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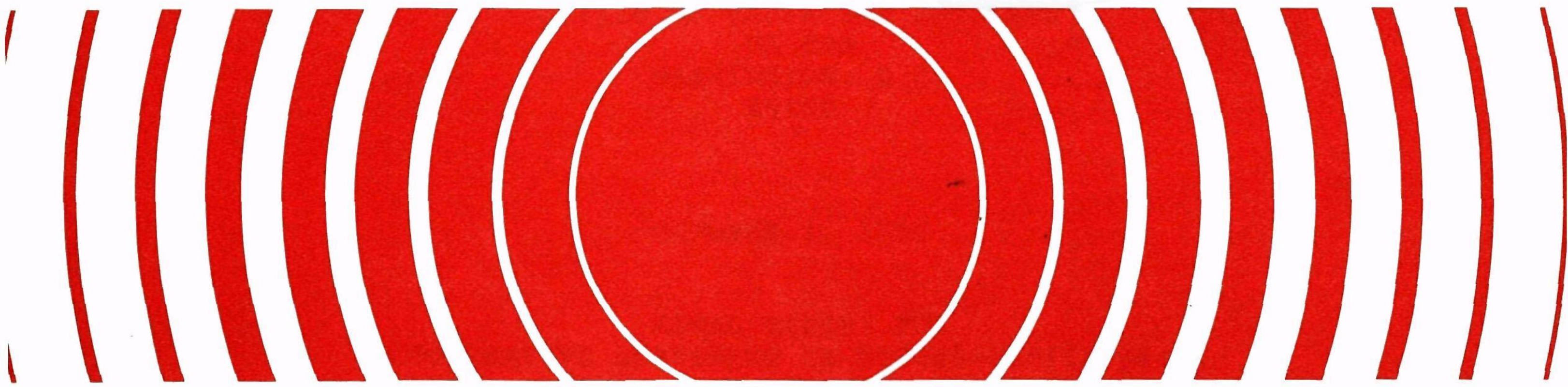
Electric Fields Under Power Lines

(Supplement to "An Examination of Electric Fields Under EHV Overhead Power Transmission Lines")



ELECTRIC FIELDS UNDER POWER LINES

(Supplement to An Examination of Electric Fields Under EHV Overhead Power Transmission Lines)

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation and to promote development of controls necessary to protect the public health and safety. This report examines magnetic field strengths and compares electric field strength measurement techniques under extra-high-voltage overhead power transmission lines. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

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INTRODUCTION

In 1976, the Environmental Protection Agency published a report on the electric fields produced by extra-high-voltage (EHV) overhead transmission lines [1]. In that report, an analytical study was made of the electric fields due to 345-kV, 500-kV, and 765-kV transmission lines and the results compared to actual measurements on several typical transmission lines. The measured and calculated values of electric field strength agreed very well. Since the publication of that report, we have received inquiries about the electric fields produced by lower voltage overhead transmission lines. The first part of this report extends the earlier analysis [1] to include 115-kV and 230-kV double circuit transmission lines. The second part of this report examines the electric field strengths due to multiple 500-kV transmission lines. The results of measurements of magnetic field strength produced by 500-kV transmission lines have been published elsewhere [2].

ANALYTICAL EVALUATION OF FIELD STRENGTHS

A number of methods have been used to obtain theoretical values for the electric field strength beneath overhead transmission lines [3] The method used to calculate electric field strengths in this report is one developed by Mr. John Walker of the Bonneville Power Administration, Portland, Oregon [4]. The procedure is implemented by a computer program which takes as input the electrical and geometric characteristics of the line. This data includes the height of the line conductors above ground, the number and geometry of the subconductors (if more than one is used) for each phase of the line, the line to neutral voltage on each conductor, the diameter of each subconductor, the phase spacing for the line, and the coordinates of the desired calculation point (i.e., the point at which one wishes to compute the field strength). This calculation is based on the fundamental field equation

$$E = q/2\Pi\varepsilon_0 r, \text{ where} \qquad (1)$$

E is field strength in volts/meter
q is charge per unit length in coulombs/meter
ε_0 is permittivity of air = 8.85×10^{-12} farads/meter
r is distance from the charge in meters.

When the geometry in the cross-section of interest is known, the only unknown in the above equation is q, the charge on the conductor. The charge can be calculated from

$$q = CV \quad \text{where} \qquad (2)$$

C is capacitance per unit length in farads/meter
V is voltage impressed on the conductor in volts.

The procedure incorporates the method of images where a set of equal and opposite charges are placed directly below the earth's surface at the same distance the conductors were above the earth. The cross-section of line charges now consists of charges representing the conductors and opposite charges on the conductor images in the earth to produce a line of zero potential at the earth's surface. The field strength due to the energized conductor can then be computed at any point. This program was modified to run on the IBM 370 computer available to EPA and was subsequently modified to determine values for the horizontal and vertical components of the field strength in addition to the total magnitude. The predictive results of this program were compared to actual field measurements as reported in the previously mentioned EPA study [1]. The excellent agreement between the two methods supports the use of this predictive model as an analytical tool.

Specifications for the 115-kV and 230-kV double circuit lines were supplied by the Baltimore Gas and Electric Company [5]. Both newer and older tower designs were supplied with the information listed in Table 1 and illustrated in Figure 1. For each of these designs, there is only one subconductor per phase.

Figures 2 and 3 show the electric field strengths under worst case conditions for the 115-kV and 230-kV towers respectively. Under these conditions, the electric field strengths are larger than what would occur under normal use. The field strengths were computed for a lowest line clearance of 30 feet. This is the minimum design clearance, yet the lowest line clearance under normal operating conditions is 45 feet and since the wire hangs in a catenary curve between two towers, the average height of the lowest wire is approximately 60 feet.

Table 1

Specifications for 115-kV and 230-kV Double Circuit Transmission Lines

	New 115kV	Old 115kV	New 230kV	Old 230kV
Configuration	I	II	II	II
Dimensions (ft)				
Horizontal				
GW1-GW2	N/A	26.5	12	20
A-A'	16	23	23	35
B-B'	21	30	25	48
C-C'	17	23	23	40
Vertical				
GW-A	12	11	17	21
A-B	10	13	18	23.5
B-C	10	13	14	23.5
Diameter (in)				
Subconductor	1.504	1.504	1.735	1.735
Groundwire	.385	.385	.385	.385

Number of Subconductors in Bundle: 1 for all lines

Relative Phase of Bundles: A=B'
C=A'
B=C'

FIGURE 1.
DESIGN SPECIFICATIONS OF BGE 115kV AND 230kV TOWERS. (NOT TO SCALE)

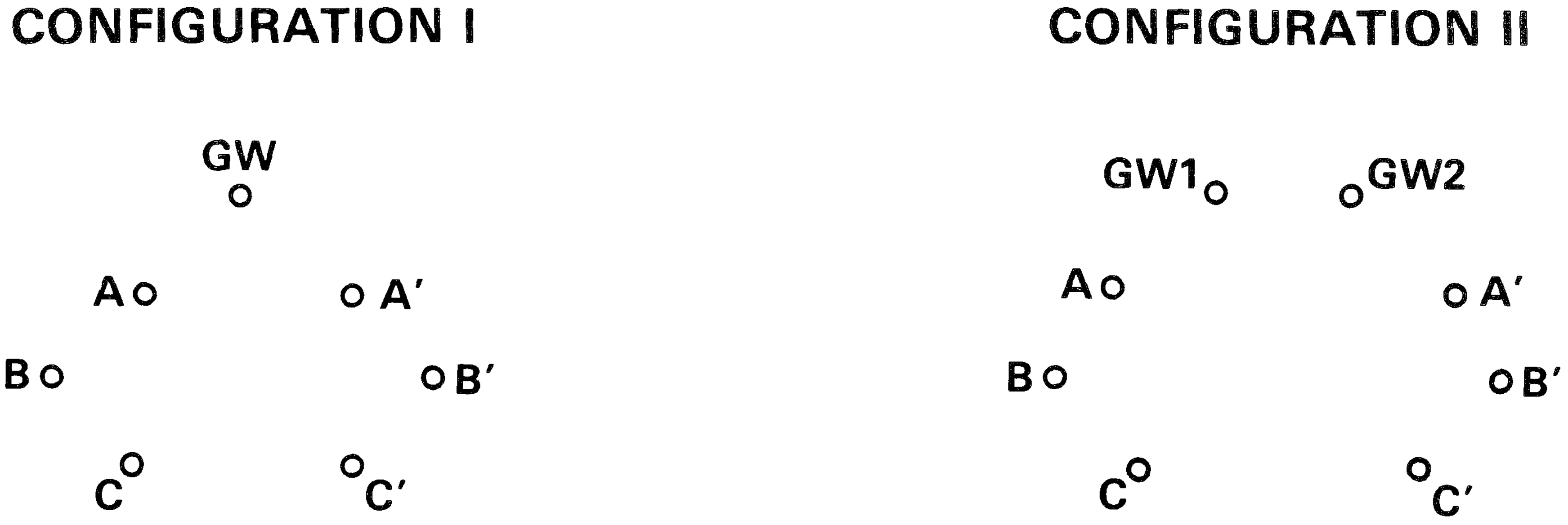


Figure 2. Electric Field Strength Profile for a 115 kV Double Circuit Line

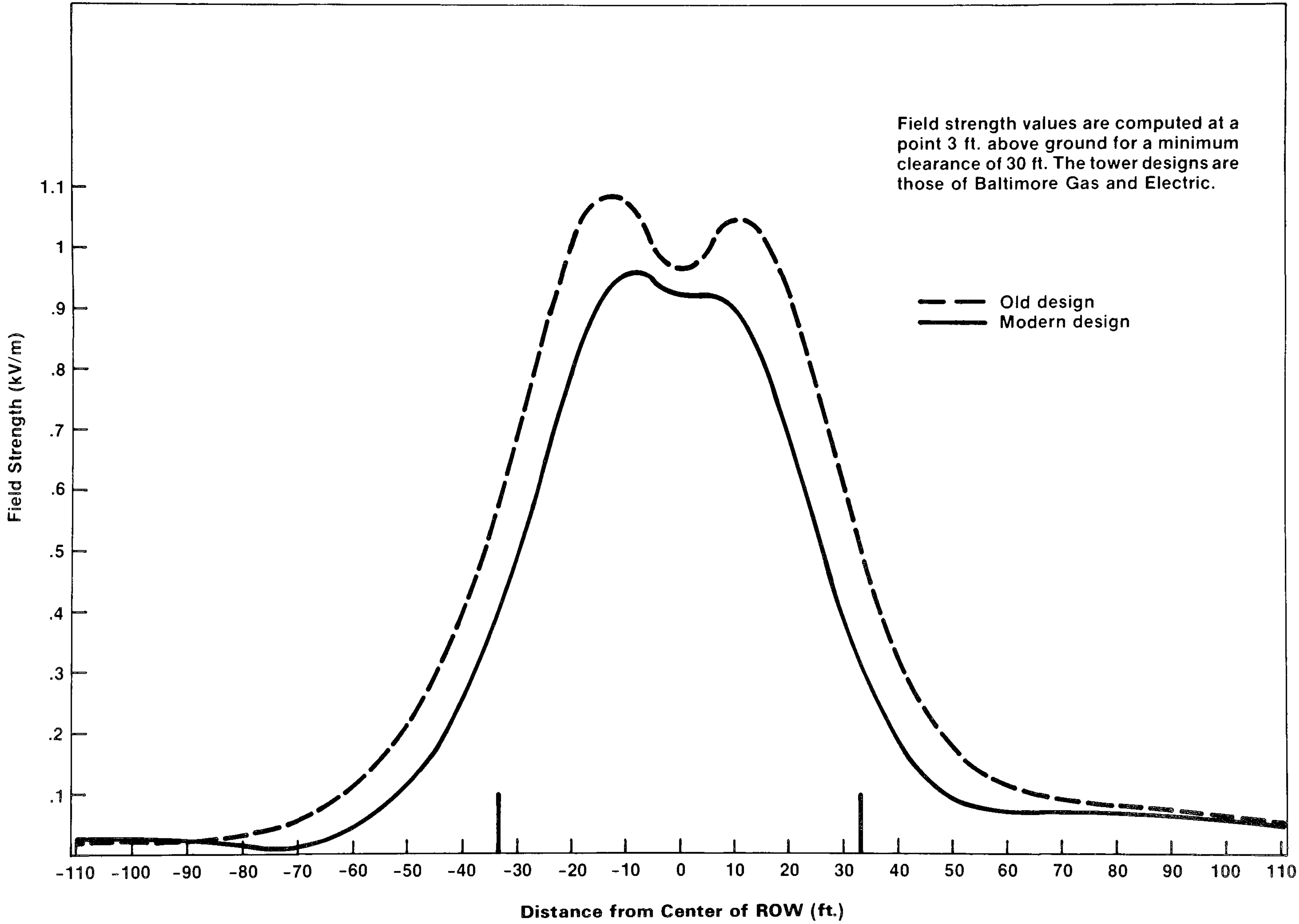
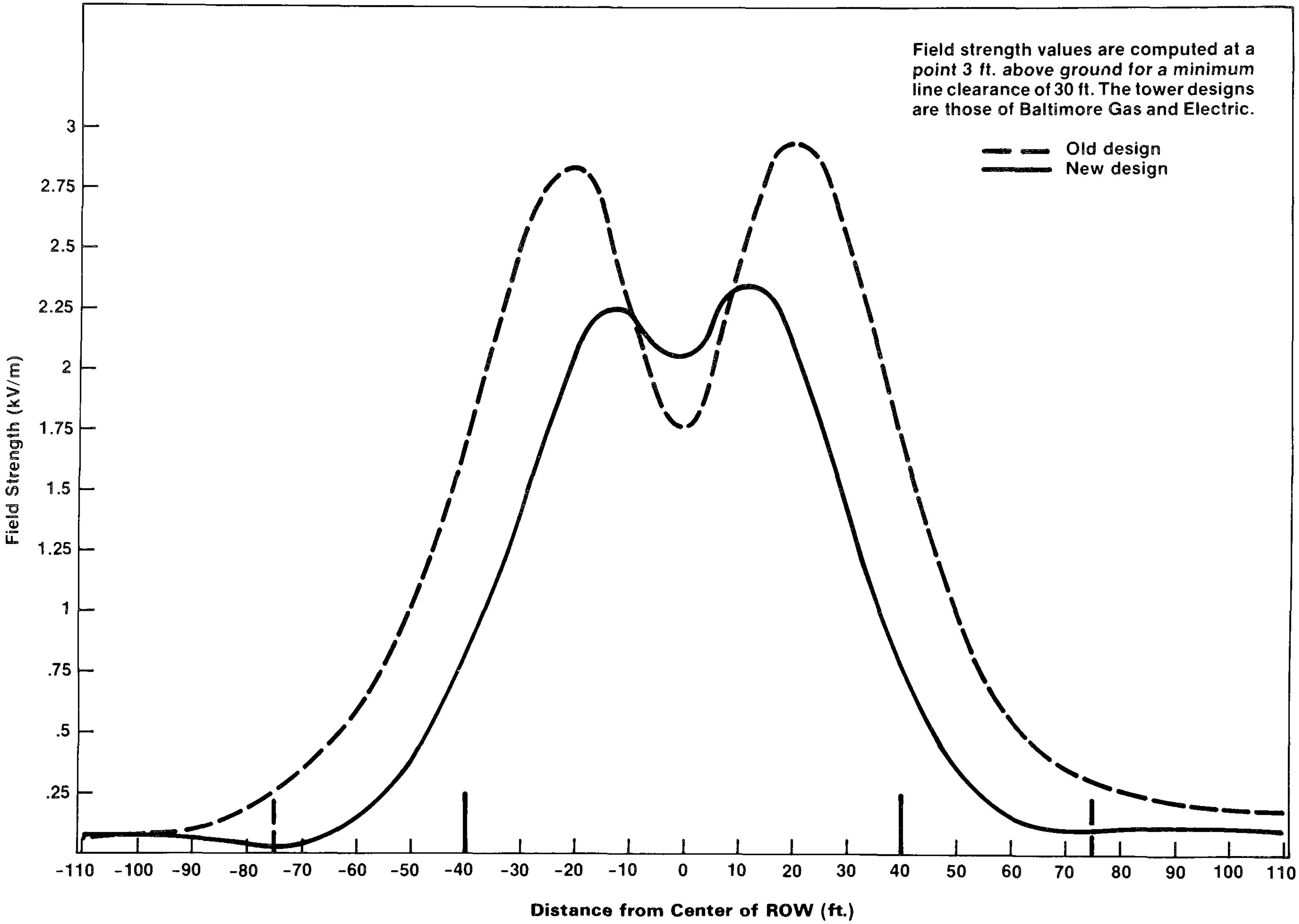


Figure 3 Electric Field Strength Profile for a 230 kV Double Circuit Line



Field strength values are computed at a *point 3 ft. above ground for a minimum* line clearance of 30 ft. The tower designs are those of Baltimore Gas and Electric.

As can be seen from these two figures, the field strengths for the older towers are in general higher with the result that the right-of-way (ROW) widths are wider. The asymmetry in the figures is due to the asymmetry in the phase relationships of the conductors. At a height of 3 feet above ground, the electric field strength is under 1 kV/m everywhere for the newer design 115-kV lines and under 1 kV/m at distances greater than 20 feet from the center of the ROW for the older design. Similarly, the 1 kV/m distances for the newer and older design 230-kV double circuit lines are 36 and 50 feet respectively. The ROW widths on these figures are represented by the vertical lines on the horizontal axis.

The variation of the electric field strength profiles with the height of the clearance for the old design of the 115-kV and 230-kV double circuit lines are shown in Figures 4 and 5. The old design towers were chosen for this display because of the generally higher fields, thus maintaining a worst case analysis. The results here follow the same pattern for double circuit lines that emerged in earlier analysis [1]. The electric field decreases everywhere at ground level as the line clearance increases, whereas for single circuit lines and for large distances from the center of the ROW, the reverse is true.

For the 115-kV line, the peak field ranges from 1.05 kV/m to 0.46 kV/m as the line clearance varies from 30 feet to 50 feet. For the 230-kV line, the peak field ranges from 2.94 kV/m to 1.24 kV/m as the line clearance again varies from 30 feet to 50 feet. This peak occurs at a distance of 20 feet from the center of the ROW for the 230-kV double circuit line while in the case of the 115-kV transmission line, the position of the peak varies between the center of the ROW and a point 12 feet from the center.

Figures 6 and 7 show the variation of the peak electric field strength at various heights above ground for line clearances of 30, 35, 40, and 45 feet for the same 115-kV and 230-kV double circuit lines. It is clear that for moderate changes in the height above ground, there is only a small change in the electric field, as long as the height above ground does not approach the line clearance, as evidenced by the case of the 30 foot line clearance. As the line height above ground increases, the influence of the test height on the field strength near the ground decreases, as shown by the increasingly flatter curves.

Figure 4. Electric Field Strength Profile for a 115 kV Double Circuit Line

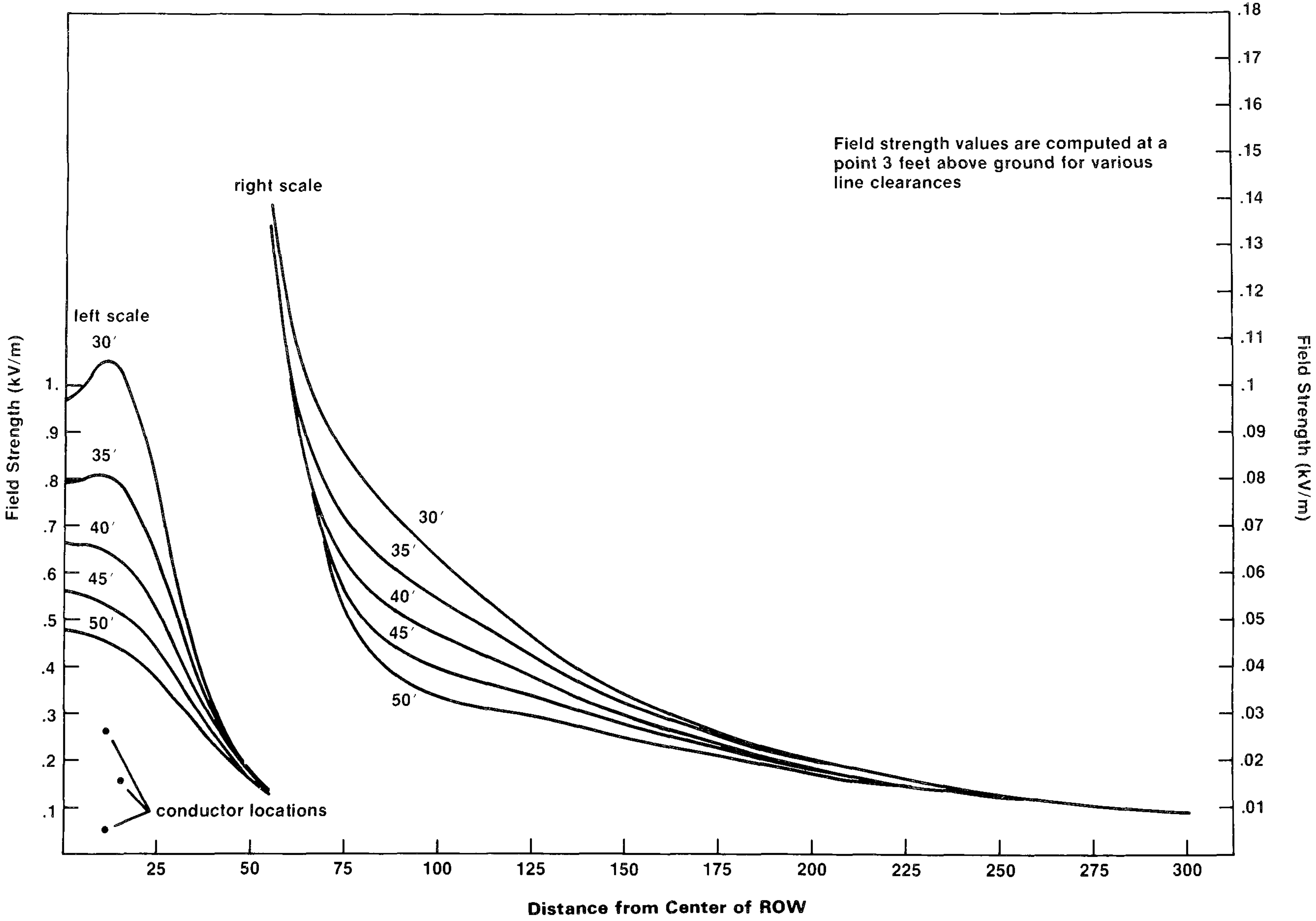


Figure 5. Electric Field Strength Profile for a 230 kV Double Circuit Line

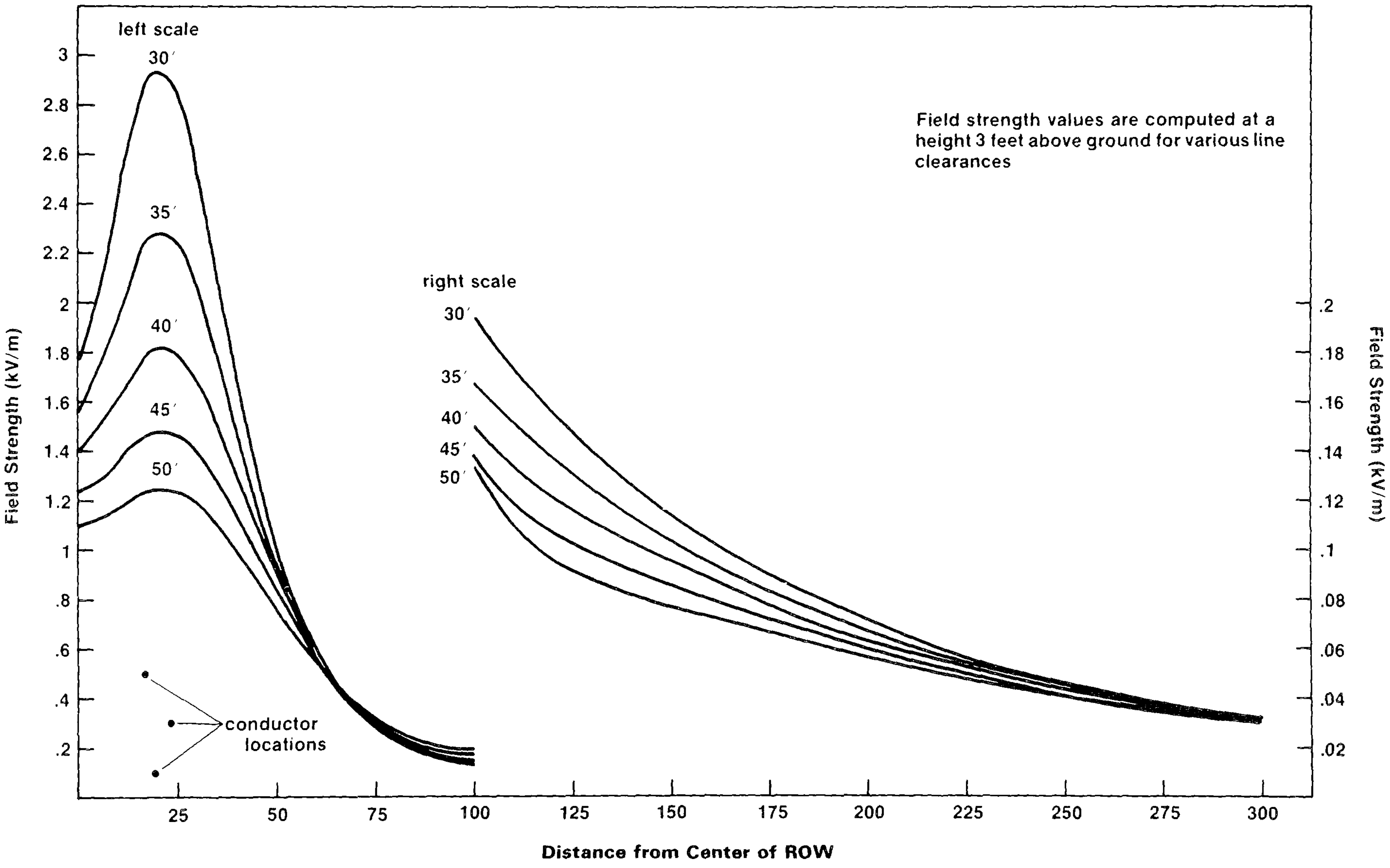


Figure 6. Variation in Field Strength as a Function of Height Above Ground for a 115 kV Double Circuit Line

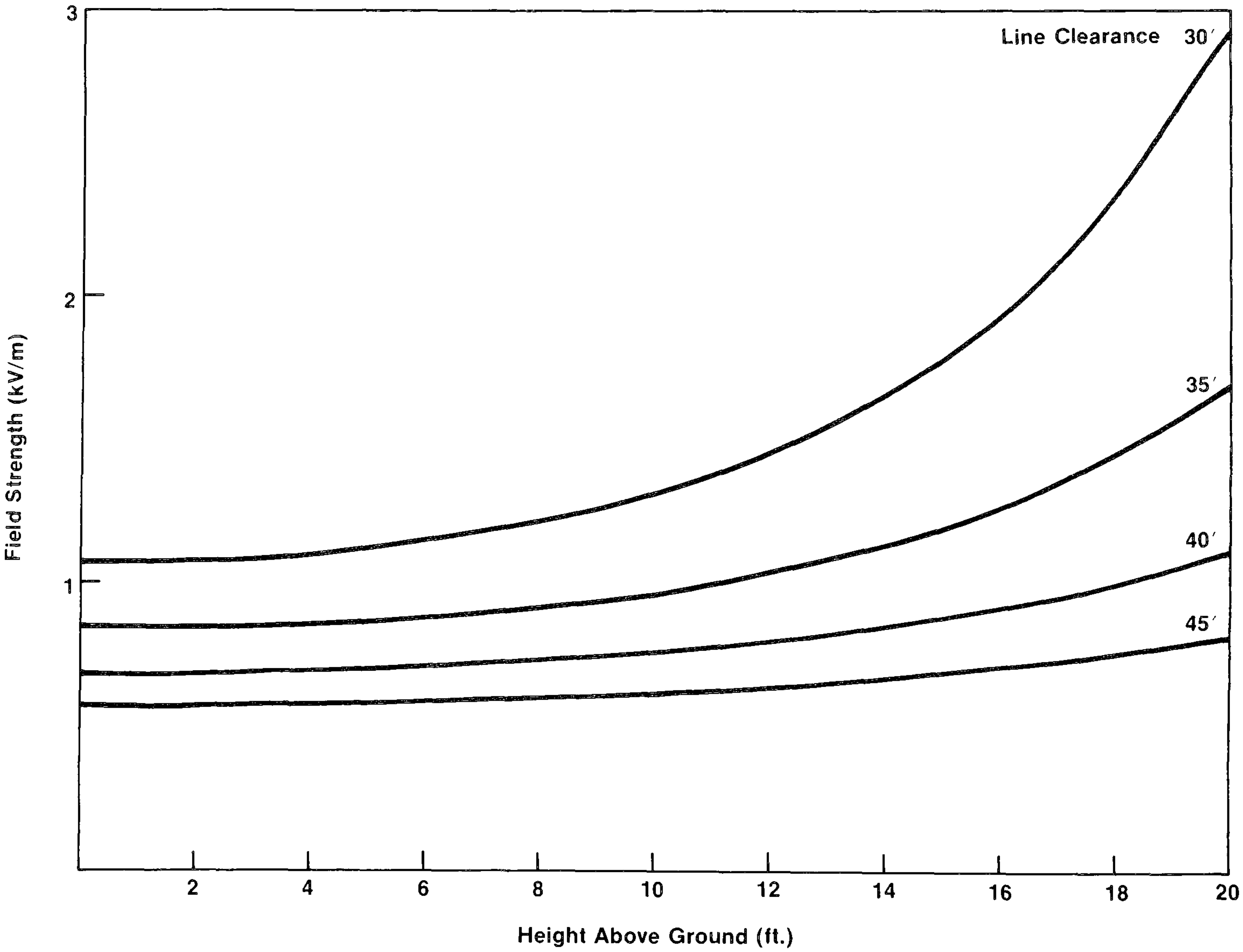
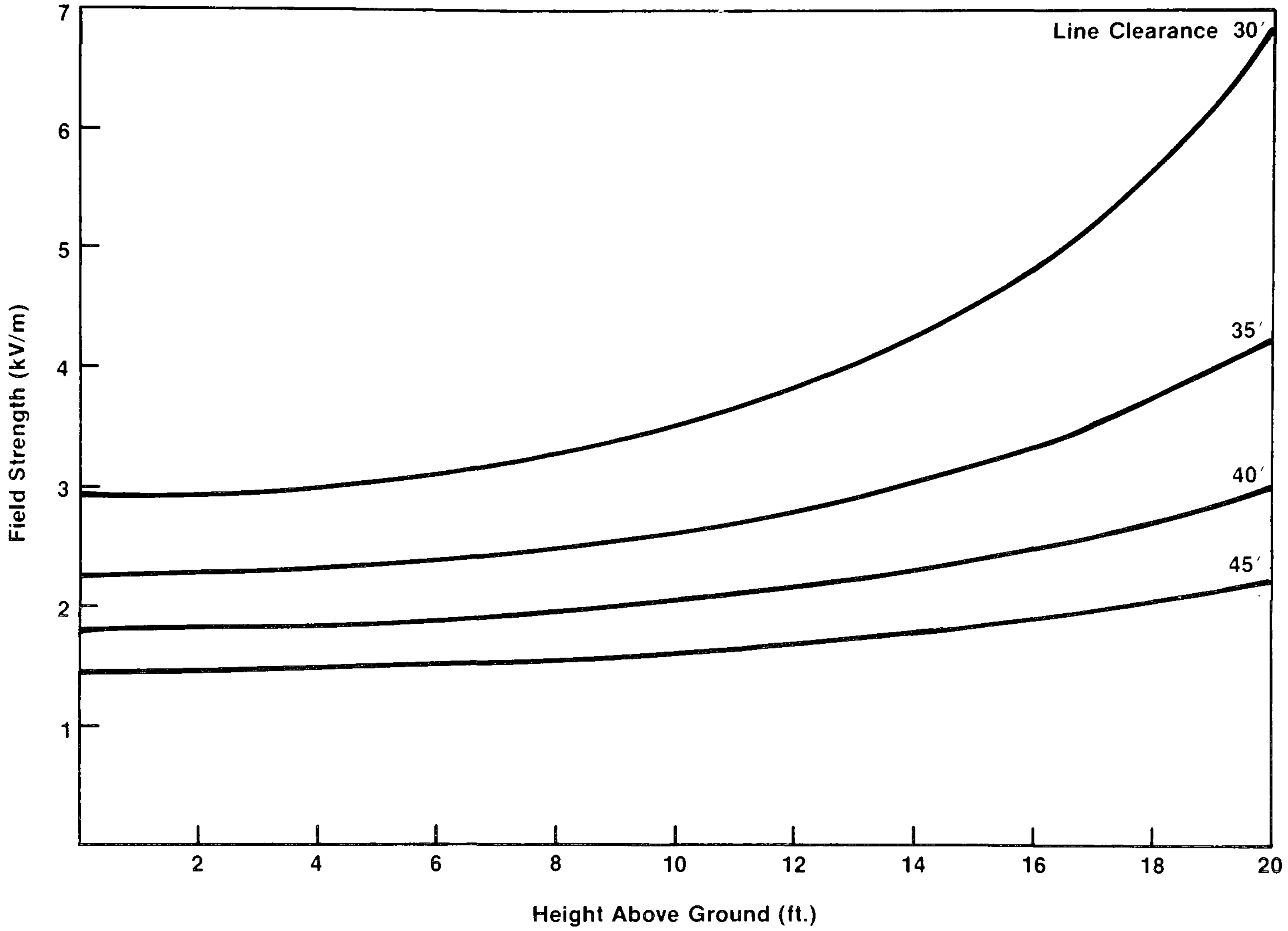


Figure 7. Variation in Field Strength as a Function of Height Above Ground for a 230 kV Double Circuit Line



When examining the electric field profiles for multiple transmission lines, or even for double circuit lines, it is imperative to know the relative phase of each of the conductors. An example is the 500-kV single circuit line characterized in Table 2. The specifications for this line were supplied by Arkansas Power and Light [6]. When two of these 500-kV lines are placed side by side, in parallel and spaced 140 feet apart, the electric field profile can look like either of the two curves shown in Figure 8, depending on the relative phases of the conductors. Outside of the right-of-way, the profiles are almost identical but inside the ROW, the fields are markedly different. At the center of the right-of-way, the field can be as large as 5.55 kV/m or as low as 1.75 kV/m depending on the phase design. Note that for the upper curve, the phases are mirror images of each other, not so for the lower curve.

Multiple lines can usually be found emanating from power plants. In Arkansas, for example, three 500-kV single circuit lines, in parallel, spaced 140 feet apart and with a right-of-way that extends to 90 feet beyond the outside towers, can be found leaving a nuclear power plant and traversing near rural properties. Each line is identical and also described in Table 2. The electric field profile, along with a comparison profile of a single 500-kV single circuit line, is illustrated in Figure 9. The relative phase of each conductor bundle is denoted at the top of the figure. Clearly, the three lines together can produce higher fields inside the right-of-way, but only 27% higher at the peaks. Outside their respective right-of-ways, the fields due to both configurations are almost identical, as seen in Figure 10, which is a plot of the difference between the field strength due to the three lines and the field strength due to the one line as a function of the distance from the edge of their respective right-of-ways. As can be seen from this figure, the differences are indeed minor - the largest difference which occurs at the right-of-way edge, is less than 3%. In fact, on one side of the ROW, the field due to the single line is greater than the field due to the three lines for distances from the edge of the ROW up to about 260 feet.

Table 2

Specifications for 500-kV Single Circuit Transmission Lines

Conductors	
Height (ft)	50
Horizontal Positions (ft)	-30.25, 0, +30.25
Diameter (in)	1.165
Number of Subconductors	3
Subconductor Spacing (in)	18
Groundwires	
Height (ft)	95
Horizontal Positions (ft)	-20.25, +20.25
Diameter (in)	.433

Figure 8. Variation of Multiple Line Electric Field Profile with Phase

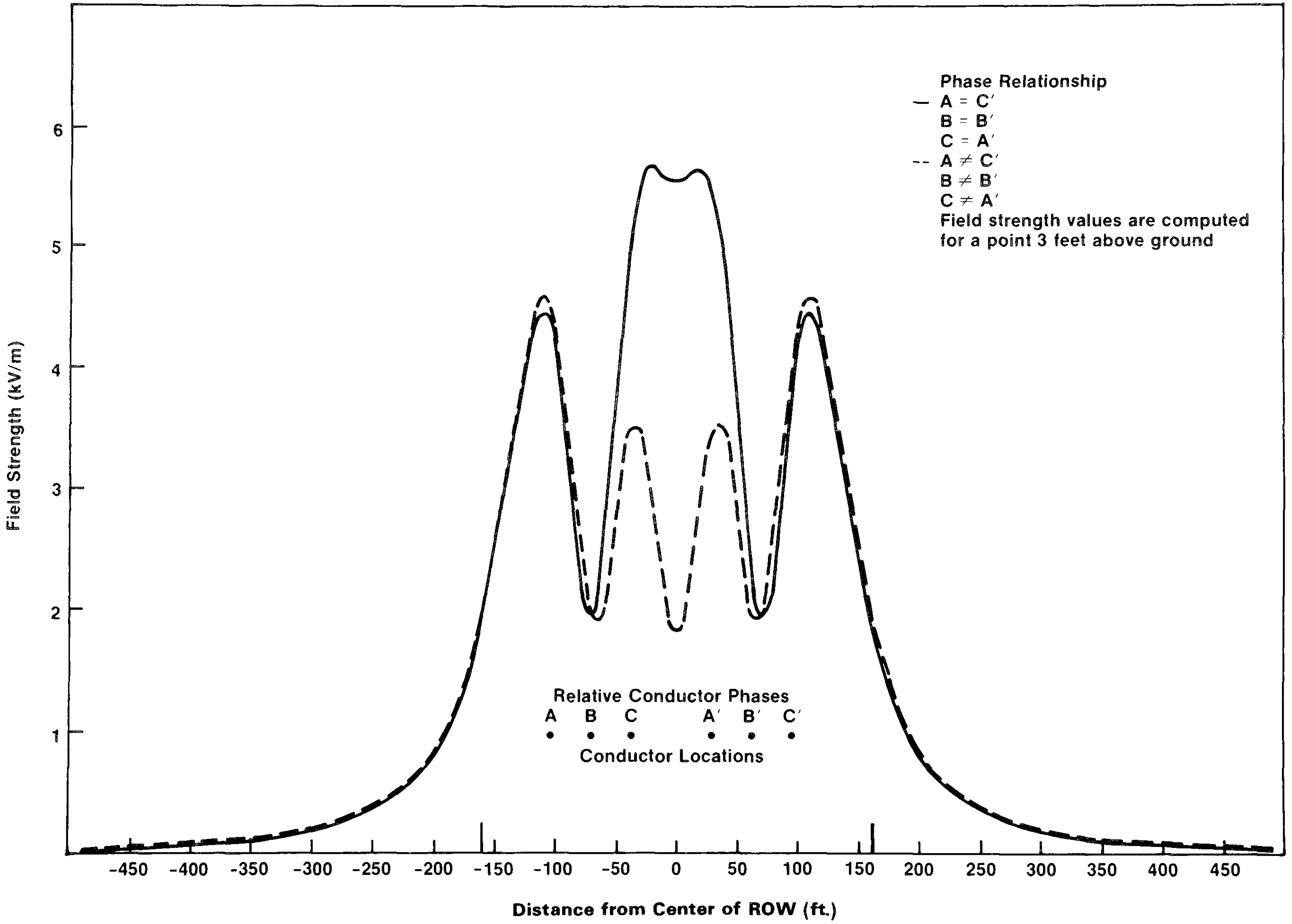


Figure 9. Comparison of Electric Field Strengths Due to a Single 500 kV Single Circuit Line to Three 500 kV Single Circuit Lines

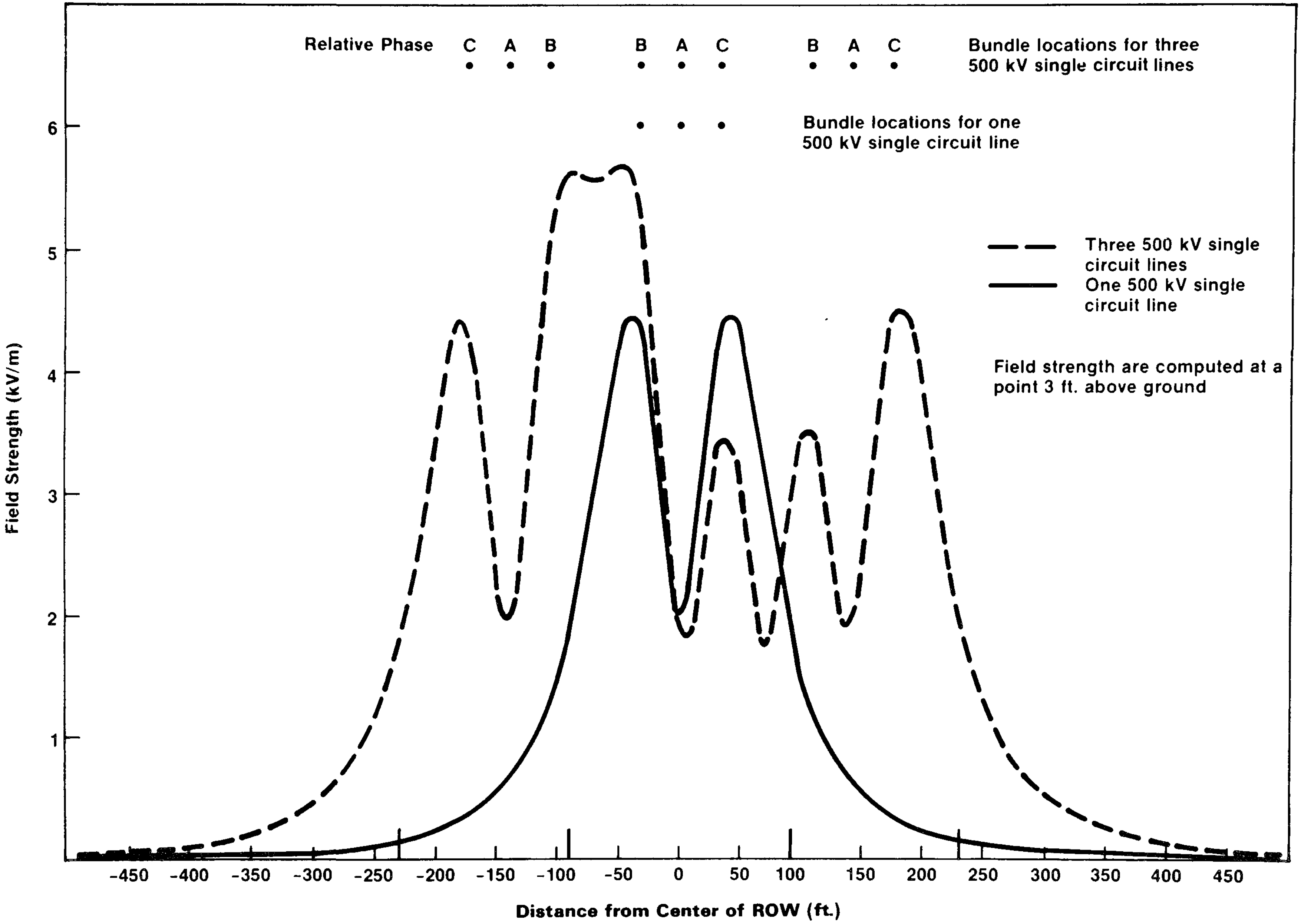
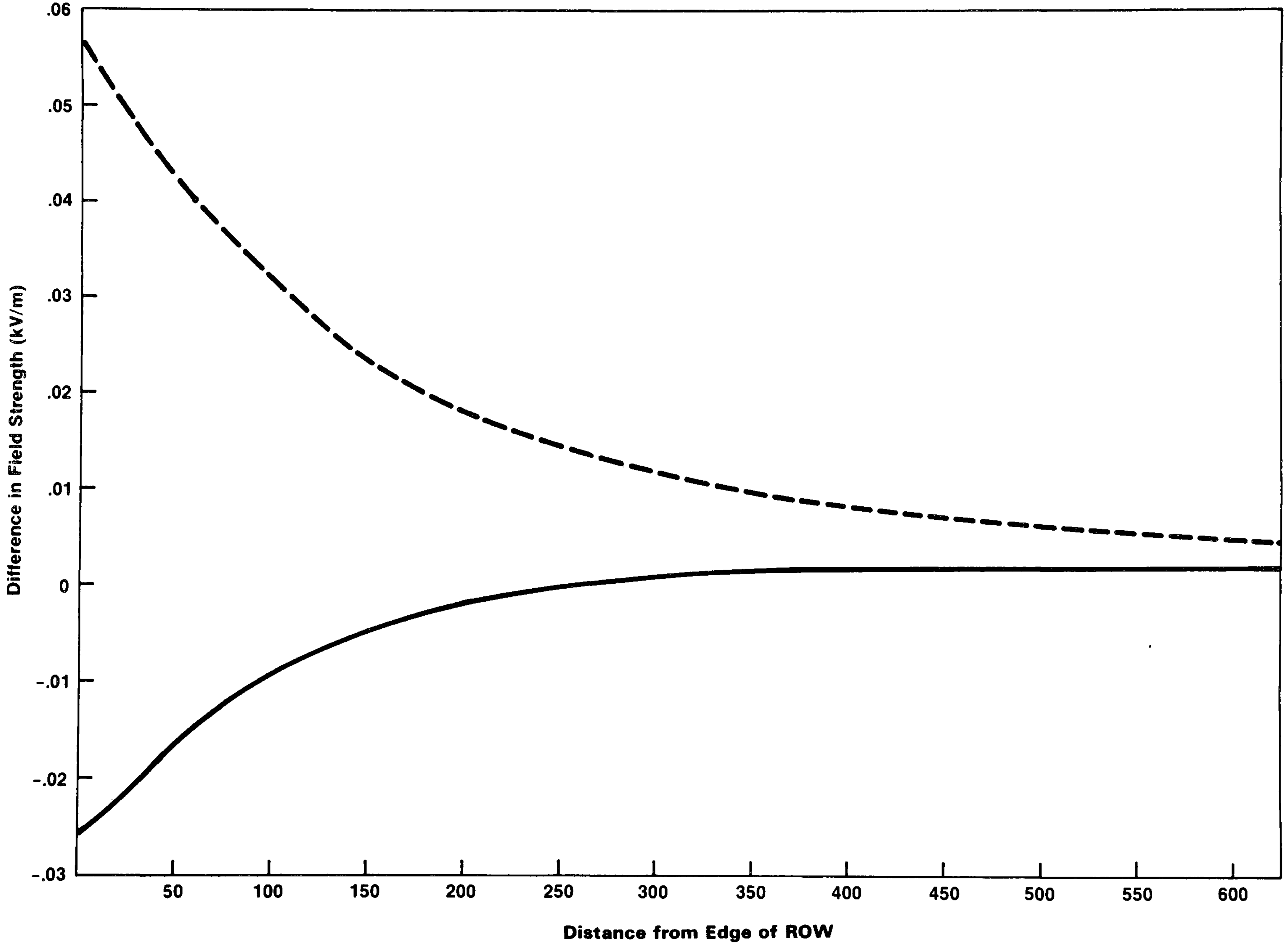


Figure 10. Difference in Field Strengths Plotted in Figure 9 as a Function of the Distance from the Edge of the ROW



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