VIII. DESIGN CATEGORIES AND RECOMMENDATIONS

Description of PG&E Transmission Facilities

PG&E's transmission system consists of approximately 13,800 miles of overhead and 104 miles underground lines. The following table summarizes mileages for single circuit and double circuit overhead lines by voltage category:

Voltage	Single Circuit Line Miles	Double Circuit Line Miles	Total Line Miles
60 kV	3500	300	3800
70 kV	1400	100	1500
115 kV	2500	1800	4300
230 kV	500	2400	2900
500 kV	1300	0	1300

TABLE 2 - PG&E's Transmission System

The remaining sections of this document provide information on the various standard PG&E transmission line designs. This document only discusses design options currently used by PG&E and does not attempt to present alternative design options that may be available elsewhere in the industry. The sections are arranged according to the following transmission line design categories (see Appendix-B for conductor spacings of various structures) :

- Overhead 60kV and 70kV Lines
  - Single Circuit
  - Double Circuit
- Overhead 115kV Lines
  - Single Circuit
  - Double Circuit
- Overhead 230kV Lines
  - Single Circuit
  - Double Circuit
- Overhead 500kV Lines
- Underground Transmission Lines

All of the magnetic field strength numbers provided in this section are computed at a height of 3' above ground level and are based on a balanced current flow. The current magnitudes used for the calculations are as follows:

Line Voltage	Amperes
60-70 kV	300
115 kV	300
230 kV	500
500 kV	1000

TABLE 3 - Current Magnitudes Used for Calculations

Although these numbers were selected because they generally represent "typical" system wide current magnitudes in these types of lines, they are only used in this document to give a ranking or comparison of the various structure types. They are not intended to give typical magnetic field values.

The field strength for a different current value may often be obtained using a linear extrapolation of the values provided. For single circuit configurations, the linear extrapolation is straightforward and accurate. However, for multiple circuit configurations, caution must be exercised because the extrapolation may not be possible if the circuits have different currents values.

There are various general loading conditions often used for magnetic field strength calculations. These include:

- Normal Current (time weighted average current)
- Heavy Load Current (system peak, all lines in service)
- Maximum Steady State Design Current (the design capability of the line)
- Emergency Maximum Current (System peak, with one line out of service)

It is recommended that the present year Heavy Load Current value be used for magnetic field strength calculations. This condition gives the highest realistic strength value. When presenting the magnetic field strength data, it should be noted that the load often varies significantly over the time of day or throughout the year. If it does, it may be desirable to perform some type of averaging on the current or differentiate between the currents levels for the various time intervals.

In addition to determining the appropriate current value to use, it is important to use the correct conductor height. All conductors have sag in the center of the span, and the magnitude of this sag depends on the stringing tension and weight of conductor. Therefore, the conductor height near the towers is generally greater than at midspan. To maintain consistency and provide the highest realistic value, it is recommended that the midspan conductor height or the lowest ground clearance point be used. The midspan minimum height should be calculated or measured under heavy load current conditions.

The tables on the following pages provide magnetic field strengths for conductor heights of both 30' and 45'. This height would be the minimum conductor clearance from ground at the maximum sag point or minimum ground clearance point. The remainder of the line, especially adjacent to the supporting structures, would be at a higher height, and would therefore, have a lower magnetic field strength at ground level.

Some circuit configurations are asymmetrical and will produce different magnetic field strength profiles on either side of the center line. The values provided in the tables are the maximum field values (Bmax) at the designated locations for the specific configurations and stated conditions.

Single Circuit Overhead 60kV and 70kV Lines

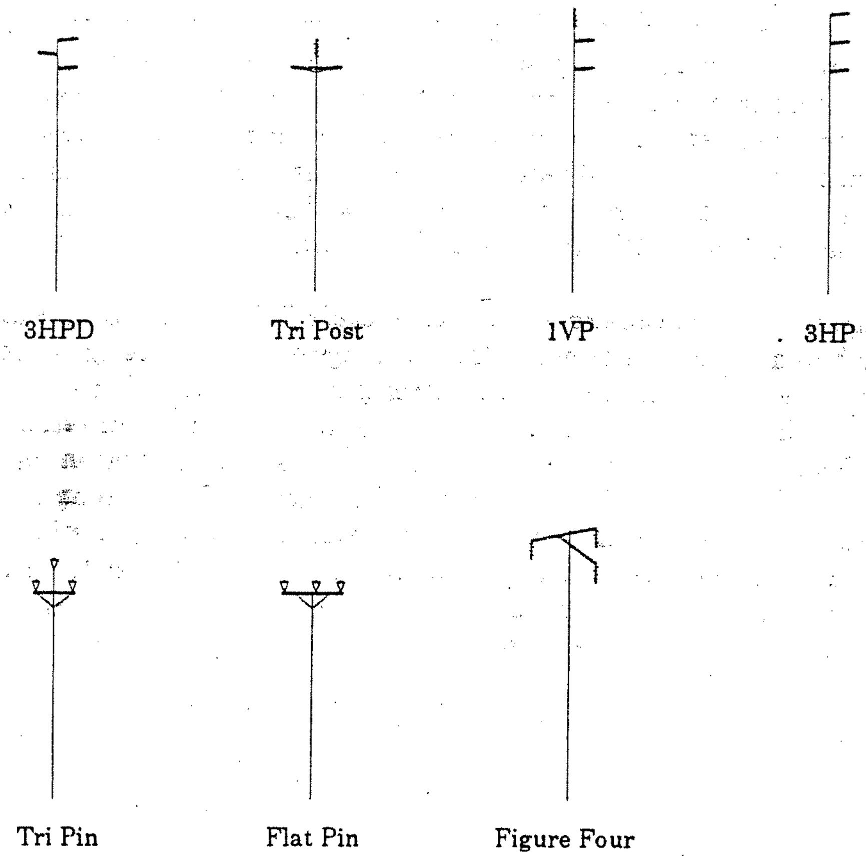
Figure 5 on the following page illustrates seven typical single circuit overhead 60kV and 70kV line configurations commonly used in the PG&E system. The following table outlines expected magnetic field strength levels at a height of three feet above ground level for a single transmission line utilizing each of these configurations at a conductor height of 30 and 45 feet. Information on double circuit configurations is provided in the next section.

Structure Type	Rank	30' Height			45' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
Tri Pin	1	16.1	3.7	1.1	6.7	2.8	1.0
3HPD	2	16.8	4.4	1.4	7.4	3.3	1.2
Tri Post	3	22.2	5.2	1.6	9.3	3.9	1.4
3HP	4	18.3	5.8	1.8	8.4	4.3	1.6
Flat Pin	5	24.8	5.8	1.8	10.5	4.4	1.6
1VP	6	19.5	6.1	1.9	9.1	4.5	1.7
Figure Four	7	26.1	7.6	2.3	11.8	5.6	2.1

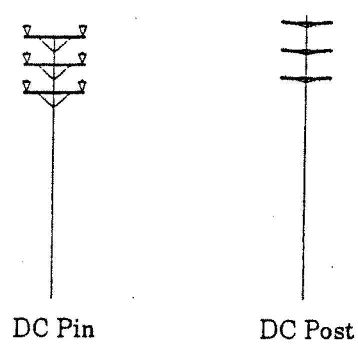
TABLE 4 - Calculated Magnetic Fields for 60kV and 70 kV Single Circuit Line Configurations

The Bpeak figure is the highest magnetic field value obtained for each configuration. Although the Bpeak value usually occurs directly underneath the line, it sometimes occurs a little off the centerline if the physical conductor arrangement is asymmetrical (i.e. Figure Four Structure). B50 is the field strength expected 50 feet from the centerline, and B100 is the field strength at 100 feet from the centerline. These figures are in milligauss and are based on a balanced 300 ampere load current.

The configurations are ranked according to their B50 values (minimum conductor height) from smallest to largest magnetic field strength produced. This ranking is used because the field strength at the edge of the right of way, and not directly under the transmission line, is usually the item of interest. Because right of way widths for transmission lines often vary for each line, the B50 value was used to best simulate the field strength at the edge of the right of way. The previous table also shows that, at a location 50 feet from the line, increasing the conductor height from 30 feet to 45 feet lowers the magnetic field strength approximately 25% for all of the configurations (Bpeak is lowered by 60%).



SINGLE CIRCUIT 60kV AND 70kV STRUCTURES



DOUBLE CIRCUIT 60kV and 70kV Structures

FIGURE 5 - 60kV and 70kV Structures

Comparing the figures this table, it can be seen that the Tri Pin and 3HPD configurations are low field configurations and produce 30-50% lower fields than higher field configurations such as 3HP, 1VP, Flat Pin and Figure 4. (The terms "low field" and "high field" are used for comparison purposes only and are not intended to define what is considered an absolute low or high field level.) The Tri Post design used by PG&E uses 14" extension brackets to spread-out the phases. This is done for aesthetics and to allow longer span lengths. If this design is used without the extension brackets, it would also be a low field configuration.

Although there are many miles of the Tri Pin design in the PG&E System, Pin Type insulators are no longer available for purchase. A similar construction configuration may be accomplished utilizing post insulators on the Tri Pin crossarms. However, this modification to the Tri Pin design is not recommended where future 115kV conversion is anticipated because of cantilever load limitations on the crossarms.

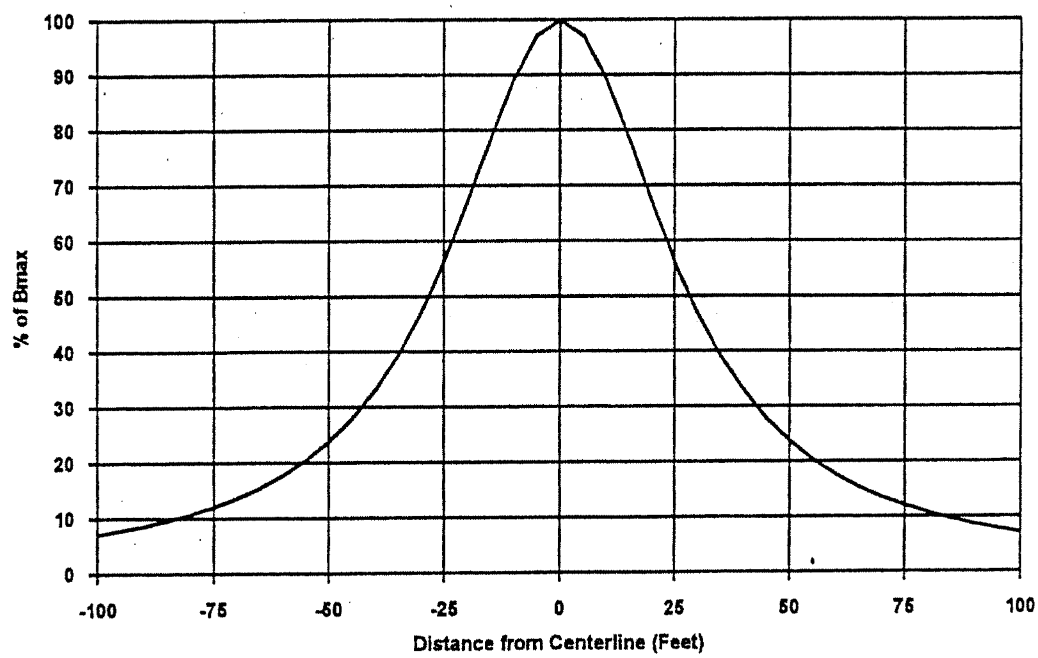


FIGURE 6 - "Typical" Magnetic Field Strength Profile

Figure 6 above shows a typical magnetic field strength profile that illustrates how the magnetic field decreases with distance from the conductor.

The previous table shows that field strengths 50 feet from the line are approximately 30% of the maximum field strengths directly under it. At 100 feet the field strengths are only 10% of the maximum field.

The phasing configuration on single circuit lines does not affect the magnitude of the magnetic field produced. But most wood pole lines, including all of the 60kV and 70kV single circuit designs discussed in this section, commonly have distribution circuits installed beneath the transmission circuit. Proper phasing of these combination hybrid lines can reduce the strength of the magnetic field similar to that achieved for double circuit transmission lines discussed later in this section. The evaluation of these hybrid circuits is complex because the current flow on distribution circuits is often unbalanced and can fluctuate considerably through time. A low field phase configuration at one time during the year may be a high field configuration at another time.

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of new 60kV and 70kV single circuit transmission lines.
- Use low field configuration designs, where practical, on new lines as long as operations, safety, and maintenance aren't compromised.
- On existing lines, replace high field configurations with low field designs when rebuilding or reconductoring the lines.
- Evaluate and optimize phasing configurations on hybrid transmission/distribution lines to minimize the magnetic field strength.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.
- Increase the right of way width in populated areas.

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

Double Circuit Overhead 60kV and 70kV Lines

Figure 5 shows two typical double circuit overhead 60kV and 70kV line configurations and Table 5 outlines the expected magnetic field strength levels for these structure configurations with 300 amperes load per circuit (balanced) and various phasing options:

Str. Type & Phasing	Rank	30' Height			45' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
DC Post							
ABC/CBA	1	10.8	1.7	0.3	3.5	1.1	0.3
ABC/CAB	3	17.1	5.5	1.7	8.2	4.1	1.6
ABC/ABC	5	34.1	10.6	3.4	16.3	7.9	3.1
DC Pin							
ABC/CBA	2	12.0	2.0	0.4	3.9	1.3	0.3
ABC/CAB	4	16.9	5.6	1.7	8.1	4.1	1.6
ABC/ABC	6	33.5	10.6	3.4	16.2	7.9	3.1

TABLE 5 - Calculated Magnetic Fields for 60KV and 70kV Double Circuit Line Configurations

Both double circuit configurations essentially produce the same magnetic field strength levels.

The table also shows that increasing the minimum height of the conductors 15 feet (from 30' to 45') will decrease the magnetic field 50 feet from the centerline by approximately 35%.

The magnetic field strengths 50 feet from the centerline are approximately 15% of the maximum field strength using the ABC/CBA cross phasing design. At 100 feet the field strength level is less than 5% of the maximum field strength level (See Figure 6 for a typical magnetic field strength profile that illustrates how the magnetic field decreases with distance from the conductor).

As is shown in the table, the phase configuration on double circuit lines can decrease the magnetic field strength by approximately 70%. This represents the most significant field reduction technique that can be easily applied to either new or existing lines. Cross phasing, where one circuit is phased in the reverse order of the other circuit, e.g., Circuit #1= ABC and circuit #2= CBA is the lowest field phase configuration. Note that <u>cross phased double circuit lines can produce lower strength magnetic fields than single circuit lines</u>.

When both circuits of a double circuit line are in the same phase order, e.g., Circuit #1= ABC and Circuit #2= ABC and are tied together and "paralleled", by installing horizontal ties between the phases, a superbundle or high field configuration is established. An alternative method of paralleling circuits is to install "diagonal" ties between the top phase on one circuit to the bottom phase on the adjacent circuit. This diagonal tie technique avoids creating a superbundle configuration but, in most cases, it results in electrical clearance problems between the diagonal tie and the middle phase. The clearance problems are especially prominent in older tower designs. This technique should only be used after these clearances have been properly evaluated.

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of new 60kV and 70kV double circuit transmission lines.
- Use cross phasing on all new lines.
- Cross phase all existing lines that are not paralleled.
- Cross phase superbundle lines including paralleled lines where possible.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.
- Increase the right of way width in populated areas.

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

Single Circuit Overhead 115kV Lines

Figure 7 illustrates eight typical single circuit overhead 115kV line configurations and Table 6 outlines the calculated magnetic field strength levels at a height of 3 feet above ground level associated with these configurations at 300 amperes load current (balanced):

Structure Type	Rank	30' Height			45' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
T1	1	23.9	5.7	1.7	10.1	4.3	1.5
3HPD	2	22.5	6.2	1.9	10.0	4.6	1.7
TPS-2	3	32.6	8.1	2.4	14.1	6.1	2.2
1VP	4	25.1	8.5	2.8	12.0	6.3	2.5
SL	5	30.3	8.7	2.7	13.9	6.5	2.5
3HP	6	24.6	8.9	2.8	11.8	6.4	2.5
Wishbone	7	34.0	9.3	2.8	15.1	6.9	2.6
H-Frame	8	53.6	16.6	4.9	25.7	12.2	4.4

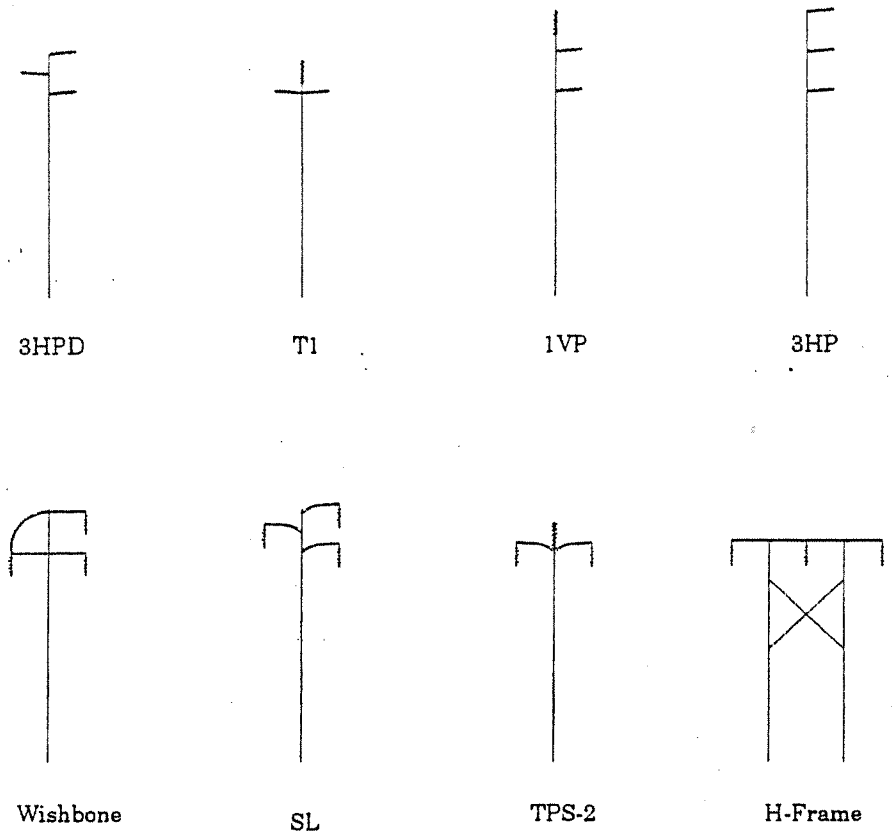
TABLE 6 - Calculated Magnetic Fields for 115kV Single Circuit Line Configurations

The levels for the lower field T1 and 3HPD designs are only 35-65% of the levels than the higher field configurations (Wishbone & H-Frame). The H-Frame design, a structure commonly used in snow loading areas, produces almost twice the magnetic field strength of any other structure type.

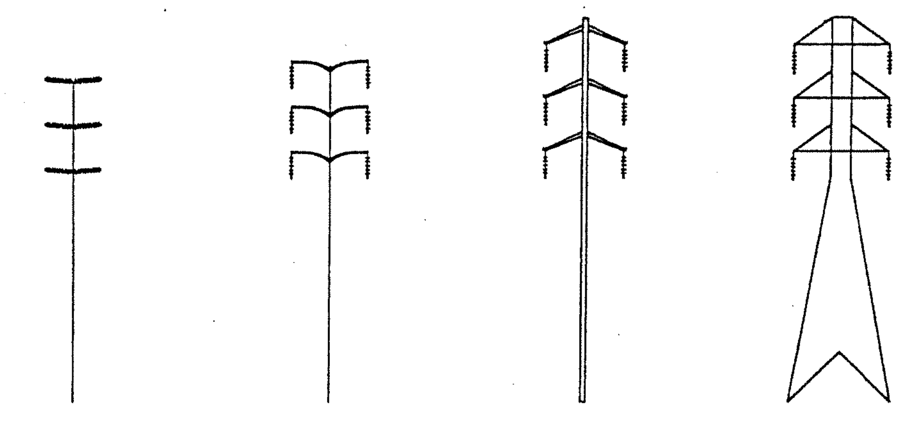
Increasing conductor height 15 feet lowers the magnetic field strength by approximately 25% at a location 50 feet from the centerline for all line configurations.

The magnetic field level 50 feet from the centerline is approximately 25% of the maximum field strength for most designs. At 100 feet the field level is slightly less than 10% of the maximum field strength level (See Figure 6 for a typical magnetic field strength profile that illustrates how the magnetic field decreases with distance from the conductor).

Phase configuration for single circuit lines does not affect the magnetic field strength levels but, many single circuit 115kV lines are commonly constructed with distribution underbuild. As indicated in the 60kV Single Circuit Section, proper phasing of these hybrid lines can reduce the strength of the magnetic field similar to that achieved for double circuit transmission lines.



SINGLE CIRCUIT 115kV STRUCTURES



*Additional conductor spacings for Live Line Maintenance
**Additional circuit spacings for bundled-conductors

DOUBLE CIRCUIT 115kV Structures

FIGURE 7 - 115kV Structures

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of new 115kV single circuit transmission lines.
- Use low field configurations designs, where practical, on new lines as long as operation, maintenance and safety aren't compromised.
- On existing lines, replace high field configurations with low field designs when rebuilding or reconductoring the lines.
- Evaluate and optimize phasing configurations on hybrid transmission/distribution lines to minimize the magnetic field strength.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.
- Increase the right of way width in populated areas.
- In snow loading areas where H-Frame construction is commonly used, investigate installing two pole delta configurations in areas where field strength reduction is desired. (Note that this is not a standard PG&E design and is not shown in Figure 7).

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

Double Circuit Overhead 115kV Lines

Figure 7 illustrates four typical double circuit 115kV line configurations commonly used in the PG&E system. Table 7 presents the calculated magnetic field strength levels at 3 feet above ground level for each of these structure configurations with 300 amperes load per circuit (balanced) and using various phasing options:

Str. Type & Phasing	Rank	30' Height			45' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
DC Post							
ABC/CBA	1	14.7	2.7	0.5	4.9	1.7	0.4
ABC/CAB	7	22.8	8.1	2.6	11.3	6.0	2.4
ABC/ABC	13	45.6	15.5	5.2	22.7	11.5	4.6
SL2							
ABC/CBA	2	19.7	3.8	0.7	6.8	2.4	0.6
ABC/CAB	8	22.2	8.5	2.7	11.0	6.1	2.4
ABC/ABC	14	42.2	15.6	5.2	21.9	11.5	4.6
V2S-D							
ABC/CBA	3	20.4	4.0	0.8	7.1	2.6	0.7
ABC/CAB	9	23.9	9.6	3.1	12.5	6.9	2.8
ABC/ABC	15	47.6	17.8	6.0	24.8	13.1	5.4
V2SL-D							
ABC/CBA	5	26.1	5.7	1.2	9.6	3.7	1.0
ABC/CAB	12	26.8	12.2	4.0	14.6	8.7	3.5
ABC/ABC	18	52.8	21.8	7.7	28.8	16.1	6.8
2A							
ABC/CBA	4	25.0	5.2	1.0	9.0	3.4	0.9
ABC/CAB	10	25.2	10.1	3.2	12.1	7.1	2.8
ABC/ABC	16	43.5	17.9	6.1	23.8	13.1	5.4
BI							
ABC/CBA	6	28.8	6.6	1.3	10.8	4.2	1.1
ABC/CAB	11	26.5	10.8	3.3	11.8	7.4	2.9
ABC/ABC	17	38.7	18.1	6.1	22.5	13.1	5.4

TABLE 7 - Calculated Magnetic Fields for 115kV Double Circuit Line Configurations

Double circuit post (DC Post) type design has magnetic field strength of 60-75% of the levels of the other double circuit designs. All single pole designs (DC Post, SL2, V2S-D, and V2SL-D) have lower field strengths than lattice steel tower designs (2A and BI) because the phases are more compact on single pole structures.

Increasing the conductor height by 15 feet (30' to 45') will decrease the magnetic field strength at 50 feet from the centerline by approximately 35% for most configurations.

The phase configuration on double circuit lines can decrease the magnetic field strength by approximately 65%, assuming equal currents on both circuits. This represents the most significant field reduction technique that can be easily applied to either new or existing lines. Cross phasing (ABC/CBA) is the low field phasing configuration and ABC/ABC phasing is the high field configuration, as is the case for 60kV and 230kV double circuit lines. Cross phased double circuit 115kV lines produce lower magnetic field strengths than single circuit 115kV lines.

When both circuits of a double circuit line are in the same phase order, e.g., Circuit #1= ABC and Circuit #2= ABC and are tied together and "paralleled", by installing horizontal ties between the phases, a superbundle or high field configuration is established. An alternative method of paralleling circuits is to install "diagonal" ties between the top phase on one circuit to the bottom phase on the adjacent circuit. This diagonal tie technique avoids creating a superbundle configuration but, in most cases, it results in electrical clearance problems between the diagonal tie and the middle phase. The clearance problems are especially prominent in older tower designs. This technique should only be used after these clearances have been properly evaluated.

The table on the previous page shows that field strengths 50 feet from the centerline are approximately 20% of the maximum field strength directly under the line for the configurations studied. At 100 feet the field is less than 5% of the maximum field strength level (See Figure 6 for a typical magnetic field strength profile that illustrates how the magnetic field decreases with distance from the conductor).

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of double circuit 115kV lines.
- Use cross phasing on all new lines.
- Cross phase all existing lines that are not paralleled.
- Cross phase all paralleled lines where possible.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.
- Increase the right-of-way width in populated areas.

- Where practical, install single pole rather than lattice steel design for new 115kV double circuit lines.

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

230kV Overhead Lines

Figure 8 on page 32 illustrates three typical 230kV overhead line configurations and the following table presents expected magnetic field strength levels at 3 feet above ground level associated with each of these configurations at 500 amperes load per circuit (balanced):

Str. Type & Phasing	Rank	30' Height			45' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
H-Frame	12	103.0	42.7	12.2	55.7	30.0	11.0
V2S-D							
ABC/CBA	1	60.7	16.0	3.3	24.5	10.3	2.8
ABC/CAB	5	56.7	25.2	8.0	26.0	17.2	7.0
ABC/ABC	11	77.2	41.2	14.7	47.5	29.8	13.0
V2SL-D							
ABC/CBA	3	68.0	19.7	4.4	28.6	12.7	3.7
ABC/CAB	8	63.4	29.6	9.6	29.4	20.1	8.4
ABC/ABC	14	81.2	46.7	17.3	51.0	33.8	15.2
V2SB-D							
ABC/CBA	4	71.3	21.5	5.0	30.6	13.8	4.2
ABC/CAB	9	66.8	32.1	10.6	31.3	21.7	9.2
ABC/ABC	15	84.5	50.0	18.9	53.5	36.2	16.6
3N							
ABC/CBA	2	66.2	19.0	4.2	27.7	12.0	3.5
ABC/CAB	7	61.0	28.0	9.0	28.0	19.0	7.8
ABC/ABC	13	77.3	44.2	16.2	48.3	31.8	14.2
RV							
ABC/CBA	6	77.0	28.0	6.5	35.8	17.7	5.4
ABC/CAB	10	70.5	36.2	11.4	33.2	23.5	9.8
ABC/ABC	16	74.5	51.2	19.4	46.8	36.0	16.9

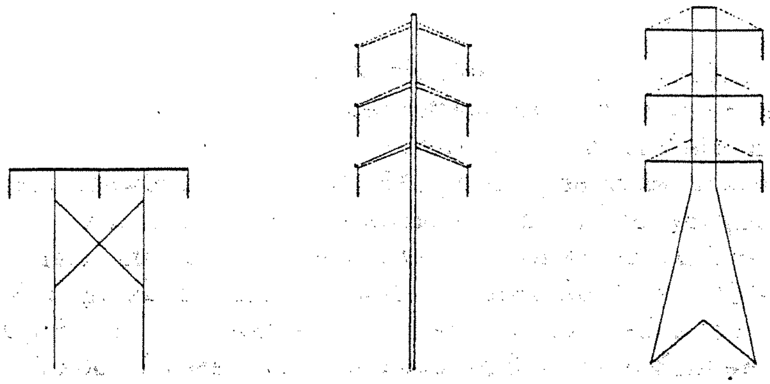
TABLE 8 - Calculated Magnetic Fields for 230kV Line Configurations

The double circuit tubular steel pole design V2S-D produces similar field strengths to the equivalent 3N lattice steel design. The field strength levels for both double circuit designs are approximately half of that of the single circuit H-Frame design.

The phase configuration on double circuit 230kV lines can decrease the magnetic field strength underneath the line by approximately 15% and at 100 feet from the line they can reduce the field strength by almost 80%. On the 230kV examples cross phasing (ABC/CBA) is not always the low field phasing configuration. In these examples, ABC/CAB phasing often produces slightly lower field strengths directly underneath the line than the cross phasing (ABC/CBA) configuration. However, cross phasing is the low field configuration at a distance of 50 feet or more from the line. Superbundle phasing is the high field configuration as in the cases for 60kV, 70kV and 115kV lines. Cross phased double circuit 230kV lines produce lower magnetic fields than a single circuit 230kV line.

When both circuits of a double circuit line are in the same phase order, e.g., Circuit #1= ABC and Circuit #2= ABC and are tied together and "paralleled", by installing horizontal ties between the phases, a superbundle or high field configuration is established. An alternative method of paralleling circuits is to install "diagonal" ties between the top phase on one circuit to the bottom phase on the adjacent circuit. This diagonal tie technique avoids creating a superbundle configuration but, in most cases, it results in electrical clearance problems between the diagonal tie and the middle phase. The clearance problems are especially prominent in older tower designs. This technique should only be used after these clearances have been properly evaluated.

The table shows that field strengths 50 feet from the centerline are approximately 25% of the maximum field strength directly under the line. At 100 feet the field strength is about 5% of the maximum field level (See Figure 6 for a typical magnetic field strength profile).



*Additional conductor spacings for Live Line Maintenance

**Additional circuit spacings for bundled-conductors

FIGURE 8 - 230kV Structures

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of double circuit 230kV lines.
- Use cross phasing on all new lines.
- Cross phase all existing lines that are not paralleled.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.
- Increase the right of way width in populated areas.

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

500kV Overhead Lines

The 500kV system is different than the other voltage levels in that there is only one general design alternative that has been used throughout the PG&E 500kV system (see Figure 9). The 40' and 55' heights are the minimum ground clearance and the typical conductor heights respectively, as required in G.O. 95. This horizontal design produces magnetic field strength as indicated in the following table at a height of 3 feet above ground and with a balanced 1000 amperes load current.

Structure Type	Rank	40' Height			55' Height		
		Bpeak	B50	B100	Bpeak	B50	B100
2HVL	-	161.6	133.6	48.4	106.8	88.3	41.3

TABLE 9 - Calculated Magnetic Fields for 500kV Line Configuration

Table 9 shows that magnetic field strengths 50 feet from the centerline are about 80% of the maximum field strength directly under the line. At 100 feet, the field level is approximately 30% of the maximum field level. The rate of decrease of the magnetic field strength with horizontal distance from the line is less for 500kV lines than for lower voltage lines because of the large width of the 500kV structures and the resultant greater phase spacing.

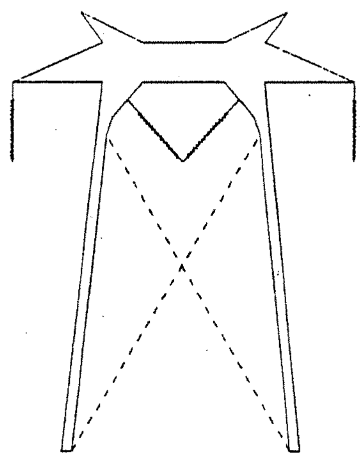
In addition to design alternatives, PG&E acquires exclusive easements and as such has much greater control over the activities that take place in and around the 500kV facilities. Additional property rights could be purchased in the form of wider rights of way, in order to minimize any increases in the field environment outside the edge of the ROW.

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of 500kV lines.
- Increase the right-of-way width in populated areas.
- Increase the conductor height of the transmission line. The actual amount of increase will depend on the field strength reduction desired.

- Investigate the delta configuration design. (Note that this is not a standard PG&E design and is not shown in Figure 9.)

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).



2HVL
(Tower)

FIGURE 9 - 500kV Structure

Underground Transmission Lines

There are two general types of underground transmission lines that are used in the PG&E system. There are solid dielectric systems where individual phase cables are typically installed in separate conduits and pipe type systems where all three phases are installed in a single conduit (See Figure 10).

Different types of underground systems are installed at the different system voltage levels due to the development state of the underground technology and concerns about system reliability. The following table provides a list of PG&E's typical underground system construction types used for new installations:

Voltage	Type of Underground System
60-70kV	High Pressure Gas Filled Pipe Type and XLPE Extruded (Solid) Dielectric Type
115kV	High Pressure Gas Filled Pipe Type
230kV	High Pressure Oil Filled Pipe Type

TABLE 10 - Underground System Construction Types

It should be noted that while PG&E has utilized solid dielectric cable for only one short 60kV application, the company has not installed 115kV or 230kV solid dielectric cable due to reliability concerns.

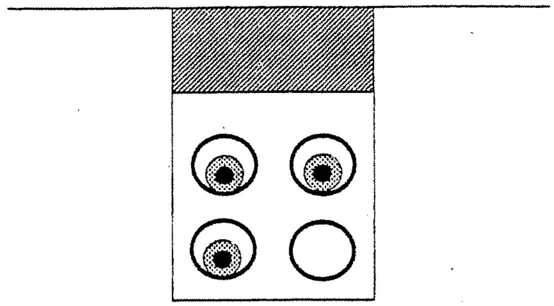
The following table shows the expected magnetic field levels for a 60kV solid dielectric system using both triangular and horizontal configurations. These magnetic field levels were calculated at 3 feet above ground level with 300 amperes per circuit (balanced):

-Underground-

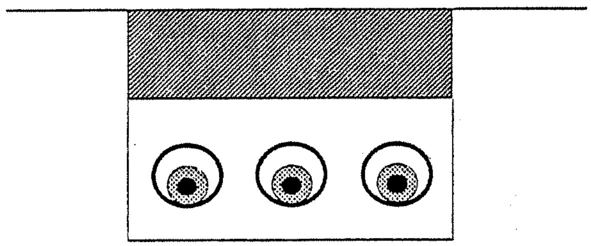
Cable Type	Rank	3 Feet Depth			4 Feet Depth		
		Bpeak	B50	B100	Bpeak	B50	B100
Solid D.- Triangular	1	41.4	0.7	0.2	31.2	0.7	0.2
Solid D. - Horizontal	2	64.5	1.0	0.3	48.1	1.0	0.3

TABLE 11 - Calculated Magnetic Fields for 60kV Underground Solid Dielectric System

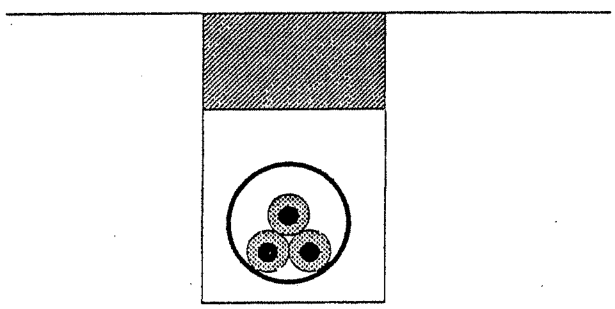
This table shows that the field level for solid dielectric triangular configuration is approximately 65% of a horizontal configuration. Bpeak is the field directly above the UG circuit, while the B50 and B100 values give the magnetic field strength at a horizontal distance of 50' and 100' respectively from the UG circuit.



Solid Dielectric Cable System - Triangular Configuration



Solid Dielectric Cable System - Horizontal Configuration



Pipe Type System

FIGURE 10 - Underground Lines

Increasing the depth of the underground system has the same effect as increasing the height of an overhead system. The previous table also shows that increasing the depth from 3 feet to 4 feet reduces the field strength by approximately 25%. Although not shown in the table, increasing the depth from 3 feet to 5 feet reduces the field strength by approximately 40%.

Magnetic fields for pipe type systems are difficult to analytically model and considerable research is currently underway to develop accurate prediction techniques for magnetic fields from pipe type systems. Generally it can be stated that pipe type systems produce considerably lower magnetic field levels than solid dielectric systems; typically as low as 5-10% of solid dielectric systems. This occurs because the phases are located in closer proximity, allowing greater phase to phase magnetic field strength cancellation. In addition, the steel pipe conduit also attenuates the field to a certain extent. However, the steel pipe may have net unbalance currents flowing on it which tend to increase the resultant field values.

Although these types of designs can result in substantially reduced field strengths, PG&E has not installed multiple transmission circuits in the same duct bank because of mutual heating effects and increased reliability risks. Cross phasing on multiple circuits installations can reduce the magnetic field strength from self contained systems to slightly less than an equivalent double circuit overhead line. However, as with all multiple underground circuits located in close proximity to each other, a mutual heating effect exists that will derate the cables (reduce the allowable ampacity of each circuit).

Magnetic field strength levels produced by underground lines may be greater than equivalent overhead lines when measured directly above the center of the line at a height of 3' above ground level. But, since these fields most often decrease very rapidly with horizontal distance from the underground system, the magnetic field levels from underground lines are normally less than overhead lines when measured several feet from the centerline. Figure 11 on the following page presents an example of a comparison between the magnetic fields produced by an underground circuit and an equivalent overhead line. It illustrates how the field strength falls off at a distance from the line.

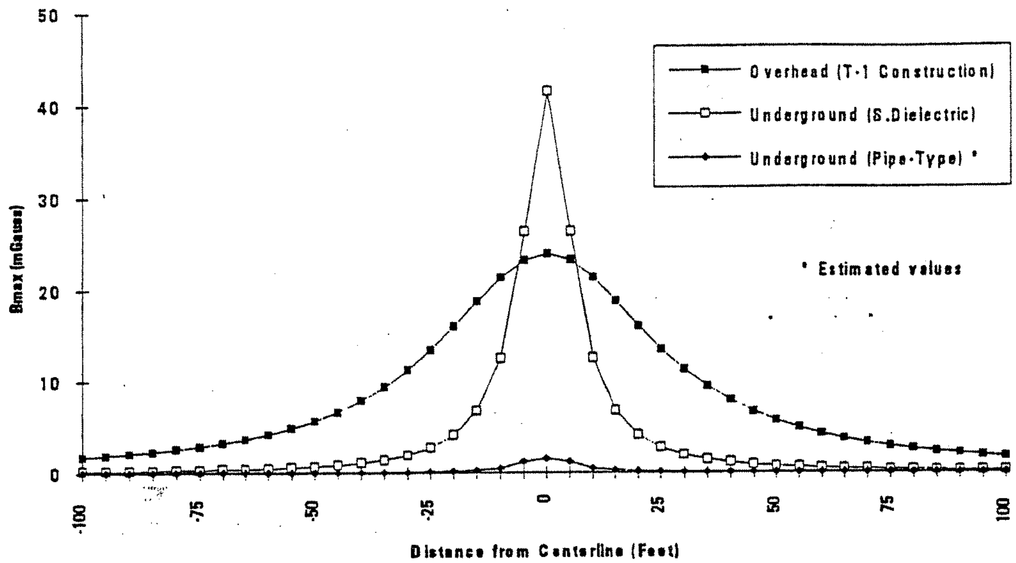


FIGURE 11 - Example EMF Comparison Between Overhead and Underground Lines

Percentage field reduction and costs, should be considered along with other environmental and design issues (see Section IV) when determining the appropriate reduction techniques for each specific case. The following is a list of considerations for field reduction:

- When feasible, avoid areas of public concern in the routing of new underground transmission lines
- Use triangular configuration for solid dielectric systems, where practical.
- Increase the minimum depth of underground systems.

Field reduction technique selection should be checked against the fulfillment of the Corporate EMF Policy (Section III).

APPENDIX - A
GLOSSARY

Alternating Current (AC) - Electric current that reverses its direction at regular intervals or periods. An AC field also changes strength and direction in a rhythmically repeating cycle.

Ampere (A)- The unit of measure of electric current; specifically, a measure of the rate of flow of electrons past a given point in an electric conductor such as a power line.

$\bar{\mathbf{B}}$ - The magnetic flux density vector, a vector field, expressed in tesla (SI units) or milligauss (Gaussian units).

Balanced Currents - A set of conductors whose currents instantaneously sum to zero are said to have balanced currents. A three-phase electric power transmission line is said to have balanced currents if the phase currents are equal in magnitude and at 120 electrical degrees with respect to each other (only positive-sequence symmetric components).

Circuit - A closed conducting path for the flow of current. For AC electrical circuits, there are three phases per circuit.

Conductor - A material that allows the flow of charge. The wires on transmission lines are conductors.

Current - The flow of electrically charged particles. The unit is ampere (A).

Direct Current (DC) - Electric current that flows in a single direction and at a constant voltage. A DC field is also steady and does not change strength or direction over time.

Electric Field ($\bar{\mathbf{E}}$) - A vector field describing the electrical force on a unit charge in space. Electrical charges are a source of electric fields. The electric field from a power line is an alternating, 60-Hz field due to charges on the conductors. The intensity of the electric field is expressed in volts per meter (V/m) or kilovolts per meter (kV/m).

Extremely Low Frequency (ELF) - ELF denotes the frequency range below 300 Hz.

EMF - A non-scientific term in popular use to refer to Electric and Magnetic Fields (or, Electro Magnetic Fields). This term is often used to describe magnetic fields only.

Ferromagnetic Materials - Materials exhibiting a strong magnetic moment which can be aligned with an applied magnetic field. Ferromagnetic materials exhibit large values of relative permeability (e.g., iron alloys).

Field - A space within which magnetic and/or electric lines of force are active. Different points in space would have different values of these electric and/or magnetic fields.

Frequency - The number of complete cycles of a periodic wave form per unit time. The units of frequency are Hertz (Hz).

Gauss (G) - A common unit (Gaussian Units) of measure for magnetic fields. A milligauss (mG) is one thousandth of a gauss. There are 10,000 gauss in one tesla (T - SI Units) or 1 milligauss (mG) equals to 0.1 microtesla (μT). The gauss is a unit used to describe magnetic flux density (B), or magnetic flux lines per unit of cross-sectional area. The gauss is one maxwell (one flux line) per square centimeter, or webers per square meter. .

$\overline{H}$ - The magnetic field intensity vector, a vector field, usually expressed in ampere per meter.

Hertz (Hz)- the unit of frequency; equivalent to one cycle per second. In America, AC power has a frequency of 60 Hz. In most of Europe, AC power has a frequency of 50 Hz. Radio waves have frequencies of many thousands or millions of hertz. Abbreviated Hz.

Magnetic Field - A magnetic field (H) exists in the region near a permanent magnet or current semi-major axis represents the magnitude and direction of the maximum value of the magnetic field, and whose semi-minor axis represents the magnitude and direction of the field a quarter cycle later at its minimum value.
The unit of magnetic field strength in the MKS (SI) system is the ampere-turn per meter, or simply, the ampere per meter (A/m), which is mmf per unit length. One ampere-turn per meter is the magnetic field strength in the interior of an elongated, uniformly wound solenoid that is excited with a linear current density in its winding of one ampere per meter of axial distance. (In the CGS system, the oersted is the unit of magnetic field strength.
Sometimes the magnetic field is described incorrectly using the units of its magnetic flux density (B) with SI units of tesla and Gaussian units of gauss (or mG). One milligauss equals 0.1 microtesla (μT). Magnetic field and magnetic flux density are related by the permeability of the material or medium in which they are characterized. The ratio of flux density (B) to field (H) is the permeability.

Neutral - Neutral is the wire at ground potential carrying the return current of energized wires.

Phase - The measure of the progression of a periodic wave form in time of space from a chosen instant or position. Most high voltage, ac transmission lines have three conductors or conductor bundles with the phase of the voltage in each advanced 120 degrees or one-third of a cycle relative to the others.

Polarization - The description of the angular variation with time of either the electric or the magnetic field vector at a fixed point is the field polarization. If the spatial components of the field are all in phase with each other, the field is said to be linearly polarized (the field vector will oscillate back and forth along a line with time). If, on the other hand, the individual spatial components of the field are not all in phase, the field will be elliptically polarized (the field vector traces out an ellipse with time). An elliptically polarized field can be described by its semi-major axis (or maximum value) and its semi-minor axis (minimum value) a quarter cycle later. The field ellipse is completely specified by its degree of polarization (ratio of minor/major axis) and its orientation (the spatial direction of its major axis). A polarized field with a degree of polarization of unity (major and minor axes are equal) is said to be circularity polarized since its field ellipse will trace out a circle with time.

Power - The time rate at which work is done. Electrical power is proportional to the product of current and voltage. The unit is the Watt (W).

Profile (of magnetic field) - A plot of the magnitude of the field as a function of horizontal distance, usually at a height of three feet from the ground plan.

Permeability - The property of a material by which it changes the flux density in a magnetic field from the value in air is called its permeability (it is analogous to permittivity, for electric field).

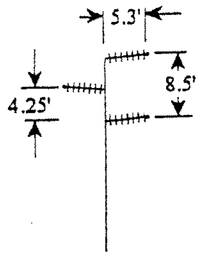
Resultant Value of Magnetic Flux Density - The square root of the sum of the squares of the three orthogonal (x, y, and z) field vectors.

r.m.s. (root mean square) - The square root of the average of the squares of individual values. For a sinusoidal variable, such as the amplitude of 60Hz alternating current, the r.m.s. value equals the peak value divided by the square root of two. Measured and calculated E&M field levels are usually r.m.s values.

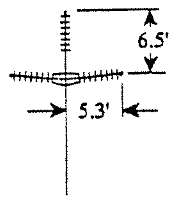
Vectors - Vector quantities, or vectors, are those which can be represented on a map or a model by a directed line segment, where the length of the line represents the magnitude and the arrow represents the direction.

Voltage (V) - The electrical potential energy difference per unit charge between two points. The unit is the volt .

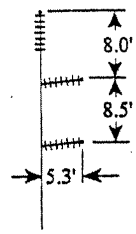
APPENDIX - B
CONDUCTOR SPACINGS



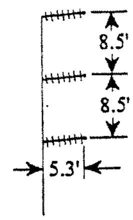
3HPD



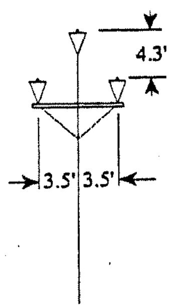
Tri Post



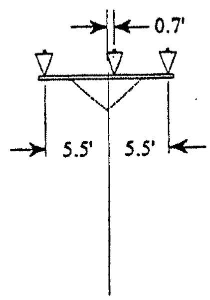
1VP



3HP



Tri Pin



Flat Pin

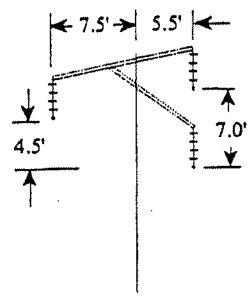
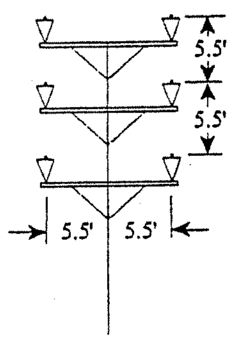
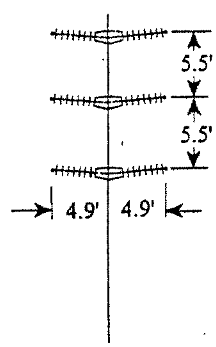


Figure Four

SINGLE CIRCUIT 60kV AND 70kV STRUCTURES

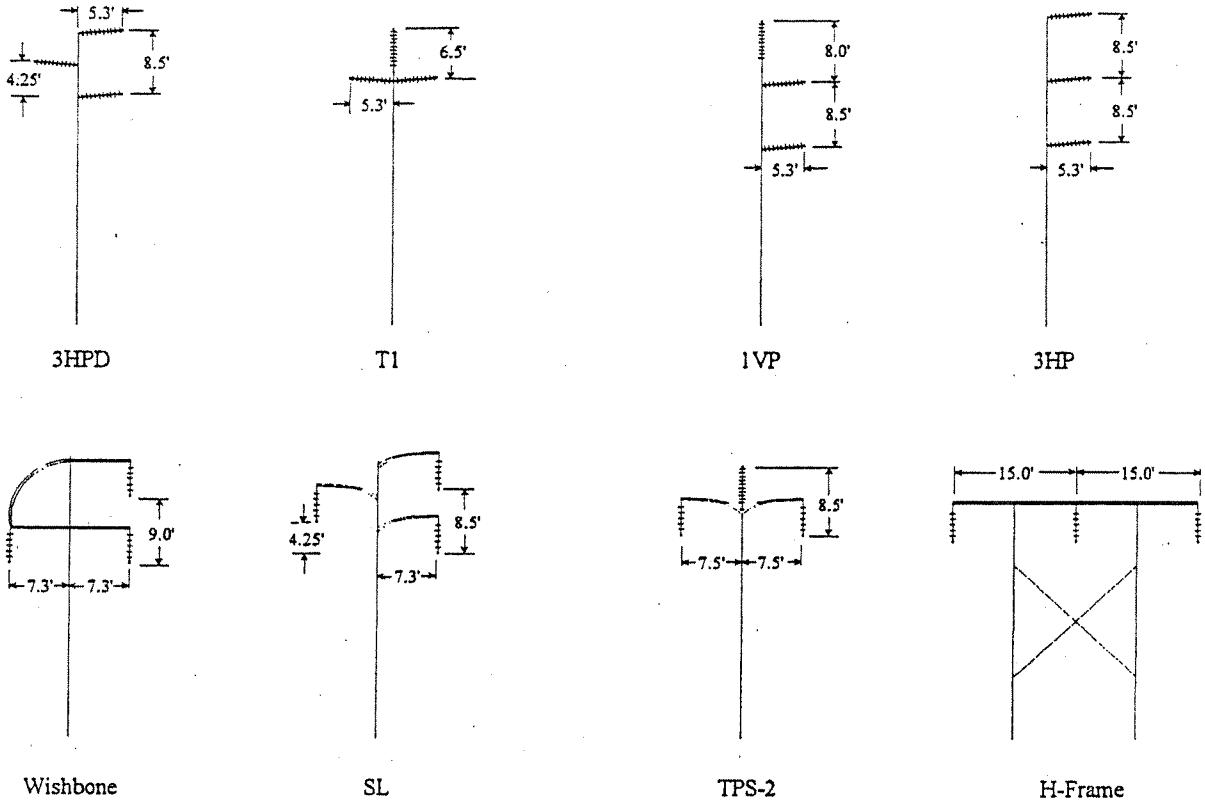


Flat Pin

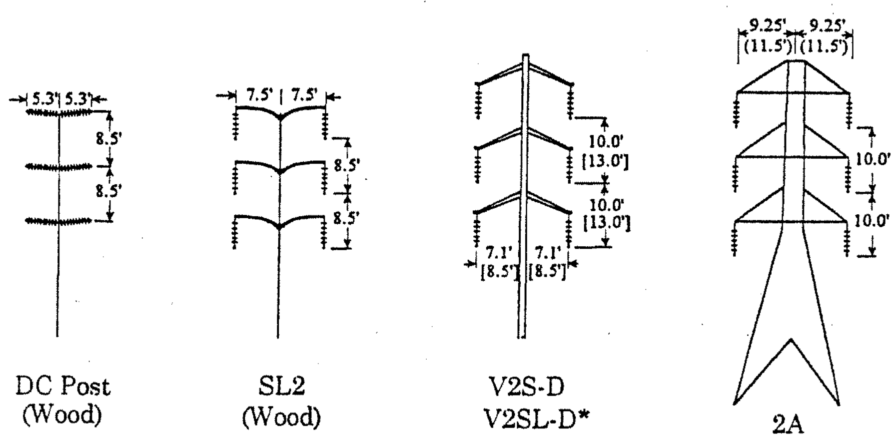


DC Post

DOUBLE CIRCUIT 60kV and 70kV STRUCTURES



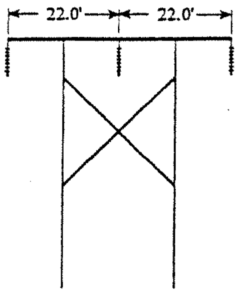
SINGLE CIRCUIT 115kV STRUCTURES



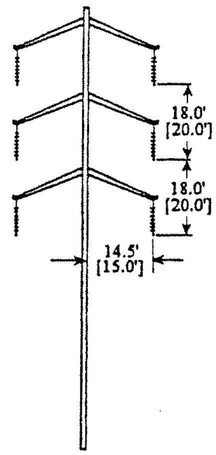
* Additional conductor spacings for Live Line Maintenance. Spacing for V2SL-D are in brackets [ ].

**Additional circuit spacings for bundled-conductors. Spacing for BI tower are in parenthesis ( ).

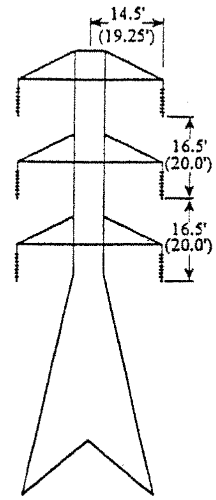
DOUBLE CIRCUIT 115kV STRUCTURES



H-Frame
(Wood)



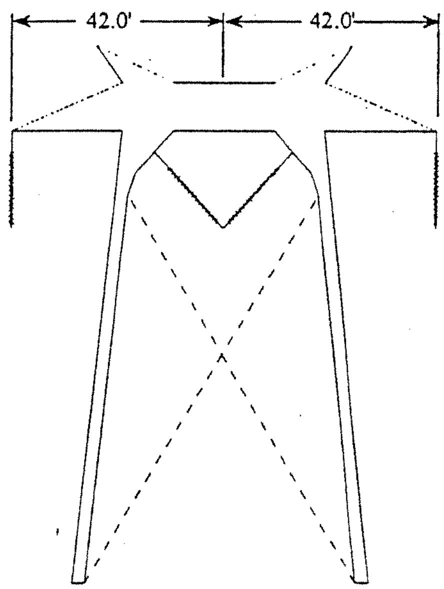
V2S-D
V2SL-D*
V2SB-D**
(TSP)



3N
RV**
(Tower)

* Additional conductor spacings for Live Line Maintenance
**Additional circuit spacings for bundled-conductors.
Spacing for V2SB-D are in brackets [ ] and spacing for RV tower are in parenthesis ( ).

230kV STRUCTURES



2HVL
(Tower)

500kV STRUCTURE

APPENDIX - C
FIELD MANAGEMENT PLAN

I. General Description of Project

Project Name: ______________________________

Project Lead: ______________________________

Transmission Line(s): ______________________________

Distribution Line(s) Underbuilt: ______________________________

Other Lines in the Vicinity: ______________________________

Scope of Work: ______________________________

____

____

Base Cost of Project: ______________________________

II. General Description of Surrounding Land Uses

Schools or Daycare ______________________________

____

Residential ______________________________

____

Commercial/Industrial ______________________________

____

Recreational ______________________________

____

Agricultural, Rural ______________________________

____

Undeveloped Land (Zoned for Residential) ______________________

____

Undeveloped Land (Zoned for Commercial/Industrial) ____________

____

Unpopulated, Forested, Government Owned Land ________________

____

III. No Cost Field Reduction to be Implemented

Existing Field Level at the Peak: ______________________________

Existing Field Level at the Edge of the Right of Way: ______________

Base Case Field Level at the Peak: ____________________________

Base Case Field Level at the Edge of the Right of Way: ____________

Note: All Percent Reduction is Calculated at the Edge of the Right of Way, and is Compared to the Base Case Field Level.

<u>No Cost Field Reduction #1</u>

Description: ____

____

Percent Reduction : ____________________________________

<u>No Cost Field Reduction #2</u>

Description: ____

____

Percent Reduction : ____________________________________

No Cost Field Reduction #3

Description: ______________________________

____

Percent Reduction : ______________________________

IV. Priority Areas where Low Cost Measures are to be Applied

____

____

____

____

____

____

____

V. Low Cost Magnetic Field Reduction Options

Note: All Percent Reduction is Calculated at the Edge of the Right of Way, and is Compared to the Base Case Field Level.

Low Cost Option #1

Description: ______________________________

____

Percent Reduction: ______________________________

Cost: ______________________________

Low Cost Option #2

Description: ______________________________

____

Percent Reduction: ______________________________

Cost: ______________________________

Low Cost Option #3

Description: ______________________________

____

Percent Reduction: ______________________________

Cost: ______________________________

VI. Conclusion - Field Reduction Options Selected

Description: ______________________________

____

____

Percent Reduction: ______________________________

Cost: ______________________________

Reason for selection: ______________________________

____

____

____

____

____