Consideration of Interference Analysis for Wireless Systems in VHF/UHF Bands with Geographic Information

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Abstract

With the help of Rec. ITU-R P.1546 and geography information system, the interference analysis for the fixed wireless system and radar is presented based upon the frequency-distance rules with minimum coupling loss. To obtain the computational results, real geography information on the map was taken for the given area of 80x60[km]^2, and field strength and path profile were illustrated for radar and fixed wireless system operating at 2.7 GHz, for convenience. In addition the interference effect of receiver has been also examined as function of radar beam direction including protection ratio and frequency dependent rejection. The developed interference analysis can be actually applied to assess interoperability for wireless systems in the VHF and UHF bands.

Keywords: *Rec. ITU-R P.1546, Interference, Protection Ratio, Frequency Dependent Rejection, Geography Information*

1. Introduction

The radio spectrum is a vital but limited natural resource which provides the means to convey audio, video or other information content over distances. However it can only be used optimally if compatibility is assured between wireless systems located in the same or adjacent frequency bands. Nowadays due to better propagation characteristics in VHF/UHF and microwave bands, spectrum utilities get more increase in these bands compared with others [1, 2]. Thus the interference analysis in these bands has been greatly issued and much studied for assuring interoperability or compatibility for wireless systems. Basically there are two methodologies to analyze the interference criteria. One is to use Monte Carlo Analysis-SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) [3,4], which is a statistical methodology for the simulation of random process by randomly taking values from a probability density function. The other is the Minimum Coupling Loss (MCL) method, which has been extensively used for estimation of interference mechanism even though it is rigid and difficult to implement in many case not be described in static terms [5].

In recent military frequency bands are confronted with 3 changes in operational, technical, and regulatory aspects [6]. The first requires higher bandwidth, greater mobility, and greater agility under a net-centric warfare (NCW). The second asks for the growing spectrum requirement, caused by explosive demands in mobile communications with advanced wireless technologies during the last 10 years, and such a change in civil applications brings about the threat of shortage in military use, which gradually results in encroachment of military bands. And regulations require frequency sharing and harmonization, including impacts of host nation sovereignty and World Radiocommunication Conference.

Together with these trends nowadays the battle fields make some features, resulting from the complex combination with various battle elements and enable each one to share information in real time under NCW environment. In order to make assurance on interoperability for various frequency dependent systems under such environment, in advance, it is mandatory to analyze interference or compatibility for the battlefield scenarios. Recent studies in civil applications have been presented in the microwave band over radio relay systems, fixed satellite, fixed wireless access, and WiMAX from frequency coordination point of view [7-11]. In addition interference evaluations in inter-working multi-hop wireless networks, ad-hoc and sensor networks were also conducted including interference cancellation in OFDMA systems [12-14].

But researches in military utilities are rarely presented due to military specialty. Hence interference analysis and its implementation with geographic information are essential to clarify interoperability for systems in VHF/UHF bands, with constraint in limited military spectrum resource.

In this paper, to make one of solutions for analyzing frequency coordination under NCW environment, formulations for interference analysis based on MCL method are presented by Rec. ITU-R P.1546 combined with geographic information, and performance evaluations are also conducted between radar and fixed wireless system (FWS) for assumed system parameters including a frequency dependent rejection (FDR) as well as protection ratio.

2. Formulation of Received Signal and Protection Ratio

The interference power P_r (dBm) of the receiver (Rx), combined with the basic transmission loss of 1 kW ERP referred to Rec. ITU-R P.1546[15] , is given by [8]

$$P_r = E_{P.1546} + P_I + G_I + G_V - L_I - L_V - 20\log_{10} f - 139.3 - FDR \tag{1}$$

where P_r is the peak power of interfering system (dBm), G_I is the antenna gain of the interfering system in the direction of the victim receiver (dBi), G_V is the antenna gain of the victim receiver in the direction of the interfering system (dBi), L_I and L_V are the insertion losses of interfering system and victim receiver (dB), respectively. And $E_{P.1546}$ is the field strength $E(dB(\mu V/m))$ for 1kW ERP, f is the frequency (MHz) and FDR is the frequency dependent rejection (dB) given by [5]

$$FDR(\Delta f) = 10\log_{10}\left[\int_0^\infty S(f)df \Big/ \int_0^\infty S(f)R(f+\Delta f)df\right] \tag{2}$$

where $S(f)$ is the transmitter power spectral density, $R(f)$ is the receiver selectivity with the receiver tuned to the transmitter frequency, and Δf is the tunned transmitter frequency minus the tuned receiver frequency. For the special case of the interfering system operated at co-channel to the victim receiver, the simplified form of FDR is given by

$$FDR = \max(0, 10\log_{10}(B_I / B_V)) \tag{3}$$

where B_I is the emission bandwidth of the interference system and B_V is the input bandwidth of the victim receiver.

Figure 1 shows the geometry of FWS and radar with respect to the Rx height of FWS, where Rx may be interfered with radar. Let's define two vectors, $\vec{S}$ from Rx to transmitter (Tx) and $\vec{I}$ from Rx to radar. Then one may have a S-I plane with a unit normal vector of $\hat{a}$, and the discrimination angle θ between two lines can be readily derived by the inner product of two vectors, which is given by

$$\cos\theta = \frac{\vec{S} \bullet \vec{I}}{|\vec{S}||\vec{I}|} \tag{4}$$

$$\vec{S} = (x_S - x_{Rx})\hat{x} + (y_S - y_{Rx})\hat{y} + (z_S - z_{Rx})\hat{z} \tag{5}$$

$$\vec{I} = (x_I - x_{Rx})\hat{x} + (y_I - y_{Rx})\hat{y} + (z_I - z_{Rx})\hat{z} \tag{6}$$

where Tx and Rx positions are given by $r_S(x_S, y_S, z_S)$ and $r_{Rx}(x_{Rx}, y_{Rx}, z_{Rx})$, respectively, and interferer position is denoted by $r_I(x_I, y_I, z_I)$, and $\hat{x}$, $\hat{y}$, and $\hat{z}$ are a unit vector of each direction of x, y, and z, respectively. The magnitude of each vector represents the distance on S-I plane. In order to take geographic information into account, transformation of spherical to rectangular coordination should be applied. Then each position data on the rectangular coordination can readily obtained from latitude, longitude, and altitude on the spherical coordination.

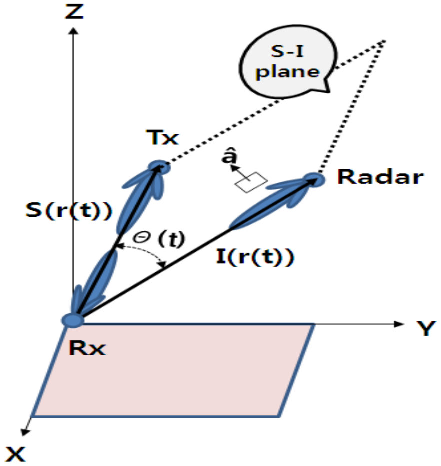


Figure 1. Geometry of Tx-Rx of FWS and Radar

The degradation of received signal caused by multiple interferers, assumed as the white Gaussian noise, is expressed by [16]

$$(C/N)_t = [(N/C) + (I/C)]^{-1} \tag{7}$$

$$(I/C) = [(I_1/C) + (I_2/C) +, \ldots, +(I_n/C)] \tag{8}$$

where $(C/N)_t$ is the total degraded (C/N) due to multiple interferences, and $(I_i/C)(i = 1,2,\ldots,n)$ is the i-th interference-to- carrier ratio.

Relating the calculated carrier-to-interference ratio of the link $(C/I)_{link}$ with protection ratio (PR), equivalent to minimum required (C/I) reflecting maximum allowable interference, PR is given by

$$(C/I)_{link} \geq PR(=(C/I)_{\min-rqrd}) \tag{9}$$

Therefore Figure 2 depicts the concept of PR including (I/N) and $(C/N)_{\min-rqrd}$, where variables k, T, and B are Boltzmann's constant ($1.38\times10^{-23} J/K$), Kelvin temperature ($290K$), and the receiver bandwidth in Hz, respectively.

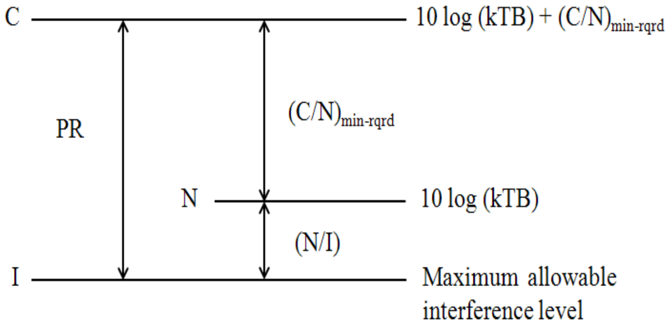


Figure 2. Concept of Protection Ratio

3. Computational Results and Discussions

To show some computational results, real geography information containing latitude, longitude, and altitude was selected as shown in Figure 3, where it covers the area of $80\times60[km^2]$. For arbitrary locations of Tx, Rx, and Radar1/2 in Figure 3, the geometry of systems is illustrated like Figure 4 comprising two S-I planes. The path profiles with 1st Fresnel zone are depicted in Figure 5 for Tx-Rx, Radar1-Rx, and Radar2-Rx links.

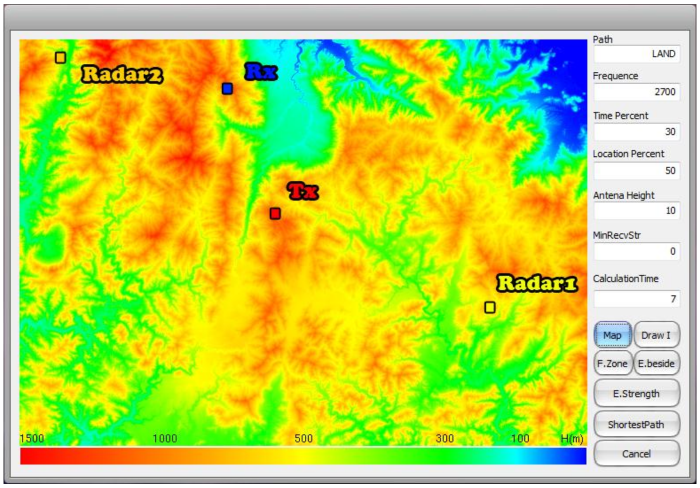

Path: LAND
Frequence: 2700
Time Percent: 30
Location Percent: 50
Antena Height: 10
MinRecvStr: 0
CalculationTime: 7

Figure 3. Geographic Information and System Locations

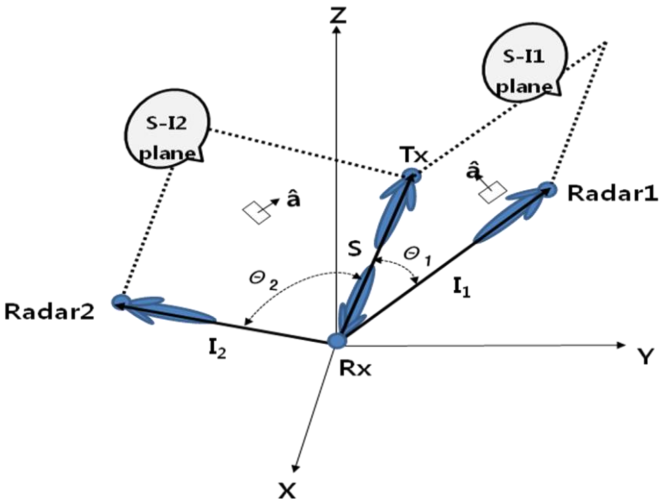
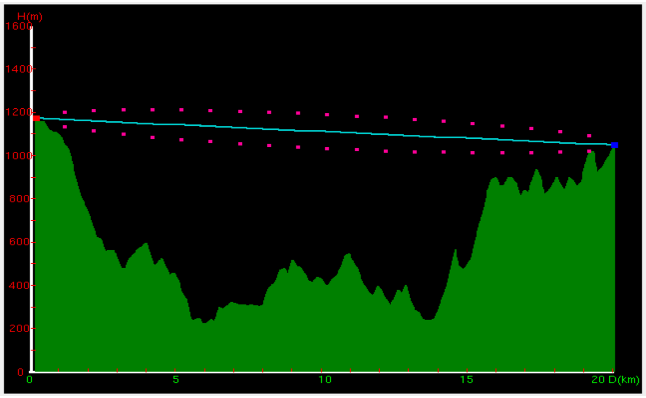
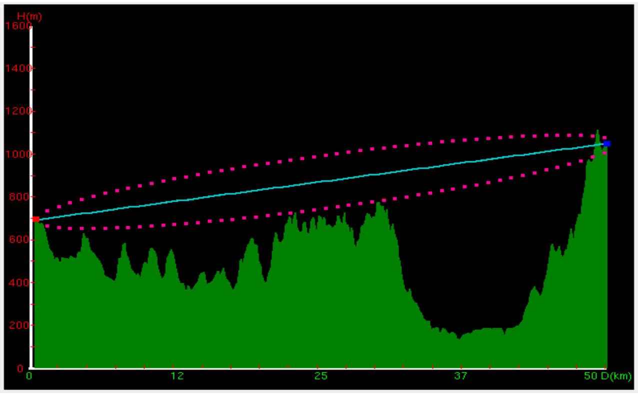


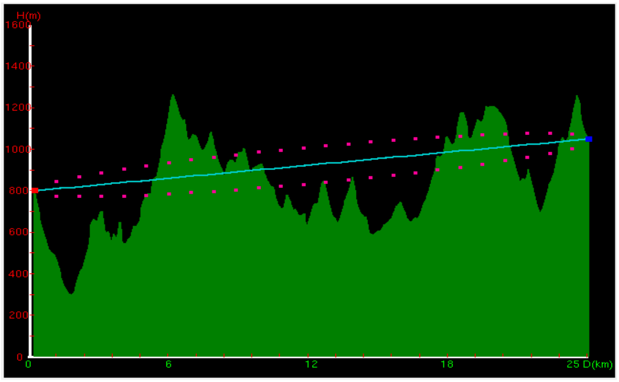
Figure 4. Geometry of Systems with Two Interferers



(a) Tx-Rx



(b) Radar1-Rx



(c) Radar2-Rx

Figure 5. Path Profile for Wanted and Unwanted Links

The assumed FWS parameters are shown in Table 1 where FWS is the radio relay system for transmitting data. For instance and simplicity the operating frequency of 2.7 GHz was taken with bandwidth of 40 MHz. From Table 1, it can be noted that the calculated *PR* yields 32.3 dB for the maximum allowable interference level of $I/N=-6$ dB which degrades the receiver threshold level of 1.0 dB.

Table 1. Assumed FWS Parameters and *PR*

Parameters	Values	Remarks
Tx power	27 dBm	Center freq. =2.7 GHz
Ant. gain	40 dBi	$G_t=G_r$
$(C/N)_{min\text{-}rqrd}$	26.3 dB @ BER 10^{-6}	64-QAM w/o coding
N	-97.98 dBm	BW=40 MHz
C	-71.68 dBm	
I	-103.98 dBm	I/N= -6.0 dB
$PR(=C/I)$	+32.3 dB	FDR= 0 dB

Figure 6 shows BER performances for FWS with 64-QAM as a function of C/I. As for the curve of $C/I=\infty$ dB, it is equivalent to the curve of C/N without interference. As can be expected from (7), BER performances are getting worse as the interference power increases.

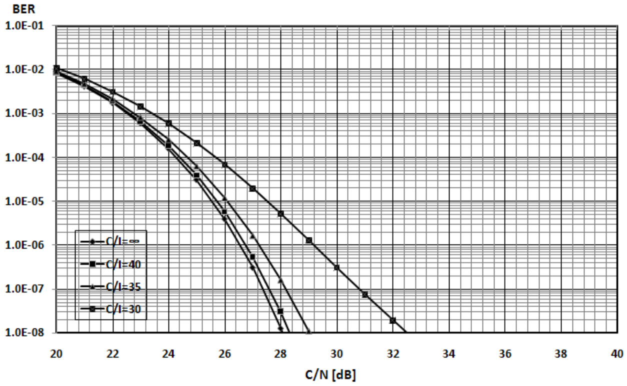


Figure 6. BER Performances for *C/I*

On the other hand, to examine the effect of *PR* with respect to *FDR*, it was assumed that radar interferes with Rx of FWS. For instance, we chose Radar1 spectrum mask $S(f)$ noted by the solid line and Rx selectivity $R(f)$ noted by the dotted line in Figure 7 [17]. Figure 8 indicates the calculated *FDR* as a function of frequency offset. For computing *FDR* the integration interval was taken from -45 MHz to $+45$ MHz over the center frequency of FWS because the cumulative power beyond that interval is negligible. Table 2 summarized the minimum required *PR* of FWS over frequency offset. Also one may calculate *PR* from *FDR* of Radar2 for the specified spectrum mask noted by the solid line in Figure 9[18] and Figure 10 illustrates the resultant output of *FDR*.

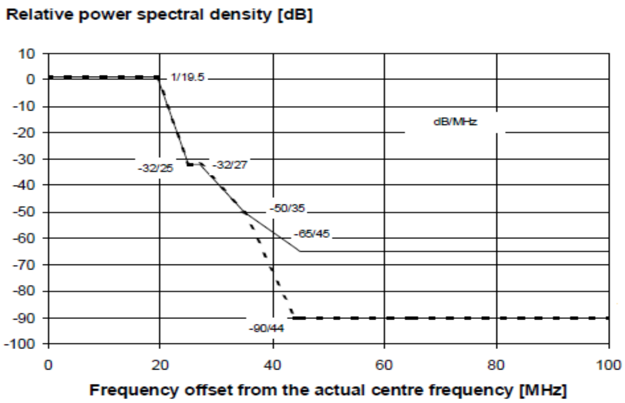


Figure 7. Radar1 Spectrum Mask (solid line) and Receiver Selectivity (dotted line)

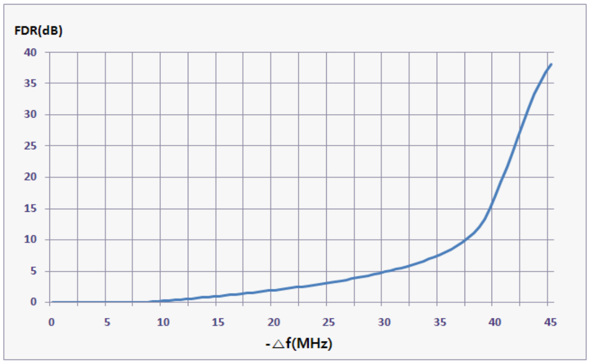


Figure 8. Calculated Values of *FDR* between Radar1 and Rx

Table 2. Required *PR* of Rx for Radar1

$-\Delta f$ (MHz)	*FDR* (dB)	*PR* (dB)
0	0	32.3
10	0.23	32.07
20	1.96	30.34
30	4.86	27.44
40	17.07	15.23

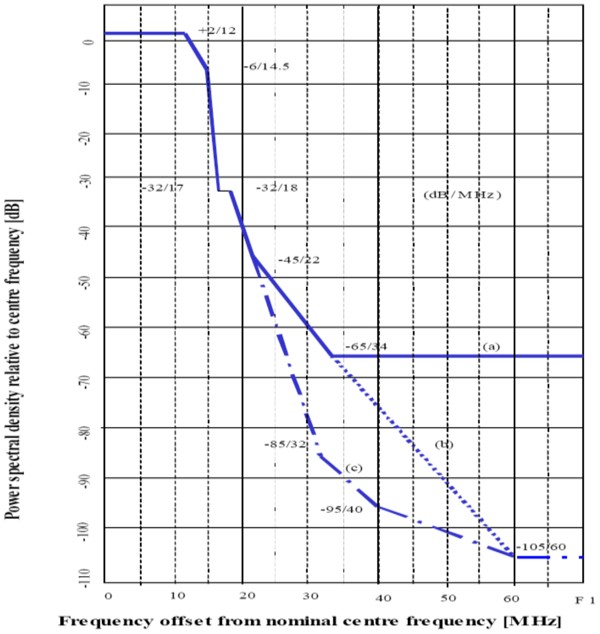


Figure 9. Spectrum Mask of Radar2 noted by Curve (a)

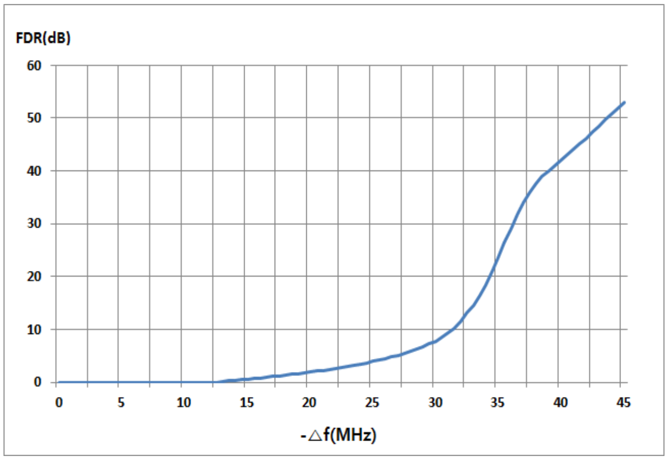


Figure 10. Calculated Values of *FDR* between Radar2 and Rx

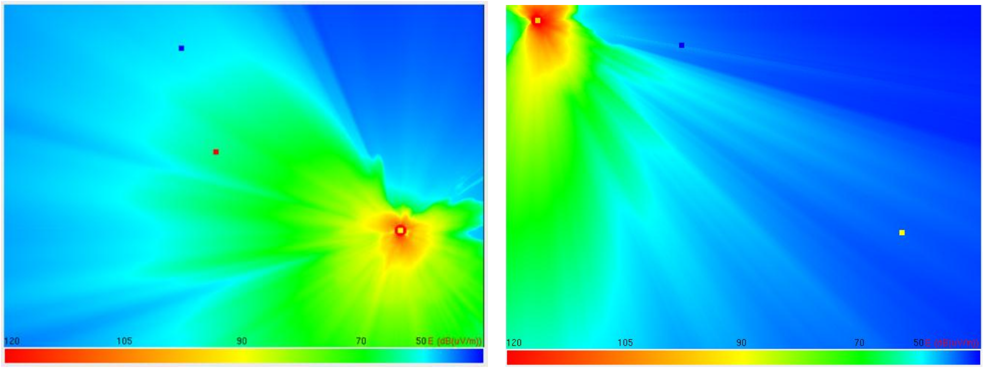
To check the effect of interference between FWS and radars for assuring interoperability, we considered the case of radar interfering with Rx of FWS. Table 3 illustrates the assumed radar parameters. For convenience, the centre frequency of radar and its peak power were taken as 2.7 GHz and 40 dBm, respectively. FWS is operated at the co-channel with radars with system losses $L_I = L_V = 0$ dB. Then *FDR* of 0 dB can be readily obtained from (3) because Rx bandwidth is the same as Radar1 or greater than Radar2.

In addition, to calculate the antenna gain we adopted a rotationally symmetrical antenna patterns for both systems. As for FWS, $D/\lambda = 18$ was selected where D is the maximum size of antenna and λ is the wavelength of frequency [19, 20].

Table 3. Characteristics of Radar1/2 Systems

Parameters	Assumed values
Center frequency	2.7 GHz
Peak power	Radar: 40 dBm (10Watts)
Main beam gain	40 dBi $(G_t=G_r)$
Pulse width	0.1 μsec
Rx IF bandwidth	Radar1/2: About 40/28 MHz @ 3 dB
Pulse repetition rate	2000 pps
Distance from Rx	Radar1/2: 50 km/ 25km
Radar altitude	Radar1/2 : About 344 m /252 m lower than Rx

With a view to calculating the interference power from (1) under Tables 1 and 3, the azimuth angles between Tx-Rx and Rx-Radar1/2 can be calculated by scalar product of two vectors, signal $\vec{S}$ and interference $\vec{I}$, which results in about 30.8 ° and 118.3 ° on S-I1 and S-I2 planes of Figure 4, respectively. Figure 11 illustrates the distribution of field strength values $E(dB(\mu V/m))$ around Radar1 and Radar2 on the map. Field strength values were found from Rec. ITU-R P.1546 combined with geographic information for 1 kW ERP, where the receiver height is 10 m equivalent to the representative height of ground cover around Rx, and percentages of time and location are 30 and 50, respectively. Then it enables us to calculate the received interference power of Rx over Radar1 and Radar2, based on the geographic information on the map resulting in the effective height of transmitting antenna.



(a) Radar1 (b) Radar2

Figure 11. Field Strength Distributions Around Radars

Finally as one of computational results, Figure 12 shows interference powers at Rx caused by two radars as a function of radar azimuth angle for frequency offset $\Delta f = -30$ MHz. The azimuth angle 0 ° is set in the direction of main beam of radar on the S-I plane in Figure 4. Since the discrimination angles between FWS and radars are already known, Rx antenna gains in the direction of radars can be easily determined [19]. As can be seen in Figure 11 (b), interference power at Rx caused by Radar2 is much lower than the maximum allowable interference level of -103.98 dBm. However interference power at Rx due to Radar1 is greater than -103.98 dBm for the angle less than 4.5 °. In consequence, it can be concluded that to assure the compatibility for Rx of FWS, Radar1 should have at least the off-axis angle greater than 4.5 ° from main beam direction under the assumed system parameters, frequency offset $\Delta f = -30$, and $I / N = -6$ dB.

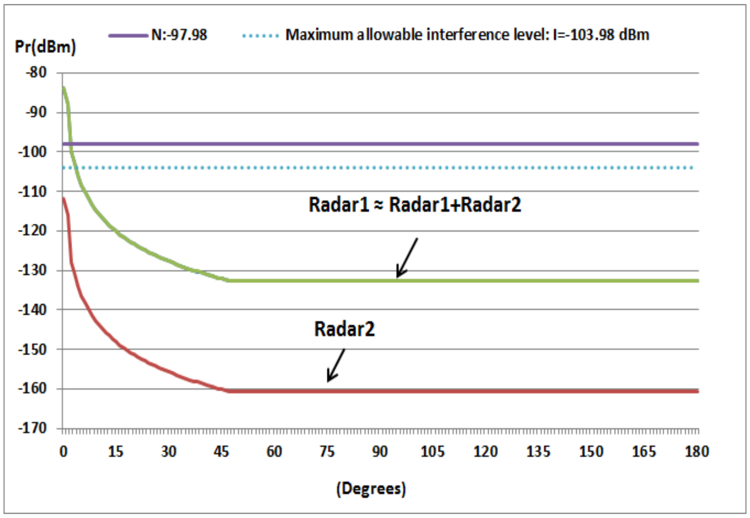


Figure 12. Received Interference Power of Rx for Radar Azimuth Angles

4. Conclusions

In this paper, taking advantage of radio propagation prediction of Rec. ITU-R P.1546 combined with geographic information, formulations of interference signal and discrimination angle have been presented to assess compatibility for wireless systems. The frequency-distance separation rule was adopted for interference analysis based on the minimum coupling loss with the maximum allowable interference level. To show some computational results for assumed system parameters, real geography data on the map were taken, and performance evaluations including protection ratio, frequency dependent rejection, and azimuth angle of radar main beam were also accomplished for fixed wireless system, interfered with radar operating at co-channel as well as frequency offset.

The presented formulation and method for interference analysis can be actually applied to evaluate frequency coordination or interoperability between wireless systems under the net-centric warfare in the VHF and UHF bands.

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