2.5 CONCLUSION

The figures in Section 2.3 show substantial variability of the height at which the peak field strength occurs. This variability can be seen over frequency and power line topology. In all cases where the operating frequency is above 6 MHz, the peak field strength occurred at heights greater than 1 meter. Below 6 MHz, the wavelengths are greater than four times the modeled power line height (12 meters) and under such conditions, it is expected that increased in-phase coupling between the power line and ground will lead to the highest values of electric field at or near ground level as explained below.

A long wire radiator is linearly polarized in the plane formed by the wire and the radial vector from the center of the wire to the observation point. Therefore, the direction of the linear polarization changes from point to point. Near ground, the polarization is almost vertical, especially when the height of the wire is small compared to wavelength. This is evident from graphical depiction of the vertical electric field in Figure 2-17 (p. 2-14) and comparison of this field with the two horizontal fields at 1 meter, as shown in Figures 2-15 and 2-16 (p. 2-12 and p. 2-13).

The figures illustrating the height for peak field strength, and the difference between the overall peak field strength and the peak at 1 meter show variability over the frequency range and also show variability from one power line structure to the next. One reason for this is that the ratio of the measurement height to wavelength changes and another reason is that all calculations are performed at a distance of 10 meters from the BPL energized power line. The figures in Section 2.4 show that the difference between peak field strength at any height and the peak field strength at 1 meter tends to range from about 4 to 6 dB.

Calculations for the real-world power line model (*see* Figure 2-2) produced results in substantial agreement with these findings. This model consists of a topology most closely resembling that of the "ver36n" model (over most of its extent, this model has a three-phase vertical with neutral configuration). The 80^{th}-percentile data for this model levels off at just above 4 dB at higher frequencies, as does the data for "ver36n."

In light of the variability of height where peak field strength occurs, NTIA recommends that measurements be performed at a height of 1 meter and use of a height correction factor of 5 dB. This will eliminate the need for an exhaustive search for the peak field in the height dimension, which could require considerable time and would not provide any statistical easement.

SECTION 3
MEASUREMENT DISTANCE ALONG POWER LINE AWAY FROM BPL DEVICES

3.1 INTRODUCTION

As noted in NTIA's Phase 1 report, compliance measurement testing commissioned by BPL equipment vendors and service providers has generally focused on radiated emissions measured on radials from the BPL device under test. However, current FCC guidelines also state that the Part 15 devices and all attached wiring should be considered when measuring radiated emissions.[7] In the Commission's BPL NPRM, the proposed measurement guidelines specify the measurement locations along the power line away from a BPL device.[8] In this section, NTIA evaluates the location along the length of the power line where the peak field strength occurs and the likelihood of finding the peak level at the prescribed locations.

3.2 METHODOLOGY

Field strength predictions from the power line models described in Section 2 were evaluated for the location of peak field strength along the length of the power line. The data correspond to the location 10 meters from the power line where the field strength was at its peak at a height of 1 meter and the location where the field strength was at its overall peak.

3.3 RESULTS

Figures 3-1 through 3-18 show the location where field strength is at its peak level along the power line for a variety of simulated power line configurations and over the frequency range of 2 to 50 MHz. Distances are expressed in terms of wavelengths away from the BPL device. The locations along the power line (10 meters from the power line) where the overall peak and the peak at a measurement height of 1 meter occur are displayed in each figure.

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[7] *See* 47 C.F.R. §15.31(g)-(k).

[8] *See* BPL NPRM, Appendix C at ¶2.b.2 – "Testing shall be performed at distances of 0, ¼, ½, ¾, and 1 wavelength down the line from the BPL injection point on the power line. Wavelength spacing is based on the mid-band frequency…"

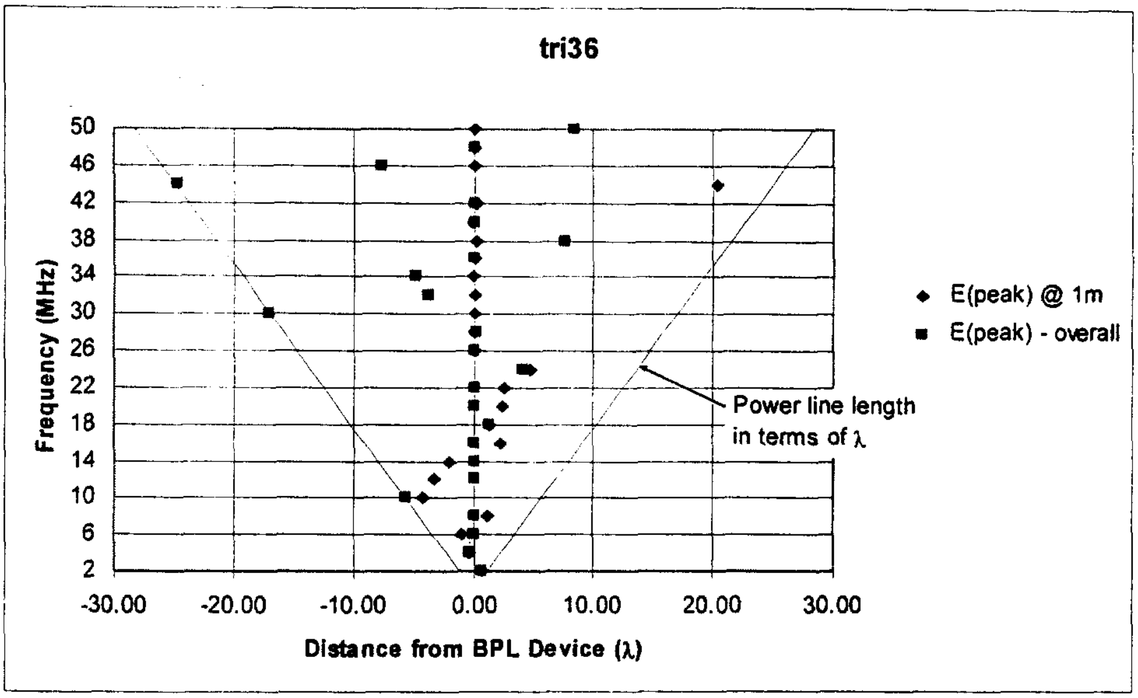

Figure 3-1: Location of peak field strength along the power line – tri36 topology

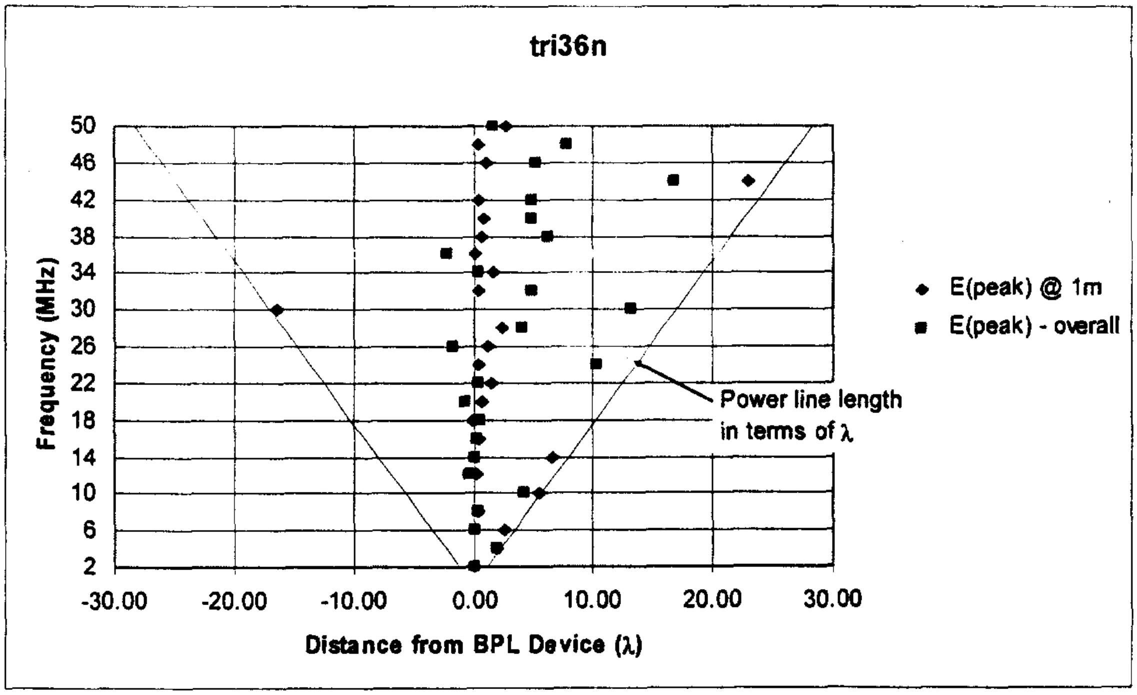

Figure 3 -2: Location of peak field strength along the power line – tri36n topology

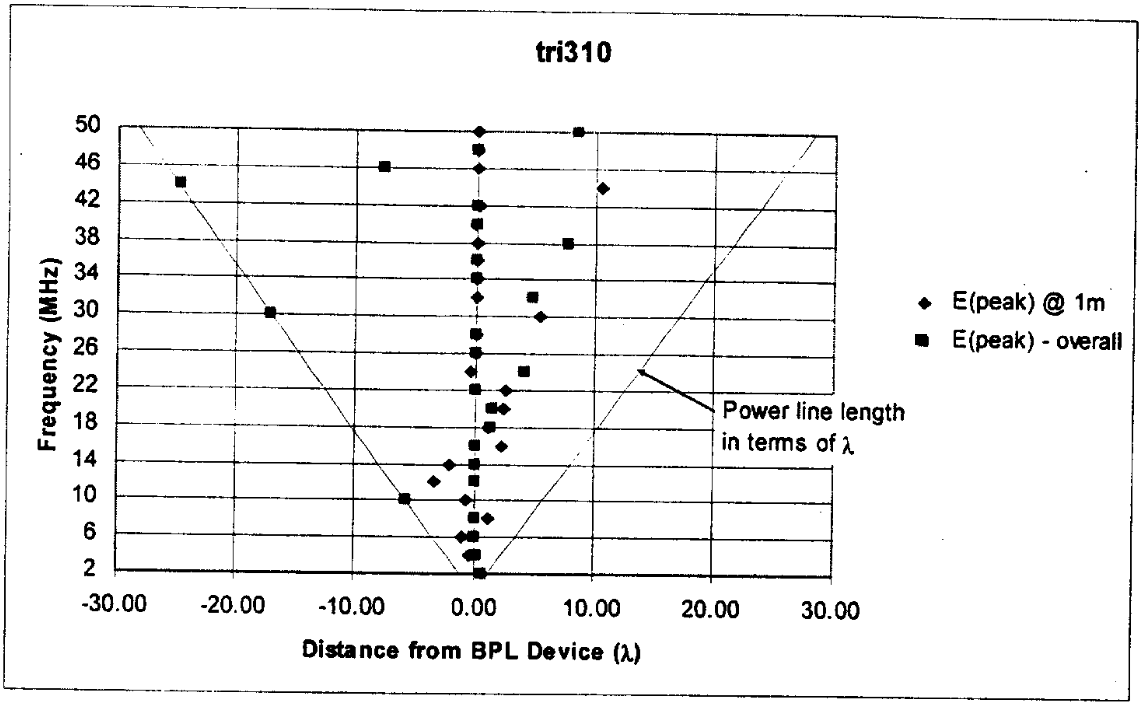

Figure 3-3: Location of peak field strength along the power line – tr310 topology

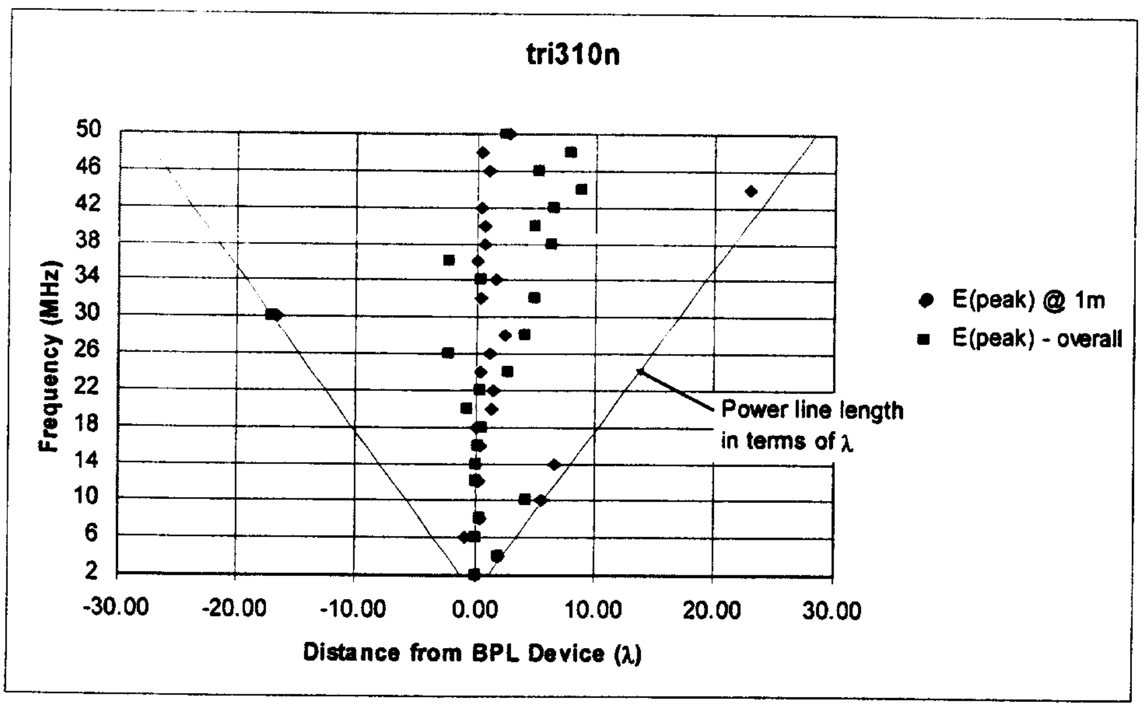

Figure 3-4: Location of peak field strength along the power line – tri310n topology

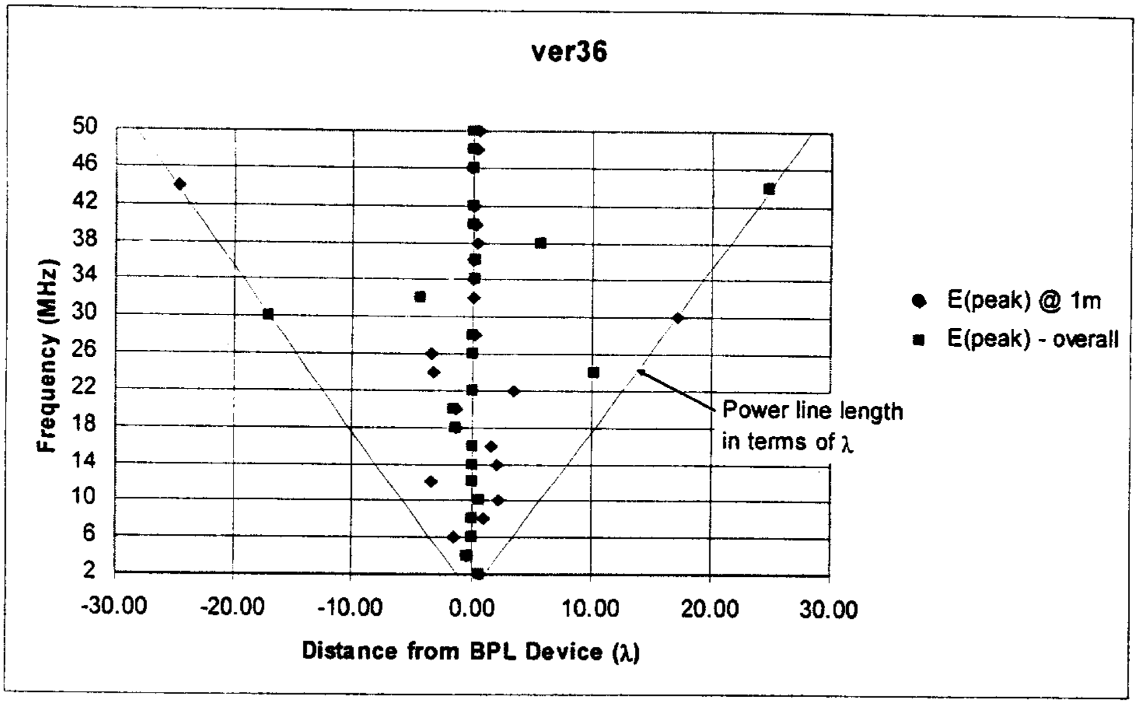

Figure 3-5: Location of peak field strength along the power line – ver36 topology

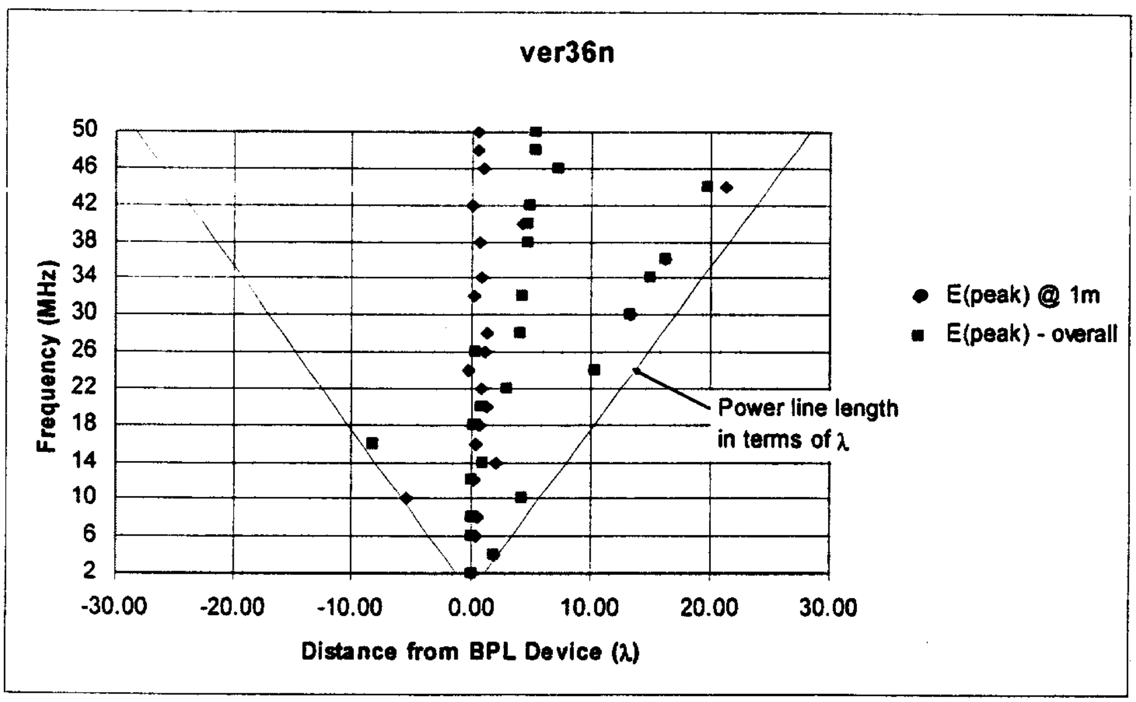

Figure 3-6: Location of peak field strength along the power line – ver36n topology

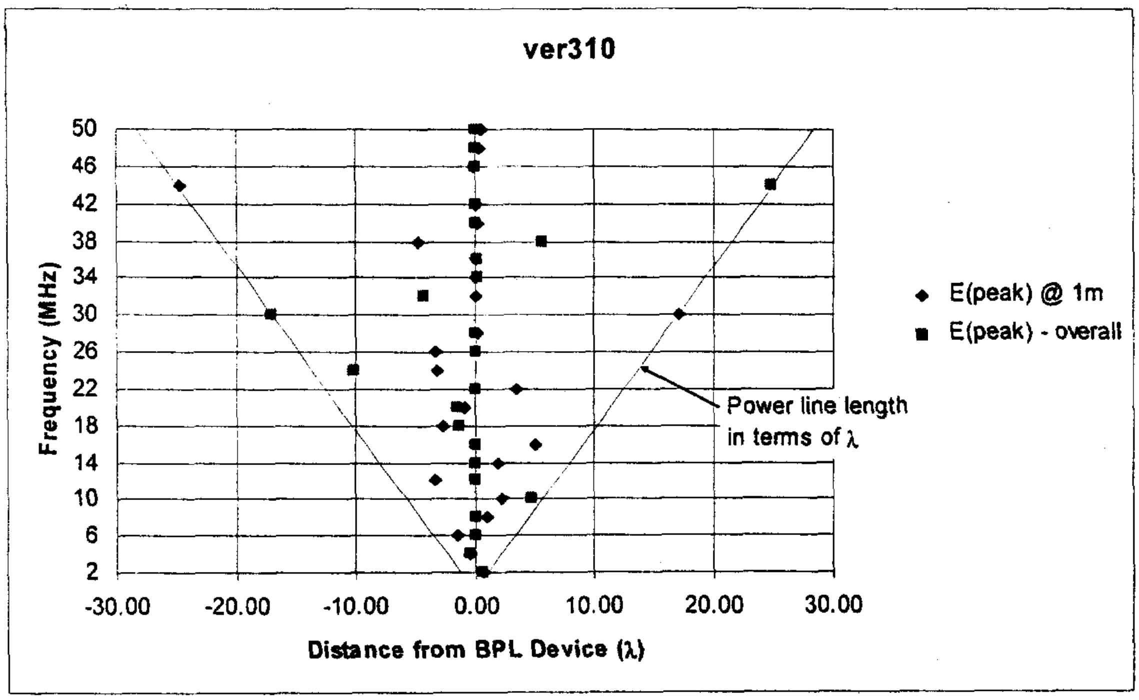

Figure 3-7: Location of peak field strength along the power line – ver310 topology

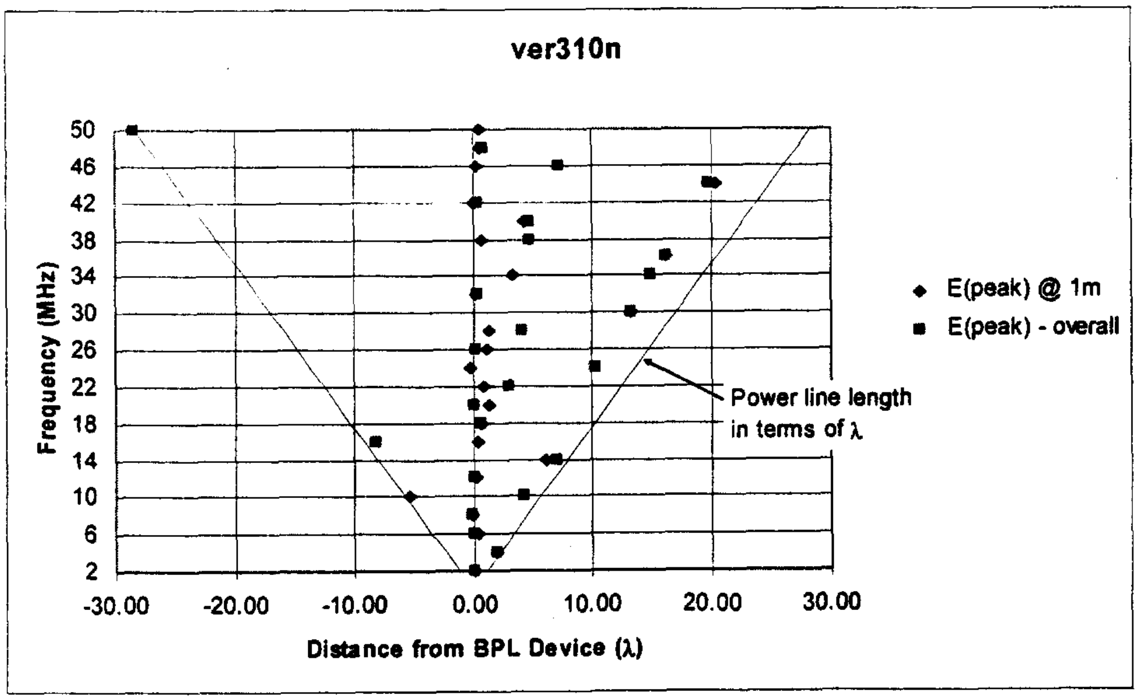

Figure 3-8: Location of peak field strength along the power line – ver310n topology

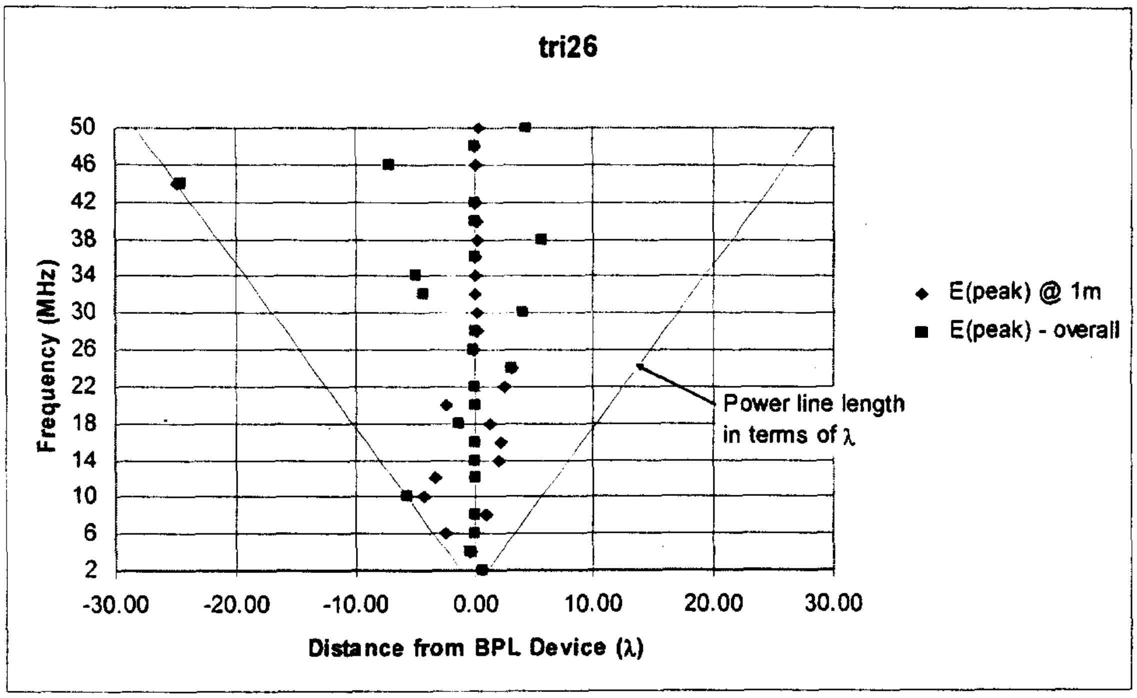

Figure 3-9: Location of peak field strength along the power line – tri26 topology

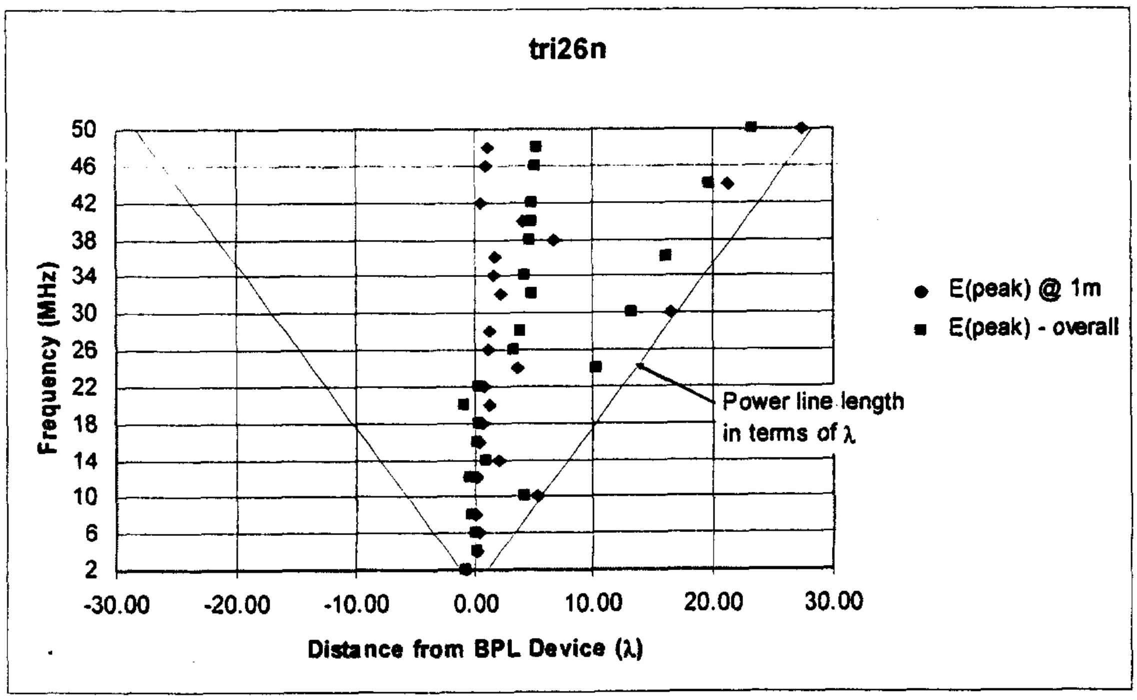

Figure 3-10: Location of peak field strength along the power line – tri26n topology

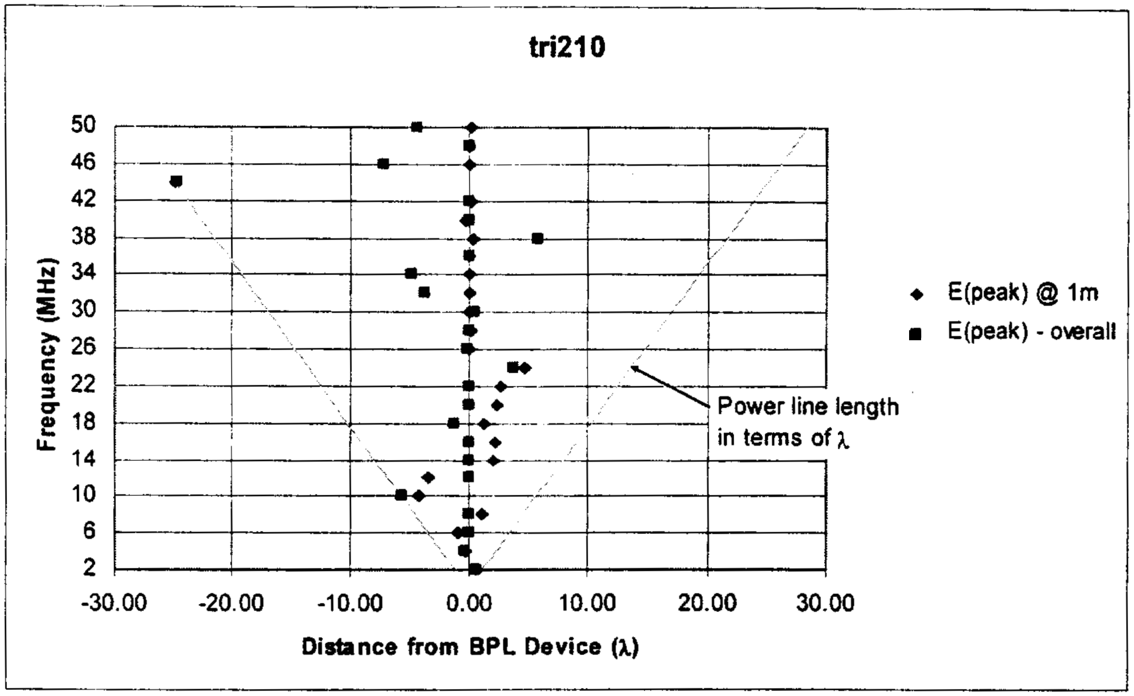

Figure 3-11: Location of peak field strength along the power line – tri210 topology

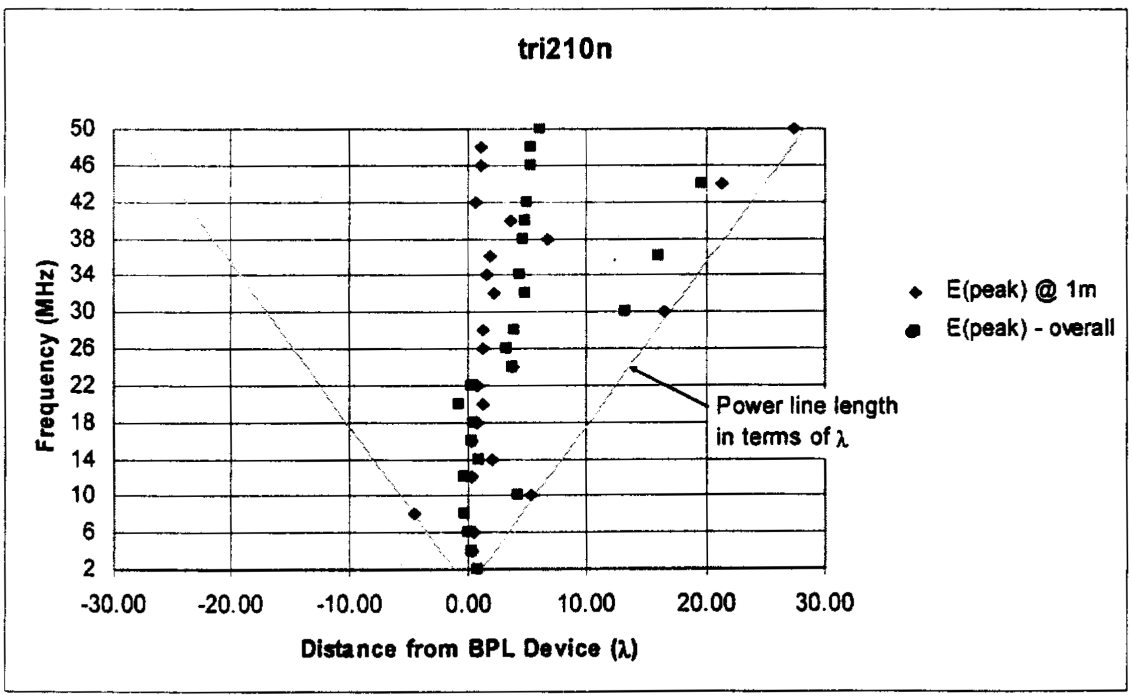

Figure 3-12: Location of peak field strength along the power line – tri210n topology

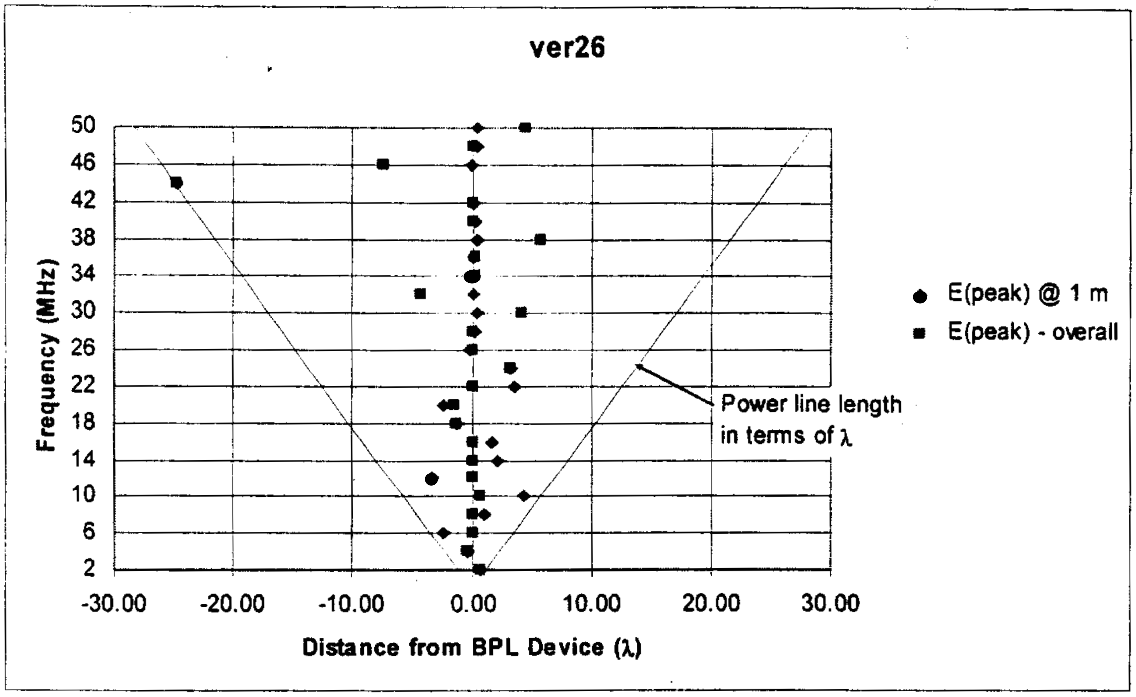

Figure 3-13: Location of peak field strength along the power line – ver26 topology

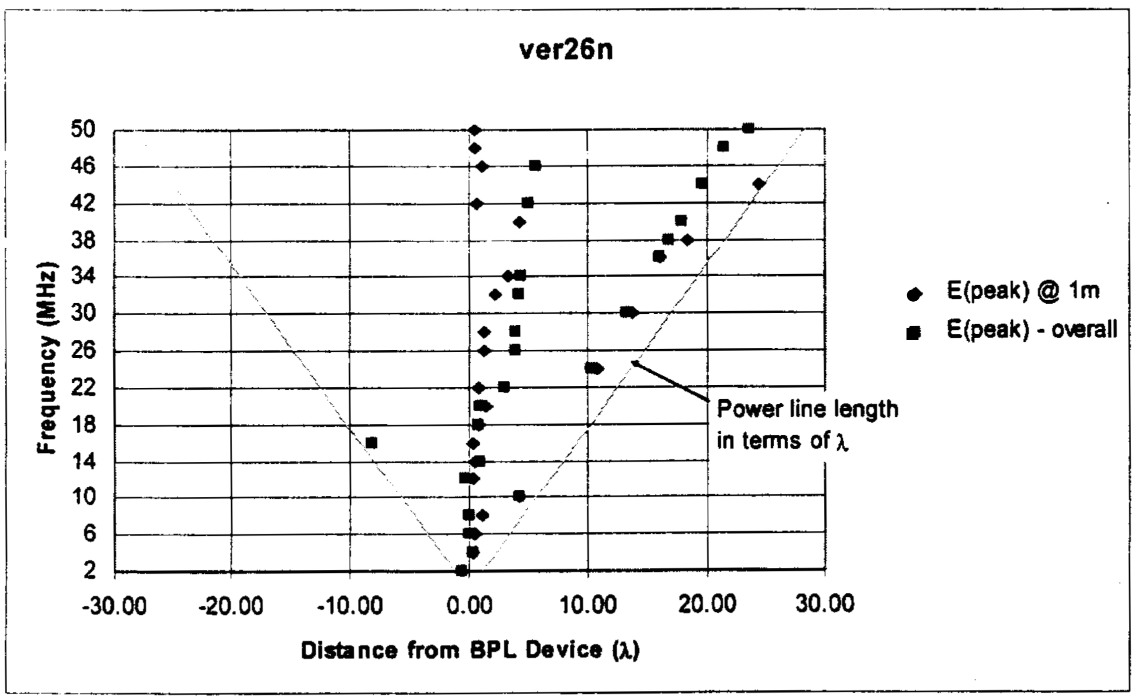

Figure 3-14: Location of peak field strength along the power line – ver26n topology

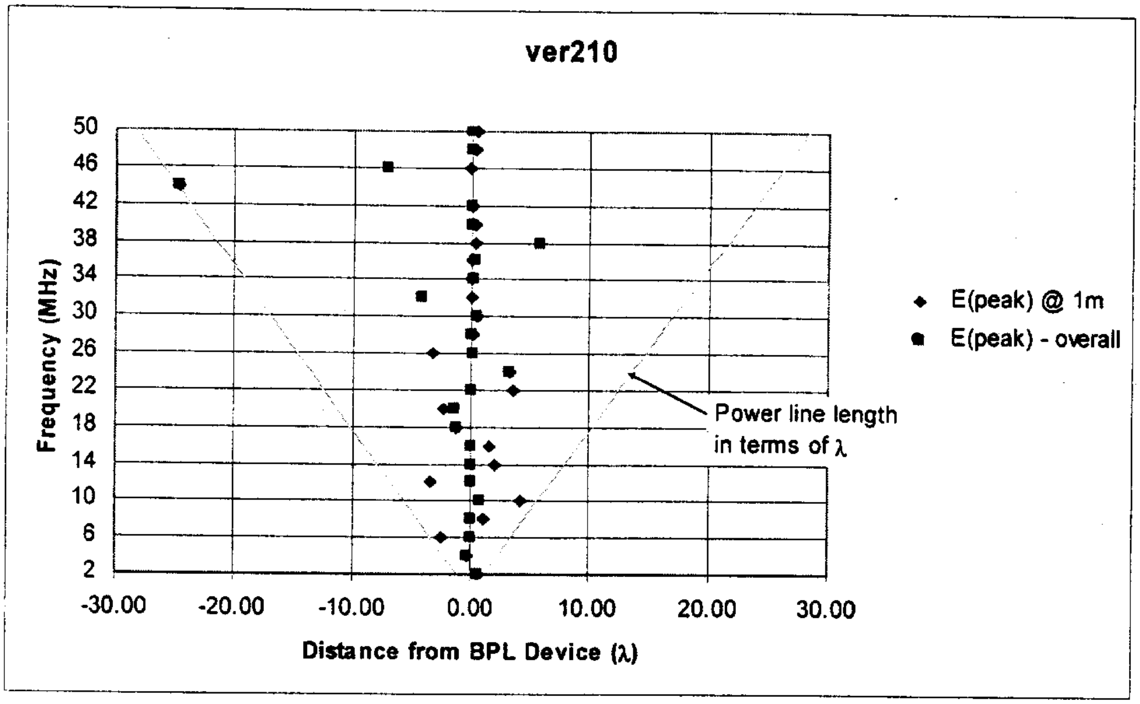

Figure 3-15: Location of peak field strength along the power line – ver210 topology

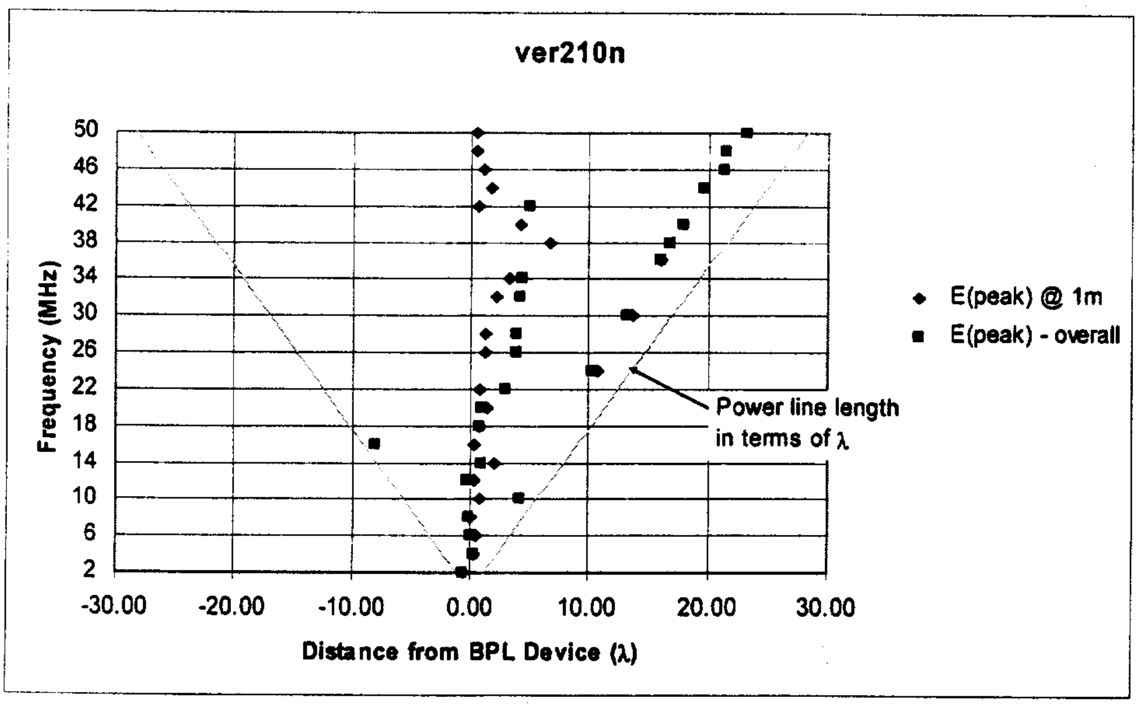

Figure 3-16: Location of peak field strength along the power line – ver210n topology

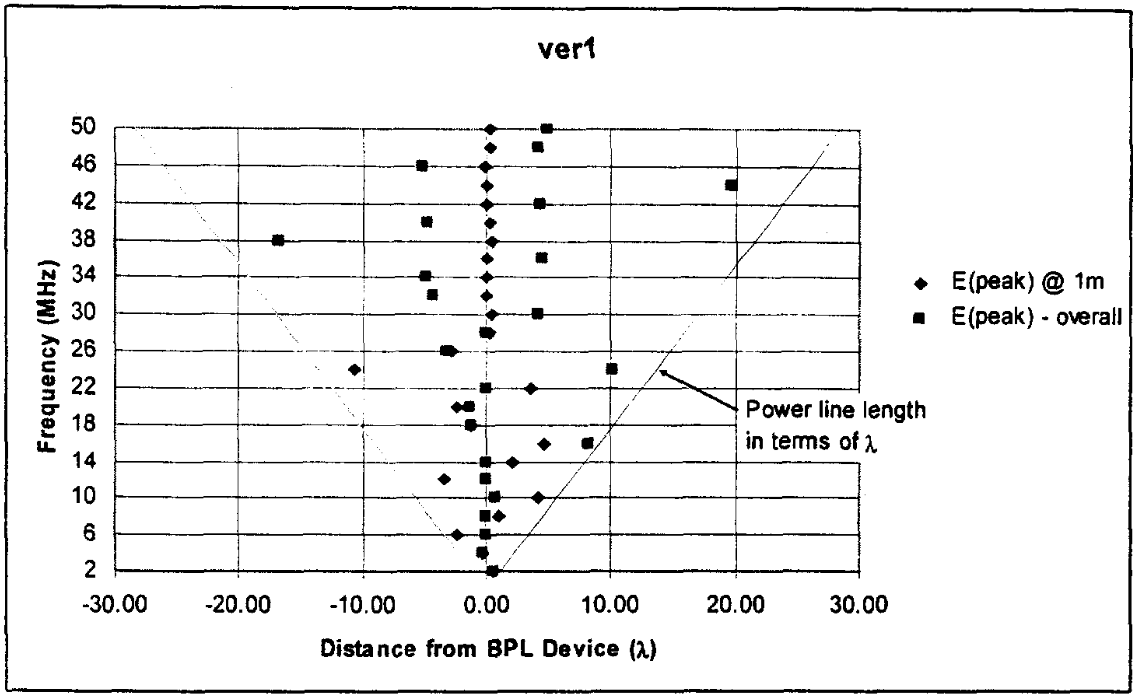

Figure 3-17: Location of peak field strength along the power line - ver1 topology

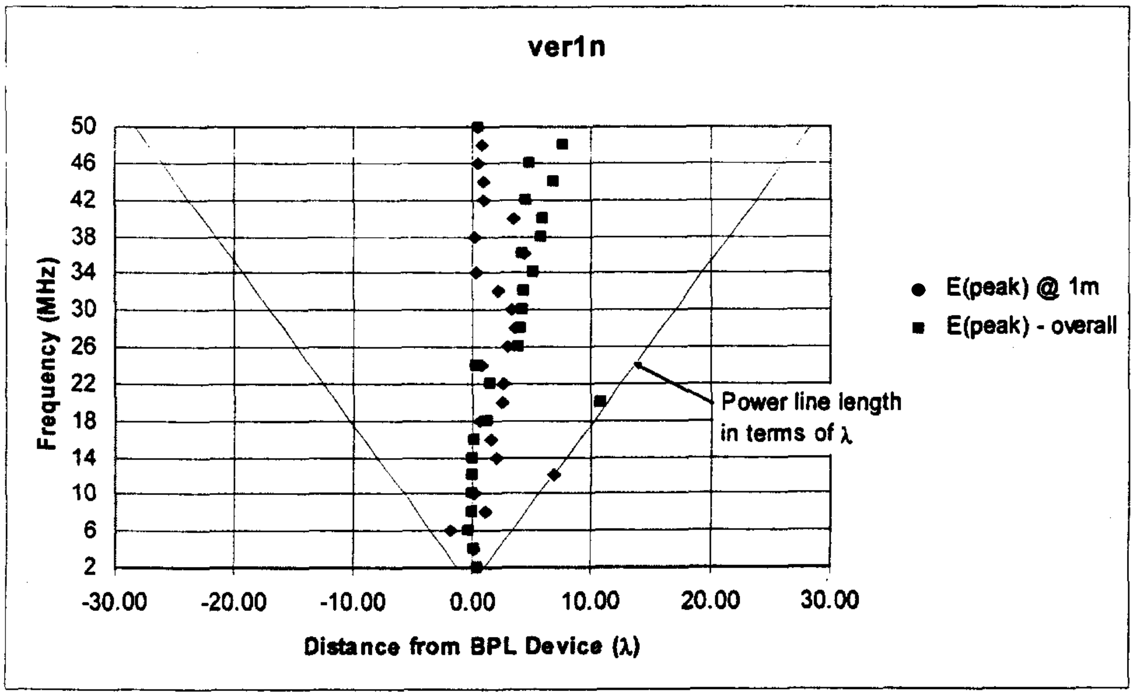

Figure 3-18: Location of peak field strength along the power line – ver1n topology

3.4 CONCLUSION

From the figures in Section 3.3, the locations all along the length of the power line where the field strength is at its peak, both at heights of 1 meter and overall, vary widely. For any given power line configuration, at some frequencies the peak occurs adjacent to or near the BPL device, while at other frequencies the peak occurs at substantial distances from the BPL device at an impedance discontinuity. There are also many frequencies where the field strength peaks at various distances along the power line. The variability of these results from power line to power line is due to different degrees of asymmetry in the power line structures and the fact that the electric field was calculated at a fixed horizontal distance (10 meters) from the power lines. The signal source was positioned on an outer conductor at a small positive (x-axis) offset from the center of the power line structure. The results are more asymmetric when a neutral wire is added to the power line structure, due to introduction of additional asymmetry. These results argue against use of the measurement locations proposed in the Commission's BPL NPRM. NTIA recommends that field strength measurements be performed at a 10 meter horizontal distance from an Access BPL power line, at points all along key segments of the power line where the maximum field strength from BPL emissions is expected to occur. In its ongoing Phase 2 study, NTIA will continue to investigate emissions along the power lines and recommend criteria for choosing representative segments of power line to measure.

SECTION 4
IONOSPHERIC PROPAGATION OF BPL SIGNALS

4.1 INTRODUCTION

Sky wave ionospheric propagation may occur above the power line horizon for frequencies between 1.7 MHz and 30 MHz, as discussed in NTIA's Phase 1 report. Sky wave propagation may be represented by rays which are refracted and reflected from the ionosphere and is responsible for signal transmission to distances ranging from hundreds to thousands of kilometers, depending on elevation angle of the radiated field, frequency and parameters of the ionosphere that exhibit temporal and spatial variability. The ionosphere, which ranges from about 60 to 600 km in height, acts as a low-conductivity dielectric.[9] In general, sky waves are reliable for radiocommunications up to about 30 MHz, above which this mode of propagation is sporadic.

Sky waves suffer large losses mainly due to ionospheric absorption and polarization coupling losses. In a widespread deployment of BPL systems, there may be aggregation of co-frequency BPL emissions toward the ionosphere. The modeling results in the Phase I report suggest that there is relatively strong radiation in directions above the power line horizon (*i.e.*, higher than radiation toward directions below the power lines), and so, aggregation of BPL signals at locations above power lines may be more significant than at lower heights where BPL signal propagation is less efficient.

4.2 ANALYTICAL MODELING OF SKY WAVE PROPAGATION

The goal of this preliminary analysis of aggregation and ionospheric propagation from widespread deployment of BPL systems was to gauge whether it could lead to interference in the near-term (next few years). Accordingly, the analysis has a worst-case orientation.

To make predictions regarding the large-scale effects of a widespread BPL deployment, NTIA employed the VOACAP HF propagation software developed at its Institute of Telecommunication Sciences (ITS).[10] NTIA modeled propagation under a range of times, months and frequencies to determine potentially worst-case I/N conditions. In this process, NTIA used VOACAP's "point-to-point" mode to find potential time, seasonal and frequency combinations that produced the highest I/N levels between several points around the nation. VOACAP's "area" mode was then used to further refine these predictions by determining the geographic coverage of relatively high I/N levels due to single transmitters placed around the nation as propagation factors were varied.

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[9] *See e.g.*, Propagation of Radio Waves, Edited by M. P.M Hall, L. W. Barclay and M. T. Hewitt, IEE, London, 1996.

[10] VOACAP is available from the NTIA Institute for Telecommunication Sciences, URL: http://elbert.its.bldrdoc.gov/hf.html.

Using these values, NTIA then ran VOACAP in its area mode to obtain interfering signal and noise power values in a fixed 31×31-point grid of receiving points covering the United States and centered on Kansas City, Missouri. For this step, NTIA placed BPL devices in the geographic center of each county in the United States (including Alaska and Hawaii). Each of the BPL transmitters (corresponding to a county) was assigned a radiated power that would produce field strength at the level of the Part 15 limit as measured using existing procedures. The total radiated power of each BPL device is shown in Table 4-1. These power levels were scaled by the number of active BPL devices expected to serve the urban households in each county.[11]

Table 4-1: BPL Total Radiated Power

Frequency (MHz)	Power (dBW/Hz)
4	-104.26
15	-101.79
25	-99.35
40	-123.15

Several other factors were taken into consideration when predicting the interference-to-noise ratio. BPL devices will not all operate at the Part 15 limit; therefore, the average field strength was assumed to be 4 dB below the Part 15 limit. The analysis was based on RMS values; therefore an adjustment was made to convert the quasi-peak BPL signal level to an RMS level. Finally, since the devices in the system do not all operate at the same frequency, an allowance of 6 dB was given (*i.e.*, 1 in 4 BPL injectors are assumed to be co-frequency). These adjustment factors are listed in Table 4-2.

Table 4-2: Adjustment Factors

Factor	Adjustment (dB)
Devices operating at levels below Part 15 limits	4
Quasi-Peak to RMS S/N difference	3
Co-frequency distribution factor	6
Total	13

All simulated BPL transmitters were given an average antenna pattern based upon the NTIA NEC far-field simulations of a complex power line model (Figure 2-2). This model was based upon a real Medium Voltage (MV) power line configuration at a test BPL deployment area. The NEC-derived far-field patterns were arithmetically averaged over azimuth, assuming a random distribution of power line orientations, which resulted in gain patterns with variation in elevation only.

The VOACAP program's variable inputs for this analysis are listed in Table 4-3.

[11] For this preliminary analysis, NTIA assumed that a BPL injector has the data handling capacity to support an average of 30 customers, and 1 of 4 urban households is a BPL customer. In other words, one BPL injector was assumed per 120 urban households.

Table 4-3: VOACAP Input Parameters

Variable	Value	Comment
Smoothed Sunspot Number (SSN)	150	Yields efficient propagation
Month	December	Yields good propagation and low noise
Time (UTC)	18:00	
Frequency (MHz)	23	
Manmade Noise at 3 MHz (dBW/Hz)	-164	Relatively low value
BPL Total Radiated Power (dBW/Hz)	-100	Maximum coupled BPL power for compliance with limit*

4.3 RESULTS

Aggregated output for a simulated nationwide deployment of over 700,000 Access BPL devices is depicted in Figure 4-1. The calculated hourly median I/N (VOACAP refers to it as S/N) level under these circumstances are greater than –17 dB over the continental United States, with hourly median I/N levels through much of the central United States between -8.4 dB and -11 dB. Thus, the highest expected hourly median increase in ambient noise due to the assumed extensive deployment of BPL devices would be less than 1 dB.

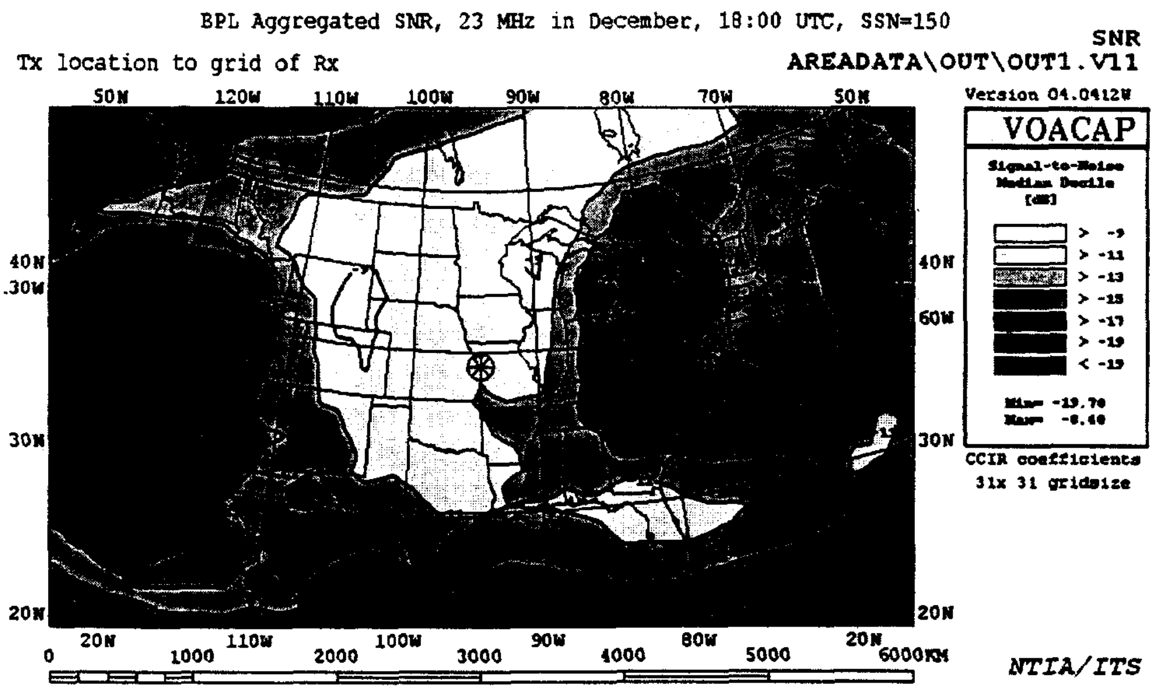

Figure 4-1: Aggregated BPL I/N levels due to ionospheric propagation (Existing Rules, Worst-Case Oriented Analysis)

* The maximum coupled BPL power that yields compliance with field strength limits can vary substantially among different power lines.

4.4 CONCLUSION

NTIA's worst-case oriented analysis of ionospheric propagation and aggregation of emissions from Access BPL systems indicates that interference via this mechanism will not occur in the near term. Considering realistically dispersed deployments of BPL systems, it would take hundreds of thousands of Access BPL devices operating under existing rules to cause a 1 dB increase in median noise. Under NTIA's recommended rule elements, chiefly the 5 dB height correction factor and power control, it would take millions of BPL devices to increase the median noise by 1 dB.

SECTION 5
INTERFERENCE RISK ANALYSES

5.1 INTRODUCTION

In its Phase 1 study, NTIA analyzed the risk of interference to various representative federal radio systems assuming BPL devices are operating at Class B emissions limits above 30 MHz under the current Part 15 rules. The interference risks were evaluated for two interfering signal thresholds: a doubling of receiver noise floor (I+N/N = 3 dB) that would result in interference in a low percentage of cases, and a ten fold increase in receiver noise floor (I+N/N = 10 dB) that would result in interference in a moderate percentage of cases. This section extends the Phase I study interference risk analyses to include operation of BPL devices at current Part 15 limits for Class A digital devices. In addition, the effect of NTIA's recommended 5 dB height correction factor is evaluated for the case of a land-mobile receiver in close proximity to an Access BPL power line.

5.2 BPL OPERATIONS AT CURRENT PART 15 RULES ABOVE 30 MHz

NTIA analyzed four representative federal radio systems assuming operation at Class A emissions limits above 30 MHz.[12] Figures 5-1 through 5-3 show the percent of locations, by distance from the Access BPL power lines, which could experience a noise floor increase of 3 or 10 dB. Both Class A and B results are plotted for land mobile, fixed and maritime stations, respectively.

Figures 5-4 through 5-6 illustrate the noise floor increase that an aeronautical receiver would experience at various altitudes and horizontal distances from the centroid of an area where BPL systems are deployed. As in the NTIA Phase 1 study, this deployment area has a 10 kilometer radius and the assumed density of co-frequency active BPL devices was one per square kilometer. Both Class A and B results are shown for the aeronautical receiver operating at an altitude of 6, 9 and 12 kilometers.

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[12] *See* NTIA Phase 1 Study, at §6.

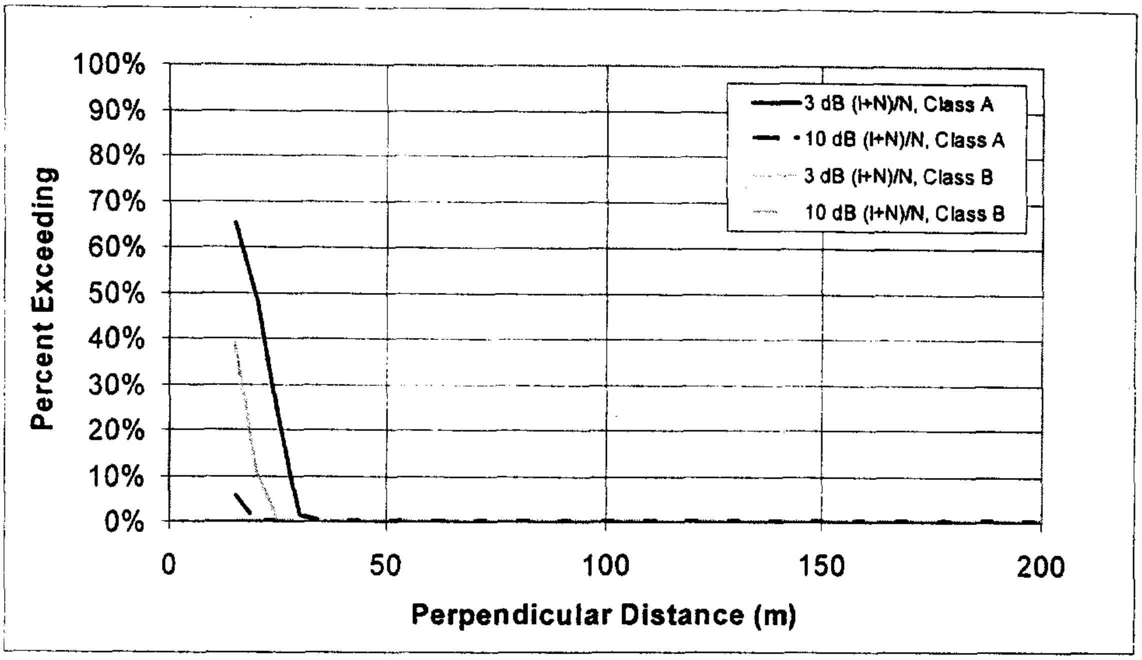

Figure 5-1: Percent of locations, by distance, exceeding the specified (I+N/N) levels at 40 MHz – Land-mobile receiver

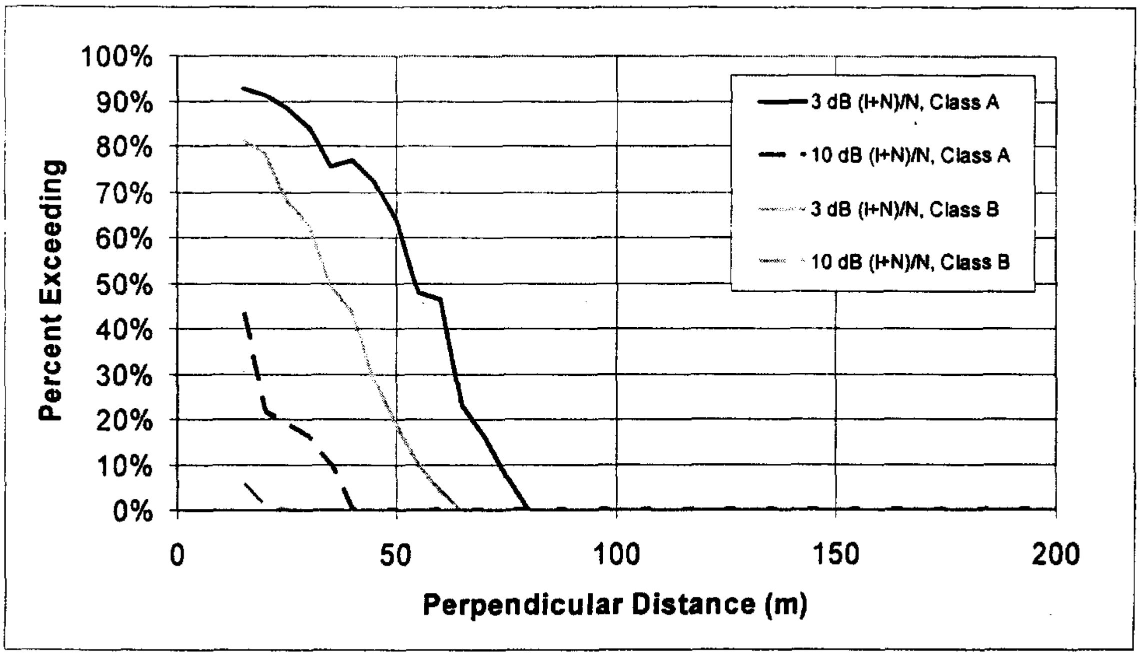

Figure 5-2: Percent of locations, by distance, exceeding the specified (I+N)/N levels at 40 MHz – Fixed receiver

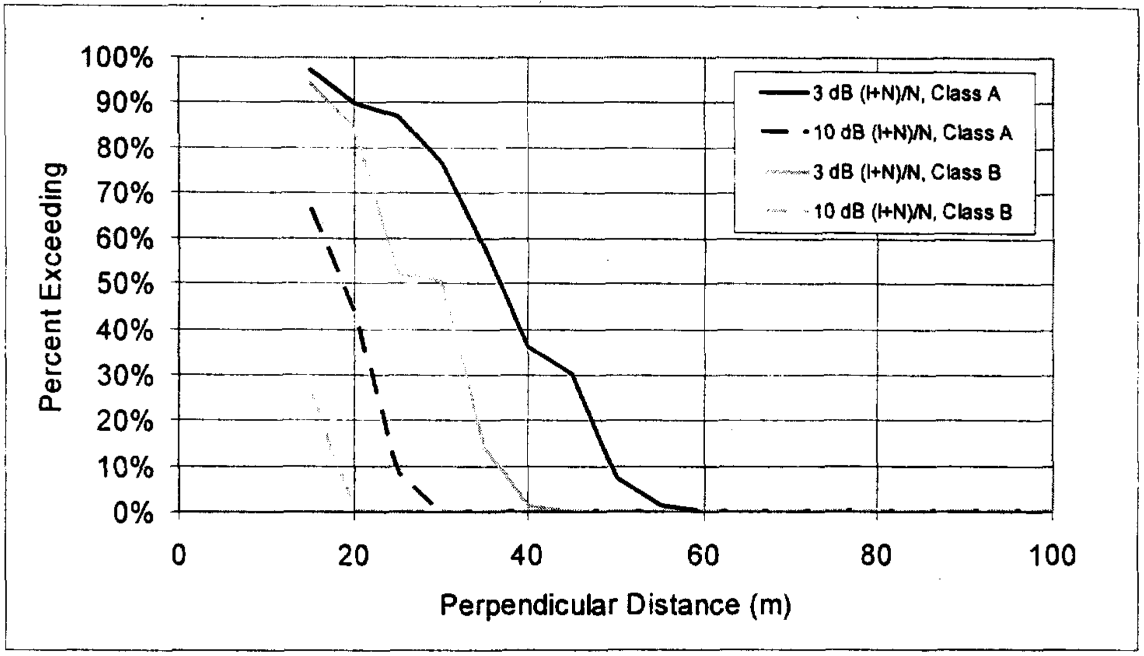

Figure 5-3: Percent of locations, by distance, exceeding the specified (I+N)/N levels at 40 MHz – Maritime receiver

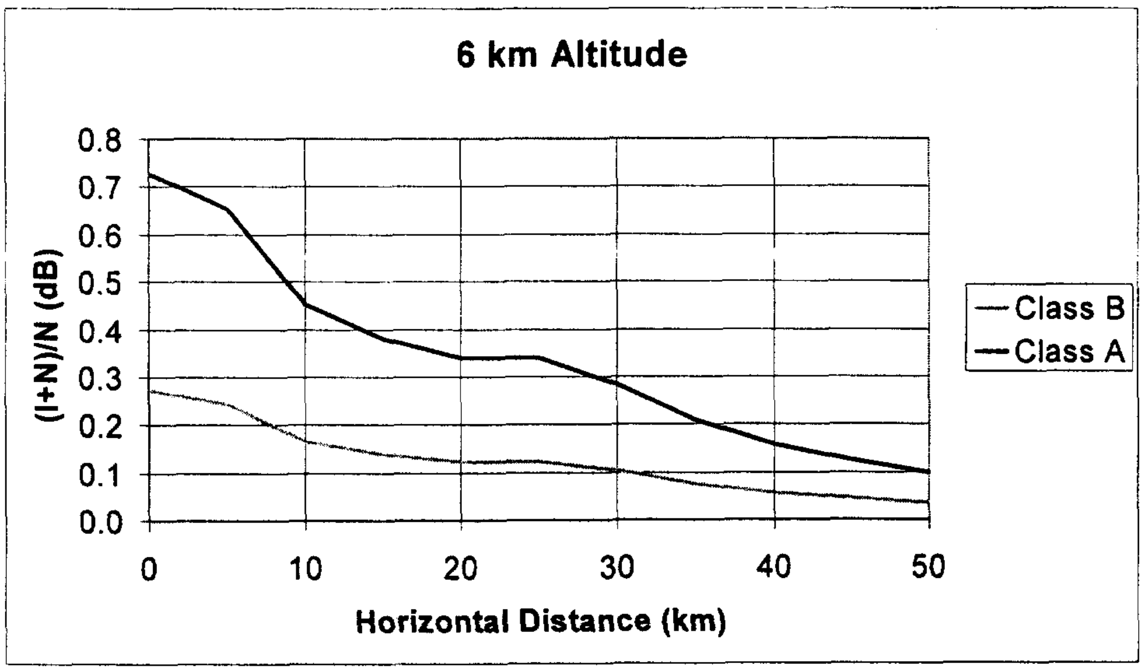

Figure 5-4: Calculated (I+N)/N level for an aeronautical receiver at the specified distance and 6 km altitude from a BPL deployment, with 300 BPL devices visible to the receiver in a 314 km^2 area – 40 MHz

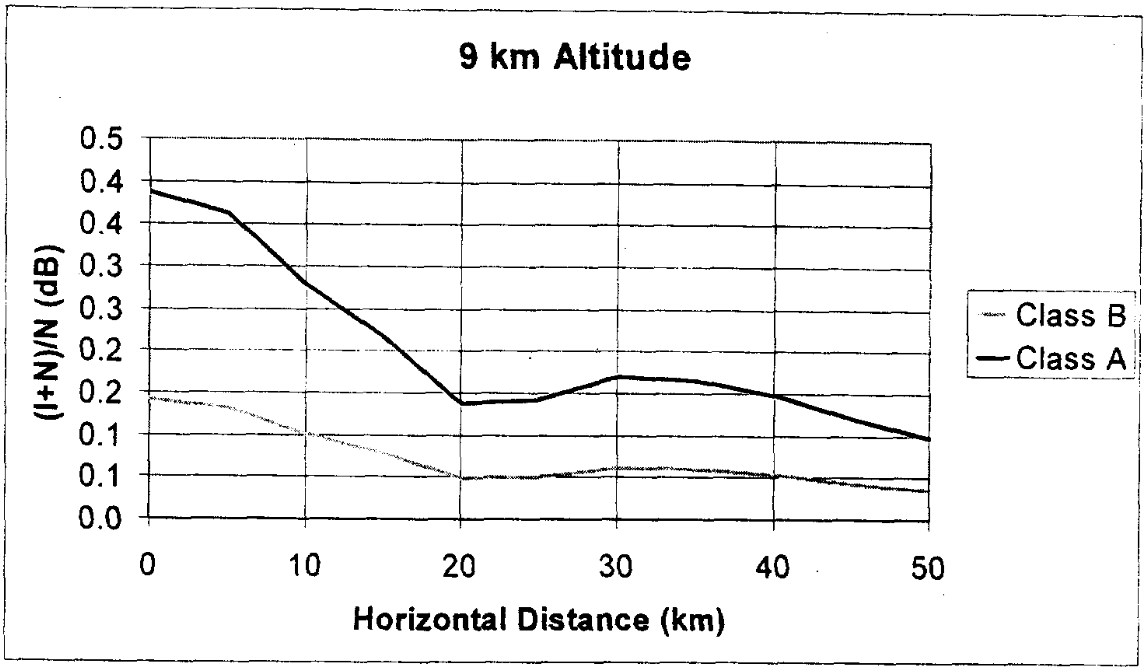

Figure 5-5: Calculated (I+N)/N level for an aeronautical receiver at the specified distance and 9 km altitude from a BPL deployment, with 300 BPL devices visible to the receiver in a 314 km² area – 40 MHz

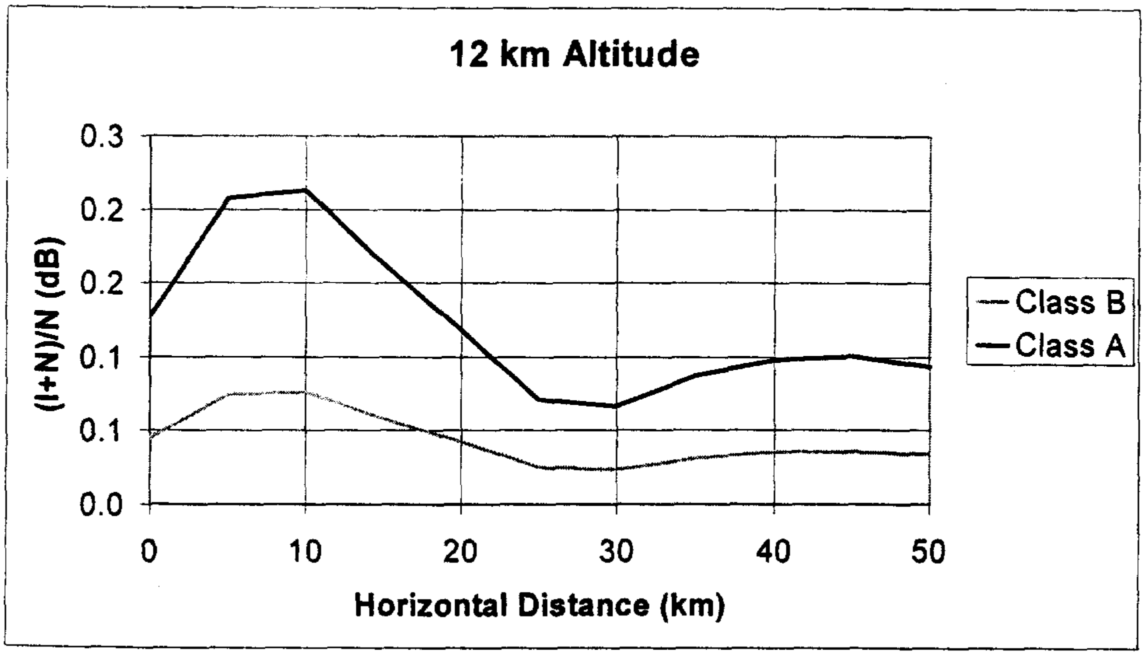

Figure 5-6: Calculated (I+N)/N level for an aeronautical receiver at the specified distance and 12 km altitude from a BPL deployment, with 300 BPL devices visible to the receiver in a 314 km² area – 40 MHz