参考資料９－２

平成１７年９月２６日

# 高速電力線搬送通信に関する研究会（参考資料）

## ITU-Rの動き紹介：ITU-R WP3Lの議長レポート

林政克(日経ラジオ社)

Received:　5 October 2004

Subject: Question ITU-R 228/3

United States of America

WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW RECOMMENDATION

Radiation and propagation of emissions from access PLT systems using overhead power lines

(See draft new Question in Doc. 3/2)…（別紙）

NTIAのレポートのエッセンスで、ITU-RでPLCからの放射特性に関する勧告にするための作業文書。昨年のWP3Lにおいて審議後、Annex 11 to WP 3L Chairman's Report（Annex 11 to Document 3L/41-E）として議長レポートに添付し、継続検討されることとなった。

INTERNATIONAL TELECOMMUNICATION UNION

**RADIOCOMMUNICATION
STUDY GROUPS**

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## United States of America

## WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW RECOMMENDATION

## Radiation and propagation of emissions from access PLT systems using overhead power lines

(See draft new Question in Doc. 3/2)

## 1 Introduction

In the United States, measurements of radiated emissions from Power Line Telecommunication (PLT) systems have been performed to determine spatial distributions of field strength from various outdoor, overhead power line configurations. These PLT systems are experimental and their emission levels do not necessarily comply with applicable new national regulations that are under development in the United States. Models of typical PLT systems were analyzed using the Numerical Electromagnetics Code (NEC) to further predict and characterize field strength distributions. These models are theoretical and address simplified physical models of power lines and important environmental elements; however, there is good correlation between measurements and the corresponding NEC results from a detailed model of a system that was measured.

Definitions are being developed in the United States for "in house" and "access" PLT systems, which are referred to as Broadband over Power Line (BPL) systems. This paper addresses emissions from outdoor, overhead power lines used by access PLT systems. Typical overhead power line topologies in the United States include:

- Medium Voltage (MV) lines (e.g., 13.8 kV) used for distribution from power substations throughout neighborhoods to step-down transformers typically serving six households (e.g., 13.8 kV step-down to the United States standard 115/230 Volt residential service);
- Low Voltage (LV) service lines between local step-down transformers (e.g., pole mounted) to meters at the customer premises;
- High Voltage (HV) transmission lines (not considered herein).

Detailed results of initial measurements and analyses are included in a technical report published by National Telecommunications and Information Administration of U.S. Department of Commerce [1].

## 2 Background

In the subject range of frequencies, 1.7-80 MHz, BPL devices and the power lines that carry BPL signals have the potential to act as unintentional radiators. The amount of radiation depends on the symmetry of the network at radio frequencies. Symmetry is defined in terms of impedance between conductors and ground. If for a two wire line, the impedance between each conductor and ground is equal, the line is symmetrical or balanced. A lack of symmetry leads to an unwanted, common mode signal. Common mode currents flow in parallel in both conductors, while return portions flow through ground. Balanced lines are necessary for differential mode transmission in which currents are equal in magnitude and flow in opposite directions on the signal conductors. The fields radiating from these conductors tend to cancel each other in the far field area. On parallel or nearly parallel, non-concentric conductors, common mode currents at radio frequencies produce more radiation than differential mode currents [2].

Any impedance discontinuity in a transmission line, which may arise from a BPL coupling device, a transformer, branch or a change in the direction of the line, may produce radiation directly and by reflections of signals forming standing waves that are radiated from the conductors. Even if the RF energy is injected into one of two or more conductors, the remaining wires generally act as parasitic radiators and, therefore, the lines can act as an array of antenna elements at certain frequencies. Radiation may come from one or more point radiators corresponding to the impedance discontinuities as well as one or more power lines.

The space surrounding a radiator can be divided into three regions: the reactive near-field, the radiating near field and the far field. The criteria for defining these field boundaries are not rigid and the field distribution changes very gradually as the boundaries are crossed [3]. Also, the locations of the above regions depend on the extent of the line responsible for most of the radiation. For interference through sky waves, and at distances seen by aircraft receivers, far fields are important. NEC, used with realistic physical arrangements and impedances of the power lines, has been applied to simulate the current distribution on the power lines and the radiated fields.

The propagation mechanisms of concern for BPL emissions toward or below the power line horizon will be by ground waves. For emissions in directions above the power line horizon, the propagation may be either by space and ground waves for shorter distances or by sky waves for larger distances. Sky waves suffer large losses mainly due to ionospheric absorption and polarization coupling losses. Emissions in directions above the power lines may either constructively or destructively aggregate via sky wave or via ground wave and space wave, and emissions toward or below the power lines generally may aggregate via ground wave in a similar manner [4].

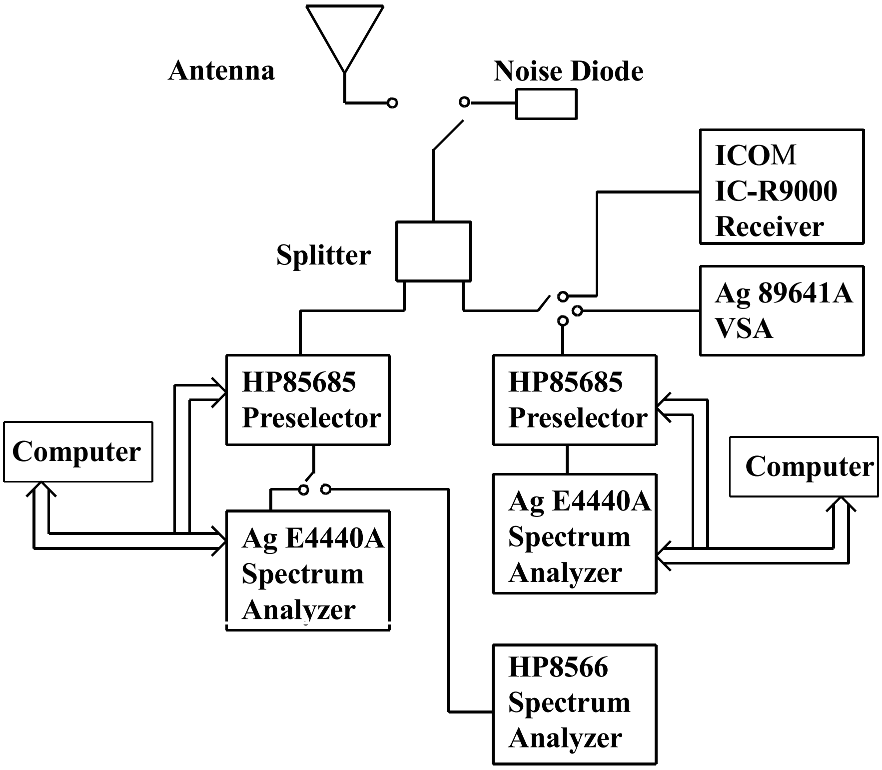
## 3 Measurement results

During the period August to November 2003, measurements were performed with a goal of quantifying key aspects of power line emissions. The measurements were conducted at three sites where BPL systems are currently deployed in the United States. All three of the sites had BPL signals on the MV wires and two of the sites also used BPL on the LV wires. Three relevant types of measurements of fundamental emission were performed:

1) BPL signal power at locations along and near an energized line;
2) BPL signal power at various distances away from an energized line;
3) BPL signal power at different receiving antenna heights and polarization orientations.

These measurements were made using an instrumented measurement vehicle and either an antenna positioned 10 meters above the ground on a telescopic mast, or 2 meters above the ground on a wooden tripod. Four types of antennas were used. A small discone antenna over a small ground plane was used to measure the electric fields above 30 MHz. Below 30 MHz, small shielded loops were used to measure the magnetic fields, and a rod antenna over a small ground plane was used for measuring the electric fields. To measure the received power that would be seen by a mobile unit, an off-the-shelf 2.1 meter base-loaded whip antenna was mounted on the roof of a vehicle at an approximate height of 1.5 meters. The whip antennas were narrow-banded so several of them were used to cover the measurement frequencies. The measurement system block diagram is shown in Figure 1.

FIGURE 1



**BPL measurement system block diagram**

The occasional sampling of environmental noise power levels with the BPL system turned off showed that they were lower than the levels predicted by Recommendation ITU-R P.372-8. Thus, the sites for these measurements have relatively low noise power levels and use of the higher noise power levels predicted by Recommendation ITU-R P.372-8 in our analyses may bias results toward underestimation of signal levels.

### 3.1 BPL signal power along an energized power line

The peak received power due to the electric field generated by BPL signals was measured with a rod antenna at a height of 2 meters at various points along a power line. Three mutually orthogonal components of the electric field were measured. These measurements indicate that there is a strong BPL electric field (relative to noise) along and near the BPL power line and in general, the field does not measurably decay with distance from the device (along the power lines). In at least one case, the electric field actually increased with increasing distance from the BPL device. This is thought to be due to BPL signal reflection by one or more impedance discontinuities and the generation of standing or traveling waves. In general, the location variability in the field is thought to be due to the presence of standing or traveling waves in the current distribution along the power line. The magnetic field using a loop antenna at 2 meters height was not measurable along the power line at most locations (the instrumentation had a noise figure of 13 dB).

The peak received power due to the electric field was measured with the whip antenna mounted on the top of a vehicle at various distances from the BPL device, along the power lines, at distances of approximately 40 meters from the power line. The results are similar to those obtained from the electric field measurements using the rod antenna. The measurements at one site at a frequency of 32.70 MHz and at a height of 10 meters indicate that after an initial decrease of received power with increasing distance from the BPL device along the power line, the power remains at about the same level with increasing distance along the power line. The diagram of a measurement site and a plot of the power levels measured with a rod antenna along the power line at 28.298 MHz are given in Figures 2 and 3 respectively.

FIGURE 2

**Site for measurements along and away from the power line**

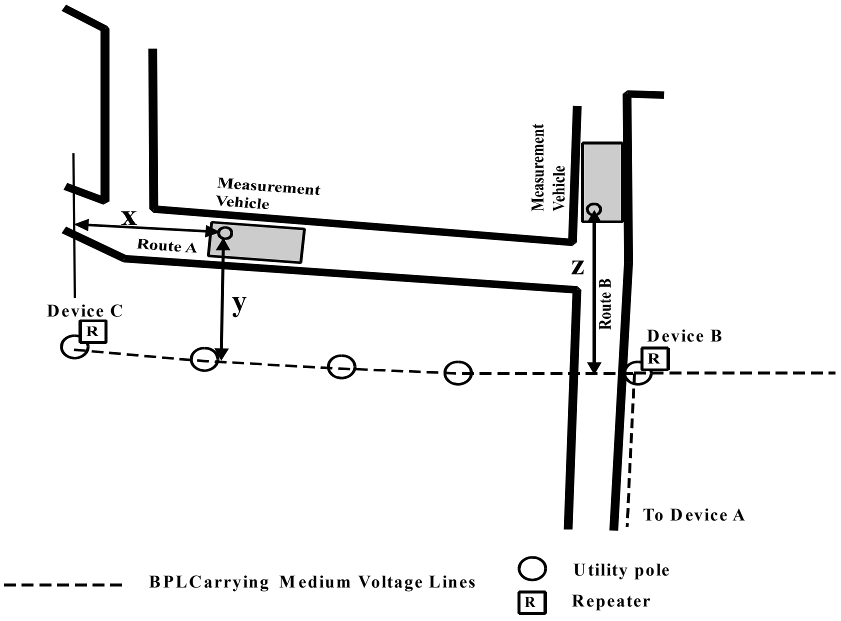
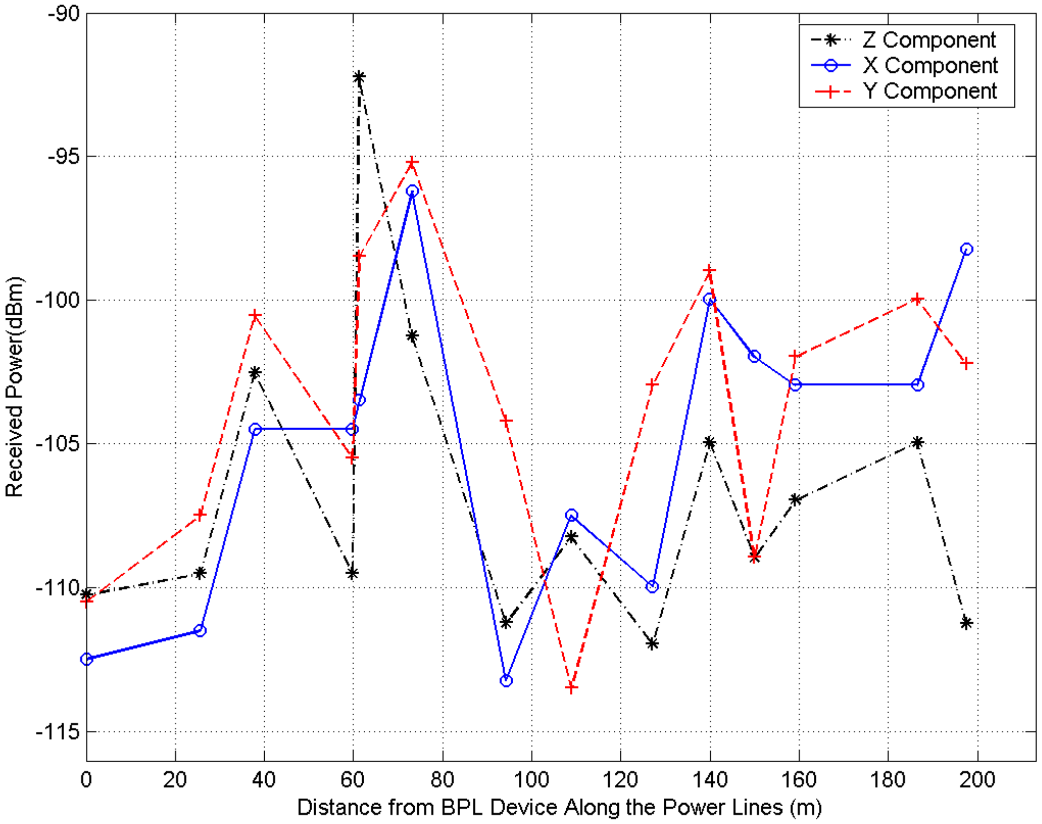


FIGURE 3

**Measured power levels along Route A at 28.298 MHz, rod antenna***



## 3.2 BPL signal power at various distances from the power line

The peak received power due to the magnetic field was measured at one site with a loop antenna directly under the power line at a height of 2 meters and a weak BPL magnetic field was detected on four frequencies (4.4 MHz, 8.8 MHz, 23.8 MHz, and 28.8 MHz). At a distance of approximately 50 meters perpendicular to the power line, BPL signals were received at only 28.8 MHz. The peak received power due to the electric field at various distances from the power line was measured with a vertically polarized whip antenna at 4.26 MHz, 7.30 MHz and 28.78 MHz. The results indicate that there is generally a decrease in received power with an increase in distance from the BPL device and power line, but the decrease was not monotonic at 28.78 MHz. A plot of the power levels measured on Route B with a whip antenna away from the power line is given in Figure 5. The received power (electric field) and the manner in which it decreased with increasing distance varied substantially at different frequencies.

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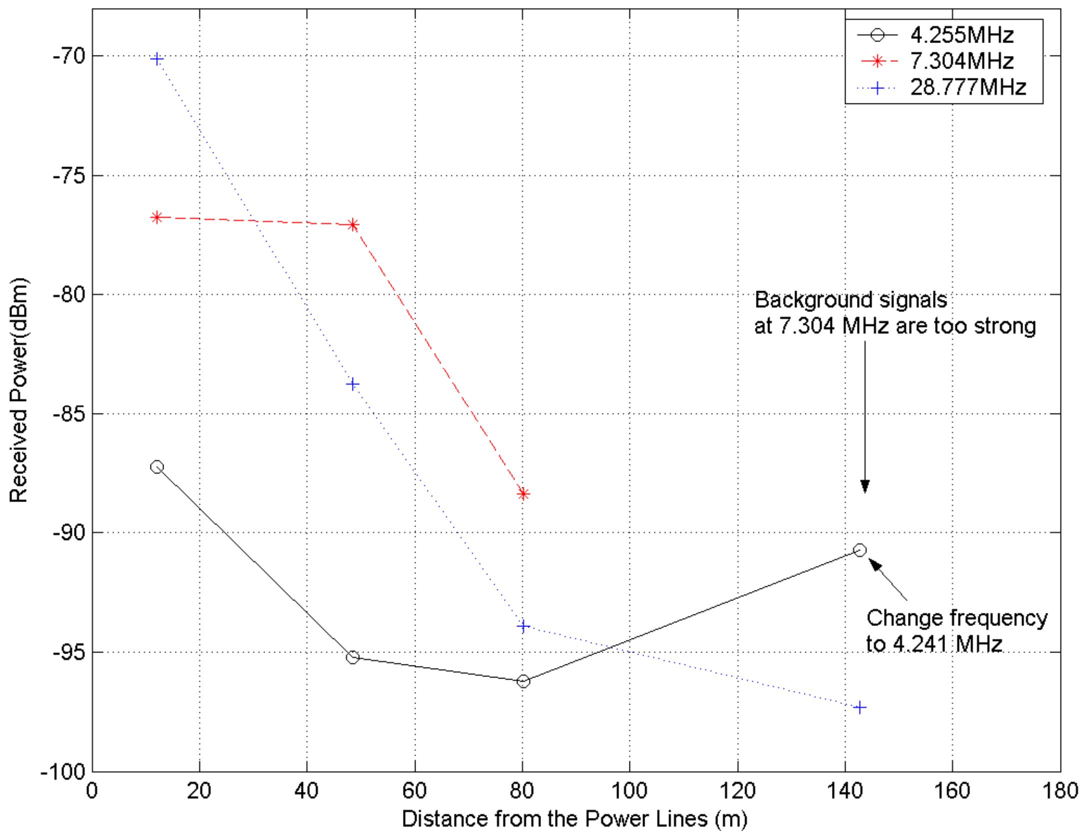
* Lines connecting data points illustrate potential trends but not expected interpolated values.

FIGURE 4

**Measured power levels at various distances on Route B from the power line (Whip antenna)**[*]



At the same site, the peak received power due to the vertical electric field was measured with the whip antenna at various distances from the power line along a path from Device C of Figure 2 approximately perpendicular to the power line. These results are shown in Figure 6. Even though the received power generally decreases with increasing distance, there are some amplitude oscillations. This non-monotonic behavior is thought to be mainly due to near-field effects and not ground reflections; however, underground power lines that branched from the BPL transmission line were noted to run across the measurement path in the vicinity of a local peak measured signal power level.

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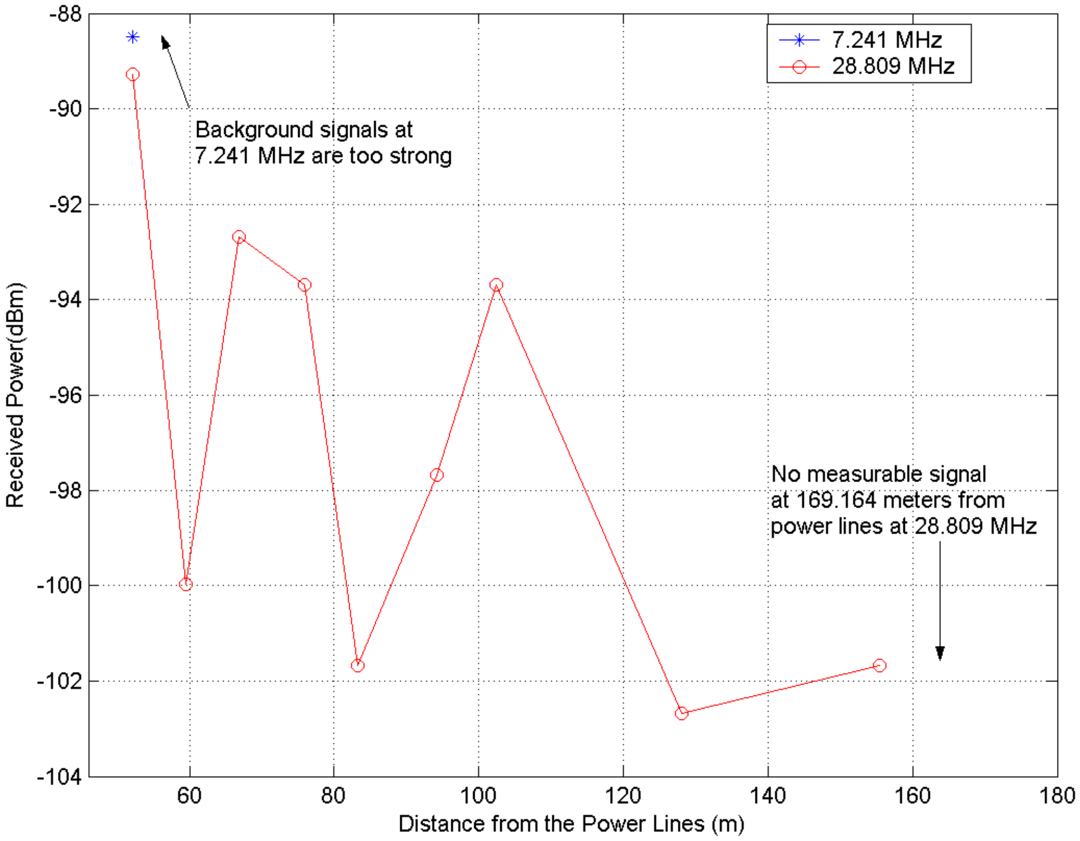
[*] Lines connecting data points illustrate potential trends but not expected interpolated values

FIGURE 5

**Measured power levels away from power line at Device C (Whip antenna)***



The whip antenna was used to measure peak received power due to the vertical electric field at two other sites. At one site, the signal decreased to an immeasurable level within 200 m. At the second site, comprising a complex arrangement of power lines with many turns and BPL devices, the signal power significantly exceeded the ambient noise power beyond approximately 500 m.

Measurements were also conducted using a discone antenna with vertical polarization at a height of 3.4 meters above ground in another power line configuration shown in Figure 7. Pulse power measurements were made at three different frequencies (35.05 MHz, 39.93 MHz and 45.40 MHz) at various distances from the power line as shown in Figure 8. In this case, the results indicate that the received power decreases as distance from the power line (r) increases at a rate lower than would be predicted by $1/r^2$ (space wave loss).

FIGURE 6

**Site for BPL measurements at various distances from the power line (Discone antenna)**

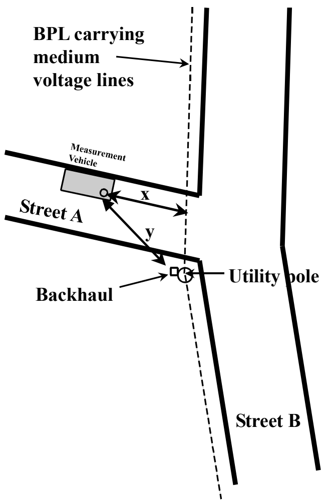
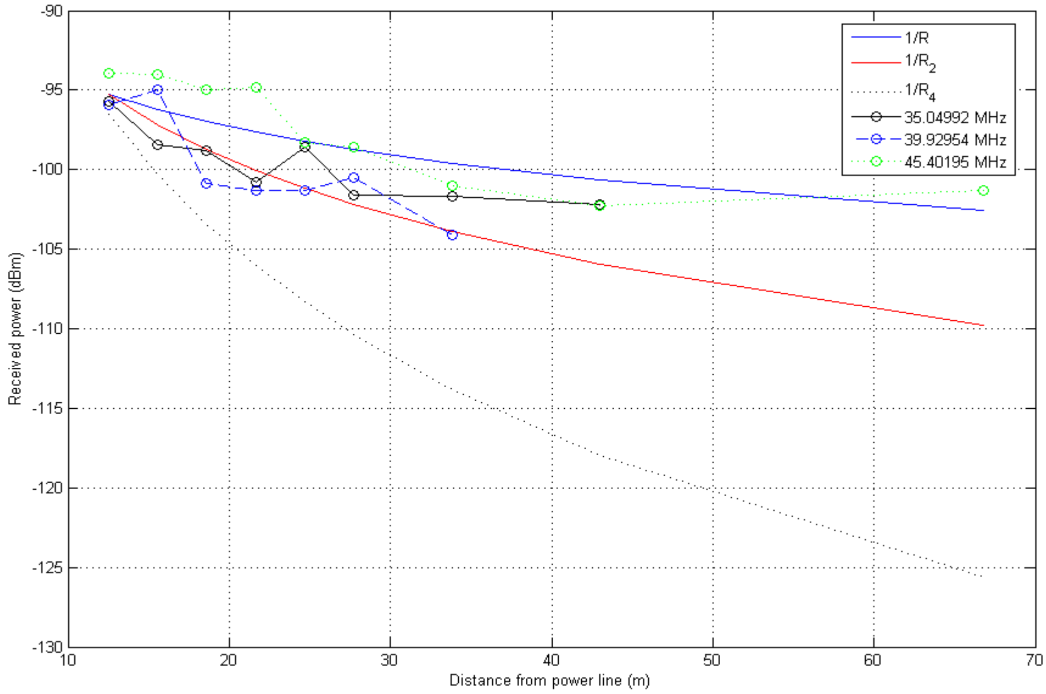


FIGURE 7

**Received pulse power at various distances from the power line (Discone antenna)***



### 3.3 Measurement of BPL using different antenna heights

Measurements of BPL emissions from MV lines were performed using two different antenna heights. The results show that in general, the measured power levels were substantially higher at the greater antenna height. For example, at a distance of 7.9 meters from the power line, the 100% duty cycle power measured at a frequency of 32.70 MHz and at a 10 meter antenna height was 4.8 to 10.7 dB greater than at 2 meters. The pulse power at a 10 meter antenna height for this same frequency was 8.2 to 15.1 dB higher than at 2 meters.

Measurements were also made of emissions from a LV power line carrying BPL signals from a LV coupler near a pole-mounted transformer to a house. The phase lines were twisted about the neutral line. A loop antenna was oriented to maximize the reception of the horizontal magnetic field. The antenna was located at 8.7 meters from the utility pole near the midpoint of the LV line from the power line, and measurements were made at antenna heights of 2 meters and 10 meters at frequencies of 5 MHz, 6.43 MHz, 10.74 MHz and 18.38 MHz, each with resolution bandwidths of 3 kHz, 10 kHz and 30 kHz. The measured power at a 10 meter height was always larger than the power measured at 2 meter height (by 3-9 dB). Table 2 includes results from both these measurements for 100% duty cycle power.

TABLE 2

**Measured 100% duty cycle power at two different antenna heights**

| Frequency | Bandwidth | 2 meter height | 10 meter height | Difference |
|---|---|---|---|---|
| 6.43 MHz | 3 kHz | –113.3 dBm | –108.7 dBm | 4.6 dB |
| 6.43 MHz | 10 kHz | –109.1 dBm | –106.4 dBm | 2.7 dB |
| 18.38 MHz | 3 kHz | –115.3 dBm | –106.6 dBm | 8.7 dB |
| 32.70 MHz | 30 kHz | –101.1 dBm | –96.3 dBm | 4.8 dB |
| 32.70 MHz | 10 kHz | –111.4 dBm | –100.7 dBm | 10.7 dB |

## 4 Modeling of power lines using NEC [5]

Extensive work was done at NTIA on modeling of power lines by NEC on several typical arrangements of MV power lines as well as a real section of MV power line, where measurements were done. The outcome of these analyses will be described in the following sub-sections.

### 4.1 Simplified models of three phase MV power lines [6]

The modeled power lines consisted of three, straight horizontal parallel copper wires 8.5 meters above a ground with average characteristics (conductivity $\sigma = .005$ mS, relative permittivity $\varepsilon_r = 15$). Each wire had a diameter of 0.01 meter (approximating 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 wires, which ran parallel to the x axis ($y = 0$). The equivalent of a BPL inductive coupler was placed on the center segment of the wire and was modeled as a voltage source of 1 volt in series with a resistor that represented the source impedance (equivalent to a current source). The other two phase wires ran parallel to the x axis at $y = 0.6$ and $y = 1.2$ meters.

All three orthonormal components of electric and magnetic field intensities ($E_x$, $E_y$, $E_z$ in dBµV/m, $H_x$, $H_y$ and $H_z$ in dBµA/m) in the near field were plotted in a plane two meters above the ground at frequencies of 2 MHz, 10 MHz, and 40 MHz. Three different line lengths of 100 m, 200 m and

340 m were used with four different impedance conditions for the source and loads. The impedance conditions were as follows: source impedance of 150 Ω with load impedance of 50 Ω and 575 Ω, and source impedance of 575 Ω with 50 Ω and 575 Ω load impedances. The field strengths were plotted as contours in 5 dB increments for four different ranges of x and y coordinates, *i.e.*, 0 to 20 m, 0 to 200 m, 0 to 1 000 m and 0 to 18 000 m. The far field radiation patterns were also plotted in vertical planes at several azimuth angles. The complete results of the above simulation work are available at NTIA and a few have been included in the NTIA report mentioned earlier.

The far field patterns indicate that there are more lobes in the radiation pattern as the ratio of line length to wavelength (L/λ) increases. Varying source and load impedances have minor effects. The transmission line analyzed here has a characteristic impedance of approximately 575 Ω, therefore, when the load and source impedance are both 575 Ω, the line acts as a traveling wave antenna. The highest radiation was generally associated with the combination of source impedance of 150 Ω and load impedance of 50 Ω which corresponds to the largest impedance mismatch among the cases considered here. In the azimuth angle of 0°, *i.e.*, along the direction of the power lines, the elevation pattern has several lobes and the largest lobe is generally around 30° or lower elevation above the horizontal plane containing the power lines. The larger the L/λ ratio, the lower is this main elevation angle. However, as the azimuth angle increases to 90°, there are fewer lobes and the maximum gain is in or near the vertical direction.

Tables 5, 6 and 7 summarize the results of the near field plots at 2 meters above the ground for three components of the electric field for various combinations of input parameters. Several general trends can be seen from the near field plots at 2 meters from ground near a typical power line configuration.

Table 5 summarizes the characteristics of the vertically polarized electric field, $E_{z.}$ For the vertical electric field $E_z$, the peak field is never at the BPL source; instead, 2 to 20 local peaks occur near and under the power lines. The first peak occurs at approximately λ/4 down the wire from the device. Several peaks of slightly higher strength occur down the wire at λ/2 intervals. The number of peaks depends on the L/λ ratio. As frequency increases, the peak decreases, but the number of local peaks along the line increases. The peaks gradually diminish down the line because of RF attenuation and radiative losses. As mentioned earlier, varying source and load impedances has only a minor effect on peak field strength (less than 5 dB min-max variation), and peaks generally decrease as the source & load impedances are changed as follows (in decreasing order of peak vertical electric field strength): 150 & 50 Ω;, 150 & 575 Ω; 575 & 50 Ω; and 575 & 575 Ω.

Tables 6 and 7 summarize characteristics of horizontally polarized electric fields $E_x$ and $E_{y.}$ The peak horizontally polarized field is never at the BPL source for the perpendicular case (as was the case for vertical polarization); instead, 2 to 24 local peaks occur at various distances from the BPL source with the first peak occurring at approximately 0.75λ and subsequent peaks occurring at approximately λ/2 intervals occurring at about λ/4 on either side of the wire. In contrast, the peak field is always at the BPL source for the parallel case with additional peaks down the line of equal or lower field strength.

## TABLE 5

## Summary of electric fields seen by an antenna having vertical polarization

| **Source & load impedance** | **BPL frequency** | **Length of line** | **Peak field** | **Number of peaks**[1] | **Minimum distance between peak field and BPL device** |
|---|---|---|---|---|---|
| **(Ω)** | **(MHz)** | **(m)** | **(dBµV/m)** | | **(m)** |
| 150 & 575 | 2 | 100 | 83-85 | 2 | 18-26 |
| 575 & 50 | 2 | 100 | 83-85 | 2 | 27 |
| 150 & 50 | 2 | 100 | 86 | 2 | 18-37 |
| 575 & 575 | 2 | 100 | 81 | 2 | 30.5 |
| 150 & 575 | 10 | 100 | 75-79 | 4 | 10 |
| 575 & 50 | 10 | 100 | 74-77 | 4 | 11.6 |
| 150 & 50 | 10 | 100 | 74-79 | 3 | 10 |
| 575 & 575 | 10 | 100 | 71-75 | 3 | 11 |
| 150 & 50 | 40 | 100 | 69-76 | 8 | 2.1 |
| 575 & 50 | 40 | 100 | 69-73 | 8 | 2.1 |
| 575 & 575 | 40 | 100 | 70-75 | 7 | 1.8 |
| 150 & 575 | 40 | 100 | 72-77 | 6 | 2.1 |
| 150 & 50 | 2 | 200 | 84-86 | 2 | 18-37 |
| 575 & 50 | 2 | 200 | 82-85 | 2 | 29 |
| 575 & 575 | 2 | 200 | 79-81 | 2 | 30.5 |
| 150 & 575 | 2 | 200 | 85 | 1 | 18-30.5 |
| 150 & 50 | 10 | 200 | 75-80 | 4 | 10 |
| 575 & 50 | 10 | 200 | 75-78 | 4 | 9.75 |
| 150 & 575 | 10 | 200 | 74-79 | 4 | 9.75 |
| 575 & 575 | 10 | 200 | 71-75 | 4 | 10.7 |
| 150 & 50 | 40 | 200 | 71-74 | 8 | 2.1 |
| 575 & 575 | 40 | 200 | 68-74 | 7 | 1.8 |
| 575 & 50 | 40 | 200 | 72-74 | 6 | 1.8 |
| 150 & 575 | 40 | 200 | 71-76 | 5 | 2.1 |
| 150 & 50 | 2 | 340 | 80-83 | 3 | 24.4 |
| 575 & 575 | 2 | 340 | 76-79 | 3 | 29 |
| 150 & 575 | 2 | 340 | 82 | 3 | 25.9 |
| 575 & 50 | 2 | 340 | 81 | 3 | 21.3 |
| 575 & 575 | 10 | 340 | 68-74 | 8 | 6.4 |
| 575 & 50 | 10 | 340 | 73-77 | 7 | 6.1 |
| 150 & 50 | 10 | 340 | 76-79 | 6 | 15.24 |
| 150 & 575 | 10 | 340 | 72-78 | 2 | 6.4 |
| 150 & 575 | 40 | 340 | 71-77 | 10 | 4 |
| 575 & 575 | 40 | 340 | 67-73 | 10 | 4.9 |
| 575 & 50 | 40 | 340 | 70-76 | 9 | 4.6 |
| 150 & 50 | 40 | 340 | 73 | 2 | 16 |

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[1] All peak levels of vertically polarized electric field strength occurred near and under the power lines and all local peaks had approximately the same level. The statistics are presented for one-half the overall length of the power line, which is center fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

TABLE 6

**Summary of electric fields seen by an antenna having horizontal-parallel polarization**

| **Source & load impedance (Ω)** | **BPL frequency (MHz)** | **Length of line (m)** | **Field at source[2] (dBµV/m)** | **Number of secondary peaks[3]** |
|---|---|---|---|---|
| 150 & 50 | 2 | 100 | 68 | 2 |
| 150 & 575 | 2 | 100 | 67 | 2 |
| 575 & 50 | 2 | 100 | 67 | 2 |
| 575 & 575 | 2 | 100 | 63 | 2 |
| 150 & 50 | 2 | 200 | 68 | 2 |
| 150 & 575 | 2 | 200 | 67 | 2 |
| 575 & 50 | 2 | 200 | 67 | 2 |
| 575 & 575 | 2 | 200 | 63 | 2 |
| 150 & 50 | 2 | 340 | 69 | 3 |
| 150 & 575 | 2 | 340 | 68 | 3 |
| 575 & 50 | 2 | 340 | 67 | 3 |
| 575 & 575 | 2 | 340 | 65 | 3 |
| 150 & 50 | 10 | 100 | 76 | 5 |
| 150 & 575 | 10 | 100 | 75 | 3 |
| 575 & 50 | 10 | 100 | 74 | 3 |
| 575 & 575 | 10 | 100 | 72 | 0 |
| 150 & 50 | 10 | 200 | 77 | 5 |
| 150 & 575 | 10 | 200 | 76 | 3 |
| 575 & 50 | 10 | 200 | 75 | 3 |
| 575 & 575 | 10 | 200 | 72 | 3 |
| 150 & 50 | 10 | 340 | 75 | 5 |
| 150 & 575 | 10 | 340 | 74 | 5 |
| 575 & 50 | 10 | 340 | 74 | 5 |
| 575 & 575 | 10 | 340 | 70 | 5 |
| 150 & 50 | 40 | 100 | 82 | 1 |
| 150 & 575 | 40 | 100 | 81 | 1 |
| 575 & 50 | 40 | 100 | 79 | 0 |
| 575 & 575 | 40 | 100 | 78 | 0 |
| 150 & 50 | 40 | 200 | 82 | 1 |
| 150 & 575 | 40 | 200 | 81 | 1 |
| 575 & 50 | 40 | 200 | 78 | 0 |
| 575 & 575 | 40 | 200 | 78 | 1 |
| 150 & 50 | 40 | 340 | 76 | 1 |
| 150 & 575 | 40 | 340 | 81 | 1 |
| 575 & 50 | 40 | 340 | 80 | 1 |
| 575 & 575 | 40 | 340 | 76 | 0 |

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[2] Peak horizontal-parallel electric field strength always occurred near the BPL device.

[3] Secondary peaks levels were recorded if they were within 5 dB of the overall peak level near the BPL device. The statistics are presented for one-half the overall length of the power line, which is center fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

## TABLE 7

## Summary of electric fields seen by an antenna having horizontal-perpendicular polarization

| Source & load impedance (Ω) | BPL frequency (MHz) | Length of line (m) | Peak field (dBμV/m) | Distance of peak (m) | Number of Peaks[4] | Minimum distance from BPL device (m) |
|---|---|---|---|---|---|---|
| 150 & 50 | 2 | 100 | 70 | +/-3-6 | 1 | 18.3-30.5 |
| 150 & 575 | 2 | 100 | 64-69 | +/-4.6-6.4 | 2 | 18.3-27.4 |
| 575 & 50 | 2 | 100 | 69 | +/-3-6 | 1 | 19.8-30.5 |
| 575 & 575 | 2 | 100 | 58-65 | +/-4-7.6 | 2 | 27.4 |
| 150 & 50 | 2 | 200 | 70 | +/-3-6 | 1 | 17.7-33.5 |
| 150 & 575 | 2 | 200 | 64-69 | +/-4.6-7.6 | 2 | 27.4 |
| 575 & 50 | 2 | 200 | 69 | +/-5.2 | 2 | 19.8-36.6 |
| 575 & 575 | 2 | 200 | 58-65 | +/-4.6-7.6 | 2 | 29 |
| 150 & 50 | 2 | 340 | 60-67 | 0 | 4 | 15.2 |
| 150 & 575 | 2 | 340 | 61-66 | +/-3-6.7 | 3 | 12.8-24.4 |
| 575 & 50 | 2 | 340 | 60-65 | +/-3-6.7 | 2 | 27.4 |
| 575 & 575 | 2 | 340 | 57-63 | +/-4.6-6 | 3 | 25.9 |
| 150 & 50 | 10 | 100 | 60-67 | +/-3-7.6 | 2 | 9.75 |
| 150 & 575 | 10 | 100 | 63-67 | +/-5.5 | 2 | 9.75 |
| 575 & 50 | 10 | 100 | 58-65 | +/-3.7-7 | 2 | 9.75 |
| 575 & 575 | 10 | 100 | 57-63 | +/-4-7 | 3 | 15.2 |
| 150 & 50 | 10 | 200 | 62-67 | +/-3-7.6 | 3 | 9.75 |
| 150 & 575 | 10 | 200 | 61-67 | +/-5.2-6.4 | 3 | 9.5 |
| 575 & 50 | 10 | 200 | 60-65 | +/-3-7.6 | 3 | 5.2 |
| 575 & 575 | 10 | 200 | 57-63 | +/-4.6-7.9 | 3 | 9.5 |
| 150 & 50 | 10 | 340 | 62-65 | +/-3-7.6 | 12 | 15.2 |
| 150 & 575 | 10 | 340 | 60-65 | +/-4.9-6.4 | 2 | 6.4 |
| 575 & 50 | 10 | 340 | 60-63 | +/-3-6.7 | 6 | 6.4 |
| 575 & 575 | 10 | 340 | 52-61 | +/-3.7-7 | 7 | 6.7 |
| 150 & 50 | 40 | 100 | 71-73 | +/-3-7.6 | 4 | 6.1 |
| 150 & 575 | 40 | 100 | 65-73 | +/-4.6-11.6 | 4 | 9.75 |
| 575 & 50 | 40 | 100 | 69-71 | +/-5.5-9.1 | 5 | 6.1 |
| 575 & 575 | 40 | 100 | 63-69 | +/-4.6-10.7 | 6 | 5.8 |
| 150 & 50 | 40 | 200 | 68-73 | +/-3-10 | 5 | 5.5 |
| 150 & 575 | 40 | 200 | 66-73 | +/-3-9.1 | 5 | 10 |
| 575 & 50 | 40 | 200 | 62-72 | +/-3.7-10.4 | 5 | 6.1 |
| 575 & 575 | 40 | 200 | 69 | +/-5.5-9.1 | 5 | 5.8 |
| 150 & 50 | 40 | 340 | 64 | +/-3-9.1 | 4 | 7 |
| 150 & 575 | 40 | 340 | 69-72 | +/-5.5-7 | 6 | 3 |
| 575 & 50 | 40 | 340 | 64-70 | +/-3-9.1 | 6 | 3 |
| 575 & 575 | 40 | 340 | 64-66 | +/-5.2-7 | 5 | 3 |

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[4] The statistics are presented for one-half the overall length of the power line, which is centre fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

The far field patterns, the near field surface plots and measurements along power lines indicate that there are standing waves along the power line. Also, measurements have indicated that the electric fields at 10 meter high antenna are much higher than that at 2 meter high antenna.

In the case of power line simulation for a BPL system, the most obvious consideration is the addition of parallel wires, such as an Earth-grounded neutral line (assuming the three-phase lines are arranged in a “wye” configuration) and telephone and cable wires, which are typically found under the neutral. To determine the effects of a neutral line on the model considered above, sample simulations with and without a neutral wire were run and the resulting outputs compared to one another.

As can be seen in Figure 8 for a frequency of 4 MHz, the addition of a grounded neutral line increases the gain of the power lines. The impact is dependent upon frequency. The increase in gain is less than 2 dB, and the overall shape of the radiation pattern remains the about the same. Simulations at other frequencies have indicated that the change in gain becomes less at higher frequencies. Computations of electric field magnitude showed that inclusion of a neutral line increased levels of electric field around the modeled power line

## 4.2 Model of an actual power line

NTIA also constructed an extensive NEC model based upon an actual MV distribution branch in one of the BPL deployment areas where NTIA conducted field measurements. This model, depicted in Figure 9, was designed using power line maps as well as actual observation. The three components of the electric field were determined at heights of 1 meter and 2 to 20 meters (in two-meter increments) for the entire area adjacent to the power line structure. Figures 10 through 12 illustrate the variation in field strength in all three polarizations at 1 meter and at the height of the power lines (12 meters). Table 8 shows the heights corresponding to the peak field strength in any polarization at a distance of ten meters from the power line, for four measurement frequencies 4.303, 8.192, 22.957 and 28.298 MHz evaluated with this model.

FIGURE 8

**Comparison of NEC model with and without a parasitic multi-grounded neutral at 4 MHz**

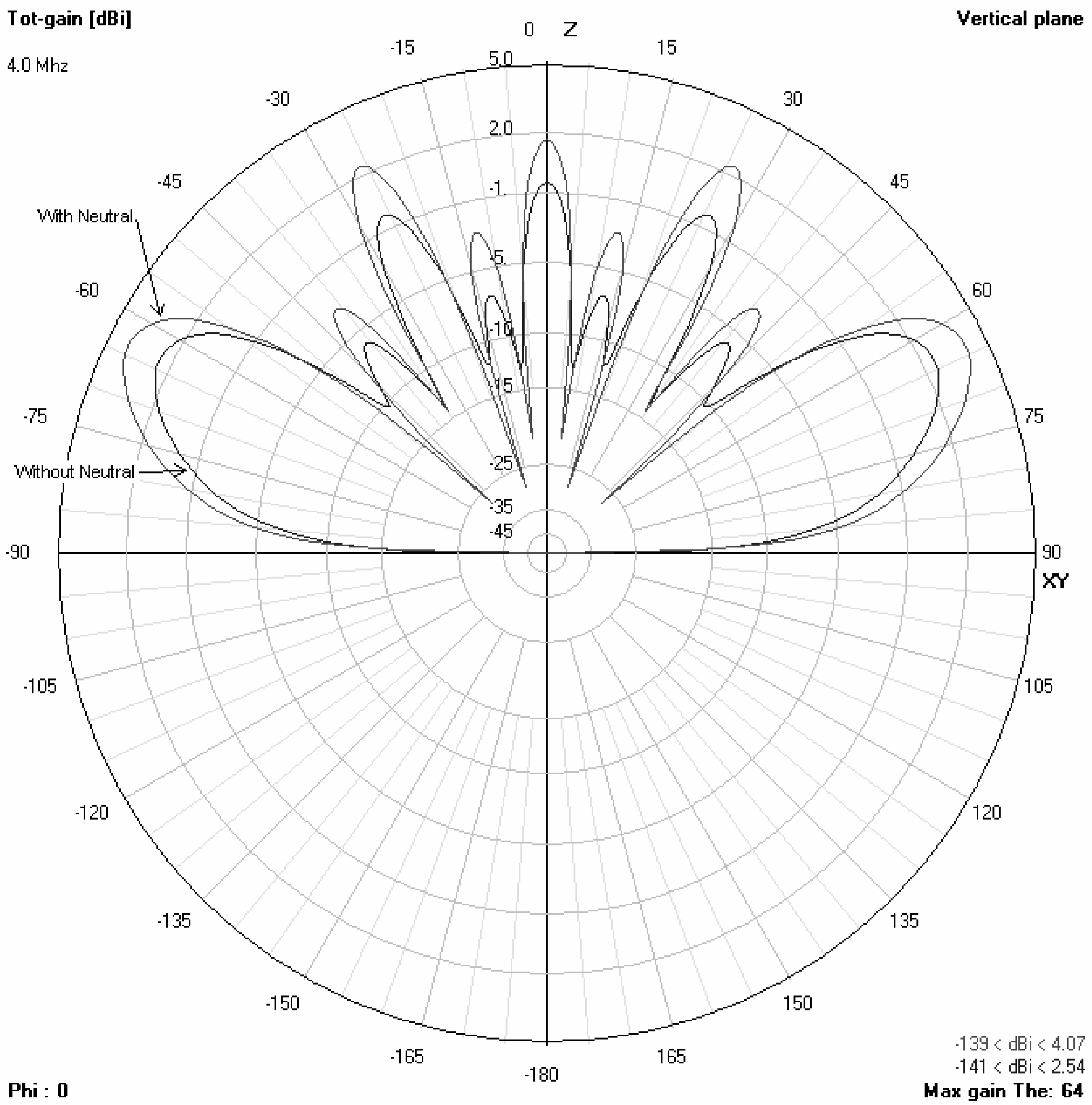


FIGURE 9

**NEC model of actual power line carrying BPL signals**

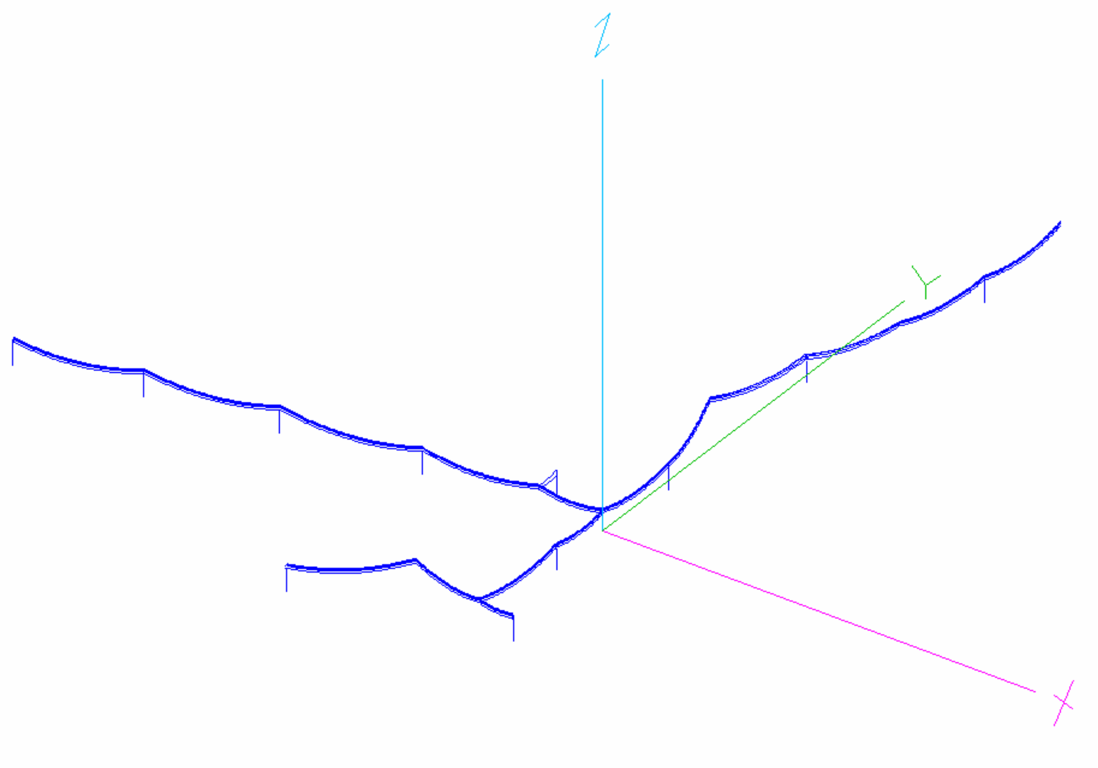
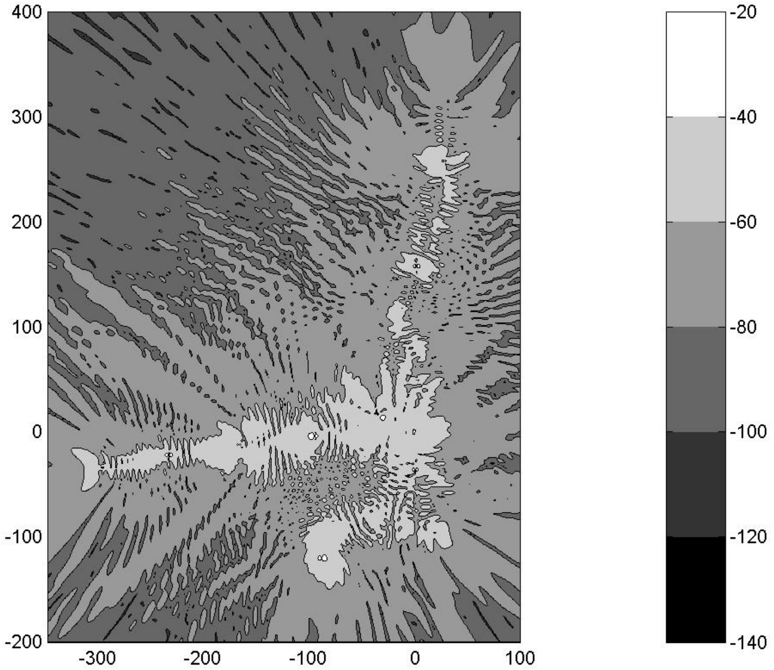


FIGURE 10



**X-axis electric field values surrounding power line structure at 28.298 MHz. Top: 1 meter height. Bottom: 12 meter height. Axis values in meters; relative electric field values in dB.**

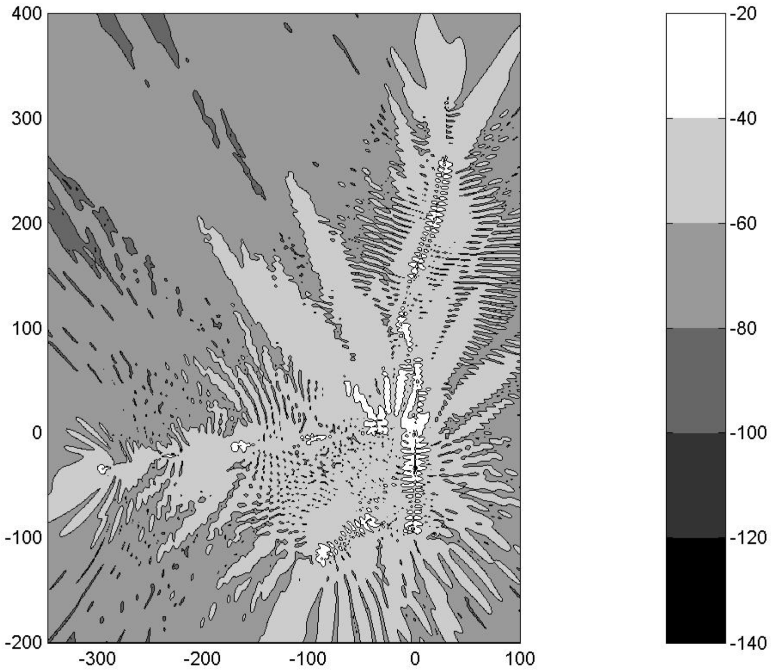


FIGURE 11

**Y-axis electric field values surrounding power line structure at 28.298 MHz.
Top: 1 meter height. Bottom: 12 meter height.**

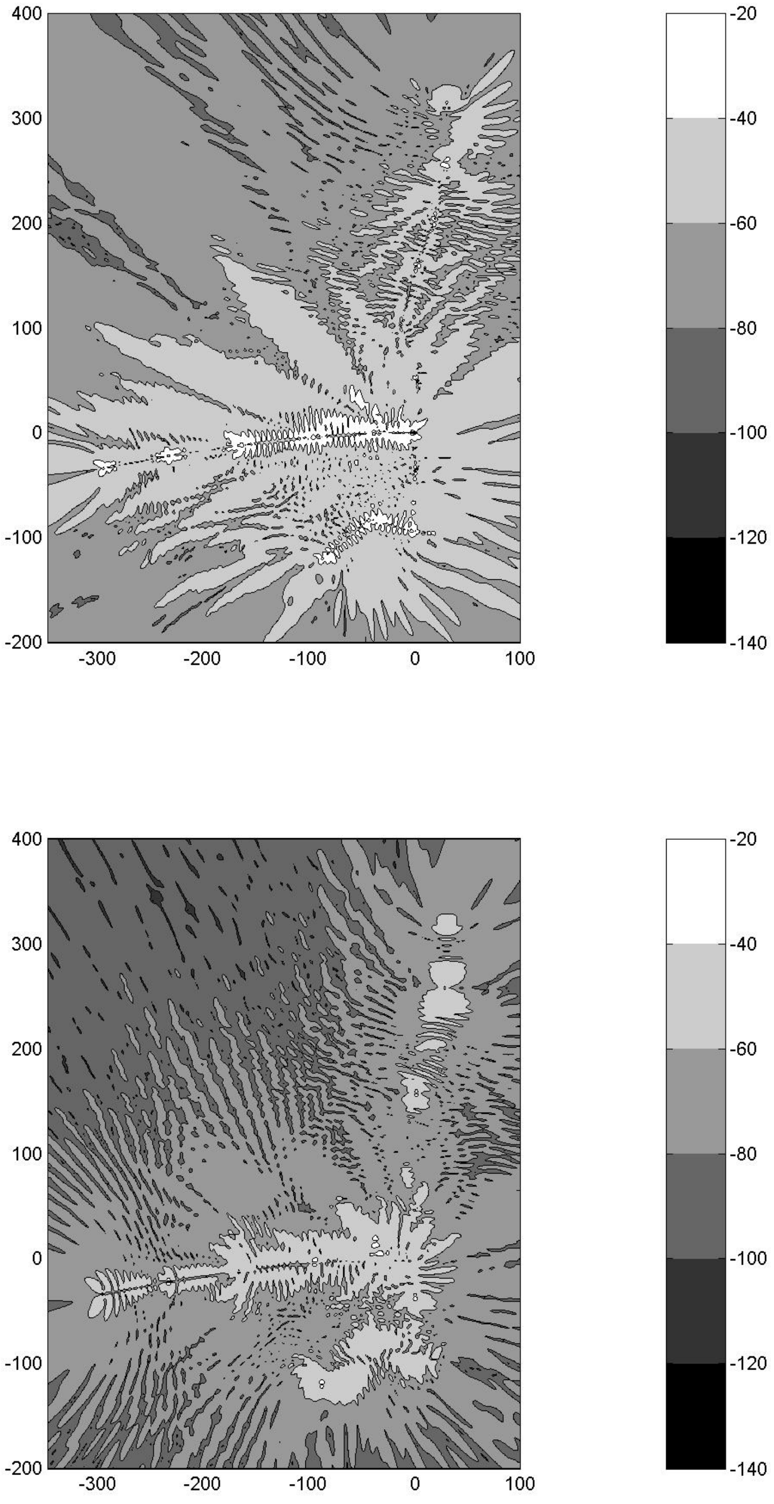
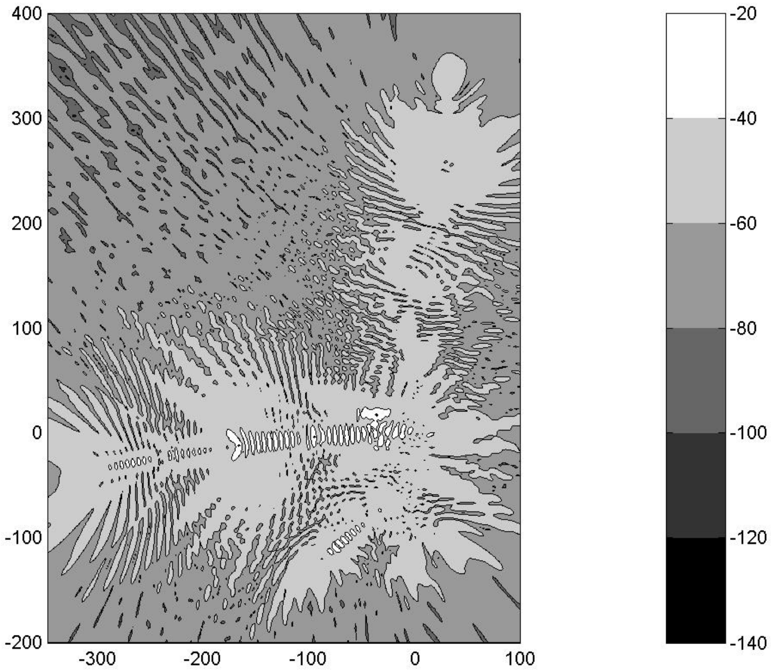


FIGURE 12

**Z-axis electric field values surrounding power line structure at 28.298 MHz.**
**Top: 1 meter height. Bottom: 12 meter height.**


400
300
200
100
0
-100
-200
-300
-200
-100
0
100
-20
-40
-60
-80
-100
-120
-140

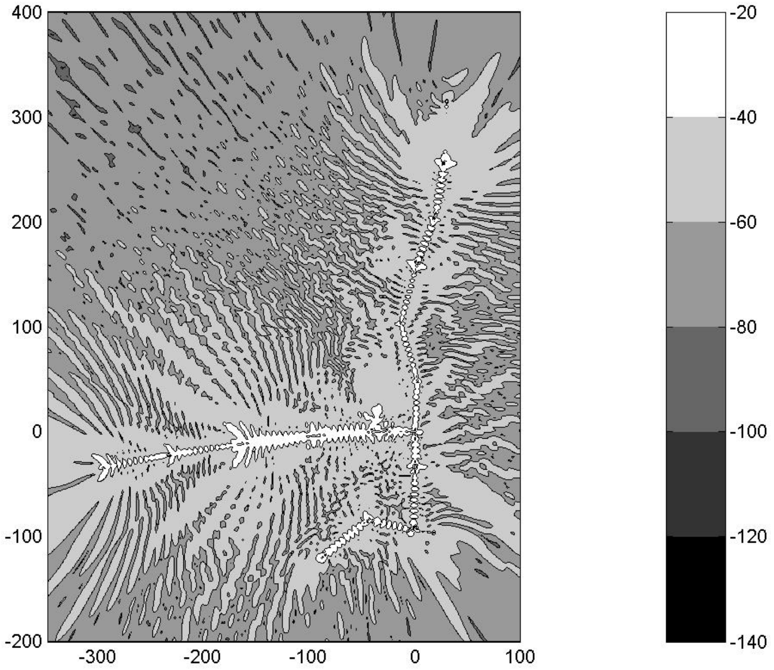

400
300
200
100
0
-100
-200
-300
-200
-100
0
100
-20
-40
-60
-80
-100
-120
-140

TABLE 8

**Height corresponding to peak field strength for four measurement frequencies for the power line model shown in Figure 9**

| **Frequency (MHz)** | 4.303 | 8.192 | 22.957 | 28.298 |
|---|---|---|---|---|
| **Height (m)** | 10 | 9 | 8 | 9 |

## 4.3 Modeling of a variety of power lines

A number of power line models were created using the NEC software to gain a greater understanding of the effects various physical topologies might have on the electric fields radiated by BPL signals on power lines. The electric and magnetic field strength results in any polarization, over a range of heights and at any position along the length of the power line model were then evaluated statistically.

NTIA evaluated several different power line topologies to calculate three-axis electric field values in a vertical grid located 10 meters from the power line at heights ranging from 1 to 20 meters in one meter increments. A distance of 10 meters was chosen because this is the measurement distance proposed by U.S. Federal Communications Commission (FCC) in their Notice of Proposed Rule Making (NPRM) on BPL [7]. These calculations were made along the length of the modeled power lines in one-meter increments, and at frequencies from 2 to 50 MHz (in 2 MHz increments). The eighteen relatively simple power line topologies listed in Table 9 were considered. The orientation of power line conductors for these topologies is depicted in Figure 13.

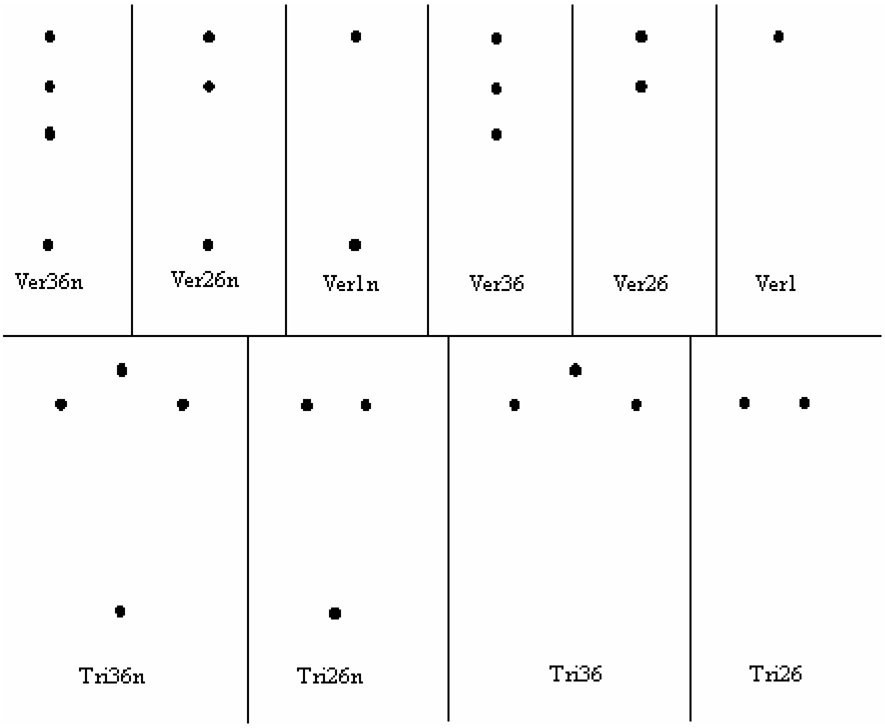
TABLE 9

**Power line topologies used to identify locations of peak fields**

| **Model Name** | **Number of Wires** | **Wire Configuration** | **Multi-grounded neutral with 3 transformers** | **Wire Spacing** |
|---|---|---|---|---|
| tri26 | 2 | triangular-horizontal | not included | 0.6 meters |
| tri210 | 2 | triangular-horizontal | not included | 1.0 meters |
| tri36 | 3 | triangular-horizontal | not included | 0.6 meters |
| tri310 | 3 | triangular-horizontal | not included | 1.0 meters |
| tri26n | 2 | triangular-horizontal | included | 0.6 meters |
| tri210n | 2 | triangular-horizontal | included | 1.0 meters |
| tri36n | 3 | triangular-horizontal | included | 0.6 meters |
| tri310n | 3 | triangular-horizontal | included | 1.0 meters |
| ver1 | 1 | vertical | not included | n/a |
| ver26 | 2 | vertical | not included | 0.6 meters |
| ver210 | 2 | vertical | not included | 1.0 meters |
| ver36 | 3 | vertical | not included | 0.6 meters |
| ver310 | 3 | vertical | not included | 1.0 meters |
| ver1n | 1 | vertical | included | n/a |
| ver26n | 2 | vertical | included | 0.6 meters |
| ver210n | 2 | vertical | included | 1.0 meters |
| ver36n | 3 | vertical | included | 0.6 meters |
| ver310n | 3 | vertical | included | 1.0 meters |

FIGURE 13

**Power line topologies as viewed in the plane orthogonal to the power lines**



One of the effects studied was the variation of electric field strengths with height. The difference between peak field strength at any height and the peak field strength at 1 m, based on 80th percentile values for the "tri36" and "tri 36n" are given in Figures 14 and 15 respectively. The 80th percentile values eliminate the localized emission peaks that are unlikely to be encountered by a radio receiver randomly located in close proximity to an Access BPL power line.

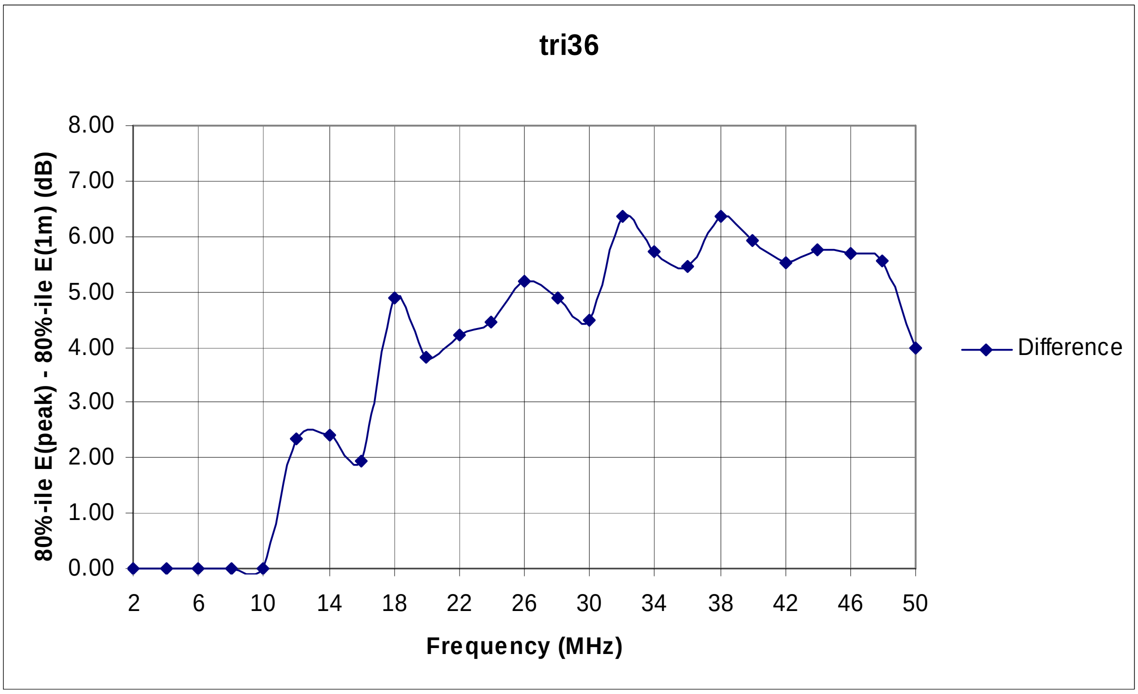
The Figures 14 and 15 show substantial variability of the height at which the peak field strength occurs. In all cases where the operating frequency is above 6 MHz, the peak field strength occurred at heights greater than 1 meter. Below 6 MHz, the wavelengths are greater than four times the modeled power 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.

Field strength predictions from the power line models were also evaluated to identify locations 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 at heights between 1 m and 20 m. The locations 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 for "tri36" and "tri36n" are shown in Figures 16 and 17 respectively. Distances are expressed in terms of wavelengths away from the BPL device.

In general, 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 in a vertical plane 10 meters from the BPL energized power line. 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 discussed in a previous section produced results in substantial agreement with these findings.

From Figures 16 and 17, 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 in a vertical plane 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 and transformers (connected between the neutral line and one MV phase line) are added to the power line structure, due to introduction of additional asymmetry.

FIGURE 14



**Difference between peak field strength at any height and the peak field strength at 1 meter, based on 80th percentile values; tri36 power line topology**

FIGURE 15

**Difference between peak field strength at any height and the peak field strength at 1 meter, based on 80th percentile values; tri36n power line topology**

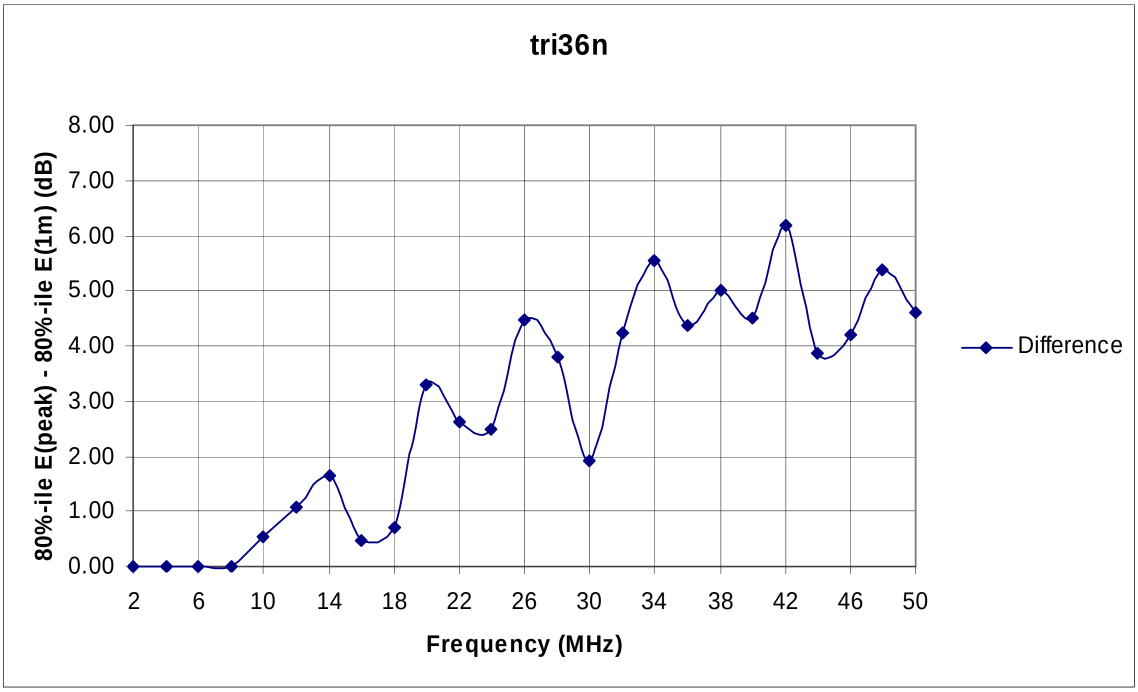

tri36n
80%-ile E(peak) - 80%-ile E(1m) (dB)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2
6
10
14
18
22
26
30
34
38
42
46
50
Frequency (MHz)
Difference

FIGURE 16

**Location of peak field strength along the power line – tri36 topology**

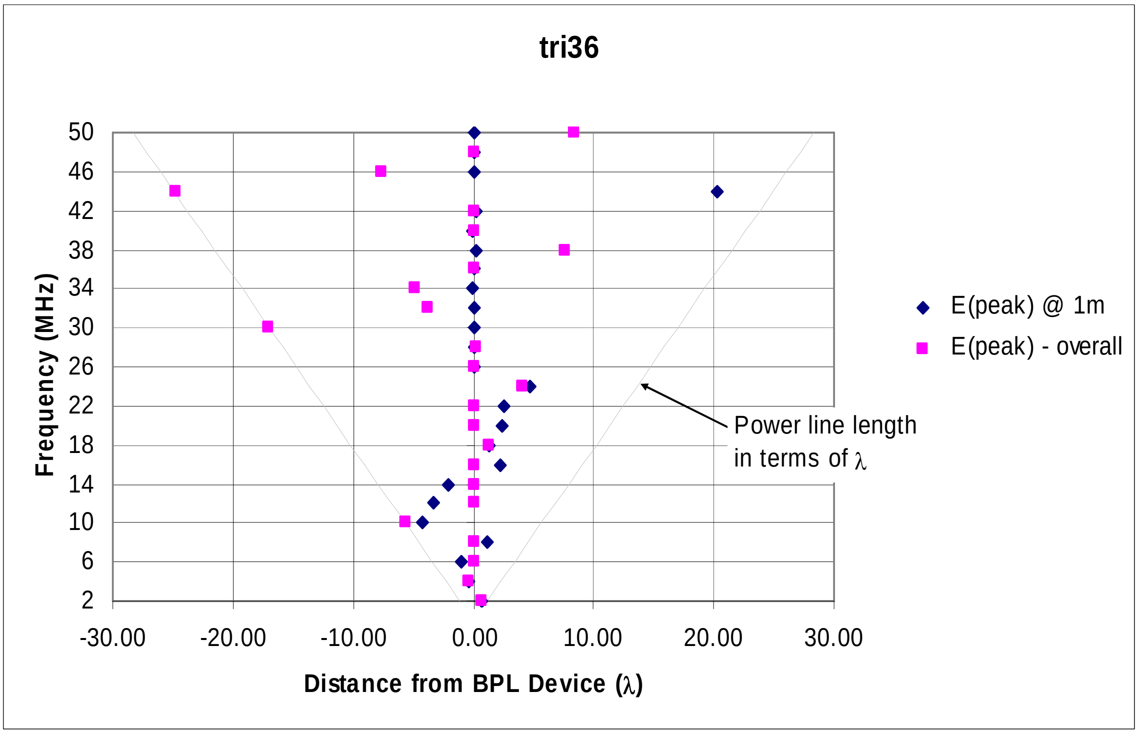
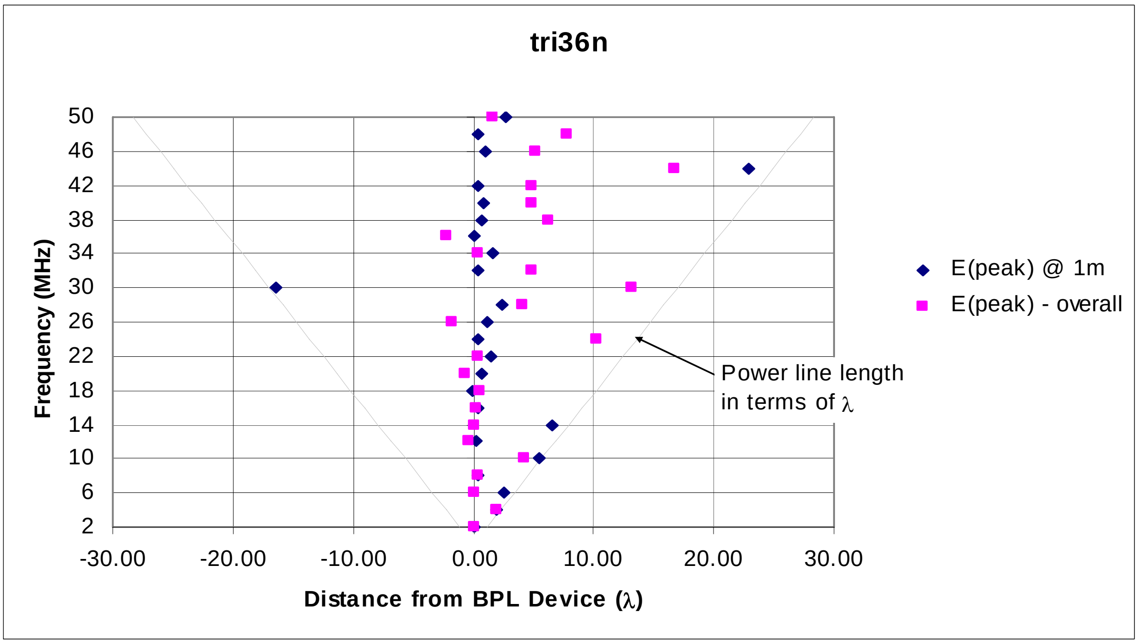


FIGURE 17

**Location of peak field strength along the power line – tri36n topology**



### 4.4 Analytical modeling of sky wave propagation

To make predictions regarding the large-scale effects of a widespread BPL deployment, NTIA is employing the ICEPAC HF propagation software developed at its Institute of Telecommunication Sciences (ITS).[5] NTIA is modeling propagation under a range of times, months and frequencies. In this process, NTIA is using ICEPAC's "point-to-point" mode. Software was written to sum the emissions received from all geographic locations where BPL systems may be deployed. This work is ongoing. A relatively simpler HF propagation prediction method in Recommendation ITU-R P.533 is recommended by the International Telecommunication Union. The technique used in Recommendation ITU-R P.533 is similar to ICEPAC for distances less than 7 000 km.

## 5 Relevant trends and issues of concern

Several trends were observed raising a number of issues which need to be addressed in answer to the draft question on PLT systems.

First, in the near field, both measurements and simulation indicate that peak field strength does not necessarily occur near the injection points and the measured or calculated fields do not decay appreciably along the line. The simulation shows that a number of peaks can occur down the wire depending on the L/λ ratio, resulting in larger number of smaller peaks as frequency increases. The peaks gradually diminish down the line because of losses.

Second, the number of lobes in the far field radiation patterns increases with the L/λ ratio. In a direction along the power line (zero azimuth), the largest lobe is generally at an elevation angle of 30° or becomes lower, as the L/λ ratio increases. However, in a direction perpendicular to the line, maximum radiation is in or near the vertical.

Finally, both the measurements and the simulation have indicated that the field strengths at larger heights above ground are always a few dB larger than the corresponding field strengths at 1 or 2 meters above ground. Moreover, since the radiation from the power line is linearly polarized in the plane containing the line and the radius vector, the direction of polarization changes from point-to-point. At low measurement heights and at small horizontal distances from the power line, the polarization is almost vertical. Therefore, there is less difference in vertical electric field at different heights.

## 6 References

[1] "Potential interference from broadband over power line (BPL) systems to federal radiocommunications at 1.7-80 MHz", NTIA Report 04-413, April 28, 2004.

[2] "Physical and regulatory constraints for communication over the power supply grid", M. Gebhardt, F. Weinman and K. Dostert, IEEE Communications Magazine, May 2003, pp. 84-90.

[3] "Antenna theory, analysis and design", C. A. Balanis, John Wiley, 1982.

[4] "Propagation of radiowaves", 2nd Edition, edited by Les Barclay, IEE, London, 2003.

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

[5] Numerical Electromagnetics Code – NEC-4 Method of Moments, Part I: User's Manual, Part II: NEC Program Description - Theory, Part III: NEC Program description – Code, Gerald J. Burke, January 1992.

[6] The Lineman's and Cableman's Handbook, E. B. Kurtz and T. M. Shoemaker, Fifth Edition, McGraw Hill, 1976.

[7] Amendment of Part 15 regarding new requirements and measurement guidelines for access broadband over power line systems, notice of proposed rule making, ET Docket No. 04-37, February 23, 2004.