SECTION 6
ANALYSIS OF INTERFERENCE POTENTIAL TO VARIOUS SERVICES

6.1 INTRODUCTION

The potential impact of a single access BPL device to representative ground-based federal receivers is examined in this section, as is the impact of multiple co-frequency BPL devices on in-flight aeronautical receivers. Because of the wide range of federal systems that are of concern, representative systems in the fixed, land-mobile, maritime and aeronautical services were chosen for analysis.[44] The criteria for evaluating the risk of interference are defined in terms equivalent to moderate and high potential risk levels.

6.2 METHODOLOGY

It was assumed that the BPL systems conform to Part 15 field strength limits using existing BPL compliance measurement practices. Analyses of potential interference to fixed, land-mobile and maritime mobile services used the same methodology. For distances less than one kilometer, a NEC-4.1 model of a three-phase power line driven with a single source was used to estimate electric field strengths, from which received BPL interfering signal power was derived. Analyses of potential interference to aeronautical systems followed a somewhat different approach. An analytical model was developed using a Matlab software shell. In this time simulation, an aircraft operating an aeronautical mobile receiver was flown over and near a BPL deployment area. BPL signal levels were calculated with the aircraft either approaching or directly above the service area.

For all services, the calculated received BPL signal power was used with median background noise values to determine expected (I+N)/N characteristics at the potential radio receiver sites. This parameter was used to illustrate the effective increases in the radio receiver noise power level due to the combination of BPL interfering signals and noise. Calculations were performed at 4 MHz, 15 MHz, 25 MHz and 40 MHz using the same type of BPL system and power line configuration, but in the case of potential interference to aircraft radios, the power lines were randomly oriented.

In these interference calculations, it was recognized that the Part 15 field strength limits are defined in terms of quasi-peak and, as used in interference analyses, the power

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[44] Maritime and aeronautical services also have ground-based receivers. Although not specifically addressed in NTIA’s modeling, these stations are expected to be impacted similarly to the fixed service case modeled by NTIA.

levels for noise are root mean square (rms) values. Consequently, to compute a valid ratio of the two, or more specifically the power ratio (interference-plus-noise)-to-noise, (I + N)/N, a quasi-peak-to-rms conversion factor should be applied to the interfering signal power levels so that I and N both are specified as rms values. From a theoretical standpoint, the conversion factor for a pure sinusoidal signal is zero dB, whereas for a non-frequency-agile pulse-like signal having a uniform pulse repetition rate, quasi-peak levels can exceed rms by about 10 dB. BPL signals are expected to fall between these two extremes depending on their duty cycle. Limited measurements documented in Appendix D (See Section D.3.4) for a system employing OFDM modulation, show the conversion factor from quasi-peak to rms to be in the range of 0 to 5 dB. For this preliminary study, quasi-peak values were assumed to exceed rms values by 5 dB. Further study of this factor is needed.

6.3 RISK EVALUATION CRITERIA

6.3.1 Interfering Signal Thresholds

A given level of unwanted (interfering) signal power may cause interference ranging from barely perceptible to harmful levels depending on the magnitude of environmental and equipment noise, the desired signal level, as well as the temporal variability of each of these parameters.[45] Because these and several underlying parameters may vary substantially among locations and over time, the level of interference caused by BPL systems is both temporally and spatially stochastic. Other important considerations are whether the radio system is operating continuously or only occasionally (*e.g.*, as a back-up means of communications) and the speed with which harmful interference can be eliminated should it occur. These considerations relate to risk tolerance.

If the received desired signal is consistently very much more powerful than the noise and unwanted BPL signals, interference will not occur and receiver performance is dictated by the ratio of desired signal to noise power. Likewise, if the received unwanted BPL signal is very weak in relation to environmental noise power, it is unlikely to cause interference and receiver performance is dictated by desired signal and noise power levels. It is instructive to consider both permutations of variables for evaluation of BPL interference risks, namely, the ratio of received BPL signal power to noise power under conditions of strong and weak desired signal levels. As shown in Equations 6-1 through 6-3, below, this interference-to-noise power ratio (I/N) relates directly to an increase in the receiver noise floor or a reduction in the ratio of desired signal-to-total noise (*i.e.*, the ratio (N+I)/N or -ΔS/N).

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[45] "Interference" is defined in 47 C.F.R., §2.1. “Parties responsible for equipment compliance should note that the limits specified in this part will not prevent harmful interference under all circumstances.” 47 C.F.R. §15.15(c).

$$\Delta S/N = -(N+I)/N = -10\log(10^{0.1(I/N)} + 1) \quad (6\text{-}1)$$

$$\Delta S/N \approx -(I/N), \text{ for } I/N > 6 \text{ dB} \quad (6\text{-}2)$$

$$I/N \approx F_u - F_{am},\ F_{am} >> \text{receiver system noise figure} \quad (6\text{-}3)$$

where:

$\Delta S/N$	is the change in signal-to-noise power ratio (dB) caused by the unwanted signal (always a negative number corresponding to a reduction of S/N);
I/N	is the ratio of unwanted signal power to total receiver system noise power (dB), with power levels measured in the same reference bandwidth;
F_u	is the field strength of the BPL signal (dB(μV/m)); and
F_{am}	is the total field strength of all environment radio noise (dB(μV/m)).

In order to minimize potential interference and promote efficient reuse of assigned and adjacent frequencies, by treaty, radio transmission systems should not radiate substantially more power than what is needed to fulfill communications requirements.[46] For most frequency sharing situations, it is well established in international and domestic spectrum management practices to generally limit interfering signal levels in a manner that preserves good control over radio system performance by designers and operators (*e.g.*, (I+N)/N = 0.5 or 1 dB). However, for the interference risk evaluation herein, the focus is on risks under the most typical situations (*i.e.*, the statistical mode of possible scenarios). Less favorable situations are not considered, *e.g.*, where desired signals are near the minimum levels needed to fulfill performance objectives. Thus, in general, it is assumed herein that substantial and perhaps harmful interference will occur in a high percentage of cases if the (I+N)/N ratio exceeds 10 dB (a factor of 10). It is assumed that substantial interference will occur in a smaller but still significant percentage of cases if (I+N)/N is 3 dB (a factor of 2, or a doubling of the "noise floor" of the receiver). There is still a small probability that interference will occur with (I+N)/I of 1 dB or less (I/N of -6 dB or less) and, at the least, unwanted signals at these levels manifest interference during signal fading (*i.e.*, reductions in communications availability). In this phase of study, the extent of geographic areas associated with various levels of (I+N)/N are determined. Levels of (I+N)/N of 3 dB and 10 dB are considered as important interference risk thresholds because these levels relate to moderate and high likelihood of interference, respectively, for unknown levels of desired signal power.

To put the 3 dB and 10 dB (I+N)/N levels (S/N reductions) in perspective, Figure 6-1 illustrates the S/N reduction caused by an unwanted signal at the Part 15 limit level. Figure 6-1 shows that in an environment having the typical median noise power level of a residential environment (Kansas City, MO), field strength at the Part 15 limit would reduce the S/N by over 15 dB.

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[46] *See e.g.*, ITU Radio regulation Nos. 3.3, 4.3, 4.11, and especially 15.2 ("Transmitting stations shall radiate only as much power as is necessary to ensure a satisfactory service.")

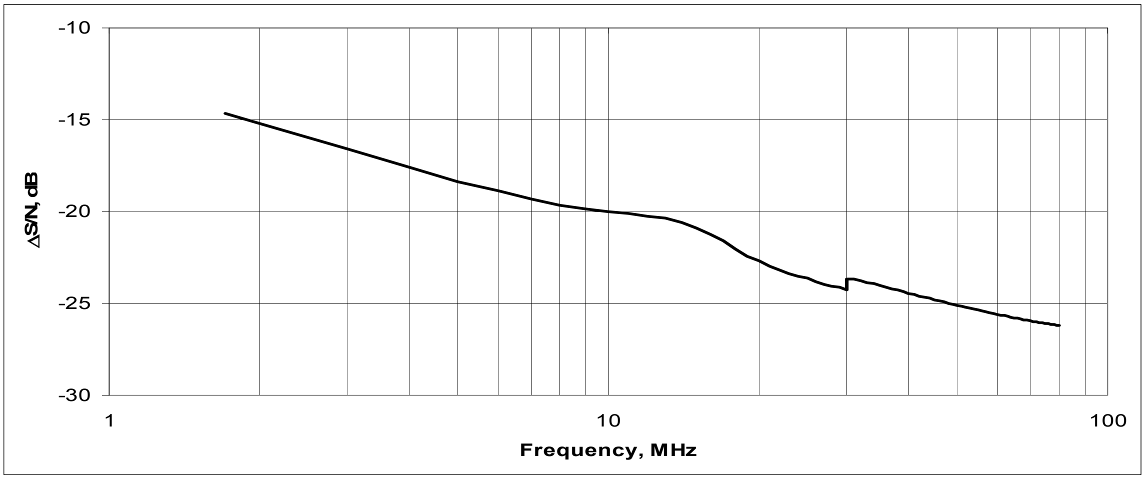

Figure 6-1: Change in Receiver Signal-to-Noise Power Ratio Caused By Unintentional Emissions at the Part 15 Limit[47]

To illustrate the extent of area in which (I+N)/N is greater than or equal to 3 dB, Figure 6-2 depicts the range of separation distances generally needed between a receiving antenna and one Part 15 device acting as a single-point source and radiating power toward the antenna at a level that exactly complies with the Part 15 field strength limit. As noted above, actual BPL system radiating characteristics will be considered in the interference risk analysis, and so, radiation at the level of the present Part 15 limits would occur only in the direction(s) of peak radiation.

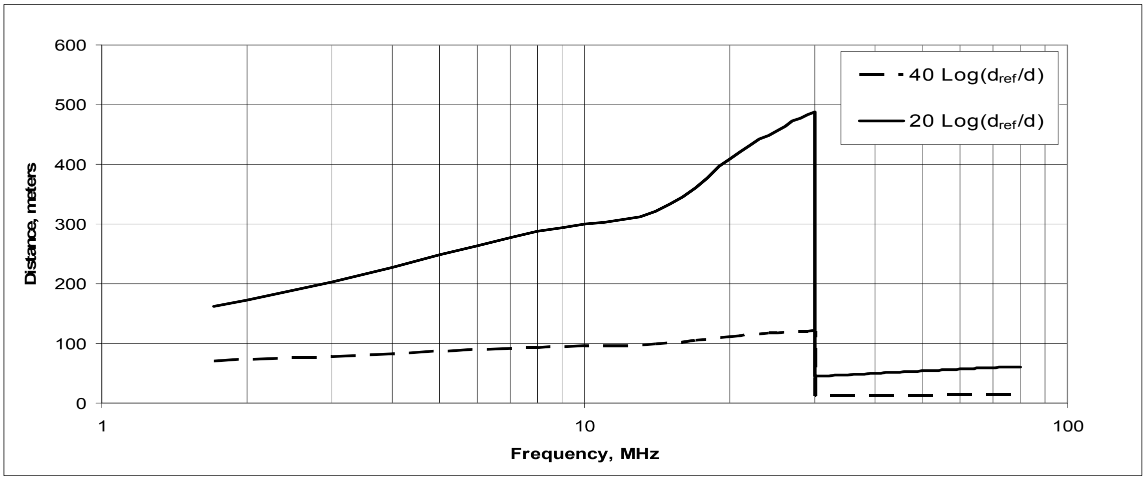

Figure 6-2: Distance at which external noise levels equal FCC Part 15 radiated emission limits (Class B)[48]

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[47] Above 30 MHz, the limit and bandwidth for Class B devices is assumed in Figure 6-1. Noise levels used are median for Kansas City, MO.

[48] Figure 6 assumes that Fam = Fu (see equation 6-3). The “40 Log…” curve is representative for a point source radiating toward a radio antenna located at most a few meters above the ground. The “20 Log…” curve pertains to a radio antenna located well above ground level (*e.g.*, >10 meters).

6.3.2 Noise Calculations

For the purposes of this study, ambient background noise was calculated using the Institute for Telecommunication Science's NOISEDAT computer program.[49] This program implements the data contained in the ITU-R Rec. P.372-8 discussed in section 5.4.4. Noise was calculated for a centrally-located geographic point (Kansas City, Kansas.) for all times of the day and seasons of the year under residential conditions. From this data, the median noise levels at each frequency of interest were used as background noise for (I+N)/N calculations. The one exception to this regime for the noise power levels used for off-shore ship station calculations, for which noise data at a location off the Atlantic coast near Wallops Flight Facility in Virginia under "quiet rural" conditions was used.

After adjusting for a single-sideband (SSB) receiver noise bandwidth of 2.8 kHz for frequencies less than 30 MHz and a bandwidth of 16 kHz for frequencies greater than 30 MHz, the noise power levels listed in Table 6-1 were used.

Table 6-1: Noise power values for (I+N)/N calculations.

Service	Location and Conditions	Noise Power, dBW (N_{dBW})			
		4 MHz	15 MHz	25 MHz	40 MHz
Land Stations[50]	39.12 N, 94.62 W, Residential	-111.3	-128.8	-135.6	-134.3
Ship Stations	37.69 N, 75.25 W, Quiet Rural	-119.3	-136.9	-150.0	-147.5

6.4 INTERFERENCE MODELS

NEC modeling for this report was used to derive electric field strength and far-field radiation patterns due to a power line energized by a single BPL device. Electric field strength levels generated by the simulated BPL system in areas where the representative ground-based receivers typically operate were evaluated statistically.

6.4.1 Receiving Systems

Representative systems from the land-mobile, fixed, maritime and aeronautical services were chosen, and system characteristics were subsequently used in interference calculations. Various parameters from all the chosen systems are listed in Table 6-2.

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[49] NOISEDAT is available from the ITU Website, URL: http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html.

[50] Land stations include land mobile, fixed, maritime coast and aeronautical stations.

Table 6-2: Receive system characteristics used in interference study.

Receiver Characteristics (2-30 MHz)	**STATION TYPE**			
	Fixed and Land	**Land Mobile**	**Maritime Mobile**	**Aeronautical**
Bandwidth (kHz)	2.8	2.8	2.8	2.8
Modulation	J3E	J3E	J3E	J3E
Antenna Type	Horizontal dipole	Vertical whip	Vertical whip	Vertical whip
Antenna Height (m)	42.7	2	9	6, 9, & 12 km
Antenna Length (m)	24.4	3	4	3
Polarization	Horizontal	Vertical	Vertical	Vertical or horizontal
Noise Environment	Residential	Residential	Quiet Rural	Residential
Antenna Gain (towards horizon) dBi	0	-4.8 @ 4 MHz -0.9 @ 15 MHz 0.3 @ 25 MHz	0	0
Horizontal distance from BPL	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-50 km from center of BPL service area
Interference Criteria (I+N)/N	3 & 10 dB	3 & 10 dB	3 & 10 dB	3 & 10 dB
Receiver Characteristics (30-50 MHz)				
Bandwidth (kHz)	16	16	16	16
Modulation	F3E	J3E	J3E	J3E
Antenna Type	Vertical whip	Vertical whip	Vertical whip	Vertical blade
Antenna Height (m)	42.7	2	9	6, 9, & 12 km
Antenna Length (m)	6	2	2	2
Polarization	Vertical	Vertical	Vertical	Vertical
Noise Environment	Residential	Residential	Quiet Rural	Residential
Antenna Gain (towards horizon) dBi	3	2	2	0
Horizontal distance from BPL	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-50 km from center of BPL service area
Interference Criteria (I+N)/N	3 & 10 dB	3 & 10 dB	3 & 10 dB	3 & 10 dB

6.4.2 Power Line Model

The NEC power line model used in these analyses consisted of three parallel straight wires, each 340 meters long, spaced in a horizontally parallel configuration 0.6 meters apart. The three wires were given conductivity characteristics equal to copper wire and AWG 4/0 diameter. They were placed 8.5 meters above a "Sommerfeld" ground with average characteristics (relative permittivity $\varepsilon_r = 15$, conductivity $\sigma = .005$ Siemens/meter) to simulate land-mobile and fixed service conditions, and above a Sommerfeld ground with saltwater characteristics (relative permittivity $\varepsilon_r = 81$, conductivity $\sigma = 5$ Siemens/meter) to simulate power lines along a coast line for maritime conditions. One of the outer power lines was center-fed using a voltage source to simulate the BPL coupler. The source was set to provide 1 volt. The source impedance (modeled by serially loading the segment upon which the source was placed) was given a real impedance of 150 Ω.

The ends of the long wires were connected together at each end by inter-phase loads of 50 Ω each (wires 1 and 2 and wires 2 and 3 were connected in this manner) to simulate a degree of system loading and discontinuity.

The wires used for this model were segmented following recommendations from Lawrence Livermore National Laboratories NEC documentation. Specifically, segment length was set to provide 20 segments per wavelength at the desired frequency, rounded up to an odd number of segments. This resulted in 340-meter-long wires consisting of 91, 341, 567 and 907 segments each for 4 MHz, 15 MHz, 25 MHz and 40 MHz, respectively. Convergence testing (by increasing the number of segments for each frequency) and average gain testing indicated good model stability and behavior.

6.5 INTERFERENCE CALCULATIONS

6.5.1 Scaling Output Power to Meet FCC Part 15 Limits

FCC Part 15 measurement procedures generally follow American National Standards Institute (ANSI) publication C63.4-1992, which specifies measurements with both vertical and horizontal polarization. To ensure the modeled radiation from the wires met FCC Part 15 limits consistent with existing BPL measurement practices, initial NEC runs were executed to find the expected electric field in the x-, y- and z-vector directions at a height of one meter above the ground, 30 meters away from the wire on which the voltage source was placed, for 4 MHz, 15 MHz and 25 MHz, and at a distance of 3 meters away at 40 MHz. The rms values of the NEC-calculated electric field x, y and z-vectors would be found in a straightforward manner, assuming a sinusoidal BPL test signal, as shown in the following equation.

$$E_x = \frac{E_{\circ x}}{\sqrt{2}}, E_y = \frac{E_{\circ y}}{\sqrt{2},} E_z = \frac{E_{\circ z}}{\sqrt{2}} \qquad (6\text{-}4)$$

where

E_{ox}, E_{oy}, E_{oz} are the magnitudes of the NEC-calculated x-, y- and z-vector electric-fields

The calculated electric field values were then divided by the FCC Part 15 limits (30 μV for frequencies less than 30 MHz, 100 μV for frequencies greater than 30 MHz), and the maximum such value found along the line in any vector was used to scale all subsequent electric field calculations. Because measured quasi-peak values of field strength are expected to be near or slightly exceed the above rms values (see Appendix D, Section D.3.4), this scaling process may yield adjusted field strength values slightly in excess of values needed for compliance using a quasi-peak detector. The purpose of this exercise was to ensure the radiated signal complied with FCC Part 15 limits for each frequency.

6.5.2 Analysis Methodology for Land-Mobile, Fixed and Maritime Services

After the initial “scaling” runs, NEC simulations were performed to find the spatial distribution of electric field strength values. The calculations were made for a geographic grid of points with 5 meter spacing along and away from the line to a distance of 1 km, at heights of 2 meters, 42.7 meters and 9 meters to simulate land mobile vehicle, mobile-base/fixed and ship antennas, respectively. This grid included points lateral to the power lines and excluded points off the end of the modeled power line, as it was felt that the arbitrary ending of the power line at both ends of the power line layout would yield unrealistic radiation properties in nearby areas. The NEC simulations indicated substantial radiation off the ends of the line, and real-world power lines do indeed terminate at many points.

Electric field values were calculated using NEC’s ground wave capability for distances greater than one kilometer from the line. These values were calculated in cylindrical coordinates, meaning values were found for a given distance and height in a circle around the power line model. Values were calculated in 5-degree increments at distance increments of 100 meters from 1 km to 4 km, at the same antenna heights used for near-field calculations.

In addition to the above NEC runs, a “close-in” simulation was completed to gather fine detail along the line at land-mobile antenna height (two meters). This was done to determine the degree of potential interference expected to be found on streets next to power line runs. This “close-in” run was done using NEC’s near-field facility on a grid with 0.5 meter spacing out to a distance of 15 meters from the line.

Once calculated, the electric field values were scaled and the relevant real field value (E_x for the vertical land mobile antenna, E_y and E_z for horizontal fixed and maritime antennas) was translated into received interfering signal power as follows:

$$\begin{aligned} P_{(dBW)} &= 20 \cdot Log_{10}\left(E_{V/m}\right) - 20 \cdot Log_{10}\left(F_{MHz}\right) + G_{r(dBi)} \\ &\quad + 10 \cdot Log_{10}\left(BW\right) + 10 \cdot Log_{10}(\phi) + \delta + 12.8 \end{aligned} \tag{6-5}$$

where

$E_{V/m}$ is the received signal strength in V/m

F_{MHz} is the measurement frequency in MHz

G is the gain of the receiving antenna

BW is the ratio of receiver to measurement bandwidth

ϕ is the average duty cycle

δ is a quasi-peak to rms measurement factor

For the purposes of this study, the *average duty cycle* (ϕ) was taken to be 55%, which was midway between an always-on (100%) downstream signal and an intermittent (10%) upstream customer-to-internet signal. Additionally, to compensate for differences between ambient noise levels expressed in rms values and BPL signal radiation measured using quasi-peak detection, a *measurement factor* (δ) adjustment of -2 dB was applied to the calculated received BPL signal power.

From the received signal power and the background noise, the (I+N)/N ratio was calculated at each point in the assumed receiver operating areas:

$$\left(I + N\right)\Big/ N = 10 \cdot Log_{10}\left[1 + 10^{\left(P_{dBW} - N_{dBW}\right)/10}\right] \tag{6-6}$$

Once these calculations were complete, the percentages of locations for each distance value (near field and ground wave calculations) or in areas around the BPL-energized line (for close-in land-mobile situations) exceeding given (I+N)/N values were determined.

6.5.3 Analysis Methodology for Aeronautical Service

In order to calculate interference to an aircraft receiver, several parameters were defined:

- BPL service area: circular area of 10 km radius (6.2 miles)

- Number and density of co-channel BPL transmitters: 1200, 300, and 75 deployed over an area of 314 km^2, with approximately 0.5, 1, and 2 km separation between units, respectively
- BPL unit radiated power:
    - For 4 MHz: -69.8dBW/2.8 kHz
    - For 15 MHz: -67.3dBW/2.8 kHz
    - For 25 MHz: -64.9dBW/2.8 kHz
    - For 40 MHz: -81.1dBW/16.0 kHz

BPL device output power was derived from the NEC scaling runs. NEC-calculated power line input power was scaled by the square of the scaling factor for each frequency, as well as by the ratio between the receiver and measurement bandwidths. Additionally, NEC was used to find the far-field directional gain pattern from the modeled power lines for all frequencies of interest. Simulations were run using the directional gain pattern in azimuthal directions both parallel and perpendicular to the main radiation lobe of the power line. The average directional gain levels for each elevation were found for the two patterns (Figure 6-3) used in the analysis.

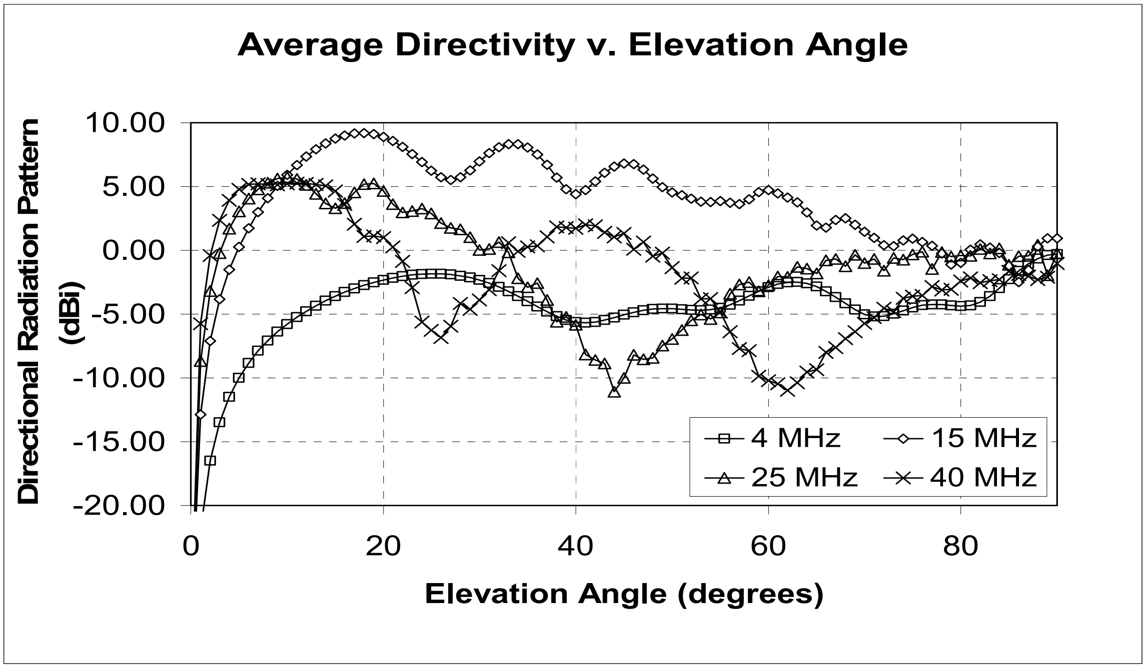


Figure 6-3: Average far field directional gain antenna patterns used for aeronautical interference calculations.

As mentioned previously, a Matlab model was used to simulate an aircraft at various heights and horizontal distances from the centroid of a BPL deployment area. This model simulated the signal effects of multiple BPL devices in different deployment cells at the aircraft location.

As with interference calculations for the other services, several additional factors were taken into account. Two of these, duty cycle (ϕ) and quasi-peak to rms measurement factor (δ) were discussed in subsection 6.5.2, and the same values were used here (55% and -2 dB, respectively). An additional adjustment factor, *polarization mismatch*, was used with aeronautical service calculations. This factor was designed to compensate for the fact that the aeronautical service antenna used in this simulation was vertically polarized, whereas the BPL structure was horizontally polarized. Both structures interacted with radiation of the opposite polarization in NEC simulations. For example, the BPL structure produced significant (or even primary) radiation that was vertically polarized in most azimuthal directions. Further, over a significant number of azimuthal directions, the short aeronautical antenna could be expected to respond well to both horizontally- and vertically-polarized radiation. Nonetheless, for a small number of orientations a cross-polarization effect would likely reduce coupling between the BPL structure and the receiving antenna. In order to account for this effect, an overall decrease of 1 dB in the received BPL signal was assumed.

6.6 RESULTS OF INTERFERENCE CALCULATIONS

6.6.1 Land-Mobile Service

Calculations of close-to-the-line interference potential for vehicular land-mobile receivers due to a BPL transmitter operating at FCC Part 15 limits show that there would be significant increases in the noise floor due to interference. As can be seen in Table 6-3, for frequencies less than 30 MHz, virtually all points close to the line would experience (I+N)/N levels greater than 10 dB. In other words, there would be at least a ten-fold increase in total receiver noise power on the street adjacent to the BPL device and power lines. At 40 MHz, a majority of the areas in a road along the power line would see this level of interference.

Table 6-3: Percent of points exceeding specified interference level, by frequency, for land-mobile receiver system within 15 meters of a BPL-energized power line. Radiated power and noise are into a 2.8 kHz bandwidth for 4 MHz, 15 MHz and 25 MHz, and a 16 kHz bandwidth at 40 MHz.

Frequency (MHz)	Radiated Power (dBW)	Noise (dBW)	3 dB (I+N)/N	10 dB (I+N)/N	20 dB (I+N)/N	30 dB (I+N)/N	40 dB (I+N)/N	50 dB (I+N)/N
4	-69.8	-111.3	99.3%	93.2%	54.7%	6.2%	0.0%	0.0%
15	-67.3	-128.8	99.8%	99.7%	95.7%	59.5%	4.3%	0.0%
25	-64.9	-135.6	99.8%	99.0%	92.1%	58.5%	18.5%	0.0%
40	-81.1	-134.3	87.9%	49.2%	10.0%	0.0%	0.0%	0.0%

The increases in the noise floor a land-mobile system might encounter along a BPL-energized power line are further illustrated in Figure 6-4. In this figure, (I+N)/N values are depicted using colors from red to blue, with dark red representing 50 dB and dark blue representing zero.

It can be inferred from these calculations that a vehicle-mounted HF receiver operating in a residential environment on a roadway adjacent to a BPL-energized power line may experience harmful interference, depending upon the frequency, the distance along the line away from the BPL transmitter, the BPL transmitter duty cycle and the number of BPL devices on the line.

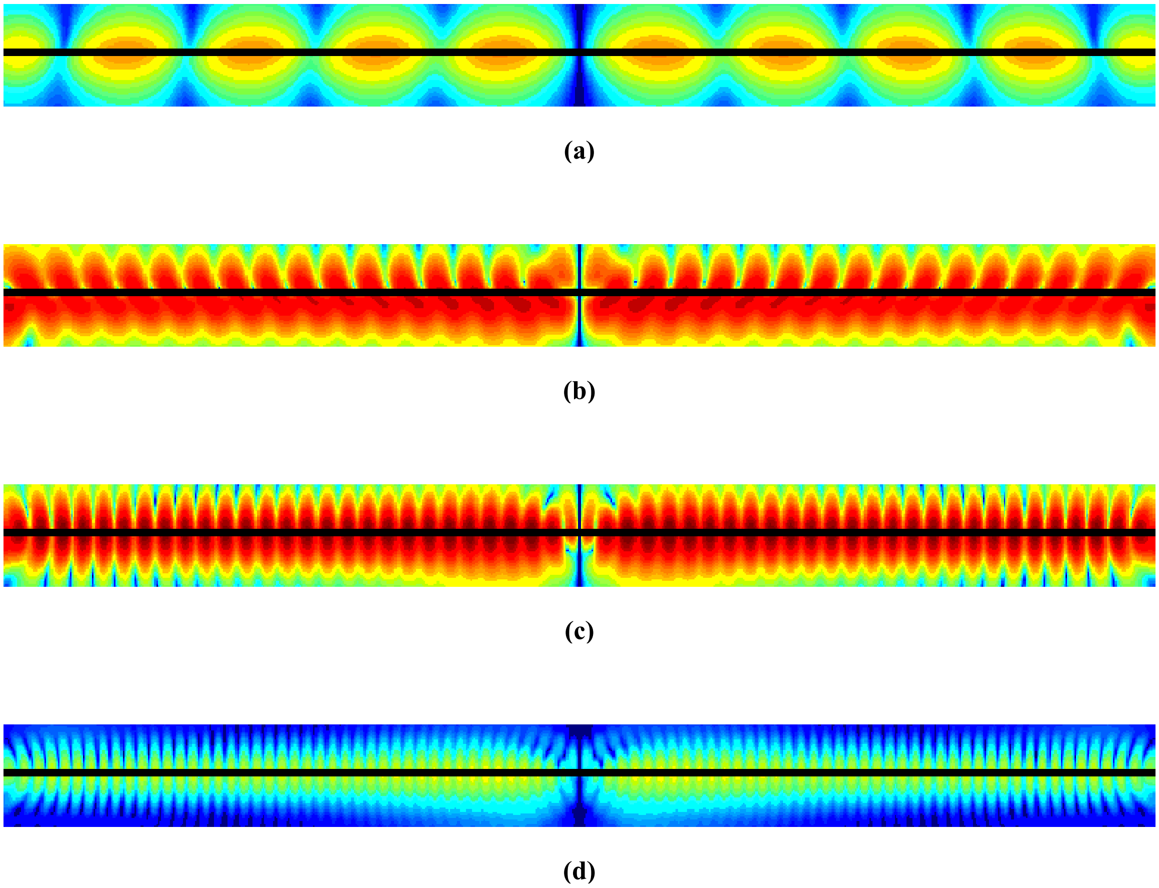
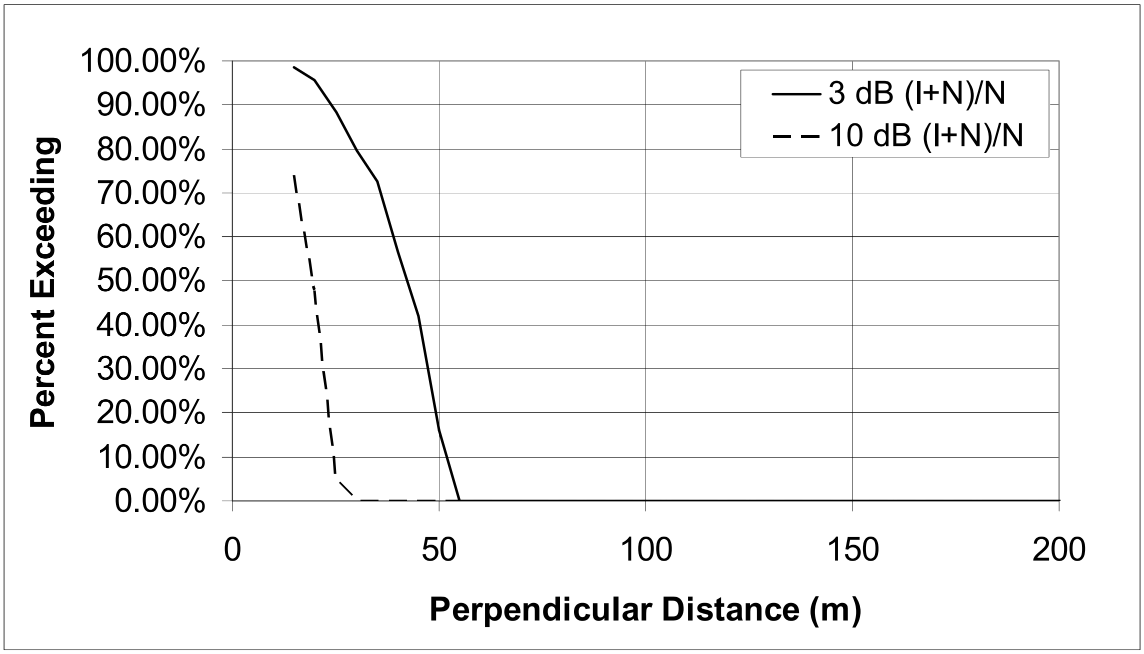


Figure 6-4: (I+N)/N values around the modeled power line, to a distance of 15 meters. Colors represent a range from zero dB (dark blue) to 50 dB (dark red). a) 4 MHz. b) 15 MHz. c) 25 MHz. d) 40 MHz. The BPL structure is denoted with a dark horizontal line in the center of each plot.

Near-field calculations of interference levels stemming from a single BPL device, out to a distance of one kilometer from the power line, indicated a sharp falloff in the level of interference with distance. As shown in Figure 6-5, out to distances on the order of 120 meters from the power line, a land-mobile receiver operating in the modeled noise environment could experience interference.

Ground wave calculations of interference levels at a distance from one to four kilometers were in good agreement with those for the near field. Results at a nominal one kilometer near-field/ground-wave juncture were well-matched. In no areas adjacent to, and more than 120 meters from the power lines would the modeled land-mobile system be likely to experience significant interference from a single BPL transmitter operating at FCC Part 15 limits.



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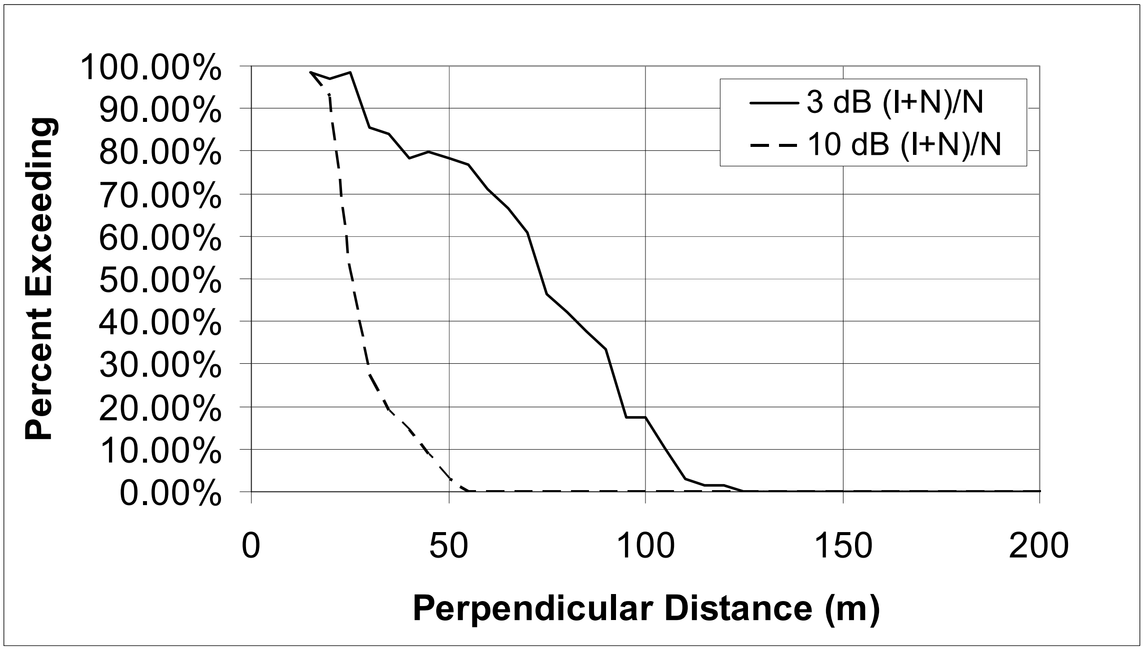
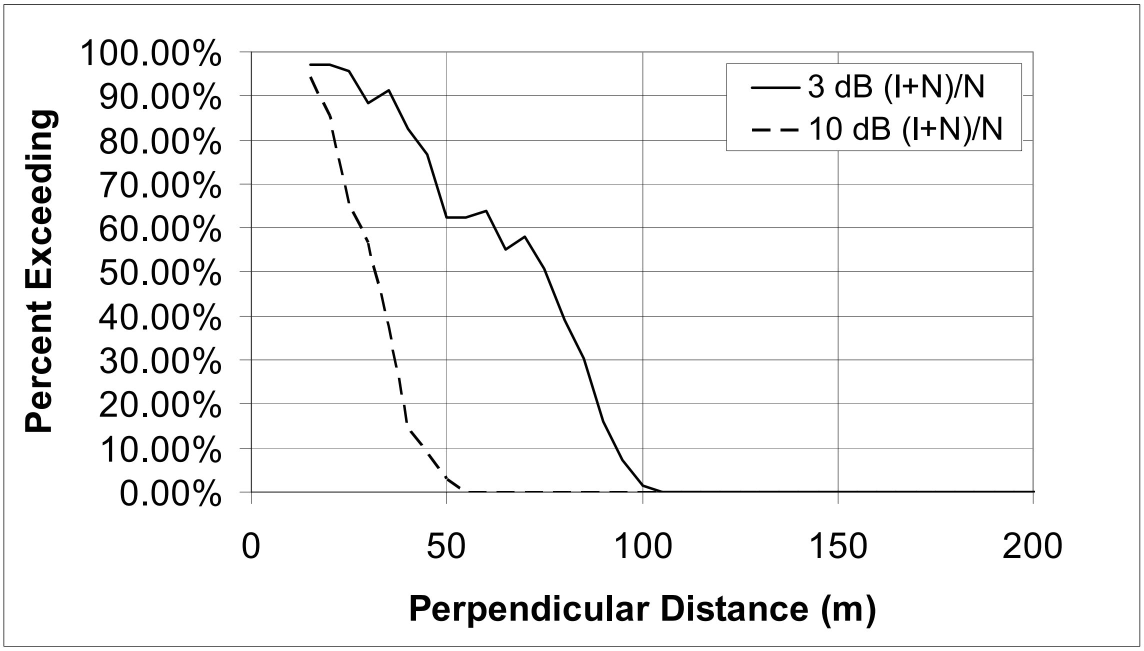


(b)

Figure 6-5: Percent of near-field points, by distance, where a land-mobile receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at Part 15 limits. a) 4 MHz. b) 15 MHz.



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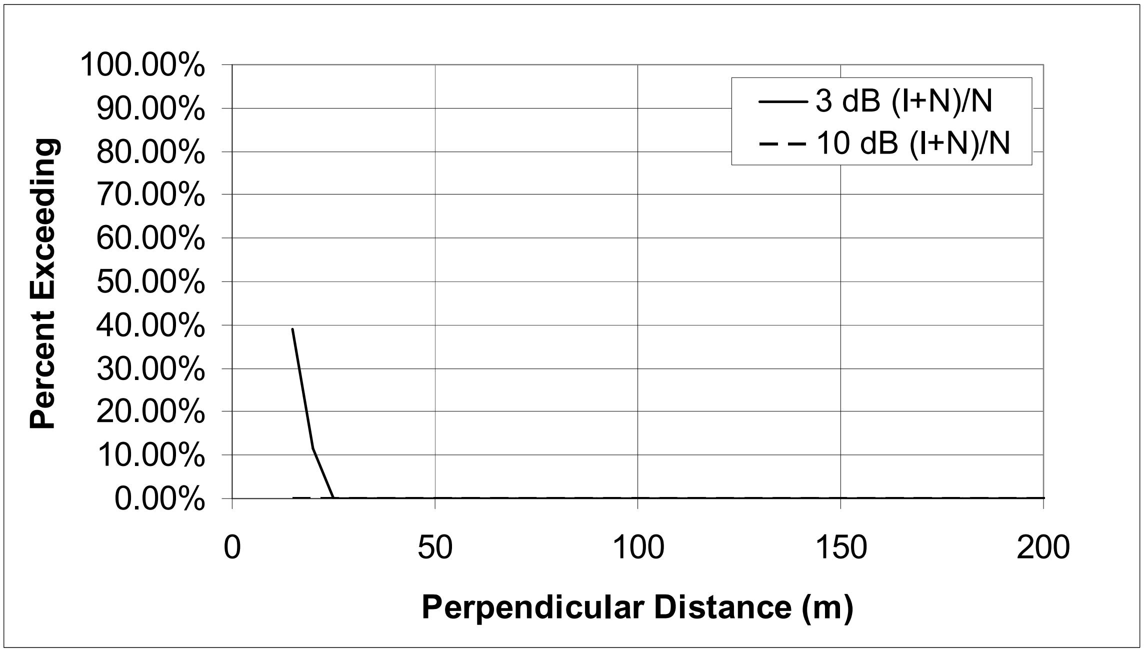


(d)

Figure 6-5 continued: c) 25 MHz. d) 40 MHz.

6.6.2 Fixed Service

NEC interference calculations for an assumed fixed service or mobile base station receiving antenna found substantial (I+N)/N values at greater distances from the line than those found for land mobile receivers. This was especially true at 15 and 25 MHz.

The near field results are depicted in Figure 6.6. As can be seen, at 15 MHz the potential for a 3dB (I+N)/N level exists beyond 500 meters away, and at 25 MHz some locations more than 700 meters away could see this level of interference. Additionally, locations past 300 and 400 meters from the BPL-energized line on 15 MHz and 25 MHz, respectively, could experience (I+N)/N levels in excess of 10 dB.

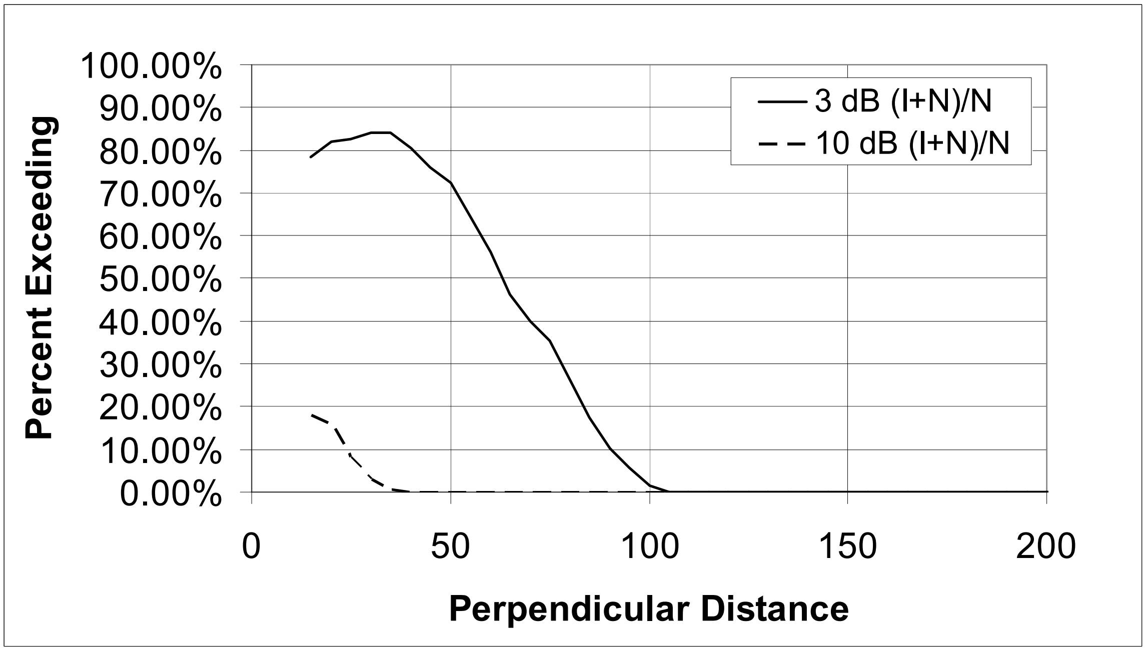
The differences in potential interference found with different frequencies are partly due to the ambient noise floor decreases as the frequency is increased. However, the increased gain of the modeled antenna with frequency also plays a part, which means that higher gain antennas and lower-noise areas could face greater risks of interference at lower frequencies. Likewise, receivers with lower-gain antennas and high-noise environments would likely experience less degradation in the noise floor, but would likely also see a reduced S/N. This is true for all of the services modeled.

6.6.3 Maritime Service

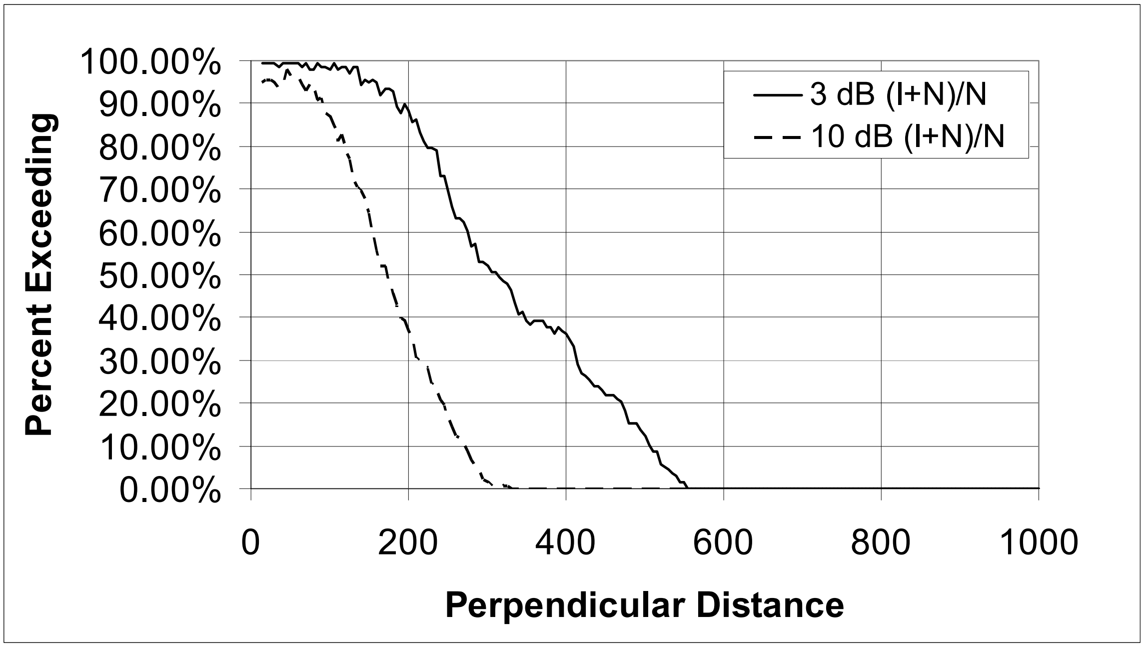
As noted previously, the calculations for a ship receiver differed from the fixed and land-mobile services in two important respects: the use of lower ambient noise levels and the use of salt-water ground characteristics. This model assumed a power line running along the shoreline, and the ship receiver possibly in a bay or harbor.

Results for the simulated maritime receiver were similar to those for the fixed service receiver. Substantial areas near the shore (near field) would likely see greater than 3 dB increases in the noise floor. As with the other services, this effect would be most pronounced at 25 MHz with the assumed power lines. According to the calculations, a single BPL device could S/N at 25 MHz by 3 dB for more than 50% of points within 100 meters of the shore (Figure 6-7).

Despite the lower noise levels seen by the simulated system at distances greater than one kilometer from shore, calculations indicated that at no point would the simulated system experience (I+N)/N levels greater than 3 dB.

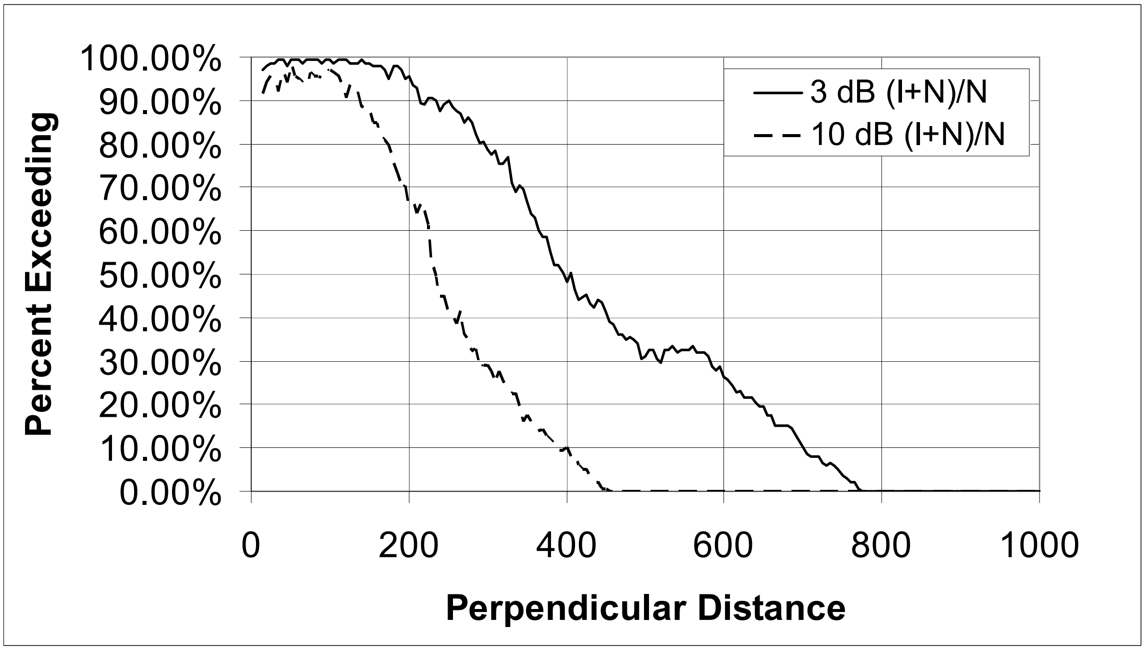


(a)

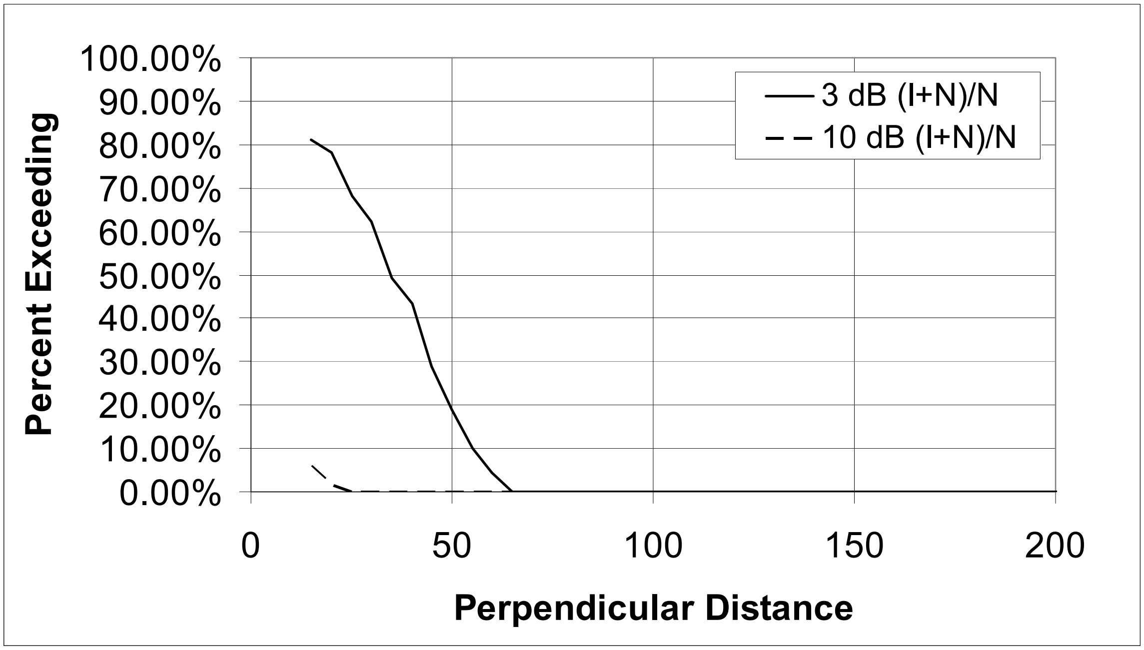


(b)

Figure 6-6: Percent of near-field points, by distance, where a fixed receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at FCC Part 15 limits. a) 4 MHz. b) 15 MHz.

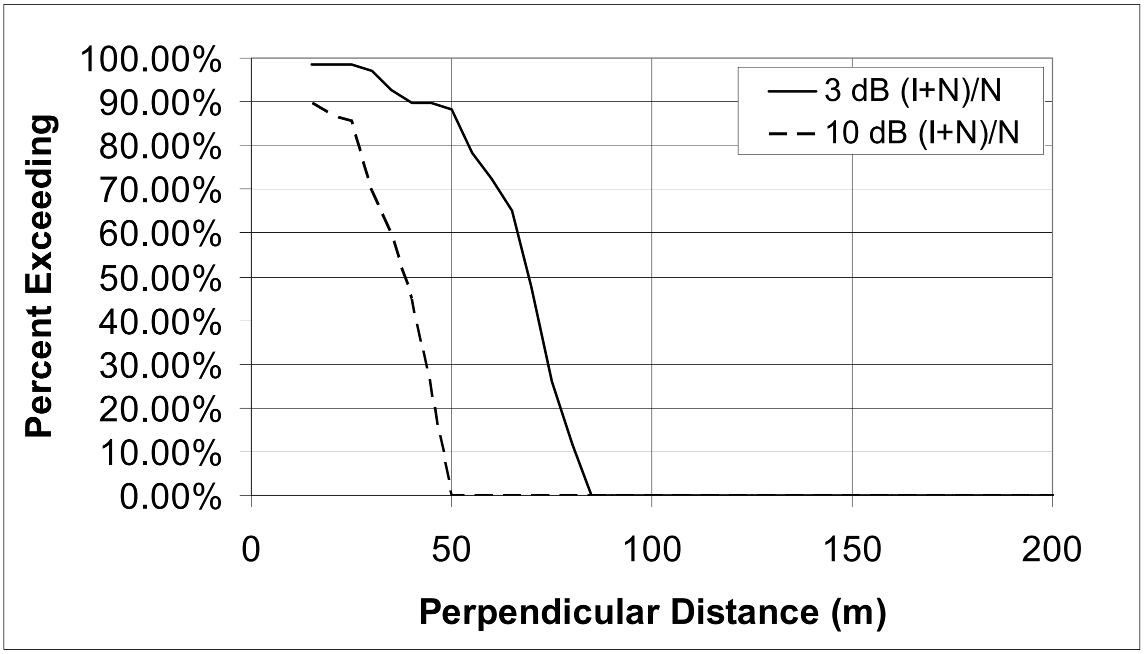


(c)

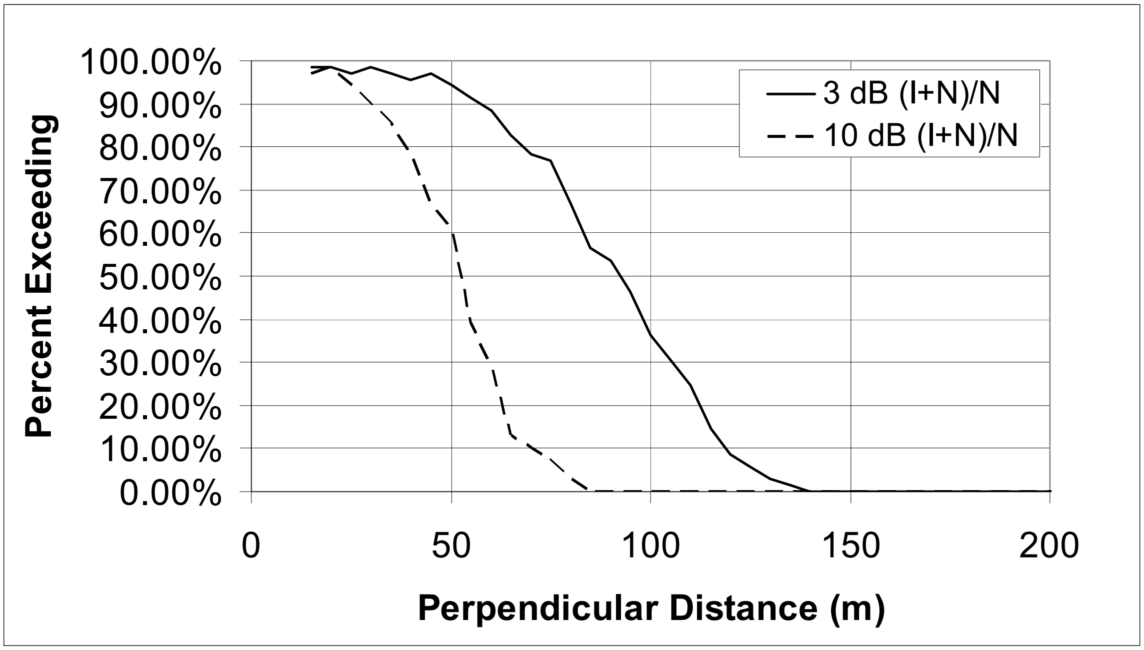


(d)

Figure 6.6 continued: c) 25 MHz. d) 40 MHz.

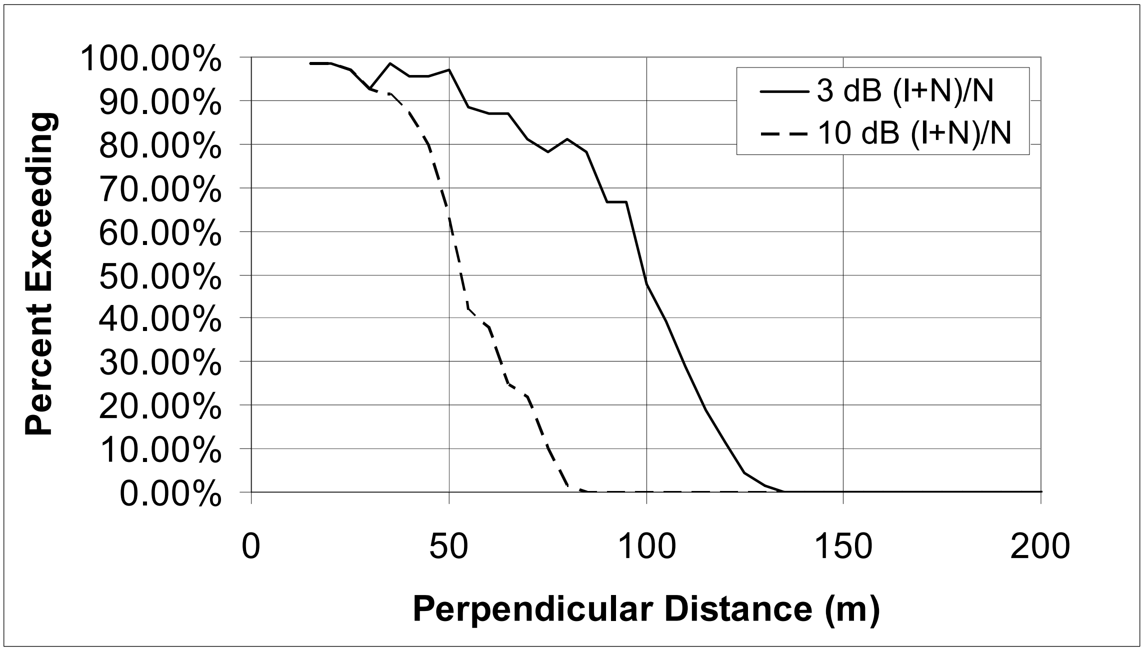


(a)

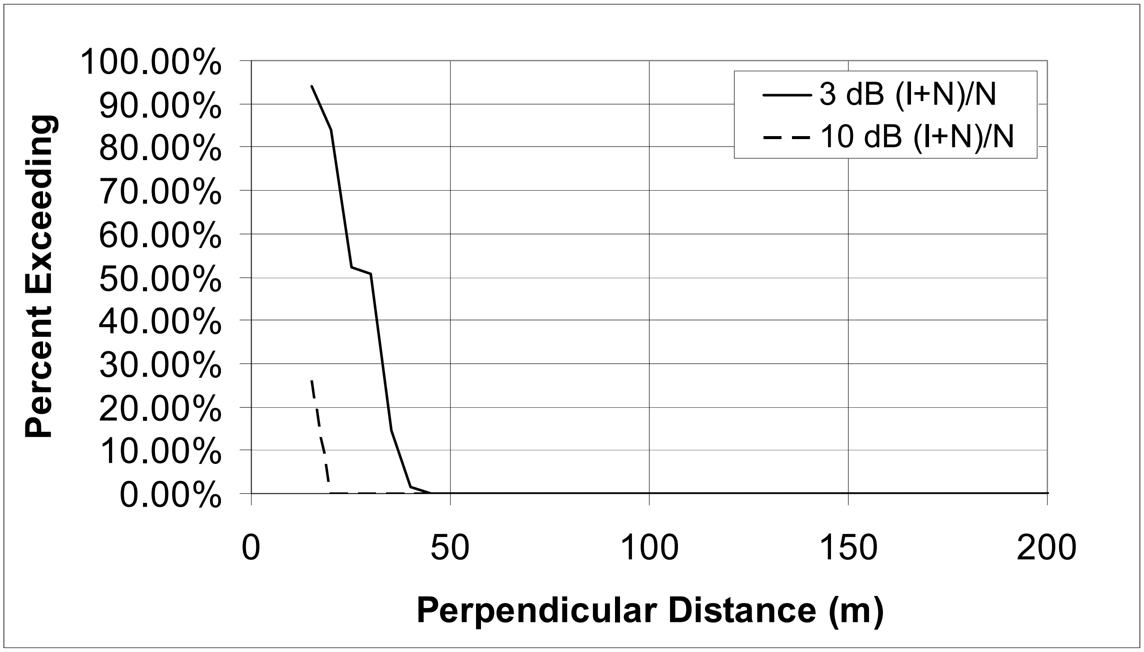


(b)

Figure 6-7: Percent of near-field points, by distance, where a maritime receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at FCC Part 15 limits. a) 4 MHz. b) 15 MHz.



(c)



(d)

Figure 6-7 continued: c) 25 MHz. d) 40 MHz.

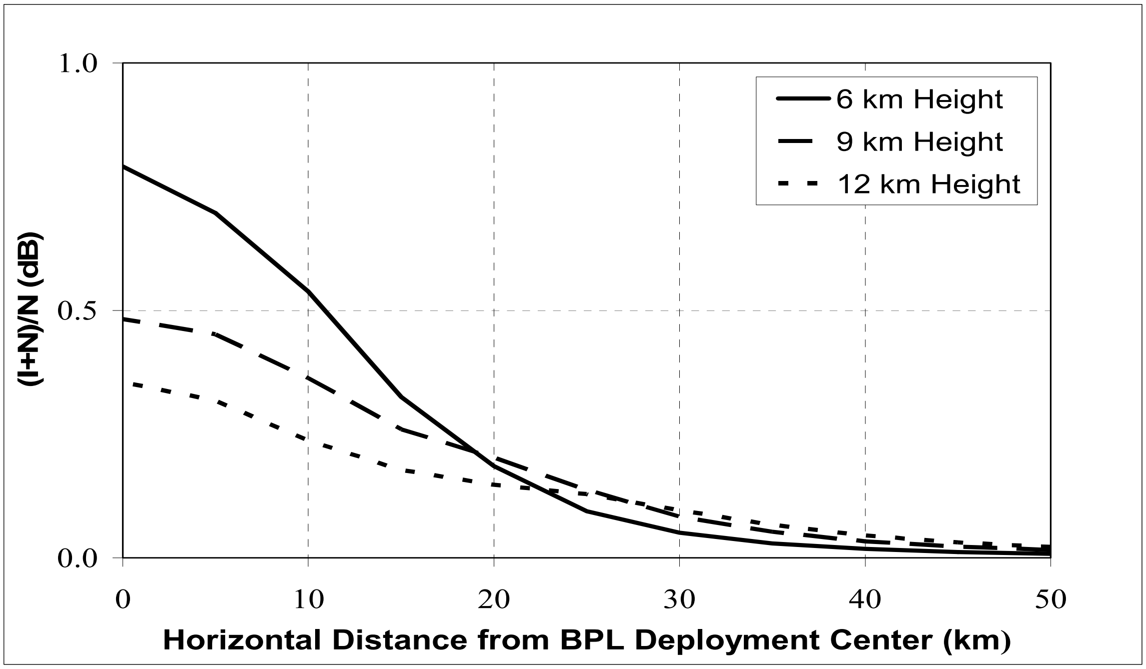
6.6.4 Aeronautical Service

The analysis of potential interference to aeronautical transceivers covered modeled deployments of 1200, 300, and 75 co-frequency BPL devices in an area of 10 km radius. Results indicated that multiplying the number of BPL devices by a factor of four produced a straightforward 6 dB increase in aggregate interfering BPL signal power; therefore only the analysis with 300 units is presented. The calculated data is listed in Table 6-4 and shown graphically in Figure 6-8.

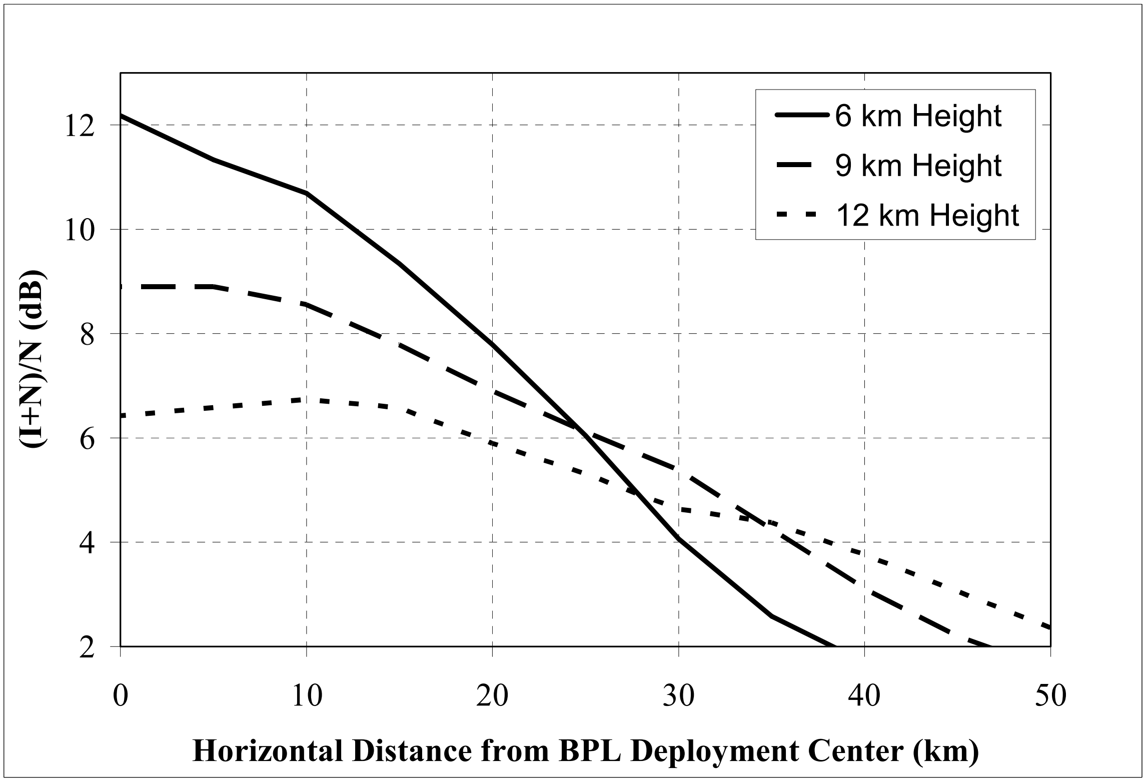
Table 6-4: Calculated (I+N)/N values, in dB, for aircraft receiver at listed distance, frequency and height, with 300 BPL units visible to the receiver in a 314 km^2 area.

	(I+N)/N (dB) 4 MHz			(I+N)/N (dB) 15 MHz			(I+N)/N (dB) 25 MHz			(I+N)/N (dB) 40 MHz		
Height Distance	6 km	9 km	12 km	6 km	9 km	12 km	6 km	9 km	12 km	6 km	9 km	12 km
0 km	0.8	0.5	0.4	12.2	8.9	6.4	8.9	6.3	5.7	0.3	0.1	0.0
5 km	0.7	0.5	0.3	11.3	8.9	6.6	9.2	6.5	5.5	0.2	0.1	0.1
10 km	0.5	0.4	0.2	10.7	8.6	6.7	9.6	6.2	4.5	0.2	0.1	0.1
15 km	0.3	0.3	0.2	9.3	7.8	6.6	9.0	6.1	3.8	0.1	0.1	0.1
20 km	0.2	0.2	0.1	7.8	6.9	5.9	8.4	6.7	4.3	0.1	0.0	0.0
25 km	0.1	0.1	0.1	6.0	6.1	5.3	7.4	6.3	5.0	0.1	0.1	0.0
30 km	0.1	0.1	0.1	4.1	5.4	4.6	6.4	5.6	5.0	0.1	0.1	0.0
35 km	0.0	0.1	0.1	2.6	4.3	4.4	5.5	4.8	4.6	0.1	0.1	0.0
40 km	0.0	0.0	0.0	1.7	3.1	3.8	4.6	4.4	3.9	0.1	0.1	0.0
45 km	0.0	0.0	0.0	1.1	2.2	3.1	3.6	4.1	3.3	0.0	0.0	0.0
50 km	0.0	0.0	0.0	0.7	1.6	2.4	2.8	3.6	3.1	0.0	0.0	0.0

As the figures indicate, an aircraft traveling above or near the modeled BPL deployment area could see substantial S/N degradation. These calculations include parts of the far-field radiation pattern (off the ends of the power lines, or on-axis) that exhibited potentially elevated power gain levels. Further study is needed of representative power line gain levels in skyward directions.

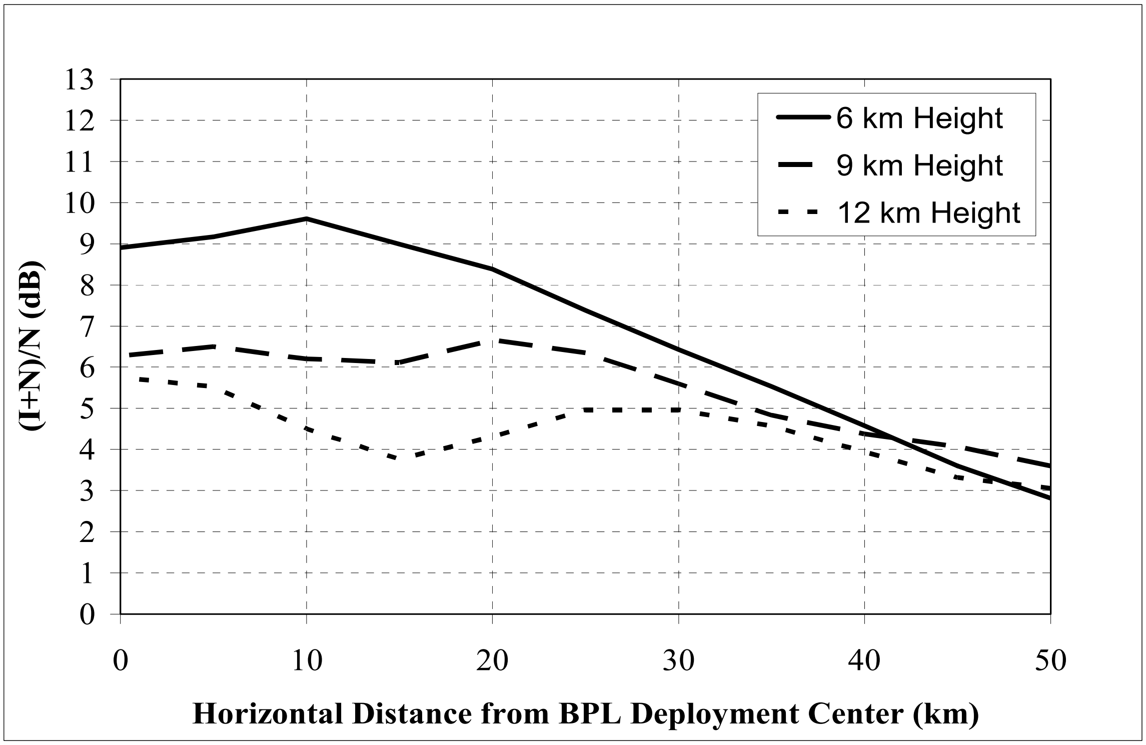


(a)

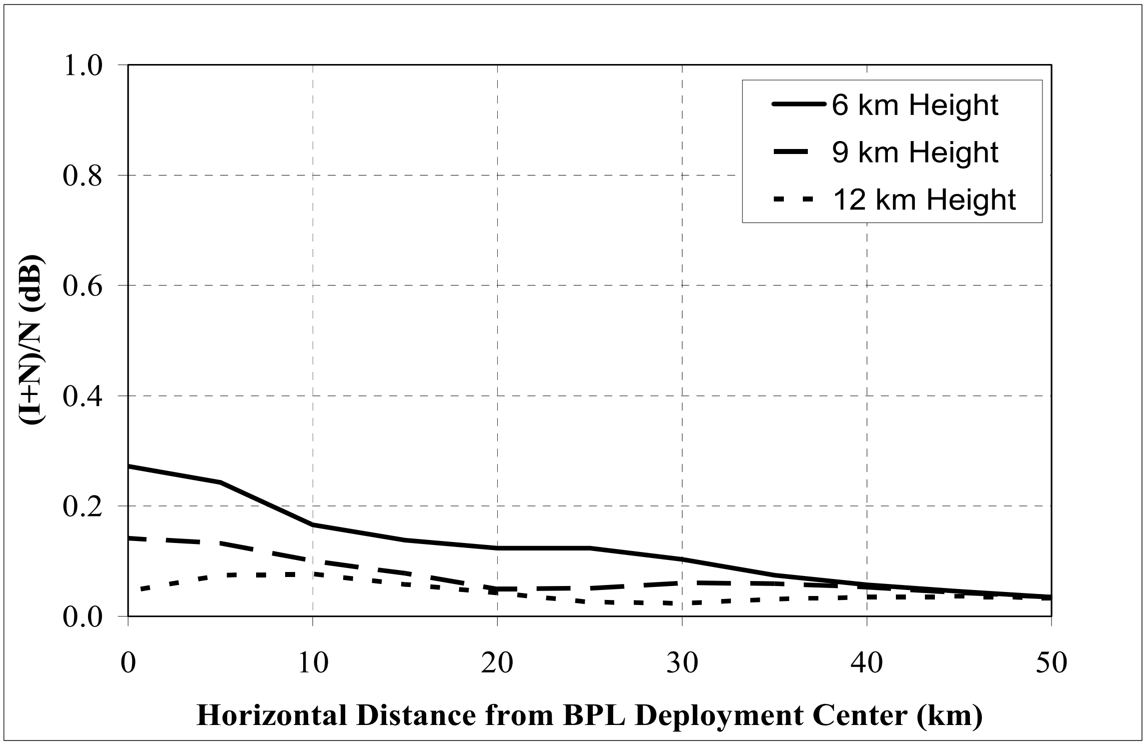


(b)

Figure 6-8: Calculated (I+N)/N level for an aeronautical receiver at the specified distance and height from a BPL deployment, with 300 BPL devices visible to the receiver. (a) 4 MHz. (b) 15 MHz.



(c)



(d)

Figure 6-8 continued: c) 25 MHz d) 40 MHz

6.7 CONCLUSION

Interference risks were estimated using NEC models for four representative types of federal radio stations operating in the fixed and mobile services: a land vehicular radio; shipborne radio; a fixed or mobile-base station with roof top antenna; and an aircraft radio in flight. These risks were gauged from the extent of geographic areas in which BPL emissions would reduce the ratio of desired radio signal power to ambient noise power by amounts associated with moderate and high probabilities of interference (*i.e.*, 3 dB and 10 dB reductions in (S/N), respectively). Along with the four representative radio stations, a three-phase power line structure was modeled using NEC. Predicted nationwide, Springtime, median ambient noise power levels were assumed and analyses were performed at four frequencies between 1.7 – 80 MHz. The BPL device output was adjusted to produce emissions at the limits of Part 15 for unintentional radiators (Class B above 30 MHz), as generally determined by compliance measurement practices extant with the exception that measurement distances were applied with respect to the BPL device and power lines rather than only the BPL device. This exception generally results in compliance at BPL output power levels lower than output levels that yield compliance when distances are measured from the BPL device. For all of these analyses, the frequencies at which the lowest and highest reductions in S/N occur may change for different power line configurations.

The results for the vehicular mobile receiver predict that the received BPL signal power near the Earth surface falls off rapidly with distance from the lines. For the two frequencies at which the highest BPL signal power levels were received (15 MHz and 25 MHz), signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at fifty percent of the locations within seventy and seventy five meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within twenty-five and thirty meters of the power lines. The distances within which these thresholds were exceeded at fifty percent of locations were modestly smaller at a third frequency (4 MHz) and much smaller at the fourth frequency (40 MHz). In all land vehicular cases considered, reductions in S/N were less than 3 dB and 10 dB beyond one-hundred-and-twenty-five meters and fifty-five meters, respectively.

The results for the fixed service (or mobile base station) receiver predict that the received BPL signal power falls off less rapidly with distance from the power lines than occurred for the land vehicle case. For the two frequencies at which the highest BPL signal power levels were received, signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at fifty percent of the locations within three-hundred-and-ten and four-hundred meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within one-hundred-and-seventy-five and two-hundred-and-thirty meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond seven-hundred-and-seventy meters and four-hundred-and-fifty meters, respectively.

The results for the shipborne receiver predict that the received BPL signal power falls off rapidly with distance from the power lines, but less rapidly than for the land vehicle case. For the two frequencies at which the highest BPL signal power levels were received, signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at fifty percent of the locations within one-hundred meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within fifty-five meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond one-hundred-and-thirty-five meters and eighty-five meters, respectively.

For the aircraft receiver, aggregate interference effects were considered for simultaneously active, co-frequency BPL systems deployed at a density of one per square kilometer over an area having ten (10) kilometers radius. The power lines were assumed to be randomly oriented and an average of the power line far-field gain levels were used in each direction under consideration. Aircraft were assumed to be operating at altitudes of 6 to 12 km at locations ranging from zero to fifty (50) kilometers from the center of the BPL deployment area. Results showed that aggregate interference levels to the aircraft could exceed average ambient RF noise levels at two frequencies (15 MHz and 25 MHz), at distances ranging from thirty-three kilometers (six kilometers altitude) to over fifty kilometers (altitudes between six and twelve kilometers). The S/N reduction exceeded 10 dB at only one frequency, at six kilometers altitude within twelve kilometers of the center of the BPL deployment area. At the two frequencies where the assumed BPL systems produced the lowest interfering signal power levels (*i.e.*, 4 MHz and 40 MHz), S/N reductions peaked at about 0.8 dB and 0.3 dB directly over the center of the BPL deployment area. Higher or lower densities of active co-frequency BPL units would raise or lower the predicted interference levels in direct proportion to the unit density.