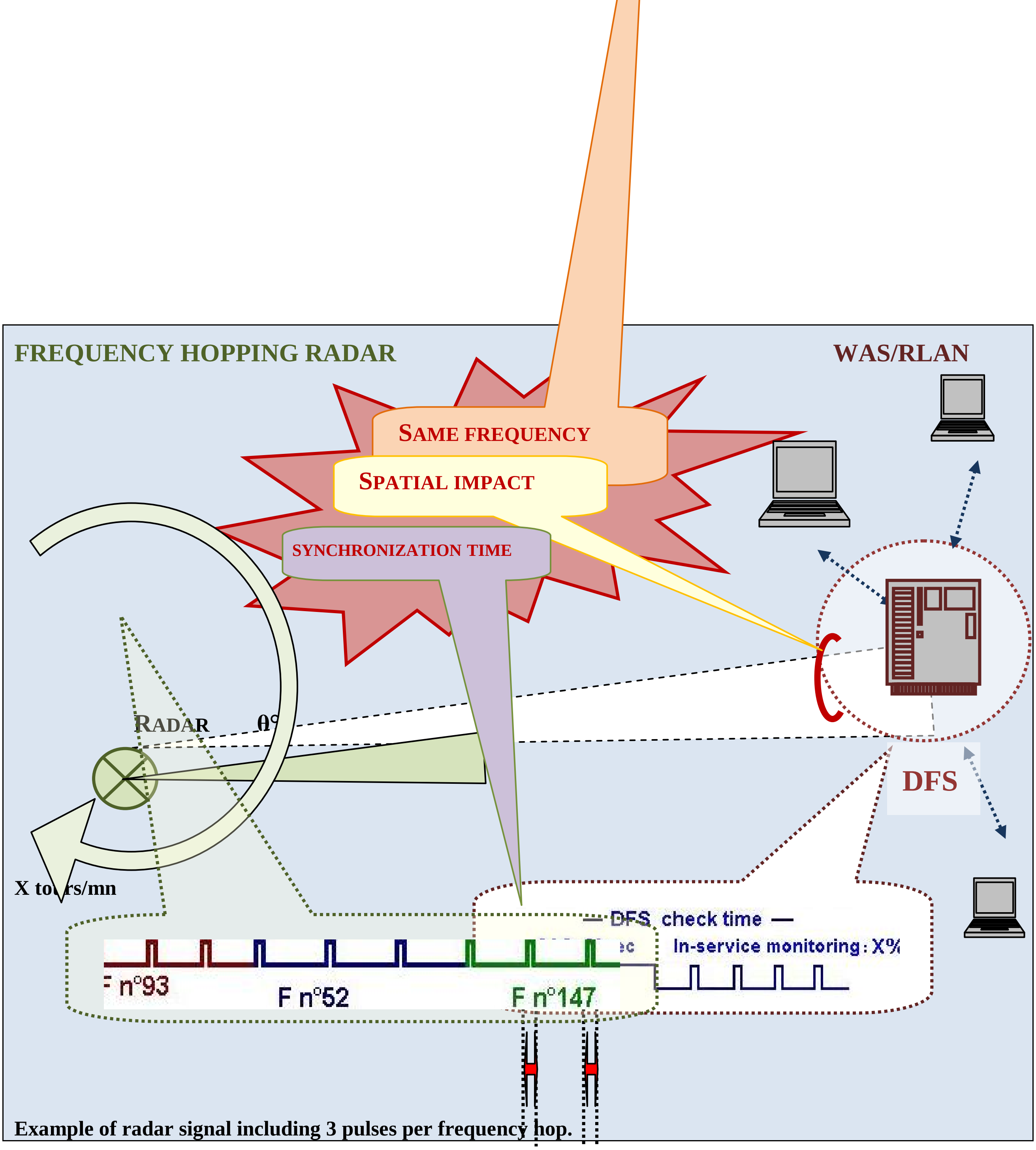


FIGURE 3



3 Definitions

3.1 WAS/RLAN characteristics (ref. (1) and (2)).

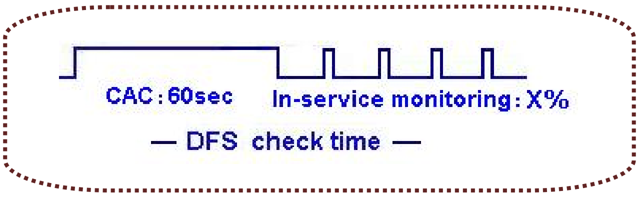
Recommendation ITU-R M.1652 recommendation provides the DFS characteristics. Coexistence with hopping radars is very succinctly treated in § 3.1.1.

In this study, it is considered that WAS/RLAN use the entire frequency band 5 250-5 850 MHz, and that the used channel width is equal to 20 MHz.

Assumptions on DFS (cf. parameters and definition in Annex A) are presented below. According to ETSI standard DFS has 2 different functioning phases:

when RLAN is put “on”, it must at least listen 60 seconds before using the channel: this is the “Channel Availability Check time” (CAC).

After selection of a channel by RLAN, RLAN transmit on this channel. It transmits and listens during a percentage of time (X%), in the aim to detect potential presence of a new radar:
this is the “In service monitoring” (called CIS in this study).



Note: in the ETSI standard (i.e. for radar test signals in fixed frequency), DFS detection probability is set to 60% , for the 2 operating phases (cf. Annex A table D5), except for meteorological radars (99,99%).

Interpretation of DFS detection (assumption): when a signal radar is received, the WAS/RLAN can decide that « n » pulses are necessary to consider that it is a radar. In this study this parameter is **N.detect.** According to signal seen by DFS and the value of **N.detect** parameter, the following table illustrates number of de counted collisions in probability calculations (for 4 examples):

TABLE 1

		Pulses illustration for one burst	N.Detect 1	N.Detect 3	N.Detect 6	N.Detect 9
radar signal seen by DFS, on the same frequency	**Burst 1**	□■□□□□□□□□□□□□□□□□□	1	0	0	0
	Burst 2	□■□■□■□□□□□□□□□□□□□	3	1	0	0
	Burst 3	□■□■□■□■□■□■□□□□□□□	6	4	1	0
	Burst 4	□■□■□■□■□■□■□■□■□■□	9	7	4	1

Parameters taken into account are summarized in the table below:

TABLE 2

DFS	CAC	Cycle "In service monitoring"	N.Detect
Value	60s	300ms (*50ms*) *(this value is not fixed in the standards)*	1 ; 3 ; 6 ; 9
% of listen time	100%	80 to 20%	
comment		*1- listen time is randomly placed in the 300ms* *2- min value for WAS/RLAN activity is 30%*	

Note: some of these parameters are taken into account in the simulations. They should be modified for future simulations.

3.2 Radar characteristics

Recommendation ITU-R M.1638 recommendation gives radar characteristics of the 5 250-5 850 MHz frequency band. Currently use of frequency hop is recognized (cf. §2 of recommendation), but there is no definition for the hopping frequency parameters.

Radar signal is composed of pulses with a width **L** (µs), transmitted with a repetition frequency **Fr (**or a repetition period **PRI)**: **Fr** = 1/**PRI**. Radar signal is transmit on a frequency F**i**, and hops on another frequency F**j** after **P** pulses have been transmitted on frequency F**i**.

Radar antenna speed parameter is $\mathbf{N_b}$.tr/min and radar antenna aperture is **θ°**.

Radar transmits on a number of frequencies equal to $\mathbf{N_f}$. Among the different drawing methods of frequencies, 2 methods (**M**) are used:

– Type **M**1: random draw (on the $\mathbf{N_f}$ possible frequencies at each drawing),

– Type **M**2: random draw without replacement (on the $\mathbf{N_f}$ possible frequencies minus frequencies already used)

Parameters range used in the calculation:

TABLE 3

RADAR parameters							
Signal parameters					Frequency hopping		
Rotation speed	Antenna Aperture	Pulse Width	Pulse Repetition Interval	Bandwidth	Nb of frequency	Nb of pulses on a frequency	drawing method
N_b (Tr/s)	θ (°)	L (µs)	PRI (ms)	(MHz)	N_f	P	M
0,5 ; 1 ; 2	2 ; 10	1 ; 3 ; 10 ; 20	0,5 ; 1 ; 2	5	50 à 400	1 ; 3 ; 6 ; 10	1 or 2

Note:

1: correspondence between (PRI & nb pulse) and frequency hopping rate.

TABLE 4

PRI (ms)	Nb of pulse	Hopping rate (Hz)
0.5	1	2 000
	3	666
	6	333
	10	200
1	1	1 000
	3	333
	6	166
	10	100
2	1	500
	3	166
	6	83
	10	50

2: In this study, it is considered that **PRI** and pulse width are constant for each probability calculation (several types of radars use variable pulse width and also variable **PRI**: these are «staggered» signals; this characteristic are not been integrated in this study).

3.3 Probability calculation.

Probability calculations are realised for a great number of iteration (**N.it** >10 000). This corresponds to a duration long enough to be representative of a real situation (1 iteration corresponds to about 1 second).

It is considered that there is an "**elementary collision**" when there is coincidence between DFS listen time and radar pulse transmission.

A « collision » is counted when there are **N.detect** successive elementary collisions (cf. figure 4).

The following calculation is realised:

$\mathbf{P\_{collision}}$: it is the probability that there is at least one collision during one radar rotation.

From this result, it can be deduced the probability that there is at least 1 collision during **N** rotations. For example, the probability that there is at least 1 collision for N=60 rotations:

$$\mathbf{P\_{60t}} = 1 - (1 - \mathbf{P\_{collision}})^{N} = 1 - (1 - \mathbf{P\_{collision}})^{60}$$

Note: *calculations are realised with a software developed with "Python 2.7"*

This software may be given if necessary. Explanations and comments (included in the software) are in French, (A calculation with 96 combinations takes about 10 hours).

4 Simulations

(Note: For detail see Annex B)

Calculation are realised with parameters combinations in the table below (in blue, adjustable parameters):

TABLE 5

Number of iterations	RLAN parameters	Radar parameters		
N.it :	**cf. figure 4**	**cf. figure 5**	**Nb of frequencies:**	**Mode :**
50000	**CAC time (0 or 60 s)** **CAC % (100%)** **CIS time (300ms)** **CIS % (20 ; 50 ; 80%)** **N.detect: 1 or 3**	**Rotation speed (0.5 ; 1 ; 2)** **Antenna aperture (2 to 10)** **Pulse width (1 ; 3 ; 10 ; 20)** **Pulse repetition interval (0.5 à 2)** **Nb of pulses on one frequency (1 ; 3 ; 6 ; 10)**	**200 (50 to 400)**	**M1 or M2**

Preliminary calculations show that:

– Results in Mode M1 are close to results in Mode M2 (see Annex **B**, table **B-6**),

– Results are similar for calculations with different number of hopping frequencies (50 à 400),

According to many possible combinations and to these first results, all following calculations are realised for the M1 radar mode and for a number of radar frequencies equal to 200. They are divided in 2 types:

– DFS/RLAN in CAC mode (see Annex **B**, table **B-1**)

– DFS/RLAN in service monitoring (Annex **B**, tables **B-2** to **B-6**)

The complete results are given in Annex B. Probabilities are expressed in %. A colour scale is superposed on to the results in the table:

				probability (%)						
0	10	20	30	40	50	60	70	80	90	100

5 Analysis

Based on the results of the simulations:

– Radar antenna rotation speed hardly influences results (0.5 ; 1 ; 2). Antenna rotation speed has an impact on the detection probability: the greater the rotation speed, the lower the probability (cf. table B7),

– **PRI** value hardly influences the results (0.5; 1; 2), cf. synthesis §4.1

– Probability is in proportion with the percentage of DFS listen time,

The DFS listen time of reference is 80% for the study. It should be noted that in the European standard, the percentage of WAS/RLAN activity is fixed to a minimum of 30%, which implies a percentage of listen time not higher than than70%.

– The duration of DFS listen time has no impact on the results, as long as the percentage of listen time is the same (cf. Table B5),

– The number of pulses per burst that can be detected by DFS (1 ; 3 ; 6 ; 9) has a major impact on the results: they are detailed in the following paragraph.

6 Conclusions

6.1 Summary of the study

This study has highlighted, from a statistical point of view, the difficulties for a DFS mechanism to be in the situation to detect frequency hopping radar signals.

Considering the significant number of parameters to take in account, the results of the simulations have been presented in several tables as matrixes of scenarios based on the various characteristics of radar emissions crossed with the number of radar pulses the DFS requires (real or possible) in order to operate the tests of recognition of a radar signal. For each scenario, a probability for the DFS (called probability of collision) to see the radar signal varies between 0 and 1.

Whatever the combinations of parameters, the lowest probability of collision is in the case of an emission of a single narrow width pulse per frequency. Two other factors reduce the probability:

– generally, the higher the PRI is, the lower the probability of collision, whatever the number and the width of pulses are;

– the rotation speed of the radar antenna has a significant impact. The higher the rotation speed is, the lower the probability of collision.

For a radar with hopping mode M1 and 200 frequencies, the conclusions are the following:

WAS/RLAN in CAC phase (see Annex B, table B-1):

If the DFS is able to deal with a single radar pulse (**N**.detect=1), probabilities of collision would be quite good (between 87 and 100%) whatever the parameters of the radar signal (PRI, pulse width, number of pulses).

If the DFS is able to deal with "only" a sequence of 3 pulses, the collision probability varies from 0.2% to 100% depending on the radar parameters (e.g.. the rotation speed).

If the DFS is able to deal with 6 pulses, the probability becomes extremely low, except in some specific cases and for 9 pulses (corresponding to the possibilities of current DFS), the radar signal will almost never be in position to be detected.

WAS/RLAN in 'in service monitoring' (see Annex B, tables B-2-, B-3-, B-4-):

With a listen time of the DFS of 80%, the probability of collision varies between:

– 5 and 55% (DFS at **N**.detect = 1): probabilities are better when the **PRI** is low (7.8 to 55%) and worse for higher **PRI** (4.6 to 20%).

– 0.01 and 23%, (DFS at **N**.detect = 3): probabilities are better when the **PRI** is low (0.1 to 23%) (0.01 to 4,9%).

– 0 and 11%, (DFS at **N**.detect = 6): probabilities when the **PRI** is low varies between 0.2 to 11,3% and worse for higher **PRI** (0 to 1,2%).

– Between 0 and 6.7%,(DFS at **N**.detect = 9) : probabilities are already low when the **PRI** is low (0 to 6,7%) and equal to 0 when for higher **PRI**.

For a shorter listening time (50% and 20%), probabilities are significantly degraded.

These results demonstrate that a DFS designed to detect a radar signal with 9 pulses per frequency hop can hardly meet the conditions to detect a radar signal with hopping after 6 pulses or less or with high PRI and rotation speed.

For the “in service monitoring” phase, even with a listen time of 80% and a DFS that could manage “1 pulse per hop”, a combination of high pulse repetition interval and high rotation speed of the radar antenna, makes DFS unable to detect the radar signal.

As a consequence, DFS specifications should be improved in order to ensure adequate protection to frequency hopping radars.

According to this study results, a DFS designed for a radar signal of 3 pulses or less could be statistically in a good situation to detect radars except those hopping after each pulse. However, this would also depend on other parameters described in the chapter hereafter and the probability of detection could remain low.

6.2 Limits of the study

The results of the study correspond to the probability that the DFS to receive the radar signal. When the probability is high enough, this doesn’t mean that the signal will be recognized as a radar emission by the DFS. The following correction settings (among several others) should be taken in account to further assess the DFS efficiency and its probability to detect the radar:

1 the probability of recognition of the radar signal by the DFS (indeed the signal may not be recognized);

2 corrections should be applied in order to take in account the possible variations of radar parameters (pulse width and PRI can change after each frequency hop or after a burst);

3 corrections associated to the radar signal detection threshold of the DFS.

Based on the above factors, real probabilities for a DFS to test successfully a radar signal will be necessarily lower.

Another significant factor should also be taken in account in order to assess the impact of RLAN/DFS on radar operations. Depending on the context of operation, frequency hopping radars can use a “listen before talk” like mode, eliminating for a given period the occupied frequencies. With RLANs operating in the vicinity of hopping radar, could drastically reduce the possibility to use this mode and affect their operational performances.

ANNEX A

Several administrations and standards organizations have developed DFS test methodology.

In Europe, ETSI has developed test methods to evaluate DFS compliance with the requirements.

ETSI standard EN 301 893 V1.7.1 defines 6 different types of radar test patterns:

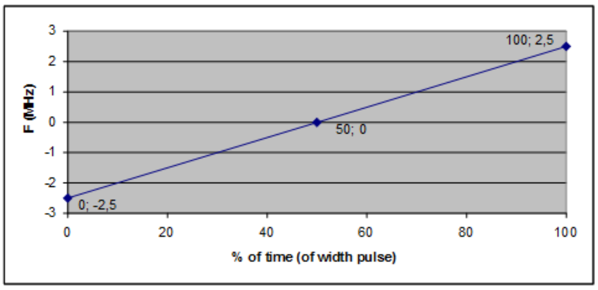
FIGURE 4

(Table D4 in the Annex of ETSI EN301893 V1.7.1)

Radar test signal # (see notes 1 to 3)	Pulse width W [µs]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,5	5	200	1 000	1	10 (see note 6)
2	0,5	15	200	1 600	1	15 (see note 6)
3	0,5	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,5	2	300	400	2/3	10 (see note 6)
6	0,5	2	400	1 200	2/3	15 (see note 6)

NOTE 1: Radar test signals 1 to 4 are constant PRF based signals. See figure D.1. These radar test signals are intended to simulate also radars using a packet based Staggered PRF. See figure D.2.

NOTE 2: Radar test signal 4 is a modulated radar test signal. The modulation to be used is a chirp modulation with a ±2,5 MHz frequency deviation which is described below.



NOTE 3: Radar test signals 5 and 6 are single pulse based Staggered PRF radar test signals using 2 or 3 different PRF values. For radar test signal 5, the difference between the PRF values chosen shall be between 20 PPS and 50 PPS. For radar test signal 6, the difference between the PRF values chosen shall be between 80 PPS and 400 PPS. See figure D.3.

NOTE 4: Apart for the Off-Channel CAC testing, the radar test signals above shall only contain a single burst of pulses. See figures D.1, D.3 and D.4.
For the Off-Channel CAC testing, repetitive bursts shall be used for the total duration of the test. See figures D.2 and D.5. See also clauses 4.7.2.2, 5.3.8.2.1.3.1 and 5.3.8.2.1.3.2.

NOTE 5: The total number of pulses in a burst is equal to the number of pulses for a single PRF multiplied by the number of different PRFs used.

NOTE 6: For the CAC and Off-Channel CAC requirements, the minimum number of pulses (for each PRF) for any of the radar test signals to be detected in the band 5 600 MHz to 5 650 MHz shall be 18.

FIGURE 5

(Table D5, detection probability in annex of ETSI EN301893 V1.7.1)

Parameter	**Detection Probability (P_d)**	
	Channels whose nominal bandwidth falls partly or completely within the 5 600 MHz to 5 650 MHz band	**Other channels**
CAC, Off-Channel CAC	99,99 %	60 %
In-Service Monitoring	60 %	60 %
NOTE: P_d gives the probability of detection per simulated radar burst and represents a minimum level of detection performance under defined conditions. Therefore P_d does not represent the overall detection probability for any particular radar under real life conditions.		

Definition:

available channel: channel identified as available for immediate use as an *Operating Channel*

burst: period during which radio waves are intentionally transmitted, preceded and succeeded by periods during which no intentional transmission is made

channel availability check time (CAC): time while RLAN listens radar signal after which RLAN starts transmissions

cycle "In service monitoring": time while RLAN transmits and listens radars signals

ANNEX B

B-1- RLAN in CAC (100%) – Radar in mode M1 200F Comparison for 1, 3, 6 and 9 pulses

B1	RLAN 'CAC mode'													
	Radar (200F M1)						Collision Probability				Probability calculated for 60 rotations			
	Rot	angle	pri	width	nb puls	mode	9pulses	6pulses	3 pulses	1 pulse	9pulses	6pulses	3 pulses	1 pulse
1	1	2	2	0,001	1	1	0,00	0,00	0,01	13,3	0,00	0,00	0,72	100,0
2	1	2	2	0,001	3	1	0,00	0,00	1,35	7,7	0,00	0,00	55,70	99,2
3	1	2	2	0,001	6	1	0,00	0,00	2,86	6,5	0,00	0,00	82,44	98,3
4	1	2	2	0,001	10	1	0,00	0,00	3,55	6,0	0,00	0,00	88,55	97,6
5	1	2	2	0,003	1	1	0,00	0,00	0,01	13,4	0,00	0,00	0,72	100,0
6	1	2	2	0,003	3	1	0,00	0,00	1,45	7,9	0,00	0,00	58,32	99,3
7	1	2	2	0,003	6	1	0,00	0,00	2,75	6,5	0,00	0,00	81,21	98,2
8	1	2	2	0,003	10	1	0,00	0,00	2,97	5,9	0,00	0,00	83,60	97,4
9	1	2	2	0,01	1	1	0,00	0,00	0,01	13,2	0,00	0,00	0,48	100,0
10	1	2	2	0,01	3	1	0,00	0,00	1,48	8,0	0,00	0,00	59,02	99,3
11	1	2	2	0,01	6	1	0,00	0,00	2,83	6,3	0,00	0,00	82,18	98,0
12	1	2	2	0,01	10	1	0,00	0,00	3,60	5,8	0,00	0,00	88,89	97,3
13	1	2	2	0,02	1	1	0,00	0,00	0,00	13,1	0,00	0,00	0,24	100,0
14	1	2	2	0,02	3	1	0,00	0,00	1,57	7,7	0,00	0,00	61,26	99,2
15	1	2	2	0,02	6	1	0,00	0,00	2,77	6,3	0,00	0,00	81,51	98,0
16	1	2	2	0,02	10	1	0,00	0,00	3,27	5,9	0,00	0,00	86,38	97,3
17	1	2	1	0,001	1	1	0,00	0,00	0,04	25,1	0,00	0,00	2,14	100,0
18	1	2	1	0,001	3	1	0,00	0,06	6,04	11,9	0,00	3,42	97,61	99,9
19	1	2	1	0,001	6	1	0,00	0,44	5,29	8,6	0,00	23,06	96,16	99,6
20	1	2	1	0,001	10	1	0,00	1,64	5,38	7,2	0,00	62,92	96,38	98,9
21	1	2	1	0,003	1	1	0,00	0,00	0,06	24,8	0,00	0,00	3,54	100,0
22	1	2	1	0,003	3	1	0,00	0,04	5,86	12,1	0,00	2,61	97,33	100,0
23	1	2	1	0,003	6	1	0,00	0,69	5,39	8,5	0,00	33,91	96,41	99,5
24	1	2	1	0,003	10	1	0,00	1,79	5,29	7,2	0,00	66,12	96,16	98,9
25	1	2	1	0,01	1	1	0,00	0,00	0,03	24,7	0,00	0,00	1,67	100,0
26	1	2	1	0,01	3	1	0,00	0,03	5,95	12,1	0,00	2,02	97,48	100,0
27	1	2	1	0,01	6	1	0,00	0,64	5,51	8,3	0,00	32,05	96,66	99,5
28	1	2	1	0,01	10	1	0,00	1,49	5,36	7,3	0,00	59,32	96,34	98,9
29	1	2	1	0,02	1	1	0,00	0,00	0,05	24,5	0,00	0,00	2,84	100,0
30	1	2	1	0,02	3	1	0,00	0,05	5,93	12,1	0,00	2,96	97,45	100,0
31	1	2	1	0,02	6	1	0,00	0,59	5,27	8,9	0,00	29,89	96,13	99,6
32	1	2	1	0,02	10	1	0,00	1,31	5,13	7,3	0,00	54,78	95,75	98,9
33	1	2	0,5	0,001	1	1	0,00	0,00	0,11	43,2	0,00	0,00	6,50	100,0
34	1	2	0,5	0,001	3	1	0,02	0,50	14,72	19,8	0,96	25,88	99,99	100,0
35	1	2	0,5	0,001	6	1	0,23	5,09	9,84	12,9	12,90	95,64	99,80	100,0
36	1	2	0,5	0,001	10	1	2,24	5,15	7,14	10,0	74,31	95,82	98,83	99,8
37	1	2	0,5	0,003	1	1	0,00	0,00	0,09	43,5	0,00	0,00	5,15	100,0
38	1	2	0,5	0,003	3	1	0,01	0,54	14,31	20,1	0,84	27,56	99,99	100,0
39	1	2	0,5	0,003	6	1	0,26	5,03	9,88	12,7	14,46	95,47	99,81	100,0
40	1	2	0,5	0,003	10	1	2,02	4,79	7,42	10,4	70,68	94,74	99,02	99,9
41	1	2	0,5	0,01	1	1	0,00	0,00	0,11	43,1	0,00	0,00	6,61	100,0
42	1	2	0,5	0,01	3	1	0,01	0,49	14,55	20,3	0,36	25,35	99,99	100,0
43	1	2	0,5	0,01	6	1	0,25	5,11	9,80	13,0	14,05	95,71	99,79	100,0
44	1	2	0,5	0,01	10	1	2,42	5,12	8,45	10,0	77,03	95,74	99,50	99,8
45	1	2	0,5	0,02	1	1	0,00	0,00	0,10	43,8	0,00	0,00	5,94	100,0
46	1	2	0,5	0,02	3	1	0,01	0,51	14,35	20,0	0,60	26,24	99,99	100,0
47	1	2	0,5	0,02	6	1	0,26	4,87	9,59	12,6	14,36	94,99	99,76	100,0
48	1	2	0,5	0,02	10	1	3,23	4,94	7,63	9,7	86,04	95,22	99,14	99,8
49	0,5	2	2	0,001	1	1	0,00	0,00	0,05	23,3	0,00	0,00	1,43	100,0
50	0,5	2	2	0,001	3	1	0,00	0,05	5,60	12,6	0,00	1,55	82,27	98,3
51	0,5	2	2	0,001	6	1	0,00	0,38	5,82	8,4	0,00	10,90	83,45	92,8
52	0,5	2	2	0,001	10	1	0,00	2,10	4,91	7,0	0,00	47,03	77,93	88,8
53	0,5	2	2	0,003	1	1	0,00	0,00	0,03	24,1	0,00	0,00	0,84	100,0
54	0,5	2	2	0,003	3	1	0,00	0,04	6,08	12,3	0,00	1,31	84,75	98,1
55	0,5	2	2	0,003	6	1	0,00	0,66	5,35	8,9	0,00	18,02	80,77	93,9
56	0,5	2	2	0,003	10	1	0,00	1,70	5,53	6,6	0,00	40,28	81,84	87,3
57	0,5	2	2	0,01	1	1	0,00	0,00	0,04	25,6	0,00	0,00	1,31	100,0
58	0,5	2	2	0,01	3	1	0,00	0,05	5,63	12,1	0,00	1,55	82,43	97,9
59	0,5	2	2	0,01	6	1	0,00	0,46	5,57	9,0	0,00	13,02	82,09	94,0
60	0,5	2	2	0,01	10	1	0,00	1,37	4,95	7,7	0,00	33,85	78,21	91,1
61	0,5	2	2	0,02	1	1	0,00	0,00	0,04	25,6	0,00	0,00	1,07	100,0
62	0,5	2	2	0,02	3	1	0,00	0,07	6,42	11,8	0,00	2,02	86,36	97,7
63	0,5	2	2	0,02	6	1	0,00	0,60	5,35	8,8	0,00	16,62	80,77	93,8
64	0,5	2	2	0,02	10	1	0,00	1,54	5,36	6,6	0,00	37,22	80,85	87,0
65	0,5	2	1	0,001	1	1	0,00	0,00	0,11	43,7	0,00	0,00	3,31	100,0
66	0,5	2	1	0,001	3	1	0,00	0,52	14,30	19,6	0,00	14,38	99,03	99,9
67	0,5	2	1	0,001	6	1	0,25	5,15	9,64	13,2	7,18	79,54	95,23	98,6
68	0,5	2	1	0,001	10	1	2,24	5,04	8,19	9,8	49,32	78,83	92,30	95,4
69	0,5	2	1	0,003	1	1	0,00	0,00	0,13	43,5	0,00	0,00	3,88	100,0
70	0,5	2	1	0,003	3	1	0,01	0,52	15,05	20,0	0,24	14,48	99,25	99,9
71	0,5	2	1	0,003	6	1	0,29	5,27	9,58	13,2	8,29	80,30	95,13	98,6
72	0,5	2	1	0,003	10	1	1,41	4,89	7,97	9,8	34,73	77,79	91,72	95,4
73	0,5	2	1	0,01	1	1	0,00	0,00	0,14	42,9	0,00	0,00	4,00	100,0
74	0,5	2	1	0,01	3	1	0,01	0,49	14,28	20,1	0,36	13,75	99,02	99,9
75	0,5	2	1	0,01	6	1	0,30	5,08	9,46	13,0	8,73	79,10	94,92	98,5
76	0,5	2	1	0,01	10	1	3,05	5,14	9,08	10,0	60,49	79,49	94,24	95,7
77	0,5	2	1	0,02	1	1	0,00	0,00	0,12	43,2	0,00	0,00	3,54	100,0
78	0,5	2	1	0,02	3	1	0,01	0,51	14,50	20,0	0,36	14,27	99,09	99,9
79	0,5	2	1	0,02	6	1	0,24	4,94	9,84	13,0	6,84	78,10	95,53	98,5
80	0,5	2	1	0,02	10	1	1,21	5,13	8,85	9,7	30,64	79,41	93,79	95,3
81	0,5	2	0,5	0,001	1	1	0,00	0,00	0,28	67,6	0,00	0,00	8,18	100,0
82	0,5	2	0,5	0,001	3	1	0,04	1,28	29,39	34,0	1,31	32,14	100,00	100,0
83	0,5	2	0,5	0,001	6	1	0,77	13,42	17,74	21,0	20,65	98,68	99,71	99,9
84	0,5	2	0,5	0,001	10	1	8,04	10,52	12,22	14,9	91,91	96,44	98,00	99,2
85	0,5	2	0,5	0,003	1	1	0,00	0,00	0,24	67,6	0,00	0,00	7,07	100,0
86	0,5	2	0,5	0,003	3	1	0,06	1,38	29,02	33,5	1,78	34,17	100,00	100,0
87	0,5	2	0,5	0,003	6	1	0,70	13,57	18,08	21,1	18,90	98,74	99,75	99,9
88	0,5	2	0,5	0,003	10	1	7,42	10,35	13,21	14,6	90,10	96,23	98,57	99,1
89	0,5	2	0,5	0,01	1	1	0,00	0,00	0,35	68,0	0,00	0,00	10,04	100,0
90	0,5	2	0,5	0,01	3	1	0,07	1,43	29,67	33,9	2,02	35,12	100,00	100,0
91	0,5	2	0,5	0,01	6	1	0,64	13,85	18,36	21,3	17,52	98,86	99,77	99,9
92	0,5	2	0,5	0,01	10	1	7,35	10,43	13,36	14,5	89,88	96,33	98,65	99,1
93	0,5	2	0,5	0,02	1	1	0,00	0,00	0,27	68,1	0,00	0,00	7,73	100,0
94	0,5	2	0,5	0,02	3	1	0,03	1,30	29,43	33,8	0,84	32,38	100,00	100,0
95	0,5	2	0,5	0,02	6	1	0,63	13,76	18,02	20,5	17,22	98,82	99,74	99,9
96	0,5	2	0,5	0,02	10	1	7,66	10,00	12,62	14,7	90,84	95,76	98,25	99,2

B-2- RLAN ‘In service monitoring’ 3 pulses – Radar in mode M1 200F

Comparison for 20%, 50% and 80% of listen time

B2	RLAN 'In Service monitoring' (300ms, 3pulses)								
	Radar (200F M1)						Collision probability		
	Rot	angle	pri	width	nb puls	mode	80%	50%	20%
1	1.0	2.0	2.0	0.001	1	1	0,01	0,01	0,00
2	1.0	2.0	2.0	0.001	3	1	0,93	0,68	0,26
3	1.0	2.0	2.0	0.001	6	1	2,06	1,07	0,52
4	1.0	2.0	2.0	0.001	10	1	2,39	1,72	0,58
5	1.0	2.0	2.0	0.003	1	1	0,01	0,00	0,00
6	1.0	2.0	2.0	0.003	3	1	1,15	0,76	0,31
7	1.0	2.0	2.0	0.003	6	1	2,16	1,23	0,50
8	1.0	2.0	2.0	0.003	10	1	2,52	1,72	0,71
9	1.0	2.0	2.0	0.01	1	1	0,00	0,00	0,00
10	1.0	2.0	2.0	0.01	3	1	1,32	0,62	0,29
11	1.0	2.0	2.0	0.01	6	1	1,95	1,17	0,44
12	1.0	2.0	2.0	0.01	10	1	2,20	1,63	0,49
13	1.0	2.0	2.0	0.02	1	1	0,01	0,01	0,00
14	1.0	2.0	2.0	0.02	3	1	1,02	0,75	0,29
15	1.0	2.0	2.0	0.02	6	1	2,39	1,19	0,50
16	1.0	2.0	2.0	0.02	10	1	2,74	1,59	0,62
17	1.0	2.0	1.0	0.001	1	1	0,03	0,03	0,01
18	1.0	2.0	1.0	0.001	3	1	4,57	2,95	1,12
19	1.0	2.0	1.0	0.001	6	1	4,31	2,59	1,11
20	1.0	2.0	1.0	0.001	10	1	4,43	2,58	1,05
21	1.0	2.0	1.0	0.003	1	1	0,04	0,01	0,01
22	1.0	2.0	1.0	0.003	3	1	4,70	2,78	1,10
23	1.0	2.0	1.0	0.003	6	1	4,17	2,61	1,17
24	1.0	2.0	1.0	0.003	10	1	4,28	2,42	1,03
25	1.0	2.0	1.0	0.01	1	1	0,05	0,02	0,01
26	1.0	2.0	1.0	0.01	3	1	4,68	2,88	1,05
27	1.0	2.0	1.0	0.01	6	1	4,50	2,72	1,00
28	1.0	2.0	1.0	0.01	10	1	4,29	2,68	0,96
29	1.0	2.0	1.0	0.02	1	1	0,03	0,02	0,01
30	1.0	2.0	1.0	0.02	3	1	4,34	3,10	1,10
31	1.0	2.0	1.0	0.02	6	1	4,55	2,94	1,04
32	1.0	2.0	1.0	0.02	10	1	4,04	2,62	1,18
33	1.0	2.0	0.5	0.001	1	1	0,09	0,05	0,03
34	1.0	2.0	0.5	0.001	3	1	11,53	7,38	2,76
35	1.0	2.0	0.5	0.001	6	1	7,37	4,93	1,88
36	1.0	2.0	0.5	0.001	10	1	6,37	3,49	1,61
37	1.0	2.0	0.5	0.003	1	1	0,08	0,07	0,01
38	1.0	2.0	0.5	0.003	3	1	11,44	7,15	2,77
39	1.0	2.0	0.5	0.003	6	1	7,85	4,83	1,90
40	1.0	2.0	0.5	0.003	10	1	6,53	3,68	1,62
41	1.0	2.0	0.5	0.01	1	1	0,10	0,05	0,01
42	1.0	2.0	0.5	0.01	3	1	11,81	7,04	2,77
43	1.0	2.0	0.5	0.01	6	1	7,88	5,10	1,97
44	1.0	2.0	0.5	0.01	10	1	6,46	4,12	1,50
45	1.0	2.0	0.5	0.02	1	1	0,07	0,08	0,03
46	1.0	2.0	0.5	0.02	3	1	11,57	7,26	2,78
47	1.0	2.0	0.5	0.02	6	1	7,63	4,99	1,96
48	1.0	2.0	0.5	0.02	10	1	6,64	4,05	1,73
49	0.5	2.0	2.0	0.001	1	1	0,04	0,04	0,00
50	0.5	2.0	2.0	0.001	3	1	4,25	3,00	1,14
51	0.5	2.0	2.0	0.001	6	1	3,90	2,82	1,10
52	0.5	2.0	2.0	0.001	10	1	4,16	2,60	1,04
53	0.5	2.0	2.0	0.003	1	1	0,02	0,02	0,01
54	0.5	2.0	2.0	0.003	3	1	4,47	2,83	1,16
55	0.5	2.0	2.0	0.003	6	1	4,46	2,57	1,08
56	0.5	2.0	2.0	0.003	10	1	4,37	2,54	1,01
57	0.5	2.0	2.0	0.01	1	1	0,01	0,02	0,01
58	0.5	2.0	2.0	0.01	3	1	4,90	2,70	1,33
59	0.5	2.0	2.0	0.01	6	1	4,56	2,51	1,16
60	0.5	2.0	2.0	0.01	10	1	4,41	2,55	1,04
61	0.5	2.0	2.0	0.02	1	1	0,04	0,02	0,01
62	0.5	2.0	2.0	0.02	3	1	4,38	3,08	1,12
63	0.5	2.0	2.0	0.02	6	1	3,82	2,79	1,02
64	0.5	2.0	2.0	0.02	10	1	4,23	2,53	0,94
65	0.5	2.0	1.0	0.001	1	1	0,07	0,04	0,02
66	0.5	2.0	1.0	0.001	3	1	11,28	7,59	2,78
67	0.5	2.0	1.0	0.001	6	1	7,85	5,10	1,97
68	0.5	2.0	1.0	0.001	10	1	6,17	4,17	1,42
69	0.5	2.0	1.0	0.003	1	1	0,06	0,06	0,00
70	0.5	2.0	1.0	0.003	3	1	11,45	7,10	2,91
71	0.5	2.0	1.0	0.003	6	1	8,15	4,80	2,04
72	0.5	2.0	1.0	0.003	10	1	6,19	4,04	1,56
73	0.5	2.0	1.0	0.01	1	1	0,08	0,06	0,01
74	0.5	2.0	1.0	0.01	3	1	11,19	7,46	2,82
75	0.5	2.0	1.0	0.01	6	1	7,89	4,97	2,01
76	0.5	2.0	1.0	0.01	10	1	5,98	3,89	1,67
77	0.5	2.0	1.0	0.02	1	1	0,08	0,09	0,03
78	0.5	2.0	1.0	0.02	3	1	11,27	7,00	2,92
79	0.5	2.0	1.0	0.02	6	1	7,82	4,82	2,19
80	0.5	2.0	1.0	0.02	10	1	5,75	4,34	1,68
81	0.5	2.0	0.5	0.001	1	1	0,22	0,12	0,02
82	0.5	2.0	0.5	0.001	3	1	23,15	14,20	5,94
83	0.5	2.0	0.5	0.001	6	1	14,38	9,36	3,43
84	0.5	2.0	0.5	0.001	10	1	10,38	6,75	2,63
85	0.5	2.0	0.5	0.003	1	1	0,24	0,13	0,04
86	0.5	2.0	0.5	0.003	3	1	22,68	14,77	5,84
87	0.5	2.0	0.5	0.003	6	1	14,15	8,98	3,65
88	0.5	2.0	0.5	0.003	10	1	10,25	6,50	2,66
89	0.5	2.0	0.5	0.01	1	1	0,22	0,09	0,04
90	0.5	2.0	0.5	0.01	3	1	23,02	14,85	5,91
91	0.5	2.0	0.5	0.01	6	1	14,30	8,29	3,52
92	0.5	2.0	0.5	0.01	10	1	10,73	6,48	2,61
93	0.5	2.0	0.5	0.02	1	1	0,17	0,11	0,05
94	0.5	2.0	0.5	0.02	3	1	22,16	14,78	5,86
95	0.5	2.0	0.5	0.02	6	1	14,89	8,86	3,71
96	0.5	2.0	0.5	0.02	10	1	10,61	6,64	2,83

B-3- RLAN ‘In service monitoring’ 9 pulses – Radar in mode M1 200F comparison for 20%, 50% and 80% of listen time

B3	RLAN 'In Service monitoring' (300ms, 9pulses)								
	Radar (200F M1)						Collision probability		
	Rot.	angle	pri	width	nb pulse	mode	80%	50%	20%
1	1.0	2.0	2.0	0.001	1	1	0,00	0,00	0,00
2	1.0	2.0	2.0	0.001	3	1	0,00	0,00	0,00
3	1.0	2.0	2.0	0.001	6	1	0,00	0,00	0,00
4	1.0	2.0	2.0	0.001	10	1	0,00	0,00	0,00
5	1.0	2.0	2.0	0.003	1	1	0,00	0,00	0,00
6	1.0	2.0	2.0	0.003	3	1	0,00	0,00	0,00
7	1.0	2.0	2.0	0.003	6	1	0,00	0,00	0,00
8	1.0	2.0	2.0	0.003	10	1	0,00	0,00	0,00
9	1.0	2.0	2.0	0.01	1	1	0,00	0,00	0,00
10	1.0	2.0	2.0	0.01	3	1	0,00	0,00	0,00
11	1.0	2.0	2.0	0.01	6	1	0,00	0,00	0,00
12	1.0	2.0	2.0	0.01	10	1	0,00	0,00	0,00
13	1.0	2.0	2.0	0.02	1	1	0,00	0,00	0,00
14	1.0	2.0	2.0	0.02	3	1	0,00	0,00	0,00
15	1.0	2.0	2.0	0.02	6	1	0,00	0,00	0,00
16	1.0	2.0	2.0	0.02	10	1	0,00	0,00	0,00
17	1.0	2.0	1.0	0.001	1	1	0,00	0,00	0,00
18	1.0	2.0	1.0	0.001	3	1	0,00	0,00	0,00
19	1.0	2.0	1.0	0.001	6	1	0,00	0,00	0,00
20	1.0	2.0	1.0	0.001	10	1	0,00	0,00	0,00
21	1.0	2.0	1.0	0.003	1	1	0,00	0,00	0,00
22	1.0	2.0	1.0	0.003	3	1	0,00	0,00	0,00
23	1.0	2.0	1.0	0.003	6	1	0,00	0,00	0,00
24	1.0	2.0	1.0	0.003	10	1	0,00	0,00	0,00
25	1.0	2.0	1.0	0.01	1	1	0,00	0,00	0,00
26	1.0	2.0	1.0	0.01	3	1	0,00	0,00	0,00
27	1.0	2.0	1.0	0.01	6	1	0,00	0,00	0,00
28	1.0	2.0	1.0	0.01	10	1	0,00	0,00	0,00
29	1.0	2.0	1.0	0.02	1	1	0,00	0,00	0,00
30	1.0	2.0	1.0	0.02	3	1	0,00	0,00	0,00
31	1.0	2.0	1.0	0.02	6	1	0,00	0,00	0,00
32	1.0	2.0	1.0	0.02	10	1	0,00	0,00	0,00
33	1.0	2.0	0.5	0.001	1	1	0,00	0,00	0,00
34	1.0	2.0	0.5	0.001	3	1	0,02	0,01	0,00
35	1.0	2.0	0.5	0.001	6	1	0,23	0,13	0,05
36	1.0	2.0	0.5	0.001	10	1	1,71	1,18	0,40
37	1.0	2.0	0.5	0.003	1	1	0,00	0,00	0,00
38	1.0	2.0	0.5	0.003	3	1	0,01	0,00	0,00
39	1.0	2.0	0.5	0.003	6	1	0,18	0,13	0,04
40	1.0	2.0	0.5	0.003	10	1	1,75	1,04	0,34
41	1.0	2.0	0.5	0.01	1	1	0,00	0,00	0,00
42	1.0	2.0	0.5	0.01	3	1	0,01	0,00	0,00
43	1.0	2.0	0.5	0.01	6	1	0,24	0,13	0,04
44	1.0	2.0	0.5	0.01	10	1	1,69	0,99	0,42
45	1.0	2.0	0.5	0.02	1	1	0,00	0,00	0,00
46	1.0	2.0	0.5	0.02	3	1	0,01	0,00	0,00
47	1.0	2.0	0.5	0.02	6	1	0,22	0,10	0,05
48	1.0	2.0	0.5	0.02	10	1	1,33	0,93	0,49
49	0.5	2.0	2.0	0.001	1	1	0,00	0,00	0,00
50	0.5	2.0	2.0	0.001	3	1	0,00	0,00	0,00
51	0.5	2.0	2.0	0.001	6	1	0,00	0,00	0,00
52	0.5	2.0	2.0	0.001	10	1	0,00	0,00	0,00
53	0.5	2.0	2.0	0.003	1	1	0,00	0,00	0,00
54	0.5	2.0	2.0	0.003	3	1	0,00	0,00	0,00
55	0.5	2.0	2.0	0.003	6	1	0,00	0,00	0,00
56	0.5	2.0	2.0	0.003	10	1	0,00	0,00	0,00
57	0.5	2.0	2.0	0.01	1	1	0,00	0,00	0,00
58	0.5	2.0	2.0	0.01	3	1	0,00	0,00	0,00
59	0.5	2.0	2.0	0.01	6	1	0,00	0,00	0,00
60	0.5	2.0	2.0	0.01	10	1	0,00	0,00	0,00
61	0.5	2.0	2.0	0.02	1	1	0,00	0,00	0,00
62	0.5	2.0	2.0	0.02	3	1	0,00	0,00	0,00
63	0.5	2.0	2.0	0.02	6	1	0,00	0,00	0,00
64	0.5	2.0	2.0	0.02	10	1	0,00	0,00	0,00
65	0.5	2.0	1.0	0.001	1	1	0,00	0,00	0,00
66	0.5	2.0	1.0	0.001	3	1	0,01	0,00	0,00
67	0.5	2.0	1.0	0.001	6	1	0,23	0,06	0,03
68	0.5	2.0	1.0	0.001	10	1	1,80	1,22	0,48
69	0.5	2.0	1.0	0.003	1	1	0,00	0,00	0,00
70	0.5	2.0	1.0	0.003	3	1	0,01	0,00	0,00
71	0.5	2.0	1.0	0.003	6	1	0,20	0,12	0,03
72	0.5	2.0	1.0	0.003	10	1	2,42	1,08	0,32
73	0.5	2.0	1.0	0.01	1	1	0,00	0,00	0,00
74	0.5	2.0	1.0	0.01	3	1	0,00	0,00	0,00
75	0.5	2.0	1.0	0.01	6	1	0,18	0,10	0,04
76	0.5	2.0	1.0	0.01	10	1	2,37	1,00	0,55
77	0.5	2.0	1.0	0.02	1	1	0,00	0,00	0,00
78	0.5	2.0	1.0	0.02	3	1	0,01	0,00	0,00
79	0.5	2.0	1.0	0.02	6	1	0,24	0,10	0,05
80	0.5	2.0	1.0	0.02	10	1	1,92	0,82	0,32
81	0.5	2.0	0.5	0.001	1	1	0,00	0,00	0,00
82	0.5	2.0	0.5	0.001	3	1	0,05	0,03	0,02
83	0.5	2.0	0.5	0.001	6	1	0,58	0,32	0,14
84	0.5	2.0	0.5	0.001	10	1	6,71	3,25	1,50
85	0.5	2.0	0.5	0.003	1	1	0,00	0,00	0,00
86	0.5	2.0	0.5	0.003	3	1	0,03	0,03	0,00
87	0.5	2.0	0.5	0.003	6	1	0,56	0,42	0,10
88	0.5	2.0	0.5	0.003	10	1	6,54	3,42	1,50
89	0.5	2.0	0.5	0.01	1	1	0,00	0,00	0,00
90	0.5	2.0	0.5	0.01	3	1	0,02	0,03	0,01
91	0.5	2.0	0.5	0.01	6	1	0,50	0,32	0,13
92	0.5	2.0	0.5	0.01	10	1	5,49	3,52	1,58
93	0.5	2.0	0.5	0.02	1	1	0,00	0,00	0,00
94	0.5	2.0	0.5	0.02	3	1	0,04	0,02	0,02
95	0.5	2.0	0.5	0.02	6	1	0,57	0,37	0,10
96	0.5	2.0	0.5	0.02	10	1	5,89	4,02	1,60

B-4- RLAN ‘In service monitoring’ – Radar in mode M1 200F

Comparison for 1, 3, 6 and 9 pulses

B4	RLAN ' In service monitoring ' (300ms 80%)									
	Radars (M1 200F)						Collision probability			
	Rot	angle	pri	width	nb pulse	mode	9pulses	6pulses	3pulses	1pulses
1	1	2	2	0,001	1	1	0,00	0,00	0,01	10,49
2	1	2	2	0,001	3	1	0,00	0,00	0,93	6,38
3	1	2	2	0,001	6	1	0,00	0,00	2,06	5,25
4	1	2	2	0,001	10	1	0,00	0,00	2,39	4,99
5	1	2	2	0,003	1	1	0,00	0,00	0,01	10,15
6	1	2	2	0,003	3	1	0,00	0,00	1,15	6,44
7	1	2	2	0,003	6	1	0,00	0,00	2,16	5,11
8	1	2	2	0,003	10	1	0,00	0,00	2,52	4,62
9	1	2	2	0,01	1	1	0,00	0,00	0,00	10,21
10	1	2	2	0,01	3	1	0,00	0,00	1,32	6,45
11	1	2	2	0,01	6	1	0,00	0,00	1,95	5,29
12	1	2	2	0,01	10	1	0,00	0,00	2,20	4,90
13	1	2	2	0,02	1	1	0,00	0,00	0,01	10,72
14	1	2	2	0,02	3	1	0,00	0,00	1,02	6,32
15	1	2	2	0,02	6	1	0,00	0,00	2,39	5,10
16	1	2	2	0,02	10	1	0,00	0,00	2,74	4,62
17	1	2	1	0,001	1	1	0,00	0,00	0,03	19,88
18	1	2	1	0,001	3	1	0,00	0,03	4,57	9,41
19	1	2	1	0,001	6	1	0,00	0,35	4,31	6,86
20	1	2	1	0,001	10	1	0,00	1,10	4,43	5,87
21	1	2	1	0,003	1	1	0,00	0,00	0,04	19,81
22	1	2	1	0,003	3	1	0,00	0,04	4,70	9,87
23	1	2	1	0,003	6	1	0,00	0,35	4,17	6,82
24	1	2	1	0,003	10	1	0,00	1,10	4,28	5,70
25	1	2	1	0,01	1	1	0,00	0,00	0,05	20,36
26	1	2	1	0,01	3	1	0,00	0,03	4,68	9,39
27	1	2	1	0,01	6	1	0,00	0,52	4,50	7,16
28	1	2	1	0,01	10	1	0,00	1,08	4,29	5,92
29	1	2	1	0,02	1	1	0,00	0,00	0,03	20,12
30	1	2	1	0,02	3	1	0,00	0,03	4,34	9,36
31	1	2	1	0,02	6	1	0,00	0,38	4,55	7,07
32	1	2	1	0,02	10	1	0,00	1,07	4,04	5,48
33	1	2	0,5	0,001	1	1	0,00	0,00	0,09	34,84
34	1	2	0,5	0,001	3	1	0,02	0,39	11,53	16,32
35	1	2	0,5	0,001	6	1	0,23	4,05	7,37	9,68
36	1	2	0,5	0,001	10	1	1,71	3,99	6,37	7,81
37	1	2	0,5	0,003	1	1	0,00	0,00	0,08	34,28
38	1	2	0,5	0,003	3	1	0,01	0,44	11,44	16,02
39	1	2	0,5	0,003	6	1	0,18	4,08	7,85	10,28
40	1	2	0,5	0,003	10	1	1,75	3,93	6,53	7,99
41	1	2	0,5	0,01	1	1	0,00	0,00	0,10	34,73
42	1	2	0,5	0,01	3	1	0,01	0,40	11,81	16,55
43	1	2	0,5	0,01	6	1	0,24	4,08	7,88	10,43
44	1	2	0,5	0,01	10	1	1,69	4,21	6,46	7,98
45	1	2	0,5	0,02	1	1	0,00	0,00	0,07	34,30
46	1	2	0,5	0,02	3	1	0,01	0,44	11,57	16,22
47	1	2	0,5	0,02	6	1	0,22	4,12	7,63	10,08
48	1	2	0,5	0,02	10	1	1,33	4,09	6,64	8,01
49	0,5	2	2	0,001	1	1	0,00	0,00	0,04	20,48
50	0,5	2	2	0,001	3	1	0,00	0,04	4,25	9,55
51	0,5	2	2	0,001	6	1	0,00	0,34	3,90	6,46
52	0,5	2	2	0,001	10	1	0,00	1,18	4,16	5,11
53	0,5	2	2	0,003	1	1	0,00	0,00	0,02	19,38
54	0,5	2	2	0,003	3	1	0,00	0,02	4,47	9,86
55	0,5	2	2	0,003	6	1	0,00	0,48	4,46	6,96
56	0,5	2	2	0,003	10	1	0,00	0,92	4,37	5,42
57	0,5	2	2	0,01	1	1	0,00	0,00	0,01	19,60
58	0,5	2	2	0,01	3	1	0,00	0,04	4,90	10,22
59	0,5	2	2	0,01	6	1	0,00	0,21	4,56	7,31
60	0,5	2	2	0,01	10	1	0,00	1,09	4,41	5,57
61	0,5	2	2	0,02	1	1	0,00	0,00	0,04	19,94
62	0,5	2	2	0,02	3	1	0,00	0,04	4,38	9,42
63	0,5	2	2	0,02	6	1	0,00	0,47	3,82	6,37
64	0,5	2	2	0,02	10	1	0,00	0,56	4,23	6,13
65	0,5	2	1	0,001	1	1	0,00	0,00	0,07	35,04
66	0,5	2	1	0,001	3	1	0,01	0,32	11,28	16,24
67	0,5	2	1	0,001	6	1	0,23	3,89	7,85	10,49
68	0,5	2	1	0,001	10	1	1,80	4,06	6,17	7,97
69	0,5	2	1	0,003	1	1	0,00	0,00	0,06	36,24
70	0,5	2	1	0,003	3	1	0,01	0,33	11,45	16,45
71	0,5	2	1	0,003	6	1	0,20	4,08	8,15	10,71
72	0,5	2	1	0,003	10	1	2,42	3,88	6,19	7,98
73	0,5	2	1	0,01	1	1	0,00	0,00	0,08	34,34
74	0,5	2	1	0,01	3	1	0,00	0,40	11,19	15,92
75	0,5	2	1	0,01	6	1	0,18	3,91	7,89	10,46
76	0,5	2	1	0,01	10	1	2,37	4,04	5,98	7,81
77	0,5	2	1	0,02	1	1	0,00	0,00	0,08	35,52
78	0,5	2	1	0,02	3	1	0,01	0,34	11,27	15,91
79	0,5	2	1	0,02	6	1	0,24	4,07	7,82	10,24
80	0,5	2	1	0,02	10	1	1,92	3,81	5,75	7,84
81	0,5	2	0,5	0,001	1	1	0,00	0,00	0,22	53,95
82	0,5	2	0,5	0,001	3	1	0,05	1,15	23,15	27,14
83	0,5	2	0,5	0,001	6	1	0,58	10,50	14,38	16,77
84	0,5	2	0,5	0,001	10	1	6,71	8,22	10,38	11,45
85	0,5	2	0,5	0,003	1	1	0,00	0,00	0,24	55,68
86	0,5	2	0,5	0,003	3	1	0,03	1,06	22,68	26,59
87	0,5	2	0,5	0,003	6	1	0,56	11,31	14,15	16,62
88	0,5	2	0,5	0,003	10	1	6,54	7,64	10,25	12,17
89	0,5	2	0,5	0,01	1	1	0,00	0,00	0,22	54,43
90	0,5	2	0,5	0,01	3	1	0,02	1,03	23,02	26,81
91	0,5	2	0,5	0,01	6	1	0,50	10,36	14,30	16,63
92	0,5	2	0,5	0,01	10	1	5,49	8,66	10,73	12,48
93	0,5	2	0,5	0,02	1	1	0,00	0,00	0,17	52,97
94	0,5	2	0,5	0,02	3	1	0,04	0,96	22,16	26,11
95	0,5	2	0,5	0,02	6	1	0,57	10,91	14,89	17,32
96	0,5	2	0,5	0,02	10	1	5,89	8,07	10,61	11,75

B-5- RLAN en phase 'In service monitoring' – Radar in mode M1 200F

Comparison between 300ms and 50ms

B5	RLAN 'In Service monitoring' (80% , 3pulses)							
	Radar parameters						Proba collision	
	Rot	angle	pri	width	nb puls	mode	300ms	50ms
1	1.0	2.0	2.0	0.001	1	1	0,010	0,004
2	1.0	2.0	2.0	0.001	3	1	0,928	1,030
3	1.0	2.0	2.0	0.001	6	1	2,062	1,556
4	1.0	2.0	2.0	0.001	10	1	2,394	2,432
5	1.0	2.0	2.0	0.003	1	1	0,008	0,004
6	1.0	2.0	2.0	0.003	3	1	1,152	0,940
7	1.0	2.0	2.0	0.003	6	1	2,156	1,868
8	1.0	2.0	2.0	0.003	10	1	2,518	2,728
9	1.0	2.0	2.0	0.01	1	1	0,004	0,010
10	1.0	2.0	2.0	0.01	3	1	1,320	1,050
11	1.0	2.0	2.0	0.01	6	1	1,950	1,792
12	1.0	2.0	2.0	0.01	10	1	2,200	2,614
13	1.0	2.0	2.0	0.02	1	1	0,006	0,008
14	1.0	2.0	2.0	0.02	3	1	1,016	1,198
15	1.0	2.0	2.0	0.02	6	1	2,388	1,904
16	1.0	2.0	2.0	0.02	10	1	2,736	1,880
17	1.0	2.0	1.0	0.001	1	1	0,034	0,024
18	1.0	2.0	1.0	0.001	3	1	4,570	3,852
19	1.0	2.0	1.0	0.001	6	1	4,306	4,650
20	1.0	2.0	1.0	0.001	10	1	4,434	3,726
21	1.0	2.0	1.0	0.003	1	1	0,042	0,034
22	1.0	2.0	1.0	0.003	3	1	4,704	4,544
23	1.0	2.0	1.0	0.003	6	1	4,168	3,766
24	1.0	2.0	1.0	0.003	10	1	4,280	4,402
25	1.0	2.0	1.0	0.01	1	1	0,046	0,038
26	1.0	2.0	1.0	0.01	3	1	4,676	3,884
27	1.0	2.0	1.0	0.01	6	1	4,502	4,158
28	1.0	2.0	1.0	0.01	10	1	4,286	3,896
29	1.0	2.0	1.0	0.02	1	1	0,034	0,028
30	1.0	2.0	1.0	0.02	3	1	4,344	4,146
31	1.0	2.0	1.0	0.02	6	1	4,550	4,230
32	1.0	2.0	1.0	0.02	10	1	4,036	4,328
33	1.0	2.0	0.5	0.001	1	1	0,088	0,090
34	1.0	2.0	0.5	0.001	3	1	11,534	12,166
35	1.0	2.0	0.5	0.001	6	1	7,366	8,104
36	1.0	2.0	0.5	0.001	10	1	6,368	5,640
37	1.0	2.0	0.5	0.003	1	1	0,076	0,096
38	1.0	2.0	0.5	0.003	3	1	11,436	11,394
39	1.0	2.0	0.5	0.003	6	1	7,846	7,488
40	1.0	2.0	0.5	0.003	10	1	6,528	7,260
41	1.0	2.0	0.5	0.01	1	1	0,102	0,096
42	1.0	2.0	0.5	0.01	3	1	11,814	11,230
43	1.0	2.0	0.5	0.01	6	1	7,882	7,452
44	1.0	2.0	0.5	0.01	10	1	6,464	6,412
45	1.0	2.0	0.5	0.02	1	1	0,070	0,082
46	1.0	2.0	0.5	0.02	3	1	11,572	11,868
47	1.0	2.0	0.5	0.02	6	1	7,628	7,350
48	1.0	2.0	0.5	0.02	10	1	6,644	6,766
49	0.5	2.0	2.0	0.001	1	1	0,040	0,032
50	0.5	2.0	2.0	0.001	3	1	4,252	4,392
51	0.5	2.0	2.0	0.001	6	1	3,904	4,324
52	0.5	2.0	2.0	0.001	10	1	4,164	4,556
53	0.5	2.0	2.0	0.003	1	1	0,016	0,016
54	0.5	2.0	2.0	0.003	3	1	4,472	4,340
55	0.5	2.0	2.0	0.003	6	1	4,464	4,204
56	0.5	2.0	2.0	0.003	10	1	4,372	4,276
57	0.5	2.0	2.0	0.01	1	1	0,012	0,012
58	0.5	2.0	2.0	0.01	3	1	4,904	3,884
59	0.5	2.0	2.0	0.01	6	1	4,556	4,048
60	0.5	2.0	2.0	0.01	10	1	4,408	4,084
61	0.5	2.0	2.0	0.02	1	1	0,036	0,024
62	0.5	2.0	2.0	0.02	3	1	4,380	4,296
63	0.5	2.0	2.0	0.02	6	1	3,816	4,212
64	0.5	2.0	2.0	0.02	10	1	4,232	3,864
65	0.5	2.0	1.0	0.001	1	1	0,068	0,056
66	0.5	2.0	1.0	0.001	3	1	11,284	10,040
67	0.5	2.0	1.0	0.001	6	1	7,852	8,204
68	0.5	2.0	1.0	0.001	10	1	6,168	7,476
69	0.5	2.0	1.0	0.003	1	1	0,060	0,076
70	0.5	2.0	1.0	0.003	3	1	11,452	11,516
71	0.5	2.0	1.0	0.003	6	1	8,148	6,808
72	0.5	2.0	1.0	0.003	10	1	6,188	5,588
73	0.5	2.0	1.0	0.01	1	1	0,084	0,080
74	0.5	2.0	1.0	0.01	3	1	11,188	12,100
75	0.5	2.0	1.0	0.01	6	1	7,888	8,368
76	0.5	2.0	1.0	0.01	10	1	5,980	6,652
77	0.5	2.0	1.0	0.02	1	1	0,084	0,084
78	0.5	2.0	1.0	0.02	3	1	11,268	10,680
79	0.5	2.0	1.0	0.02	6	1	7,820	7,408
80	0.5	2.0	1.0	0.02	10	1	5,752	6,956
81	0.5	2.0	0.5	0.001	1	1	0,216	0,212
82	0.5	2.0	0.5	0.001	3	1	23,147	22,995
83	0.5	2.0	0.5	0.001	6	1	14,379	14,699
84	0.5	2.0	0.5	0.001	10	1	10,380	10,724
85	0.5	2.0	0.5	0.003	1	1	0,240	0,216
86	0.5	2.0	0.5	0.003	3	1	22,675	20,459
87	0.5	2.0	0.5	0.003	6	1	14,151	14,915
88	0.5	2.0	0.5	0.003	10	1	10,248	10,584
89	0.5	2.0	0.5	0.01	1	1	0,220	0,264
90	0.5	2.0	0.5	0.01	3	1	23,015	26,143
91	0.5	2.0	0.5	0.01	6	1	14,303	13,911
92	0.5	2.0	0.5	0.01	10	1	10,728	11,544
93	0.5	2.0	0.5	0.02	1	1	0,168	0,196
94	0.5	2.0	0.5	0.02	3	1	22,159	20,539
95	0.5	2.0	0.5	0.02	6	1	14,891	14,331
96	0.5	2.0	0.5	0.02	10	1	10,608	10,940

B-6- RLAN 'In service monitoring' – 200F

Comparison between Mode M1 and mode M2

B6	RLAN 'In Service monitoring' (80%, 3pulses)							
	Radar parameters						Collision probability	
	Rot	angle	pri	width	nb pu	mode	M1	M2
1	1.0	2.0	2.0	0.001	1	1	0,010	0,002
2	1.0	2.0	2.0	0.001	3	1	0,928	1,096
3	1.0	2.0	2.0	0.001	6	1	2,062	2,428
4	1.0	2.0	2.0	0.001	10	1	2,394	2,604
5	1.0	2.0	2.0	0.003	1	1	0,008	0,008
6	1.0	2.0	2.0	0.003	3	1	1,152	1,136
7	1.0	2.0	2.0	0.003	6	1	2,156	2,148
8	1.0	2.0	2.0	0.003	10	1	2,518	2,878
9	1.0	2.0	2.0	0.01	1	1	0,004	0,004
10	1.0	2.0	2.0	0.01	3	1	1,320	0,964
11	1.0	2.0	2.0	0.01	6	1	1,950	2,258
12	1.0	2.0	2.0	0.01	10	1	2,200	2,590
13	1.0	2.0	2.0	0.02	1	1	0,006	0,006
14	1.0	2.0	2.0	0.02	3	1	1,016	1,074
15	1.0	2.0	2.0	0.02	6	1	2,388	2,014
16	1.0	2.0	2.0	0.02	10	1	2,736	2,316
17	1.0	2.0	1.0	0.001	1	1	0,034	0,014
18	1.0	2.0	1.0	0.001	3	1	4,570	4,888
19	1.0	2.0	1.0	0.001	6	1	4,306	4,354
20	1.0	2.0	1.0	0.001	10	1	4,434	4,558
21	1.0	2.0	1.0	0.003	1	1	0,042	0,020
22	1.0	2.0	1.0	0.003	3	1	4,704	4,754
23	1.0	2.0	1.0	0.003	6	1	4,168	4,462
24	1.0	2.0	1.0	0.003	10	1	4,280	4,062
25	1.0	2.0	1.0	0.01	1	1	0,046	0,028
26	1.0	2.0	1.0	0.01	3	1	4,676	4,552
27	1.0	2.0	1.0	0.01	6	1	4,502	4,296
28	1.0	2.0	1.0	0.01	10	1	4,286	4,192
29	1.0	2.0	1.0	0.02	1	1	0,034	0,030
30	1.0	2.0	1.0	0.02	3	1	4,344	4,322
31	1.0	2.0	1.0	0.02	6	1	4,550	4,208
32	1.0	2.0	1.0	0.02	10	1	4,036	4,724
33	1.0	2.0	0.5	0.001	1	1	0,088	0,070
34	1.0	2.0	0.5	0.001	3	1	11,534	11,680
35	1.0	2.0	0.5	0.001	6	1	7,366	7,998
36	1.0	2.0	0.5	0.001	10	1	6,368	6,322
37	1.0	2.0	0.5	0.003	1	1	0,076	0,078
38	1.0	2.0	0.5	0.003	3	1	11,436	11,536
39	1.0	2.0	0.5	0.003	6	1	7,846	7,804
40	1.0	2.0	0.5	0.003	10	1	6,528	6,480
41	1.0	2.0	0.5	0.01	1	1	0,102	0,058
42	1.0	2.0	0.5	0.01	3	1	11,814	11,402
43	1.0	2.0	0.5	0.01	6	1	7,882	8,026
44	1.0	2.0	0.5	0.01	10	1	6,464	6,618
45	1.0	2.0	0.5	0.02	1	1	0,070	0,058
46	1.0	2.0	0.5	0.02	3	1	11,572	11,522
47	1.0	2.0	0.5	0.02	6	1	7,628	7,986
48	1.0	2.0	0.5	0.02	10	1	6,644	6,258
49	0.5	2.0	2.0	0.001	1	1	0,040	0,020
50	0.5	2.0	2.0	0.001	3	1	4,252	4,596
51	0.5	2.0	2.0	0.001	6	1	3,904	4,512
52	0.5	2.0	2.0	0.001	10	1	4,164	4,392
53	0.5	2.0	2.0	0.003	1	1	0,016	0,024
54	0.5	2.0	2.0	0.003	3	1	4,472	4,780
55	0.5	2.0	2.0	0.003	6	1	4,464	4,572
56	0.5	2.0	2.0	0.003	10	1	4,372	4,188
57	0.5	2.0	2.0	0.01	1	1	0,012	0,012
58	0.5	2.0	2.0	0.01	3	1	4,904	4,620
59	0.5	2.0	2.0	0.01	6	1	4,556	4,408
60	0.5	2.0	2.0	0.01	10	1	4,408	4,284
61	0.5	2.0	2.0	0.02	1	1	0,036	0,016
62	0.5	2.0	2.0	0.02	3	1	4,380	4,704
63	0.5	2.0	2.0	0.02	6	1	3,816	4,444
64	0.5	2.0	2.0	0.02	10	1	4,232	3,868
65	0.5	2.0	1.0	0.001	1	1	0,068	0,056
66	0.5	2.0	1.0	0.001	3	1	11,284	12,116
67	0.5	2.0	1.0	0.001	6	1	7,852	7,560
68	0.5	2.0	1.0	0.001	10	1	6,168	6,864
69	0.5	2.0	1.0	0.003	1	1	0,060	0,084
70	0.5	2.0	1.0	0.003	3	1	11,452	11,328
71	0.5	2.0	1.0	0.003	6	1	8,148	7,544
72	0.5	2.0	1.0	0.003	10	1	6,188	6,492
73	0.5	2.0	1.0	0.01	1	1	0,084	0,072
74	0.5	2.0	1.0	0.01	3	1	11,188	11,424
75	0.5	2.0	1.0	0.01	6	1	7,888	8,156
76	0.5	2.0	1.0	0.01	10	1	5,980	6,228
77	0.5	2.0	1.0	0.02	1	1	0,084	0,068
78	0.5	2.0	1.0	0.02	3	1	11,268	11,828
79	0.5	2.0	1.0	0.02	6	1	7,820	8,044
80	0.5	2.0	1.0	0.02	10	1	5,752	6,156
81	0.5	2.0	0.5	0.001	1	1	0,216	0,104
82	0.5	2.0	0.5	0.001	3	1	23,147	23,215
83	0.5	2.0	0.5	0.001	6	1	14,379	14,715
84	0.5	2.0	0.5	0.001	10	1	10,380	11,000
85	0.5	2.0	0.5	0.003	1	1	0,240	0,140
86	0.5	2.0	0.5	0.003	3	1	22,675	23,823
87	0.5	2.0	0.5	0.003	6	1	14,151	14,515
88	0.5	2.0	0.5	0.003	10	1	10,248	10,044
89	0.5	2.0	0.5	0.01	1	1	0,220	0,132
90	0.5	2.0	0.5	0.01	3	1	23,015	23,159
91	0.5	2.0	0.5	0.01	6	1	14,303	13,695
92	0.5	2.0	0.5	0.01	10	1	10,728	10,636
93	0.5	2.0	0.5	0.02	1	1	0,168	0,128
94	0.5	2.0	0.5	0.02	3	1	22,159	23,311
95	0.5	2.0	0.5	0.02	6	1	14,891	14,471
96	0.5	2.0	0.5	0.02	10	1	10,608	10,300

B-7- Radar 'In Monitoring Service', mode M1 200F

Comparison between rotation speed of the radar antenna

B7	RLAN 'In Service monitoring Service' (80%)							
	Radars Parameters					Collision probability		
	angle	pri	width	nb puls	mode	Rot. 2	Rot. 1	Rot. 0,5
1	2.0	2.0	0.001	1	1	0,000	0,010	0,040
2	2.0	2.0	0.001	3	1	0,000	0,928	4,252
3	2.0	2.0	0.001	6	1	0,000	2,062	3,904
4	2.0	2.0	0.001	10	1	0,000	2,394	4,164
5	2.0	2.0	0.003	1	1	0,000	0,008	0,016
6	2.0	2.0	0.003	3	1	0,000	1,152	4,472
7	2.0	2.0	0.003	6	1	0,000	2,156	4,464
8	2.0	2.0	0.003	10	1	0,000	2,518	4,372
9	2.0	2.0	0.01	1	1	0,000	0,004	0,012
10	2.0	2.0	0.01	3	1	0,000	1,320	4,904
11	2.0	2.0	0.01	6	1	0,000	1,950	4,556
12	2.0	2.0	0.01	10	1	0,000	2,200	4,408
13	2.0	2.0	0.02	1	1	0,000	0,006	0,036
14	2.0	2.0	0.02	3	1	0,000	1,016	4,380
15	2.0	2.0	0.02	6	1	0,000	2,388	3,816
16	2.0	2.0	0.02	10	1	0,000	2,736	4,232
17	2.0	1.0	0.001	1	1	0,010	0,034	0,068
18	2.0	1.0	0.001	3	1	1,057	4,570	11,284
19	2.0	1.0	0.001	6	1	2,102	4,306	7,852
20	2.0	1.0	0.001	10	1	2,780	4,434	6,168
21	2.0	1.0	0.003	1	1	0,016	0,042	0,060
22	2.0	1.0	0.003	3	1	1,069	4,704	11,452
23	2.0	1.0	0.003	6	1	2,083	4,168	8,148
24	2.0	1.0	0.003	10	1	2,640	4,280	6,188
25	2.0	1.0	0.01	1	1	0,009	0,046	0,084
26	2.0	1.0	0.01	3	1	1,031	4,676	11,188
27	2.0	1.0	0.01	6	1	2,307	4,502	7,888
28	2.0	1.0	0.01	10	1	2,529	4,286	5,980
29	2.0	1.0	0.02	1	1	0,006	0,034	0,084
30	2.0	1.0	0.02	3	1	1,186	4,344	11,268
31	2.0	1.0	0.02	6	1	2,129	4,550	7,820
32	2.0	1.0	0.02	10	1	2,574	4,036	5,752
33	2.0	0.5	0.001	1	1	0,031	0,088	0,216
34	2.0	0.5	0.001	3	1	4,782	11,534	23,147
35	2.0	0.5	0.001	6	1	4,219	7,366	14,379
36	2.0	0.5	0.001	10	1	4,173	6,368	10,380
37	2.0	0.5	0.003	1	1	0,021	0,076	0,240
38	2.0	0.5	0.003	3	1	4,703	11,436	22,675
39	2.0	0.5	0.003	6	1	4,367	7,846	14,151
40	2.0	0.5	0.003	10	1	4,169	6,528	10,248
41	2.0	0.5	0.01	1	1	0,041	0,102	0,220
42	2.0	0.5	0.01	3	1	4,645	11,814	23,015
43	2.0	0.5	0.01	6	1	4,245	7,882	14,303
44	2.0	0.5	0.01	10	1	4,264	6,464	10,728
45	2.0	0.5	0.02	1	1	0,035	0,070	0,168
46	2.0	0.5	0.02	3	1	4,668	11,572	22,159
47	2.0	0.5	0.02	6	1	4,302	7,628	14,891
48	2.0	0.5	0.02	10	1	4,233	6,644	10,608

ANNEX G

Analysis of the co-existence of RLAN systems and radiolocation service systems in the 5 350-5 470 MHz and 5 725-5 850 MHz band and evaluation of DFS as a mitigation technique

1 Introduction

This analysis addresses DFS, as it is currently described in the Recommendation ITU-R M.1652-1, and the ability of this mechanism to adequately prevent the interference of radiolocation services.

The DFS mechanism was originally introduced in Resolution **229 (WRC-03)** as a mitigation method to avoid interference from WLAN/RLAN systems in the bands 5 250-5 350 MHz and 5 470-5 725 MHz to other systems in these bands including radars. In this Resolution **229 (Rev.WRC-12)**, ITU-R is invited to “continue studies on suitable test methods and procedures for the implementation of dynamic frequency selection, taking into account practical experience”. Information on the practical implementation and the experience with DFS can be found in documents within various organizations including ETSI, IEEE and CEPT.

Currently under WRC-15 agenda item 1.1 the bands 5 350-5 470 MHz and the 5 725-5 925 MHz are considered as potential candidate bands for IMT and other terrestrial mobile broadband applications.

In both frequency bands a primary allocation to the Radiolocation service exists.

The existing ship-borne and ground-based radar systems, that are intensively operating in Italy under this allocation in the C-band, need to be considered in the sharing and compatibility studies with terrestrial mobile broadband applications WLAN/RLAN that are undertaken within the scope of Resolution **233 (WRC-12)** in order to protect the relevant assets.

In the second section of this attachment some technical considerations will be reported relying on a set of radars whose unclassified characteristics were already shared into the European unclassified community; then an energetic computation shows how radar performances are heavily degraded if no mitigation technique is considered on the WLAN/RLAN side.

In the third section the DFS technique performances are evaluated versus the unclassified set of radars, then computed and shown in the fourth section.

The overall conclusions are reported in the fifth section and some applicable reference documents are listed in the sixth section.

2 RLAN/WLAN signal power level received by 5 GHz radars

Since for Search & Track radar the key performance indicator is the detection probability and it depends on the target power level compared to the surrounding noise, in this section some numerical evaluations are computed to estimate the level of the additional noise entering the receiving channel and due to the RLAN/WLAN signal.

The numerical computation relies on the technical description of the WLAN/RLAN base stations described in Resolution **229 (WRC-03)**, as well as some quantitative characteristics of a set of C-band radars[detailed in Document 5B/475 Annex 12[18]**]**.

The goal is to check whether or not the extension of civil transmissions in a military bandwidth can hinder the radar performances that are fundamental for the survivability of relevant military assets such as carriers, just to say one.

Starting from the standard radar equation shown in equation (1), it is possible highlight the terms corresponding to the presence of a target and to the way back to the receiver.

$$P_{Rx} = P_{Tx}\, L_{Tx}\, G_{Tx}\, \frac{1}{4\pi\, Rg^2}\, \sigma\, \frac{1}{4\pi\, Rg^2}\, \frac{G_{Rx}\,\lambda^2}{4\pi}\, L_{Rx} \qquad (1)$$

In the equation, the referred terms are the followings:

P_{Rx} is the received power level,

P_{Tx} is the transmitted power level,

L_{Tx} is the power loss in the transmission chain,

G_{Tx} is the transmission antenna gain,

$\frac{1}{4\pi\, Rg^2}$ is the one-way propagation factor,

σ is the target equivalent area,

$\frac{G_{Rx}\,\lambda^2}{4\pi}$ is the receiving antenna equivalent area,

L_{Rx} is the power loss in the receiving chain.

Therefore the power level of the signal received by another antenna after a one-way path is described in equation (2):

$$P_{Rx} = P_{Tx}\, L_{Tx}\, G_{Tx}\, \frac{1}{4\pi\, Rg^2}\, \frac{G_{Rx}\,\lambda^2}{4\pi}\, L_{Rx} \qquad (2)$$

If the receiver is a radar, then P_{Rx} has to be compared to $P_N = K\, B\, F\, T_0$ to estimate the radar performances degradation, where:

K = $1.3806488 \times 10^{-23}$ J/K is the Boltzmann constant,

B is the radar bandwidth,

F is the receiver chain noise factor,

18 [Annex 12 to Working Party 5B Chairman’s Report, ‘preliminary draft revision of Recommendation ITU-R M.1638-1’, ‘Characteristics of and protection criteria for sharing studies for radiolocation (except ground based meteorological radars) and, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz’, 9 January 2014.]

T_0 is the room temperature.

Looking at the radars characteristics[in Document 5B/475 **Annex 12]**, the minimum detectable signal (MDS) values are reported for each radar. Starting from the specified values and going through some considerations, it is possible to get to the maximum signal power that enters the radar receiving chain without any performance degradation:

a) a basic target reflectivity fluctuation model (Swerling 0) is assumed, therefore 12 dB have to subtracted from the MDS to get the power noise level P_N ;

b) to avoid any radar performance degradations any other signals must be 10 dB lower than the noise level.

According to Resolution **229 (WRC-03)** the maximum e.i.r.p. for RLAN base stations is 50 mW/MHz; considering radar bandwidths fully overlapped by a base station channel, 20 MHz minimum large, this value has to be multiplied by the radar bandwidth to get to the effective e.i.r.p. to use in equation (2).

Assuming P_{Rx} equal to the MDS minus 22 dB, it's possible to compute the minimum distances between a WLAN/RLAN base station and the radars[in Document 5B/475 **Annex 12].**

TABLE 1

		radar 1	radar 2	radar 3	radar 4	radar 5	radar 6	radar 7	radar 8	radar 9	radar 10	radar 11	radar 12
input	Radar bandwidth [MHz]	4	5	3,6	3,6	8,33	1,5	5	62	4	4	6	1,55
input	RLAN EIRP [dBW]	-7,0	-6,0	-7,4	-7,4	-3,8	-11,2	-6,0	0,0	-7,0	-7,0	-5,2	-11,1
input	RADAR G_{Rx} [dB]	38,3	54	47	45,9	42	28	30	26	30	33	16	25
input	RADAR L_{Rx} [dB]	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
input	MDS [dBw]	-105	-107	-100	-117	-100	-107	-94	-90	-110	-115	-111	-116
output	Max Ext. Signal NO Interference [dBW]	-127	-129	-122	-139	-122	-129	-116	-112	-132	-137	-133	-138
output	Minimum range NO interference [Km]	266	2285	387	2413	331	63	32	26	182	458	50	127

		radar 13	radar 14	radar 15	radar 16	radar 17	radar 18	radar 19	radar 20	radar 21	radar 22	radar 23
input	Radar bandwidth [MHz]	0,8	470	1,8	5	6	2	1,25	0,4	0,8	5	5
input	RLAN EIRP [dBW]	-14,0	0,0	-10,5	-6,0	-5,2	-10,0	-12,0	-17,0	-14,0	-6,0	-6,0
input	RADAR G_{Rx} [dB]	43	40	42	34	37,5	38,5	44,5	40	44,5	35	31,5
input	RADAR L_{Rx} [dB]	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
input	MDS [dBw]	-107	-100	-112	-109	-106	-123	-109	-115	-120	-103	-108
output	Max Ext. Signal NO Interference [dBW]	-129	-122	-134	-131	-128	-145	-131	-137	-142	-125	-130
output	Minimum range NO interference [Km]	258	407	613	288	334	1531	482	324	1368	162	192

As an energetic only computation, the numbers in Table 1 Do not consider the Earth surface curvature. For instance, accounting for a geometry with a base station and a radar at 100 m and 40 m respectively above the sea level, their maximum radio visibility is equal to some 67 km.

Therefore the 23 radars above considered are almost always disturbed by civil communication as soon as they cross the WLAN/RLAN radio horizon.

It is worth noting that here the considered scenario includes a single emitting base station. It is very likely to see real scenarios with many base stations emitting within the maximum radar radio visibility.

As a result of the above computation, it is possible to infer that the most of the radars are strongly affected by interference because of civil communication in the C-band.

3 Dynamic Frequency Selection to mitigate interference to 5 GHz radars

DFS was initially designed to mitigate the interference effects due to co-existence of WLAN/RLAN transmissions and radar activities for meteorological applications in the bandwidth 5 600-5 650 MHz. It is worth noting that meteorological radars don't rely on any frequency diversity and don't have demanding requirements on track formation ranges as the military radars do.

According to Ref.2, DFS is based on the ability in the WLAN/RLAN of performing some tasks:

a) Channel Availability Check (CAC): any channels have to be sensed before their utilization,

b) In-Service Monitoring (ISM): all occupied channels have to be **continuously** checked during WAS transmissions,

c) Channel Release (CR): upon radar signal detection in any occupied channels, these channels have to be released by the WLAN/RLAN.

Therefore the mitigation performance achieved by the DFS depends on the following parameters:

a) DFS detection threshold: –62 dBm for devices with a maximum e.i.r.p. of < 200 mW and –64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W averaged over 1 μs,

b) Channel availability check time: 60 s,

c) Non-occupancy period: 30 min,

d) Channel move time: < 10 s.

where:

a) DFS detection threshold is the minimum power level the radar signal needs to have in the WLAN/RLAN receiver to prevent from channel occupancy or to stop transmitting;

b) Channel availability check time is the length of the CAC before channel occupation;

c) Non-occupancy period is how much the WLAN/RLAN will consider a channel already occupied and useless for communications;

d) Channel move time is defined as the period needed by a WLAN/RLAN to cease all transmissions on operating channel upon detection of a radar signal in that channel.

Table 2 shows the required detection performances during the CAC and the ISM tasks:

TABLE 2

Parameter	Detection Probability (P_d)	
	Channels whose nominal bandwidth falls partly or completely within the 5 600 MHz to 5 650 MHz band	Other channels
CAC, Off-Channel CAC	99,99 %	60 %
In-Service Monitoring	60 %	60 %

All the WLAN/RLAN HW producers have to comply with any test signal bursts in Table 3:

TABLE 3

Radar test signal # (see notes 1 to 3)	Pulse width W [µs]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,5	5	200	1 000	1	10 (see note 6)
2	0,5	15	200	1 600	1	15 (see note 6)
3	0,5	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,5	2	300	400	2/3	10 (see note 6)
6	0,5	2	400	1 200	2/3	15 (see note 6)

For instance when a radar emits a burst of a minimum of 20 pulses at the same frequency having a PRF in the range 2 000 ÷ 3 000 Hz, with a duty in the range 4% ÷ 12% and it reaches the WLAN/RLAN receiver with a power not smaller than –62 dBm, then a CAC task on channel overlapped with the radar bandwidth shall detect the radar presence with a 99.99% probability and then prevent the WLAN/RLAN from using this channel for 30 minutes at least.

If instead a WLAN/RLAN communication is already established on a channel and a radar starts transmitting in a frequency portion included in this channel with the same waveform above, then the ISM shall detect instantaneously the radar presence and release the channel in less than 10 seconds.

4 DFS performances versus surveyed radars

In this section it is necessary to evaluate whether the DFS can really prevent the radars detailed in Ref. 2 from being disturbed.

One side a radar sensitivity function (RSF) can be defined as the ratio between the received WLAN/RLAN signal power in the radar bandwidth and its MSPNoDeg as defined in section 2, while on the other side a WLAN/RLAN sensitivity function (WSF) can be defined as the ratio between the radar signal in RLAN receiving chain and the DFS Detection Threshold.

$$RSF = P_{TxRLAN}\ L_{TxRLAN}\ G_{TxRLAN}\ \frac{1}{4\pi\ Rg^2}\ \frac{G_{RxRad}\ \lambda^2}{4\pi}\ L_{RxRad}\ \frac{1}{MSPNoDeg}$$

$$WSF = P_{TxRad}\ L_{TxRad}\ G_{TxRad}\ \frac{1}{4\pi\ Rg^2}\ \frac{G_{RxRLAN}\ \lambda^2}{4\pi}\ L_{RxRLAN}\ \frac{1}{DFS\_DTh}$$

If WSF is bigger than RSF, then it can be taken for granted that every time a radar is disturbed by a WLAN/RLAN signal (RSF > 1), it happens that the DFS threshold is passed (also WSF > 1) and the radar presence is detected with the probabilities stated in Table 3.

Looking at equation (2), the following assumptions are useful:

Radar L_{Rx} = 2.5 dB;

Radar $G_{Rx} = G_{Tx}$;

WLAN/RLAN L_{Rx} = 3 dB;

WLAN/RLAN $G_{Rx} = G_{Tx}$ = 21 dB, as described in Ref.4.

It is worth noting that the ratio of RSF with WSF is fully independent of the distance as well as the geometry between radars and WLAN/RLAN base station.

TABLE 4

	radar 1	radar 2	radar 3	radar 4	radar 5	radar 6	radar 7	radar 8	radar 9	radar 10	radar 11	radar 12
RADAR P_{TX} [dBW]	33,0	64,5	60,8	60,0	52,2	55,6	54,5	30,0	20,0	49,5	26,0	44,0
RADAR BW [MHz]	4	5	3,6	3,6	8,33	1,5	5	62	4	4	6	1,55
RADAR L_{RX} [dB]	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
RADAR MDS [dBW]	-105	-107	-100	-117	-100	-107	-94	-90	-110	-115	-111	-116
RADAR Th [dBW]	-127	-129	-122	-139	-122	-129	-116	-112	-132	-137	-133	-138
RLAN L_{RX} [dB]	3	3	3	3	3	3	3	3	3	3	3	3
RLAN EIRP [dBW]	-7,0	-7,0	-7,4	-7,4	-7,0	-11,2	-7,0	-7,0	-7,0	-7,0	-7,0	-11,1
RLAN G_{XX} [dB]	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0
RLAN P_{TX} [dBW]	-28,0	-28,0	-28,4	-28,4	-28,0	-32,2	-28,0	-28,0	-28,0	-28,0	-28,0	-32,1
RLAN Th [dBW]	-92	-94	-92	-92	-94	-92	-94	-94	-92	-92	-94	-92
S(RLAN) - S(RADAR) [dB]	25,5	57,0	58,7	40,9	51,7	50,3	60,0	39,5	7,5	32,0	14,5	29,6

	radar 13	radar 14	radar 15	radar 16	radar 17	radar 18	radar 19	radar 20	radar 21	radar 22	radar 23
RADAR P_{TX} [dBW]	58,8	47,0	60,0	23,0	48,5	38,8	54,0	55,4	54,8	40,8	48,5
RADAR BW [MHz]	0,8	470	1,8	5	6	2	1,25	0,4	0,8	5	5
RADAR L_{RX} [dB]	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
RADAR MDS [dBW]	-107	-100	-112	-109	-106	-123	-109	-115	-120	-103	-108
RADAR Th [dBW]	-129	-122	-134	-131	-128	-145	-131	-137	-142	-125	-130
RLAN L_{RX} [dB]	3	3	3	3	3	3	3	3	3	3	3
RLAN EIRP [dBW]	-14,0	-7,0	-10,5	-7,0	-7,0	-10,0	-12,0	-17,0	-14,0	-7,0	-7,0
RLAN G_{XX} [dB]	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0	21,0
RLAN P_{TX} [dBW]	-35,0	-28,0	-31,5	-28,0	-28,0	-31,0	-33,0	-38,0	-35,0	-28,0	-28,0
RLAN Th [dBW]	-92	-94	-92	-94	-94	-92	-92	-92	-92	-94	-94
S(RLAN) - S(RADAR) [dB]	56,2	46,5	49,0	13,5	41,9	16,3	47,5	47,9	39,3	37,3	39,9

Table 4 shows how WSF is always bigger than RSF for all the radars considered in Ref.2, and lead to the conclusion that WLAN/RLAN e.i.r.p. and sensitivity seem to be adequate to the CAC purpose.

Being the maximum power emitted by WLAN/RLAN specified by the e.i.r.p., it's important to note that in the comparison WSF and RSF, a smaller RLAN antenna gain results in a smaller ratio. For instance there is a meaningful difference if in the exercise with the radar number nine the e.i.r.p. equal to –7 dBW is achieved transmitting –28 dBw throughout an antenna having a gain equal to 21 dB or transmitting –7 dBW throughout an isotropic antenna. Indeed in the second case it cannot be taken for granted that the WLAN/RLAN stops the communication when the sensor is disturbed.

In order to evaluate the ISM performance it makes sense to consider a scenario when a frequency hopping radar status is switched from "Peaceful time" to "War time". Indeed in this case a much larger set of frequencies are enabled to achieve much better radar performance and higher resilience against intentional interference.

Soon after the switch any operating RLAN devices have to detect the presence of radar signals, but the DFS specification seems to not specify the maximum allowed latency before the detection of the radar signal upon t/he start of the radar transmission.

Indeed in the Rec. ITU-R M.1652-1 it is currently stated that "...the radar detection function continuously searches for radar signal ..." but doesn't specify any maximum allotted time between a radar transmission and his detection by the DFS. In the same document "channel move time is defined as the period needed by a WAS to cease all transmissions on operating channel upon detection" of a radar signal in that channel. Therefore the DFS reaction time, that's the time interval from the beginning of a radar transmission and the release of the channel, is the sum of the maximum allotted time above and the channel move time.

A delay in channel release could mean a delay in target detection, track formation and weapon fire. In case of sea skimmer approaching at 500 m/s, a delay of 5 sec before in-service monitoring summed with 10 sec to shutdown the communication can lead to 7.5 km of reduced track formation range with respect to the corresponding performances in case of no WLAN/RLAN being transmitting.

Assuming a radar rotating at 1 sec, just a similar delay can be required by a mitigation technique that needs to be compliant with current radar requirements.

Given the classification level of radar threats, a quantitative analysis of the radar performances degradation in presence of WLAN/RLAN signal cannot be divulgated.

5 Conclusions

Numerical evaluations, fed by WLAN/RLAN specifications and a set of acknowledged sensors characteristics, have highlighted the importance of a mitigation technique to prevent radars from being disturbed by WLAN/RLAN base stations operating in 5 GHz band.

The DFS mitigation technique needs to be revised to have a reaction time, computed as radar signal detection time plus “channel move time”, comparable with the radar antenna rotation time to not hinder the target discovery when radars are switched from peaceful-time mode to war-time mode.

6 Reference documents

(1) Resolution 229 (COM5/16) (WRC-03): Use of the bands 5 150-5 250, 5 250-5 350 MHz and 5 470-5 725 MHz by the mobile service for the implementation of wireless access systems including radio local area networks;

(2) Document 5B/475-E, 9 January 2014: **Annex 12** – Preliminary draft revision of Recommendation ITU.R M.1638-1 – Characteristics of and protection criteria for sharing studies for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz;

(3) ETSI EN 301 893 V1.7.1 (2012-06): Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of Article 3.2 of the R&TTE Directive;

(4) WLAN Radio Frequency Design Considerations (http://www.cisco.com/c/en/us/support/docs/wireless-mobility/wireless-lan-wlan/23231-powervalues-23231.html).

ANNEX H

Compatibility studies between RLAN systems and shipborne radiodetermination systems in the 5 350-5 470 MHz frequency range

1 Introduction

In order to support requirements for non-IMT broadband nomadic wireless access systems including RLAN, sharing feasibility studies have been called for in the frequency range 5 350-5 470 MHz.

The frequency range 5 350-5 470 MHz is comprised of two frequency bands: 5 350-5 460 MHz and 5 460-5 470 MHz. The 5 350-5 460 MHz band is allocated to the Earth exploration-satellite (active), radiolocation, aeronautical radionavigation, and space research (active) services. The 5 460-5 470 MHz frequency band is allocated to the Earth exploration-satellite (active), radiolocation, radionavigation, and space research (active) services.

This Report provides results of a study on the feasibility of RLAN systems operating in the 5 350-5 470 MHz frequency bands with incumbent primary shipborne radiodetermination systems.

2 Background

This analysis uses DFS procedures and modelling characteristics as specified below. It includes an analysis of DFS with a threshold of -64 dBm as a potential mitigation technique. The analysis includes a combined channel detection, channel close time and channel move time of 250 milliseconds.

In particular, this study tested the current DFS detection threshold (–64 dBm) to detect shipborne radiodetermination systems operating in the 5 350-5 470 MHz bands while not exceeding the shipborne receiver protection threshold based on an I/N = –6 dB (Rec. ITU-R M.1638-1).

3 Technical characteristics

3.1 Technical characteristics of shipborne radiodetermination systems

The technical characteristics for the shipborne radiodetermination systems considered in this analysis are shown in Table 5 (information taken from Recommendation ITU-R M.1638).

TABLE 5

Radar characteristics

Characteristics	Radar 10	Radar 7 (Q)	Radar 12	Radar 20
Function	Radionavigation, Surface and Air Search	Multifunction Surface and air search	Radiolocation	Multi-function
Tuning range (MHz)*	5 250–5 875 (5400)	5 450-5 825 (5450)	5 400-5 900 (5410)	5 400–5 700 (5410)
Transmitter peak power into antenna (kilowatts)	90	285	25	350
Modulation	Bi-phase Barker Code	unmodulated Pulse	Coded Pulse	Un-modulated Pulse
Pulse Width (μs)	0.30-14.0	0.1/0.25/1.0	0.32	2
Pulse repetition rate (pps)	4 000-5 000	2 400/1 200/ 750	8 000	250-500
RF emission bandwidth –3 dB –20 dB	 12	5.0/4.0/1.2 16.5/12.5/7.0	1.55 20	0.4 2.88
Antenna main beam gain (dBi)	33	30	25	40
Antenna polarization	Horizontal	Horizontal	Vertical	Horizontal
Horizontal beamwidth (deg)	1.8	1.6	2	1.7
Antenna horizontal scan rate (deg/sec)	6 - 60	90	N/A	6
Antenna horizontal scan type	360	240° sector	360	360
Vertical beamwidth (deg)	7	28.0	26	1.7
Antenna vertical scan type	Fixed at 3.5° wrt horizontal	Fixed at 14° wrt horizontal	Fixed at 13° wrt horizontal	Fixed at 0.85° wrt horizontal
Antenna Gain Pattern	ITU-R M.1851	ITU-R M.1851	ITU-R M.1851	ITU-R M.1851
Antenna height (m)	45	40	30	10
Antenna motion	Scanning	Scanning	Scanning	Scanning
Receiver Intermediate Frequency 3 dB bandwidth (MHz)	11	1.2, 10 (1.2)	7	0.5
Receiver noise figure (dB)	3	10	4	2
Noise Power (dBm)	-100.6	-103.2, -94.0	-101.5	-115.0
Receiver Protection Threshold (dBm) Based on an I/N =-6 dB	-106.6	-109.2, -100.0	-107.5	-121.0
* Values in parenthesis are the ones used in this study				

A 2 dB insertion loss for the receivers is included in the analysis.

As shown in Table 1, Radar 10, Radar 7, and Radar 12 all employ short (sub-microsecond) pulse widths. Maritime radiodetermination systems employ narrow pulse widths to improve detection capabilities in cluttered environments. Using narrow pulses improves the range resolution and reduces the radial dimension of the illuminated clutter. Noting that various domestic regulations already require DFS detection to 0.5 µsec, the ability of DFS to detect sub-microsecond pulses (0.1 µsec to 0.5 µsec) is not known at this time.

3.1.1 Description of Recommendation ITU-R M.1851 antenna pattern

Since the antennas in this study use a "fan" beam in which the vertical beamwidth is much broader than the horizontal, they are modelled using the Recommendation ITU-R M.1851 "cosine" pattern because it is a function of beamwidth. In the analysis the beamwidth used for the Rec. ITU-R M.1851 pattern is calculated for each link as the half power beamwidth in the direction of the RLAN device. The following two tables are taken from Rec. ITU-R M.1851 and describe the pattern used, which is plotted in Figure 2.

TABLE 6

Rec. ITU-R M.1851 cosine directivity pattern

Relative shape of field distribution f(x) where −1 ≤ x ≤ 1	**Directivity pattern F(μ)**	**θ3 half power beam-width (degrees)**	**μ as a function of θ3**	**First side-lobe level below main lobe peak (dB)**	**Proposed mask floor level (dB)**
COS(π*x/2)	$\frac{\pi}{2}\left[\frac{\cos(\mu)}{\left(\frac{\pi}{2}\right)^2-\mu^2}\right]$	$68.8\left(\frac{\lambda}{l}\right)$	$\frac{\pi\cdot 68.8\cdot\sin(\theta)}{\theta_3}$	−23	−50

TABLE 7

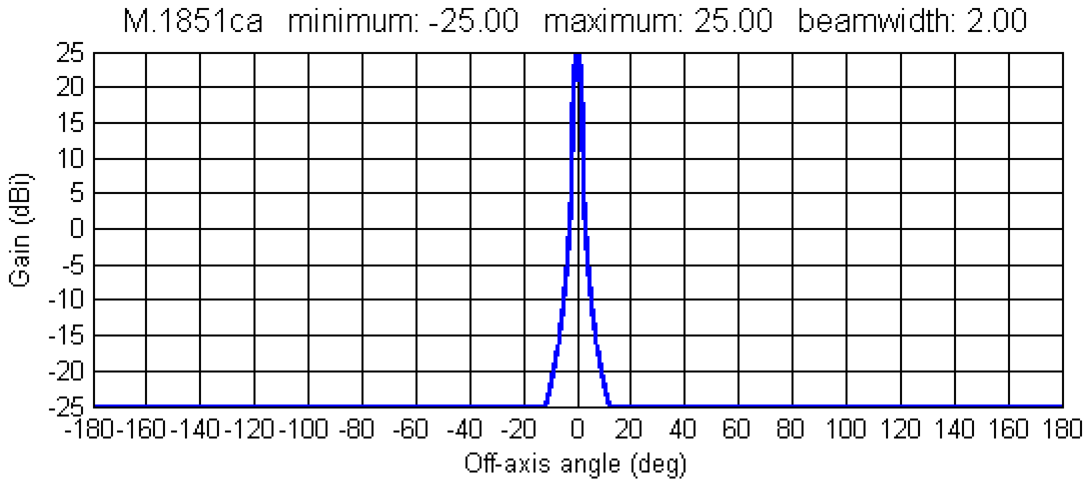
Rec. ITU-R M.1851 cosine mask equation beyond pattern break point

Pattern type	**Mask equation beyond pattern break point where mask departs from theoretical pattern (dB)**	**Peak pattern break point where mask departs from theoretical pattern (dB)**	**Average pattern break point where mask departs from theoretical pattern (dB)**	**Constant added to the peak pattern to convert it to average mask (dB)**
COS	$-17.51\cdot\ln\left(2.33\cdot\frac{\lvert\theta\rvert}{\theta_3}\right)$	−14.4	−20.6	−4.32

3.1.2 Antenna patterns used in this study

FIGURE 2

Sample antenna pattern (horizontal beamwidth of Radar 12)



3.2 Radar deployments

The analysis considers shipborne scanning radars.

3.2.1 Shipborne scanning radars

In this study, the shipborne scanning radar will be located at set increments from the distribution centre with distance increments of 70, 50, 30, 10, and 1 km.[19] The radar uses a scanning antenna beam where the beam begins at azimuth angles of 0°. For Radars 10, 12, and 20, the antenna moves in the clockwise direction in 1° increments through an angle of 720°. For Radar 7, the antenna moves in 1° increments back and forth once through a 240° sector centred at the centre of the RLAN distribution. The antenna elevation angles are as shown in Table 1 (Antenna vertical scan type).

3.3 Mobile system parameters and deployment

The RLAN devices will be randomly distributed over three regions: urban, suburban, and rural. The three regions exist within concentric circles as shown in Figure 3.

[19] Results were shown to be independent of azimuth of radar with respect to the center, as expected.

FIGURE 3

RLAN device deployment regions

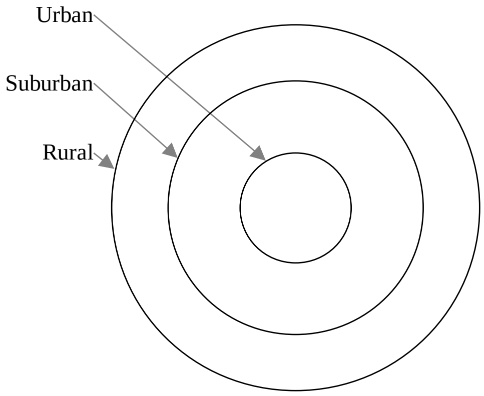


Table 8 provides the radius of each RLAN deployment zone.

TABLE 8

Deployment zones

RLAN Deployment Region	Radius from the centre (km)
Urban	0 to 5
Suburban	5 to 15
Rural	15 to 30

The population used for the baseline is 5.25 million people. Table 9 provides the population distribution within each zone in the RLAN device environment.

TABLE 9

Population Zones

Total Population	Population split	Percent	Population in Zone
5 250 000	Urban	30%	1 575 000
	Suburban	50%	2 625 000
	Rural	20%	1 050 000

Number of On-tune, Active RLAN devices

The following methodology was used to determine the number of on-tune active RLAN devices.

Step 1: Determine base population size by zone

Step 2: Apply a Busy Hour factor to determine the base population by zone

Step 3: Apply Market Factor (percent of users with devices) by zone

Step 4: Apply System Factor (number of cells) by zone

Step 5: Apply Activity Factor (percent of cell operating) by zone

Step 6: Apply Bandwidth Factor (percent of devices on-tune based on bandwidth distribution model)

Using the six step methodology the number on-tune active RLAN devices per 20 MHz are forecasted in Table 10. Appendix A goes into more detail to determine the number of on-tune RLAN devices used in this study as a function of radar centre frequency and bandwidth.

TABLE 10

RLAN On-tune, Active Devices

	Population	**Step 2 Busy Hour Factor**	**Busy Hour Population**	**Step 3 † Market**	**Step 4 † System**	**Step 5 † Activity**	**Step 6 * Bandwidth**
Urban	1 575 000	71%	1 118 250	894 600	62 622	15 656	
Suburban	2 625 000	64%	1 680 000	1 344 000	94 080	23 520	
Rural	1 050 000	47%	493 500	246 750	49 350	4 935	
Total						44 111	5 186 Per 20 MHz

The market, system, and activity factors used in the calculations are shown in Table 11.

TABLE 11

Market/System/Activity Factors

†	**Market**	**System**	**Activity**
Urban	80%	7%	25%
Suburban	80%	7%	25%
Rural	50%	20%	10%

The distribution of channel bandwidths for the number active RLAN devices in a 20 MHz bandwidth is shown in Table 12.

TABLE 12

Distribution of RLAN Channel Bandwidths

Start Channel	*	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
5 150 MHz	Percent	10%	25%	50%	15%
End Channel	Devices	4 411	11 028	22 056	6 616
5 850 MHz	Channels	35	17	8	4
	On-tune	126	649	2 757	1 654

Technical parameters

The baseline will include RLAN devices employing omni-directional antennas. For each time step the RLAN device power, operating bandwidth, and height will be randomly determined using a uniform random variable.

The RLAN device equivalent isotropically radiated power (e.i.r.p.) level distribution for the baseline is shown in Table 13.

TABLE 13

RLAN power distribution[20]

RLAN e.i.r.p. Level	200 mW (Omni-Directional)	80 mW (Omni-Directional)	50 mW (Omni-Directional)	25 mW (Omni-Directional)
RLAN device percentage (Indoor operation)	18%	26%	14%	37%
RLAN device percentage (Outdoor operation)	0.9%	1.3%	0.8%	2%

This study will consider a limit on the e.i.r.p. of 200 mW to determine sharing feasibility. If higher power levels are submitted, additional studies will be required.

The RLAN device transmitter bandwidth distribution for the baseline is shown in Table 14.

TABLE 14

Bandwidth distribution

RLAN Transmitter Bandwidth	20 MHz	40 MHz	80 MHz	160 MHz
RLAN Device Percentage	10 %	25 %	50 %	15 %

The RLAN antenna pattern is omni-directional. A 3 dB polarization mismatch loss was included as well as a random total additional loss of 0-4 dB to represent enclosure loss, body loss, etc.

Table 15 provides the distribution of RLAN device antenna heights for each RLAN deployment zone.

20 The e.i.r.p. levels and percentages are derived from: 1) predictions of shipped devices for various devices classes; 2) expected e.i.r.p. of the device classes; 3) matching the percentages from the sum of the rows in device distribution and 4) traffic mix in a Basic Service Set between Access Point and client.

TABLE 15

Distribution of RLAN device antenna heights

RLAN deployment zone	Antenna height (meters)
Urban	1.5 to 28.5 (3 meter increments)
Suburban	1.5, 4.5
Rural	1.5, 4.5

For omni-directional RLANs, the antenna heights are randomly selected using a uniform probability distribution from the set of floor heights at 3 meter steps specified in Table for the Urban, Suburban and Rural zones.

The analysis will examine sharing in a scenario comprised of 95 percent of the RLAN devices modelled with building attenuation and 5 percent without building attenuation.

4 Analysis

4.1 Assumptions:

a) **RLAN totals, densities and distribution**: The RLAN characteristics used in this study are the latest available or projected characteristics. For example, this study uses a total RLAN population of 44 111 on-tune and active devices, which results in 5 186 active devices for different receiver bandwidth.

b) **Propagation modelling**: The propagation model utilized was Recommendation ITU-R P.452-15 where the RLAN distribution centre will be located near Los Angeles, CA.[21, 22] The percentage of time will be set at 50 percent, and the surface refractivity will be set at 330. For cases where the distance between emitter and receiver is less than 1 km, free space loss will be used.

c) **Building loss:** This analysis also includes an additional reduction for indoor RLANs due to building loss. This additional loss is a Gaussian random variable with mean 17 dB and standard deviation 7 dB. Any values that would fall below 0 dB are set to 1 dB. This can be modeled with the following Matlab code:

building_att_dB= Max(0,17+7*randn) (1)

d) **Clutter loss:** This study also includes the clutter loss of Recommendation ITU-R P.452-15 Equations 57 and 57a to account for the effects of ground cover in cases where the obstacles could typically intercede on the interfering signal path. For emitters in the rural area, the “High crop fields” clutter category of Table 4 of that Recommendation is utilized. For the suburban area, “Suburban” is utilized and for the urban area “Urban” is utilized. These clutter losses are shown in Table 12, and they are applied only in cases where the elevation angle from the RLAN to the radar is less than the associated maximum elevation angle specified in Table 13. The latter maximum elevation angles were computed using the clutter heights and distances specified in Table 4 of Recommendation ITU-R P.452, and negative elevation angles were truncated at 0° because they will not occur in this analysis. No clutter loss is assumed when the

[21] Rec. ITU-R P.452-15 was approved for adoption by correspondence in June 2013.

[22] 33.976753° – 118.108672°.

elevation angle of the interfering signal path exceeds the applicable maximum elevation angle shown in Table 13.

TABLE 12

Clutter losses values used in study

<table>
<tr><th rowspan="2">Ht (m)</th><th colspan="3">Clutter Loss (dB)</th></tr>
<tr><th>High crop fields</th><th>Suburban</th><th>Urban</th></tr>
<tr><td>1.5</td><td>17.3</td><td>19.6</td><td>19.7</td></tr>
<tr><td>4.5</td><td>0[23]</td><td>16.0</td><td>19.6</td></tr>
<tr><td>7.5</td><td colspan="2" rowspan="8">These cases do not occur given the assumed heights of RLAN devices (see Table)</td><td>18.8</td></tr>
<tr><td>10.5</td><td>15.1</td></tr>
<tr><td>13.5</td><td>6.8</td></tr>
<tr><td>16.5</td><td>1.3</td></tr>
<tr><td>19.5</td><td>0</td></tr>
<tr><td>22.5</td><td>0</td></tr>
<tr><td>25.5</td><td>0[23]</td></tr>
<tr><td>28.5</td><td>0</td></tr>
</table>

TABLE 13

Elevation angles below which clutter losses could typically occur

<table>
<tr><th rowspan="2">Ht (m)</th><th colspan="3">Maximum Elevation Angle (degrees)</th></tr>
<tr><th>High crop fields</th><th>Suburban</th><th>Urban</th></tr>
<tr><td>1.5</td><td>1.4</td><td>16.7</td><td>42.8</td></tr>
<tr><td>4.5</td><td>0.0</td><td>10.2</td><td>37.8</td></tr>
<tr><td>7.5</td><td colspan="2" rowspan="8">These cases do not occur given the assumed heights of RLAN devices (see Table)</td><td>32.0</td></tr>
<tr><td>10.5</td><td>25.4</td></tr>
<tr><td>13.5</td><td>18.0</td></tr>
<tr><td>16.5</td><td>9.9</td></tr>
<tr><td>19.5</td><td>1.4</td></tr>
<tr><td>22.5</td><td>0.0</td></tr>
<tr><td>25.5</td><td>0.0</td></tr>
<tr><td>28.5</td><td>0.0</td></tr>
</table>

a) **RLAN channel bandwidths:** This study uses RLAN channel bandwidths of 20, 40, 80 and 160 MHz.

b) **RLAN DFS detection threshold bandwidths:** This study uses a DFS detection threshold of -64 dBm and DFS bandwidth of 20 MHz independent of the RLAN channel bandwidth. If the radar power into an RLAN DFS detector exceeds the detection threshold, that device is turned off for the remainder of the simulation.

[23] Any values that would fall below 0 dB are set to 0 dB.

c) **Probability of Coincidence (POC) and pulse widths:** A range of values was considered for POC given that determination of a value is specific to equipment implementation and a value that can be addressed by operational changes to the RLAN listening periods. The expected POC is highly dependent on the pulse repetition rate (PRR) of the radar system and even at the lowest values for radars in this band is expected to be near a POC of 1 for all radars.

4.2 Methodology:

4.2.1 DFS detection model description

DFS is a mechanism that dynamically detects signals from other systems and avoids co-channel operation with these systems. When the DFS detection threshold is exceeded for a particular RLAN, the model generates a uniform random number between 0 and 1 and compares it to the probability of a radar pulse overlapping with an RLAN burst rest "listening" period, which in this model is referred to as the probability of coincidence (POC). The DFS detection occurs when coincidence has been declared and when the received power from the radar in the RLAN detector exceeds the detection threshold. The POC is based on the packet length and the timing of the RLAN transmissions. This received signal level from the radar at the input of the RLAN receiver is evaluated by using Equation 2.

$$I^{RLAN} = P_{RADAR} + G_{RADAR} + G_{RLAN} - L_{Radar} - L_P - L_C - L_A - FDR \qquad (2)$$

Where:

I^{RLAN} = Received interference power at the output of the RLAN antenna (dBm)

P_{RADAR} = Peak power of the radar (dBm)

G_{RADAR} = Antenna gain of the radar in direction of the RLAN (dBi)

G_{RLAN} = Antenna gain of the RLAN in direction of the radar (dBi)

L_{RADAR} = radar transmit insertion loss (dB)

L_P = Propagation loss (dB)

L_C = Clutter loss due to ground cover (dB)

L_A = Additional loss due to building and non-specific terrain losses (dB)

FDR = Frequency dependent rejection (dB)

The FDR used is the following:

$$FDR = \max\left(0,\ 20\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \qquad (3)$$

Where:

B_{tx} = Bandwidth of the radar transmitter

B_{rx} = Bandwidth of the RLAN DFS receiver

4.2.2 Analysis model description

Equation 2 is calculated for each RLAN in the distribution. The value obtained is then compared to the DFS detection threshold under investigation. Any RLAN for which the threshold has been exceeded will begin to move to another channel, and thus is not considered (for the remainder of the simulation) in the calculation of interference to the radar, as given by Equation 4.

$$I^{RADAR} = P_{RLAN} + G_{RLAN} + G_{RADAR} - L_{RADAR} - L_P - L_C - L_A - FDR \qquad (4)$$

Where:

I^{RADAR} = Received interference power at the input of the radar receiver (dBm)
P_{RLAN} = Power of the RLAN (dBm)
G_{RLAN} = Antenna gain of the RLAN in the direction of the radar (dBi)
G_{RADAR} = Antenna gain of the radar in the direction of the RLAN (dBi)
L_{RADAR} = Radar receiver insertion loss (dB)
L_P = Radiowave Propagation loss (dB)
L_C = Clutter loss due to ground cover (dB)
L_A = Additional loss due to building and non-specific terrain losses (dB)
FDR = Frequency dependent rejection (dB)

Using Equation 4, the values are calculated for each RLAN being considered in the simulation that has not detected energy from the radar in excess of the DFS detection threshold. These values are then used in the calculation of the aggregate interference to the radar by the RLANs using Equation 5.

$$I^{AGG} = 10\log[\sum_{j=1}^{N} I_j^{Radar}] + 30 \qquad (5)$$

Where:

I^{AGG} = Aggregate interference to the radar from the RLAN devices (dBm)
N = Number of RLANs remaining in the simulation
I^{RADAR} = Interference into the radar from an individual RLAN device (watts)

It is necessary to convert the interference power calculated in Equation 4 from dBm to watts before calculating the aggregate interference seen by the radar using Equation 5.

The propagation model used in the analysis was Recommendation ITU-R P.452-15.

In addition to the propagation loss, this analysis includes an additional reduction due to building and non-specific terrain losses.

In this analysis, the RLAN transmitters will be operating co-frequency with the radar receivers and the FDR is computed using Equation 6.

$$FDR = \max\left(0, 10\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \qquad (6)$$

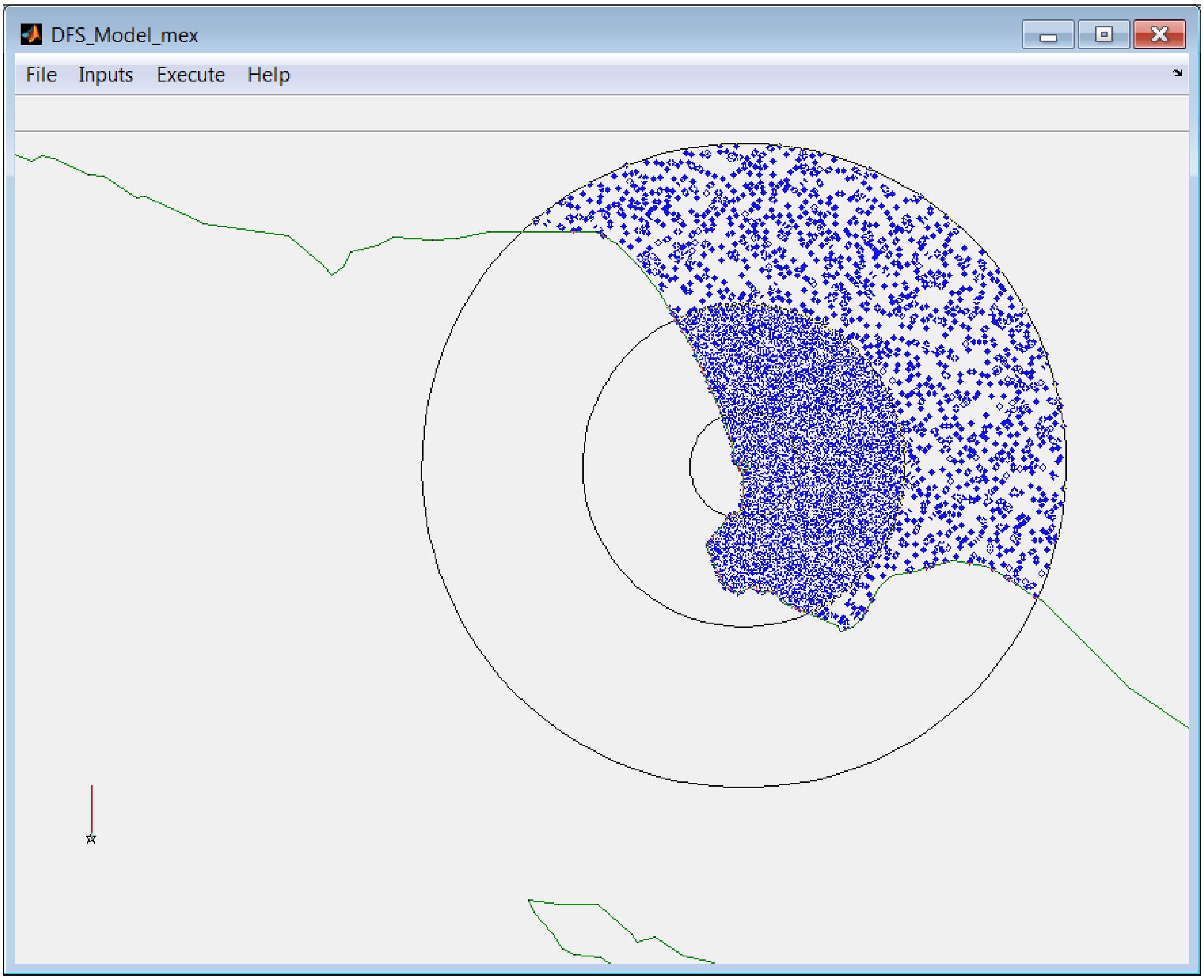
Where:

B_{tx} = Bandwidth of the RLAN transmitter

B_{rx} = Bandwidth of the radar receiver

FIGURE 4

RLAN emitter distribution used in this study



Since a worst-case study involving shipborne radars would move the radar close to the shore, this study modifies the RLAN distribution by moving the centre of the distribution 100 metres inland. Any emitters that would be in the ocean are removed. The density of the remaining emitter distribution is increased proportionately so that the total number of emitters is close to 5 186.[24]

5 Results

The following two figures show samples of the outputs produced in this study. The first graph in Figure 6 shows the number of RLANs that are turned off as a result of DFS detection process (DFS threshold of -64 dB) during the simulation. The second and third graph show the aggregate received power from the RLANs at the output of the radar receive antenna as a function of simulation time and distance. The fourth graph shows the maximum (in blue) received power level at the output of any of the RLAN antennas that is used in the DFS detection process as a function of distance during the simulation. For this sample case, the maximum aggregate interference power at the input of the radar receiver is 3.51 dB above the maritime radar receiver protection threshold. In other words, in

[24] The irregular shape of the coastline yielded a final total of 5 203 emitters which was thought to be close enough to the target 5 186.

this sample case, the radar protection threshold is exceeded. The analysis results for each radar system are presented as a series of these four graphs.

FIGURE 5

Sample model output

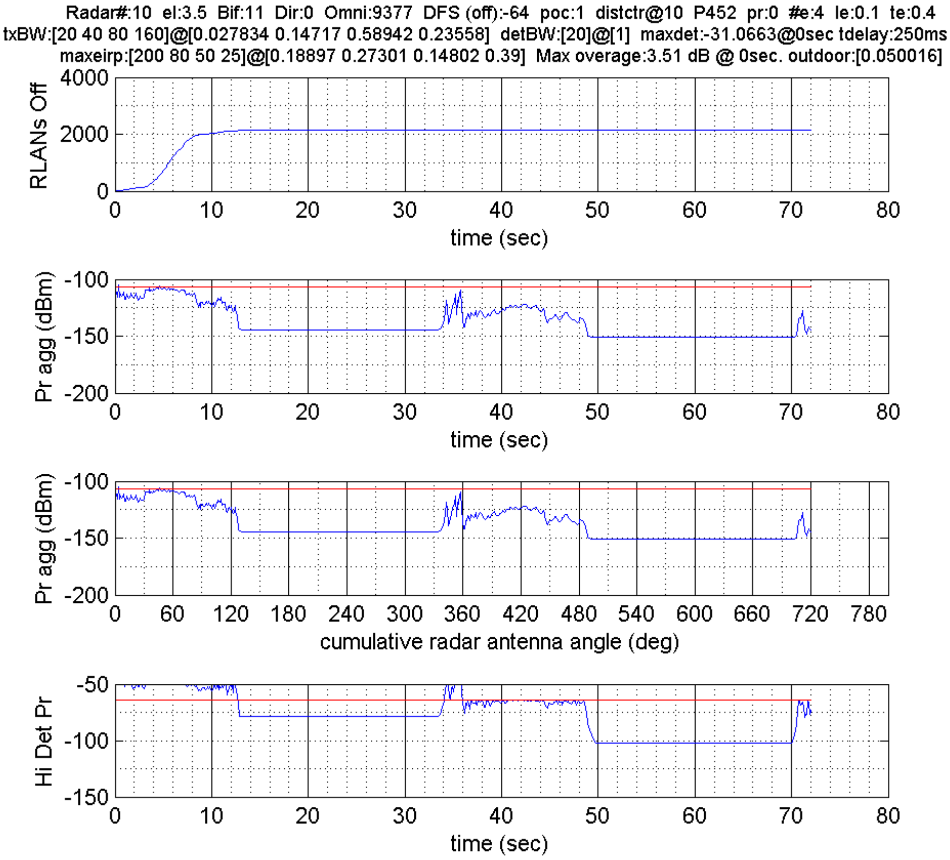
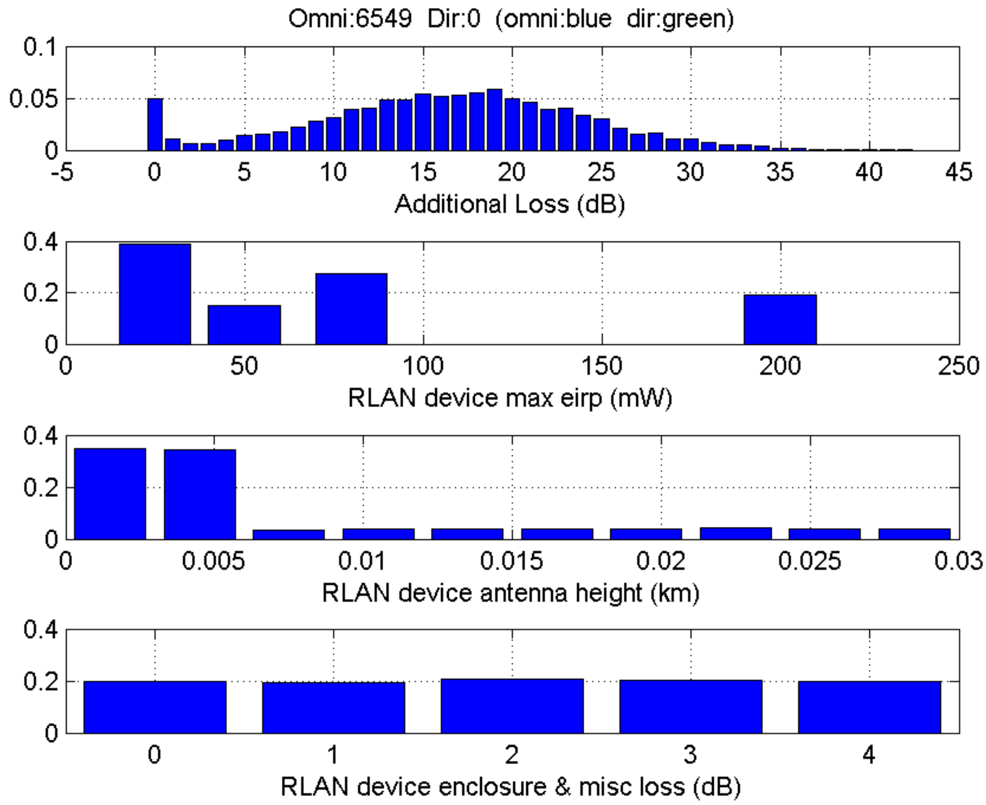


Figure 6 is provided to verify that random distributions in the study are as expected. It shows normalized histograms of additional loss, and emitter maximum e.i.r.p. and antenna heights used.

FIGURE 6

Sample random distributions output



5.1 Radar 10 Analysis Results for a 11 MHz bandwidth using POC of 100 Percent

The following figure shows the main output of this study for Radar 10 at 70 km from the distribution centre. The first graph in shows the number of RLANs that are turned off as a result of DFS detection process during the simulation. The second and third graphs show the aggregate received power from the RLANs at the output of the radar receiver as a function of simulation time and distance. The red line is the receiver protection threshold. The fourth graph is a function of distance showing the maximum received power level at the output of any of the RLAN receivers that are not turned off. The red line is the DFS detection threshold (-64 dBm) utlized in this study. For this simulation, the maximum aggregate interference power at the output of the radar receiver is approximately 11.7 dB below the shipborne receiver protection threshold and it happened 6.3 seconds into the simulation. In other words, in this scenario, the radar protection threshold is not exceeded. The analysis results in the remainder of this paper are presented as a series of these four graphs. The following table explains the title in each figure.

TABLE 14

Explanation of figure headings

el:3.5	The antenna elevation angle was 3.5° wrt the horizontal.
Dir:0	There were no RLANs with directional antennas
Omni:5203	There were 5203 RLANs with omni-directional antennas
DFS(off):-64	DFS turned any RLAN off (that exceeded a detection threshold of -64 dBm) for the remainder of the simulation.[25]
poc:1	The probability of coincidence was 1 (i.e. 100%).
distctr@70	The radar started 70 km away from the RLAN distribution centre
P452	The propagation model used was ITU-R P.452-15
#e:0	The number of interference events was 0.[26]
le:	The longest event was (seconds)
RLAN transmit bandwidths were 20, 40, 80, and 160 MHz occurring in exactly the percentages of total RLANs listed, respectively	
The detection bandwidth was 20 MHz for 100% of the RLANs.	
Max overage:-18.3151 dB@6.1sec	The maximum over threshold was -18.3151, which occurred when the radar was 6.1 seconds into the simulation in the second graph.
outdoor:0.049971	Exactly 4.9971% of the RLANs were outdoor

[25] The number of RLANs that did not turn off is the difference between the total number of RLANs and the number of RLANs that are turned off from first graph.

[26] An interference event is defined as a series of consecutive time steps in which the interference threshold is exceeded. There may be more than one event during a simulation so we also concern ourselves with the length of the longest event, which is the next row in the table.

FIGURE 7

Radar 10 at 70 km

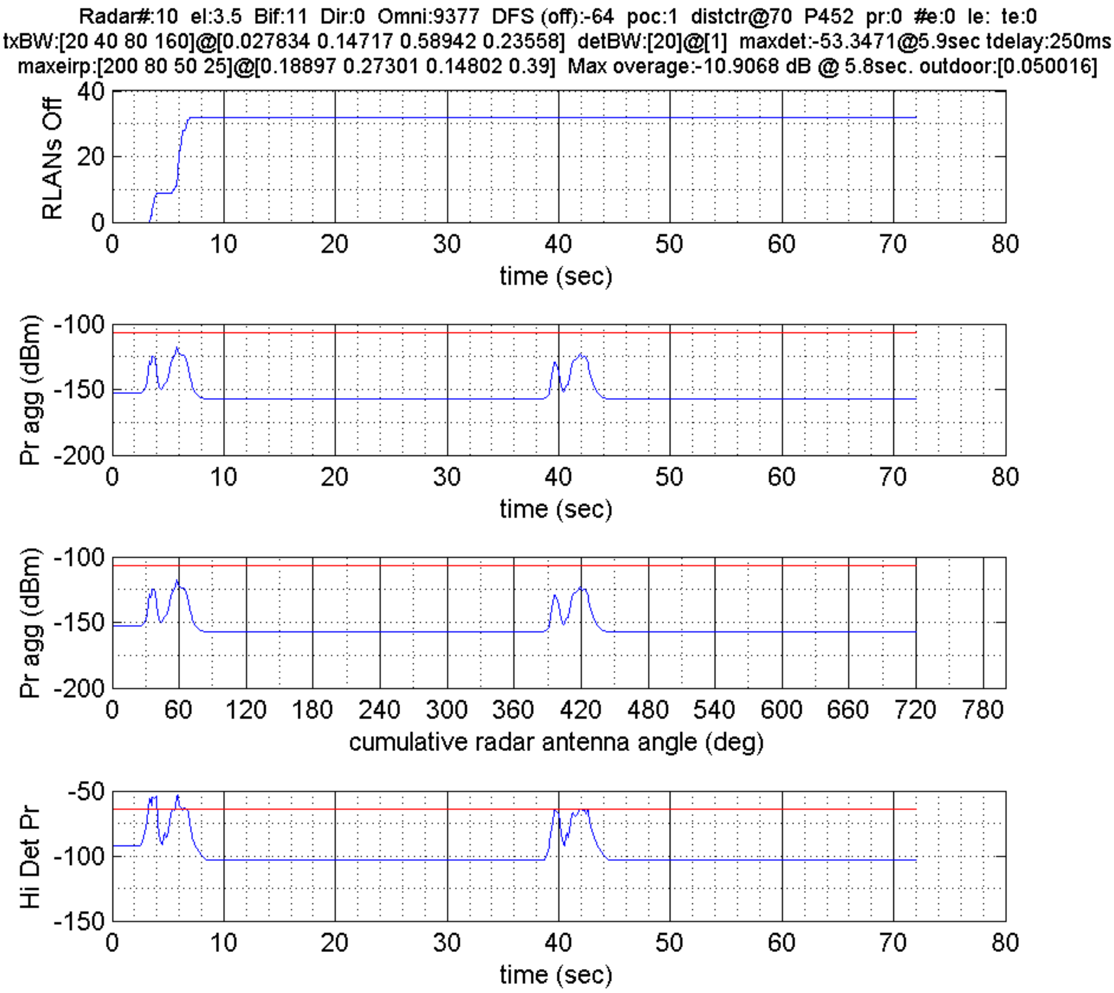


FIGURE 8

Radar 10 at 50 km

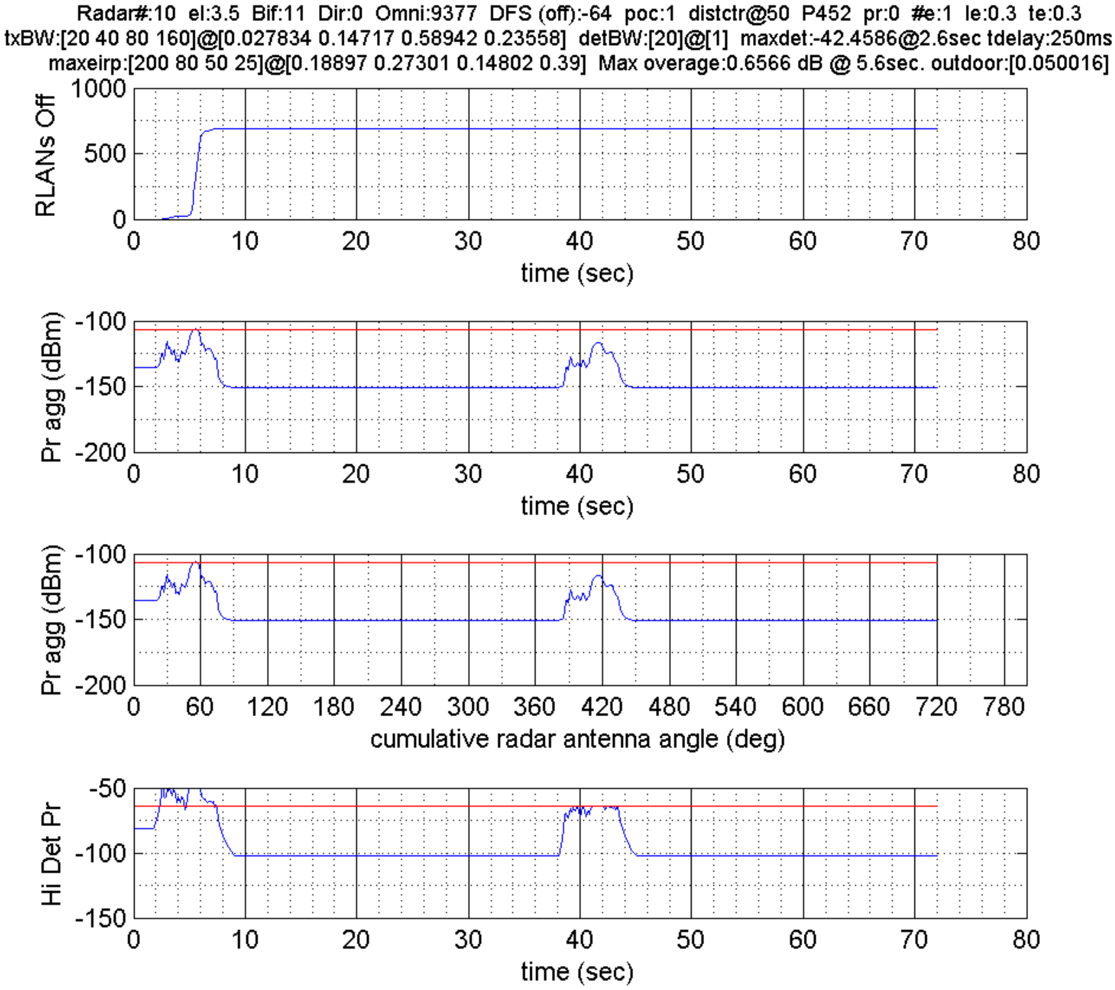


FIGURE 9

Radar 10 at 30 km

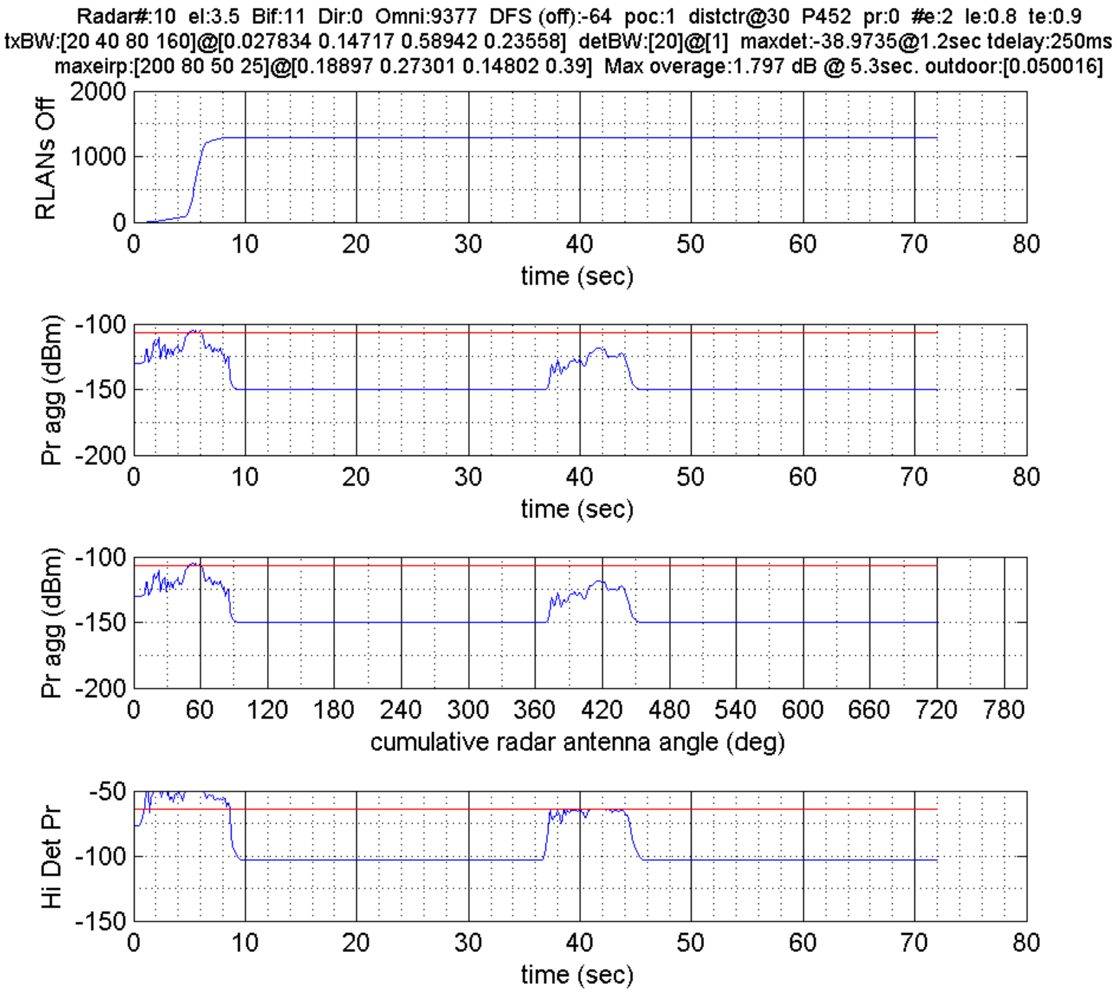


FIGURE 10

Radar 10 at 10 km

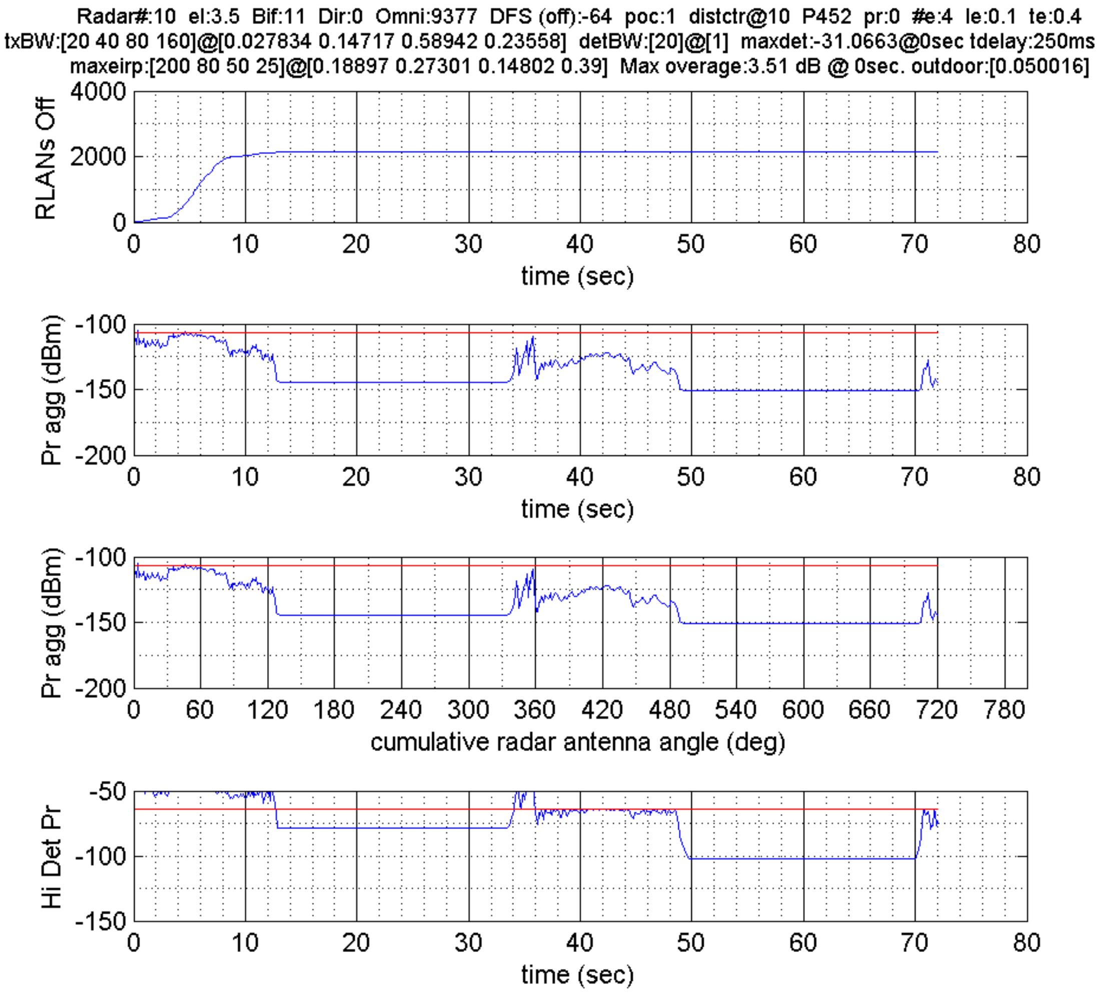
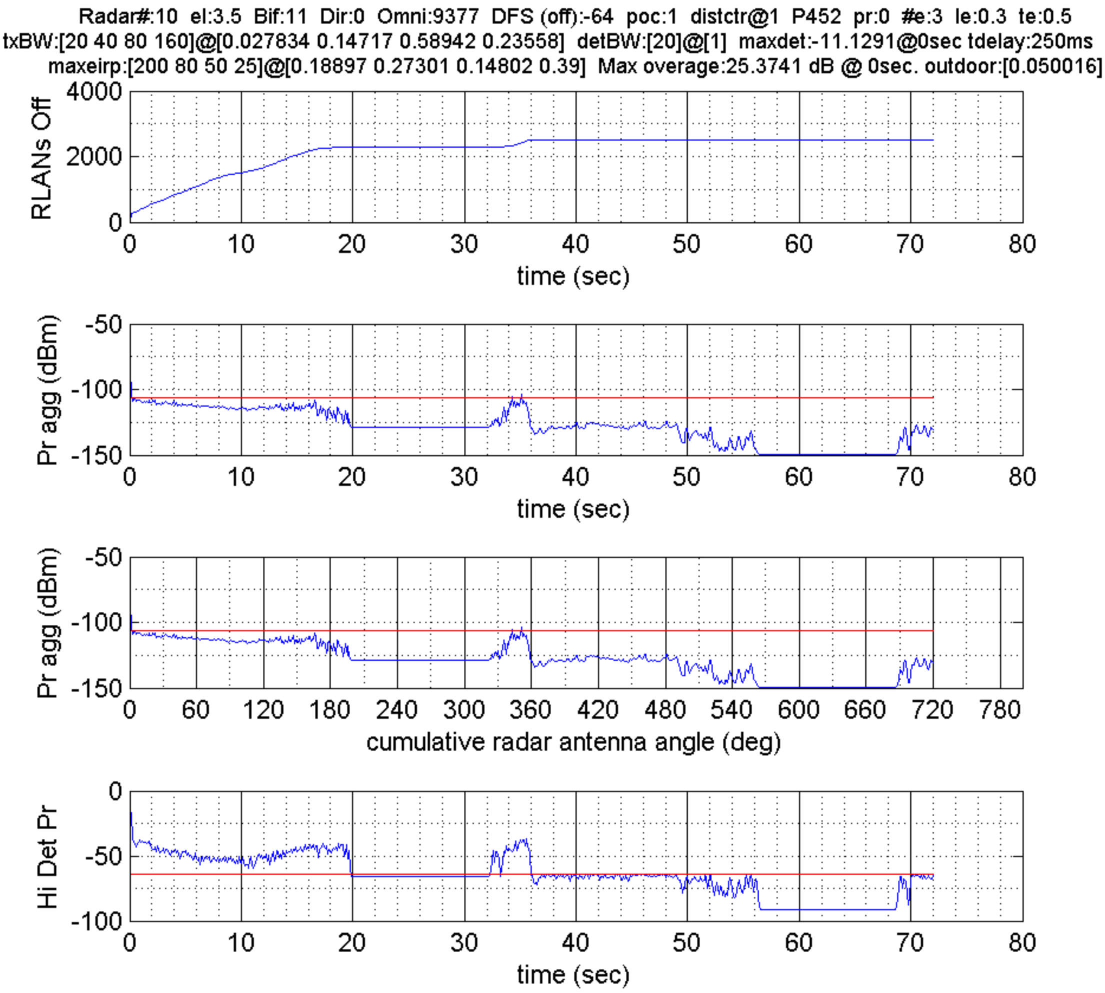


FIGURE 11

Radar 10 at 1 km



5.2 Radar 7 Analysis Results for a 1.2 MHz bandwidth using POC of 100 Percent

FIGURE 12

Radar 7 with 1.2 MHz bandwidth at 70 km

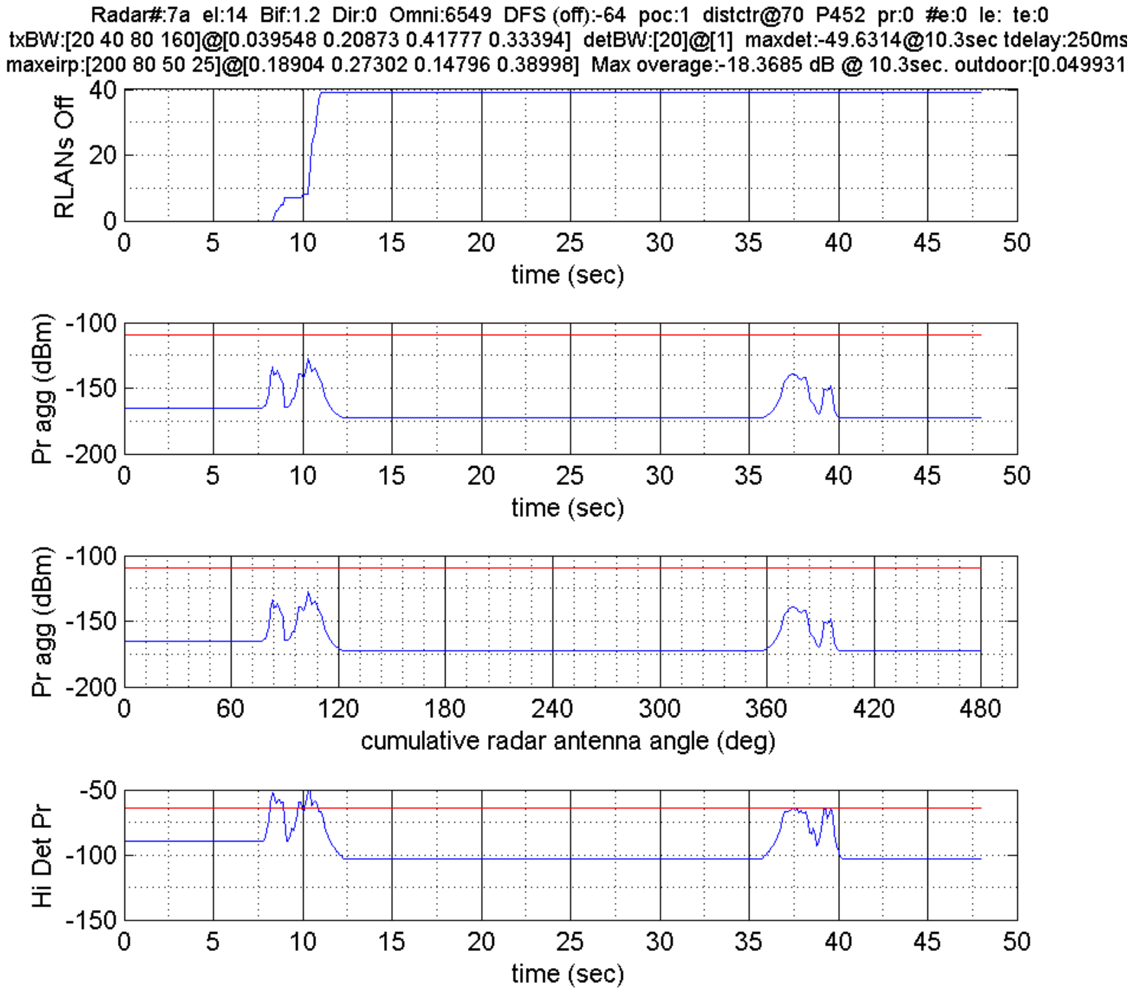


FIGURE 13

Radar 7 with 1.2 MHz bandwidth at 50 km

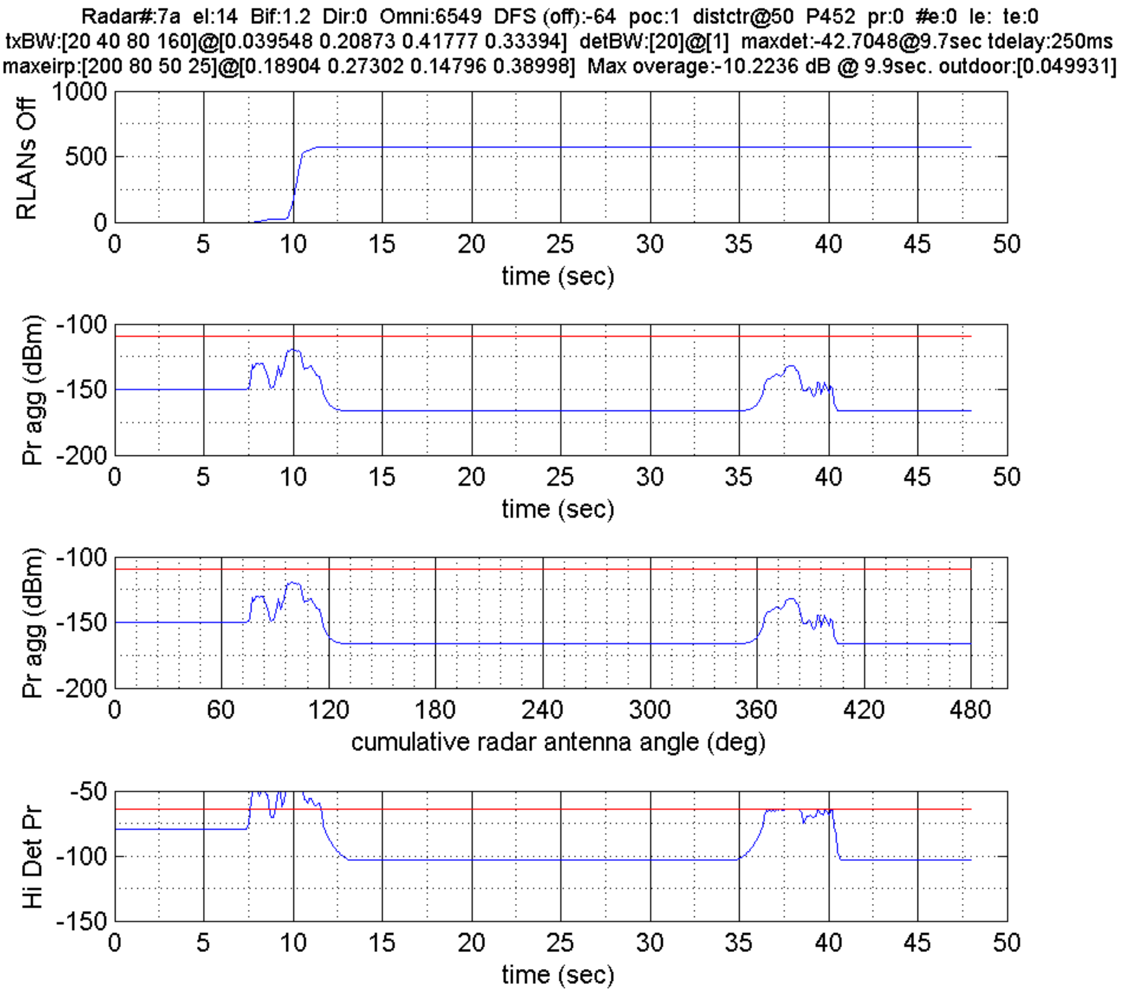


FIGURE 14

Radar 7 with 1.2 MHz bandwidth at 30 km

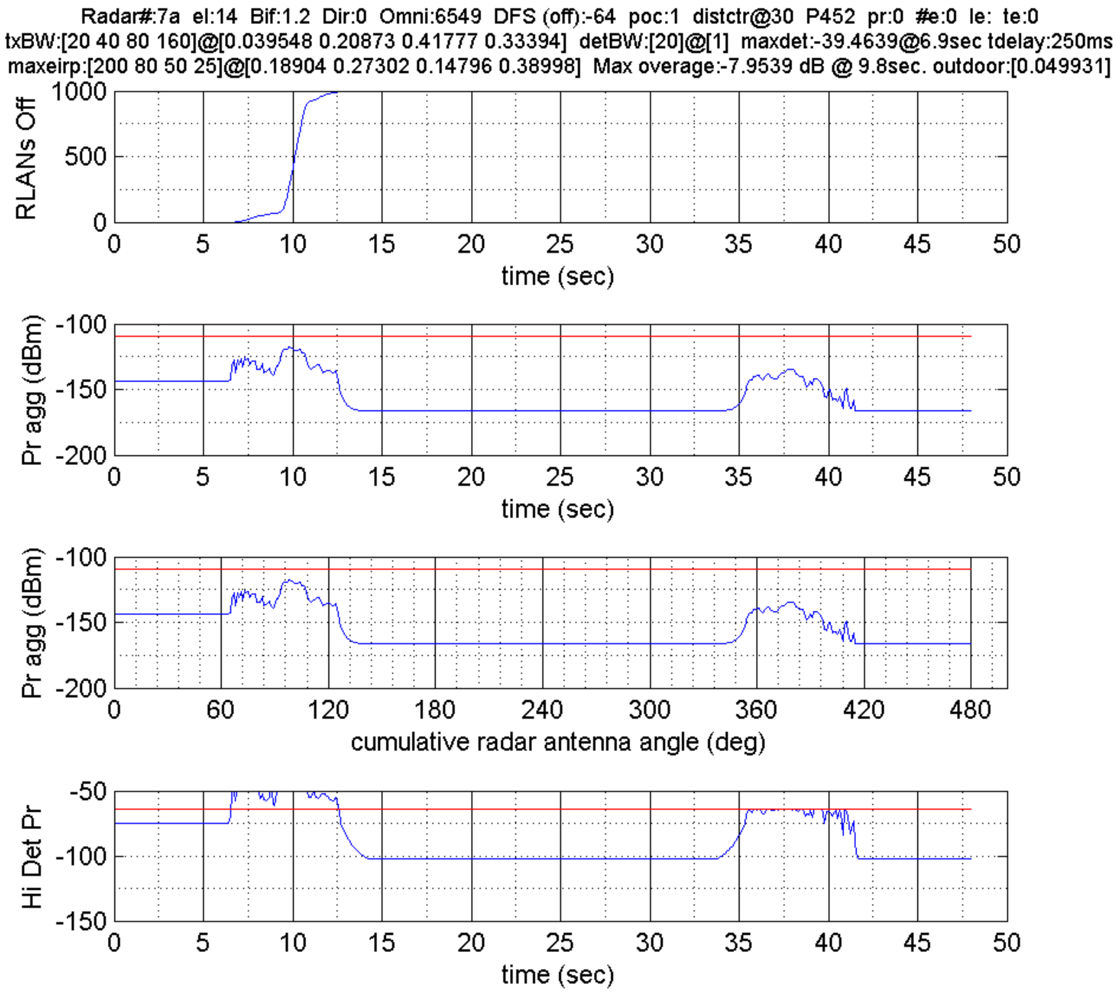


FIGURE 15

Radar 7 with 1.2 MHz bandwidth at 10 km

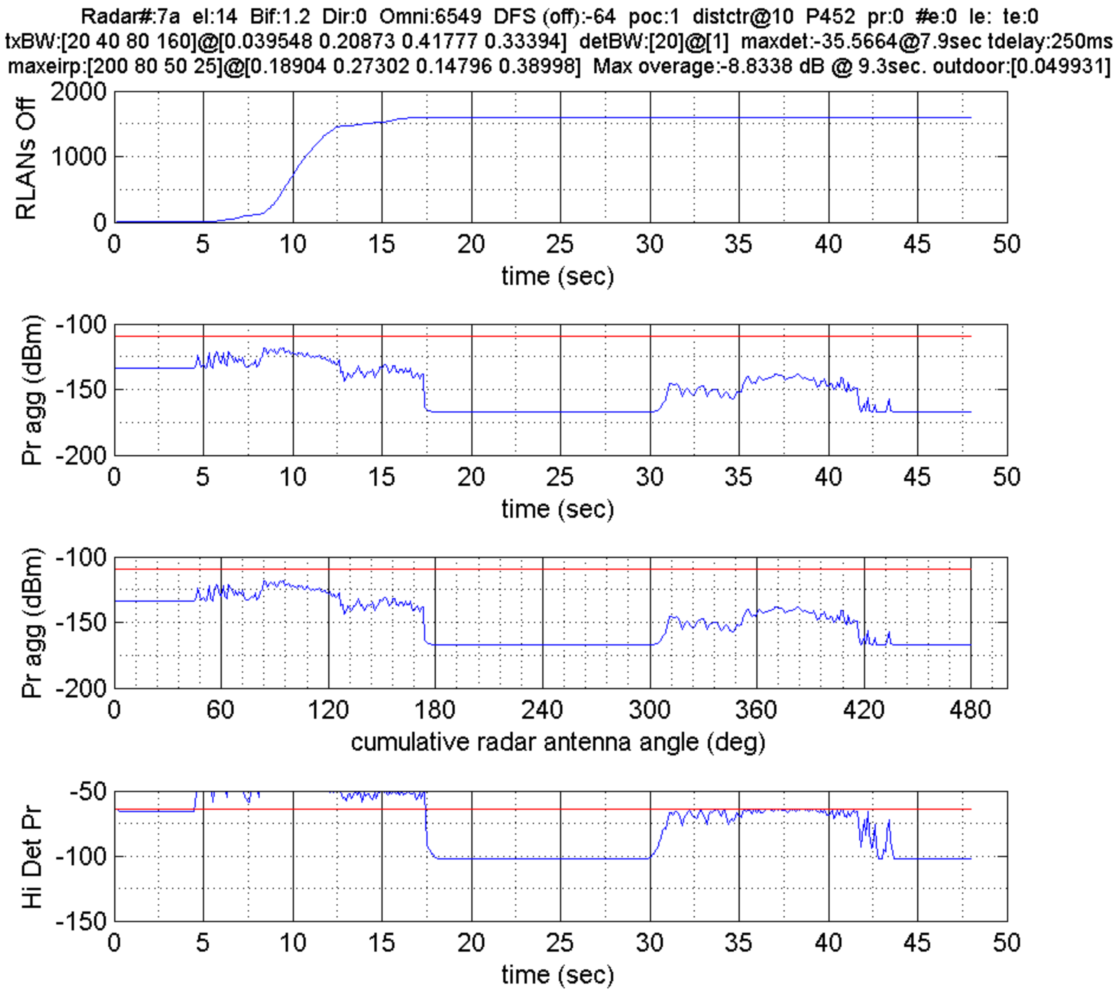
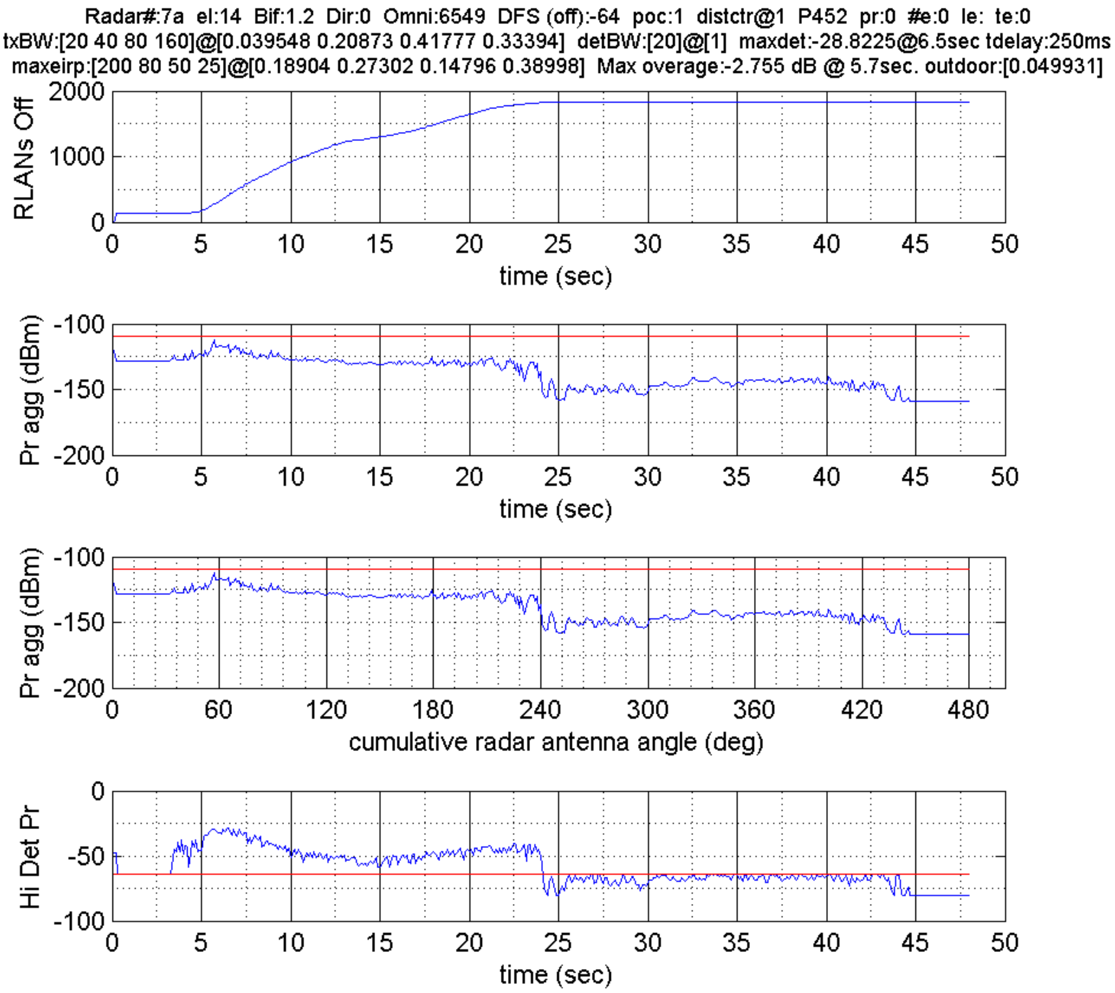


FIGURE 16

Radar 7 with 1.2 MHz bandwidth at 1 km



5.3 Radar 7 Analysis Results for a 10 MHz bandwidth using POC of 100 Percent

FIGURE 17

Radar 7 with 10 MHz bandwidth at 1 km

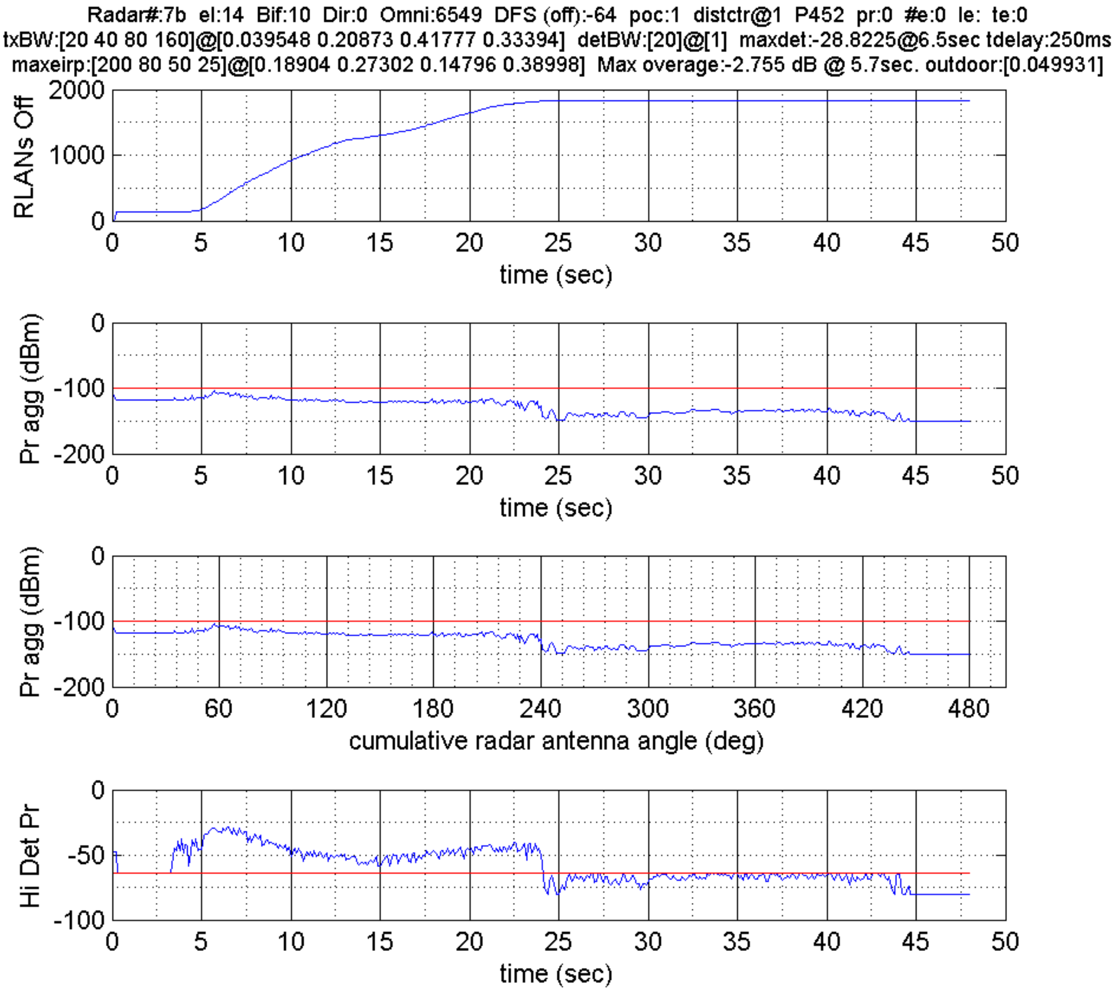


FIGURE 18

Radar 7 with 10 MHz bandwidth at 10 km

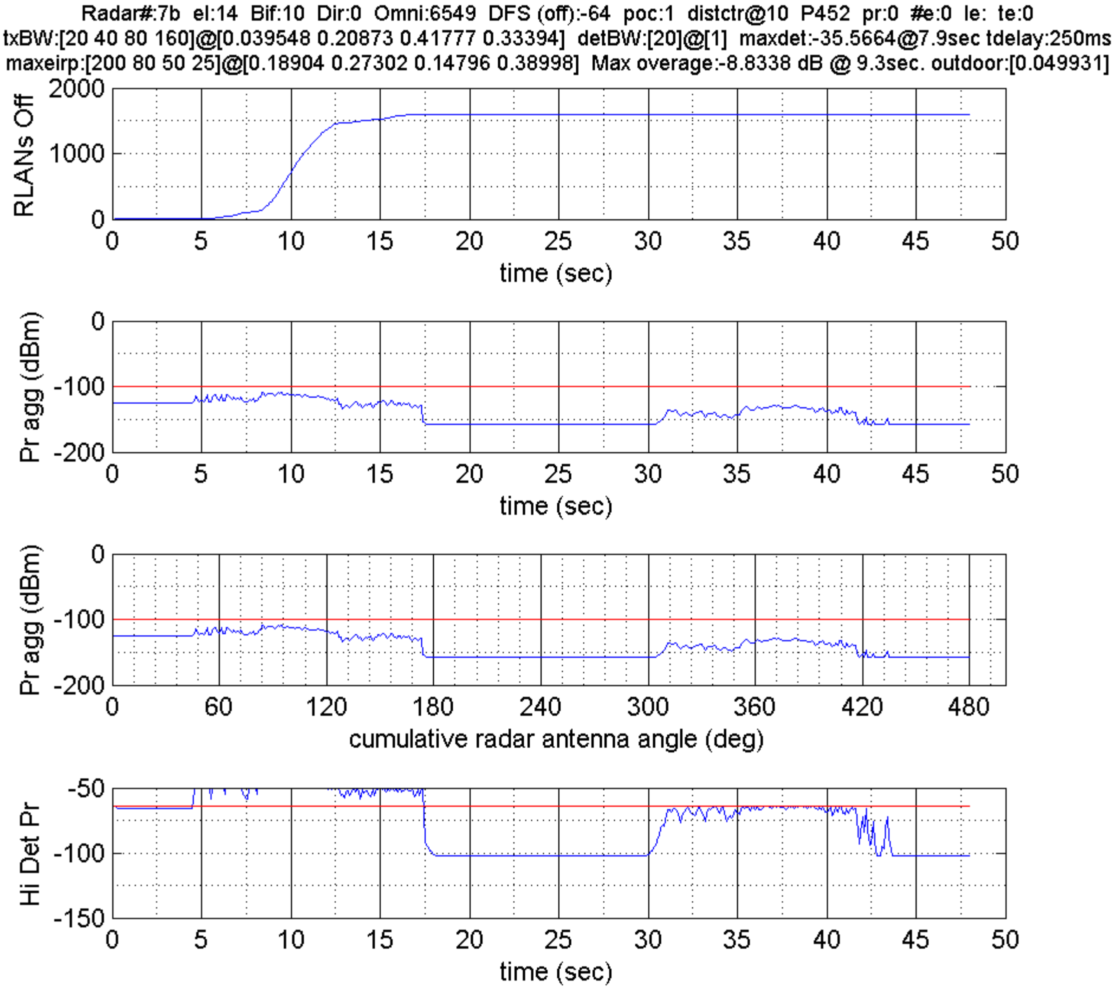


FIGURE 19

Radar 7 with 10 MHz bandwidth at 30 km

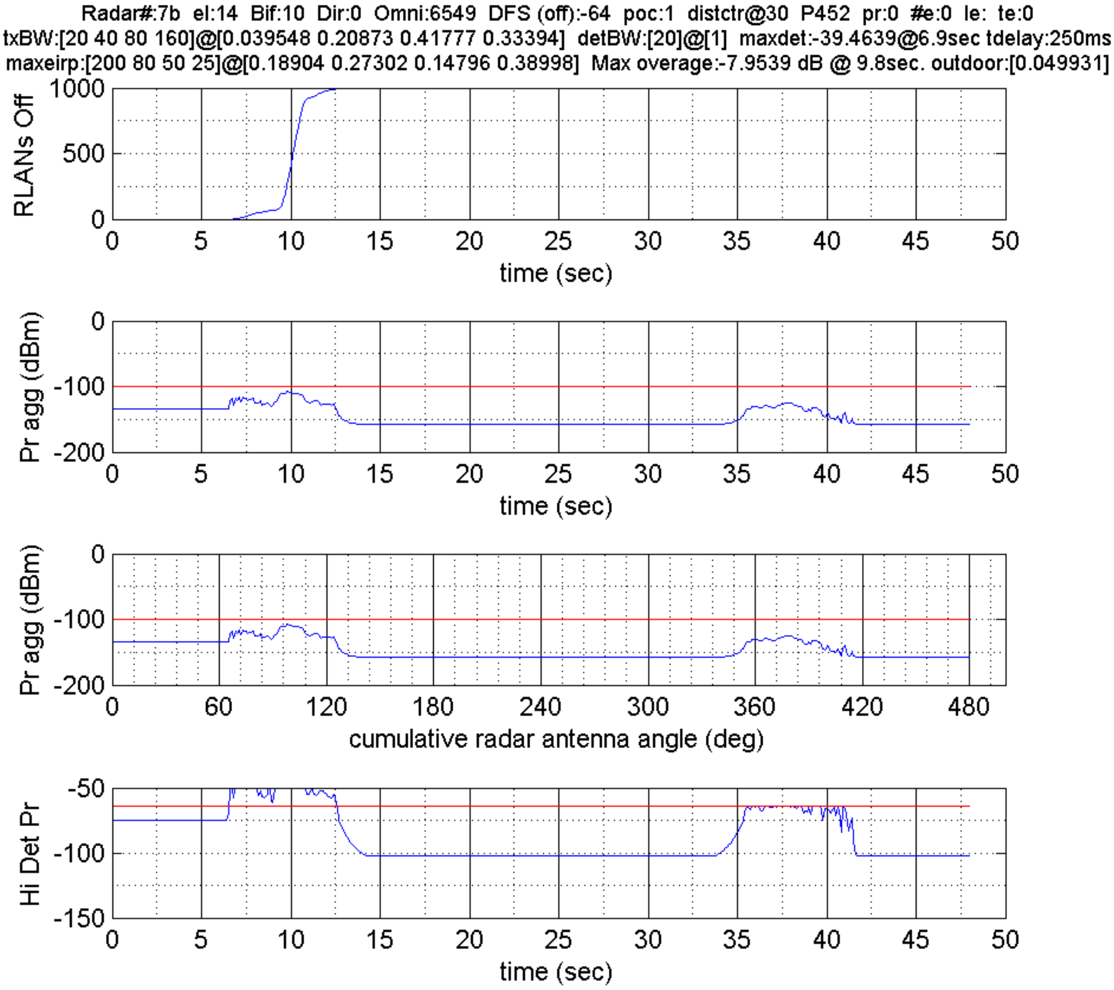


FIGURE 20

Radar 7 with 10 MHz bandwidth at 50 km

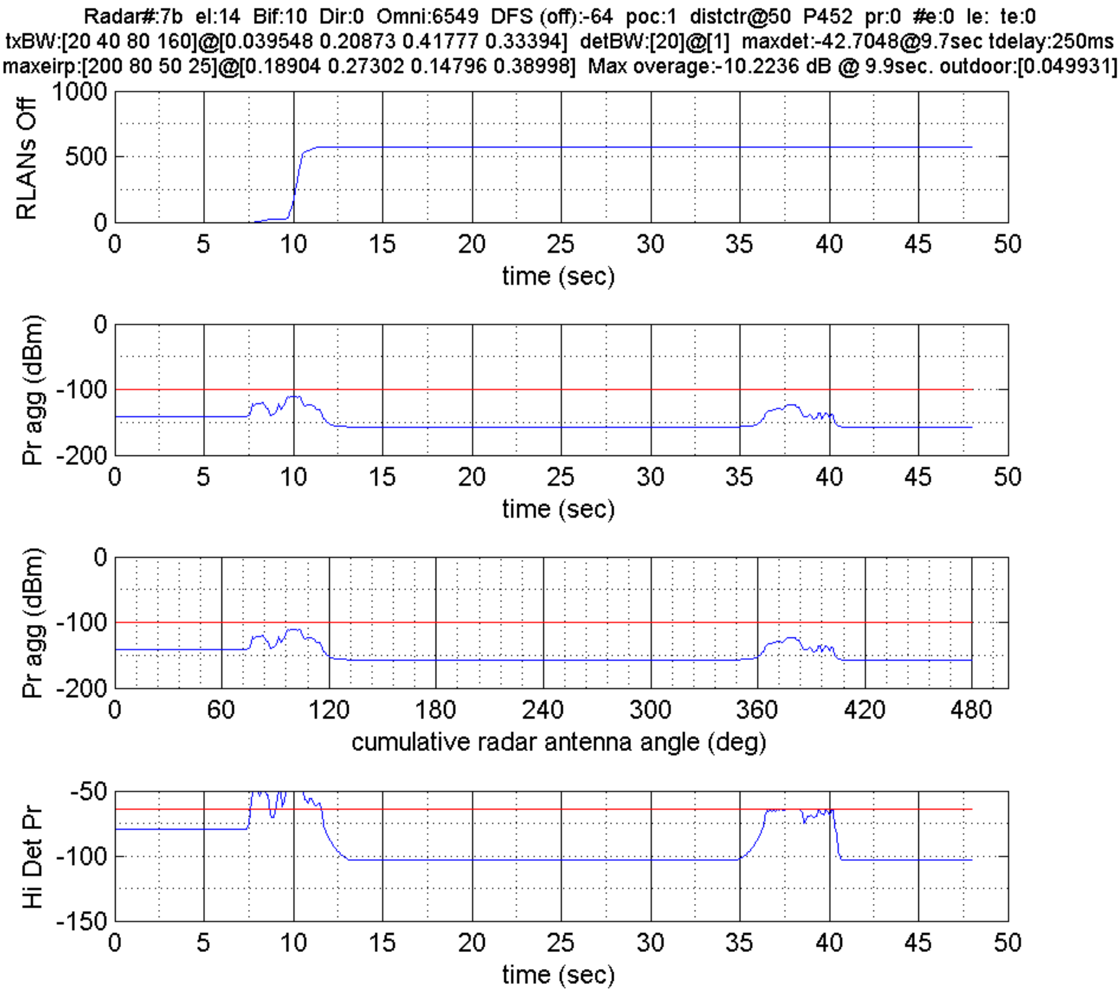
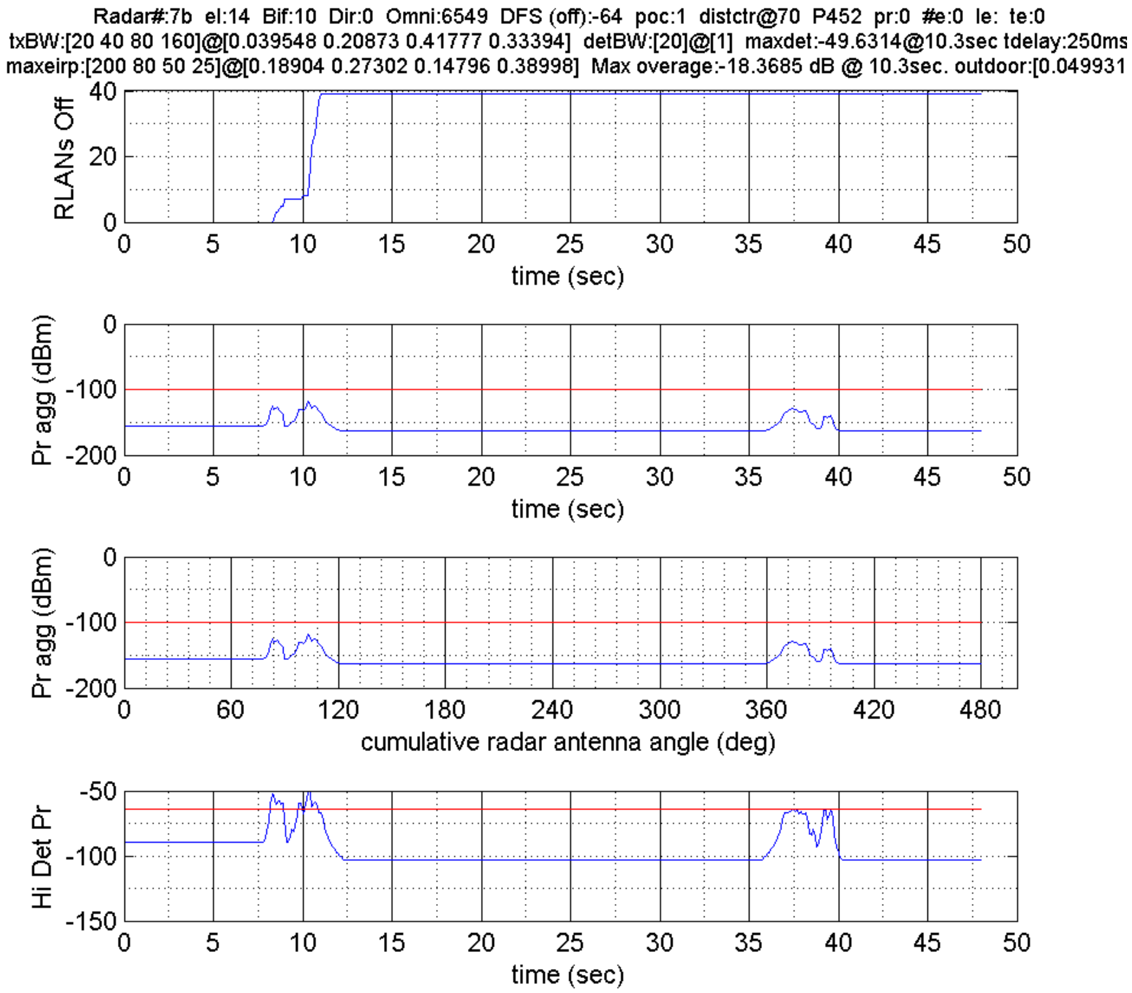


FIGURE 21

Radar 7 with 10 MHz bandwidth at 70 km



5.4 Radar 12 Analysis Results for a 7 MHz bandwidth using POC of 100 Percent

FIGURE 22

Radar 12 at 1 km

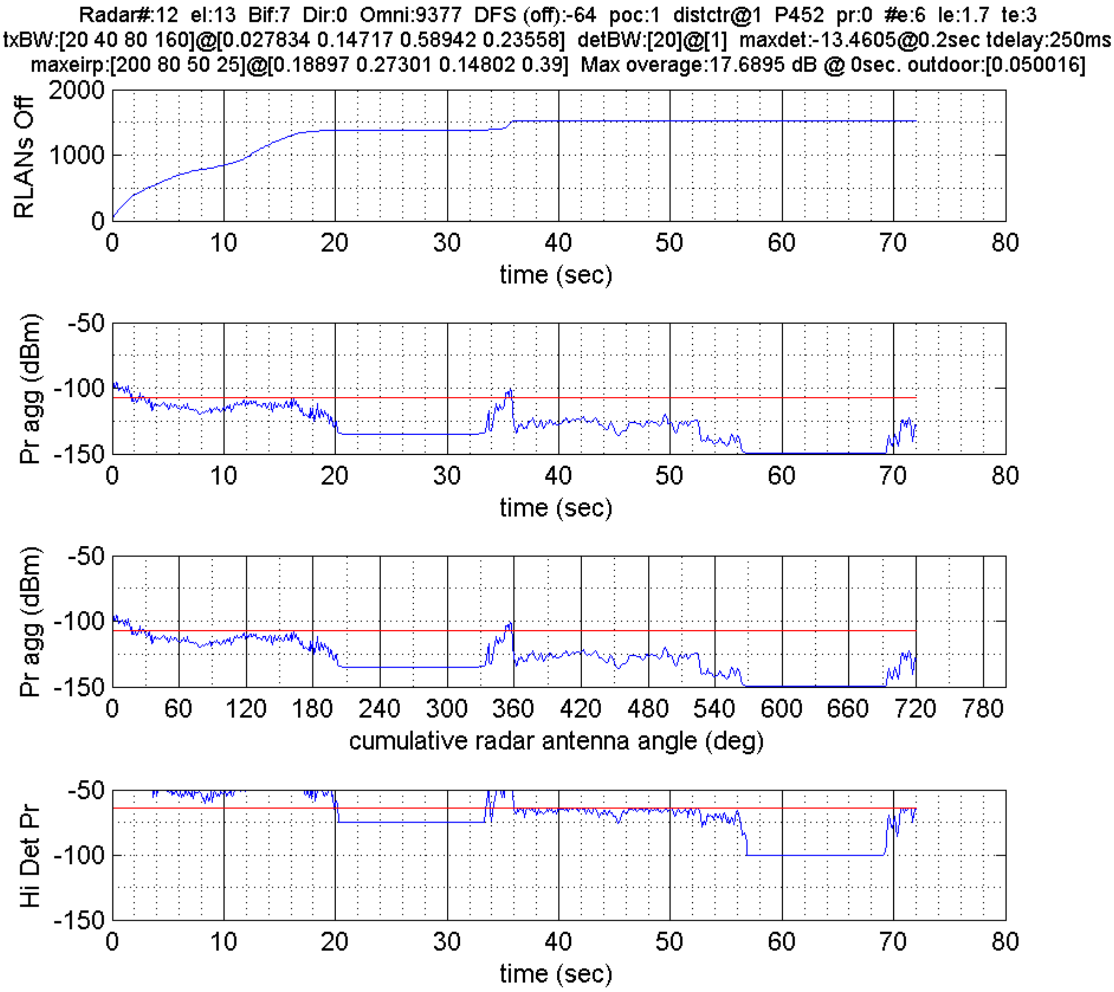


FIGURE 23

Radar 12 at 10 km

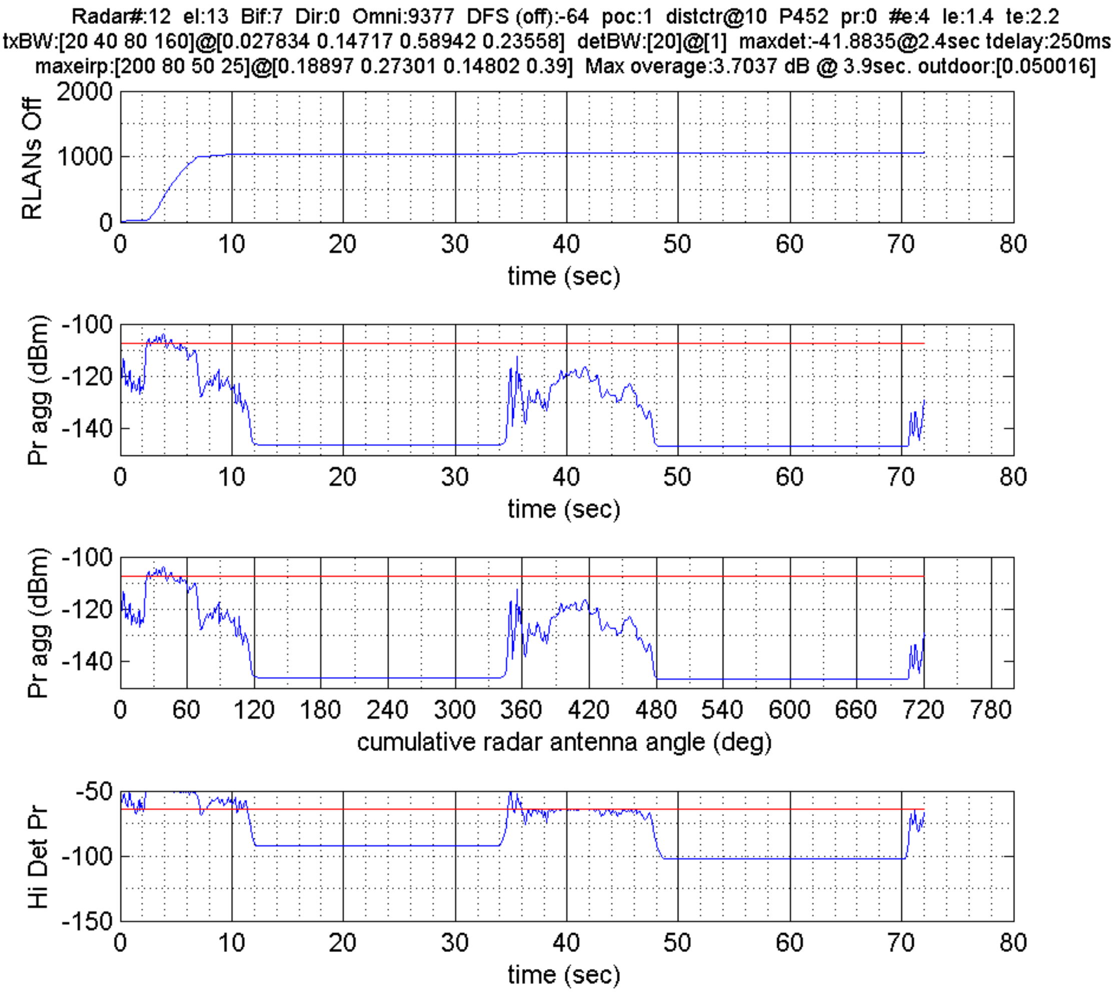


FIGURE 24

Radar 12 at 30 km

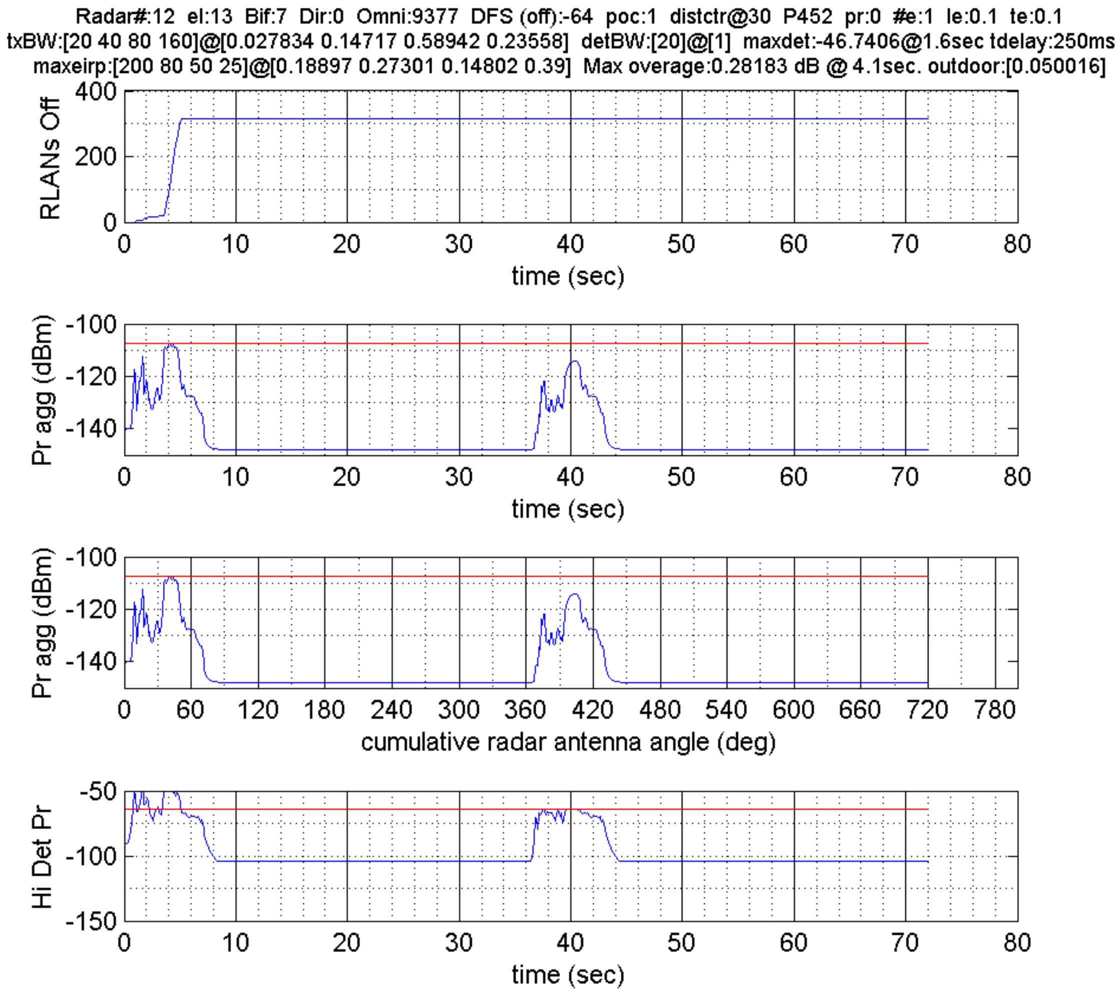


FIGURE 25

Radar 12 at 50 km

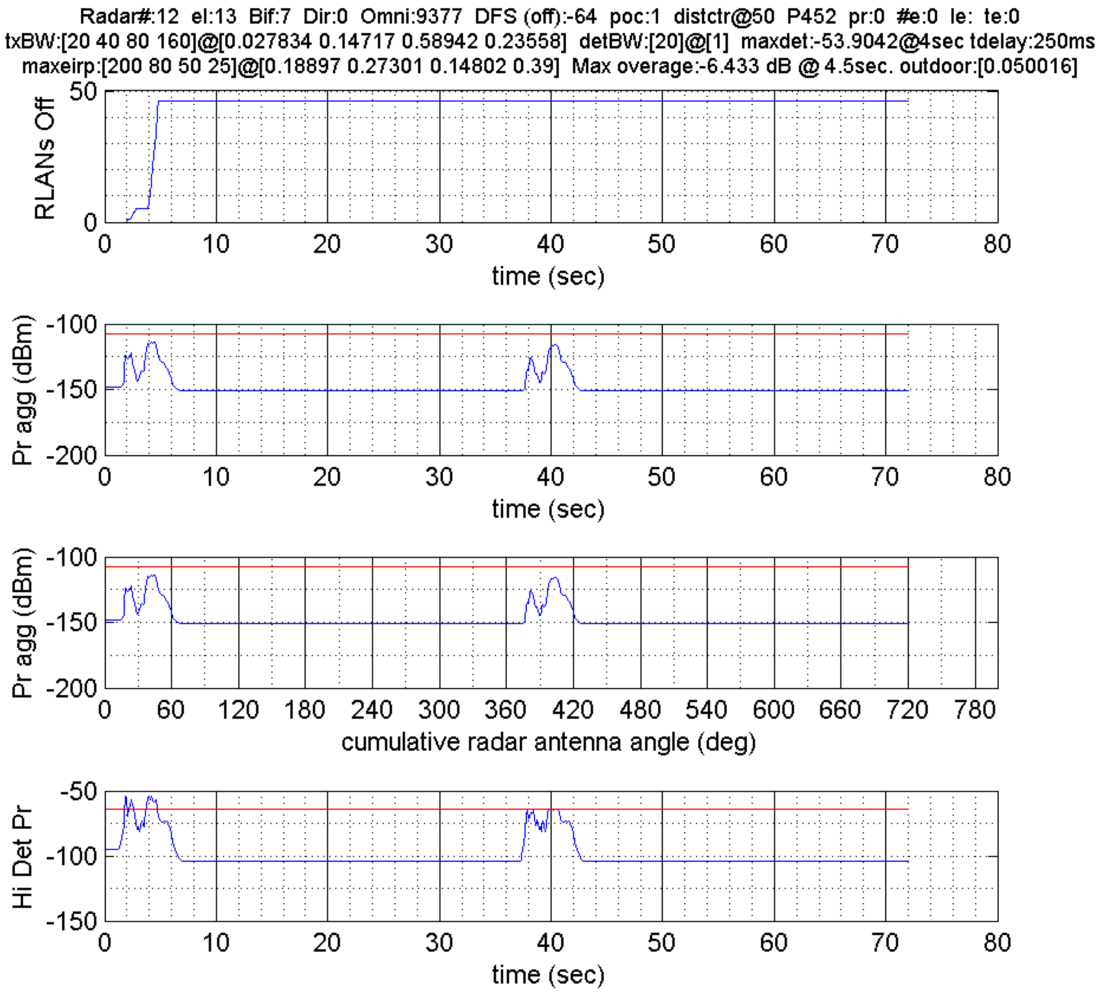
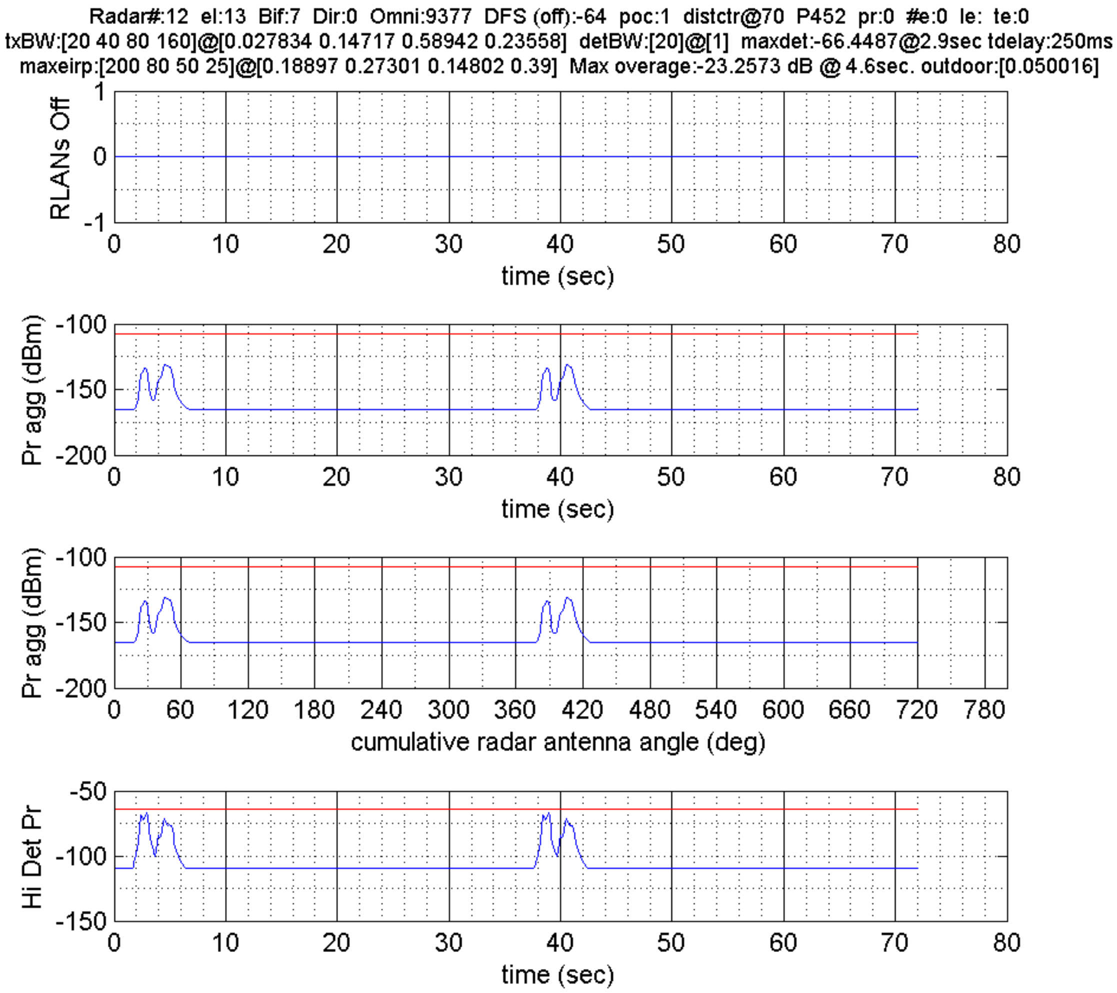


FIGURE 26

Radar 12 at 70 km



5.4 Radar 20 Analysis Results for a 0.5 MHz bandwidth using POC of 100 Percent

FIGURE 27

Radar 20 at 1 km

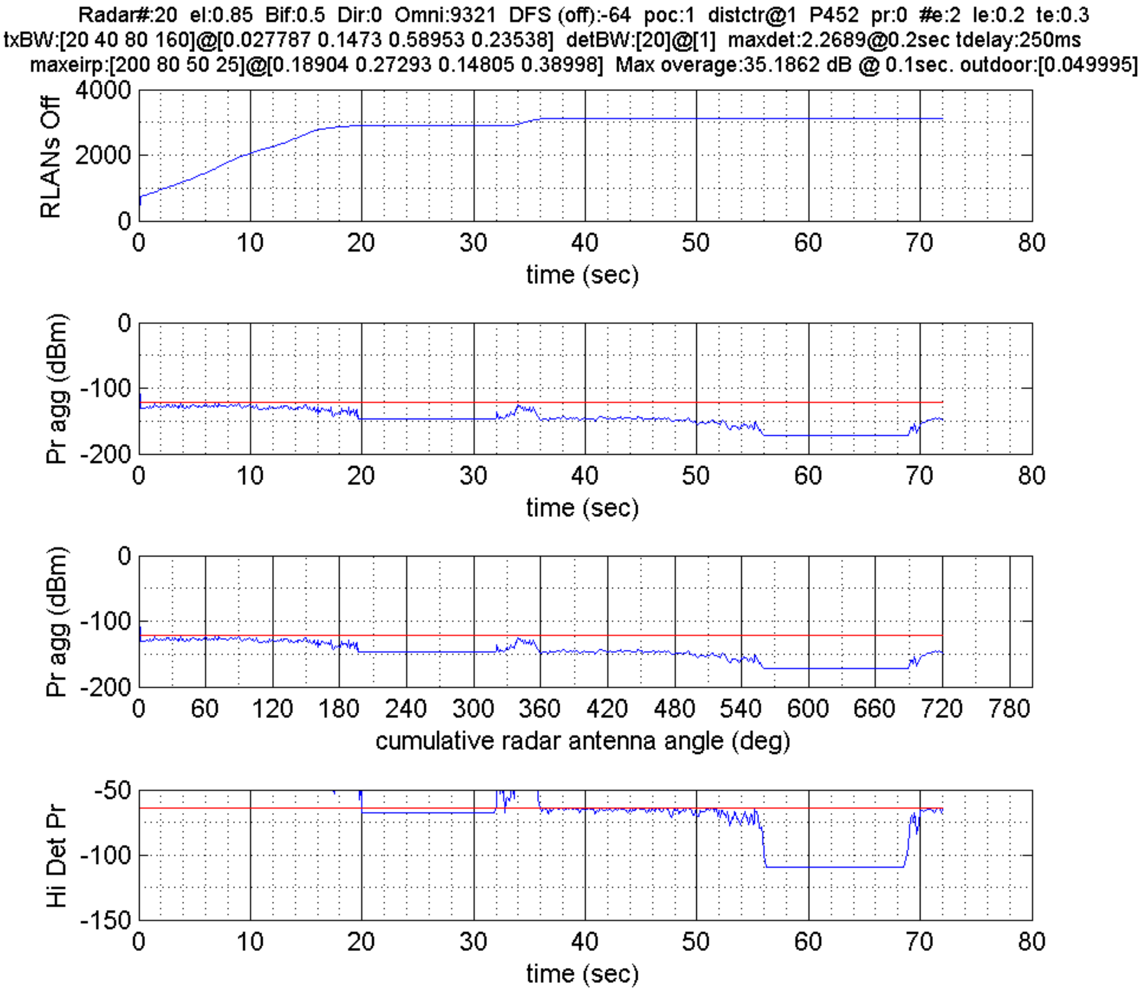


FIGURE 28

Radar 20 at 10 km

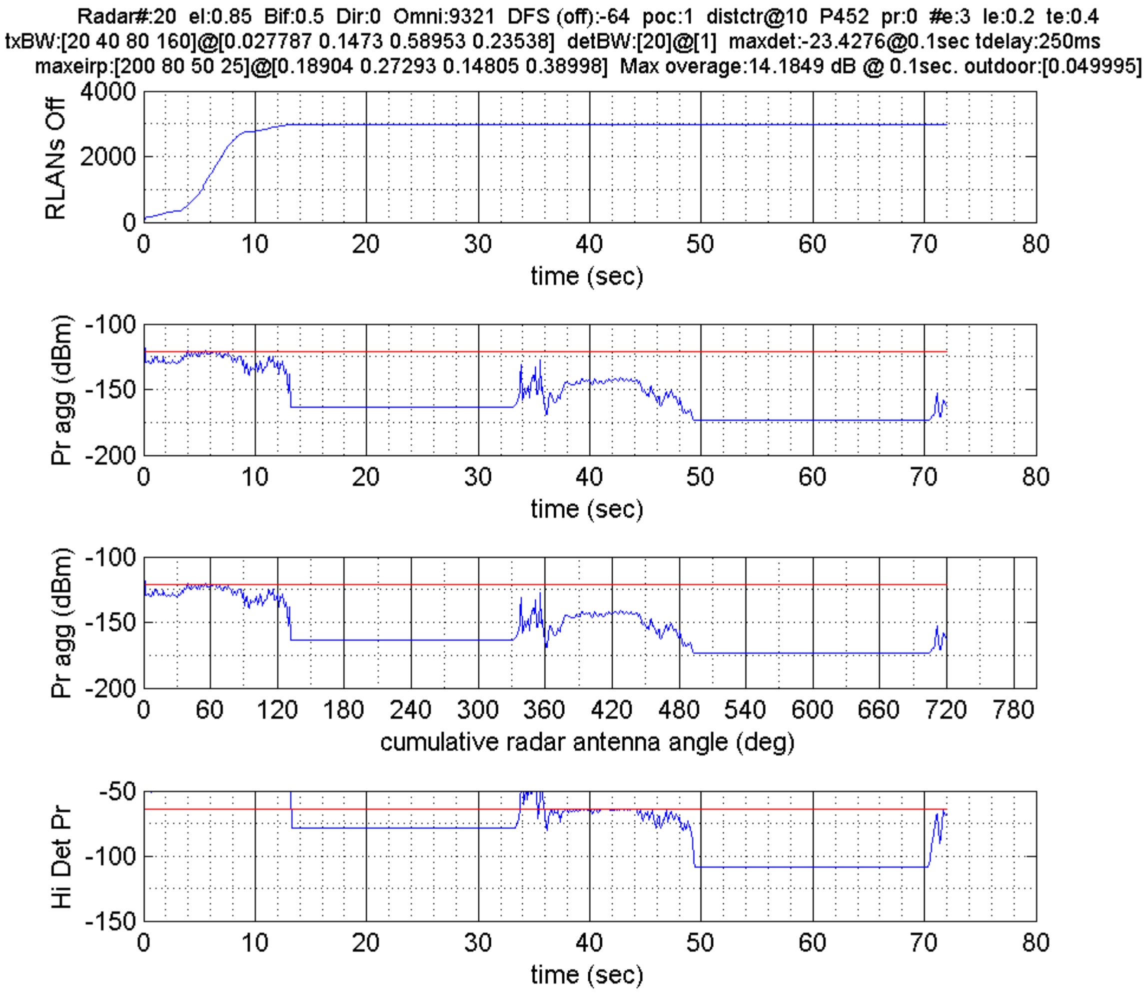


FIGURE 29

Radar 20 at 30 km

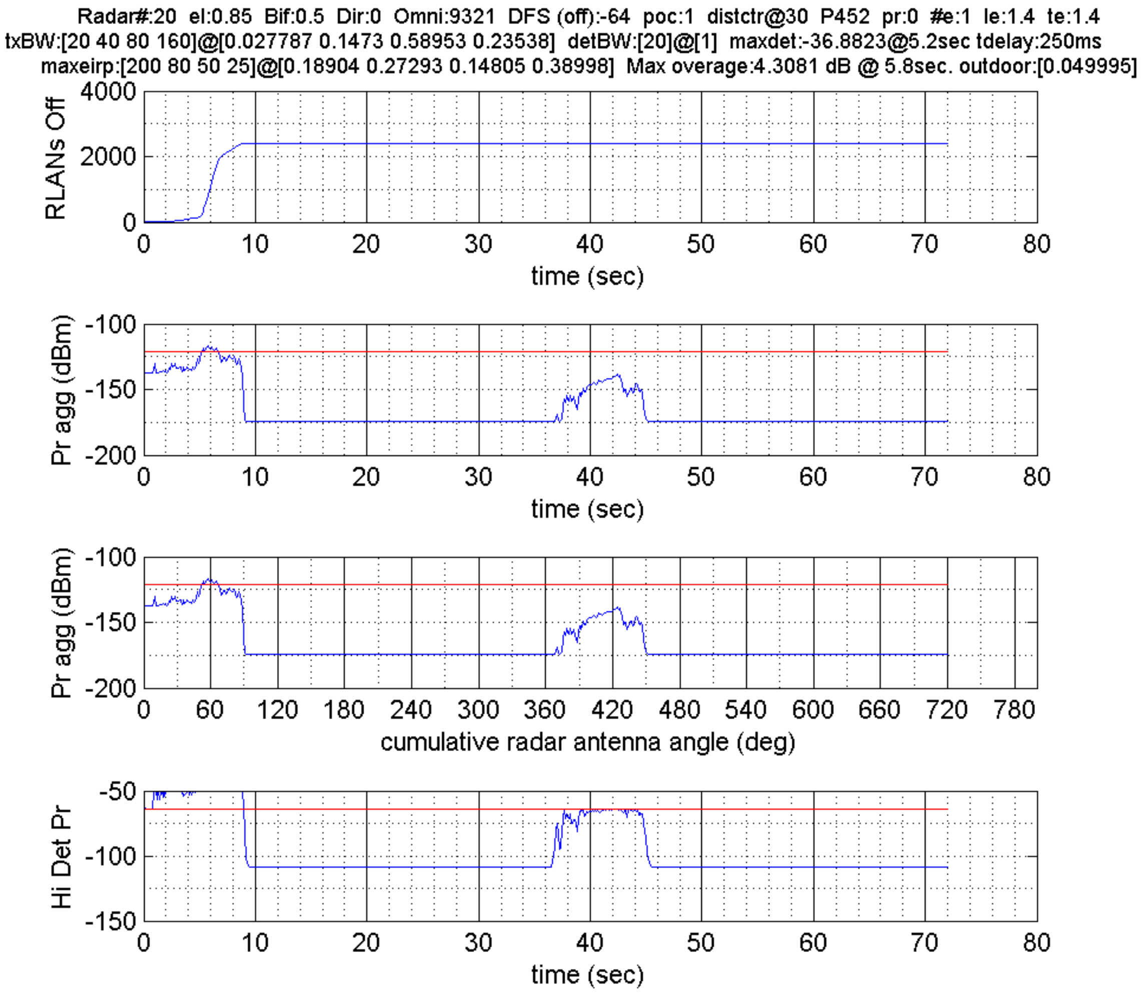


FIGURE 30

Radar 20 at 50 km

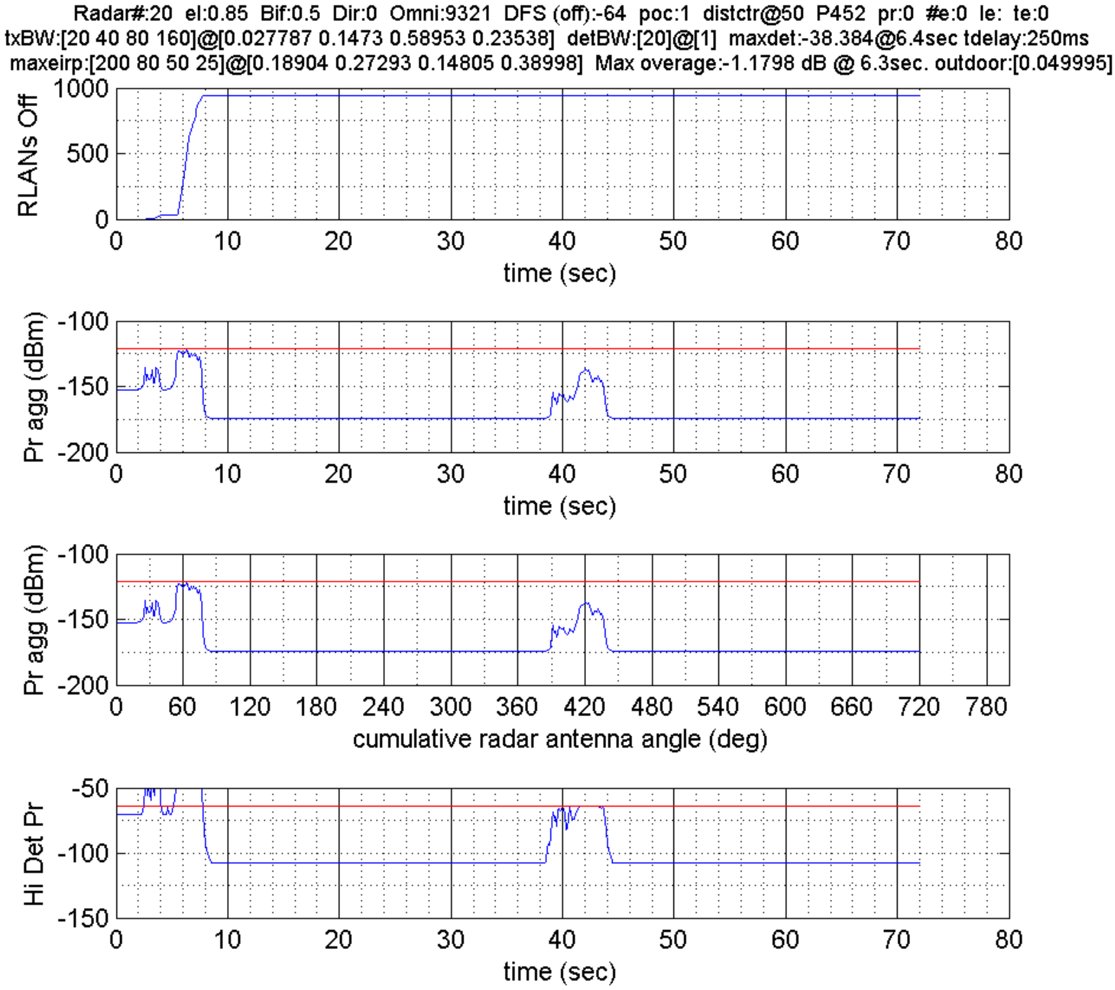
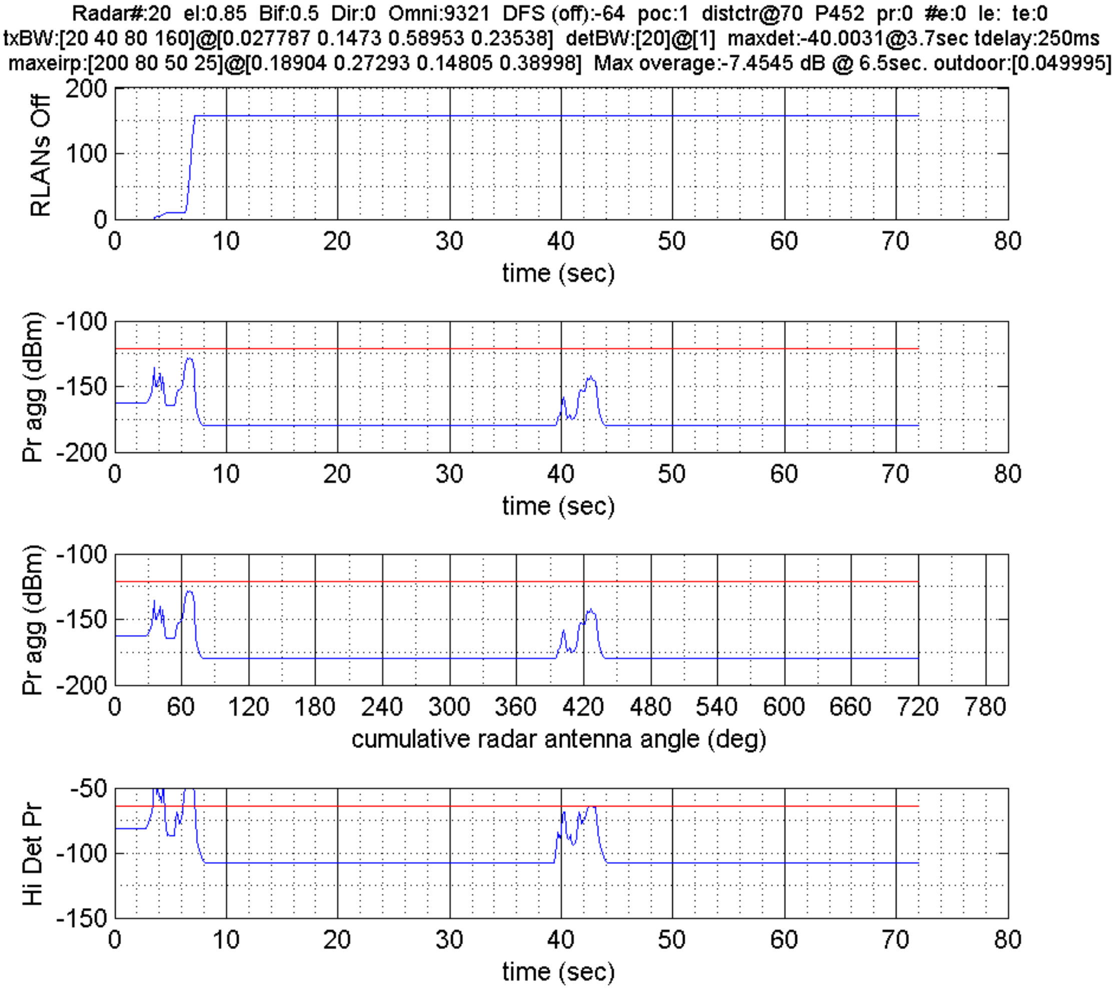


FIGURE 31

Radar 20 at 70 km



6 Conclusions

This study investigated the feasibility of RLAN systems operating in the 5 350-5 470 MHz frequency bands with incumbent primary maritime radiodetermination systems. This study indicates that incumbent shipborne radiodetermination systems may be protected with no changes to existing DFS if sub-microsecond pulse width radars (0.1 µsec to 0.5 µsec) can be detected by RLAN when RLAN mitigation techniques are limited to the following: dynamic frequency selection (threshold of -64 dBm), predominantly indoors (95%), and maximum e.i.r.p. of 200 mW.

Many of the maritime radars employ sub-microsecond pulses to improve detection capabilities in cluttered environments. Various domestic regulations already require DFS detection to 0.5 µsec but the ability of DFS to detect sub-microsecond pulses (0.1 µsec to 0.5 µsec) is not known at this time.

The expected POC is highly dependent on the pulse repetition rate of the radar system and at the lowest values of PRR for radars in this band is expected to be near a POC of 1 for all radars. The POC may also vary depending on additional time requirements for detection needed to ensure the ability of RLAN to detect 0.1 µsec to 0.5 µsec radar pulses. Further study on the actual POC's is required. Based on this study, the aggregate interference levels from the RLAN emitters exceed the protection threshold for most radars analysed for a short period of time (< 2 sec.); however, further study to determine the full impact to maritime radar operations based on the actual POC's is required.

Studies on alternate mitigation measures have not been completed in the ITU and further study is required to determine their applicability.

ANNEX I

Sharing between RLANs and radiolocation systems in the 5 350-5 470 MHz frequency range

1 Introduction

This analysis provides the results of a study between proposed RLAN systems and incumbent ground-based radiodetermination systems operating in the 5 350-5 470 MHz frequency range.

2 Background

Recommendation ITU-R M.1652 provides information on DFS procedures and modelling. DFS performance, detection and operational requirements were established in 2003 to mitigate interference into radars operating in the 5 250-5 350 MHz and 5 470-5 725 MHz bands. The study incorporated the following mitigation techniques: DFS (threshold of –64 dBm), predominately indoors (95%) and low power (maximum e.i.r.p. of 200 mW).

This study provides an analysis of mitigation techniques required to detect ground-based radiodetermination systems in the 5 350-5 470 MHz frequency range while not exceeding the ground-based receiver protection threshold based on an I/N = –6 dB (Recommendation ITU-R M.1638-1).

3 Technical characteristics

3.1 Technical characteristics of ground-based radiodetermination systems

The following tables summarize the radar and RLAN characteristics considered for this analysis. Radiolocation system characteristics are taken from Recommendation ITU-R M.1638.

TABLE 1

Radar characteristics

Characteristics	Radar 2	Radar 3	Radar 5
Function	Instrumentation	Instrumentation	Instrumentation
Platform type (airborne, shipborne, ground)	Ground	Ground	Ground
Tuning range (MHz) *	5 350-5 850 (5400)	5 350-5 850 (5400)	5 400 – 5900 (5400)
Modulation	None	None	Chirp pulse
Tx power into antenna (kW)	2800	1200	165
Pulse width (us) *	.25/1.0/5.0 (.25)	.25/1.0/5.0 (.25)	100
Pulse repetition rate (pps) *	160, 640 (640)	160, 640 (640)	320
Chirp bandwidth (MHz)	N/A	N/A	8.33
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic	Parabolic	Phased array
Antenna polarization	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular
Antenna main beam gain (dBi)	54	47	42
Antenna elevation beamwidth (deg)	0.4	0.8	1.0
Antenna azimuthal beamwidth (deg)	0.4	0.8	1.0
Antenna horizontal scan rate (deg/sec)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)
Antenna horizontal scan type (continuous, random, 360º, sector, etc.) (deg)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)
Antenna vertical scan rate (deg/sec)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)
Antenna vertical scan type (continuous, random, 360º, sector, etc.) (deg)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)
Antenna Gain Pattern	Rec. ITU-R M.1652	Rec. ITU-R M.1652	Rec. ITU-R M.1652
Antenna height (m)	20	8-20 (20)	20
Receiver IF 3 dB bandwidth (MHz)	4.8,2.4,0.25 (4.8)	4,2,1 (4)	8
Receiver noise figure (dB)	5	5	5

* The values contained in parenthesis are the ones used in this study.

3.2 Mobile system parameters

The RLAN devices will be randomly distributed over three regions: urban, suburban, and rural. The three regions exist within concentric circles as shown in Figure 1.

FIGURE 1

RLAN device deployment regions

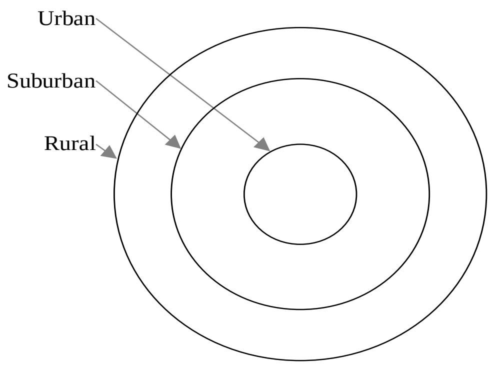


Table 2 provides the radius of each RLAN deployment zone.

TABLE 2

Deployment Zones

RLAN Deployment Region	Radius from the centre (km)
Urban	0 to 5
Suburban	5 to 15
Rural	15 to 30

The population used for the baseline is 5.25 million people. Table 3 provides the population distribution within each zone in the RLAN device environment.

TABLE 3

Population zones

Total Population	Population split	Percent	Population in Zone
5 250 000	Urban	30%	1 575 000
	Suburban	50%	2 625 000
	Rural	20%	1 050 000

Number of On-tune, Active RLAN devices

The following methodology was used to determine the number of on-tune active RLAN devices:

Step 1: Determine base population size by zone.

Step 2: Apply a Busy Hour factor to determine the base population by zone.

Step 3: Apply Market Factor (percent of users with devices) by zone.

Step 4: Apply System Factor (determine number of cells) by zone.

Step 5: Apply Activity Factor (percent of cells operating) by zone.

Step 6: Apply Bandwidth Factor (percent of devices on-tune based on bandwidth distribution model).

Using the six step methodology, the number on-tune active RLAN devices per 20 MHz are forecasted in Table 4.

TABLE 4

RLAN On-tune, active devices

	Population	**Step 2 Busy Hour Factor**	**Busy Hour Population**	**Step 3 † Market**	**Step 4 † System**	**Step 5 † Activity**	**Step 6 * Bandwidth**
Urban	1 575 000	71%	1 118 250	894 600	62 622	15 656	
Suburban	2 625 000	64%	1 680 000	1 344 000	94 080	23 520	
Rural	1 050 000	47%	493 500	246 750	49 350	4 935	
Total						44 111	5 186 Per 20 MHz

TABLE 5

Market/System/Activity Factors

†	**Market**	**System**	**Activity**
Urban	80%	7%	25%
Suburban	80%	7%	25%
Rural	50%	20%	10%

The distribution of channel bandwidths for the number active RLAN devices in a 20 MHz bandwidth is shown in Table 6.

TABLE 6

Distribution of RLAN channel bandwidths

Start Channel	*	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
5 150 MHz	Percent	10%	25%	50%	15%
End Channel	Devices	4 411	11 028	22 055	6 617
5 850 MHz	Channels	35	17	8	4
	On-tune	126	649	2 757	1 654

Technical parameters

For each time step the RLAN device power, operating bandwidth, and height will be randomly determined.

The RLAN device e.i.r.p. level distribution for the baseline is shown in Table 7.

TABLE 7

RLAN power distribution[27]

RLAN e.i.r.p. level	**200 mW (Omni-Directional)**	**80 mW (Omni-Directional)**	**50 mW (Omni-Directional)**	**25 mW (Omni-Directional)**
RLAN Device Percentage (Indoor operation)	18%	26%	14%	37%
RLAN Device Percentage (Outdoor operation)	0.9%	1.3%	0.8%	2%

This study considers a limit on the e.i.r.p. of 200 mW to determine sharing feasibility. If higher power levels are submitted, additional studies will be required.

The RLAN device transmitter bandwidth distribution for the baseline is shown in Table 8.

TABLE 8

Bandwidth distribution

RLAN Transmitter Bandwidth	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
RLAN Device Percentage	10%	25 %	50 %	15 %

The RLAN antenna pattern is omnidirectional with –4 dBi effective gain in all directions.

[27] The e.i.r.p. levels and percentages are derived from: 1) predictions of shipped devices for various devices classes; 2) expected e.i.r.p. of the device classes; 3) matching the percentages from the sum of the rows in device distribution and 4) traffic mix in a Basic Service Set between Access Point and client.

Table 9 provides the distribution of RLAN device antenna heights for each RLAN deployment zone.

TABLE 9

Distribution of RLAN device antenna heights

RLAN Deployment Zone	Antenna Height (meters)
Urban	1.5 to 28.5 (3 meter increments)
Suburban	1.5, 4.5
Rural	1.5, 4.5

For omni-directional RLANs the antenna heights are randomly selected using a uniform probability distribution from the set of floor heights at 3 meter steps specified in Table 9 for the Urban, Suburban and Rural zones.

This analysis examines a scenario comprised of 95 percent of the RLAN devices operating indoors and 5 percent operating outdoors.

4 Methodology

The RLAN positions, pointing vectors, and RF characteristics are distributed based on the model described in Section 3.2 above. The radar is initially located some distance from the city centre. At each time step in the simulation, the radar location and pointing vector is determined based on the position and scanning characteristics of the radar. Then the power received by the RLAN devices is computed based on the RLAN and radar positions, pointing vectors, and RF characteristics. Any RLAN devices with a receive power that is above the DFS threshold are turned off, and remain off for the duration of the simulation. The aggregate interference into the radar from any RLANs that remain active is computed. Results are presented in a graph of the aggregate interference into the radar as a function of time.

The RLAN receive power is calculated as follows:

$$I_{RLAN} = P_{Radar} + G_{Radar}(\theta_{Radar}) - FL_{Radar} + G_{RLAN}(\theta_{RLAN}) - PL - CL - BL - FDR_{RLAN}$$

where:

I_{RLAN} = Interference power into RLAN, dBm

P_{Radar} = Radar signal power, dBm

$G_{Radar}(\theta_{Radar})$ = Radar antenna gain in direction of RLAN, dBi

FL_{Radar} = Radar insertion loss, dB

$G_{RLAN}(\theta_{RLAN})$ = RLAN antenna gain in direction of radar, dBi

PL = Propagation loss including clutter losses, dB

CL = Clutter losses, dB

BL = Building penetration loss, dB

FDR_{RLAN} = Frequency dependent rejection into RLAN, dB

The FDR applicable to the RLAN receiver is approximated as follows:

$$FDR_{RLAN} = \max(0{,}10 \times \log_{10}(BW_{Radar} / BW_{RLAN})$$

where:

BW_{Radar} = Bandwidth of radar signal, Hz

BW_{RLAN} = Detection bandwidth of RLAN device, Hz

The interference power into the RLAN is compared with the DFS threshold to determine which RLANs remains active.

The interference into the radar from each active RLAN is calculated as follows:

$$I_{Radar} = PD_{RLAN} + G_{RLAN}(\theta_{RLAN}) + G_{Radar}(\theta_{Radar}) - FL_{Radar} - PL - CL - BL + 10 \times \log 10(BW_{Radar})$$

where:

I_{Radar} = Interference power into radar from individual RLAN, dBm

PD_{RLAN} = RLAN signal power density, dBm/Hz

The radar signal bandwidth is assumed to be fully occupied by RLAN emissions.

The aggregate interference into the radar from all active RLANs in the 20 MHz channel (N_{RLAN}) is computed as follows:

$$I_{Total,Radar} = 10 \times \log_{10}\left(\sum_{i=1}^{N_{RLAN}} 10^{(I_{Radar,i}/10)}\right)$$

where:

$I_{Total,Radar}$ = Aggregate interference power into radar, dBm

5 Propagation characteristics

The propagation model utilized is from Recommendation ITU-R P.452-15.

Building losses for indoor RLAN devices are determined from a normal distribution with a mean of 17 dB and a standard deviation of 7 dB, with the restriction that the building loss cannot be less than one.

Clutter losses at the radar and RLAN locations are determined using the elevation angle dependent model adapted from Recommendation ITU-R P.452-14 as described in Appendix 1.

This study also includes the clutter loss of Recommendation ITU-R P-452-15 Equations 57 and 57a to account for the effects of ground cover in cases where the obstacles could typically intercede on the interfering signal path. For emitters in the rural area, the “High crop fields” clutter category of Table 4 of that Recommendation is utilized. For the suburban area, “Suburban” is utilized, and for the urban area, “Urban” is utilized. These clutter losses are shown in Table 10 and they are applied only in cases where the elevation angle from the RLAN to the radar is less than the associated maximum elevation angle specified in Table 11. The latter maximum elevation angles were computed using the clutter heights and distances specified in Table 4 of Recommendation ITU-R P.452, and negative elevation angles were truncated at 0° because they will not occur in this analysis. No clutter loss is assumed when the elevation angle of the interfering signal path exceeds the applicable maximum elevation angle shown in Table 11.

TABLE 10

Clutter losses values used in study

Ht (m)	Clutter Loss (dB)		
	High crop fields	**Suburban**	**Urban**
1.5	17.3	19.6	19.7
4.5	0[28]	16.0	19.6
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table 9)		18.8
10.5			15.1
13.5			6.8
16.5			1.3
19.5			0
22.5			0[2]
25.5			0[2]
28.5			0[2]

TABLE 11

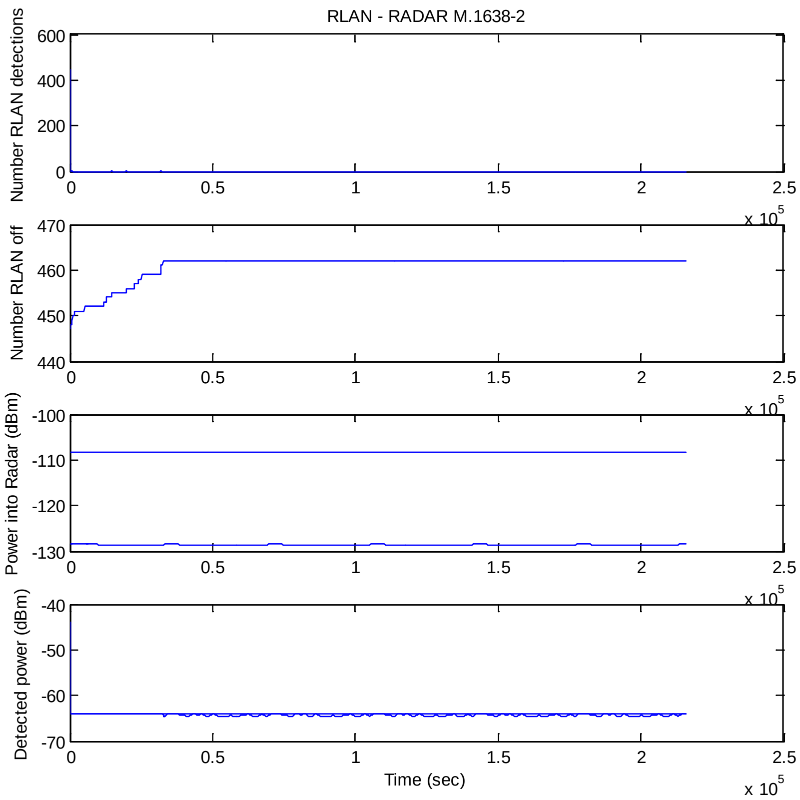
Elevation angles below which clutter losses could typically occur

Ht (m)	Maximum Elevation Angle (degrees)		
	High crop fields	**Suburban**	**Urban**
1.5	1.4	16.7	42.8
4.5	0.0	10.2	37.8
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table 10)		32.0
10.5			25.4
13.5			18.0
16.5			9.9
19.5			1.4
22.5			0.0
25.5			0.0
28.5			0.0

[28] Any values that would fall below 0 dB are set to 0 dB.

6 Results

Radar 2



RADAR (M.1638-2):

Radar location TX / RX	: [10.0, 0] / [10.0, 0] [km, deg]
Target height / range / offset	: 0 / [0, 0] / 0 km
FDR for each RLAN bandwidth	: [0.0, 0.0, 0.0, 0.0] dB
Protection requirement	: -108.2 dBm

RLAN:

Number in 1 Hz of radar bandwidth	: 5186
Activity factor	: 100.0 %
Percent deployment AP / Client	: 0.0 / 100.0 %
AP percent outdoor	: 0.0 %
AP EIRP	: [200.0, 200.0, 200.0, 200.0] dBm
AP EIRP percent indoor	: [25.0, 25.0, 25.0, 25.0] %
AP EIRP percent outdoor	: [0.0, 0.0, 0.0, 0.0] %
AP transmit peak gain / pattern	: -4.0 dBi / ND
AP receive peak gain / pattern	: -4.0 dBi / ND
AP losses	: 4.0 dB
Client percent outdoor	: 5.0 %
Client EIRP	: [200.0, 80.0, 50.0, 25.0] dBm
Client EIRP percent indoor	: [18.0, 26.0, 14.0, 37.0] %
Client EIRP percent outdoor	: [0.9, 1.3, 0.8, 2.0] %
Client transmit peak gain / pattern	: -4.0 dBi / ND
Client receive peak gain / pattern	: -4.0 dBi / ND
Client losses	: 4.0 dB
Bandwidth	: [20.0, 40.0, 80.0, 160.0] MHz
Bandwidth percent deployment	: [10.0, 25.0, 50.0, 15.0] %
DFS detection threshold	: -64.0 dBm
DFS detection probability	: 100.0 %
DFS detection delay	: 0.4 sec
DFS aggregate detections	: Inf
DFS aggregate period	: 0.0 sec
DFS aggregate delay	: 0.0 sec

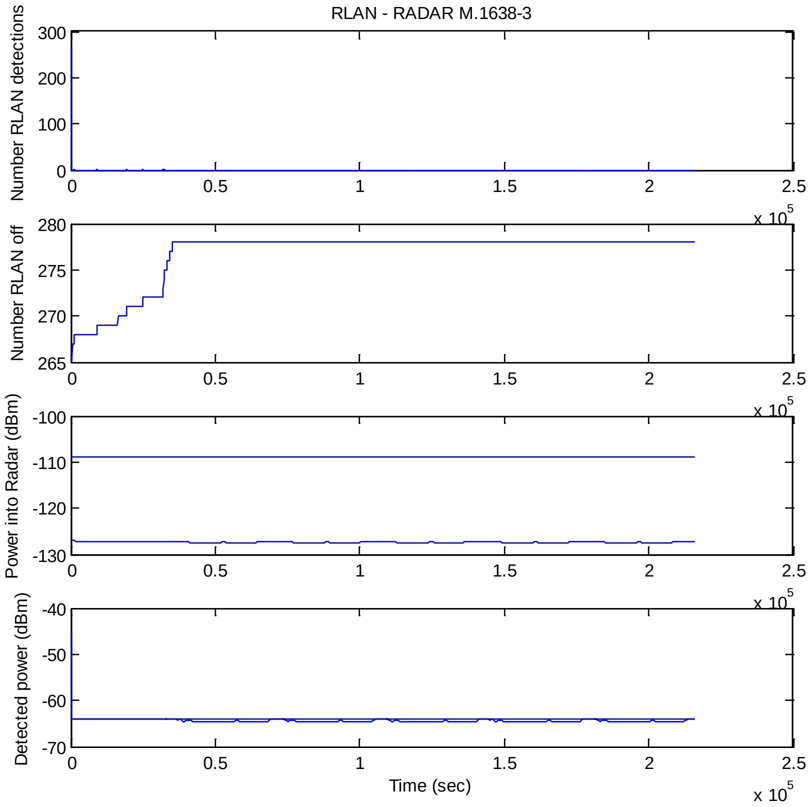
Simulation parameters:

Time increment	: 100.00 sec
Propagation model	: P.452
Building loss mean / SD / min	: 17.0 / 7.0 / 1.0 dB

Results summary:

Radar max exceedance	: -20.1 dB
Interference duration	: 0.0 sec

Radar 3



RADAR (M.1638-3):

Radar location TX / RX	: [10.0, 0] / [10.0, 0] [km, deg]
Target height / range / offset	: 0 / [0, 0] / 0 km
FDR for each RLAN bandwidth	: [0.0, 0.0, 0.0, 0.0] dB
Protection requirement	: -109.0 dBm

RLAN:

Number in 1 Hz of radar bandwidth	: 5186
Activity factor	: 100.0 %
Percent deployment AP / Client	: 0.0 / 100.0 %
AP percent outdoor	: 0.0 %
AP EIRP	: [200.0, 200.0, 200.0, 200.0] dBm
AP EIRP percent indoor	: [25.0, 25.0, 25.0, 25.0] %
AP EIRP percent outdoor	: [0.0, 0.0, 0.0, 0.0] %
AP transmit peak gain / pattern	: -4.0 dBi / ND
AP receive peak gain / pattern	: -4.0 dBi / ND
AP losses	: 4.0 dB
Client percent outdoor	: 5.0 %
Client EIRP	: [200.0, 80.0, 50.0, 25.0] dBm
Client EIRP percent indoor	: [18.0, 26.0, 14.0, 37.0] %
Client EIRP percent outdoor	: [0.9, 1.3, 0.8, 2.0] %
Client transmit peak gain / pattern	: -4.0 dBi / ND
Client receive peak gain / pattern	: -4.0 dBi / ND
Client losses	: 4.0 dB
Bandwidth	: [20.0, 40.0, 80.0, 160.0] MHz
Bandwidth percent deployment	: [10.0, 25.0, 50.0, 15.0] %
DFS detection threshold	: -64.0 dBm
DFS detection probability	: 100.0 %
DFS detection delay	: 0.4 sec
DFS aggregate detections	: Inf
DFS aggregate period	: 0.0 sec
DFS aggregate delay	: 0.0 sec

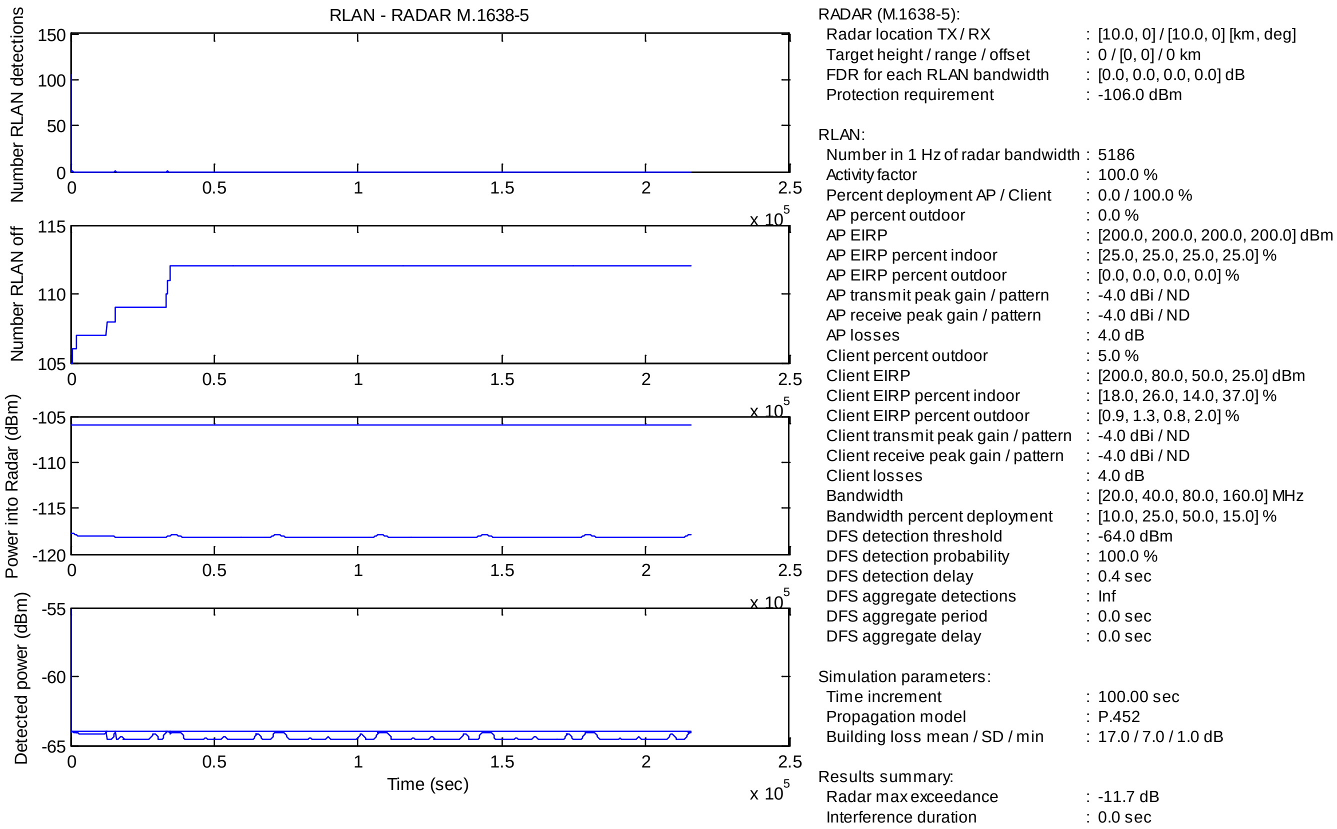
Simulation parameters:

Time increment	: 100.00 sec
Propagation model	: P.452
Building loss mean / SD / min	: 17.0 / 7.0 / 1.0 dB

Results summary:

Radar max exceedance	: -17.9 dB
Interference duration	: 0.0 sec

Radar 5



A summary of results for Radars 2, 3, and 5 is shown below.

Radar	Maximum Overage (dB)	Interference duration (sec)
Radar 2	–20.1	0.0
Radar 3	–17.9	0.0
Radar 5	–11.7	0.0

7 Conclusions

This analysis examined the potential for sharing between RLAN and radiolocation systems operating in the 5 350-5 470 MHz frequency range. The analysis utilized DFS parameters as currently specified in Recommendation ITU-R M.1652. This analysis concludes that Radars 2, 3, and 5 can be protected using DFS as currently specified (threshold of –64 dBm). Various domestic regulations already require DFS detection to .5 µsec but the ability of DFS to detect sub-microsecond pulses (0.25 µsec to .5 µsec) is not known at this time.

If different transmit powers or detection levels are applied, or if additional mitigation techniques are developed, the results may be different. Additional studies would be required to evaluate any other mitigation measures to determine their efficacy for RLAN sharing with ground-based radiodetermination systems. Studies on alternate mitigation measures have not been completed in the ITU and further study is required to determine their applicability.