SECTION 3
SPECIAL PROVISIONS FOR PREVENTION OF INTERFERENCE FROM BPL SYSTEMS

3.1 INTRODUCTION

NTIA's Phase 1 Study identified frequency bands in the 1.7 to 80 MHz frequency range for which radio operations have been specially protected in the FCC's rules or International Telecommunication Union (ITU) Radio Regulations.[25] NTIA's comments on the BPL NPRM recommended that the FCC adopt special mechanisms for preventing interference in addition to the baseline protection afforded by field strength limits, prohibition of harmful interference from BPL systems, and compliance measurement provisions.[26] The Commission adopted rules in its BPL Report and Order that delineated frequencies and areas in which these special provisions would apply.[27]

Aeronautical and maritime safety radiocommunications receivers, as well as radar and radioastronomy receivers operating at frequencies below 80 MHz may experience harmful interference from in-band emissions from relatively distant Access BPL systems. The Commission's BPL rules reduce the probability of BPL interference to such receivers by defining excluded frequency bands, exclusion zones, and consultation areas around the most sensitive federal radiocommunications facilities.[28] Within these areas, BPL systems are either prohibited outright or may be restricted from transmitting in specific frequency bands by mutual agreement between BPL service providers and federal radio operators. NTIA analyzed BPL emissions in these bands and confirmed the effectiveness of the protection radii adopted in these rules.

Excluded frequency bands (discussed in Section 3.4.1) place the greatest constraints on BPL deployment, including limitations on the flexibility for Access BPL systems to avoid other locally-used radio frequencies. Thus, frequency bands used for safety communications where co-channel emissions from numerous BPL devices may be received via line-of-sight and/or ionospheric interfering signal paths make up the excluded bands.

Exclusion zones (discussed in Section 3.4.2) are applied to protect reception at known receiver locations where safety communications must operate with weak desired signals and cooperation between BPL service providers and federal radio operators is unlikely to result in lesser constraints on BPL. Likewise, exclusion zones are applied around sensitive radio astronomy sites, which generally are located in remote, lightly populated areas (*i.e.*, little or no actual constraint on Access BPL market penetration).

Consultation areas (discussed in Section 3.4.3) are specified for receivers at known locations that must operate with very weak desired signals and where harmful interference must be prevented with a relatively high degree of certainty (rather than eliminated after discovery). Actual radio operating frequencies and other technical or operational details (*e.g.*, manufacturer and type of BPL equipment, location of BPL service) should be considered during consultations.

Sections 3.4 and 3.5 provide the technical basis for these exclusion zone and consultation area distances. The underlying interference predictions demonstrate that Access BPL systems located beyond these distances would:

- be unlikely to cause substantial interference to receivers that are intended to be protected by these provisions, even given worst-case-oriented BPL deployment configurations; and
- present a very low probability of endangerment or actual harmful interference to safety communications and non-safety communications, respectively.

3.1.1 Background

NTIA analyzed the BPL emissions levels that might be expected from MV overhead and underground power lines to determine the minimum radii of exclusion zones and consultation areas needed to meet the protection criteria for critical federal communication, radar and radioastronomy receivers. MV overhead lines are attached to utility poles at heights that typically range from 8 – 12 meters above ground. BPL signals are typically injected on one or more of the phase conductors at a utility pole. Underground power lines radiate the strongest emissions from above-ground segments, including mainly: pad mounted transformer enclosures; vertical risers where the power line emerges from underground and is routed up the side of a pole inside a metal, protective U-channel for connection with overhead power lines; and short line segments emerging from the ground and running through metal pipes for connections to the users' premises (low-voltage) or power substation (MV). The BPL signal typically is injected on the underground segment at one of the transformer pads.

NTIA's initial analyses of these distances employed a 5 dB height correction factor to account for stronger predicted levels of BPL emissions from the power line at heights other than that used for compliance measurements. In its Phase 1 Study and in the Technical Appendix to its Comments on the BPL NPRM, NTIA showed that the peak field strength typically occurs at heights greater than the 1 meter measurement height used for compliance testing, and is often found at or near the height of the power line.[29] In the BPL Report and Order, the Commission adopted NTIA's recommended height correction factor, which may be optionally applied above 30 MHz when coupled with an antenna measurement height of 1 meter. The Commission indicated that BPL emissions above 30 MHz may be measured with an antenna height ranging from 1 to 4 meters. NTIA's revised analysis no longer assumes the 5 dB correction (reduction of BPL emissions) factor in calculating the size of these protection areas.

NTIA's earlier analysis also assumed that the receiver antenna gain for fixed/or mobile-base stations was 0 dBi in the direction of the power line carrying BPL signals.

This assumption was felt to be valid for many high-gain antennas operating in the near field of a BPL power line. However, NTIA conducted NEC simulations with a representative high-gain antenna (14 dBi maximum) to validate this assumption and found that the receiver antenna gain in the direction of the BPL power line may be as much as 5 dBi, depending on frequency. In response to these results, NTIA has revised its analysis to account for receiver antenna gain toward the power line.

Theory and limited NTIA measurements show that Access BPL using underground power lines poses very small, relatively localized interference risks, radiating potentially significant emissions only from above-ground segments. Each phase wire of MV underground power lines has a ground wire that is loosely, coaxially braided or wound around the insulation of the phase conductor. This ground wire suppresses radiation. Also, soil is a high-loss propagation medium in the 1.7-80 MHz frequency range. Above-ground segments of underground power line systems act as point radiators similar to other Part 15 devices.

The calculations to determine the exclusion zones and consultation radii consider only the effect of local co-frequency BPL devices on radio receivers over line-of-sight and diffracted interfering signal paths. Ionospheric propagation of distant BPL signals and ionospheric backscatter from local BPL devices are not considered in this section of the report.

3.2 POTENTIAL VICTIM RECEIVERS

The NTIA Phase 1 Study included a characterization of Federal Government spectrum usage in the 1.7 to 80 MHz band, representative systems, and typical system parameters.[30] A number of these radiocommunication systems are considered particularly sensitive as they pertain to aeronautical and maritime safety-of-life services. Other federal systems that warrant protection include over-the-horizon radars and radioastronomy observatories. These potential victims of in-band emissions from Access BPL systems are described in the following sections.

3.2.1 Communications Receivers

The United States Coast Guard operates high frequency (HF) systems for communications between shore stations and ships, and from ship-to-ship. These systems support command and control communications with cutters, aircraft, and shore facilities for various purposes including: off shore search and rescue; drug interdiction; enforcement of laws and treaties; and Arctic and Antarctic operations. The Coast Guard relies on the HF band for services such as distress and safety communications, broadcast of maritime safety information, emergency medical assistance communications, broadcast of weather observation reports, and receipt of vessel position reports for safety purposes. In addition, the Coast Guard has an HF network that ties its major bases together throughout the continental United States (CONUS), Alaska, Hawaii, Puerto

Rico, the U.S. Virgin Islands, and the trust territories of the Pacific Ocean. The typical technical characteristics for these maritime mobile base stations are described in Table 3-1.

Table 3-1: Typical technical characteristics of Maritime Mobile base stations in the 1.7-30 MHz Band

Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
2.8	0-2	Not available	Whip, Cone/V	Single sideband-suppressed carrier, single channel, analog, telephony

The United States Customs and Border Protection Customs Over the Horizon Enforcement Network (COTHEN) provides communications support for more than 235 aircraft, numerous maritime interdiction vessels, several command offices, and numerous allied agencies including the United States Coast Guard, Drug Enforcement Administration, Border Patrol, Army, Navy, and Joint Interagency Task Forces. The typical technical characteristics for the COTHEN fixed base stations are described in Table 3-2.

Table 3-2: Typical technical characteristics of COTHEN base stations in the 1.7-80 MHz Band

Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
2.8	0	30-100	Whip/V& H	Analog, single channel, suppressed carrier, telephony

The aeronautical mobile service is subdivided into two distinct radio services; namely, aeronautical mobile route (R) and aeronautical mobile off-route (OR) services. By definition, the aeronautical mobile (R) service is reserved for communications relating to safety and regularity of flight, primarily along national or international civil air routes; while the aeronautical mobile (OR) service is intended for other communications, including those relating to flight coordination, primarily outside national or international civil air routes.[31]

Table 3-3 shows typical technical characteristics of federal systems in the aeronautical mobile (R) service. Table 3-4 shows typical technical characteristics of federal aeronautical mobile (OR) service systems in the HF band.

Table 3-3: Typical technical characteristics of Aeronautical Mobile (R) base stations (1.7-30 MHz Band)

Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
2.8	0-3	Not available	Various /V	Analog, single channel, suppressed carrier, telephony

Table 3-4: Typical technical characteristics of Aeronautical Mobile (OR) base stations (1.7-30 MHz Band)

Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations

3.5	0	6-32	Whip/V	Analog and digital, single channel, reduced or suppressed carrier, telephony and data

The size of the exclusion zones and consultation areas recommended by NTIA for base stations associated with the land mobile, maritime mobile, aeronautical mobile (R) and (OR) services result from analyzing the distances at which radiated emissions from an Access BPL source raises the noise floor by a certain amount.[32] The exclusion zone and consultation area radii were chosen to be the distance beyond which the probability that a communications receiver experiences a 1 dB increase in noise floor is negligible.

3.2.2 Radar Receivers

HF band over-the-horizon (OTH) radar systems are employed by the Department of Defense. The OTH radars use sky wave propagation to detect targets at long ranges from the radar transmitter site. The target return is a result of the backscatter signal traversing the path to the ionosphere and back to the original transmitter site (primary radar) or an alternative site (secondary site). OTH-HF radars are capable of detecting targets at distances beyond the horizon and therefore, targets located well beyond the range of the conventional microwave radar. This increased range is possible due to the ability of the HF signals to propagate well beyond the line-of-sight either by ground wave diffraction around the curvature of the Earth or by sky wave. The basic technical characteristics of the OTH radar receiver are shown in Table 3-5.

Table 3-5: Technical characteristics of the OTH radar receiver (1.7-30 MHz Band)

Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
4.2-100	9-36[*]	Not available	Phased Array/ Vertical	FM/CW or angle-modulated, single channel, with analog or digital signals.

[*] The 9 dBi and 36 dBi antenna gains are measured at 5 MHz to 28 MHz, respectively.

The protection requirement used to develop the exclusion zone for OTH radar receivers in the 1.7 to 30 MHz band is a spectral power flux density (PFD) threshold of -258 dBW/m^2-Hz.[33] This analysis assumes that the interfering BPL signal is received through a 0 dBi side lobe of the radar antenna.

3.2.3 Radioastronomy Receivers

Radio astronomical measurements are made from the Earth's surface from 2 MHz to beyond 800 GHz. The sensitivity of radio astronomy receivers greatly exceeds the sensitivity of typical communications and radar equipment. The sensitivity is defined by the smallest power level change, ΔP, at the receiver input that can be detected and measured. The interfering signal threshold levels are defined as the interfering signal level which introduces an error of 10 percent in the measurement of ΔP.

The protection criterion applicable for terrestrial interference sources is based on reception of an interfering signal through 0 dBi side lobes of a radioastronomy antenna.

The International Telecommunication Union Radiocommunications Sector (ITU-R) protection level for radioastronomy is a spectral PFD of -258 dBW/m^2-Hz in the 73.0-74.6 MHz frequency band.[34] This level is assumed for the radioastronomy exclusion zone radii analysis.

3.3 POTENTIAL SOURCES OF INTERFERENCE

Using the NEC software, NTIA modeled the field strength of MV overhead and underground BPL power lines for this analysis. A description of these models follows below.

3.3.1 Overhead Power Line Model

NTIA modeled an overhead BPL power line as three horizontal parallel copper wires, each 340 meters long and 8.5 meters (27.9 feet) above ground having average characteristics (conductivity σ = .005 S/m, relative permittivity ε_r = 15). Each wire had a diameter of 1 centimeter (approximating American Wire Gauge (AWG) gauge 4/0) and the wires were separated in the horizontal plane by 0.60 meter. The feed point was at the center of one of the outside wires, which ran parallel to the x axis (y = 0). The equivalent of a BPL coupler was placed on the center segment of the wire and was modeled as a voltage source of 1 volt in series with a 150 Ω resistor that represented the source impedance. The other two phase wires ran parallel to the x axis at y = 0.6 and y = 1.2 meters. All wires were connected at the ends to one another through 50 Ω impedances to model the loads. The overhead power line was modeled at a number of discrete frequencies ranging from 4 MHz to 74 MHz.

3.3.2 Underground Power Line Model

NTIA created a NEC model of an Underground Residential Distribution (URD) cable and a shielded, pad-mounted transformer for the radioastronomy (Section 3.4.3) and aggregation (Section 5) analyses. The modeled cable consisted of a center copper conductor 1 centimeter in diameter, surrounded by simulated cross-linked polyethylene insulation (using NEC's Insulated Wire feature) having a thickness of 6 millimeters. Around the outside of the insulation were three 12 AWG multi-grounded neutral copper wires.

The URD cable in the NEC model spanned 340 meters (+/- 170 meters along the x-axis), 1 meter below ground level. Near the origin, the cable was routed up to ground level, breaking the surface inside a wire-grid rectangular structure one meter on a side and one-half meter high. This structure represented the pad-mounted transformer casing, and was given steel conductivity. The wires composing the transformer casing were 4 millimeters thick (Figure 3-1).

Inside the transformer casing, only the center conductor of the URD cable continued above ground. The simulated BPL device was placed on this short loop of wire, 0.2 meters off the ground.

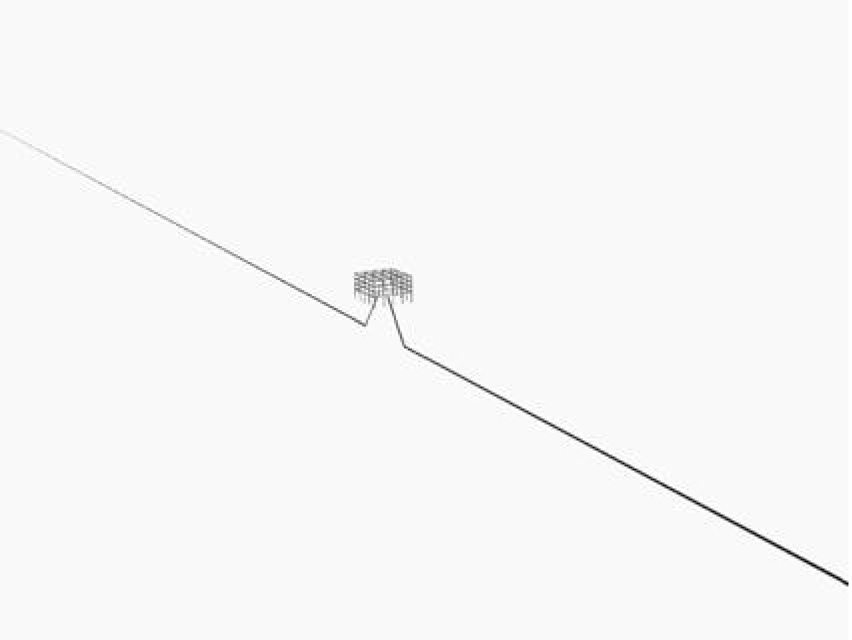

Figure 3-1: Representation of a NEC model of an underground BPL power line and transformer pad

3.3.3 Part 15 Scaling of Power Line Models

NTIA computed electric field strength values for these NEC power line models using the measurement guidelines for Access BPL systems. Below 30 MHz, the measurement guidelines specify measurement of magnetic field with a loop antenna rotated about its vertical axis (horizontal magnetic field) at a height of 1 meter. Conversion to electric field strength resulted from application of Equation 2-1 (page 2-2).

Below 30 MHz, the FCC Part 15 radiated emissions limit is specified as 30 µV/m at 30 meters horizontal distance.[35] To convert the limit to the 10 meter distance specified in the measurement guidelines for Access BPL systems, the slant range between an overhead power line and the measurement point must be used in conjunction with a 40 log correction factor. Application of Equations 2-2 (page 2-22) and 2-3 (page 2-23) with a modeled overhead power line height of 8.5 meters and measurement height of one meter, the slant range adjustment to the electric field strength limit results in an extrapolated value of the Part 15 limit at 10 meters as shown below. The peak value of E_v from the specified measurement locations along the power line was scaled to achieve the value of E_{10m} shown below. The specified measurement locations were at points ¼, ½, ¾, and 1 wavelength down the line from the BPL source.

$$E_{10m} = E_{30m} \cdot 10^{\frac{40 \cdot \log_{10}\left(\frac{30m}{\sqrt{(8.5m - 1m)^2 + (10m)^2}}\right)}{20}} \approx 172.8\ \mu V/m$$

Above 30 MHz, the Part 15 Class A emission limit of 90 μV/m, at a distance of 10 meters, applies and the measurement height ranges from 1 to 4 meters. The peak value of the horizontal and vertical electric field strength from the specified measurement locations along the overhead power line and at the specified measurement heights was scaled to the 90 μV/m emissions limit.[36]

The underground BPL system was analyzed at 74 MHz in this study; therefore, the Class A emission limit of 90 μV/m, 10 meter measurement distance, and the 1 to 4 meter measurement heights were applied. Instead of measurement points along the power line, as would be the case for overhead power lines, the underground system was measured at 16 evenly spaced radials surrounding the BPL signal source. The peak value of the horizontal and vertical electric field strength from the 16 radials surrounding the underground BPL source and at the specified measurement heights was scaled to the 90 μV/m emissions limit.

With the Part 15 calibration completed, NTIA used NEC to calculate field strength values over a range of horizontal distances from the BPL device and elevation angles determined by the assumed receive antenna.

3.4 ANALYTICAL APPROACH

3.4.1 Communications Receivers

This analysis evaluates the protection radii needed around base station receivers for the various federal radiocommunication systems discussed in Section 3.2. The NEC software tool was used to model a representative radio receiver antenna. The model was initially patterned as a horizontal dipole at 42.7 meters above ground with a gain of 0 dBi in the direction of the power line.[37] NEC models were used to calculate the electric field strength values at points along and away from the power line at the assumed height of the receiver antenna, and then translate these values into received interfering signal power levels.

NTIA subsequently developed a second NEC model to address the typical gain in the direction of the power line for a high-gain receiver antenna. This high-gain antenna was patterned after a stacked log-periodic antenna used for aeronautical radiocommunications.[38] This antenna model has a maximum gain of approximately 14 dBi for frequencies between 4 to 30 MHz, with a gain in the direction of the power line of up to 5 dBi. In order to model more accurately the BPL signal power seen by a communications receiver with a high-gain antenna, NTIA utilized NEC's Maximum Coupling feature to determine the loss of power between the modeled BPL source and the modeled stacked log-periodic antenna receive point.

The use of exclusion zones and consultation areas is intended to reduce the risk of harmful interference at these protected receiver sites. Their radii are determined by noting the distance from the modeled power line where the radiated emissions from a BPL source raise the noise floor (*e.g.*, (I+N)/N) by a certain amount. The radii chosen were determined to be the distances beyond which the probability was negligible that a communications receiver would experience an increase in noise floor of 1 dB.

The BPL interfering signal power "I" was determined from NEC power line simulations. Calculations of electric field strength for the 0 dBi receiver antenna case were made along the length of the modeled power line in 0.5 meter steps. These calculations were performed at increasing distances away from the power line at a height of 42.7 meters, the height of the assumed communications receiver antenna. For the high-gain antenna case, the field strength calculations along the power line were performed at 5 meter steps along the power line to reduce computation time for the analysis.

The noise power "N" was assumed to be the median noise level for a quiet rural noise environment. This assumption is reasonable, as most of these protected receiver sites were selected because they exhibit very low background noise levels. In addition, personnel at these sites (where manned) actively work with local utilities to prevent or correct any increases in ambient noise due to power line noise sources. The noise levels used in this analysis are listed in Table 3-6.

Table 3-6: Ambient noise level assumptions used in the communications receiver analysis[39]

Frequency	Bandwidth	Noise Power Level
4 MHz	2.8 kHz	-135.3 dBW
10 MHz	2.8 kHz	-136.7 dBW
15 MHz	2.8 kHz	-144.7 dBW
20 MHz	2.8 kHz	-147.9 dBW
25 MHz	2.8 kHz	-150.2 dBW
30 MHz	16 kHz	-144.6 dBW
40 MHz	16 kHz	-147.5 dBW

NTIA calculated the percentage of simulation points that, at a given distance around the modeled power line, resulted in a 1 dB noise floor increase. These calculations were performed at increasing distances away from the modeled power line.

3.4.2 Radar Receivers

In analyzing the protection radii for radar receivers, NTIA employed the NEC overhead power line model described in Section 3.3.1 and the Irregular Terrain Model (ITM) software to calculate the basic transmission loss due to the distance separation and diffraction of a radio frequency (RF) signal over a spherical earth.[40] The protection requirement used in this analysis for radar receivers in the 1.7 to 30 MHz band is a PFD threshold of -258 dBW/m^2-Hz. This protection criterion assumes reception of a terrestrial interfering signal through a 0 dBi side lobe of a radar antenna.

NTIA used NEC to calculate the peak electric field strength at horizontal distances of 1 to 10 kilometers from the BPL device and an elevation of 42.7 meters, the assumed height of the receiving antenna.[41] The electric field strength values computed by NEC were converted into PFD values using Equation 3-1 below:

$$PFD_{NEC}(dist) = 10 \cdot \log\left(\frac{(E(dist))^2}{120 \cdot \pi}\right) + 10 \cdot \log\left(\frac{1}{BW_{meas}}\right) + 10 \cdot \log(n_{equiv})$$

(Equation 3-1)

where

PFD_{NEC}	is the power flux density computed by NEC, in dBW/m^2-Hz;
$dist$	is the distance separation between the BPL source and the radar receiver, in meters;
E	is the electric field strength, scaled to meet Part 15 limits, in V/m;
BW_{meas}	is the Part 15 measurement bandwidth, in Hz;[42] and
n_{equiv}	is the number of equivalent-power BPL sources contributing to the PFD calculation.

PFD values are calculated based on the root mean square (RMS) value of electric field strength; therefore, the peak electric field strength values determined by the NEC simulation were adjusted downward by a factor of 6 dB.[43] The analysis assumes that the calculated PFD is based on the equivalent of four equal-power BPL signals ($n_{equiv} = 4$) operating at the Part 15 limit, accounting for potential aggregation of multiple co-frequency emission sources beyond the protection radius surrounding the radar antenna. The four simulated power lines were assumed to be oriented broadside ($\theta = 90^{\circ}$) to the receiving antenna. This assumption was used to provide a reasonable simplification of the analysis, where a widely deployed BPL system may encompass many more than four co-frequency BPL devices generating various field strength levels at or below the Part 15 limit with a variety of distances and orientations with respect to the receiving antenna.

Simulations using NEC were run to a distance of 10 km from the power line since NEC does not account for the diffraction losses that would be expected at greater distances. ITM transmission loss data was used to calculate PFD values from 10 km out to 50 km. The ITM results were based on use of the same ground parameters as NEC, and the same power line height of 8.5 meters and an assumed radar antenna height of 42.7 meters.[44] ITM input parameters are detailed in Table 3-7.

Table 3-7: ITM input parameters

Input Variable	Value
Frequency[45]	25 MHz

Antenna Heights	Transmitter – 8.5 m, Receiver – 42.7 m
Siting Criteria	Transmitter – Random, Receiver – Very Careful
Terrain Irregularity Factor, Δh	30 m
Polarization	Horizontal
Relative Permittivity	15
Ground Conductivity	0.005 S/m
Climate	Continental Temperate
Surface Refractivity	301 N-units
Percent Time	90.0%
Percent Location	50.0%
Percent Confidence	50.0%
Mode of Variability	Individual

To determine the PFD values accounting for diffraction losses that come into play at large distances from the power line, the transmission losses beyond 10 km calculated by ITM were scaled relative to the value that ITM computed at 10 km (Equation 3-2). Within 10 km of the power line, the adjusted PFD was the same as the PFD computed using NEC electric field strength directly (Equations 3-1 and 3-3a). Beyond 10 km, the scaled ITM loss values, at each distance, and the PFD computed at 10 km from NEC were used to compute the adjusted PFD (Equation 3-3b).

$$ScaledLoss_{ITM}(dist) = Loss_{ITM}(dist) - Loss_{ITM}(10\ km), \quad for\ dist \geq 10\ km$$

(Equation 3-2)

where

dist is the horizontal distance from the power line, in km;

$Loss_{ITM}$ is the path loss at a distance, in dB; and

$ScaledLoss_{ITM}$ is the path loss at a distance relative to the path loss at 10 km from the power line, in dB.

$$PFD_{Adjusted}(dist) = PFD_{NEC}(dist), \quad for\ 0 \leq dist < 10\ km$$ (Equation 3-3a)

$$PFD_{Adjusted}(dist) = PFD_{NEC}(10\ km) - ScaledLoss_{ITM}(dist), \quad for\ dist \geq 10\ km$$ (Equation 3-3b)

where

PFD_{NEC} is the power flux density computed by NEC, in dBW/m^2-Hz; and

$PFD_{Adjusted}$ is power flux density, at a distance, adjusted by the relative path loss beyond 10 km, if applicable, in dBW/m^2-Hz.

3.4.3 Radioastronomy Receivers

The methodology described in Section 3.4.2 was also used to analyze protection area requirements for radioastronomy receivers. The peak electric field strength, computed at any distance, was converted into PFD values at the receiver for comparison to the -258 dBW/m^2-Hz interference threshold.[46] This protection criterion is applicable for terrestrial interference sources based on reception of the interfering signal through 0 dBi side lobes of a radioastronomy antenna.

NEC was used to calculate electric field strength values at horizontal distances of 1 to 10 kilometers from the BPL device and at an elevation of 20 meters, the assumed height of the radioastronomy antenna. These field strength values were converted into PFD values using Equation 3-1.

The calculated values of peak electric field strength were adjusted downward by a factor of 6 dB to approximate the RMS values required for determining PFD values. As in the radar receiver analysis, the calculated PFD is based on the assumption of an equivalent of four equal-power BPL signals ($n_{equiv} = 4$), accounting for potential aggregation of multiple co-frequency emission sources beyond the protection radius surrounding the radar antenna. The four simulated power lines were assumed to be oriented broadside ($\theta = 90^{\circ}$) to the receiving antenna. This assumption was used to provide a reasonable simplification of the analysis, where a widely deployed BPL system may encompass many more than four co-frequency BPL devices generating various field strength levels at or below the Part 15 limit with a variety of distances and orientations with respect to the receiving antenna.

As indicated above, electric field strength simulations using NEC were only run to a distance of 10 km from the power line, as NEC does not account for the diffraction losses that would be expected at greater distances. ITM transmission loss data was used to calculate PFD values from 10 km out to 50 km. The ITM input parameters remained the same as for the radar receiver case, with the exception that the radioastronomy receiver antenna was assumed to have a height of 20 meters and the analysis frequency was assumed to be 74 MHz.[47] To determine the PFD values accounting for diffraction losses that come into play at large distances from the power line, the transmission losses beyond 10 km calculated by ITM were scaled relative to the value that ITM computed at 10 km (Equation 3-2). Within 10 km of the power line, the adjusted PFD was the same as the PFD computed using NEC electric field strength directly (Equations 3-1 and 3-3a). Beyond 10 km, the scaled ITM loss values, at each distance, and the PFD computed at 10 km from NEC were used to compute the adjusted PFD (Equation 3-3b).

For the underground BPL analysis, the ITM input parameter for the transmitter antenna was set to 0.2 meter.[48] This is the height at which the BPL device protrudes above ground in the NEC underground power line model. In addition, the transition to ITM-computed transmission losses was made at a distance of 1 km, the minimum separation distance supported by ITM. Unlike the overhead BPL case, the far field region for the underground BPL case is close to the BPL device because the underground wiring only protrudes above ground for a length on the order of 1 meter. The extent of the near field region for the underground case is only meters or tens of meters from the BPL device.

3.5 SIMULATION RESULTS

A summary of the simulation conditions described in Section 3.4 is provided in Table 3-8. The results for communications receivers based on limiting the noise floor increase to 1 dB are provided in Section 3.5.1. The results for limiting the PFD seen by radar and radioastronomy receivers to less than -258 dBW/m^2-Hz are described in Sections 3.5.2 and 3.5.3, respectively.

Table 3-8: Simulation Conditions

Power Line Models	**Overhead**	**Underground**
Conductors	3 horizontal	1 power / 3 neutral
Conductor Material	Copper	Copper
Conductor Thickness	1 cm (approx. AWG 4/0)	1 cm (approx. AWG 4/0)
Conductor insulation	N/A	6 mm cross-linked polyethylene
Conductor spacing	0.6 m	-
Length	340 m	340 m
Height above ground	8.5 m	-1 m
Coupler location	Center conductor, center of span	Power conductor, 0.2 m above ground
Source	1 Volt in series with 150 Ω	1 Volt
Load	50 Ω between conductors	-
Shield enclosure size	N/A	1 m x 1 m x 0.5 m high
Shield material	N/A	Steel
Shield thickness	N/A	4 mm (wire grid)
Ground Conditions		
Conductivity	σ = 0.005 S/m	
Relative permittivity	ε_r = 15	
Simulation Frequencies		
Communication Receiver	4, 10, 15, 20, 25, 30, 40 MHz	
OTH Radar	25 MHz	
Radioastronomy	74 MHz	
Number of BPL emitters	(equal power, co-frequency, broadside orientation)	
Communication Receiver	1, 2	
Radar / Radioastronomy	4	
Receiver Antenna		
Communication Receiver	Low Gain	High Gain
Type	Horizontal dipole	Stacked log-periodic
Gain towards power line	0 dBi	5 dBi
Height	42.7 m	12.5m (average)

OTH Radar		
Gain towards power line	0 dBi	
Height	42.7 m	
Radioastronomy		
Gain towards power line	0 dBi	
Height	20 m	
Noise Conditions	Quiet Rural, as per Table 3-6	
ITM Conditions		
Frequency	Radar – 25 MHz	Radioastronomy – 74 MHz
Antenna Heights		
Transmitter (Power line)	Overhead	Underground
Height	8.5 m	0.2 m
Receiver	Radar	Radioastronomy
Height	42.7 m	20 m
Siting Criteria	Transmitter – Random	Receiver – Very Careful
Terrain Irregularity Factor, Δh	30 meters	
Polarization	Horizontal	
Relative Permittivity	15	
Ground Conductivity	0.005 S/m	
Climate	Continental Temperate	
Surface Refractivity	301 N-units	
Percent Time	90.0%	
Percent Location	50.0%	
Percent Confidence	50.0%	
Mode of Variability	Individual	
Interference Criteria		
Communication Receiver	Noise Floor Increase ((I+N)/N) = 1 dB	
Radar / Radioastronomy	PFD = -258 dBW/m^2-Hz	

3.5.1 Communications Receivers

Figures 3-2 through 3-8 illustrate the percentage of points along a simulated BPL power line where the noise floor increase due to BPL emissions from 4 to 40 MHz exceeds 1 dB, in a receiver having antenna gain of 0 dBi towards the power line. These results are plotted relative to the horizontal distance away from the power line. Figures 3-9 through 3-11 show the simulation results at 4, 15 and 25 MHz for a 14 dBi gain receiving antenna having up to 5 dBi of gain in the direction of the power line. In these plots, the results are shown for the case of a single Access BPL device operating at the Part 15 limit, and for the assumed case of two equal-power co-frequency Access BPL devices operating at the Part 15 limit. This latter assumption may encompass more than two co-frequency BPL devices generating various field strength levels below the Part 15 limit. Figure 3-12 summarizes the minimum radii needed to limit the noise floor increase to 1 dB or less, assuming the presence of two equal-power co-frequency BPL devices operating at the Part 15 limit. The minimum radii correspond to the horizontal distances at which 0 percent of the data points around the simulated power line result in a 1 dB noise floor increase.

Figure 3-12 shows that distances beyond which a 1 dB increase in noise are predicted to be possible increase slowly as frequency increases from 1.7 MHz to over 10 MHz, mainly as a result of decreasing median noise power levels. Between 15 MHz and 30 MHz, the greater radiation efficiency of the BPL power line significantly increases the distances where the noise floor can increase by 1 dB or more. The gain of the modeled high-gain antenna in the direction of the BPL power line is greatest between 15 MHz and 30 MHz as well.

Distance results for 4 MHz have been applied to establish the adopted 1 km exclusion zone dimension for the 2,173.5 to 2,190.5 kHz band used by coast stations.[49] Upward rounding of the 4 MHz distance of 895 meters to 1 km and application of that distance from the boundary of the coast station facility accommodates receiver antenna location flexibility, error tolerance in the reported antenna coordinates, and the possibility that other BPL power line configurations not evaluated herein may generate higher field strength.

Among the frequencies considered, the largest distance within which a 1 dB increase in noise is predicted occurs at 25 MHz (distance of about 3.9 km). Upward rounding of this distance to 4 km would accommodate error tolerance in the reported antenna coordinates and the possibility that other BPL power line configurations and BPL signal aggregation not evaluated herein may generate higher field strength.

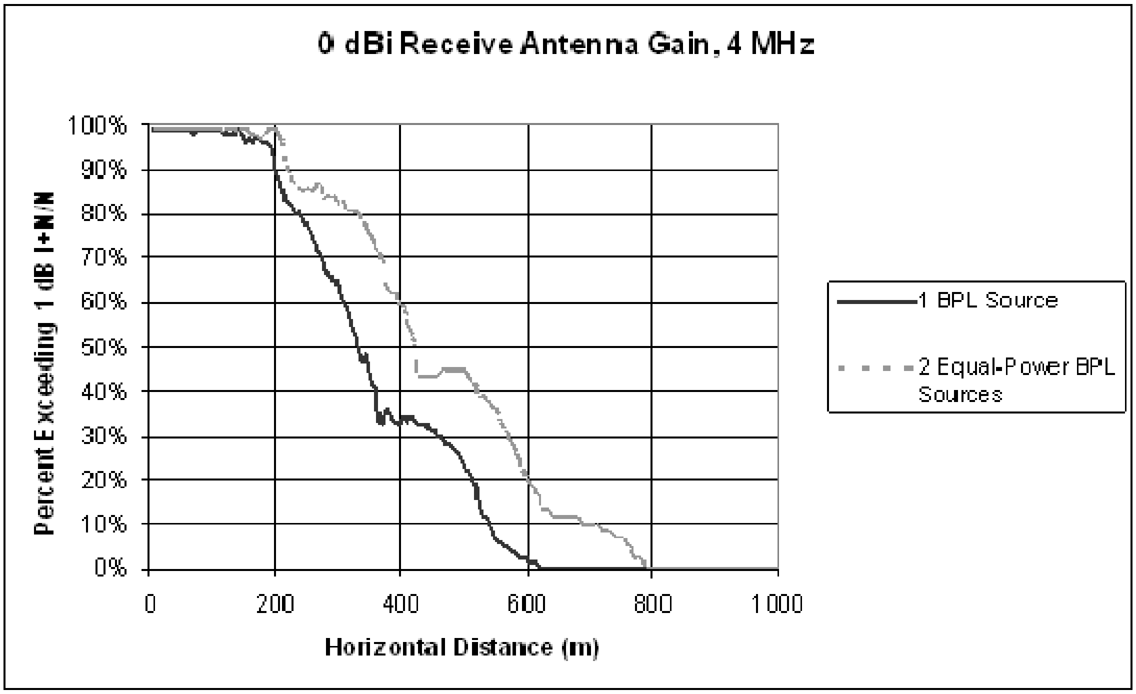

Figure 3-2: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

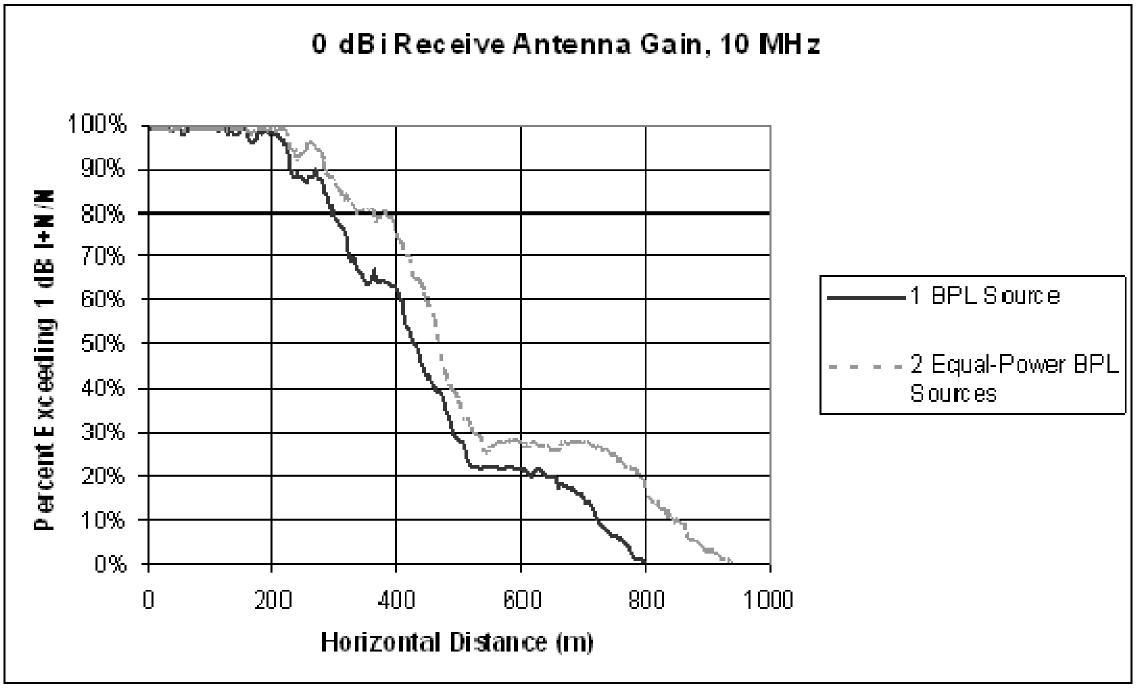

Figure 3-3: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

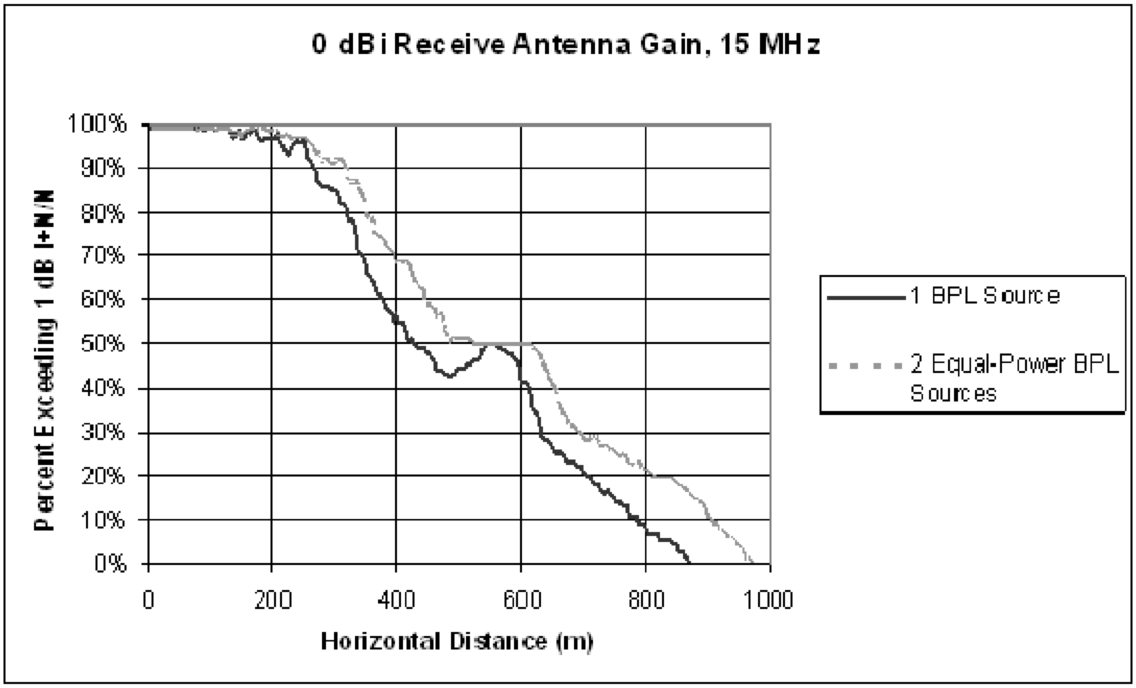

Figure 3-4: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

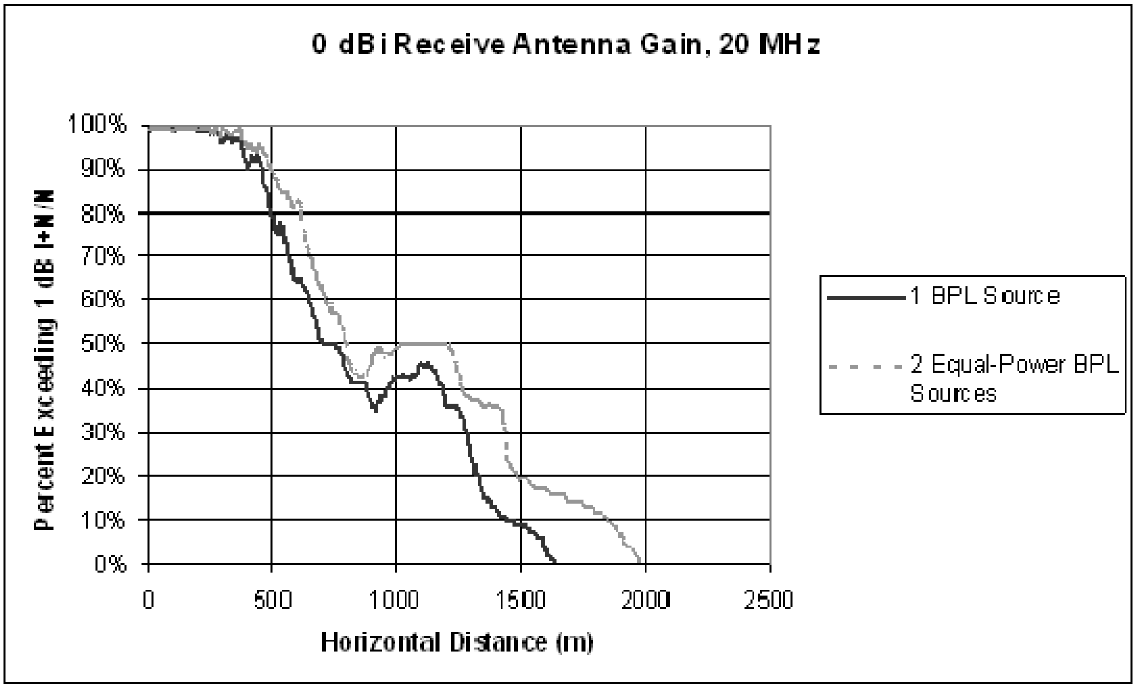

Figure 3-5: Protection Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

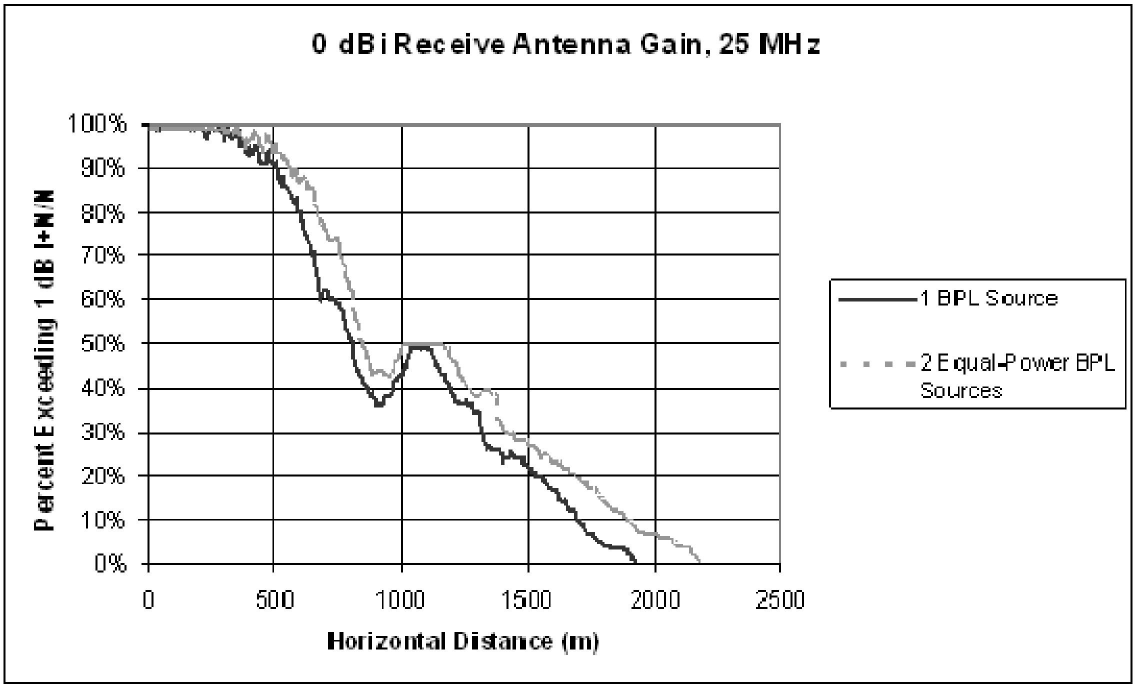

Figure 3-6: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

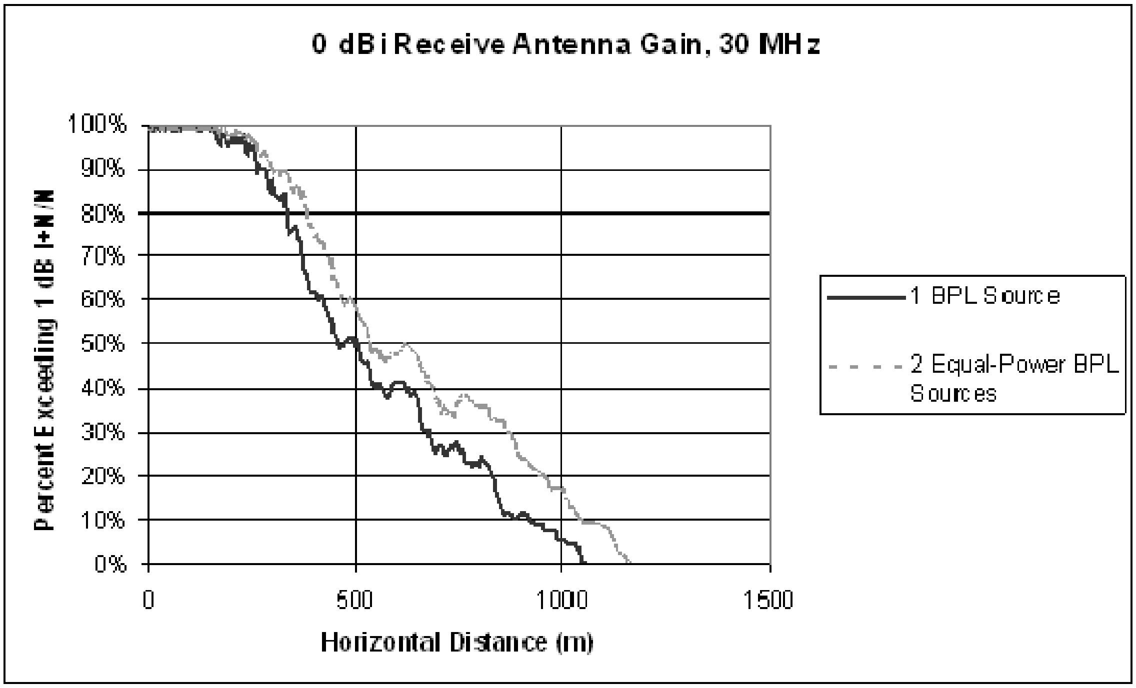

Figure 3-7: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

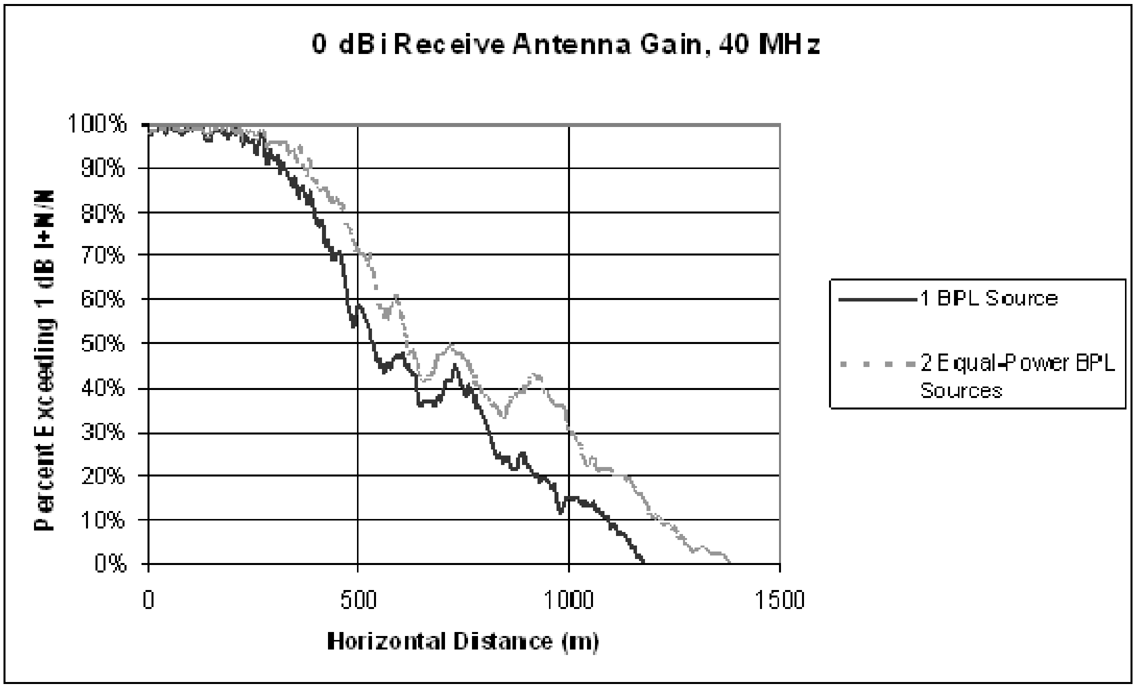

Figure 3-8: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

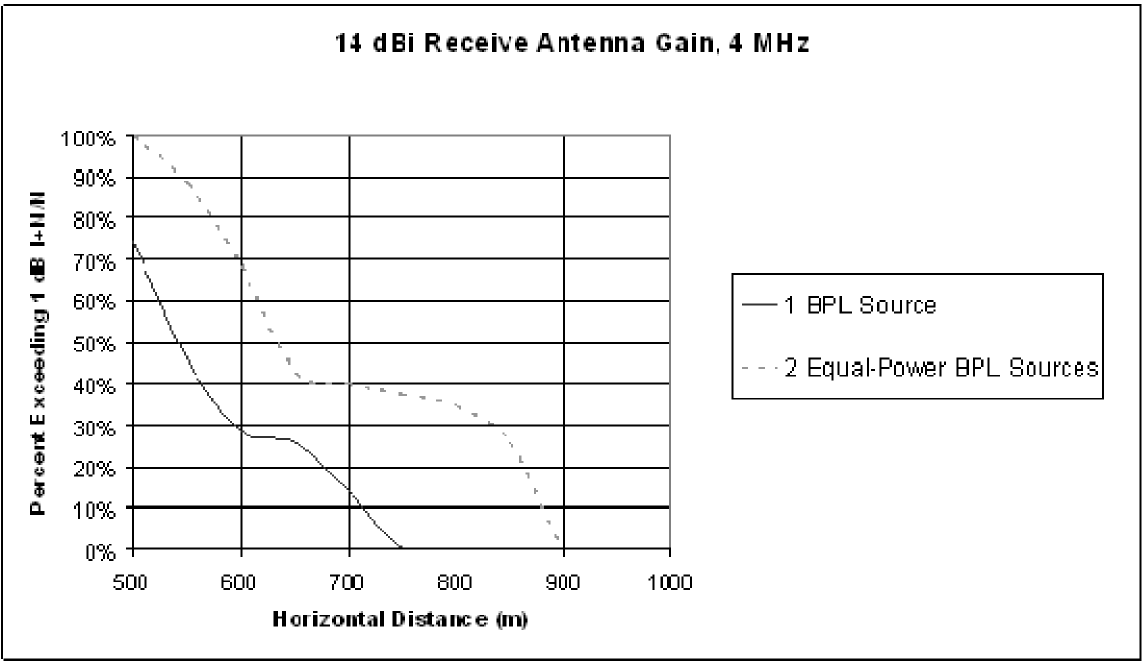

Figure 3-9: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

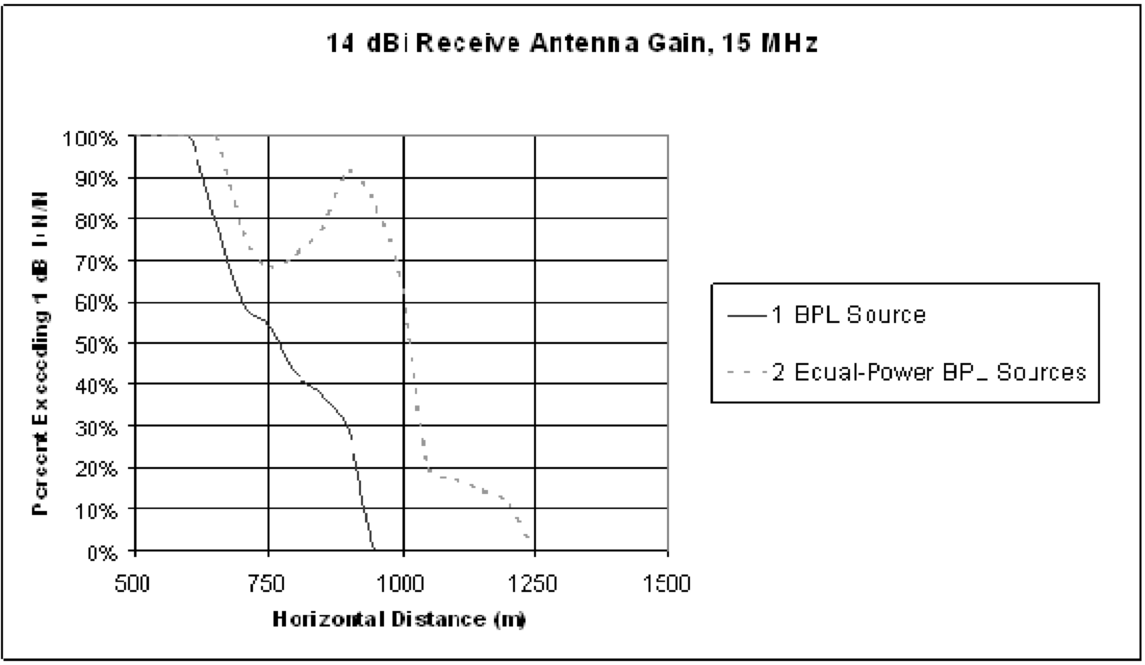

Figure 3-10: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

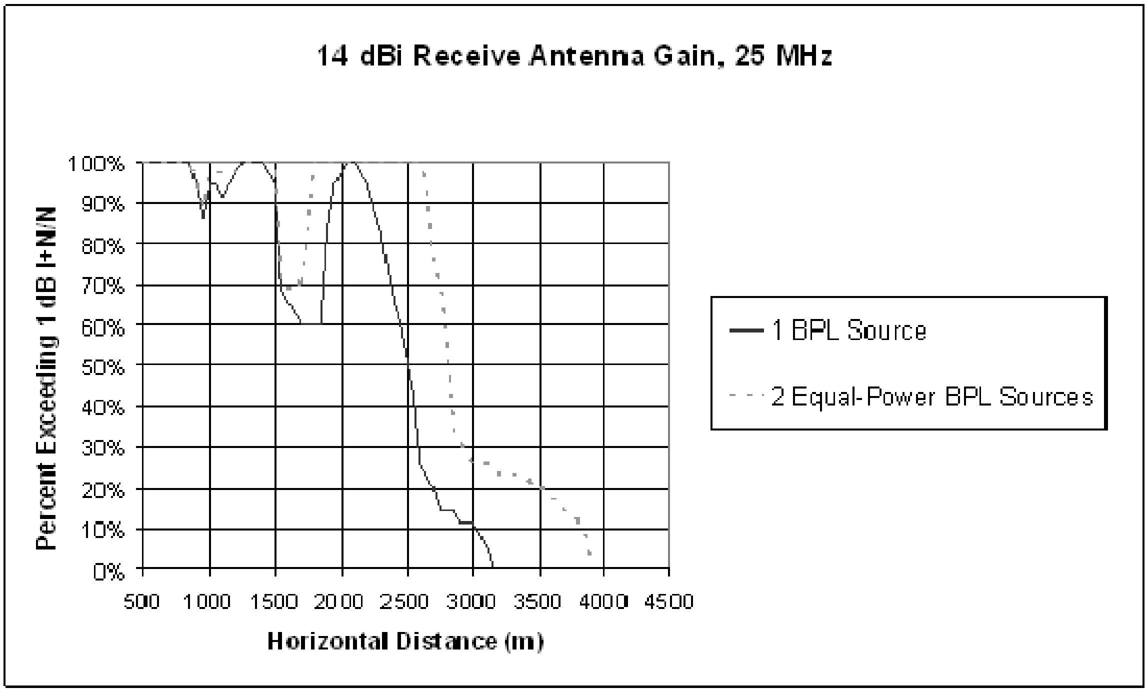

Figure 3-11: Percentage of points exceeding a 1 dB increase in noise floor as a function of distance from the power line

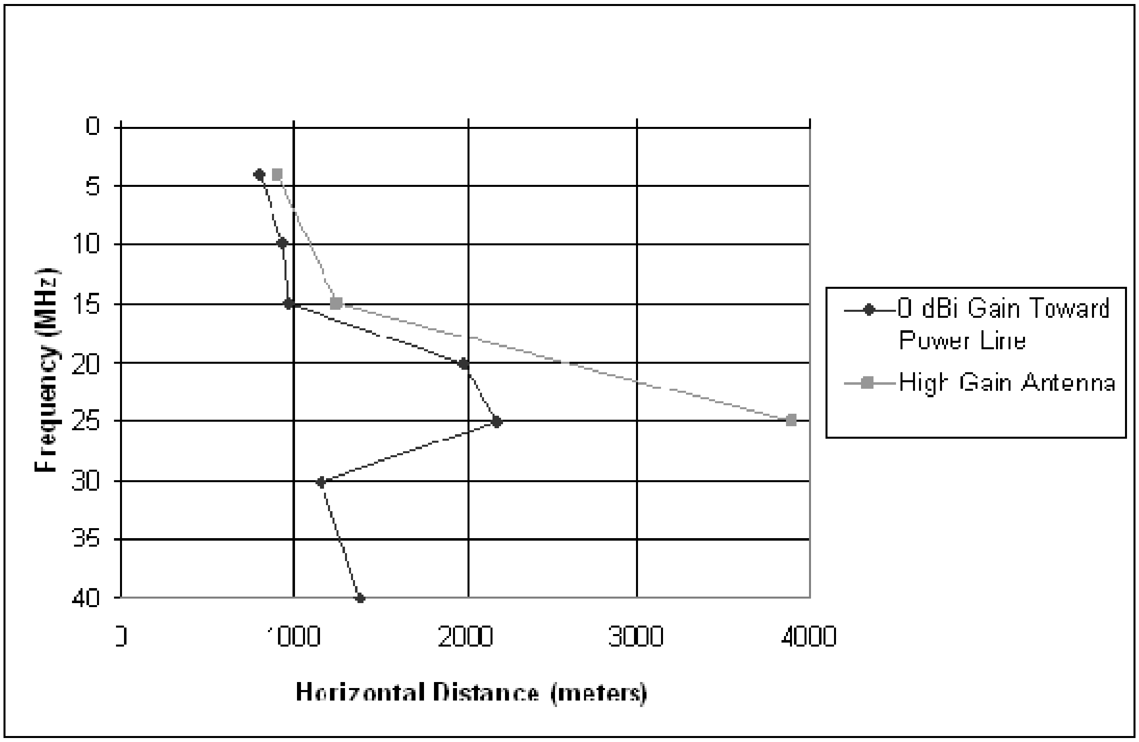

Figure 3-12: Summary of minimum protection area radii to limit noise floor increase to 1 dB or less

3.5.2 Radar Receivers

The calculated PFD at a radar receiving antenna located at various horizontal distances from multiple overhead BPL sources is shown in Figure 3-13. The results show the PFD at 25 MHz due to four equal-power co-frequency overhead BPL sources, positioned at a height of 8.5 meters above the ground and radiating at the Part 15 limit in the direction of the receiving antenna at the horizontal distances plotted below. As the results presented in Section 3.5.1 illustrate, the modeled overhead power line radiates most effectively at 25 MHz, and therefore, this frequency was chosen for evaluation in the radar receiver analysis.

Figure 3-13 shows that the maximum PFD levels begin to exceed the assumed threshold of -258 dBW/m^2-Hz at horizontal distances of 36 km or less from the power line. The Commission, in its BPL Report and Order, adopted a radius of 37 km for consultation areas around a number of critical radar receiving facilities in the 1.7 to 30 MHz frequency range.[50]

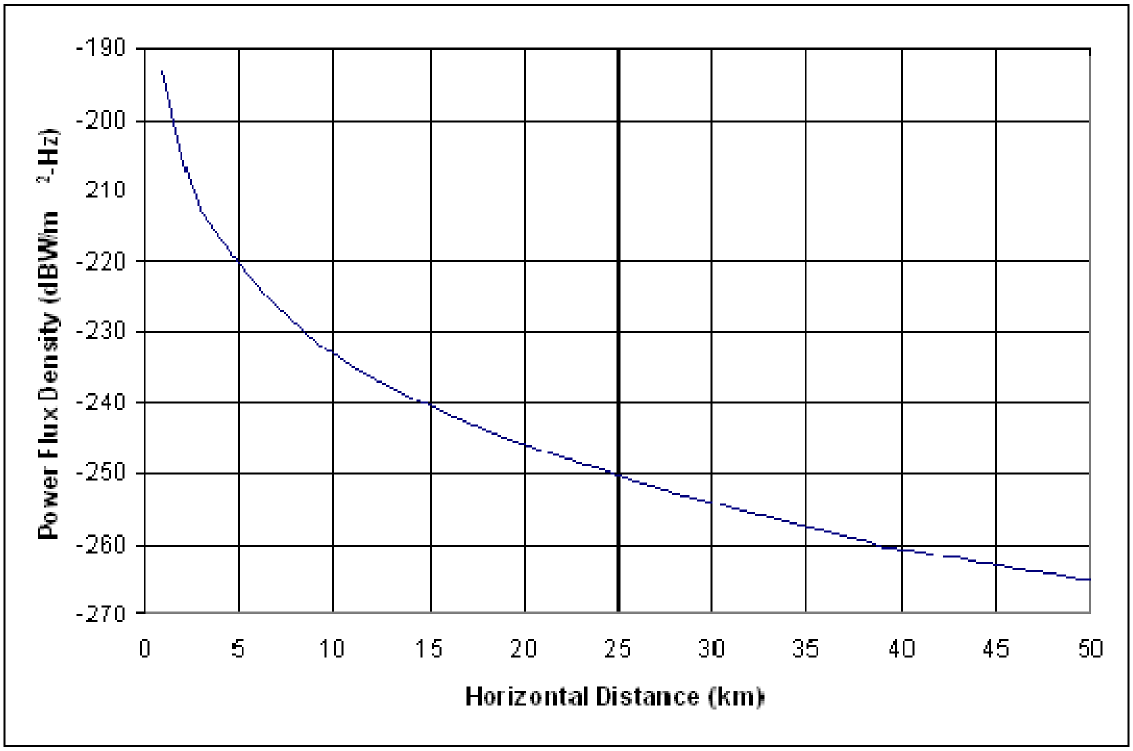

Figure 3-13: Power flux density relative to the distance from overhead BPL at 25 MHz (4 equal power co-frequency BPL signal sources)

3.5.3 Radioastronomy Receivers

The PFD levels expected at a radioastronomy antenna located at various horizontal distances from overhead and underground BPL sources are shown in the figures below. These analyses assumed that there were four equal-power co-frequency BPL sources radiating at the Part 15 limit in the direction of the receiving antenna.

For the overhead BPL power line case, the BPL sources were assumed to be positioned at a height of 8.5 meters off of the ground. In Figure 3-14, the PFD falls below the -258 dBW/m^2-Hz threshold interference level at distances greater than 27 km from the overhead BPL sources. In a letter to the FCC, NTIA requested that the Commission adopt an exclusion zone of 29 km around the boundary of the Very Large Array (VLA) radioastronomy site located in Socorro, New Mexico.[51]

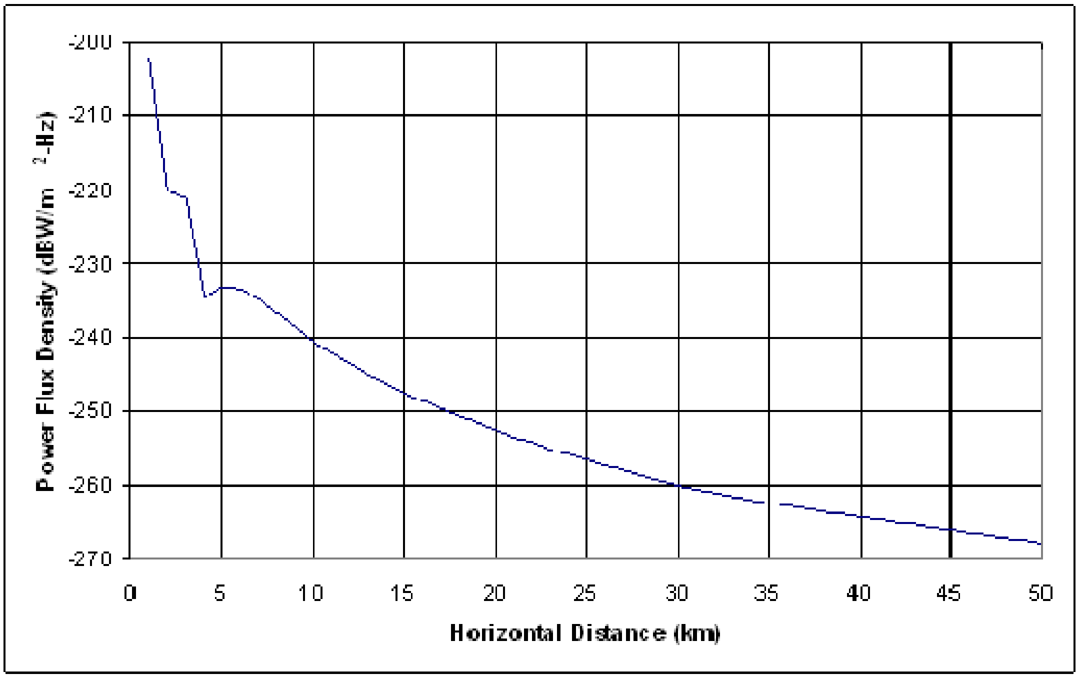

Figure 3-14: Power flux density relative to the distance from overhead BPL at 74 MHz (4 equal-power co-frequency BPL signal sources)

Figure 3-15 shows the results for the underground BPL case, assuming four equal-power co-frequency underground BPL sources radiating at the Part 15 limit in the direction of the receiving antenna.

Figure 3-15: Power flux density relative to the distance from underground BPL at 74 MHz (4 equal-power co-frequency BPL signal sources)

For the underground BPL case, the power flux density falls below the threshold interference level at distances beyond 14 km from the underground MV power lines. This somewhat exceeds the 11 km protection radius associated with the 73.0-74.6 MHz exclusion zone around the boundary of the VLA radioastronomy location. From NTIA's experience conducting field measurements on underground BPL systems, emissions levels are typically well below the Part 15 limits, and in many cases, the radiated BPL signal was not measurable.[52]

3.6 SUMMARY

Based on recommendations provided by NTIA resulting from these and earlier analyses, the Commission has specified excluded frequency bands, exclusion zones and consultation areas needed to prevent interference from BPL systems to certain federal radio operations in the 1.7 to 80 MHz frequency range. NTIA's analysis shows that, at the distances corresponding to these protection area radii, BPL emissions are expected to result in only small increases in the noise floor of protected communications receivers, or PFD levels that fall below the interference protection requirement for sensitive radioastronomy or over-the-horizon radar receivers.

These special safeguards provide an additional measure of interference protection beyond that afforded by field strength limits, prohibition of harmful interference from BPL systems, and compliance measurement provisions. The special protection provisions place only a minimal constraint on BPL deployment, as they impact only about two percent of the spectrum between 1.7 and 80 MHz. Additional special protection provisions may be needed if, at some time in the future, Access BPL devices are permitted to operate outside the 1.7 to 80 MHz frequency range.