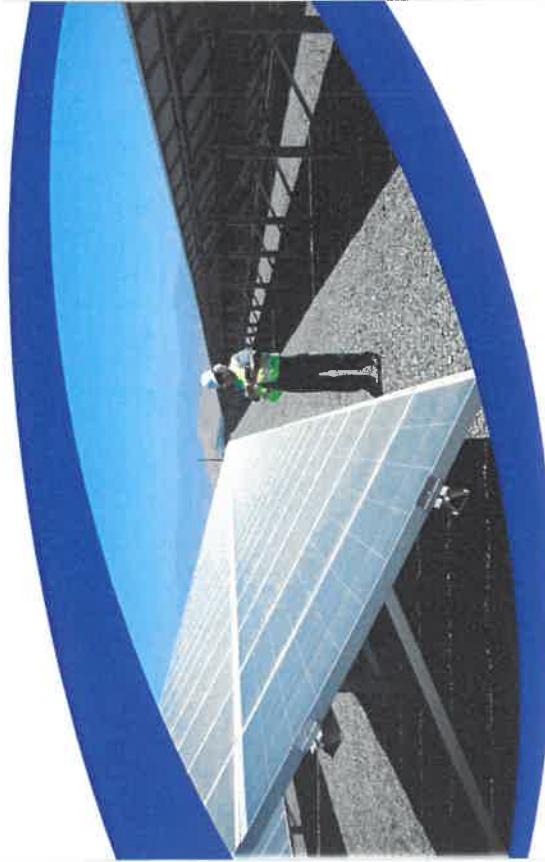


Electric and Magnetic Field Exposure Levels (0 to 3 GHz) in Occupational Environments near Photovoltaic Energy Generation Facilities



Electric and Magnetic Field Exposure Levels (0 to 3 GHz) in Occupational Environments near Photovoltaic Energy Generation Facilities

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Final Report, November 2012

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Acknowledgments

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This report describes research sponsored by EPRI.

The research team thanks Phil Hung, Glenn Sias, and Ted Luckham of Southern California Edison for their cooperation and assistance in organizing and facilitating access to the solar generation facilities surveyed in this study. The assistance of Chris Tell (Tell Associates) and Kevin Hooper (Enertech Consultants) in the field measurement effort is gratefully acknowledged. Special thanks to our EPRI Project Manager, Dr. Gabor Mezei, for his support and encouragement in guiding this research effort.

This publication is a corporate document that should be cited in the literature in the following manner:

Electric and Magnetic Field Exposure Levels (0 to 3 GHz) in Occupational Environments near Photovoltaic Energy Generation Facilities.
EPRI, Palo Alto, CA: 2012.
1023797

Abstract

Electric and magnetic field levels associated with photovoltaic generation facilities were measured and characterized in this study. This evaluation included the measurement of static (direct current [DC]) magnetic fields, power-frequency alternating current (AC) electric and magnetic fields (up to 3,000 Hz), and radio-frequency (RF) electric and magnetic fields (up to 3,000 MHz) at two electric utility solar generation facilities.

The major sources of DC magnetic fields within a solar generation facility are the inverter and the DC fuse box. Next to an inverter, DC magnetic fields can approach 3 Gauss (0.0003 T) in close proximity (1 in. [25.4 mm]) to the equipment and exhibits constant fluctuations in field intensity. Next to a DC fuse box (1 in.), DC magnetic fields can approach 2 Gauss (0.0002 T). Field levels, however, attenuated quickly with distance. For other equipment (solar panels, DC cables, and combiner boxes), measured DC magnetic fields rarely exceeded a 500 mG (0.00005 T) variation from the earth's static magnetic field, even within 1 in. of the equipment. None of these values exceeds recommended guidelines established by various organizations such as the International Council on Non-Ionizing Radiation Protection (ICNIRP), American Conference of Governmental Industrial Hygienists (ACGIH), and IEEE.

None of the equipment within the photovoltaic generation facilities surveyed exhibited significant power-frequency AC electric field levels. Equipment is typically housed within conduits or enclosures that shield the AC electric field. The major sources of AC magnetic fields are not the photovoltaic equipment (solar panels, connecting cables, combiner boxes, and fuse boxes), but rather the AC power cables (over 400 mG [0.00004 T] at 1 in. away), inverters (around 1,100 mG [0.00011 T] at 1 in. away), transformers (1,767 mG [0.0001767 T] at 1 in. away), and switchgear (432 mG [0.0000432 T] at 1 in. away). In very close proximity (within 1 in.) to inverters and transformers at some locations, measured magnetic field levels can exceed the ACGIH guideline (of 1 Gauss [0.0001 T]) for workers with implanted medical devices. However, most locations were measured to have levels below this threshold and other organization guidelines (such as IEEE and ICNIRP).

The principal sources of RF fields associated with the solar generation facility equipment were the inverters, with a fundamental frequency component at the 5-kHz switching rate for the 500-kW rated inverters. The greatest magnetic flux density was found at a single point on the surface of an inverter operating at near full output (40 μT). The greatest 5-kHz electric field strength was measured at the surface of the inverter (1.4 V/m). Magnetic flux density decreased with distance from the inverter. RF measurements were performed across the frequency range of 1 kHz to 100 kHz and electric fields from 100 kHz to 3 GHz.

Higher frequency RF measurements showed the production of broadband RF noise up to approximately 30 MHz with field strengths as great as 0.2 V/m with little detectable energy above 30 MHz. The elevated RF energy also decreased rapidly with increasing distance from the inverter. The broadband RF fields could present the possibility of RF interference with nearby communications systems.

RF electric and magnetic fields associated with inverter full-output operation did not produce uniform exposure that exceeds recommended guidance on exposure established by both IEEE and the more restrictive guidelines from ICNIRP. Although the greatest measured value at a single point on the surface of an inverter was found to exceed the ICNIRP recommended guidance for lower frequency magnetic fields, this value cannot be interpreted as uniform over the body dimensions in accordance with the description of the limit provided by ICNIRP.

Keywords

Combiner box
Electric field
Inverter
Magnetic field
Radio-frequency (RF) field
Photovoltaic
Solar array

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Section 1: Introduction

Renewable Energy and Commercial Photovoltaic Facilities

Energy which is generated from natural resources (such as sunlight, wind, geothermal heat, and ocean tides) has been described as renewable energy because it is replenished by nature. Construction of renewable energy generation facilities has increased dramatically due to the popularity of renewable energy, increased electrical productivity through modern technology, and concerns over rising fossil fuel prices. Since the beginning of the century, worldwide renewable energy generation facilities have seen tremendous growth, particularly in wind power and photovoltaic (solar) technologies. These facilities can range from large-scale wind and solar farms (capable of up to 500 MW of power generation) to local residential rooftop facilities for individual use.

Photovoltaic (PV) facilities rely on solar cells to generate static electricity. A solar cell is a thin film substrate designed to capture electrons from sunlight and create electric current. Numerous solar cells are fabricated into a photovoltaic (or solar) panel. In turn, numerous photovoltaic panels are mounted onto support frames to form an array. The amount of current produced by an array is proportional to the amount of light that strikes each solar cell and the number of cells and panels that are connected together. Arrays can be joined in series or in parallel, depending upon the desired voltage and current. Collectors allow groups of panels to combine their electrical output, which is then transferred to an inverter. The inverter converts direct current (DC) electrical power to alternating current (AC) electrical power for connection to the local electrical power grid.

Because of their increased popularity, electric utilities and private corporations are continuing to build new solar farms and installing new photovoltaic energy generation facilities on commercial building rooftops and many other locations. Components of electrical generation facilities may produce a variety of different electric and magnetic fields, ranging from static fields (due to DC currents) to power-frequency fields (due to inverters and AC transformers) to radio-frequency fields (due to the DC to AC conversion through inverters). Workers who manage these facilities may be exposed to varying levels of electric and magnetic fields. Occupational exposure to fields from photovoltaic energy generation facilities, however, is not well characterized. Hence this occupational exposure study was undertaken to characterize the range of field levels that can be encountered from components of larger, commercial photovoltaic energy generation facilities.

Section 2: Facility Descriptions

Two different site locations were selected to characterize large photovoltaic energy generation facilities. These facilities included a large scale electric utility solar energy generation facility and an industrial warehouse rooftop photovoltaic facility.

Electric Utility Solar Generation Facility

The first site visited was a large utility-owned solar generation facility in California. This 5 MW generation facility is located in the central valley near Porterville (between Fresno and Bakersfield). The facility utilizes 29,400 solar panels covering 32 acres and went online in February 2011. Figure 2-1 presents an aerial photograph of the facility.



Figure 2-1
Solar Generation Facility in Porterville, California

Figure 2-2 presents a diagram of the main components of a solar generation facility. Direct current (DC) electrical power generated from the solar panels, or arrays, is routed through combiner boxes (fused with disconnect switches) to a fuse box. DC power is then routed to an inverter, which converts DC power to alternating current (AC) electrical power. From the inverter, low-voltage AC power is stepped up to higher-voltage AC power through a transformer. Routed from the transformer through switchgear, AC electrical power is then supplied to the local electrical grid.

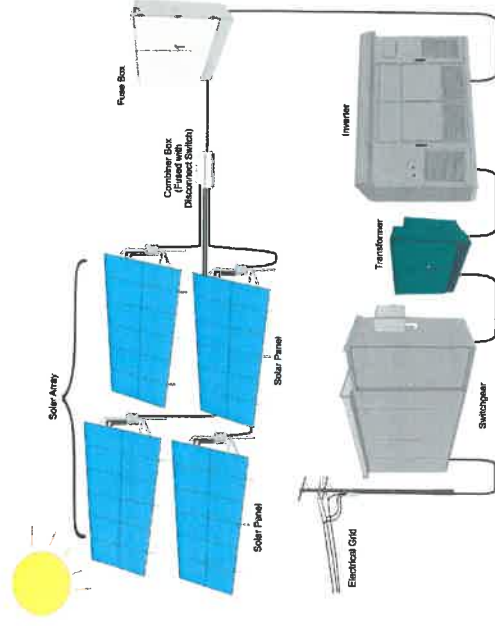


Figure 2-2
Main Components of a Solar Generation Facility

There are ten sections which comprise the Porterville facility (five on the northern side and five on the southern side). Each section is capable of producing up to 500 kW and includes solar panels, with a fuse box, inverter, and transformer located at a corner of each section (at the southwestern corner for northern sections and at the northwestern corner for southern sections – reference Figure 2-3). 12-Volt AC electrical power from each section's transformer is routed through underground cables to the farthest southwestern section where the main switchgear for the entire facility is located. Electrical power is then routed via underground cables from the switchgear out to the overhead electrical grid located along the main road west of the facility.

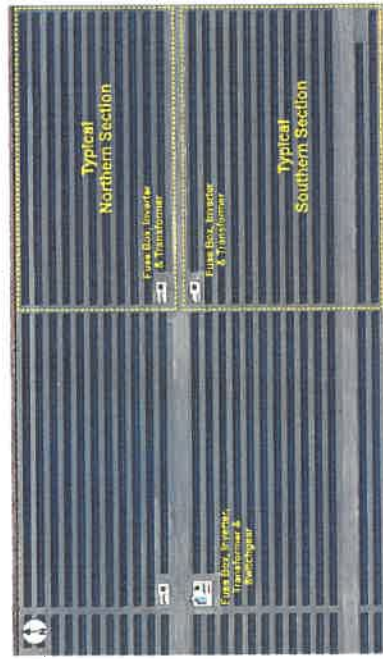


Figure 2-3
Typical Sections of the Porterville Photovoltaic Energy Generation Facility

Specifications for the solar panels, inverter, and transformer are presented below. Photographs of the solar facility equipment are presented in Figure 2-4.

Solar Photovoltaic Module:		Inverter:
Manufacturer:	Trinasolar	Manufacturer: Satcon Technology Corporation
Max Power:	230W	Input Voltage – Maximum: 600V DC
Max Power – Voltage:	30V DC	Input Current – Maximum: 1610A DC
Max Power – Current:	7.66A DC	Output Voltage – Nominal: 200V 3-Phase AC
Max System Voltage:	600V DC	Output Current – Maximum: 1444A AC
		Output Power -- Maximum: 500 kW
Transformer:		
Manufacturer:	HO	
Power Rating:	500 KVA	
High Voltage:	12000 Delta	
Low Voltage:	208Y/120	

Characterization measurements were performed twice at this facility. Initially measurements were performed on November 29, 2011, but due to cloudy weather conditions the output of the facility was very low (approximately 35 to 45 kW per inverter, or 350 to 450 kW total power output). Therefore, measurements were repeated on July 24, 2012 during summertime weather conditions. During this second visit, the output of the facility was close to maximum (approximately 400 to 490 kW per inverter, or 4 to 4.9 MW total power output).

◀ 2-3 ▶

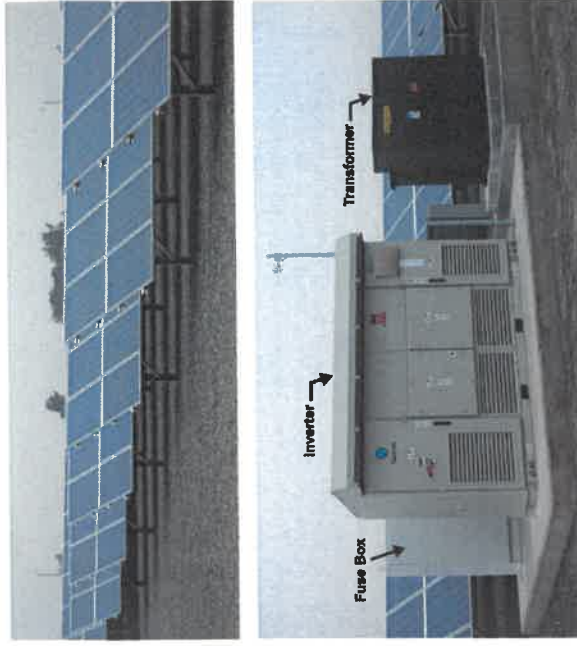


Figure 2-4
Solar Arrays and Facility Equipment at the Porterville Photovoltaic Farm

Electric Utility Industrial Rooftop Solar Generation Facility

The second site visited was a utility-owned rooftop solar generation facility. This 1.42 MW generation facility is located in Redlands, California and went online in January 2012. The facility utilizes solar panels covering the rooftop of a privately-owned commercial warehouse, with four inverter and transformer stations (enclosures) located around the warehouse building. Figure 2-5 presents an aerial photograph of the facility, while Figure 2-6 presents a schematic diagram of the system with the locations of the four inverter and transformer stations/enclosures. The eastern station is the collection point which contains the switchgear and connects the power output of the entire photovoltaic farm to the local grid via underground cables.

◀ 2-4 ▶

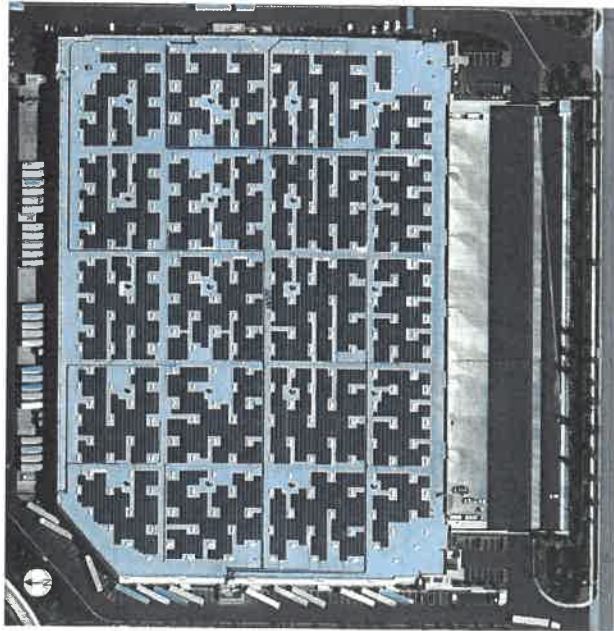


Figure 2-5
Rooftop Solar Generation Facility in Redlands, California

◀ 2-5 ▶

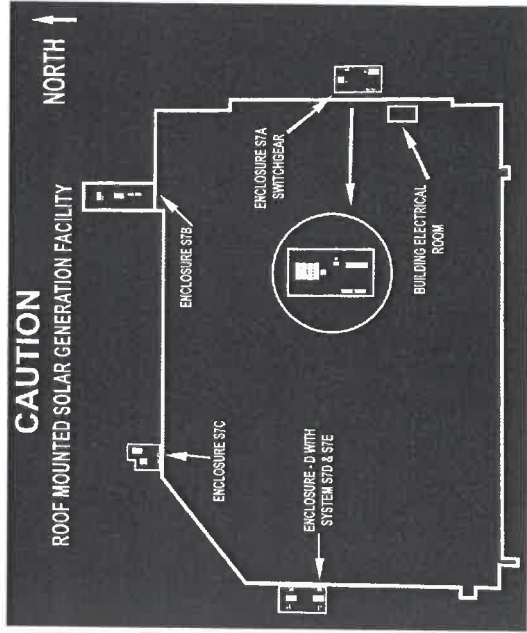


Figure 2-6
Schematic Diagram of the Locations of the Inverter & Transformer Stations

On the western side of the warehouse, DC electrical power from the westernmost solar panels is routed from the rooftop down to the western inverter/transformer enclosure. After being converted from DC to AC electrical power, power cables carry AC power back up to the rooftop and are routed along the rooftop edge to the next closest northwestern enclosure. DC power from nearby panels within this area is routed from the rooftop down to this inverter/transformer enclosure. AC power is again carried back up to the rooftop by power cables and routed along the rooftop edge to the next closest northeastern enclosure. After the third inverter/transformer enclosure, AC power is again carried back up to the rooftop by power cables and routed along the rooftop edge to the final eastern enclosure. DC power from the eastern solar panels is also routed from the rooftop down to the eastern inverter/transformer enclosure. The eastern enclosure is the final collection point which contains an inverter and transformer (for converting DC electrical power to AC) and the switchgear which allows AC power from the entire photovoltaic farm to connect into the local grid via underground cables. Figure 2-7 presents the northeastern rooftop collection point, while Figure 2-8 presents the eastern rooftop collection point.

◀ 2-6 ▶



Figure 2-7
AC and DC Power Cables at Northeastern Rooftop Collection Area



Figure 2-8
AC and DC Power Cables at Eastern Rooftop Collection Area

◀ 2.7 ▶

Specifications for the solar panels, inverter, and transformer are presented below. Figure 2-9 presents an overall view of the rooftop solar facility. Characterization measurements were performed on May 14, 2012.

Solar Photovoltaic Module:

Inverter:

Manufacturer: Sunpower
Max Power: 230W
Input Voltage – Maximum: 600V DC
Input Current – Maximum: 1610A DC

Transformer:

Manufacturer: HO
Power Rating: 500 KVA
High Voltage: 12000 Delta
Low Voltage: 208Y/120
Output Voltage – Nominal: 200V 3-Phase AC
Output Current – Maximum: 1444A AC
Output Frequency: 60 Hertz
Output Power – Maximum: 500 kW



Figure 2-9
Solar Panels on Rooftop Facility

◀ 2.8 ▶

Section 3: Static and Power-Frequency Fields

At each solar generation facility, static (DC) magnetic field and power-frequency (60 Hertz AC) electric and magnetic field measurements were performed. These measurements were conducted to characterize the fields from various components of the facility and field attenuation as a function of distance. Static (DC) magnetic field and AC electric field measurements were performed as spot readings near the equipment. Appendix A presents measurement graphs of the AC magnetic field, while Appendix B presents the fast-Fourier transform (FFT) analysis of AC magnetic field waveforms that were measured during the study.

Measurement Protocol

For each type of facility, field measurements were performed to characterize each component of the system (which includes the solar panel itself, the DC electrical conduit/collector, DC combiner box, DC fuse box, inverter, AC transformer, AC switchgear, and AC cables). Measurements were conducted at locations near the equipment where occupational access would be required.

Profile measurements were performed as a function of field versus distance away from each system component. Characterization of field levels as a function of distance included:

- Static (DC) magnetic field
- Power-frequency (60 Hertz) AC electric and magnetic fields
- AC harmonic magnetic field (up to 3000 Hertz)

A series of instantaneous measurements were taken at preset distances (for example, 1", 3", 6", 9", 1', 2', 3', 5', and 7') from the surface of each facility component at the location having the highest magnetic field or in the general area of the facility. Distance measurements were performed using a tape measure to insure accurate and repeatable distance measurements. At each measurement location, the meter would display and record the measured field level. If the field fluctuates, then the meter would be held for several seconds and an estimate of the average reading from three or four instantaneous readings would be recorded.

Because of the location and arrangement of various facility equipment, it was sometimes difficult to characterize a single component by itself without having

◀ 3-1 ▶

the field influence of other nearby equipment present. Whenever possible, distance measurements were performed towards open areas and away from other field sources. However, the presence of multiple field sources within an area is common and therefore the total field environment was characterized for occupational exposure.

Instrumentation

Static (DC) Magnetic Field Meter

For static (0 Hertz) DC magnetic field measurements, Bartington MAG-03MC1000 sensors were used. The MAG-03MC1000 is a handheld, three-axis DC magnetic field fluxgate probe. The Bartington DC sensor has a bandwidth of 0 to 3,000 Hz with a measurement range up to 10 Gauss and accuracy of about $\pm 0.5\%$. The MAG-03 probe was calibrated by the manufacturer. Enertech has designed another instrument, the EMDEX WaveCorder, to receive measurement data from the Bartington 3-axis DC sensor and record these data to a file at a sample rate of approximately once every 1.5 seconds. Figure 3-1 presents a photograph of the DC sensor, along with the EMDEX WaveCorder used to record DC magnetic field levels.

Power-Frequency Electric and Magnetic Field Meters

EMDEX II Magnetic Field Digital Exposure Meters were used to measure power-frequency (60 Hertz) AC magnetic field levels for this study. The EMDEX II is a computer-controlled, three-axis, AC exposure meter. Each of the three-axis sensors measures the magnetic field and the on-board computer calculates a resultant field value (the resultant is comparable to a maximum field value and is calculated as the square root of the sum of the squares for all three orthogonal axes ($B = \sqrt{B_1^2 + B_2^2 + B_3^2}$). The data are stored in the computer's memory and downloaded to a personal computer for analysis following the measurement session. In addition, an LCD digital display on the EMDEX II allows the user to see the magnetic field data as they are stored in the computer's memory. The EMDEX II meter has a measurement range of 0.1 milliGauss (mG) up to 3,000 mG (3 Gauss) in the frequency range of 40 to 800 Hertz. The EMDEX II recorded the magnetic field at a sample rate of once every 1.5 seconds. The accuracy of the EMDEX II meters is $\pm 2\%$.

An EMDEX II meter was also used in conjunction with an E-PROBE field sensor to measure power-frequency (60 Hertz) AC electric field levels for the study. The E-PROBE is a parallel-plate electric field sensor attached to an insulated fiberglass handle. The EMDEX II meter is placed between the two sensing plates of the E-PROBE and is connected to them via an external cable to record electric field data. The E-PROBE has a range of 1 V/m to 200 kV/m, with a resolution of 1 V/m and typical accuracy of $\pm 2\%$.

All EMDEX meters were calibrated using a 91-centimeter (cm) diameter Helmholtz coil in the Enertech research laboratory prior to the field measurements, in accordance with IEEE/ANSI Standards [1] – reference

◀ 3-2 ▶

Appendix C. Figure 3-2 presents a photograph of an EMDEX II meter, along with the EMDEX II and the E-Probe electric field sensor.



Figure 3.1
Barrington DC Magnetic Field Sensor and EMDEX WaveCorder Meter

◀ 3-3 ▶

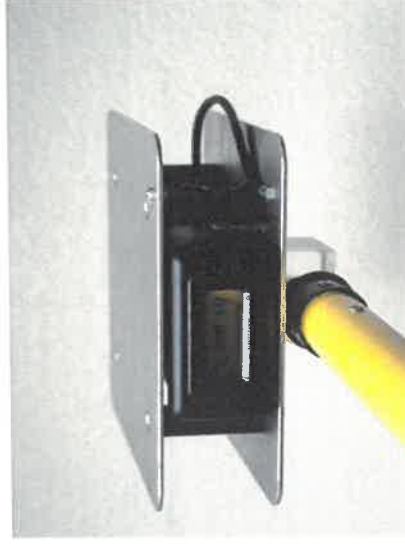


Figure 3.2
EMDEX II Recording Magnetic Field Meter and EProbe Electric Field Sensor

Besides using the EMDEX WaveCorder to record DC magnetic field data, this instrument was also used to capture magnetic field waveforms. The EMDEX WaveCorder is primarily designed as a hand-held AC magnetic field waveform measurement system, which samples, stores, displays, and allows analysis of the wave representing the time varying AC magnetic field. Measurements are

◀ 3-4 ▶

performed within a frequency bandwidth of 10 Hz - 3 kHz with the following magnetic field range:

- Magnetic Field Range: 10 Hz - 40 Hz Band: 0.5 mG - 15 Gauss (15,000 mG)
- 40 Hz - 1 kHz Band: 0.1 mG - 15 Gauss (15,000 mG)
- 1 kHz - 3 kHz Band: 0.1 mG - 7 Gauss (7,000 mG)

The WaveCorder samples the magnetic field at a fast rate (15,360 samples per second) over a pre-defined measurement period, and displays/records the resulting waveform. The WaveCorder has a typical accuracy of +/- 2%.

Ground-Based Utility Solar Generation Facility

Field measurements were performed at two different locations within the solar generation facility, as shown in Figure 3-3. Measurement location #1 was a central location with a fuse box, inverter and transformer present. Measurement location #2 was the collection station for the entire solar farm and included switchgear. From this location, the entire electrical output of the station was routed underground to roadside utility poles and risers to interconnect into the local overhead distribution system. Figure 3-4 presents diagrams of the facility equipment at each of the measurement locations.



Figure 3-3
Porterville Solar Farm – Measurement Locations

◀ 3-5 ▶

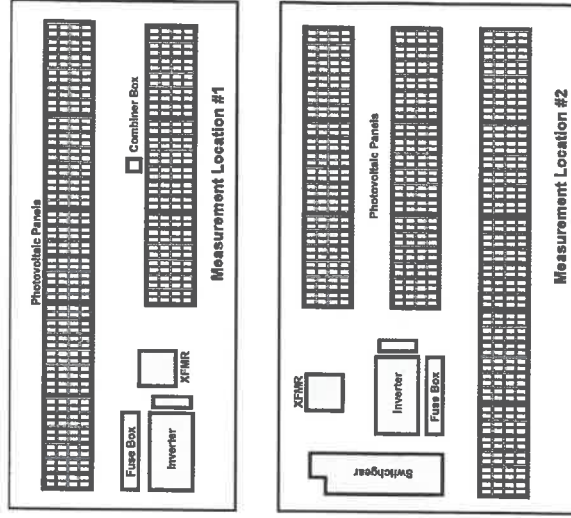


Figure 3-4
Diagrams of Porterville Facility Equipment at Each Measurement Location

Ambient Fields

Prior to performing characterization measurements of the solar equipment, measurements were conducted to characterize the ambient field at the facility. For AC electric field, there was no measurable electric field present near the center of the facility. For the earth's DC magnetic field, the field measured was about 516 mG. For the AC magnetic field, the field was less than 0.1 mG. An AC Magnetic field waveform was also conducted for the ambient field. Figure 3-5 presents the FFT analysis of the frequency components of the waveform. As shown in this graph, the lower frequency components are stronger than the higher frequency components. However, the magnitudes of these fields are very low (0.1 mG or less).

◀ 3-6 ▶



Figure 3-5
Ambient Field Within the Photovoltaic Facility – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

Photovoltaic Panels

Measurement of a Trinasolar photovoltaic panel was conducted at the end of a section of panels as a profile measurement away from the panel towards an open area between panel sections. Figure 3-6 presents a diagram of the measurement profile location, while Table 3-1 summarizes the measurement results for the panel (for both the 350-450 kW output and the 4-4.9 MW output of the facility at measurement location #1). As shown, the photovoltaic panels themselves are not a significant field source of either DC or AC fields.

Measurement of the AC magnetic field waveform was conducted near this photovoltaic solar panel. The FFT analysis of the frequency components of the waveform are very similar to the ambient levels shown in Figure 3-5, with the magnitudes of the field strength at about 0.1 mG or less. AC magnetic field waveform results are presented in Appendix B.

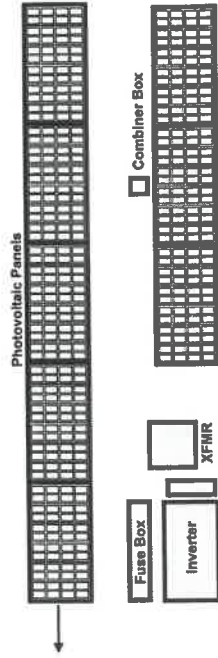


Figure 3-6
Diagram of Measurement Profile Path for Characterizing a Photovoltaic Panel at Porterville

Table 3-1
Summary of Porterville Photovoltaic Panel Measurements

350 – 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	562	0.000	0.0
3.0 - Inch	551	0.000	0.0
6.0 - Inch	552	0.000	0.0
9.0 - Inch	552	0.000	0.0
1 - Foot	559	0.000	0.0
2 - Foot	593	0.000	0.0
3 - Foot	551	0.000	0.0

4 – 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	561	0.000	0.0
3.0 - Inch	542	0.000	0.0
6.0 - Inch	524	0.000	0.0
9.0 - Inch	513	0.000	0.0
1 - Foot	508	0.000	0.0
2 - Foot	492	0.000	0.0
3 - Foot	486	0.000	0.0
5 - Foot	479	0.000	0.0

Behind each panel are small boxes (called "J"-boxes) which collect the DC current from the photovoltaic cells within that section of the panel. Panel sections are connected in series through these boxes and then routed through a DC cable/conduit to a combiner box. Figure 3-7 presents a photograph of several "J"-boxes and a DC cable conduit underneath one of the photovoltaic panels. Measurements of a "J"-box were made for at a typical panel, as shown in Table 3-2. Elevated DC and AC magnetic fields were measured in close proximity to the "J"-box (811 mG and 49 mG respectively); however there were no measurable AC electric fields near the box. The "J"-box has internal electronics (for features like performance monitoring, optimizing power output, arc-fault detection, and remote de-activation) which produce AC magnetic fields. Facility output was 4 – 4.9 MW during these measurements near measurement location #1.

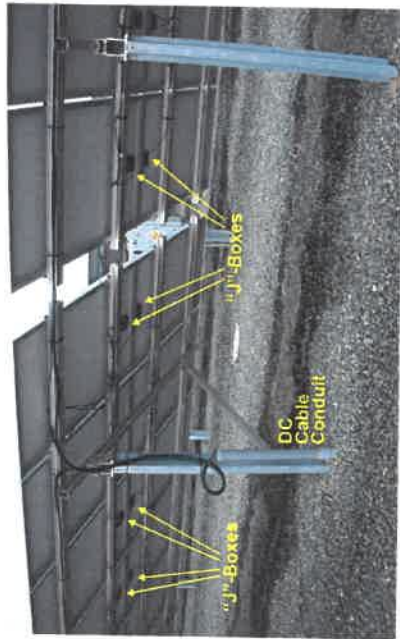


Figure 3-7
"J"-Boxes and DC Cable Conduit at Photovoltaic Panels at Porterville

Measurement of the AC magnetic field waveform was conducted near this "J"-box. The FFT analysis of the frequency components shows significant 60-Hertz, 120-Hertz, and 180-Hertz components, with diminishing harmonic frequencies down to 600 Hertz. The magnitude of the 60 Hertz component is the dominant field strength (about 37 mG). This waveform measurement was conducted about 3-inches away from the "J"-box.

Table 3-2
Summary of Photovoltaic Panel "J"-Box Measurements at Porterville

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	811	0.000	49.2
3.0 - Inch	650-711	0.000	39.8
6.0 - Inch	554	0.000	13.0
9.0 - Inch	520	0.000	8.1
1 - Foot	495	0.000	5.9
2 - Foot	455	0.000	2.4
3 - Foot	395	0.000	1.3
5 - Foot	358	0.000	0.4

DC Cables

Photovoltaic (DC) cables from multiple panels are routed into conduits before reaching local combiner boxes (Figures 3-7 and 3-8). Table 3-3 presents the measurement results for a DC cable. The DC magnetic field is higher than ambient (1034 mG versus approximately 516 mG) in close proximity to this source. However, at a distance of about 2-feet away from the conduit, static magnetic fields are reduced to ambient levels.

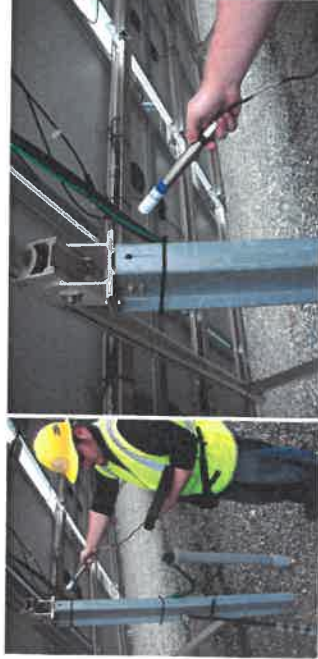


Figure 3-8
Photograph of DC Cables Under Photovoltaic Panel at Porterville

Table 3-3
Summary of DC Cable Measurements at Porterville

350 - 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1 - Inch	> 1000	0.000	0.0
3 - Inch	> 1000	0.000	0.0
6 - Inch	> 1000	0.000	0.0
9 - Inch	> 1000	0.000	0.0
1 - Foot	> 1000	0.000	0.0
2 - Foot	878	0.000	0.0
3 - Foot	571	0.000	0.0
5 - Foot	580	0.000	0.0
7 - Foot	609	0.000	0.0

4 - 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	1034	0.000	5.6
3.0 - Inch	964	0.000	2.1
6.0 - Inch	850	0.000	1.0
9.0 - Inch	743	0.000	0.6
1 - Foot	671	0.000	0.6
2 - Foot	469	0.000	0.5
3 - Foot	410	0.000	0.5
5 - Foot	431	0.000	0.5
7 - Foot	446	0.000	0.6

The DC cable conduit is not a significant source of AC magnetic fields (5.6/0.0 mG) and no AC electric fields were measured. Measurements were conducted for both the 350-450 kW and the 4-4.9 MW output loading conditions of the facility near measurement location #1. For these DC collector cables, the AC magnetic field waveform is predominantly 60 Hertz with diminishing harmonic components of 120-Hertz, 180-Hertz, and others down to about 600 Hertz.

DC Combiner Box

Measurements were conducted to characterize fields from a DC combiner box (Figure 3-9). Individual DC cables from the solar panel "T"-boxes are routed into the combiner box. Figure 3-10 presents a diagram of the measurement profile path away from a combiner box. Table 3-4 presents the measurement results for this equipment. As shown, the DC magnetic field was near ambient or slightly higher than ambient in close proximity to the combiner box (1-inch away), depending upon the facility loading. However, DC fields attenuated quickly to background levels with distance away from the combiner box. There were no appreciable AC electric or magnetic fields measured near this equipment. Measurements were conducted for both the 350-450 kW output and the 4-4.9 MW output loading conditions of the facility at measurement location #1.



Figure 3-9
Photograph of a Combiner Box at Porterville

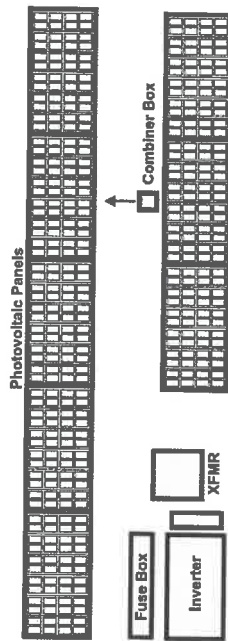


Figure 3-10
Diagram of Measurement Profile Path for Characterizing a Combiner Box

Table 3-4
Summary of DC Combiner Box Measurements at Porterville

350 – 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1 - Inch	367	0.000	0.0
3 - Inch	348	0.000	0.0
6 - Inch	372	0.000	0.0
9 - Inch	429	0.000	0.0
1 - Foot	474	0.000	0.0
2 - Foot	436	0.000	0.0
3 - Foot	508	0.000	0.0

4 – 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	756	0.000	0.3
3.0 - Inch	671	0.000	0.3
6.0 - Inch	628	0.000	0.3
9.0 - Inch	537	0.000	0.3
1 - Foot	477	0.000	0.2
2 - Foot	381	0.000	0.2
3 - Foot	436	0.000	0.2
5 - Foot	474	0.000	0.2

Measurement of the AC magnetic field waveform was conducted near this DC combiner box. Although there are 30-Hertz, 60-Hertz, 120-Hertz, and 180-Hertz components, there is also a distinct 360-Hertz component (sixth harmonic). However, the magnitudes of these fields are very low (less than 0.5 mG).

DC Fuse Box

As shown in Figures 2-3 and 2-4, each of the ten sections of the facility contained a DC fuse box, inverter, and transformer. Field measurements were conducted around the fuse box (which was located adjacent to the inverter). Figure 3-11 presents a diagram of the equipment and specific measurement locations, while Table 3-5 presents a summary of the measurement results.

Measured DC magnetic fields around the fuse box ranged from as low as 348 mG to as high as 1,709 mG, depending upon the measurement location. While some of the DC field variation may be attributed to the metal enclosure, the internal DC cables are probably the dominant DC magnetic field source. There was also some AC magnetic field variability exhibited in the measurement data, ranging from 6.3 mG to 47.3 mG around the perimeter of the fuse box. Higher AC magnetic fields were measured at the corner of the fuse box closest to the transformer (later measurements confirmed that the transformer was the source for these elevated AC magnetic fields). AC magnetic field waveform measurements were not performed near this equipment as the field sources were other nearby electrical sources which were characterized. There were no measurable AC electric fields near the fuse box due to shielding from the metal enclosure. Facility loading was at 4 to 4.9 MW during the measurements.

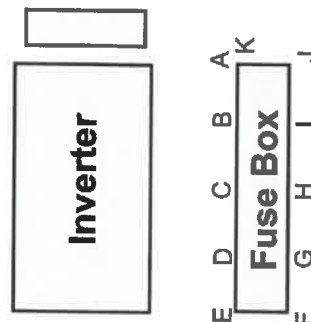


Figure 3-11
Diagram of Measurement Locations for Characterizing a DC Fuse Box

Table 3-5
Summary of DC Fuse Box Measurements at Porterville

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	348	0.000	19.7
B	774	0.000	20.1
C	305	0.000	47.3
D	1345	0.000	28.3
E	801	0.000	28.9
F	1441	0.000	15.5
G	1709	0.000	10.5
H	523	0.000	14.0
I	897	0.000	6.3
J	468	0.000	8.8
K	348	0.000	21.7

DC to AC Inverter

Four different measurements were performed around the inverter to characterize the DC and AC fields which were present. Initially, field measurements were conducted around the perimeter of the inverter. In addition, three profile measurements were conducted away from the inverter at different locations. Figure 3-12 presents a diagram of the equipment and specific perimeter measurement locations, while Table 3-6 presents a summary of the perimeter measurement results. The facility was operating at 4 to 4.9 MW during these measurements at location #2.

For the inverter, measured DC magnetic fields ranged from 352 mG to 2,770 mG, depending upon the measurement location. Considerable DC field variation was observed at locations near the inverter. There was also some AC magnetic field variability exhibited in the measurement data as well, ranging from 14.5 mG to 344.5 mG around the perimeter of the inverter. There were no measurable AC electric fields near the inverter due to shielding from the metal enclosure.

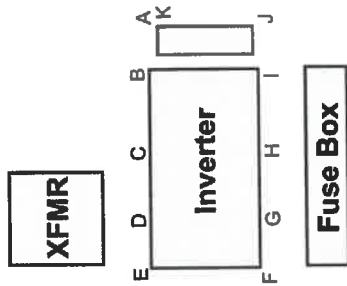


Figure 3-12
Diagram of Measurement Locations for Characterizing an Inverter

Table 3-6
Summary of DC to AC Inverter Perimeter Measurements at Porterville

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	990	0.000	31.3
B	2770	0.000	344.5
C	465	0.000	324.8
D	986	0.000	222.4
E	336	0.000	32.3
F	387	0.000	40.3
G	464	0.000	156.9
H	352	0.010	228.8
I	746	0.000	41.3
J	854	0.000	17.3
K	990	0.000	14.5

Figure 3-13 presents a diagram for the first measurement profile, which was initiated at the side of the inverter and proceeded away from the inverter and other nearby equipment. Table 3-7 presents a summary of the measurement results, which were performed at measurement location #1 with the facility operating at both 350 to 450 kW and again at 4 to 4.9 MW.

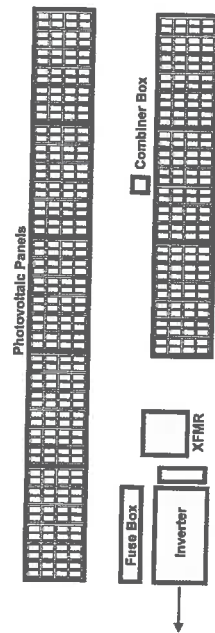


Figure 3-13
Diagram of Measurement Profile for Side of Inverter at Porterville

Table 3-7
Summary of Inverter Profile Measurements (Side of Unit) at Porterville

350 – 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	553	0.000	2.0
3.0 - Inch	512	0.000	1.8
6.0 - Inch	473	0.000	1.5
9.0 - Inch	460	0.000	1.3
1 - Foot	478	0.000	1.1
2 - Foot	526	0.000	0.7
3 - Foot	523	0.000	0.4
Ambient	561	0.000	N/A

Table 3-7 (Continued)
Summary of Inverter Profile Measurements (Side of Unit) at Porterville

4 – 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	1088	0.000	17.4
3.0 - Inch	1025	0.000	16.0
6.0 - Inch	806	0.000	14.0
9.0 - Inch	725	0.000	11.8
1 - Foot	589	0.000	11.0
2 - Foot	402	0.000	7.6
3 - Foot	345	0.000	5.2
5 - Foot	428	0.000	2.7
7 - Foot	455	0.000	1.5
10 - Foot	471	0.000	0.8
12 - Foot	476	0.000	0.6

As shown in Table 3-7, the loading output of the facility had a significant impact on the DC and AC magnetic fields from this equipment. DC magnetic fields remained close to ambient under 350 to 450 kW loading conditions, but increased to over 1 Gauss under 4 to 4.9 MW loading conditions. AC magnetic fields also increased from a few mG to about 17 mG at this location due to loading conditions. No measurable AC electric fields near the inverter were observed.

Measurement of the AC magnetic field waveform was conducted at the side of the inverter. The dominant component is of this waveform is the primary 60-Hertz component, with little harmonic content.

A second profile was performed from the inverter, starting at the front of the unit but near the base. Figure 3-14 presents a diagram for the second measurement profile, while Table 3-8 presents a summary of the measurement results. Measurements were again performed at location #1 with the facility operating at both 350 to 450 kW and again at 4 to 4.9 MW.

Considerable DC magnetic field variation was observed at locations near the front base of the inverter, as shown by the range of DC field values within the table (significant within a few seconds of time). Increased loading conditions also caused higher DC field levels (570 to 876 mG at 350 to 450 kW loading versus 495 to 1,742 mG at 4 to 4.9 MW loading within 3-feet of the equipment). Measured AC magnetic fields also increased with higher loading. However, both

the DC and AC magnetic fields attenuated quickly with distance away from the device. No measurable AC electric fields near the inverter were observed.

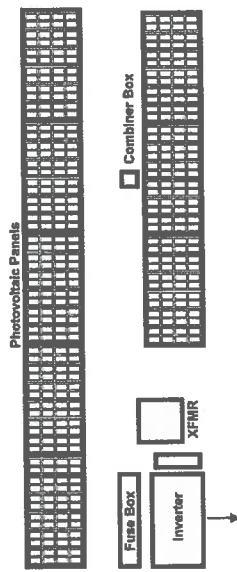


Figure 3-14
Diagram of Measurement Profile at Front of Inverter at Porterville

Table 3-8
Summary of Inverter Profile Measurements (Front Base of Unit) at Porterville

350 - 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	600 - 876	0.000	291.2
3.0 - Inch	615 - 756	0.000	201.6
6.0 - Inch	628 - 776	0.000	105.2
9.0 - Inch	622 - 721	0.000	62.4
1 - Foot	596 - 661	0.000	41.2
2 - Foot	576	0.000	13.8
3 - Foot	570	0.000	7.6
5 - Foot	Ambient	0.000	3.8
7 - Foot	Ambient	0.000	2.3
10 - Foot	Ambient	0.000	1.1
15 - Foot	Ambient	0.000	0.3

◀ 3-19 ▶

Table 3-8 (Continued)
Summary of Inverter Profile Measurements (Front Base of Unit) at Porterville

4 - 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	761 - 1742	0.000	1100
3.0 - Inch	576 - 1303	0.000	793
6.0 - Inch	223 - 779	0.000	534
9.0 - Inch	273 - 625	0.000	313.6
1 - Foot	362 - 589	0.000	217.6
2 - Foot	408 - 494	0.000	76.2
3 - Foot	495	0.000	40.4
5 - Foot	432	0.000	21.4
7 - Foot	443	0.000	11.8
10 - Foot	491	0.000	4.7
12 - Foot	490	0.000	2.7



Figure 3-15
AC Magnetic Field Measurements at Front Base of Inverter at Porterville

◀ 3-20 ▶

Measurement of the AC magnetic field waveform was also conducted near the front of the inverter, at the base of the unit. Again, the dominant component is the primary 60-Hertz component. However, the magnitude of the field at this location is much higher than was measured at the side of the unit (over 800 mG near the base at the front of the inverter versus about 23 mG at the side of the inverter).

A final measurement profile for the inverter was conducted from the front center of the unit at a measurement height of 1 meter (rather than at the base of the unit). Table 3-9 presents these measurement results. As shown in this table, measured DC magnetic fields were even stronger at this location (maximum of over 2 Gauss within 3-inches of the equipment) but again attenuated quickly with distance away from the device. Measured AC magnetic field levels were not as significant as previously measured (about 65 mG). AC electric fields were negligible due to the metallic housing around the inverter.

Another measure of the AC magnetic field waveform was conducted at the front center of the inverter. Once again, the 60-Hertz component is the dominant magnetic field frequency.

Table 3-9

Summary of Inverter Profile Measurements (Front Center of Unit) at Porterville

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	2396	0.000	65.4
3.0 - Inch	2166	0.000	71.6
6.0 - Inch	1699	0.000	69.4
9.0 - Inch	1590	0.000	60.0
1 - Foot	1216	0.000	50.0
2 - Foot	647	0.000	31.8
3 - Foot	475	0.000	20.6
5 - Foot	408	0.000	10.2
7 - Foot	412	0.000	6.1
10 - Foot	461	0.000	3.0
12 - Foot	475	0.000	1.7

AC Power Transformer

The 500 KVA transformers utilized at the Porterville solar farm are standard pad-mounted transformers. Field measurements were initially performed around the perimeter of the transformer (Figure 3-16). Measurements were performed at location #2 with the facility operating at both 350 to 450 kW and again at 4 to 4.9 MW. Table 3-10 presents the measurement results.

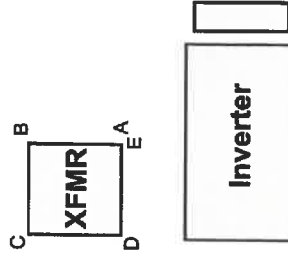


Figure 3-16
Diagram of Measurement Locations for Characterizing a Transformer

Table 3-10
Summary of Porterville Transformer Perimeter Measurements

350 - 450 kW Output of Facility

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	N/A	0.000	19.3
B	N/A	0.000	77.5
C	N/A	0.000	8.9
D	N/A	0.000	8.3
E	N/A	0.000	27.5

4 - 4.9 MW Output of Facility

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	2582	0.000	263.7
B	1596	0.000	55.7
C	614	0.000	68.7
D	1549	0.000	692.8
E	2582	0.000	222.4

Measured DC magnetic fields were about 1.5 to 2.5 Gauss in close proximity to the transformer. These elevated fields are probably due to the concentration of the earth's static magnetic field within the metallic transformer core and thick steel housing. For AC magnetic fields, levels reached almost 140 mG under the 350 to 450 kW loading conditions and almost 740 mG under the 4 to 4.9 MW loading conditions. Increased output of the facility causes increased AC magnetic fields from each of the transformers. There was no measurable AC electric field around this equipment.

Measurement of the AC magnetic field waveform was conducted near this transformer. The dominant component is the 60-Hertz component. Other notable frequency components include 180-Hertz and, to a lesser extent, 300-Hertz.

In addition to perimeter measurements, a measurement profile was performed from the transformer to the nearby inverter to characterize field strengths within this area (between these two pieces of electrical equipment. Figures 3-17 and 3-18 present a photograph and a diagram respectively of measurement location #2 and the profile path. Table 3-11 presents the measurement results under both loading conditions.

As shown, measured DC magnetic fields were elevated in close proximity to the transformer (about 1.5 to 2.5 Gauss). These elevated fields were again attributed to the concentration of the earth's static magnetic field within the metallic transformer core and thick steel housing. For AC magnetic fields, levels at this location near the transformer reached 144 mG under the 350 to 450 kW loading conditions and 1767 mG under the 4 to 4.9 MW loading conditions. Increased output of the facility causes increased AC magnetic fields from the transformer, but AC magnetic fields decreased with distance away from the transformer, but increased while approaching the inverter (at about 6-inches away from the inverter at this location, AC magnetic fields reached almost 14 mG under the 350 to 450 kW loading conditions and almost 140 mG under the 4 to 4.9 MW loading conditions). AC electric fields around this equipment were very low.



Figure 3-17
Measurement Profile Path Between Transformer and Inverter at Porterville

◀ 3-23 ▶

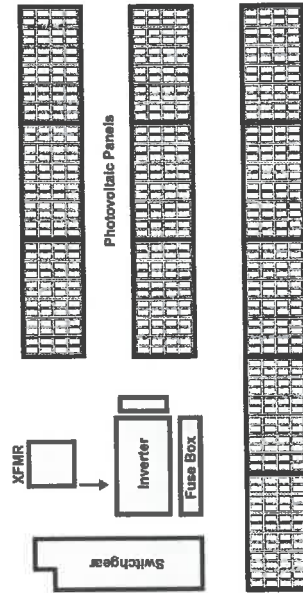


Figure 3-18
Diagram of Measurement Profile Between Transformer and Inverter at Porterville

Table 3-11
Summary of Transformer to Inverter Profile Measurements at Porterville

350 - 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1 - Inch	N/A	0.000	144.6
3 - Inch	N/A	0.000	81.8
6 - Inch	N/A	0.000	49.6
9 - Inch	N/A	0.000	34.4
1 - Foot	N/A	0.000	24.4
2 - Foot	N/A	0.000	8.7
3 - Foot	N/A	0.000	4.6
5 - Foot	N/A	0.000	4.0
7 - Foot	N/A	0.000	13.6*

NOTE: Front of Inverter is located at 7.5 foot (0.5-feet from last measurement location)

◀ 3-24 ▶

Table 3-11 (Continued)
Summary of Transformer to Inverter Profile Measurements at Porterville

4 - 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	2215	0.000	1767
3.0 - Inch	2049	0.000	1372
6.0 - Inch	1713	0.000	851
9.0 - Inch	1666	0.000	697.6
1 - Foot	1020	0.000	396.8
2 - Foot	443 - 718	0.004	172.8
3 - Foot	312 - 596	0.016	89.2
5 - Foot	361 - 457	0.004	60.0
7 - Foot	184 - 561	0.000	138.8*

NOTE: Front of Inverter is located at 7.5-foot (0.5-feet from last measurement location)

Switchgear

At measurement location #2, switchgear is also present next to the DC fuse box, inverter, and transformer station. This switchgear is the collection point for AC current produced from each section of the solar farm. Figure 3-20 presents a diagram of the switchgear equipment and associated measurement locations, while Table 3-12 presents a summary of the measurement results. The facility was operating at 4 to 4.9 MW during these measurements at location #2.



Figure 3-19
Switchgear at Porterville Solar Farm

◀ 3-25 ▶

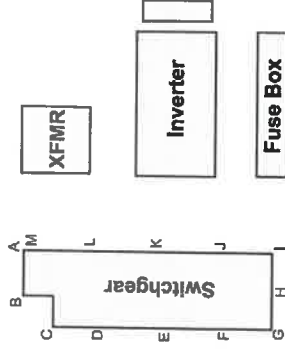


Figure 3-20
Diagram of Switchgear Measurement Locations at Porterville

Table 3-12
Summary of Switchgear Measurements at Porterville

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	740	0.000	32.9
B	537	0.000	165.5
C	527	0.000	44.9
D	394	0.000	28.1
E	138	0.000	33.3
F	601	0.000	138.7
G	726	0.000	254.4
H	550	0.000	276.8
I	432	0.000	58.9
J	151	0.000	35.5
K	325	0.000	106.3
L	395	0.000	37.1
M	740	0.000	29.1

Measured DC magnetic fields were as low as 138 mG and as high as 740 mG around the perimeter of the switchgear. These static field perturbations are probably due to the concentration of the earth's static magnetic field within the metallic housing and internal components. For AC magnetic fields, levels ranged

◀ 3-26 ▶

Table 3-13
Summary of Switchgear Profile Measurements at Porterville

350 - 450 kW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1 - Inch	Ambient	0.000	25.4
3 - Inch	Ambient	0.000	16.2
6 - Inch	Ambient	0.000	10.2
9 - Inch	Ambient	0.000	7.4
1 - Foot	Ambient	0.000	6.1
2 - Foot	Ambient	0.000	3.0
3 - Foot	Ambient	0.000	1.7
5 - Foot	Ambient	0.000	0.7
7 - Foot	Ambient	0.000	0.3

4 - 4.9 MW Output of Facility

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	41 - 816	0.000	432
3.0 - Inch	110 - 645	0.000	316.8
6.0 - Inch	75 - 461	0.000	182.4
9.0 - Inch	98 - 394	0.000	147.2
1 - Foot	123 - 389	0.000	111.0
2 - Foot	275 - 367	0.000	50.8
3 - Foot	295 - 399	0.000	29.6
5 - Foot	379 - 425	0.000	14.8
7 - Foot	411 - 452	0.000	8.9
10 - Foot	436 - 479	0.000	4.3

Underground DC and AC Conduits

Within each section of the solar farm, DC conduits house conductors which carry the generated DC current from the solar arrays to the DC fuse box. In addition, AC conduits house conductors which carry AC current from each transformer to the switchgear at measurement location #2. At measurement location #1, profile measurements were performed between the equipment station (where the DC fuse box, inverter, and transformer are located) and the solar arrays to measure DC and AC magnetic fields within this area. Figure 3-22 presents a diagram of this measurement profile location. Measurements were conducted at 1-foot above ground level and at 3-feet above ground level to

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from a low of about 28 mG to as high as 277 mG (under 4 to 4.9 MW loading conditions). There was no measurable AC electric field around this equipment.

Measurement of the AC magnetic field waveform identified the dominant component of the AC magnetic field is the 60-Hertz component. Other measured magnetic field frequencies were very low.

In addition to the perimeter measurements around the switchgear, a lateral profile was also performed to characterize field attenuation. Profile measurements were initiated at the southwest corner of the switchgear cabinet and proceeded south, away from other nearby equipment which might influence the field readings (as shown in Figure 3-21). Table 3-13 presents a summary of the measurement results.

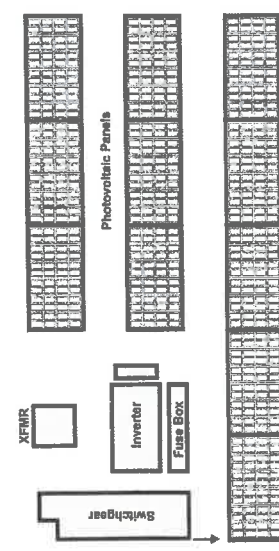


Figure 3-21
Diagram of Switchgear Profile Measurements at Porterville

For DC magnetic fields, measured values were near ambient under the 350 to 450 kW loading conditions, but varied somewhat in close proximity to the switchgear under 4 to 4.9 MW loading conditions (41 mG to 816 mG). DC fields fluctuated above and below ambient close to the switchgear equipment, with these variations decreasing with distance away from the switchgear. These variations in the static DC magnetic field intensity may be due to the close proximity of the nearby DC to AC inverter, which are more pronounced under heavier loading conditions.

For AC magnetic fields, levels ranged from just over 25 mG near the switchgear to a few milligauss at 5 to 7-feet away from the equipment under the 350 to 450 kW loading conditions. However, under the 4 to 4.9 MW loading conditions, AC magnetic fields ranged from about 432 mG near the switchgear to over 4 mG at a distance of 10-feet away from the equipment. Clearly the increased output of the facility causes increased AC magnetic fields from the switchgear. There was no measurable AC electric field around this equipment.

< 3-27 >

characterize these field sources, and for both loading conditions (350 to 450 kW and 4 to 4.9 MW loading conditions).

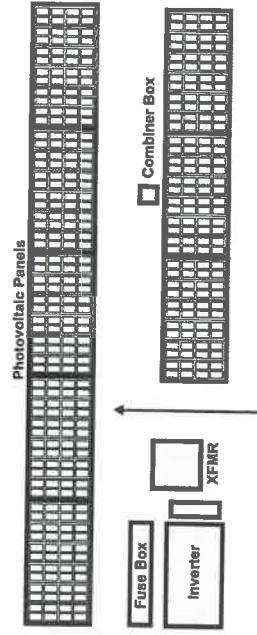


Figure 3-22
Diagram of Profile Path for Measuring Underground Cables at Porterville

Measured DC magnetic fields were within ambient levels for both measurement heights and for both loading conditions. Measured AC magnetic fields were very low (0.0 to 0.1 mG) at both elevations under the 350 to 450 kW loading conditions. However, under the 4 to 4.9 MW loading conditions, the AC magnetic field levels were elevated (3.9 mG at the 1-foot height and 2.5 mG at the 3-foot height). The location of the underground AC conduit was discernible under these higher loading conditions.

Along the western portion of the solar farm, underground cables allow AC electric power from the solar farm switchgear to flow into the local electrical grid. AC magnetic field measurements were conducted along the inside western perimeter fence to characterize fields due to these underground cables (and the nearby overhead electric distribution lines). Figure 3-23 presents a diagram of the measurement path taken during these measurements. Figure 3-24 presents a graph of these AC magnetic field measurement results. As shown, the AC magnetic field was about 2.1 mG at the northwestern corner of the solar farm, and increased to almost 2.5 mG continuing south (due to the presence of the overhead distribution line located across the street from the facility). Above the underground cables, a field of about 4.2 mG was measured. Field levels then decreased to 0 mG at the southwestern corner of the facility. No DC magnetic field or AC electric fields were measured along this profile since the purpose was to characterize the underground AC power cables.

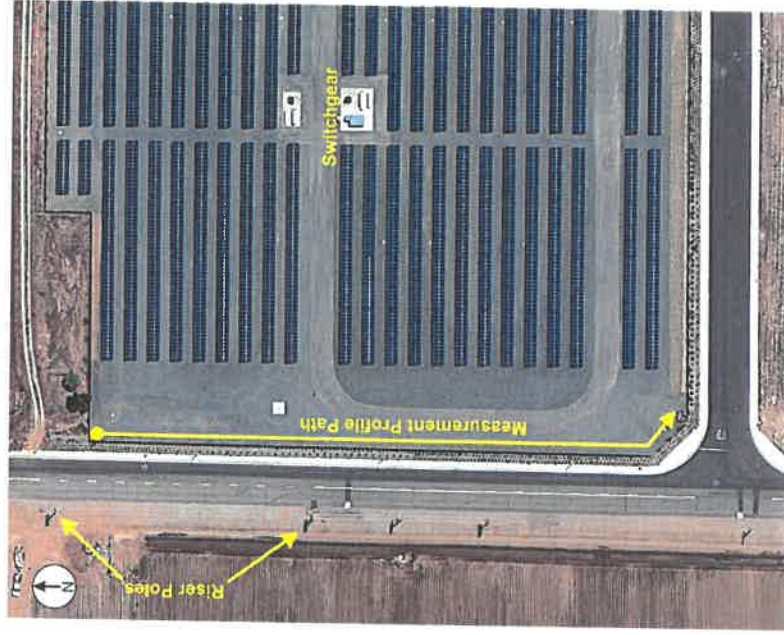


Figure 3-23
Diagram of Profile Path for Underground AC Power Cables at Porterville

Ambient Fields

Prior to performing characterization measurements of the solar equipment, measurements were performed on the rooftop to characterize the ambient field. For AC electric fields, there was no measurable electric field. For the earth's DC magnetic field, the field measured was about 615 mG. For the AC magnetic field, the field was about 0.1 mG. An AC Magnetic field waveform was also conducted for the ambient field. Lower frequency components (particularly 30 and 60-Hertz) are stronger than the higher frequency components. Distinct components in the 360-Hertz and 540-Hertz were also observed. However, the magnitudes of these fields are very low (0.1 mG or less).

Rooftop Photovoltaic Panels

Measurement of the Sunpower photovoltaic panels was conducted at the end of a section of panels, away from the panels towards an open area at the edge of the roof (Figure 3-25). Table 3-14 presents the measurement results for these panels. As shown, the photovoltaic panels themselves are not a significant field source of either DC or AC fields. The earth's ambient DC magnetic field was about 615 mG near this rooftop location (but ambient fields varied at other rooftop locations due to structural steel supports under the roof and the presence of other metallic objects).



Figure 3-25
Rooftop Solar Panel - AC Magnetic Field Measurements

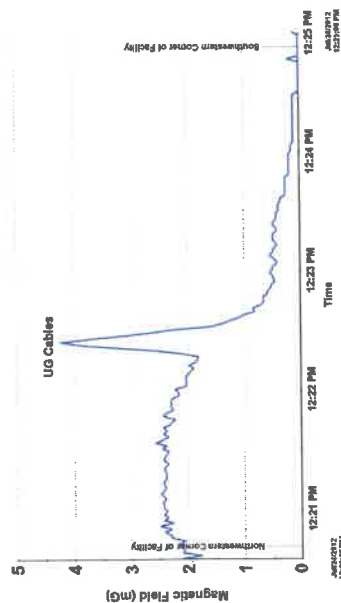


Figure 3-24
Graph of AC Magnetic Field Along Facility Western Fence Line at Porterville

Industrial Rooftop Solar Generation Facility

Electric utilities are also installing photovoltaic energy generation facilities on top of large warehouses and other large buildings. Solar arrays are installed on the rooftop, along with cabling and combiner boxes. DC power from these arrays is transported by cables to ground-level stations containing DC fuse boxes, inverters, and transformers. For this study, field measurements were performed at three different locations associated with a rooftop photovoltaic energy generation facility in San Bernardino.

The first two measurement locations for this facility were on the rooftop. Initially, measurements were performed at the eastern rooftop collection area where both AC and DC power cables are routed from the rooftop down the building to the inverter/transformer/switchgear station at ground level. Facility equipment at measurement location #1 included the solar panels themselves, a combiner box, DC power cables, and the AC power collector cable. The second rooftop measurement location was at the northeastern rooftop area (again, where AC and DC power cables are routed from the rooftop down the side of the building to a ground station). Measurements at this second location focused on the AC power cables. The final location surveyed was on the ground at the inverter/transformer/switchgear station. During the measurement period on May 14, 2012, the photovoltaic energy generation facility was reported to be producing about 1.42 MW of electrical power.

Table 3-14
Summary of Rooftop Photovoltaic Panel Measurements

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	601	0.000	0.2
3.0 - Inch	591	0.000	0.2
6.0 - Inch	573	0.000	0.2
9.0 - Inch	559	0.000	0.2
1 - Foot	578	0.000	0.1
2 - Foot	479	0.000	0.1
3 - Foot	496	0.000	0.1
5 - Foot	518	0.000	0.1
7 - Foot	508	0.000	0.1

Measurement of the AC magnetic field waveform was also conducted near the Sunpower photovoltaic panels. There is a distinct 30-Hertz component for this measurement, with decreasing magnitude as the frequency increases, as well as a distinct 360-Hertz component (sixth harmonic). However, the magnitudes of these fields are very low (less than 0.2 mG) and are probably attributable to other nearby equipment.

Rooftop DC Cable Conduit

Measurement of a DC cable conduit was conducted between sections of solar panels. The cable was encased within a metal conduit and provided electrical connection between two sections of solar panels. Figure 3-26 shows DC magnetic field measurements being conducted at this DC cable conduit, while Table 3-15 presents the measurement results at the conduit. As shown in this Table, the DC magnetic field is slightly higher than ambient (971 mG versus approximately 615 mG) in close proximity to this source. However, at a distance of about 1-foot away from the conduit, static magnetic fields are reduced to ambient levels. The DC cable conduit is not a significant source of AC electric or magnetic fields. Because of the very low AC magnetic field readings, the magnetic field waveform for this conduit was not measured.



Figure 3-26
Rooftop DC Cable Conduit - Static Magnetic Field Measurements

Table 3-15
Summary of Rooftop DC Cable Conduit Measurements

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	971	0.000	0.1
3.0 - Inch	778	0.000	0.1
6.0 - Inch	684	0.000	0.1
9.0 - Inch	557	0.000	0.1
1 - Foot	555	0.000	0.1
2 - Foot	507	0.000	0.0
3 - Foot	471	0.000	0.0
5 - Foot	488	0.000	0.0
7 - Foot	487	0.000	0.4

Rooftop DC Combiner Box

Measurements were conducted to characterize fields from a DC combiner box. Figure 3-27 presents a photograph of the DC combiner box which was measured. Individual DC cables from the solar panels are routed into the combiner box and exit within a common rubber conduit. Table 3-16 presents the measurement results for this equipment. As shown, the DC magnetic field was slightly higher than ambient in close proximity to the combiner box (703 mG at 1-inch away), but fields attenuated quickly to background levels with distance away from the combiner box.

A small AC magnetic field (2.5 mG) was measured close to the combiner box. This AC field also attenuated quickly with distance away from the device. There were no measurable AC electric fields near this equipment due to shielding from the enclosures.

Measurement of the AC magnetic field waveform was conducted near this DC combiner box. Although there are significant 30-Hertz, 60-Hertz, 120-Hertz, and 180-Hertz components, the dominant component is the 360-Hertz component (sixth harmonic). However, the magnitudes of these fields are again very low (less than 1 mG).



Figure 3-27
 Rooftop DC Combiner Box

Table 3-16
 Summary of Rooftop DC Combiner Box Measurements

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	703	0.000	2.5
3.0 - Inch	620	0.000	1.8
6.0 - Inch	582	0.000	0.9
9.0 - Inch	529	0.000	0.4
1 - Foot	515	0.000	0.1
2 - Foot	453	0.000	0.1
3 - Foot	488	0.000	0.1
5 - Foot	521	0.000	0.1
7 - Foot	467	0.000	0.1

Rooftop DC Collector Cables

A cluster of eight DC collector cables were measured near the rooftop edge. These cables were encased within rubber conduits (Figure 3-28). Measurements were conducted on each side of the cluster of cables, one to the south and parallel to an adjacent DC cable tray, and the other to the north and between DC cable trays and also an AC power cable.

Tables 3-17 and 3-18 present the measurement results for these locations. Because of the proximity to adjacent cable trays, the measured DC magnetic field remained relatively constant (about 300 to 450 mG towards the south and 500 to 750 towards the north). Measured values along the southern profile were lower than the ambient magnetic field (approximately 615 mG), while values along the northern profile were higher than the ambient, exhibiting a cancellation effect south and a contributing effect north.

For AC magnetic fields, measured values were around 11 mG near the areas of the AC power cable as it turned to approach the edge of the roof and be routed down the wall to the eastern enclosure. At this location, the AC power cable is encased in a rubber conduit to allow for the bend in the cable. As the cable routes northward in a straight line, the conduit becomes metallic and provides additional AC magnetic field shielding. There were no measurable AC electric fields as the cable was always enclosed in some type of casing.

The FFT analyses of the AC magnetic field waveforms collected for the DC collector cables (measurements conducted on both the south and north sides of the cables respectively) show that the dominant frequency measured is 60-Hertz. These results are probably due to the close proximity of the nearby AC power cable at these measurement locations.

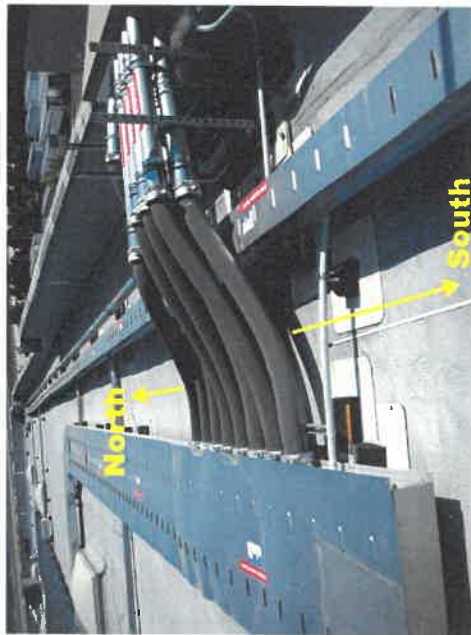


Figure 3-28
Rooflop DC Collector Cables -- Measurement Profile Locations

Table 3-17

Summary of Rooflop DC Collector Cable Measurements (South Side)

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	333	0.000	1.5
3.0 - Inch	333	0.000	2.2
6.0 - Inch	324	0.000	3.0
9.0 - Inch	308	0.000	5.9
1 - Foot	319	0.000	6.8
2 - Foot	397	0.000	0.9
3 - Foot	429	0.000	0.3
5 - Foot	434	0.000	0.1
7 - Foot	443	0.000	0.1

◀ 3-37 ▶

Table 3-18

Summary of Rooflop DC Collector Cable Measurements (North Side)

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	680	0.000	11.0
3.0 - Inch	668	0.000	7.4
6.0 - Inch	650	0.000	4.8
9.0 - Inch	650	0.000	3.3
1 - Foot	635	0.000	2.8
2 - Foot	604	0.000	2.1
3 - Foot	598	0.000	2.0
5 - Foot	753*	0.000	1.2
7 - Foot	502	0.000	0.8

* - A structural steel beam was present at the measurement location and influenced the DC magnetic field reading.

Rooflop AC Power Cable

Field measurements were also conducted near the AC power cable at the northeast collection area of the rooftop (Figure 2-7). Measurements were conducted on one side of the cable towards an open area near the rooftop edge, where the portion of the power cable is encased within a rubber conduit (rather than metal). Table 3-19 summarizes the measurement results. Because of the proximity to nearby DC cables and cable trays, the measured DC magnetic field was lower than ambient near the cable (exhibiting DC field cancellation) and increased to near ambient levels about 5 to 7-feet away from the cable.

For AC magnetic fields, measured levels were over 400 mG near the cable and decreased to less than 1 mG at a distance of about 5-feet away from the cable. This attenuation rate is roughly $1/r$ as is typical for a single AC conductor source. Again, there were no measurable AC electric fields as the cable was always enclosed in some type of casing.

For the waveform measurements, the dominant frequency measured is 60-Hertz. There is very little harmonic content exhibited from this AC magnetic field source.

◀ 3-38 ▶

Table 3-19
Summary of Rooftop AC Power Cable Measurements

Distance	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1.0 - Inch	256	0.000	412.8
3.0 - Inch	211	0.000	84.8
6.0 - Inch	271	0.000	45.0
9.0 - Inch	384	0.000	25.2
1 - Foot	386	0.000	18.8
2 - Foot	456	0.000	7.1
3 - Foot	483	0.000	2.8
5 - Foot	630	0.000	0.9
7 - Foot	654	0.000	0.5

DC Fuse Box

As shown in Figure 2-6, the eastern enclosure at ground level contained a fuse box, inverter, transformer, and switchgear. Figure 3-29 presents a diagram of the equipment and specific measurement locations for the DC fuse box, while Table 3-20 presents a summary of these perimeter measurements. Field measurements were conducted along three sides of the fuse box, which was located against the enclosure fence (Figure 3-30).

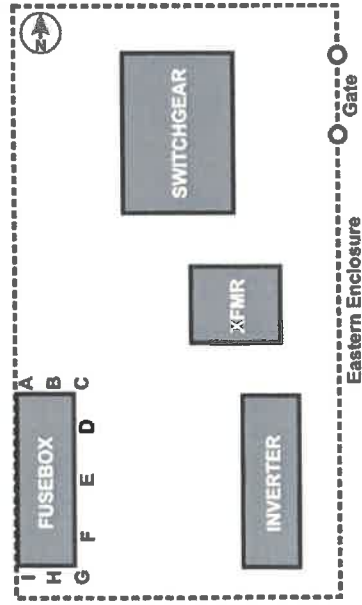


Figure 3-29
Diagram of DC Fuse Box Measurement Locations



Figure 3-30
DC Fuse Box at San Bernardino

Table 3-20
Summary of Measurements Around DC Fuse Box

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	603	0.000	5.2
B	476	0.000	14.0
C	110	0.000	12.8
D	301	0.000	6.9
E	1,032	0.000	6.5
F	320	0.000	2.5
G	893	0.000	5.0
H	441	0.000	2.8
I	790	0.000	2.8

Measured DC magnetic fields around the fuse box ranged from as low as 320 mG to as high as 1,032 mG, depending upon the measurement location. While some of the DC field variation may be attributed to the metal enclosure, the internal DC cables are probably the dominant DC magnetic field source. There was also some AC magnetic field variability exhibited in the measurement data, ranging from 2.5 mG to 14 mG around the perimeter of the fuse box. Higher AC magnetic fields were measured at the corner of the fuse box closer to the transformer (later measurements confirmed that the transformer was the source for these elevated AC magnetic fields). AC magnetic field waveform measurements were not performed near this equipment as the field sources were other nearby electrical sources which were characterized. There were no measurable AC electric fields near the fuse box due to shielding from the metal enclosure.

DC to AC Inverter

Field measurements were then performed for the DC to AC inverter. Figure 3-31 presents a photograph of the inverter, while Figure 32 presents a diagram of the measurement locations around the inverter. Table 3-21 presents a summary of the measurement results. It was reported that the inverter was operating at 457 kW during the measurement period.



Figure 3-31
DC to AC Inverter at San Bernardino

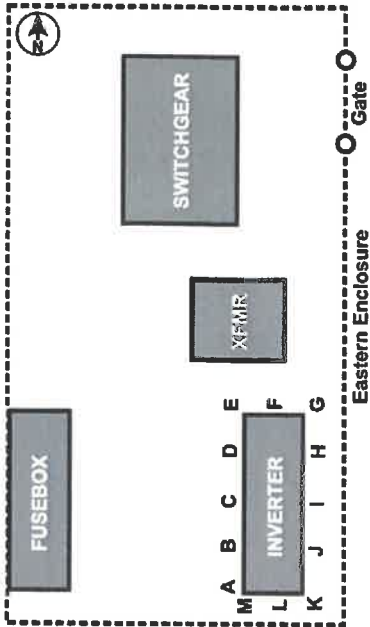


Figure 3-32
Diagram of Inverter Measurement Locations

Table 3-21
Summary of Measurements Around Inverter

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	988	0.000 - 0.010	411.2
B	655	0.000 - 0.010	654.4
C	130 - 655	0.000 - 0.010	721.6
D	753	0.000 - 0.010	689.6
E	1,600 - 2,211	0.000 - 0.010	80.3
F	1,520	0.000 - 0.010	48.7
G	1,141	0.000 - 0.010	64.9
H	1,045	0.000 - 0.010	263.5
I	776	0.000 - 0.010	612.8
J	756	0.000 - 0.010	657.6
K	452 - 728	0.000 - 0.010	296.0
L	518	0.000 - 0.010	203.2
M	452	0.000 - 0.010	472.0

For the inverter, measured DC magnetic fields ranged from 130 mG to 2,211 mG, depending upon the measurement location. Considerable DC field variation was observed near the inverter, as shown by the range of DC field values within the table. Figure 3-33 presents a graph of this DC magnetic field variability conducted at a stationary location next to the inverter. As shown in this graph, the variation in DC field strength is significant within a few seconds of time.

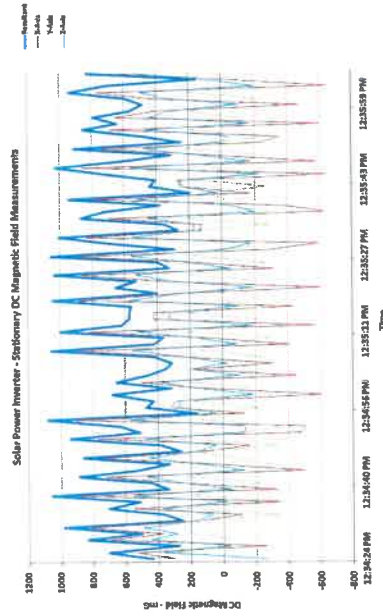


Figure 3-33
DC Magnetic Field Recording at Stationary Location Near Inverter

There was also significant AC magnetic fields exhibited from the inverter, ranging from 48.7 mG to 721 mG. Higher AC magnetic fields were measured at the front (and back) of the inverter, while lower field levels were measured closer to the nearby transformer (which may be providing some field cancellation). AC magnetic field waveform measurements were also performed near the inverter, which exhibited a dominant 60-Hertz component. Other frequency components were present but had a very low magnitude in comparison to the fundamental frequency. There were no or very low AC electric fields near the inverter due to shielding from the metal enclosure.

Field profiles were conducted of the inverter to characterize field attenuation as a function of distance away from the equipment. To avoid other nearby field sources, measurements were initiated near the southwest corner of the enclosure and proceeded west towards the fuse box (out to 10-feet). Figure 3-34 presents a diagram of the profile measurement path, while Table 3-22 presents the measurement results for DC and AC magnetic field and AC electric field. DC magnetic field levels attenuated quickly with distance, while AC magnetic fields

persisted farther away from the equipment. Again, there were no or very low AC electric fields near the inverter.

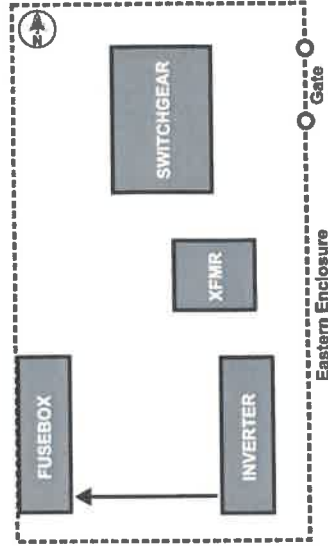


Figure 3-34
Diagram of Measurement Profile Between Inverter and Fuse Box

Table 3-22
Profile Measurements from Inverter

Distance from Inverter	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1-Inch	1,045	0.000 - 0.010	1,131.2
6-Inch	841	0.000	443.2
1-Foot	675	0.000	257.6
2-Foot	502	0.000	140.9
3-Foot	459	0.000	75.3
4-Foot	417	0.000	47.1
5-Foot	440	0.000	30.9
6-Foot	418	0.000	20.9
7-Foot	419	0.000	15.1
8-Foot	383	0.000	11.1
9-Foot	342	0.000	8.1
10-Foot	274	0.000	6.1

Transformer

Field characterization measurements were conducted around the pad-mounted transformer within the eastern enclosure. Figure 3-35 presents a diagram of the equipment and these measurement locations, while Table 3-23 presents a summary of the measurement results.

As demonstrated at the Porterville facility, increased DC magnetic fields around the transformer are largely attributable to the transformer core and steel casing concentrating the earth's static field; therefore, DC readings were not recorded here. As expected, there were significant levels of AC magnetic field exhibited near the transformer, ranging from 57.3 mG to 1,057 mG. The AC magnetic field waveform exhibited a dominant 60-Hertz component, with very little other frequency components present. There were no or very low AC electric fields near the transformer due to shielding from the metal casing.

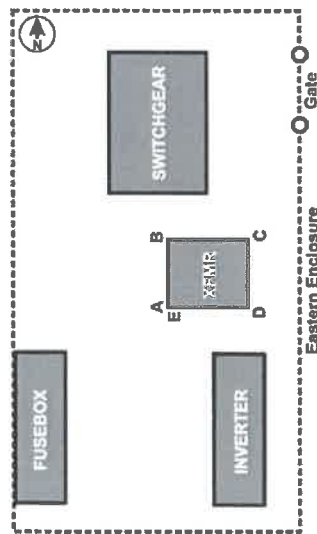


Figure 3-35
Diagram of Transformer Measurement Locations

Table 3-23
Summary of Measurements Near Transformer

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	N/A	0.000 – 0.016	865.6
B	N/A	0.000 – 0.016	193.3
C	N/A	0.000 – 0.016	57.3
D	N/A	0.000 – 0.016	193.6
E	N/A	0.000 – 0.016	1,057.6

< 3-45 >

To characterize field attenuation, a measurement profile was conducted away from the transformer as shown in Figure 3-36. Table 3-24 presents the measurement results for AC electric and magnetic fields. AC magnetic fields decreased rapidly with distance at a rate of between $1/r$ and $1/r^2$. This attenuation is typical of pad-mounted transformers, as reported in another EPRI report [2]. Again, there were no or very low AC electric field levels near the transformer.

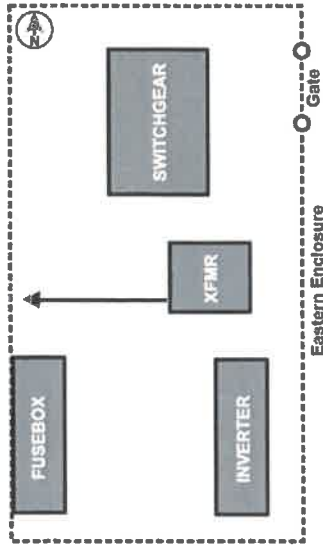


Figure 3-36
Diagram of Transformer Measurement Profile

Table 3-24
Profile Measurements from Transformer

Distance from Inverter	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1-Inch	0.000 – 0.016	961.6
1-Foot	0.000	315.2
2-Foot	0.000	134.1
3-Foot	0.000	71.3
4-Foot	0.000	40.5
5-Foot	0.000	25.9
6-Foot	0.000	17.1
7-Foot	0.000	11.9
8-Foot	0.000	9.7

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Switchgear

Finally, field measurements were conducted around the switchgear within the eastern enclosure. Figure 3-38 presents a diagram of the equipment and these measurement locations, while Table 3-25 presents a summary of the measurement results.

For the switchgear, measured DC magnetic fields ranged from about 60 mG to 959 mG and, at some locations, were probably influenced by the steel cabinet and internal components which concentrate the earth's static field. AC magnetic field levels ranged from 11.5 mG to 85.9 mG, depending upon the measurement location. Similar to the transformer, the AC magnetic field waveform exhibited a dominant 60-Hertz component with very little other frequency components present. There was no significant AC electric field measured near the transformer due to shielding of internal components from the metal cabinet.

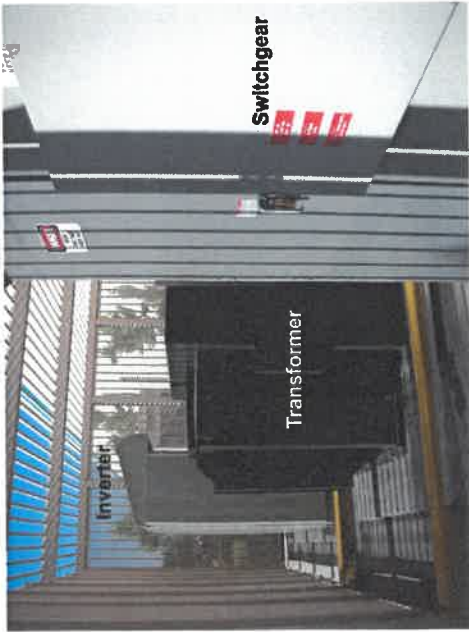


Figure 3-37
Switchgear, Transformer and Inverter at San Bernardino

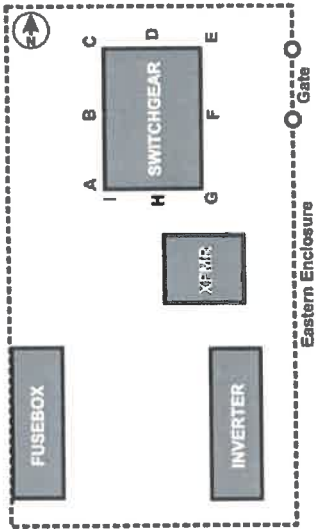


Figure 3-38
Diagram of Switchgear Measurement Locations

Table 3-25
Summary of Measurements Around Perimeter of Switchgear

Location	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
A	221	0.000	11.5
B	60	0.000	16.5
C	631	0.000	25.1
D	686	0.000	75.1
E	959	0.000	85.9
F	279	0.000	10.3
G	214	0.000	81.7
H	400	0.000	63.9
I	528	0.000	9.7

For the switchgear, a measurement profile was conducted away from the cabinet to the fence perimeter (Figure 3-39). Table 3-26 presents the measurement results for AC electric and magnetic fields. AC magnetic field levels again decrease rapidly with distance away from the equipment. There were no significant AC electric fields measured near the switchgear.

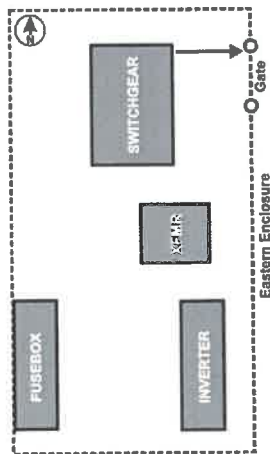


Figure 3-39
Diagram of Switchgear Measurement Profile

Table 3-26
Profile Measurements from Switchgear

Distance from Inverter	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)
1-Inch	0.000	93.5
1-Foot	0.000	28.4
2-Foot	0.000	11.6
3-Foot	0.000	6.3
4-Foot	0.000	3.8
5-Foot	0.000	3.6

Discussion of Measurement Results

Table 3-27 presents a summary of the static magnetic field and power-frequency field results for both photovoltaic facilities surveyed. For DC magnetic fields, a prominent source of occupational exposure is the DC to AC inverter. In addition to having a large outer metallic enclosure and internal metallic components (which concentrate the earth's static magnetic field), inverters take the DC current from large solar arrays and transform it to AC current. Both of the inverters surveyed have a maximum DC input rating of 1,610A. Therefore, this equipment can be a significant DC magnetic field source in close proximity to the equipment (depending upon DC load and the measurement location at the enclosure). Measured DC magnetic fields varied from an ambient level of about 516 to 615 mG to as low as 184 mG (due to field cancellation) and as high as 2,770 mG. However, the DC field attenuated quickly with distance away from the inverter and reached ambient levels within about 1 to 2-feet away from the inverter.

Table 3-27
Summary of Photovoltaic Facility Equipment and Measurement Results

Location or Equipment	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)	Dominant AC Magnetic Field Frequency (30 - 1500 Hz)
Ambient	516 - 615	0.000	0.0 - 0.1	30/60 Hz
Solar Panel	479 - 601	0.000	0.0 - 0.2	30 Hz
JT-Box	358 - 811	0.000	0.4 - 49.2	60/120/180 Hz
DC Cables	308 - 1,034	0.000	0.1 - 11.0	60 Hz
AC Power Cables	211 - 654	0.000	0.5 - 412.8	60/300 Hz
DC Combiner Box	348 - 756	0.000	0.1 - 2.5	60/360 Hz
DC Fuse Box	110 - 1,709	0.000	2.5 - 47.3	60 Hz
Inverter	184 - 2,770	0.010	6.1 - 1,131	60/300/360 Hz
Transformer	614 - 2,582	0.016	8.3 - 1,767	60 Hz
Switchgear	41 - 959	0.000	9.7 - 432	60 Hz

Another significant source of DC magnetic field is the DC fuse box. DC current from individual groups of solar arrays are routed into the fuse box. Therefore, DC currents are present but are distributed among individual circuits. Near a DC fuse box, measured DC magnetic fields varied from as low as 110 mG to as high as 1,709 mG depending upon the loading and measurement location. Similar, but lesser DC magnetic field levels were observed in the DC cables themselves (308 mG to 1,034 mG).

Measured DC magnetic fields in close proximity to the pad-mounted AC power transformers were also elevated (up to 2,582 mG). However, elevated DC magnetic fields are probably due to the concentration of the earth's static field within the transformer core and housing, which are large metallic objects, and not generated from the equipment itself.

Although solar panels, JT-boxes, DC cabling, and combiner boxes are all equipment which carry direct current, none of this equipment is a significant source of occupational DC magnetic field exposure. Measured DC magnetic fields around this equipment rarely exceeded 1 Gauss, even within 1-inch of the equipment. AC power cables and switchgear utilize AC power (rather than direct current) and therefore are also not significant DC magnetic field sources.

It should be noted that, while measured DC magnetic fields from these sources were in the range of up to 3 Gauss, the levels discussed here are comparable to or much lower than DC magnetic fields from many other common sources. For example, a typical refrigerator magnet exhibits a DC magnetic field over 13,000 mG at 1-inch away from the magnet. DC magnetic fields encountered while traveling on electric trains or trolley systems (300 to 2,000 mG) are comparable to the DC field levels measured near this photovoltaic facility equipment.

For power-frequency AC magnetic fields, a prominent source of occupational exposure is the pad-mounted AC power transformer. In close proximity to this equipment, measured AC magnetic fields can reach almost 2 Gauss. However, AC magnetic field levels attenuate quickly with distance away from the device (at a rate of between $1/r$ and $1/r^2$). The measured AC field from transformers decreased to about 10 mG or less within 8 to 10-feet away from this equipment, which is typical for this type of equipment [2].

Another source of AC magnetic field is the DC to AC inverter. Both of the inverters surveyed have a maximum AC output rating of 1,444A. Therefore, this equipment can be a significant AC magnetic field source in close proximity to the equipment (depending upon the measurement location at the enclosure). Measured AC magnetic fields reached up to 1,100 mG near this equipment. However, the AC field attenuated quickly with distance away from the inverter.

AC power cables and switchgear are also AC magnetic field sources. In close proximity to AC power cables and switchgear cabinets, measured AC magnetic fields reached about 412 mG and 432 mG respectively. In addition, the "J"-box mounted underneath of the solar panels exhibited a field of almost 50 mG in close proximity to this equipment. Again, the AC field attenuated quickly with distance away from this equipment.

Because solar panels, DC connecting cables, combiner boxes, and DC fuse boxes all utilize equipment which carries direct current, none of this equipment is a significant source of occupational AC magnetic field exposure. Measured AC magnetic fields rarely exceeded several mG, even within 1-inch of the equipment. Typically the presence of other nearby AC sources influenced the AC magnetic field readings near this equipment.

None of the photovoltaic energy generation facility equipment measured exhibited significant power-frequency electric field levels. The largest AC electric field reading was about 16 V/m (or 0.016 kV/m) near a pad-mounted transformer. All of the equipment associated with photovoltaic energy generation facilities is typically housed within conduits, cabinets, enclosures, or casings which shield the AC electric field. Therefore, occupational power-frequency electric field exposure is minimal for this type of equipment.

Section 4: Radio-Frequency Fields

In concert with the measurements of static and lower frequency fields at each solar facility as described earlier, measurements of radiofrequency (RF) fields were also accomplished at the Porterville and San Bernardino, California solar generation facilities. Because of the fundamental nature of how electrical inverters operate in which the DC output of the solar panels is chopped at a frequency of approximately 5 kHz, before being filtered and smoothed to become a relatively pure 60-Hz sinusoidal waveform, the RF measurements focused on frequencies in the 5 kHz to 100 kHz range (electric and magnetic fields). Supplemental measurements were also performed across the 100 kHz to 30 MHz range and the wide spectrum of 26 MHz to 3000 MHz for electric fields. These measurements were conducted to examine the field magnitude and spatial variation of field associated with the various components of the solar generation facilities. All measurements of RF fields were performed with spectrum analyzer based instrumentation that allowed for the detection of various frequency components that might exist across the spectrum.

Measurement Protocol

For each type of facility, field measurements were performed to determine the magnitude of the RF fields present near the solar panels, DC cables that connect the panel outputs to the inverter (including DC combiner boxes where the outputs of multiple panels are connected together for feeding the inverters) and the inverters themselves. Measurements were conducted at locations near the equipment where occupational access would be required with an emphasis on identifying the maximum value of electric and magnetic fields regardless of location.

Generally, RF instrumentation was positioned at different points relative to the equipment components to characterize the spatial dependence of measured fields on distance. Reported RF measurement data were acquired as fixed point values; the instrumentation as configured did not provide for continuous assessment of RF field as the equipment was continuously moved with respect to the potential source being examined. Measurement points were generally specified by a measured distance (using measuring tapes) between the solar component and the instrumentation. All measurements were performed over sufficient time periods to insure capture of the maximum magnitude of observed RF fields for those fields that exhibited variation in time. Whenever possible, distance measurements were performed towards open areas and away from other field sources. However,

◀ 4.1 ▶

there was always the possibility that the fields measured at a given point might be influenced by the presence of multiple field sources in the area.

Instrumentation

Several different configurations of instruments were used for the RF measurements at solar generation facilities across the broad spectrum of frequencies investigated.

Low Frequency Electric and Magnetic Fields

Low frequency RF fields were measured with a Narda model EHP-50C, initially, and, subsequently, model EHP-50D Electric and Magnetic Isotropic Field Analyzer. This device provides for simultaneous measurement of the X , Y and Z axes field magnitudes and calculates the resultant field using digital signal processing software (using the Fast Fourier Transform, FFT) that is executed on a connected laptop computer. Figure 4-1 shows the EHP-50D sensor which is connected to a laptop computer via a nonconductive fiber optic cable and a representative display from the FFT processing on a laptop screen.

The EHP instrument covers the frequency range of 5 Hz to 100 kHz, making it ideal for detection of the 5 kHz switching frequency of the inverters. Relevant specifications for the models EHP-50C and EHP-50D are provided in Tables 4-1 and 4-2 respectively. Calibration certificates for the EHP-50C and EHP-50D instruments are provided in Appendix C (Figures C-8 through C-10 and C-11 through C-15 respectively). Each set of measurements were performed by manually surveying the area near the different solar equipment components by carrying the EHP-50 instrument using a supplied dielectric handle to isolate the instrument from the user as shown in Figure 4-2.

Intermediate Frequency Electric Fields

Electric field strengths across the 100 kHz to 30 MHz frequency range were measured using two versions of a monopole antenna (AH Systems model SAS-550-1B Active Monopole, SN 854 and 865; AH Systems model SAS-551 Passive Monopole, SN 193). The model SAS-550-1B is designed to cover the frequency range of 9 kHz to 60 MHz and the model SAS-551, 9 kHz to 40 MHz. The active version of the monopole antenna is shown in Figure 4-3. Calibration data for each of the three monopole antennas are provided in Appendix C. In each case of using one of the monopole antennas, a spectrum analyzer (Narda model SRM-3006, see below) was used as the detection device connected to the respective monopole. Measured signal levels as observed on the spectrum analyzer were adjusted for the antenna factor provided by the manufacturer to obtain the electric field strength. Electric fields were measured by extending the telescoping monopole element to its full length of 41 inches (104 cm) and connecting it to the BNC connector on the top of the active electronics box in the center of the 18 inch (46 cm) by 18 inch square ground plane. Initial measurements with the active monopole were performed by attaching the ground plane to a nonconductive tripod such that the ground plane

◀ 4.2 ▶

was at a height of 1 meter above ground similar to that shown in Figure 4-4. Subsequent to the initial Porterville measurements, the monopole antenna measurements were conducted by placing the antenna directly on the ground or concrete pad that equipment upon which equipment was mounted as shown in Figure 4-5.

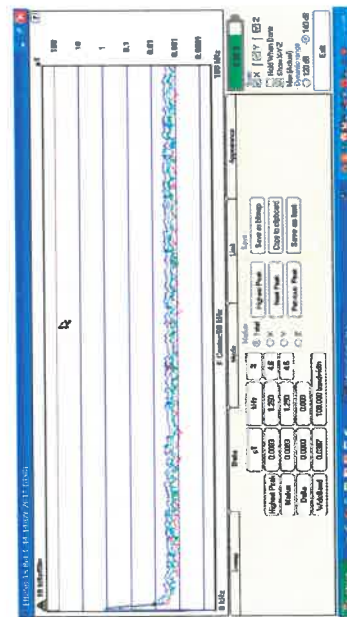
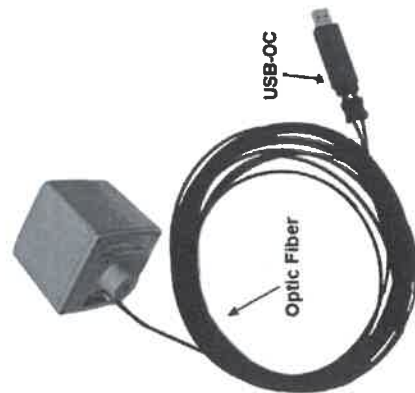


Figure 4.1
The Narda Model EHP-50D Electric and Magnetic Isotropic Field Analyzer - An example of the software display is shown in the bottom panel that shows the result of an FFT analysis of the time series data acquired by the sensor.

◀ 4.3 ▶

Table 4-1
Manufacturer's Specifications for the Narda Model EHP-50C

Functional Specifications	Electric Field	Magnetic Field
Frequency range	1 kHz to 100 MHz	0.1 mT / 10 mT
Measuring Range	1 kV/m @ 50 Hz	20 mT @ 50 Hz
Overload	200 kV/m @ 50 Hz	1 kT @ 50 Hz
Resolution	6001 V/m on 1000 display and 1 "Start Above" mode	1 kT on 1000 display and 1 "Start Above" mode
Sensitivity	0.01 V/m	1 nT
Typical 3D isotropy	0.5% (0.04 dB)	1.4% (0.12 dB)
Typical 3D isotropy	0.5% (0.04 dB)	1.4% (0.12 dB)
SPAN	100 Hz, 200 Hz, 400 Hz, 1 kHz, 2 kHz, 10 kHz, 100 kHz	1.2 % of the SPAN
Starting Frequency	Equal to the SPAN	Equal to the SPAN
Stop Frequency	Equal to the SPAN	Equal to the SPAN
Field Rejection	> 20 dB	> 20 dB
FFT	Real Time FFT analysis	Real Time FFT analysis
Internal Data Logger	1 measurement every 20 to 60 seconds	1 measurement every 20 to 60 seconds
Internal memory	1440 data with 1 000 Hz storage, 2000 data with 200 Hz storage	1440 data with 1 000 Hz storage, 2000 data with 200 Hz storage
Typical uncertainty	Without contribution of uncertainty of calibration	Without contribution of uncertainty of calibration
Magnetic probe I0	Magnetic field density range	With contribution of uncertainty of calibration
Frequency at 0 dB	0.1 μT to < 0.3 μT	4.1
	0.3 μT to < 10 μT	5.5
	10 μT to < 100 μT	3.7
	100 μT to 500 μT	4.1
Frequency from 0 Hz to 10 kHz	0.1 μT to < 0.3 μT	6.5
	0.3 μT to < 10 μT	6.1
	10 μT to < 100 μT	6.3
Electric probe II	Electric field range	Without contribution of uncertainty of calibration
Frequency at 0 dB	10 V/m to 500 V/m	7.0
	10 V/m to < 100 kV/m	8.4
	10 V/m to < 500 V/m	8.5
Frequency from 0 Hz to 10 kHz	10 V/m to < 100 kV/m	8.4
	10 V/m to < 500 V/m	8.5

The uncertainties stated in this document have been determined according to EN 61346. They were estimated as expanded uncertainty obtained applying the standard by the coverage factor k=2, corresponding to a confidence level of about 95%. The unit uncertainty of the probe derived from typical coefficients of linearity, isotropy, frequency response, temperature, relative humidity and resolution is considered as uncertainty of calibration.

(1) The temperature range is from -10°C to 23 °C and relative humidity is from 20% to 50% (2) The uncertainty of calibration used is 1.5% (3) The uncertainty of calibration used is 2.0% (4) The uncertainty of calibration used is 2.5% (5) The uncertainty of calibration used is 2.5%

◀ 4.4 ▶

Table 4-2
Manufacturer's Specifications for the Narda Model EHP-500

EHP-500		FUNCTIONAL SPECIFICATIONS ^a	
Frequency Range		Electric Field	Magnetic Field
Measurement Range ^b		5 mV/m ~ 1 kV/m 500 mV/m ~ 100 kV/m (linear measurement range, 100 dB)	0.3 nT ~ 100 μ T 30 nT ~ 10 mT (linear measurement range, 150 dB)
Overload		200 V/m	20 mT
Dynamic range		100 dB	110 dB
Resolution ^c		1 mV/m with NIST-550 0.1 mV/m with EHP-73 software 1 mV/m in Stand Alone mode	0.1 nT with NIST-550 0.1 nT with EHP-73 software 1 nT in Stand Alone mode
Isotropic result		5 μ V/m 3 mV/m	0.3 nT 0.2 nT
Field range		(5 Hz ~ 40 Hz) (40 Hz ~ 100 Hz) (not 20/50)	0.8 dB 0.35 dB
Typical 30° arc accuracy ^d		0.54 dB	0.12 dB
Linearity ^e		0.2 dB (1 V/m ~ 1 kV/m) 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 10 kHz, 100 Hz (100 Hz to 100 kHz in Stand Alone mode)	0.2 dB (200 nT ~ 10 mT)
SPAN		100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 10 kHz, 100 Hz (100 Hz to 100 kHz in Stand Alone mode)	0.2 dB (200 nT ~ 10 mT)
Short frequency		---	Equal to the SPAN
Rejection to E fields		> 20 dB	> 20 dB
Rejection to H fields		---	---
Acquisition method		Simultaneous three-axis acquisition	FFT
Spectrum analyzer method		1 measurement every 50 or 60 seconds	---
Internal data logger		Up to 24 hours regardless of the logging rate	---
Intrinsic memory ^f		---	---

(1) Using reference antenna, specifications are referred to an antenna operating temperature of 23°C and relative humidity of 50%.

(2) For the best measurement range.

(3) For the best measurement range.

(4) Typical value @ 200 Hz, see specification table EHP-500.

(5) Typical value @ 200 Hz, see specification table EHP-500.

(6) Measurement with reference antenna made on 10 standard 30° arc.



Figure 4-2
Using the Narda Model EHP-500 Electric and Magnetic Isotropic Field Analyzer to Search for Low Frequency Field Maxima



Figure 4-3
AH Systems Model SAS-550-1B Active Monopole Antenna - For measurement of electric field strengths in the range of 9 kHz to 60 MHz. The telescoping rod element is extended and connected to the BNC connector on the top of the electronics box in the center of the ground plane during measurements.

Higher Frequency RF Fields

A Narda model SRM-3006 Selective Radiation Meter (SN D-0069) was used for measurements across the spectrum of 26 MHz to 3 GHz. This instrument, shown in Figure 4-6, makes use of an isotropic probe/antenna and displays measured RF field strengths in terms of a percentage of the Federal Communications Commission (FCC) maximum permissible exposure (MPE) for the general public. The spectrum analyzer portion of the measurement system makes use of FFT technology to display measured fields as a function of frequency with the resultant field being the root-mean-squared value of the three polarization components as detected by the probe/antenna. When the basic spectrum analyzer unit is used in conjunction with an external antenna, such as one of the monopoles described above, the signal level is indicated in terms of power (dBm) or voltage (dBuV) to which the relevant antenna factor is added to obtain electric field strength. Specifications for the basic unit, the spectrum analyzer, are provided in Table 4-3. The calibration certificates for the SRM-3006 for the basic unit and the probe/antenna are provided in Appendix C.

Table 4-3
Specifications of the Narda SRM-3006 Selective Radiation Meter (Basic Unit)

SPECIFICATIONS • BASIC UNIT	
ITEM NO.	NAME
1	Measurments vs. Mode
2	Measurments vs. Line
3	Measurments on mode
4	Measurments on mode
5	Measurments on mode
6	Measurments on mode
7	Measurments on mode
8	Measurments on mode
9	Measurments on mode
10	Measurments on mode
11	Measurments on mode
12	Measurments on mode
13	Measurments on mode
14	Measurments on mode
15	Measurments on mode
16	Measurments on mode
17	Measurments on mode
18	Measurments on mode
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30	Measurments on mode
31	Measurments on mode
32	Measurments on mode
33	Measurments on mode
34	Measurments on mode
35	Measurments on mode
36	Measurments on mode
37	Measurments on mode
38	Measurments on mode
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78	Measurments on mode
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81	Measurments on mode
82	Measurments on mode
83	Measurments on mode
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86	Measurments on mode
87	Measurments on mode
88	Measurments on mode
89	Measurments on mode
90	Measurments on mode
91	Measurments on mode
92	Measurments on mode
93	Measurments on mode
94	Measurments on mode
95	Measurments on mode
96	Measurments on mode
97	Measurments on mode
98	Measurments on mode
99	Measurments on mode
100	Measurments on mode

Frequency: 4000
 $\times 10^{10} \text{ cm}^{-1}$ ν $1 > 4.5 \text{ GHz}$



Figure 4-4
Operation of the AH Systems Model SAS-550. 1B Active Monopole Antenna - Mounted at 1 meter above ground on a nonconductive tripod.



Figure 4-5
Operation of the AH Systems Model SAS-550-TB Active Monopole Antenna -
Mounted at ground level.

Table 4-3 (Continued)
Specifications of the Narda SRM-3006 Selective Radiation Meter (Spectrum Analysis Mode)

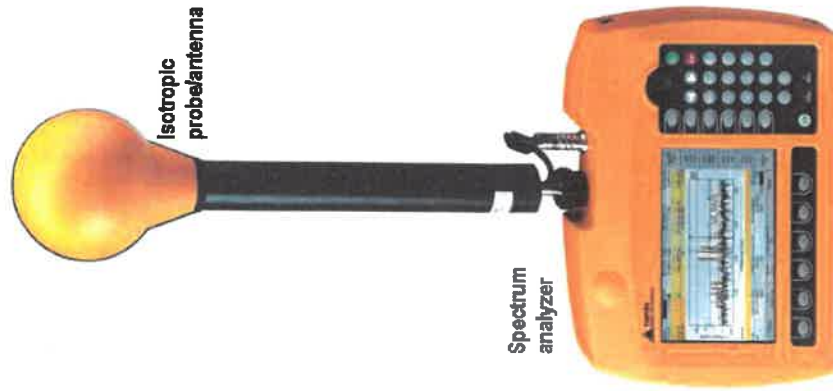
[illegible]

Figure 4-6
Narda Model SRM-3006 Selective Radiation Meter (26 MHz – 3 GHz)

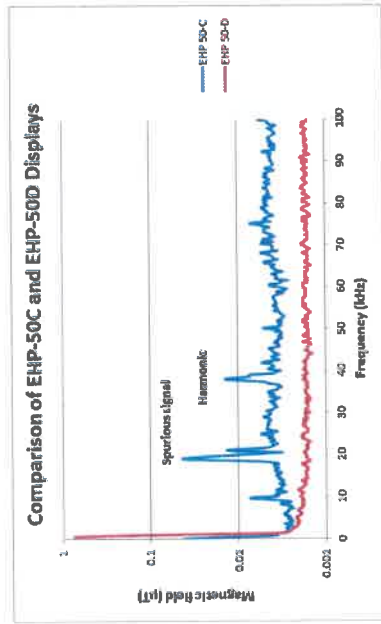


Figure 4-7
Comparative Display of the Measured Output Spectrum as Observed in a Background Environment Free of Low Frequency Sources on the Narda Model EHP-50C and EHP-50D

Another issue involved the upper level of electric field strength that can be measured with the active monopole antennas without overloading the input circuitry of the antenna. Active antennas make use of an electronic circuit that matches the very high impedance of the short, vertical antenna element and substantially amplifies the detected signal to a useable level for application to a receiver or spectrum analyzer. When RF field strengths are above a certain threshold, the active electronics of the antenna system can generate spurious signals across the spectrum. For the SAS-550-1B active monopole, this electric field strength level is approximately 102 dB μ V/m (decibels above 1 microvolt per meter) at 1 MHz. When the incident RF field exceeds this value of field strength, the electronics begin to saturate and the circuitry can produce spurious signal products that are not representative of the actual RF field emissions produced by the equipment being measured. The active version of the monopole antenna was used during the first trip to Porterville and the trip to San Bernardino solar generation facilities. Subsequently, a passive version of the monopole, which is not susceptible to production of intermodulation products from strong signals, was acquired for follow-on measurements during the second trip to the Porterville facility.

Because this study was exploratory in regard to the presence of higher frequency RF fields, most of the data presentations in this chapter display the spectral distribution of detected RF fields across various frequency bands.

Ground-Based Utility Solar Generation Facility RF Fields

RF fields were examined at the Porterville solar farm on two occasions, on November 29, 2011 (Porterville I) and July 24, 2012 (Porterville II). During the 2011 measurements, the output of the facility was running at about 10% of its full capacity due to fog and heavy overcast conditions. During the 2012 measurements, full sunlight was present and the facility was operating very near its rated capacity of 5 MW. Data displays are typically labeled as Porterville I or Porterville II to distinguish between the two separate measurement sessions.

Field measurements were conducted across three principal parts of the RF spectrum, predominantly including frequency ranges of:

- 0 – 100 kHz
- 0.5 – 30 MHz
- 26 – 3000 MHz

In some instances, other particular frequency ranges were included in the measurements to examine specific parts of the RF spectrum.

During the first visit to the Porterville facility (Porterville I), fog and overcast conditions limited the output of the facility. Inverters were observed to produce nominally between 23 and 42 kW, depending on the time during the measurement session. This corresponds to between 4.6% and 8.4% of the rated output of each inverter (each inverter was rated at 500 kW). The initial focus was on characterizing the fields associated with the inverter's switching circuits that operate at approximately 5 kHz. Using the EHP instrument, the surface of an inverter was scanned while observing for the greatest indicated magnitude of spectral field components. In this fashion, two locations were found that exhibited the greatest measured magnetic fields. Each of these measurement points were located in the lower region of the two central sections of the inverter. Subsequently, measurements of the wideband (root sum squared magnitude) magnetic flux density and electric field strength were conducted as a function of distance up to 10 feet (3 m) in front of inverter 6. Figure 4-8 shows the results of magnetic flux density measurements; the surface value is 0.67 μ T. Electric field strength is shown in Figure 4-9. The surface electric field strength is 1.04 V/m. Magnetic field is seen to decrease rapidly with increasing distance from the surface of the inverter while the electric field strength quickly reaches an ambient level that is relatively uniform beyond approximately 2 feet from the inverter. Inverter 6 was operating at an output power of 42 kW at the time of the measurements.

During the first visit to Porterville, a detailed spectral examination of the nominal 5 kHz switching frequency used by the inverter was performed. Figure 4-10 illustrates a representative display of the spectral composition of the magnetic field. This figure reveals spectral peaks at 4.750, 4.875, 5.125 and 5.250 kHz. However, the resolution bandwidth of the spectrum analyzer was 25 Hz for this measurement and may not exactly represent the actual frequencies.

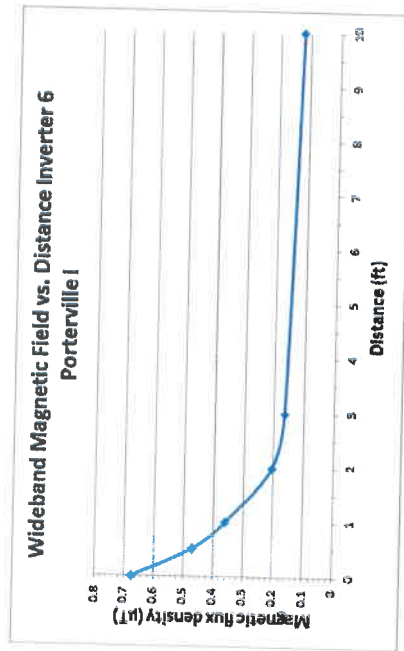


Figure 4.8
Wideband Magnetic Field vs. Distance at Inverter 6 during Porterville I
Measurements

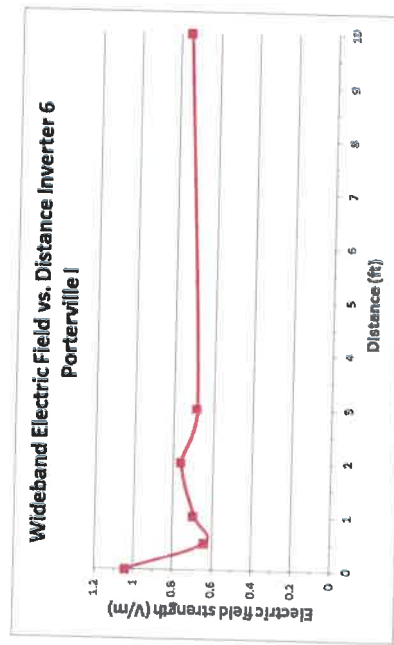


Figure 4.9
Wideband Electric Field Strength vs. Distance at Inverter 6 during Porterville I
Measurements

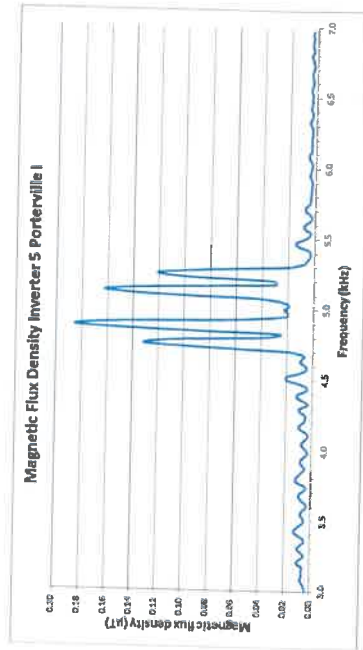


Figure 4.10
Detailed Measured Spectrum of the Magnetic Field Associated with the Switching Frequency Associated with Inverter 5 during First Round of Porterville Measurements

A spectrum plot of magnetic flux density at the surface of inverter 02 during Porterville I across the frequency range of 0 - 1000 Hz shows a predominant 60 Hz component just above 1 μT with various harmonics, the fifth harmonic being the strongest beyond the fundamental (see Figure 4-11). The wideband value from this measurement is 1.35 μT . Inverter 02 is located next to the switchgear for the Porterville facility. The inverter was operating at 23.1 kW at the time of the measurement.

A similar measurement was performed at transformer 02 at Porterville as shown in Figure 4-12. The measured magnetic field spectrum is shown in Figure 4-13 where the 60-Hz component is not surprisingly the strongest component measured. A wideband flux density value of 4.0 μT was obtained.

Besides lower frequency field measurements, higher frequency RF fields were also detected. Figure 4-14 shows use of the SRM-3006 to capture electric fields associated with operation of the frequency hopping spread spectrum radios used at the Porterville site for data communication. A small yagi antenna mounted to a pipe is used for transmission as shown in the inset to Figure 4-14. The system signals intermittently present across this range as shown in Figure 4-15. In this figure, the RF field is expressed in terms of a percentage of the maximum permissible exposure (MPE) adopted by the Federal Communications Commission (FCC). Peak field strengths at the point of measurement were equivalent to approximately 0.1% of the MPE for general public exposure.

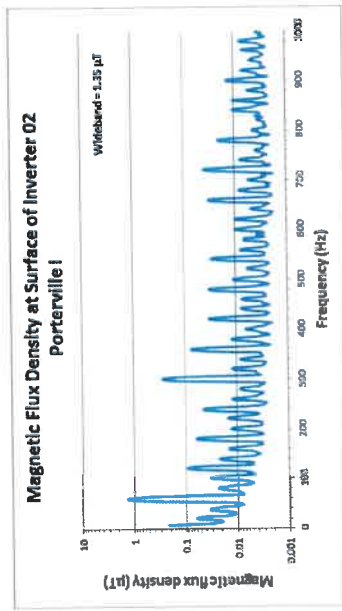


Figure 4-11
Magnetic Field at Surface of Inverter 2 during First Round of Porterville Measurements - Inverter 2 is located next to the switchgear for the solar facility. Inverter 2 was operating at 23.1 kW



Figure 4-12
Measurement of Electric and Magnetic Fields near the Surface of Transformer 02 at the Porterville Facility - A fiber optic cable connects the sensor to a laptop computer that runs the analysis software.

◀ 4-15 ▶

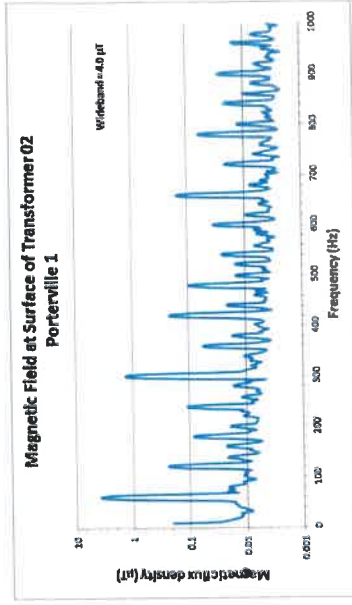


Figure 4-13
Magnetic Field at Surface of Transformer 02 during First Phase of Porterville Measurements - Note that the 60-Hz component is the strongest component measured.



Figure 4-14
Measuring the RF Field Associated with Operation of the 900 MHz Frequency Hopping Spread Spectrum Signals Emitted from the Small Yagi Antenna (shown in inset)

◀ 4-16 ▶

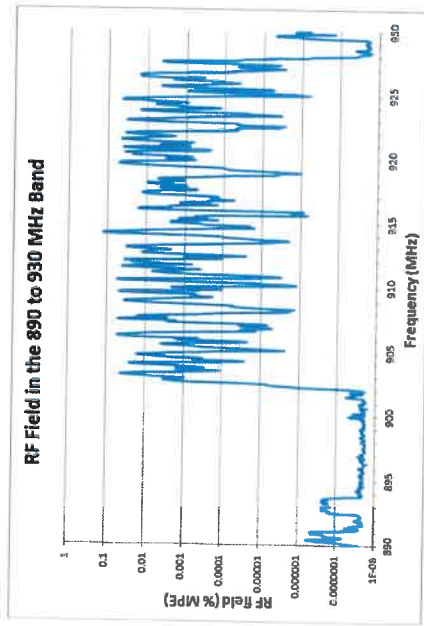


Figure 4-15
RF Field Measured in the 890 to 930 MHz Frequency Range - Frequency hopping spread spectrum signals are seen in the license free band of 902 to 928 MHz range.

Measurements across the 100 kHz to 2 MHz frequency range were made at 1 and 10 feet from inverter 5 during Porterville I. Figure 4-16 shows the difference in peak electric field strengths. At 10 feet from the inverter, the broadband RF noise is observed to be significantly reduced in magnitude and local AM radio station signals become evident as the noise floor of the measurements is reduced.

Results of a set of similar measurements are shown in Figure 4-17 for the frequency range of 100 kHz to 30 MHz. Near the inverter, the RF noise is evident across much of the band. When the detection antenna is moved away from the inverter, the observed field strength decreases. Initial measurements with the active monopole antenna were conducted with the antenna mounted on a tripod with the ground plane positioned at 1 meter above ground. Measurement data shown in Figure 4-17 were acquired with the active monopole placed directly on the ground.

Broadband, frequency selective measurements of electric fields across the full capability of the SRM-3006, 26 MHz to 3 GHz, were performed away from any of the inverters as shown in Figure 4-18 near the center of the Porterville solar facility. Figure 4-19 illustrates a typical spectrum measurement. In this figure, UHF TV broadcast signals just above 500 MHz and cellular telephone base stations, with possible contributions by the frequency hopping spread spectrum transmitters in use at the facility are evident.

◀ 4-17 ▶

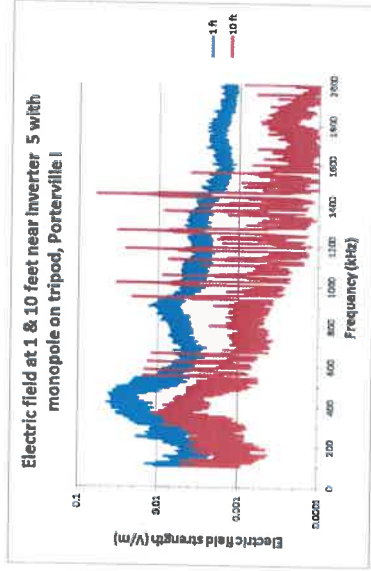


Figure 4-16
Electric Field Strength Measured at 1 and 10 Feet Adjacent to Inverter 5 using Monopole on Tripod during First Round of Porterville Measurements in the Frequency Range of 100 kHz to 2 MHz - Near the inverter, the RF noise is evident across much of the band. When the detection antenna is moved away from the inverter, the observed field strength decreases.

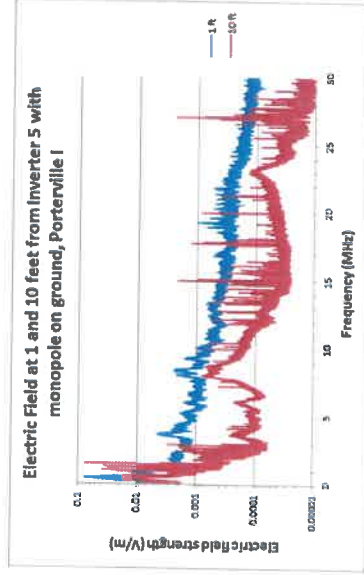


Figure 4-17
Electric Field Strength Measured at 1 and 10 Feet Adjacent to Inverter 5 using Monopole on the Ground during First Round of Porterville Measurements in the Frequency Range of 100 kHz to 30 MHz - Near the inverter, the RF noise is evident across much of the band. When the detection antenna is moved away from the inverter, the observed field strength decreases.

◀ 4-18 ▶



Figure 4-18
Performing a Measurement of the Broadband RF Fields near the Center of the Porterville Facility

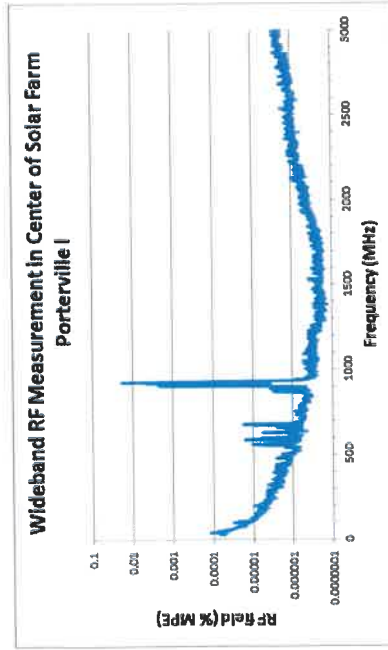


Figure 4-19
Wideband RF Measurement near the Center of the Porterville Solar Farm during First Round of Measurements in Porterville

When a second round of measurements was performed at the Porterville facility in July, 2012, measurements were again made close to inverters to examine differences between those found during the earlier visit when the inverters were only operating at roughly 8-10% of their rated capacity. Surface measurements were, once again, made starting at the surface of the inverters at the point where maximum field had been observed as illustrated in Figure 4-20. In this figure, the fiber optic cable that connects the output of the EHP-50D sensor to the

◀ 4-19 ▶

associated laptop computer running the analysis software is seen. Measurements, this time, were conducted at distances up to 25 feet (7.6 m) from inverter 10. Magnetic flux densities are plotted in Figure 4-21 where the surface value is 40.5 μT . The spatial distribution of electric field strength is shown in Figure 4-22 where it is evident that after only a few feet, the measured result becomes, essentially, independent of distance. The maximum surface value of electric field was 1.4 V/m. At the time of these measurements, the electrical output of inverter 10 was 498 kW, a factor of 11.8 times greater than the Porterville I measurements.

For the Porterville II series of measurements, a passive monopole antenna was used for detection of lower frequency RF fields and, as described above, the antenna was placed directly on the ground as shown in Figure 4-23. Electric field strengths near inverter 5 are plotted for distances of 1, 2, 3 and 10 feet from the inverter across the spectrum of 10 kHz to 100 kHz. Additional measurements were made for the 0.5 to 30 MHz frequency range at 1, 3, 10, 28.5 and 53 feet as illustrated in Figure 4-25. This figure supports the hypothesis that broadband RF fields are produced by the inverter and quickly become less with increasing distance. It can be seen that the measurement noise floor at 28.5 feet and 53 feet are essentially identical. At all frequencies, the electric field strength is no greater than about 0.2 V/m.

Limited measurements were conducted at inverter 5 to examine possible directional properties associated with the RF emissions. In this case, measurements across the 0.5 to 30 MHz band were performed at 10 feet from the inverter, one point being directly in front of the inverter and the other, also at 10 feet radially from the center of the inverter, at a 45 degree angle to a normal to the inverter. These results are shown in Figure 4-26 where the spectrums appear essentially similar but with a diminished magnitude in the 12-14 MHz range when measured at the 45 degree angle.

Because of the near full capacity output of most inverters during Porterville II, a series of measurements were performed at the maximum magnetic field point on the surface of all of the inverters to examine uniformity in measured field values. Table 4-4 lists the measured inverter output powers for each of the 10 inverters installed at the Porterville facility. The output powers ranged from 383 to 498 kW for this particular series of measurements. The average output was 445 kW.

Figure 4-27 shows the spectral measurements of magnetic fields up to 100 kHz. This figure also shows the "zero" local oscillator feed through signal of the spectrum analyzer. The 5 kHz switching frequency fundamental is evident and it is clear that the spectra fall essentially on top of one another from all of the inverters. The individual wideband values of surface flux density are tabulated in Table 4-5 where the range is 31.46 to 39.36 μT . The variability of the measured values is characterized by a standard deviation of 2.1 μT (with a 5.9% standard deviation).

◀ 4-20 ▶



Figure 4-20
Holding the EHP-50D Sensor on the Surface of an Inverter for Measurement of Magnetic Fields - The laptop computer is seen in the foreground connected to the sensor with a fiber optic cable.

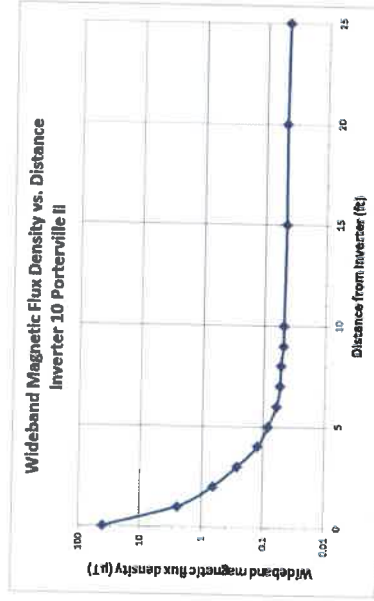


Figure 4-21
Wideband Magnetic Flux Density vs. Distance at Inverter 10 during Second Round of Porterville Measurements

◀ 4-21 ▶

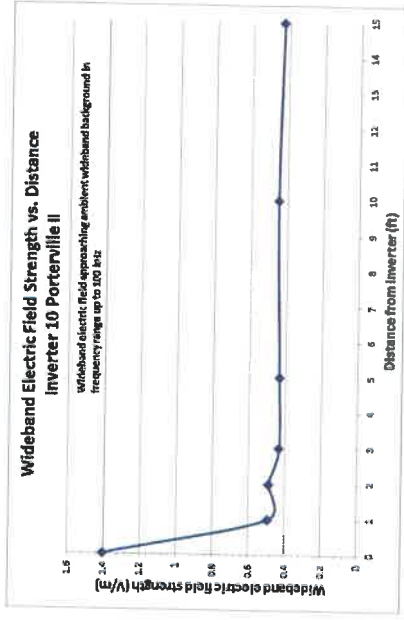


Figure 4-22
Wideband Electric Field Strength vs. Distance at Inverter 10 during Second Round of Porterville Measurements



Figure 4-23
Use of Passive Monopole Antenna with Ground Plane on the Ground

◀ 4-22 ▶

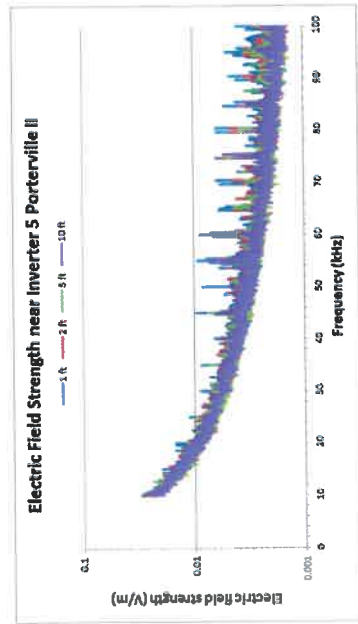


Figure 4-24
Electric Field Strength near Inverter 5 in the 10 kHz to 100 kHz Frequency Range during Second Round of Measurements at Porterville

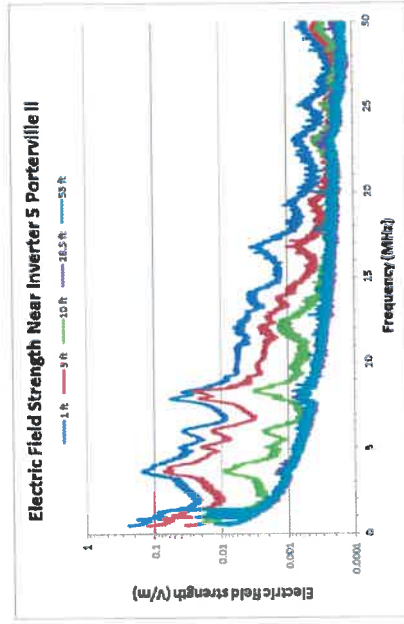


Figure 4-25
Electric Field Strength near Inverter 5 in the 0.5 MHz to 30 MHz Frequency Range during the Second Round of Measurements at Porterville

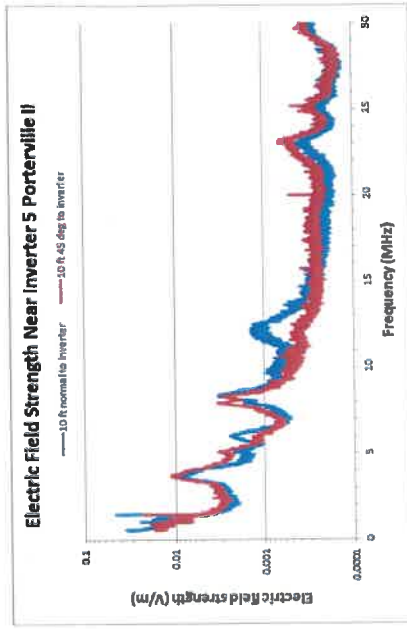


Figure 4-26
Electric Field Strength near Inverter 5 across the 0.5 MHz to 30 MHz Range at 10 Feet Normal to the Front of the Inverter and at 45 Degrees to the Front of the Inverter during the Second Round of Measurements in Porterville

Table 4-4
Inverter Output Power at the Porterville Solar Facility during Measurements on individual Inverters on July 24, 2012

Inverter	Time	Output Power (kW)
1	10:17	383
2	10:57	485
3	10:51	423
4	10:47	498
5	10:42	462
6	10:38	471
7	10:32	405
8	10:29	455
9	10:23	430
10	10:17	436
Average		445

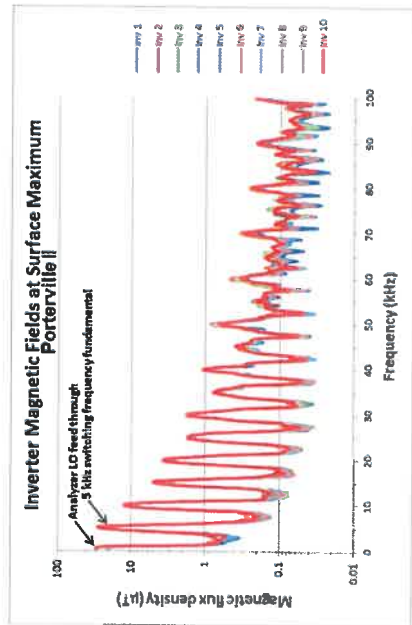


Figure 4-27
Surface Magnetic Field at Ten Inverters at Porterville during Second Round of Measurements

Table 4-5
Measured Surface Magnetic Flux Density at 10 Porterville Inverters (0-100 kHz Wideband)

Inverter	Magnetic Flux Density (μT)	Inverter Output (kW)
1	36.63	383
2	36.32	485
3	31.47	423
4	37.31	498
5	37.18	462
6	35.12	471
7	34.43	405
8	35.64	455
9	37.07	430
10	39.36	436
Mean	36.05	445
SD	2.11	36.1
% SD	5.9	8.1

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At each inverter, the surface electric field strength was also measured as illustrated in Figure 4-28. Interestingly, 9 of the 10 inverters exhibited electric field strengths of approximately 0.6 V/m with the exception of inverter 8 that showed a value of 10.5 V/m (the electric field strength at the 5 kHz fundamental of the switching frequency was 6.3 V/m). Table 4-6 lists the wideband values of electric field strength at the surface showing that inverter 8 stands out from the rest.

While the maximum surface magnetic field was always found to be located on the front of the inverters, measurements on inverter 10 were made on all four sides by sliding the sensor across each surface to observe for the maximum field. These data are provided in Figure 4-29 and confirm that the greatest fields are found on the front surface. However, there was significantly less variation found in the magnitude of electric fields on the four sides of the inverter.

RF fields measured with the SRM-3006, as illustrated in Figure 4-30, were obtained at 1, 2, 3, 10, 28.5 and 53 feet adjacent to inverter 5 during the Porterville II measurements. Figure 4-31 presents the results of these measurements and suggests that in the 26 MHz to 3 GHz frequency range, there was essentially very little difference in measured fields.

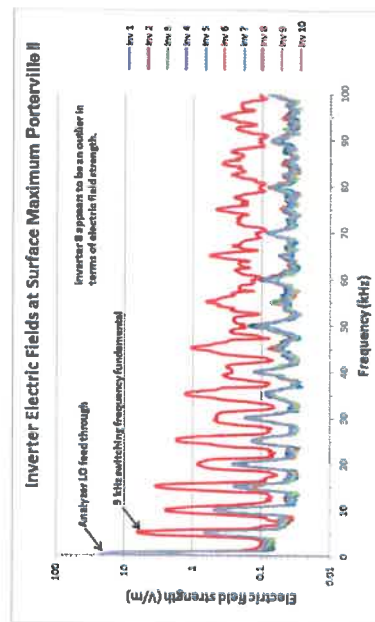


Figure 4-28
Surface Electric Field Strength at Ten Inverters at Porterville during Second Round of Measurements - Note that inverter 8 exhibits a noticeably higher electric field strength than any of the other nine inverters.

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Table 4-6
Measured Surface Electric Field Strength at 10 Porterville Inverters (0-100 kHz
Wideband)

Inverter	Electric Field Strength (V/m)	Inverter Output (kW)
1	1.13	383
2	1.21	485
3	1.20	423
4	1.27	498
5	1.23	462
6	1.14	471
7	1.16	405
8	10.48	455
9	1.17	430
10	1.32	436
Mean	2.13	445
SD	2.93	36.1
% SD	137	8.1

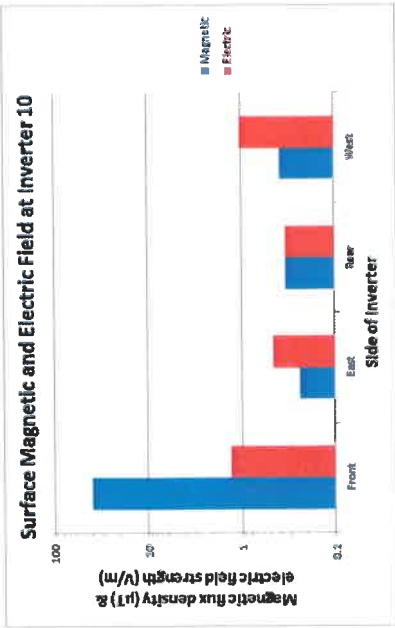


Figure 4-29
Surface Magnetic and Electric Fields at Inverter 10 on All Sides of Inverter -
Measurements acquired during Porterville II trip.



Figure 4-30
Using the SRM-3006 to Measure the Broadband RF Field as a Function of Distance
from Inverter

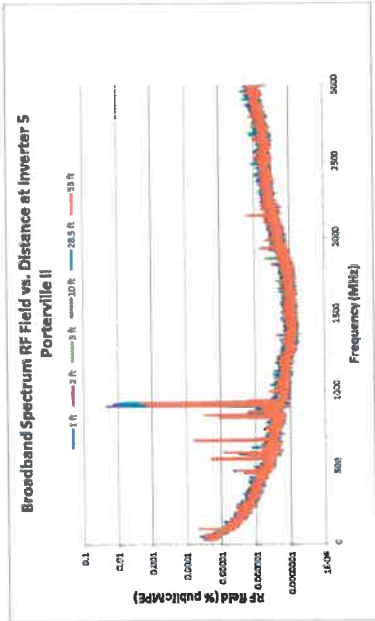


Figure 4-31
Broadband RF Field Measurements near Inverter 5 Across the Spectrum of 26 MHz
to 3000 MHz during the Second Round of Measurements in Porterville

Industrial Rooftop Solar Generation Facility RF Fields

During May 14, 2012, measurements of RF fields were conducted at a large warehouse in San Bernardino, California as described earlier. Measurements were performed on the roof near the solar panels, near a combiner box where multiple DC power cables are combined onto heavy conductors, and at a point near the northeast corner of the roof where multiple heavy cables exit the roof via conduits to the ground level mounted inverters. But, because the inverters had been observed from the Porterville measurements to be the primary source of RF fields, most of the measurement effort was applied to a single, ground mounted inverter designated as inverter I-7A that was contained within a large steel cage that also contained a large transformer and associated switch gear. Figure 4-32 is a satellite image showing several large building rooftops containing solar panels. Measurements reported here were associated with the indicated building. The inset in the figure shows the cage within which the inverter was located.

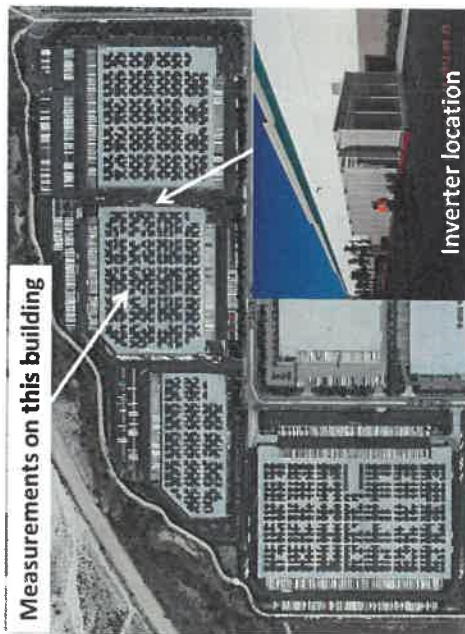


Figure 4-32
The San Bernardino Solar Site Showing the Building at which Measurements were Conducted. The inset at the lower right shows the cage in which one of five inverters with associated transformer and switch gear were installed.

Initially, broadband RF fields across the 26 MHz to 3 GHz frequency range were measured near the center of the roof, surrounded by hundreds of solar panels as illustrated in Figure 4-33. Figure 4-34 shows the EHP-50D sensor set up immediately next to a rooftop mounted combiner box containing DC cables originating from panels and combined onto large diameter cables. A

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measurement near a collection of DC power cables leading off the roof near the northeast corner is shown in Figure 4-35.

Across the 0 to 100 kHz frequency range, magnetic fields at the combiner box, near the center of the roof and near the NE corner of the roof are shown in Figure 4-36. These data show that low frequency fields at the center of the roof were essentially at the noise floor of the instrument while observable fields, at the 5 kHz switching frequency were detected at the NE corner of the roof as well as near the combiner box with the combiner box measurement showing the greatest magnitude. This finding suggests that the DC cables that lead down to the inverters do carry some 5 kHz currents as a result of the inverter operation. The levels are low but, nonetheless, present as seen in the measurements. In the case of low frequency electric fields, Figure 4-37 shows how the field strengths were related to the three different measurement locations on the roof. In this case, the combiner box yielded the greatest electric field strength but the lowest fields were found near the NE corner of the roof in the vicinity of the many cables leading down to the ground level inverters. The measurement at the center of the roof resulted in intermediate value field strengths.



Figure 4-33
Broadband RF Field Measurement being Performed near the Center of the San Bernardino Solar Facility Roof

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Figure 4-34
Measurement of Electric and Magnetic Fields near a Combiner Box on the Roof of the San Bernardino Solar Facility - The combiner box combines the DC outputs of multiple solar panels together and feeds current through the large conduit down to a ground mounted inverter.



Figure 4-35
Low Frequency Measurement near the Northeast Corner of the Roof at a Location where many DC Cables are Routed to Ground Installed Inverters

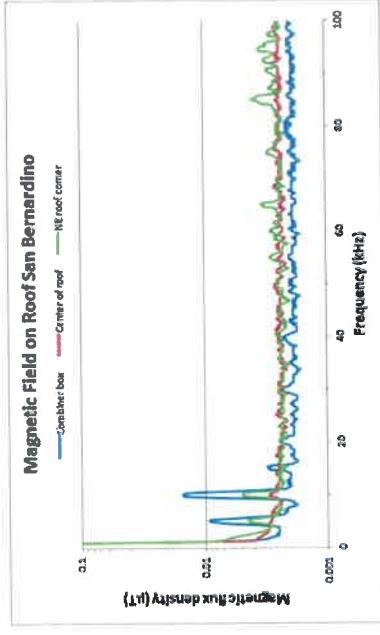


Figure 4-36
Magnetic Flux Density Measured on the Roof of the San Bernardino Building Solar Farm

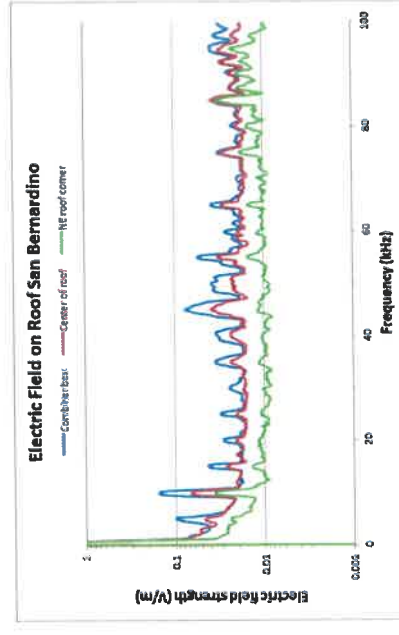


Figure 4-37
Electric Field Strength on the Roof of the San Bernardino Building Solar Farm

Broadband fields from 26 MHz to 3 GHz were measured near the center of the roof and inside and outside of the ground level cage containing the inverter under study. Figure 4-38 presents the spectral results of these measurements. The roof level measurement shows significantly enhanced UHF-TV broadcast signals compared to either of the ground level measurements (most of the Los Angeles area UHF-TV broadcasts come from Mt. Wilson). Considerable cellular telephone base activity was observed in all three situations in the 900 MHz band and the 1900 MHz band.

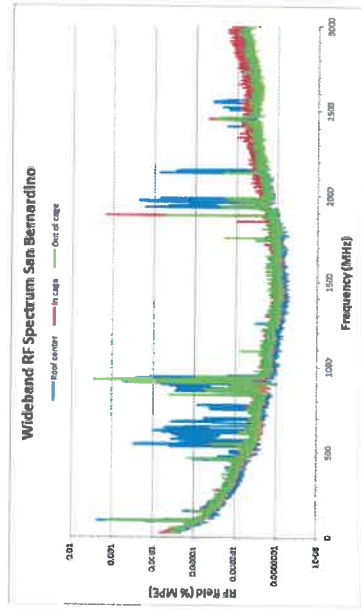


Figure 4-38
Wideband RF Spectrum Measured on the Roof of the San Bernardino Building and Inside and Outside of the Inverter Cage at Ground Level

Low frequency, wideband values of magnetic and electric fields near the ground mounted inverter are shown in Figure 4-39 for distances from 1 foot to 10 feet from the inverter. While magnetic fields are seen to decrease with distance up to 10 feet, electric field values remain relatively constant suggesting that the ambient background across the 0 – 100 kHz frequency range was essentially uniform in the measurement area due to other contributing sources.

The spectral content of the magnetic field near the San Bernardino inverter at each measurement distance is shown in Figure 4-40. The largest signal seen at the very left of the scale is the spectrum analyzer local oscillator feed through signal. The 5 kHz switching frequency field is seen along with 19 other harmonics.

Magnetic and Electric Fields near Inverter in San Bernardino

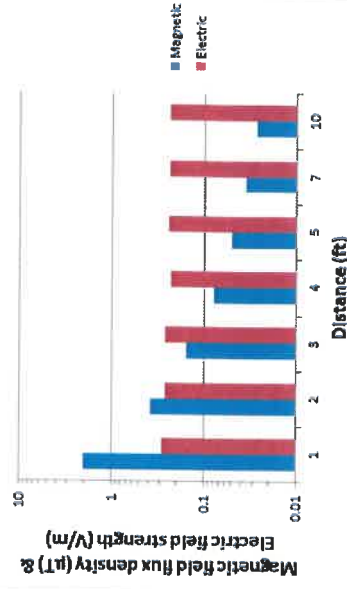


Figure 4-39
Spatial Variation of 0 - 100 kHz Electric and Magnetic Fields near the Inverter at the San Bernardino Facility

Magnetic Field Spectrum Adjacent to Inverter San Bernardino

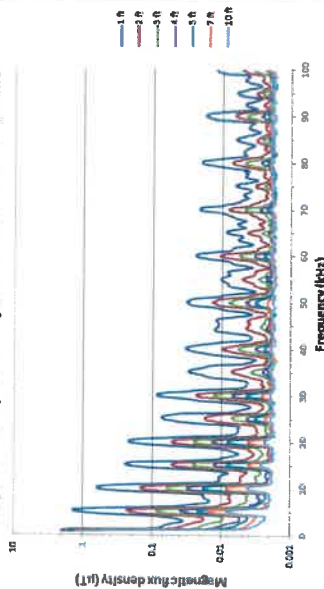


Figure 4-40
Magnetic Field Spectrum Adjacent to Inverter in San Bernardino at Different Distances

Using an active monopole antenna, electric field strengths were measured from 500 kHz to 30 MHz on the roof and at ground level at 3 feet from the inverter. These data shown in Figure 4-41 show that, depending on frequency, stronger fields are found near the inverter than away from it.

A more detailed look at the 10 kHz to 100 kHz band electric fields, using the active monopole antenna connected to the spectrum analyzer is shown in Figure 4-42. The harmonics of the switching frequency, beginning at 10 kHz, are seen to be as great when measured near one of the combiner boxes as near the inverter itself. This suggests that voltage differences across various cables within the combiner box, none of which are shielded, can give rise to greater local electric field strengths than the rather well shielded inverter cabinet.

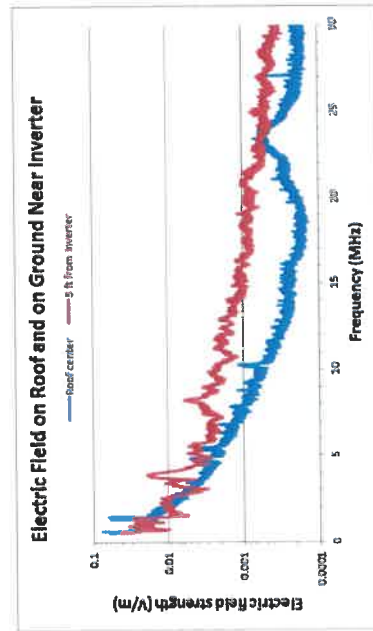


Figure 4-41
Electric Field Strength Across the Spectrum from 500 kHz to 30 MHz Measured on the Roof of the San Bernardino Building and at Three Feet in Front of the Ground Mounted Inverter

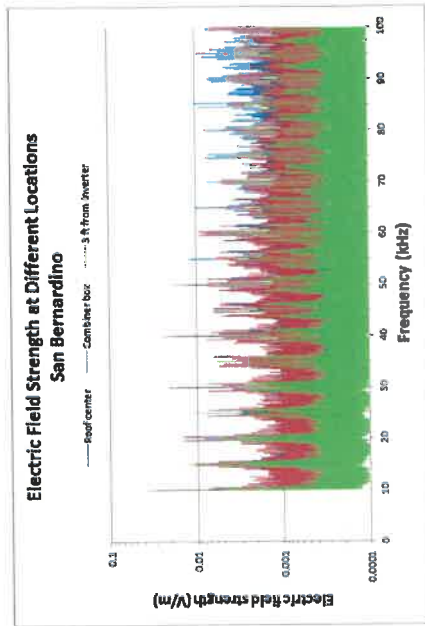


Figure 4-42
Electric Field Strength Measured at the Center of the San Bernardino Building Roof, Near a Combiner Box on the Roof and at Three Feet in Front of the Ground Mounted Inverter

Discussion of RF Measurement Results

The measurement of RF fields at the two solar generation facilities clearly reveals that the inverter switching frequency of 5 kHz is a dominant source of magnetic fields and to a lesser extent electric fields. This was evident when magnetic fields were measured at different distances from the inverter cabinet and when compared with field measurements performed near combiner boxes and DC cables. A higher resolution spectrum analysis of the switching frequency magnetic field, showing multiple frequency fields, centered about 5 kHz, is likely associated with the fact that the inverter is a three-phase inverter.

Maximum low frequency magnetic fields were observed to be directly correlated with the location of the inverter switching electronics. Figure 4-43 shows the inverter model used at both the Porterville and San Bernardino solar generation facilities. Labels show the DC input section on the left, two central switching units that make use of insulated gate bipolar transistor (IGBT) circuits, each one designed to output up to 250 kW of AC power, and the AC output section on the right. Contained within the two central units are the IGBT switching assemblies shown in Figure 4-44.

These units are located directly behind the red dots shown in Figure 4-43 that identify the points of maximum measured magnetic fields.

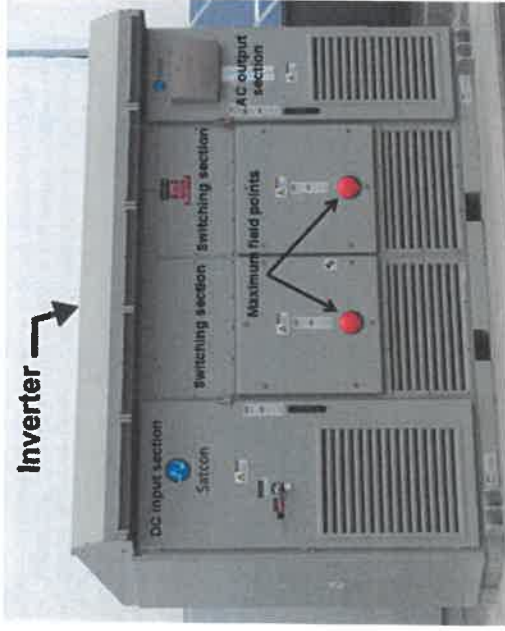


Figure 4-43
Inverter Showing the DC Input Section, the Inverting Circuit Sections and the AC Output Section - DC cables brought in from underneath the unit feed the DC input section.

Magnetic fields are greatest at the front surface of the inverter and decrease rapidly with increasing distance from the inverter. Magnetic flux densities at the surface were found to be as great as $40 \mu\text{T}$ when the inverter is operating at near its rated capacity of 500 kW. Electric field strength is, at most, a few volts per meter.

Low level, but easily detectable, RF fields across a broad range of frequencies up through 20 MHz were observed close to the inverters. While minute from a human hazard perspective, they could be the source of interference to radio communications in the immediate area. RF emissions were not evident above approximately 30 MHz.

Currents associated with the 5 kHz switching frequency of the inverter were observed to produce weak but detectable magnetic fields near the DC cables connected to solar panels and combiner boxes.

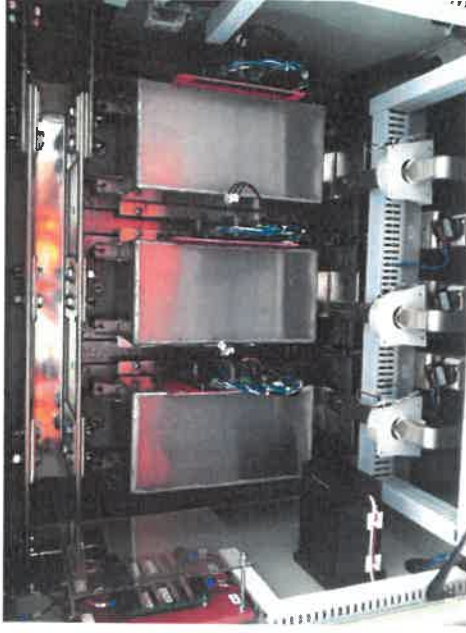


Figure 4-44
Interior Photo of the Inverter Showing the Location of IGBT (insulated gate bipolar transistor) Switching Circuitry that Chops the DC Current at a Rate of Approximately 5 kHz - Two identical sections like this one (each one capable of 250 kW) provides for an inverter rating of 500 kW. Each section produces a three phase output (bus bars seen below). Photo courtesy of Jermaine Woodall from Southern California Edison.

Section 5: Summary and Conclusions

Field measurements were performed at two large photovoltaic energy generation facilities to characterize occupational exposure to various frequencies of electric and magnetic fields. These facilities included a large scale (5 MW) ground-based solar farm and an industrial warehouse rooftop photovoltaic facility (1.42 MW). Field measurements were conducted near various components and equipment associated with each facility, including photovoltaic panels (or solar arrays), "J"-boxes, DC connecting cables, combiner boxes (fused with disconnect switches), DC fuse boxes, DC to AC inverters, power transformers, switchgear, and AC power cables.

Characterization measurements were performed twice at the ground-based solar generation facility. Initially cloudy weather conditions caused the output of the facility to be very low (approximately 350 to 450 kW total power output). Therefore, measurements were repeated during summertime weather conditions when the output of the facility was close to maximum (approximately 4 to 4.9 MW total power output).

Static and Power-Frequency Field Results

DC Magnetic Fields

Photovoltaic panels, "J"-boxes, DC cabling, and combiner boxes are equipment which generate or utilize direct current. However, none of this equipment is a significant source of occupational DC magnetic field exposure. Measured DC magnetic fields around this equipment rarely exceeded 1 Gauss, even within 1-inch of the equipment. AC power cables and switchgear utilize AC power (rather than direct current) and therefore are also not significant DC magnetic field sources.

For DC magnetic fields, a prominent source of occupational exposure is the DC to AC inverter. Since inverters are the conversion point for DC to AC current, all generated DC current flows through this equipment. Therefore, this equipment can be a significant DC magnetic field source in close proximity to the equipment (depending upon the DC load and the measurement location at the enclosure). Measured DC magnetic fields varied from an ambient level of about 516 to 615 mG to as low as 184 mG (due to field cancellation) and as high as 2,770 mG. Next to an inverter, DC magnetic fields can also have significant DC magnetic field fluctuations in field strength, varying constantly as shown in Figure 5-1. However, the DC field attenuates quickly with distance away from

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the inverter and reached ambient levels within about 1 to 2-feet away from the inverter.

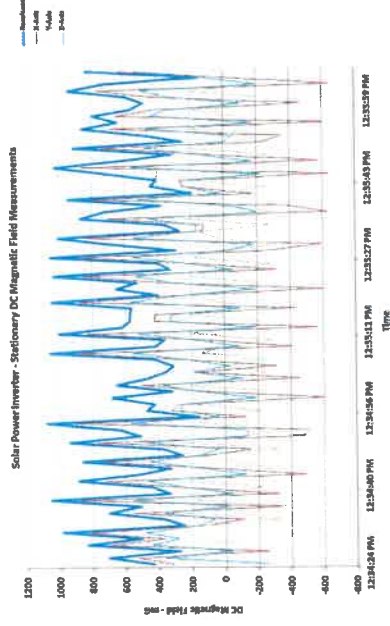


Figure 5-1
DC Magnetic Field Fluctuations at Stationary Location Near Inverter

Another significant source of DC magnetic field is the DC fuse box, since DC current from individual groups of solar arrays are routed into the fuse box.

Measured DC magnetic fields near the fuse box ranged from 110 to 1,709 mG depending upon the load and the measurement location. Similar, but lesser DC magnetic field levels were observed in the DC cables themselves (308 mG to 1,034 mG).

Measured DC magnetic fields in close proximity to the pad-mounted AC power transformers were also elevated (up to 2,582 mG). However, elevated DC magnetic fields are probably due to the concentration of the earth's static field within the transformer core and housing, which are large metallic objects, and not generated from the equipment itself.

AC Magnetic Fields

Because solar panels, connecting cables, combiner boxes, and fuse boxes utilize DC current, none of this equipment is a significant source of occupational AC magnetic field exposure. Measured AC magnetic fields rarely exceeded a few mG, even within 1-inch of the equipment. Typically the presence of other nearby AC sources influenced the AC magnetic field readings near this equipment.

The major sources of AC magnetic fields associated with a photovoltaic energy generation facility are the AC power cables, inverters, transformers, and

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switchgear. In close proximity to AC power cables and switchgear cabinets, measured AC magnetic fields reached about 412 mG and 432 mG respectively. However, the AC field attenuated quickly with distance and decreased to a few mG at a distance of several feet away from the equipment. Fields from inverters and transformers can be stronger, reaching measured levels of over 1,000 mG (1 Gauss) to almost 2,000 mG (2 Gauss) close to the equipment. The AC field from inverters and transformers also attenuated at a slower rate than power cables and the measured field decreased to about 10 mG or less within 8 to 10-feet away from this equipment. However, this rate of field decay is typical for equipment such as transformers [2]. In addition, the "J"-box mounted underneath of the solar panels exhibited a field of almost 50 mG within 1-inch of this device (presumably due to internal electronics).

AC Electric Fields

None of the equipment measured exhibited significant AC electric field levels (the largest AC electric field reading was about 16 V/m (or 0.016 kV/m) near a pad-mounted transformer. All of the equipment associated with photovoltaic energy generation facilities is typically housed within conduits, cabinets, enclosures, or casings which shield the AC electric field.

Summary of DC Magnetic Field and AC Electric and Magnetic Field Measurements

Table 5-1 presents a summary of the DC magnetic field and AC electric and magnetic field measurement results at both of the solar generation facilities surveyed.

Table 5-1
Summary of Photovoltaic Facility Equipment and Measurement Results

Location or Equipment	Static DC Magnetic Field (mG)	60 Hz Electric Field (kV/m)	60 Hz Magnetic Field (mG)	Dominant AC Magnetic Field Frequency (30 – 1500 Hz)
Ambient	516 - 615	0.000	0.0 - 0.1	30/60 Hz
Solar Panel	479 - 601	0.000	0.0 - 0.2	30 Hz
"J"-Box	358 - 811	0.000	0.4 - 49.2	60/120/180 Hz
DC Cables	308 - 1,034	0.000	0.1 - 11.0	60 Hz
AC Power Cables	211 - 654	0.000	0.5 - 412.8	60/300 Hz
DC Combiner Box	348 - 756	0.000	0.1 - 2.5	60/360 Hz
DC Fuse Box	110 - 1,709	0.000	2.5 - 47.3	60 Hz
Inverter	184 - 2,770	0.010	6.1 - 1,131	60/300/360 Hz
Transformer	614 - 2,582	0.016	8.3 - 1,767	60 Hz
Switchgear	41 - 959	0.000	9.7 - 432	60 Hz

◀ 5.3 ▶

Static and Power-Frequency Field Standards

DC Magnetic Field Standards

DC magnetic fields are encountered in everyday life. The earth has a static magnetic field of about 480 to 560 mG within the United States [3]. DC magnetic fields are also present near permanent magnets (which can include equipment such as refrigerator magnets, can openers, audio speakers, and headphones), electromagnetic equipment (such as magnetic resonance imaging equipment or MRI's, portable drills, and commercial degaussing units), and electrical transportation systems (such as electric trains or light rail systems) which utilize overhead DC carrier wires to provide energy for trolleys and passenger cars.

Presently, there are no state or federal health-based standards for limiting exposure to DC magnetic fields. However, exposure limits have been established or recommended by several different organizations. These address magnetic field exposure for a variety of conditions, including occupational exposure. In some cases, DC magnetic field exposure limits are focused on preventing interference to implanted medical devices.

The American Conference of Governmental Industrial Hygienists (ACGIH) has published "Threshold Limit Values" for occupational exposure to DC magnetic fields [4]. Field levels are specified for both whole body and limbs, and for time-weighted averages as well as maximum limits. Guidelines are also provided for workers with cardiac pacemakers - recommended exposures should not exceed 5 Gauss. Table 5-2 presents a summary of the ACGIH guidelines for DC magnetic fields.

Another organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has developed guidelines for DC magnetic fields, but not specific to persons with implanted medical devices [5]. Table 5-3 presents a summary of the ICNIRP guidelines for DC magnetic fields.

In addition, the Institute of Electrical and Electronics Engineers (IEEE) provides recommendations for DC magnetic fields [6]. These recommendations are specified for both the general public and in controlled environments,¹ but not specific to persons with implanted medical devices. Table 5-4 presents a summary of the IEEE guidelines for DC magnetic fields.

Some implanted medical device manufacturers have also reported recommendations for their equipment which are comparable to the ACGIH limits for magnetic fields and higher limits for electric fields (for example, 5 Gauss for static magnetic fields).

¹ Controlled Environment is defined by the IEEE as "An area that is accessible to those who are aware of the potential for exposure as a concomitant of employment to individuals cognizant of occupational adverse effects, or where exposure is the incidental result of passage through areas posted with numerous signs, where the environment is not accessible to the general public and those individuals having access are aware of the potential for adverse effects." (IEEE 2002)

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Based upon the DC magnetic field measurements conducted at both photovoltaic facilities, field levels were below any of these DC magnetic field guidelines. The most significant source of DC magnetic field was the DC to AC inverter. In very close proximity to this equipment (within 1-inch), the highest measured DC magnetic field was in the range of about 2.8 Gauss. This level is below the guidelines listed for the general public and for workers with implanted medical devices.

Table 5-2
ACGIH – Occupational DC Magnetic Field Exposure Guidelines

Exposure	8-Hour TWA	Ceiling
Whole body	600 Gauss (600,000 mG)	20,000 Gauss (20,000,000 mG)
Limbs	6,000 Gauss (6,000,000 mG)	50,000 Gauss (50,000,000 mG)
Cardiac pacemaker devices		5 Gauss (5,000 mG)

Table 5-3
ICNIRP – DC Magnetic Field Exposure Guidelines: Occupational and General Public

Exposure	DC Magnetic Field
Magnetic fields up to 1 Hz - Occupational	20,000 Gauss (20,000,000 mG)
Magnetic fields up to 1 Hz - General Public	4,000 Gauss (4,000,000 mG)

Reference levels are intended to be spatially distributed over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded.

Table 5-4
IEEE – DC Magnetic Field Maximum Permissible Exposure

Exposure	DC Magnetic Field
General public	118 G (1,1180,000 mG) (< 0.153 Hz)
Controlled environment	353 G (3,530,000 mG) (< 0.153 Hz)

However, the potential for interference on other types of pacemakers and implanted medical devices from DC magnetic fields depends on a number of different parameters, including the type of implanted device, the manufacturer, model, and implantation method, among other factors. Typically implanted medical devices are set specifically for an individual by their doctor or physician within the doctor's office or medical facility. As with any implanted medical device, the user should always consult with their doctor and the device manufacturer to determine safe operational parameters for use of their specific medical device and associated medical condition.

AC Electric and Magnetic Field Standards

Presently, due to a lack of scientific evidence establishing health effects resulting from power-frequency electric and magnetic field exposure, there are no state or federal health-based standards for limiting exposure to those fields. However, as with DC magnetic fields, exposure limits have been established or recommended by several different organizations. These address both electrical field and magnetic field exposure for a variety of conditions, and in some cases, exposure limits for workers with implanted medical devices.

In the "Threshold Limit Values" published by the ACGIH [4], recommended occupational exposures should not exceed 25 kV/m for AC electric fields and 10,000 mG for AC magnetic fields. Above 15 kV/m, the ACGIH recommends the use of protective clothing. For workers with cardiac pacemakers, recommended exposures should not exceed 1 kV/m for AC electric fields and 1,000 mG for AC magnetic fields. Table 5-5 presents a summary of the ACGIH guidelines for AC electric and magnetic fields.

Table 5-5
ACGIH – Occupational Threshold Limit for 60-Hertz Electric and Magnetic Field Exposure

Exposure	AC Electric Field	AC Magnetic Field
Occupational exposures should not exceed	25 kV/m (from 0 Hz to 100 Hz)	10 Gauss (10,000 mG)
For workers with cardiac pacemakers or similar medical electronic devices, maintain exposure at or below	1 kV/m (1,000 V/m)	1 Gauss (1,000 mG)

ICNIRP has also developed guidelines for AC electric and magnetic fields [5], but not specific to persons with implanted medical devices. Table 5-6 presents a summary of the ICNIRP guidelines for AC electric and magnetic fields.

Table 5-6
ICNIRP – Reference Levels for Time-Varying 60-Hertz Electric and Magnetic Fields

Exposure (60 Hz)	Electric Field	Magnetic Field
Occupational	8,333 kV/m (8,333 V/m)	10 G (10,000 mG)
General public	4,167 kV/m (4,167 V/m)	2 G (2,000 mG)

Reference levels are intended to be spatially distributed over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded.

IEEE also provides recommendations for electric and magnetic fields [6]. These recommendations are again specified for both the general public and in controlled environments,² but not specific to persons with implanted medical devices. Table 5-7 presents a summary of the IEEE guidelines for AC electric and magnetic fields.

Table 5-7
IEEE – AC Electric and Magnetic Field Maximum Permissible Exposure

Exposure (60 Hz)	Electric Field	Magnetic Field
General public	5 kV/m (5,000 V/m) ^{a,d} (from 1 Hz to 368 Hz) ^c	9.04 G (9,040 mG) (from 20 Hz to 759 Hz)
Controlled environment	20 kV/m (20,000 V/m) ^{b,c} (from 1 Hz to 272 Hz) ^c	27.1 G (27,100 mG) (from 20 Hz to 759 Hz)

- a – Within power line right-of-way, the MPE for the general public is 10 kV/m under normal load conditions.
b – Painful discharges are readily encountered at 20 kV/m and are possible at 5 – 10 kV/m without protective measures.
c – Limits below 1 Hz are not less than those specified at 1 Hz.
d – At 5 kV/m induced spark discharges will be painful to approximately 7% of adults (well-insulated individual touching ground).
e – The limit of 20,000 V/m may be exceeded in the controlled environment when a worker is not within reach of a grounded conducting object. A specific limit is not provided for this standard.

The International Committee on Electromagnetic Safety (ICES) published a guideline recommending AC magnetic field levels below 9,040 mG, based on the IEEE general public exposure value [7]. Some implanted medical device manufacturers have also reported recommendations for their equipment which are comparable to the ACGIH limits for magnetic fields and higher limits for

² Controlled Environment is defined by the IEEE as "An area that is accessible to those who are aware of the potential for exposure as a concomitant of employment, to individuals cognizant of exposure and potential adverse effects, or where exposure is the incidental result of passage through areas posted with warnings, or where the environment is not accessible to the general public and those individuals having access are aware of the potential for adverse effects." (IEEE 2002)

electric fields (for example, 6 kV/m for 60 Hz electric fields and 1 Gauss for 60 Hz magnetic fields).

Based upon the AC electric field measurements conducted at both photovoltaic facilities, field levels were below any of the AC electric field guidelines cited. Since the electrical equipment are located within metal enclosures or, like the AC power cables buried underground, electric field levels within photovoltaic facilities are very low.

Based upon the AC magnetic field measurements conducted at both photovoltaic facilities, field levels were below the occupational AC magnetic field guidelines (10 – 27.1 Gauss). However, in very close proximity to some of the AC electrical equipment (particularly the DC to AC inverters and the pad-mounted transformers), measured AC magnetic field levels in close proximity to this equipment can exceed the 1,000 mG threshold recommended for workers with implanted medical devices. Measured AC magnetic fields near the switchgear and AC power cables were below the pacemaker threshold (about 450 mG), but care should be exercised for workers with implanted medical devices as loading will directly influence AC magnetic field levels around this type of equipment.

As was the case for DC magnetic fields, the potential for interference on other types of pacemakers and implanted medical devices from AC magnetic fields depends on a number of different parameters, including the type of implanted device, the manufacturer, model, and implantation method, among other factors. Typically implanted medical devices are set specifically for an individual by their doctor or physician within the doctor's office or medical facility. As with any implanted medical device, the user should always consult with their doctor and the device manufacturer to determine safe operational parameters for use of their specific medical device and associated medical condition.

Radio-Frequency Field Results

Measurements of RF electric and magnetic fields (nominally above 1 kHz in frequency) were accomplished at a Porterville, California solar generation facility (5 MW rated capacity at full output) during two visits in November 2011 and July 2012 and at a large warehouse rooftop solar generation facility (2.5 MW rated capacity at full output) in San Bernardino, California in May 2012. The measurements performed with instrumentation capable of spectrum analysis of detected electric and magnetic fields across the frequency range of 1 kHz to 100 kHz and electric fields from 100 kHz to 3 GHz.

Measurements revealed that the principal sources of detectable RF fields associated with the solar facility equipment were the inverters that change direct current produced by solar panels into alternating current. The fundamental frequency component observed during measurements was at the 5 kHz switching rate of the 500 kW rated inverters. The greatest magnetic flux density of the 5 kHz field was 40.5 µT found at a single point on the surface of an inverter operating at near full output. The greatest 5 kHz electric field strength was measured to be 1.4 V/m at the inverter surface. At a distance of 1 foot (0.3 m)

from the inverter, magnetic flux density decreased to 2.5 μT with further reduction of field at greater distances.

Higher frequency RF measurements showed the production of broadband RF field noise up to approximately 30 MHz with little detectable energy above 30 MHz. The elevated RF energy also decreased rapidly with increasing distance from the inverter. The broadband RF fields could present the possibility of RF interference with nearby communications systems.

Radio-Frequency Field Standards

The RF electric and magnetic fields measured in this project were generally relatively weak by comparison to available recommended guidance on human exposure to such fields. Only the inverter surface magnetic field measurements exceeded the very stringent recommendations as a whole body exposure limit set by the International Commission on Non-ionizing Radiation Protection (ICNIRP, 2010). Table 5-8 provides the recommended guidance on limits for human exposure to the 5 kHz frequency range of the inverter magnetic fields from ICNIRP and the Institute of Electrical and Electronic Engineers (IEEE, 2005). The values within the table, except for the limbs from IEEE, are intended as whole-body values with the assumption that the field is essentially uniform over the body dimensions. At a distance of one foot from the inverter surface, the measured magnetic flux density was found to be reduced to the order of 2 - 3 μT . It is relevant to note that the maximum flux density found at the surface of an inverter was highly localized to a specific point; movement of the sensing probe away from this point showed greatly reduced magnetic field values. Hence, though not quantified during these measurements, the higher surface value of magnetic field is not representative of what the whole-body average value would be. As stated in the ICNIRP guidelines:

"Reference levels have been determined for the exposure conditions where the variation of the electric or magnetic field over the space occupied by the body is relatively small. In most cases, however, the distance to the source of the field is so close that the distribution of the field is non-uniform or localized to a small part of the body. In these cases the measurement of the maximum field strength in the position of space occupied by the body always results in a safe, albeit very conservative exposure assessment."

In terms of potential electric field exposure to the lower frequency RF components of fields produced by the inverters (up to 30 MHz), all measured values were found to be very much less than the recommended limits in Table 5-8. The most stringent electric field strength limit is 83 V/m (for public exposure) and this value is substantially greater than any value found during the measurements by a factor of approximately 8 times and this was in the case of one inverter that exhibited the highest measured field strength at its surface. Above 30 MHz, measurements showed that maximum RF fields, in terms of peak values, were less than about 0.1% of the MPE designated by the FCC for such frequencies.

Table 5-8
Exposure Guidance Values for the Frequency Range of 3 kHz to 5 MHz

Guidance	Applicability	Occupational		General Public	
		E (V/m)	B (μT)	E (V/m)	B (μT)
ICNIRP	Whole body	170	1000	83	27
IEEE C95.1-2005	Head/neck	1842	615	614	205
IEEE C95.1-2005	Limbs		1130		1130

Section 6: References

1. Institute of Electrical and Electronics Engineers (IEEE). *IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines*. IEEE Standard 644-1994. IEEE, 3 Park Avenue, New York, NY 10016-5997.
2. *Characterization of Magnetic Fields from Power Distribution Transformers*. EPRI, Palo Alto, CA:2009. 1019010.
3. Merrill, R.T., and McElhinny, M.W. 1983. *The Earth's Magnetic Field*. International Geophysics Series -Vol. 32, New York: Academic Press.
4. American Conference of Governmental Industrial Hygienists (ACGIH) 2012. "Threshold Limit Values for Chemical Substances and Physical Agents", ISBN 978-1-607260-48-6.
5. International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2010. Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 10 kHz), *Health Physics*, 99(6): 818-836.
6. Institute of Electrical and Electronics Engineers (IEEE) 2002. IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz. IEEE Standard C95.6, New York, NY.
7. International Committee on Electromagnetic Safety (ICES) 2002. IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95. 6-2002. Piscataway, NJ: IEEE.
8. Institute of Electrical and Electronics Engineers (IEEE). *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*. IEEE Std. C95.1-2005. IEEE, 3 Park Avenue, New York, NY 10016-5997.

Appendix A: AC Magnetic Field Measurement Data

AC Magnetic Field Graphs at Porterville (350 - 450 kW Output)

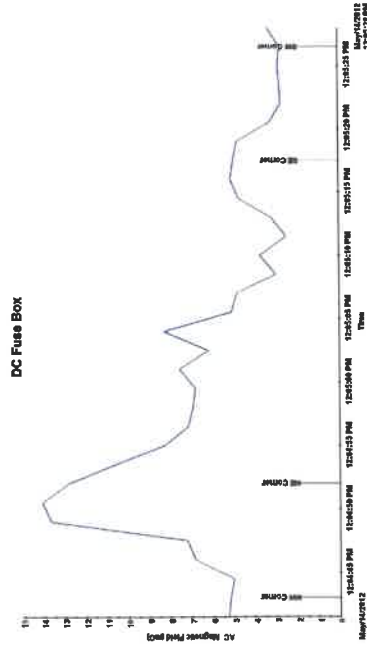


Figure A-1
Measured AC Magnetic Field Around DC Fuse Box

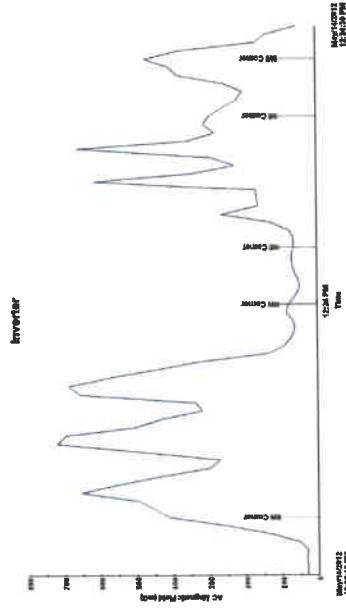


Figure A-2
Measured AC Magnetic Field Around Inverter

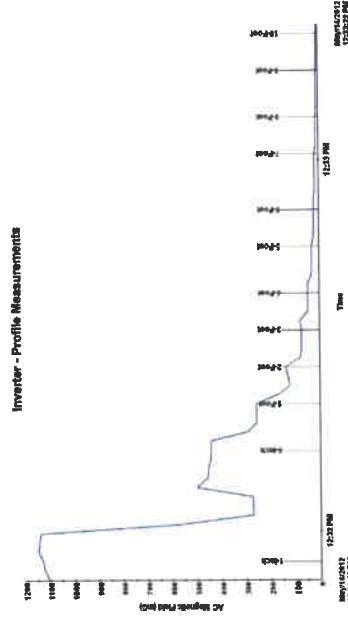
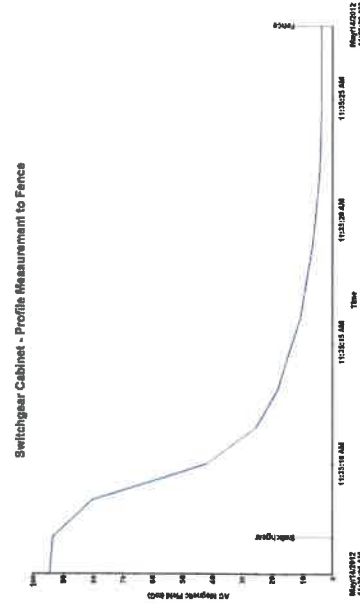
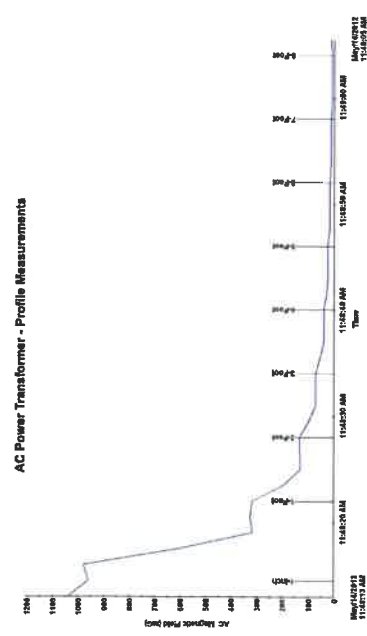
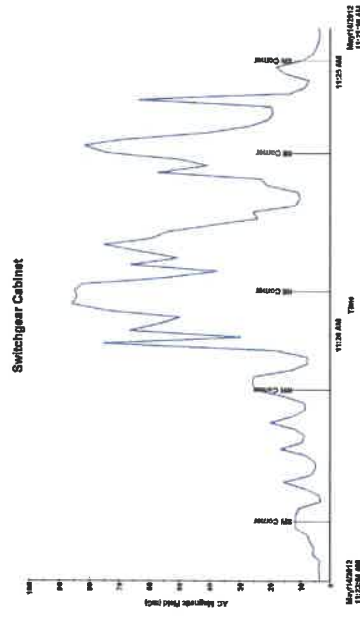
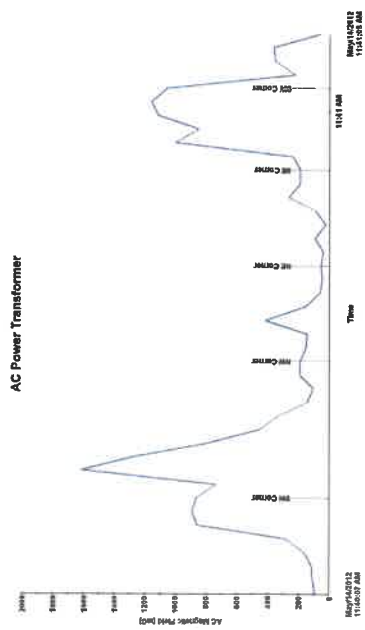


Figure A-3
Measured AC Magnetic Field Profile Away from Inverter



AC Magnetic Field Graphs at Porterville (4 - 4.9 MW Output)

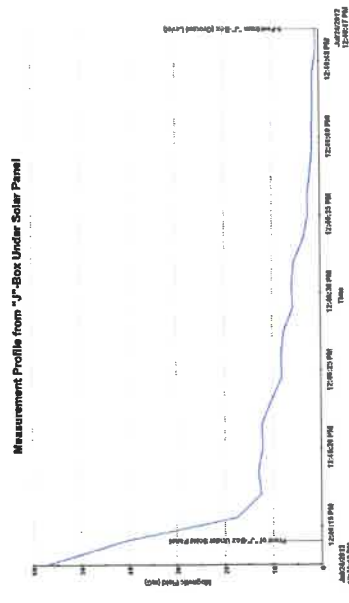


Figure A-8
Measured AC Magnetic Field Profile Away from "J"-Box Under Solar Panel

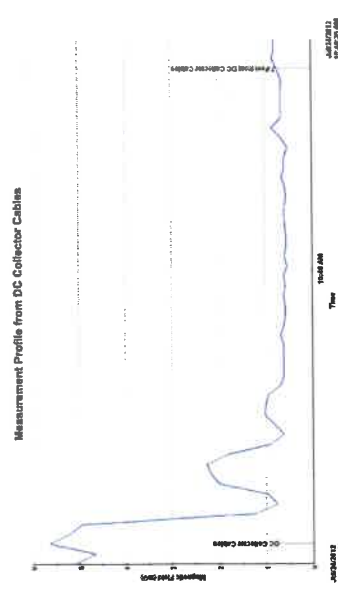


Figure A-6
Measured AC Magnetic Field Profile Away from DC Collector Cables

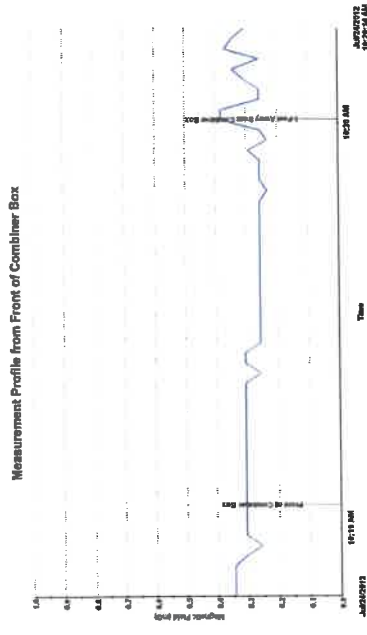


Figure A-10
Measured AC Magnetic Field Profile Away from DC Combiner Box

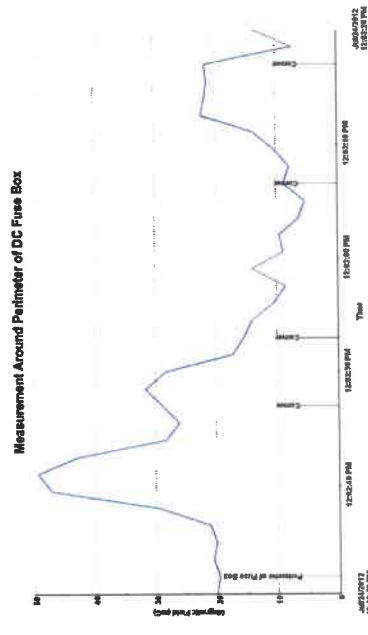


Figure A-11
Measured AC Magnetic Field Around Perimeter of DC Fuse Box

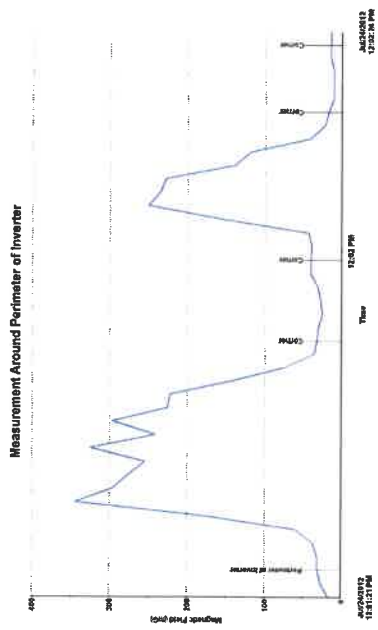


Figure A-12
Measured AC Magnetic Field Around Perimeter of Inverter

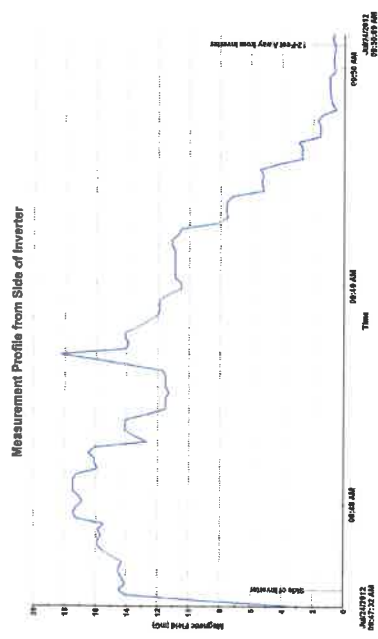


Figure A-13
Measured AC Magnetic Field Profile Away from Side of Inverter

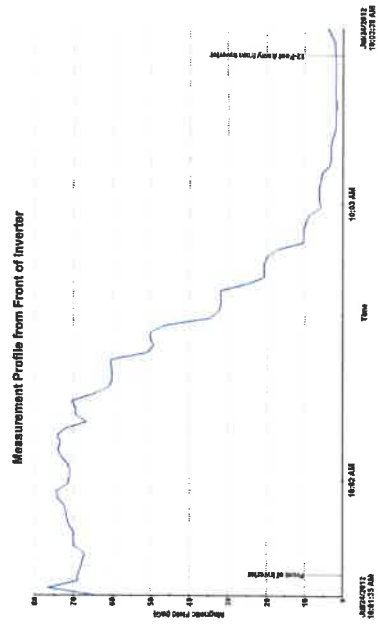


Figure A-14
Measured AC Magnetic Field Profile Away from Front of Inverter

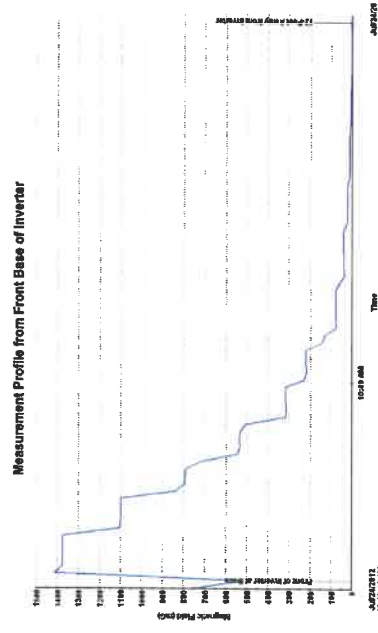


Figure A-15
Measured AC Magnetic Field Profile Away from Front Base of Inverter

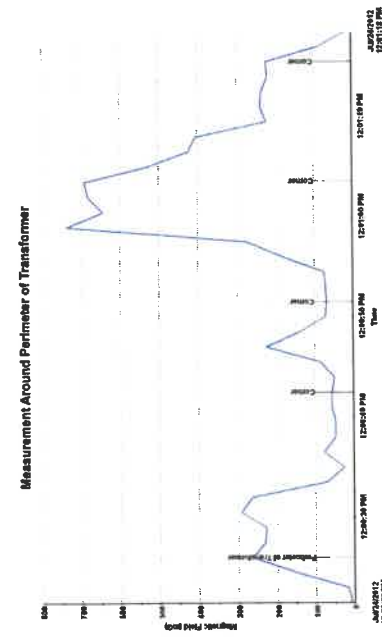


Figure A-16
Measured AC Magnetic Field Around Perimeter of Transformer

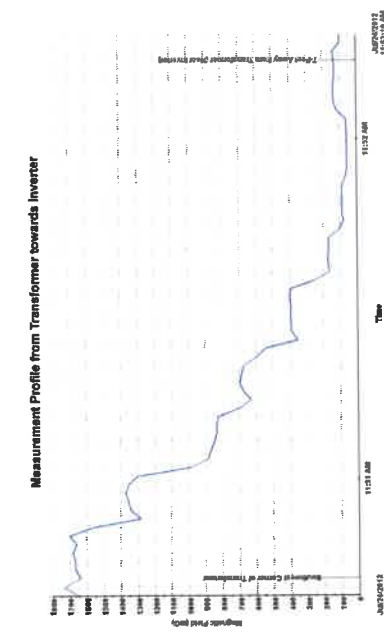


Figure A-17
Measured AC Magnetic Field Profile Away from Transformer Towards Inverter

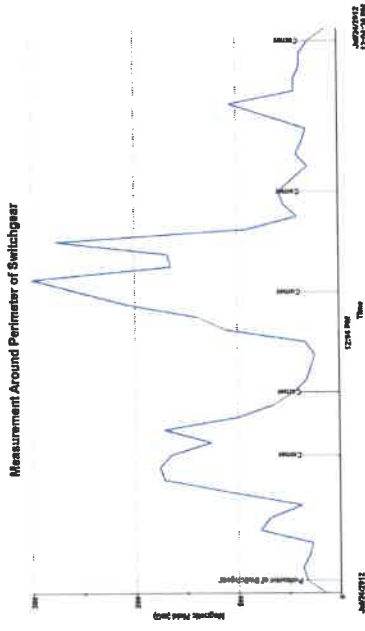


Figure A-18
Measured AC Magnetic Field Around Perimeter of Switchgear

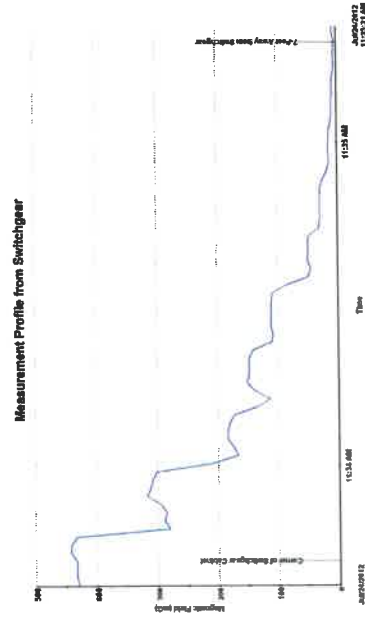


Figure A-19
Measured AC Magnetic Field Profile Away from Switchgear

Measurement Profiles Across DC and AC Underground Cables

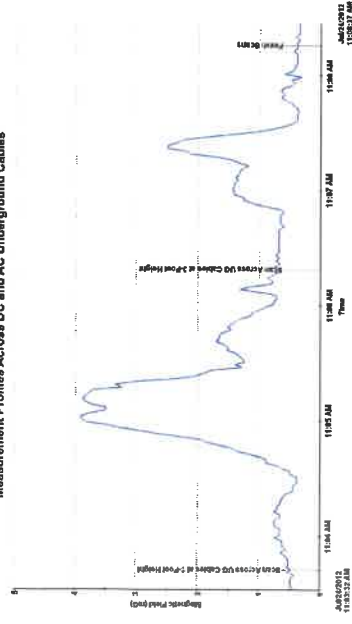


Figure A-20
Measured AC Magnetic Field Profile Across DC and AC Underground Cables

Measurement Along Western Fence Line

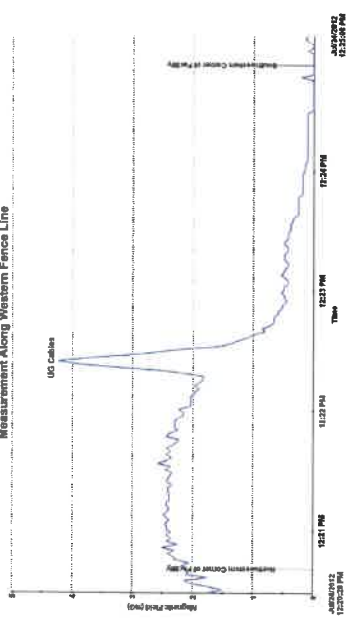


Figure A-21
Measured AC Magnetic Field Profile Along Western Facility Fence Line

AC Magnetic Field Graphs at San Bernardino (1.42 MW Output)

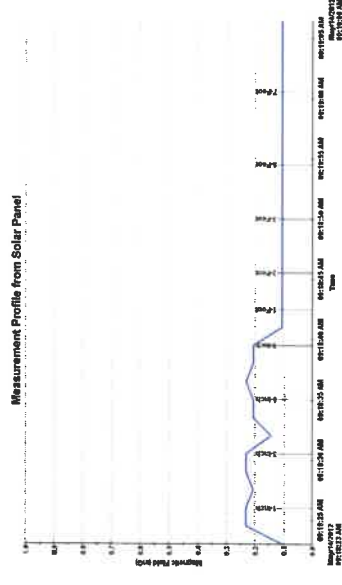


Figure A-22
Measured AC Magnetic Field Profile from Rooftop Solar Panel

Measurement Profile Away From DC Collector Pipe

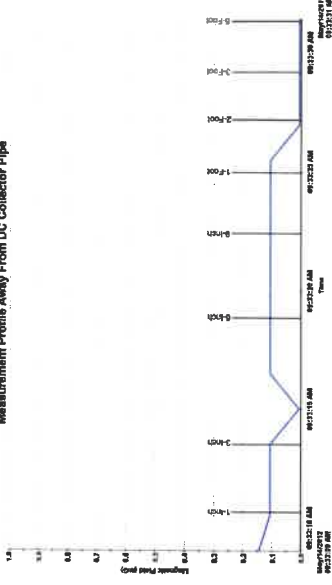


Figure A-23
Measured AC Magnetic Field Profile from Rooftop DC Collector Pipe

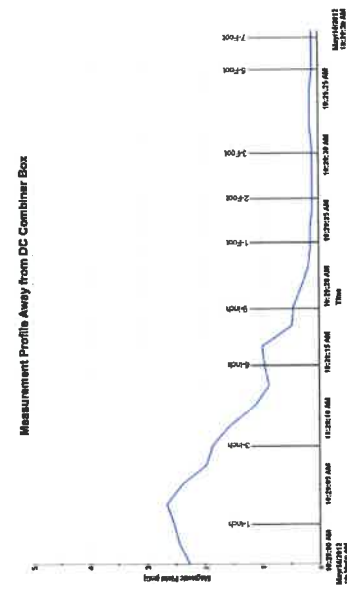


Figure A-24
Measured AC Magnetic Field Profile from Rooftop DC Combiner Box

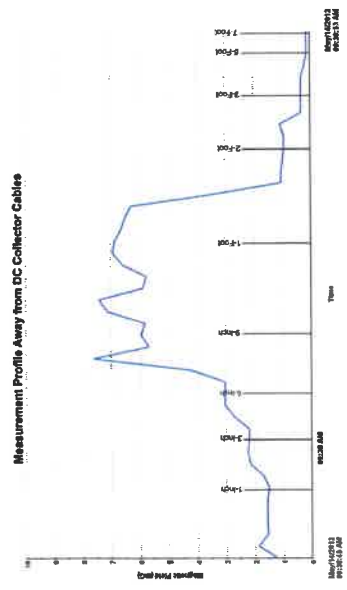


Figure A-25
Measured AC Magnetic Field Profile from Rooftop DC Collector Cables – South Side

◀ A-13 ▶

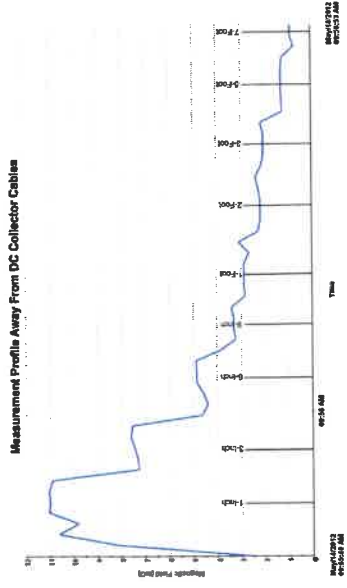


Figure A-26
Measured AC Magnetic Field Profile from Rooftop DC Collector Cables – North Side

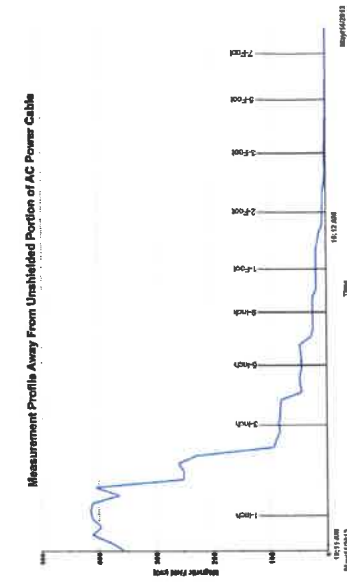


Figure A-27
Measured AC Magnetic Field Profile from Unshielded Portion of Rooftop AC Power Cable

◀ A-14 ▶

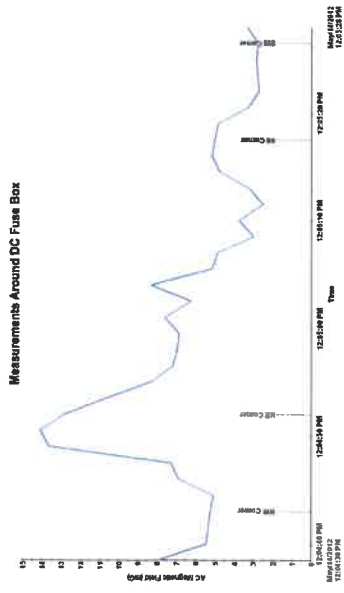


Figure A-28
Measured AC Magnetic Field Profile Around DC Fuse Box (3 Sides)

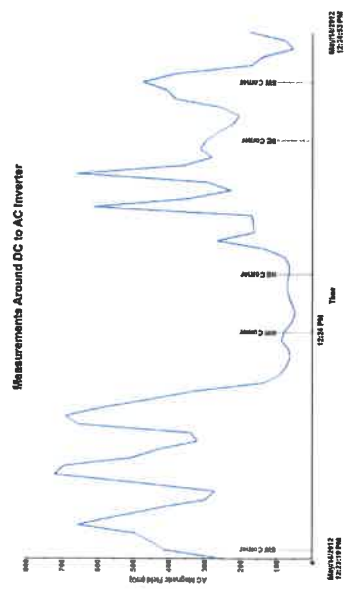


Figure A-29
Measured AC Magnetic Field Profile Around DC to AC Inverter

◀ A-15 ▶

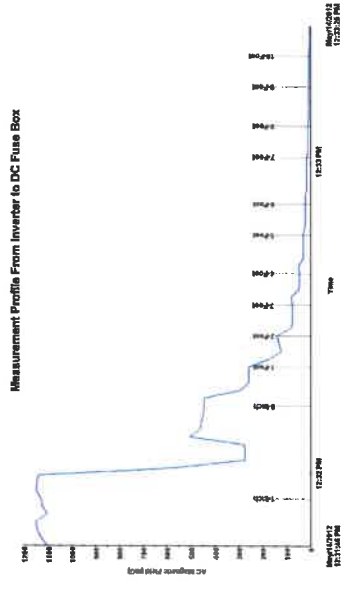


Figure A-30
Measured AC Magnetic Field Profile from Inverter to DC Fuse Box

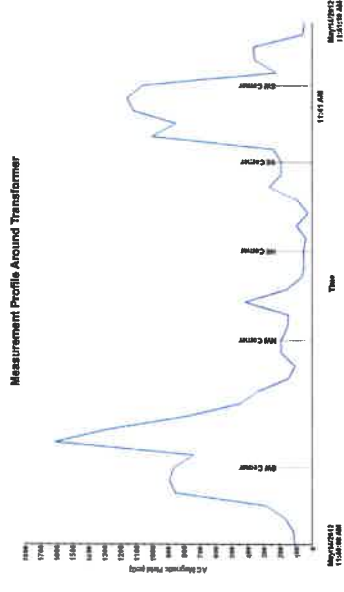


Figure A-31
Measured AC Magnetic Field Profile Around Transformer

◀ A-16 ▶

Measurement Profile Away From Transformer

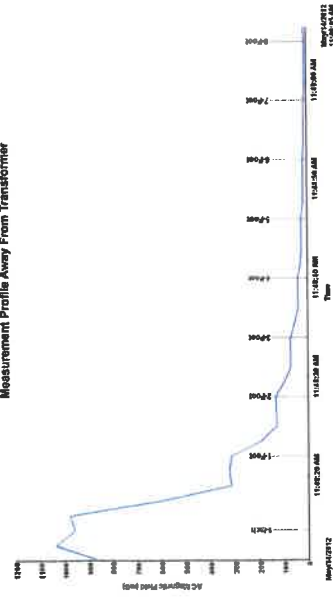


Figure A-32
Measured AC Magnetic Field Profile Away from Transformer

Measurement Profile From Switchgear to Fence

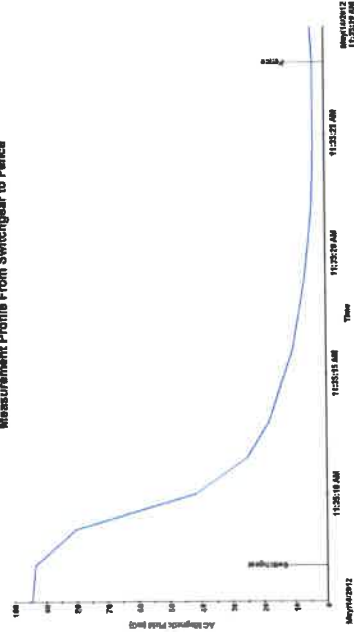


Figure A-34
Measured AC Magnetic Field Profile from Switchgear to Enclosure Fence

Measurement Profile Around Switchgear

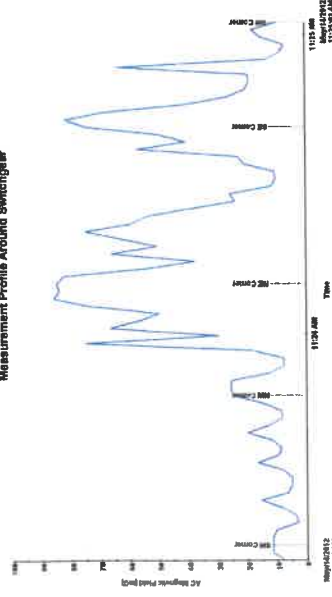


Figure A-33
Measured AC Magnetic Field Profile Around Switchgear

Appendix B: FFT Analysis of AC Magnetic Field Waveforms

FFT Analysis of AC Magnetic Field Waveforms at Porterville

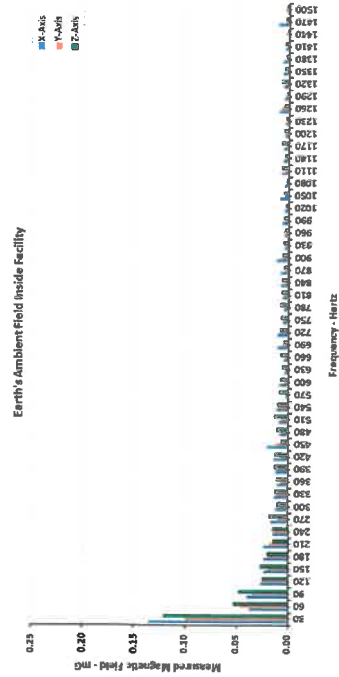


Figure B-1
Ambient Field Within the Photovoltaic Facility – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-1 ▶

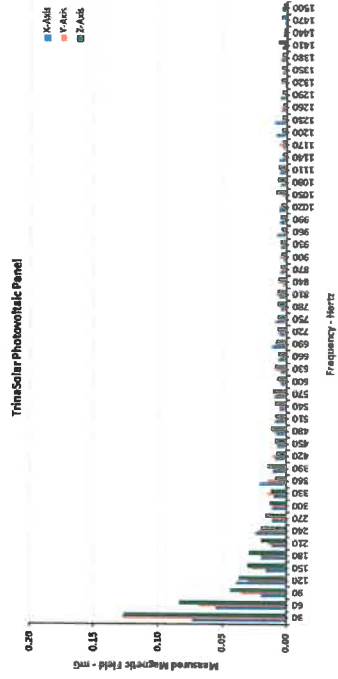


Figure B-2
Photovoltaic Panel – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

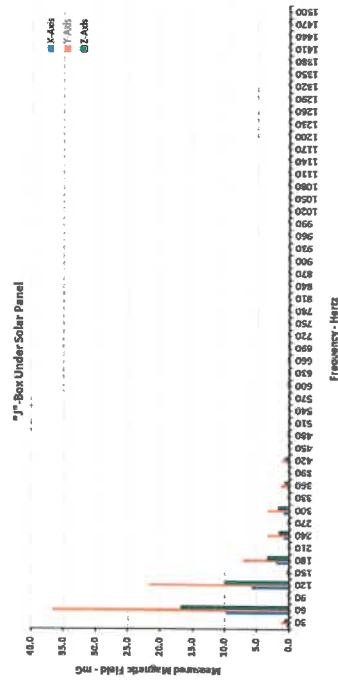


Figure B-3
"J"-Box – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-2 ▶

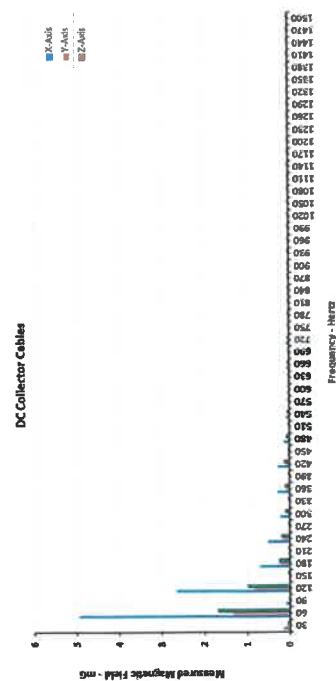


Figure B-4
DC Collector Cables - FFT Analysis of AC Magnetic Field Waveform (30 - 1500 Hz)

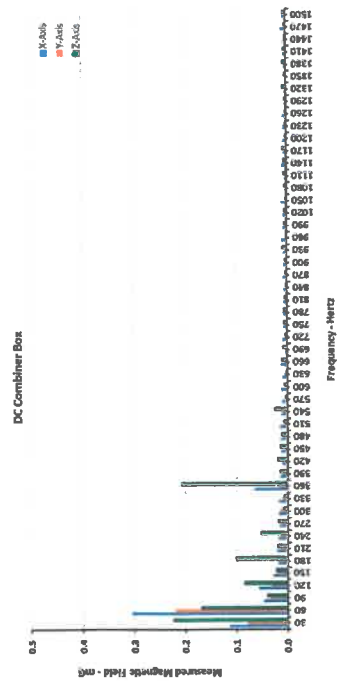


Figure B-5
DC Combiner Box - FFT Analysis of AC Magnetic Field Waveform (30 - 1500 Hz)

◀ B-3 ▶

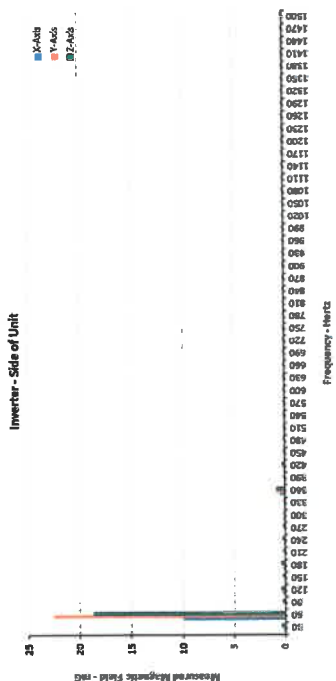


Figure B-6
Side of Inverter - FFT Analysis of AC Magnetic Field Waveform (30 - 1500 Hz)

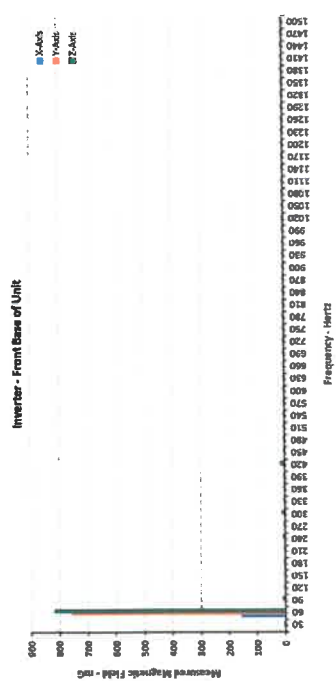


Figure B-7
Front Base of Inverter - FFT Analysis of AC Magnetic Field Waveform (30 - 1500 Hz)

◀ B-4 ▶

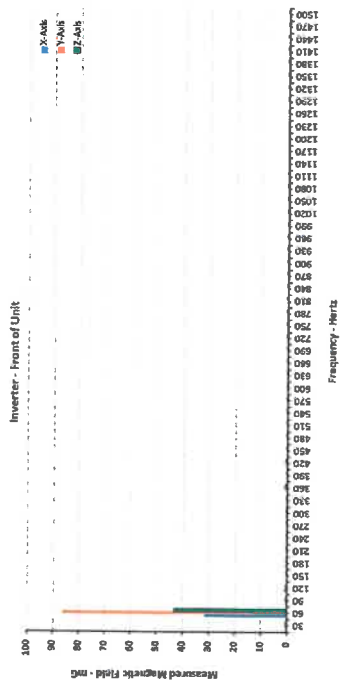


Figure B-8
Front Conifer of Inverter – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

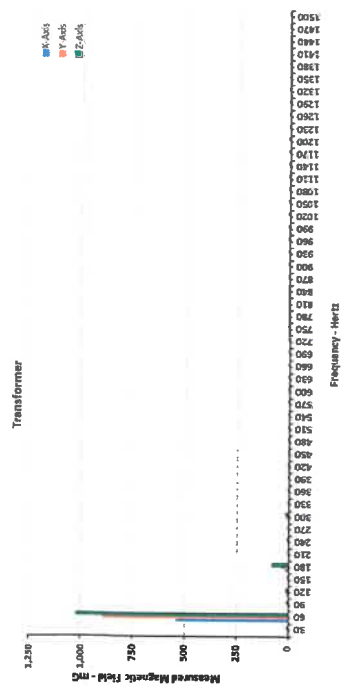


Figure B-9
Power Transformer – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

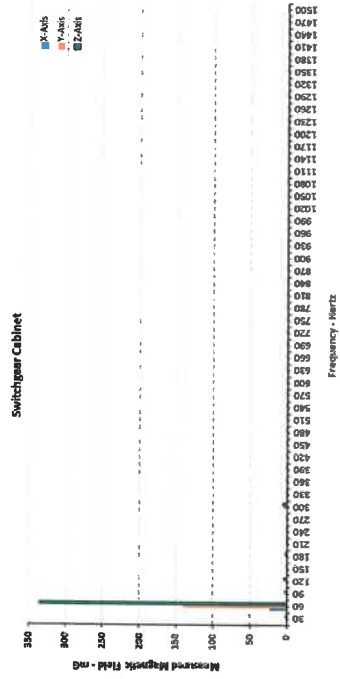


Figure B-10
Switchgear – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-5 ▶

◀ B-6 ▶

FFT Analysis of AC Magnetic Field Waveforms at San Bernardino

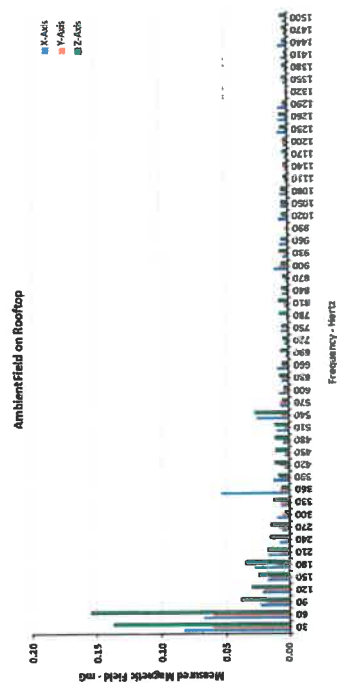


Figure B-11
Ambient Field on Rooftop – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

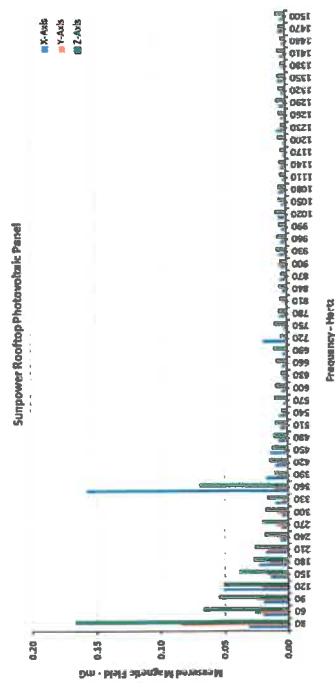


Figure B-12
Rooftop Solar Panel – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-7 ▶

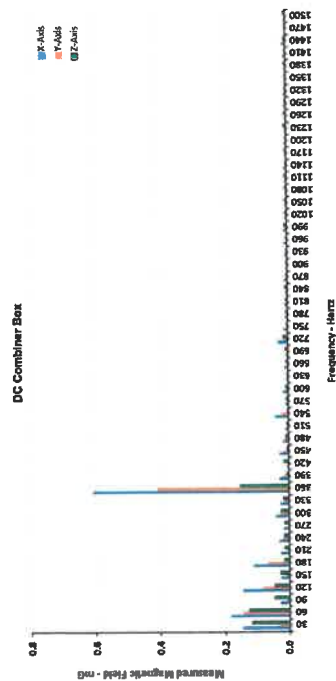


Figure B-13
Rooftop DC Combiner Box – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

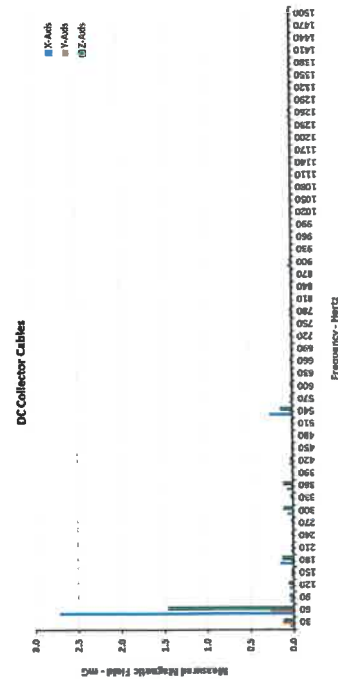


Figure B-14
Rooftop DC Collector Cables (South) – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-8 ▶

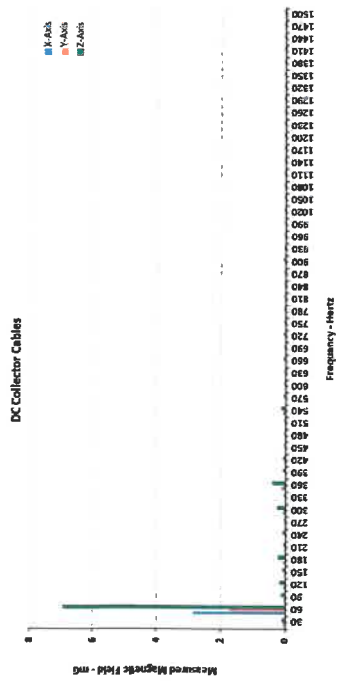


Figure B-15
Rooftop DC Collector Cables (North) – FFT Analysis of AC Magnetic Field
Waveform (30 – 1500 Hz)

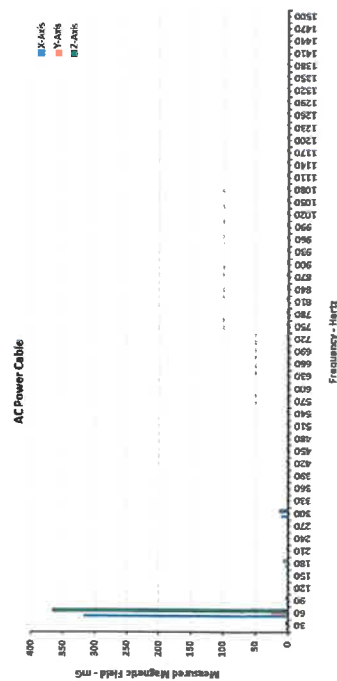


Figure B-16
Rooftop AC Power Cable – FFT Analysis of AC Magnetic Field Waveform (30 –
1500 Hz)

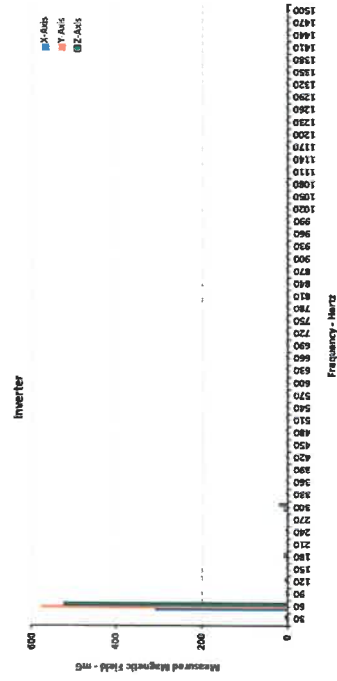


Figure B-17
Inverter – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

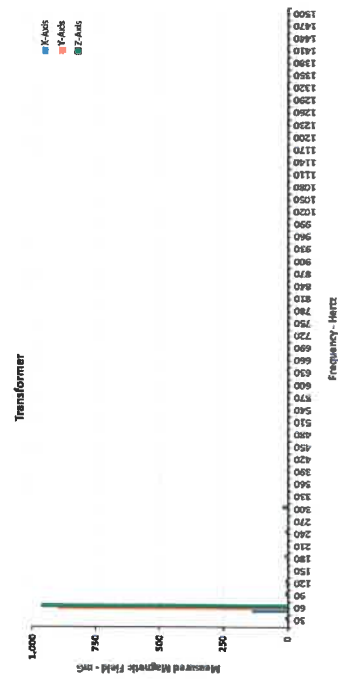


Figure B-18
Transformer – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

◀ B-9 ▶

◀ B-10 ▶

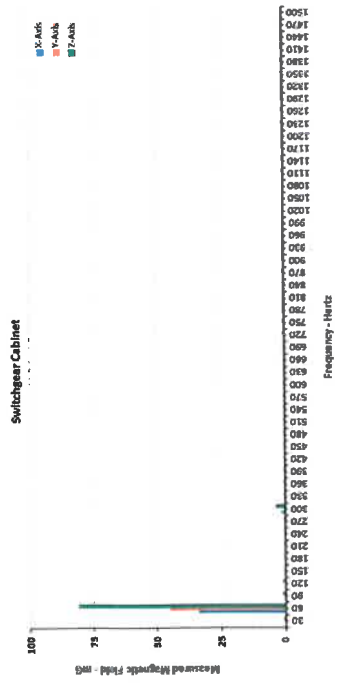


Figure B.19
Switchgear – FFT Analysis of AC Magnetic Field Waveform (30 – 1500 Hz)

Appendix C: Measurement Equipment
Calibration Documentation

Bartington®
Instruments
Certificate of Calibration

Instrument *Mag-03* Range *100* Serial No. *2485*

Results

PARAMETER	SPECIFIED	RESULTS	
		X	Y
Orthogonality Error	RMS and MRES versions $\pm 0.1^\circ$ All other versions $\pm 0.5^\circ$	$\pm 0.5^\circ$	$\pm 0.5^\circ$
Offset Error in Zero Field (aT)	Range (aT) Offset (aT) 45 ± 5 60 ± 5 70 ± 5 100 ± 5 250 ± 12 500 ± 25 1000 ± 50	$-1/2$	$3 1/2$
Scaling Error* (aT/SHz)	$\pm 0.5\%$	-0.06%	-0.03%
Scaling Error (mT/SHz)	$\pm 0.5\%$ Z Axis only		-0.03%
DC Measurement			
Frequency Response** (%)	$\pm 5\%$	-0.28%	-0.14%
Noise at 1 Hz (pTms/Hz)	Basic - 10-20 pTms/Hz Standard - 6-10 pTms/Hz Low noise - <5 pTms/Hz	6.6	6.6

* Measured at 35 Hz using a field of 100 μ T p-p.
** The response at 1 kHz referred to that at 35 Hz.

Calibration References

Bartington Mag-01 Magnetometer TE112 Serial No 0288
Bartington Mag Probe B TE113 Serial No 501
Bartington Solenoid with Current Source TE18 Serial No 001
Bartington DC Scaling Solenoid TE478

This certificate certifies that the above instrument has been fully tested and calibrated to the manufacturers published specification, due allowance having been made for the uncertainty of the measurements, in accordance with ISO10012.

The calibration was performed using working standards, which are subject to periodic verification, with the measurements being traceable to National Physical Laboratory Standards, except where none exist.

The calibration was performed in an ambient temperature of $23 (\pm 2)^\circ\text{C}$

Signature: *[Signature]* Approved Signatory

Date: *14/2/11* Recall Date: *14/2/11*

Bartington Instruments Ltd, 5, 10 & 11 Thorney Loop Business Park, Witney, Oxon, OX28 4DE, England

Figure C-1
Bartington DC Sensor - Certificate of Calibration for S/N #2485

Certificate of Calibration

Instrument: **Mag-03** **NC** Range: **1000µT** Serial No: **8372**.....

PARAMETER	UNIT UNDER TEST		
	X	Y	Z
Orthogonality error (%)	±0.5°	±0.5°	±0.5°
Offset in zero field (nT)	-2.1	8	-11.1
Scaling error (at 33 Hz) (%)	±0.03%	-0.11%	0.12%
Frequency response error at 1 Hz (%)	-0.86%	-1.16%	-0.96%
Noise at 1 Hz (pT/mV/Hz)	10.4	9.1	11.6

Calibration References

Bartington Mag-01 Magnetometer
Bartington Mag Probe B
Bartington Solenoid with Current Source
Bartington DC Scaling Solenoid

Serial No 0288
Serial No 501
Serial No 001
TE112
TE113
TE118
TE478

This certificate certifies that the above instrument has been fully tested and calibrated to the manufacturers published specification, due allowance having been made for the uncertainty of the measurements, in accordance with ISO10012.

The calibration was performed using working standards, which are subject to periodic verification, with the measurements being traceable to National Physical Laboratory Standards, except where noted.

The calibration was performed in an ambient temperature of 23 (±2) °C

Signature: *[Signature]* Approved Signatory

Date: **13/1/2012** Recall Date: **13/1/2014**.....

Bartington Instruments Ltd, 5, 10 & 11 Thamey Lane Business Park, Witney, Oxon, OX28 4JL, England

CC 1198 Issue 7

Figure C-2
Bartington DC Sensor – Certificate of Calibration for S/N #0872

◀ C-3 ▶

Certificate of Calibration

Instrument: **Mag-03** **NC** Range: **1000µT** Serial No: **4637**.....

PARAMETER	SPECIFIED	RESULTS		
		X	Y	Z
Orthogonality Error (%)	ISO and IEC61361 sections 4.0.12 All other sections ±0.5°	±0.5°	±0.5°	±0.5°
Offset Error in Zero Field (nT)	Range: (nT) 45 45 70 100 250 500 1000 450	C	-3	0.5
Scaling Error* (%)	±0.5%	0.14%	0.04%	0.11%
Frequency Response** (%)	±5%	-0.14%	-0.04%	0.11%
Noise at 1 Hz (pT/mV/Hz)	Block - 10-20 pT/mV/Hz Standard - 6-10 pT/mV/Hz Low noise - <6 pT/mV/Hz	8.5	8.6	8.1

* Measured at 33 Hz using a field of 100 µT peak-peak

** The response at 1 Hz is referred to that at 33 Hz.

Calibration References

Bartington Mag-01 Magnetometer
Bartington Mag Probe B
Bartington Solenoid with Current Source
Bartington DC Scaling Solenoid

Serial No 0288
Serial No 501
Serial No 001
TE112
TE113
TE118
TE478

This certificate certifies that the above instrument has been fully tested and calibrated to the manufacturers published specification, due allowance having been made for the uncertainty of the measurements, in accordance with ISO10012.

The calibration was performed using working standards, which are subject to periodic verification, with the measurements being traceable to National Physical Laboratory Standards, except where noted.

The calibration was performed in an ambient temperature of 23 (±2) °C

Signature: *[Signature]* Approved Signatory

Date: **13/1/2012** Recall Date: **13/1/2014**.....

Bartington Instruments Ltd, 5, 10 & 11 Thamey Lane Business Park, Witney, Oxon, OX28 4JL, England

CC 1004 Issue 14

Figure C-3
Bartington DC Sensor – Certificate of Calibration for S/N #2697

◀ C-4 ▶



EMDEX II
(STANDARD FIELD)
CERTIFICATE OF TESTING
OPERATIONS AND ACCURACY REPORT

Customer Name: enertech

Serial #: 1329 Unit Type: STD LIN: CUST

Basic Program Version: 3.0.0 Memory: 156K

Calibrated @ 50 Hz
Temperature: 25 °C / 77 °F
Relative Humidity: 20% - 60%

Magnetic Field Test:



ENERTECH Consultants
404 Schuman Avenue, Suite 2010
Great Neck, NY 11040
(408) 866-7246 FAX: (408) 866-7274
WWW.ENERTECH.NY

Actual Field (mG)		EMDEX II Readings (mG)	
Nominal (mG)			
3000		2995.2	X AXIS
2000		2000.0	
200		199.4	
20		19.8	
1		1.0	
3000		2995.1	Y AXIS
2000		1993.6	
200		198.4	
20		19.7	
1		1.0	
3000		2995.4	Z AXIS
2000		1993.1	
200		198.1	
20		19.3	
1		1.0	
Near Zero Field Test		0.0	RESULTANT
Electric Field Test:			
Nominal (mG)			
15.0 uA		15.00	EMDEX II Readings (uA)
1.5 uA		1.500	
0.15 uA		0.1500	
Ambient		0.0000	
Tester: <u>Richard Morris</u>		Inspector: <u>Richard Morris</u>	Date: <u>2-16-2012</u>

*The value of the Actual Magnetic Field is accurate to within +/-1.00% according to IEEE Standard 644-1994. The injected current, used for E-field calibration, is accurate accordingly to within +/-1.1%.

Rev: December 23, 2010

Figure C-4
EMDEX II Meter - Certificate of Calibration for S/N #1329 on 2/14/2012

< C-5 >

EMDEX II
(STANDARD FIELD)
CERTIFICATE OF TESTING
OPERATIONS AND ACCURACY REPORT

Customer Name: enertech

Serial #: 1322 Unit Type: STD LIN: CUST

Basic Program Version: 3.0.0 Memory: 156K

Calibrated @ 50 Hz
Temperature: 25 °C / 77 °F
Relative Humidity: 20% - 60%

Magnetic Field Test:



ENERTECH Consultants
404 Schuman Avenue, Suite 2010
Great Neck, NY 11040
(408) 866-7246 FAX: (408) 866-7274
WWW.ENERTECH.NY

Actual Field (mG)		EMDEX II Readings (mG)	
Nominal (mG)			
3000		2994.9	X AXIS
2000		2000.4	
200		198.4	
20		19.0	
1		1.0	
3000		2994.8	Y AXIS
2000		2000.4	
200		198.4	
20		19.0	
1		1.0	
3000		2994.6	Z AXIS
2000		2000.4	
200		198.4	
20		19.3	
1		1.0	
Near Zero Field Test		0.0	RESULTANT
Electric Field Test:			
Nominal (mG)			
15.0 uA		15.00	EMDEX II Readings (uA)
1.5 uA		1.500	
0.15 uA		0.1500	
Ambient		0.0000	
Tester: <u>Richard Morris</u>		Inspector: <u>Richard Morris</u>	Date: <u>2-16-2012</u>

*The value of the Actual Magnetic Field is accurate to within +/-1.00% according to IEEE Standard 644-1994. The injected current, used for E-field calibration, is accurate accordingly to within +/-1.1%.

Rev: December 23, 2010

Figure C-5
EMDEX II Meter - Certificate of Calibration for S/N #1322 on 2/14/2012

< C-6 >



EMDEX II
(STANDARD FIELD)

CERTIFICATE OF TESTING
OPERATIONS AND ACCURACY REPORT

Customer Name: Enertech
Serial #: 1324 Unit Type: STD UN: CU CUST: 1
Basic Program Version: 3.02 Memory: 1024 132K
Calibrated @ 60 Hz Display: 0.0 / 1 RT
Temperature: 25 °C ± 5°C Relative Humidity: 25 % ± 6%

Magnetic Field Test:		EMDEX II Readings (mG)	
Nominal (mG)	Actual Field (mG)		
3000	3000	3000.0	X AXIS
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	Y AXIS
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	Z AXIS
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	RESULTANT
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	

Electric Field Test:		EMDEX II Readings (uA)	
Nominal (mG)	Injected Current (uA)* (E-Field Sensor Current)		
15.0 uA	15.00	15.00	X AXIS
1.5 uA	1.500	1.500	
0.15 uA	0.1500	0.1500	
Ambient	0.000	0.000	
Near Zero Field Test:		EMDEX II Readings (uA)	
		15.0	Y AXIS
		1.5	
		0.15	
		0.000	
		15.0	Z AXIS
		1.5	
		0.15	
		0.000	

Tester: Robert J. Briston Inspector: Robert J. Briston Date: 8-14-2012
*The value of the actual magnetic field generated by the Helmholtz magnetic field fixture is accurate to within
± 1.00% according to IEEE Standard 644-1994. This does not represent the accuracy of the meter.
**The Injected Current used for E-field calibration is accurate to within ± 1.1%. This does not represent the
accuracy of the meter.

Figure C-6
EMDEX II Meter - Certificate of Calibration for S/N #1329 on 8/14/2012

◀ C-7 ▶



EMDEX II
(STANDARD FIELD)

CERTIFICATE OF TESTING
OPERATIONS AND ACCURACY REPORT

Customer Name: Enertech
Serial #: 1522 Unit Type: STD UN: X CUST: 1
Basic Program Version: 3.02 Memory: 1024 132K
Calibrated @ 60 Hz Display: 0.0 / 1 RT
Temperature: 25 °C ± 5°C Relative Humidity: 20 % ± 6%

Magnetic Field Test:		EMDEX II Readings (mG)	
Nominal (mG)	Actual Field (mG)		
3000	3000	3000.0	X AXIS
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	Y AXIS
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	Z AXIS
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	
1	1	1.0	RESULTANT
3000	3000	3000.0	
2000	2000	2000.0	
200	200	199.4	
20	20	20.2	

Electric Field Test:		EMDEX II Readings (uA)	
Nominal (mG)	Injected Current (uA)* (E-Field Sensor Current)		
15.0 uA	15.00	15.00	X AXIS
1.5 uA	1.500	1.444	
0.15 uA	0.1500	0.1474	
Ambient	0.000	0.000	
Near Zero Field Test:		EMDEX II Readings (uA)	
		15.0	Y AXIS
		1.5	
		0.15	
		0.000	
		15.0	Z AXIS
		1.5	
		0.15	
		0.000	

Tester: Robert J. Briston Inspector: Robert J. Briston Date: 8-14-2012
*The value of the actual magnetic field generated by the Helmholtz magnetic field fixture is accurate to within
± 1.00% according to IEEE Standard 644-1994. This does not represent the accuracy of the meter.
**The Injected Current used for E-field calibration is accurate to within ± 1.1%. This does not represent the
accuracy of the meter.

Figure C-7
EMDEX II Meter - Certificate of Calibration for S/N #1522 on 8/14/2012

◀ C-8 ▶

CERTIFICATE OF CALIBRATION
Certificato di taratura

Item	Electric and Magnetic Field Analyzer
System	
Manufacturer	Narda S.T.S. / RHM
Model	EHP50C
Model number	352VM01203
Manufacturer	
Calibration method	Internal procedure
Manufacturer	PTP 09-3

Date(s) of measurements 26.01.2011

Result of calibration

Date of issue
Date of completion

1602101

Measure Operator
*Operatore misura*Person responsible
Responsabile

This calibration certificate may not be reproduced other than in full. Calibrations performed without signatures are not valid. The user is recommended to have the report recorded at appropriate intervals.

[illegible]

COMPANY WITH QUALITY MANAGEMENT
SYSTEM CERTIFIED BY DNV
= ISO 9001:2000 =

Person responsible
Responsabile

Even So...

Figure C-8
Calibration Certificate for the Narda Model EHP-50C Electric and Magnetic Field Analyzer – Page 1

The calibration was carried out at an ambient temperature of $(23 \pm 3)^{\circ}\text{C}$ and at a relative humidity of $(50 \pm 10)\%$.

For the electric measure the probe is positioned inside a big TEM cell (section 1.8 x 1.8 meter). For the magnetic measure, the probe is placed in a region of uniform magnetic field at the centre of a Helmholtz coil system.

The probe is aligned so that the magnetic flux density at a frequency of 50 Hz measured by each of the coils approximately equal.

Calibration equipment and traceability The equipment used for this calibration are traceable to the reference listed below (accuracy rating A) and the traceability of them is guaranteed by ISO 9001 internal procedure.

Standard	Equipment	Model	Type
R/F Power	Pentax Stereo- Polarizing Polarization Oscillator	HP 8454A	MOS
Frequency	Phase-Locked Reference Oscillator	HP 6907A	MOS
DC Voltage	GSP Control System	RSB 525M	NIM
CAR 211	DC Voltage Standard	QPS OPB 100	NIM
CAR 212	DC Voltage Standard	YOKOGAWA 203Z	NIM
CAR 213	DC Voltage Standard	YOKOGAWA 203Z	NIM
AG Voltage and Current	AG Voltage Current Standard	YOKOGAWA 203H	DET
Attenuation & Relative Calibration Kit		HP 86021B - Male	DET
HP 86021B - Female		HP 86021B - Female	DET
Impulse Generator		HP 47700A	MCAD
High Rate Time		HP 47700A	MCAD
Relative Timing		HP 47700A	MCAD
Photodiode and Detector	LCR meter	HP 47700A	DET

Uncertainty of measurements

The statement of uncertainty (see first page) does not make any implication or include any estimation as to the long term stability of the calibrated monitor. The expanded uncertainties are given below

	at 50 Hz	other frequency
E-field	3%	7.5%
H-field	2%	8%
	3%	3%

Figure C-9
Calibration Certificate for the Narda Model EHR-50C Electric and Magnetic Field Analyzer – Page 2

The correction factors given in the table below are calculated from the measurement made with the probe at the orientations corresponding to the same reading on the three axes

Frequency (Hz)	1kV/m range Correction factor (dB)	100kV/m range Correction factor (dB)
40	-0.25	-0.05
50	-0.89	
60	-0.03	
100	0.10	
500	0.29	
1000	0.13	
10000	0.42	

Frequency Hz	1000 T range Correction factor (dB)	10m T range Correction factor (dB)
40	-0.13	
50	0.01	-0.03
60	0.13	
100	-0.13	
500	-0.13	
1000	-0.28	
10000	-0.41	



Merida Subway Vent Solutions S.A.
Calle 33 Surpoa Yal Larrero de Yane 2133
20000 Merida (MX)
Tel. +52 97 2500577 Fax +52 97 2646013
Manufacturing Plant: Via Sonoma, 2072
17133 Clusone del Garda (IT)
E-mail: info@merida.com Web: www.merida.com

Number 10810
M4 22000

Electric and Magnetic Field

The correlation between the two variables (number of OAs and number of OAs per 1000 CbOs) was calculated as follows: if the number of OAs was greater than 10, the number of OAs per 1000 CbOs was calculated as follows: $\text{number of OAs} / \text{number of CbOs} \times 1000$. If the number of OAs was less than 10, the number of OAs per 1000 CbOs was calculated as follows: $\text{number of OAs} \times 1000 / \text{number of CbOs}$. The correlation coefficient was calculated using the Pearson correlation coefficient formula. The correlation coefficient was calculated using the Pearson correlation coefficient formula. The correlation coefficient was calculated using the Pearson correlation coefficient formula.

COMPANY WITH IDENTIFIED MANAGEMENT
SYSTEM CERTIFIED BY DNV
DNV 9001-2000

Person responsible
Responsible

Measure operator
 An operator with the signature

Date of Issue

OPERATIONS
n. 00

28.06.2011

This calibration certificate may not be reproduced other than in full. Calibration certificates without signature are not valid. The user is warned against having the object recalibrated at inappropriate intervals.

Reproduction and possession of this document is prohibited by law. Any reproduction or possession of this document without written permission from the manufacturer is prohibited.

Figure C-10
Calibration Certificate for the Narda Model EHP-50C Electric and Magnetic Field
Analyzer – Page 3

C-11 ▲

Figure C-11
Calibration Certificates for the Narda Model EHP-50D Electric and Magnetic Field Analyzer – Page 1

C-12 ▶

at an ambient temperature of $(23 \pm 3)^{\circ}\text{C}$ and at a relative humidity of $(50 \pm 10)\%$.

The magnetic calibration was set up with the probe in a region of uniform magnetic field at the centre of a calibrated Helmholtz coil set. The current in the Helmholtz coils was controlled by the current flowing in the coil. The current waveform was sinusoidal. The current in the Helmholtz coil system was adjusted to produce a series of indicated magnetic flux densities on the instrument at various frequencies. The calibration procedure agrees with the indication of IEC 61708 'Measurement of low frequency magnetic and electric fields with regard to exposure of human beings-Special requirements for ratimeters'. The indicated magnetic flux density and the actual value of magnetic flux density were calculated from the measured currents. The magnetic coupling factor (CF) is defined as ratio between actual and indicated magnetic flux density.

CFR 101-11.101

From 0 to the second magnetic flux density and from 1 to the third about magnetic flux density

For the electric calibration the probe is positioned inside a big TEM cell (section 1.1) but 18 mm or so for each measurement, the input voltage was adjusted so that the field strength was set to a specified reading on the monitor.

[illegible]

here Co. is the expected yield strength and C_{max} is the predicted yield strength

The correction factor data are permanently stored in the Internal EEPROM.

Manufacturer	Accessories	Model	Tests
Adient	Agilent multi-line	SA601A	ISIT
Agilent	Technic and Diagnostic net Probe	ENP50C-REF	NRM
Beckman Coulter	Removal reagent	PAH 153200	MLP
Enviro	Removal Transformer	AP40 1732010	NRM
Narda	REM Cell	1818	Narda
Narda	sensing coil	HCS2001	Narda

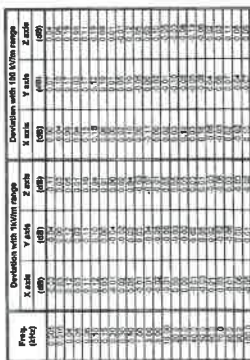
The statement of uncertainty (see first page) does not make any implication or include any substation as to the long term stability of the callibrated monitor. The relative expanded uncertainty result are given below

field	3% at 50 Hz
7.5% other frequencies	
2% at 50 Hz with 100 μ T range	
3.5% at 50 Hz with 10 mT range	
3% other frequencies	

The results of measurements in the following pages were obtained after calibration data logging and indicates the residual of the regional CF.

The results given on the tables were obtained with the axes aligned at the electric velocity or electric measurements and with axes coincident with the magnetic flux density or magnetic measurements.

of various measures.



Electric field
Frequency response for each axis at nominal field of 100 V/m.
The instrument was set as electric field measure with 100 Hz span up to the frequency of 100 Hz.
200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz.
1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz

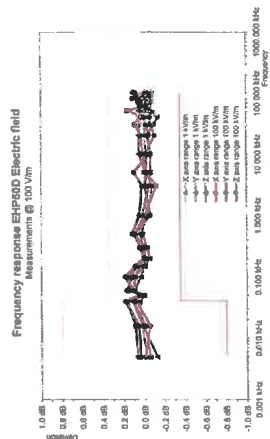


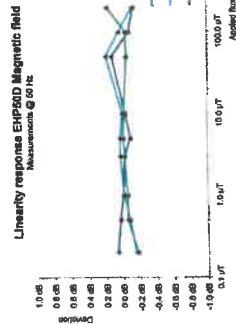
Figure C-12
Calibration Certificate for the Narda Model EHP-50D Electric and Magnetic Field
Analyzer – Page 2

Figure C-13
Calibration Certificate for the Narda Model EHP-50D Electric and Magnetic Field
Analyzer – Page 3

Magnetic Field Linearity response for each axis at nominal magnetic flux density of 20 μT and magnetic flux density below and above nominal value. The instrument was set with 100 Hz span.

Applied flux density (μT)	X axis Deviation	Y axis Deviation	Z axis Deviation
0.2	0.00	-0.00	-0.00
1.0	0.00	-0.01	-0.00
5.0	0.00	-0.01	-0.00
10.0	0.00	-0.01	-0.00
50.0	0.00	-0.01	-0.00
100.0	0.00	-0.01	-0.00
200.0	0.00	-0.01	-0.00

X axis linearity 0.15 dB
 Y axis linearity 0.17 dB
 Z axis linearity 0.17 dB



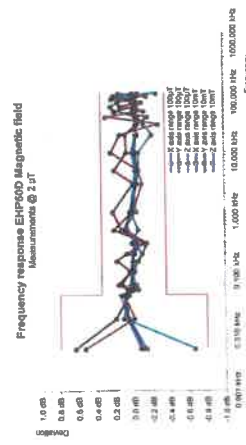
EHP600_Magna-Certificate of Calibration_01_0000010310.dlm

Figure C-15
 Calibration Certificate for the Narda Model EHP-50D Electric and Magnetic Field Analyzer – Page 5

[C-16](#)

Magnetic Field Frequency response for each axis at nominal magnetic flux density of 20 μT . The instrument was set with 100 Hz span up to the frequency of 100 Hz. 200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz, 1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz.

FREQ (MHz)	Deviation with 100Hz range			Deviation with 1000 Hz range		
	X axis	Y axis	Z axis	X axis	Y axis	Z axis
0.2	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00
10.0	0.00	0.00	0.00	0.00	0.00	0.00
50.0	0.00	0.00	0.00	0.00	0.00	0.00
100.0	0.00	0.00	0.00	0.00	0.00	0.00
200.0	0.00	0.00	0.00	0.00	0.00	0.00
500.0	0.00	0.00	0.00	0.00	0.00	0.00
1000.0	0.00	0.00	0.00	0.00	0.00	0.00
10.000	0.00	0.00	0.00	0.00	0.00	0.00
100.000	0.00	0.00	0.00	0.00	0.00	0.00
1000.000	0.00	0.00	0.00	0.00	0.00	0.00
10000.000	0.00	0.00	0.00	0.00	0.00	0.00
100000.000	0.00	0.00	0.00	0.00	0.00	0.00
1000000.000	0.00	0.00	0.00	0.00	0.00	0.00



EHP600_Magna-Certificate of Calibration_01_0000010310.dlm

Figure C-14
 Calibration Certificate for the Narda Model EHP-50D Electric and Magnetic Field Analyzer – Page 4

[C-15](#)

A.H. Systems Inc.
 9710 Cozycroft Ave. Chatsworth, CA 91311
 Phone (818) 998-0223 Fax (818) 998-6892
 E-mail: sales@A.H.Systems.com
 Web site: http://www.A.H.Systems.com

Model Number: SAS-550-1B SN: 865 Date: 10-Nov-11

Frequency	Antenna Factor (dB/m)
9 KHz	3.00
10 KHz	2.62
20 KHz	1.23
30 KHz	0.96
40 KHz	0.87
50 KHz	0.82
60 KHz	0.80
70 KHz	0.78
80 KHz	0.80
90 KHz	0.80
100 KHz	0.80
200 KHz	0.79
300 KHz	0.79
400 KHz	0.79
500 KHz	0.80
600 KHz	0.80
700 KHz	0.80
800 KHz	0.80
900 KHz	0.79
1 MHz	0.79
2 MHz	0.74
3 MHz	0.69
4 MHz	0.67
5 MHz	0.62
6 MHz	0.60
7 MHz	0.59
8 MHz	0.59
9 MHz	0.55
10 MHz	0.54
15 MHz	0.80
20 MHz	0.81
25 MHz	0.57
30 MHz	0.75
35 MHz	1.17
40 MHz	1.55
45 MHz	1.80
50 MHz	2.09
55 MHz	1.52
60 MHz	1.07

Figure C-16
 Calibration Certificate for the AH Systems Model SAS-550-1B Active Monopole
 (SN 865)

◀ C-17 ▶

A.H. Systems Inc.
 9710 Cozycroft Ave. Chatsworth, CA 91311
 Phone (818) 998-0223 Fax (818) 998-6892
 E-mail: sales@A.H.Systems.com
 Web site: http://www.A.H.Systems.com

Model Number: SAS-550-1B SN: 854 Date: 24-Apr-12

Frequency	Antenna Factor (dB/m)
9 KHz	2.39
10 KHz	1.90
20 KHz	0.05
30 KHz	-0.36
40 KHz	-0.53
50 KHz	-0.61
60 KHz	-0.63
70 KHz	-0.66
80 KHz	-0.66
90 KHz	-0.66
100 KHz	-0.61
200 KHz	-0.63
300 KHz	-0.63
400 KHz	-0.66
500 KHz	-0.66
600 KHz	-0.68
700 KHz	-0.68
800 KHz	-0.70
900 KHz	-0.68
1 MHz	-0.68
2 MHz	-0.73
3 MHz	-0.81
4 MHz	-0.85
5 MHz	-0.85
6 MHz	-0.90
7 MHz	-0.93
8 MHz	-0.97
9 MHz	-0.96
10 MHz	-0.96
15 MHz	-0.93
20 MHz	-1.04
25 MHz	-1.13
30 MHz	-1.07
35 MHz	-0.76
40 MHz	-0.47
45 MHz	-0.22
50 MHz	0.14
55 MHz	-0.28
60 MHz	-0.73

Figure C-17
 Calibration Certificate for the AH Systems Model SAS-550-1B Active Monopole
 (SN 854)

◀ C-18 ▶



Narda Safety Test Solutions GmbH
 Industriestraße 1, 72799 Plochingen, Germany
 Phone: +49 7143 9332-0 Fax: +49 7143 933 760

Calibration Certificate

Narda Safety Test Solutions hereby certifies that the object referred to in this certificate has been calibrated by qualified personnel using Narda's approved procedures. The calibration was carried out in accordance with a certified quality management system which conforms to ISO 9001

OBJECT	Selective Radiation Meter, Basic Unit, SRM-3006
MANUFACTURER	Narda Safety Test Solutions GmbH
PART NUMBER (P/N)	3006001
SERIAL NUMBER (S/N)	D-0069
CUSTOMER	
CALIBRATION DATE	2010-10-13
RESULT ASSESSMENT	within specifications
AMBIENT CONDITIONS	Temperature: (23 ± 3) °C Relative humidity: (25 to 75) %
CALIBRATION PROCEDURE	3006-2701-00A

ISSUE DATE: 2010-10-18



[Signature]
 CALIBRATED BY:
 Paul Geyer

[Signature]
 AUTHORIZED SIGNATORY:

This calibration certificate may not be reproduced other than in full accord with the conditions of the issuing laboratory. Calibration certificate without signature are not valid.

CERTIFICATE 300601-0006-20101013-73

PAGE 1 OF 9

A.H. Systems Inc.
 9710 Cozycroft Ave. Chatsworth, CA 91311
 Phone: (818) 998-9223 Fax: (818) 998-6892
 E-mail: sales@AHSsystems.com
 Web site: http://www.AHSsystems.com

Model: SAS-551 Serial Number: 193 Date: 28-Apr-12
 Calibration, Passive Monopole

Frequency	Antenna Factor (dB/m)
10 KHz	95.8
20 KHz	89.9
30 KHz	86.3
40 KHz	83.6
50 KHz	81.9
60 KHz	80.4
70 KHz	78.8
80 KHz	78.0
90 KHz	77.0
100 KHz	76.5
200 KHz	76.3
300 KHz	67.0
400 KHz	64.4
500 KHz	62.4
600 KHz	61.0
700 KHz	59.3
800 KHz	57.9
900 KHz	56.8
1 MHz	55.8
2 MHz	49.7
3 MHz	46.1
4 MHz	43.9
5 MHz	42.2
6 MHz	40.6
7 MHz	38.9
8 MHz	37.7
9 MHz	36.5
10 MHz	35.1
15 MHz	32.4
20 MHz	30.3
25 MHz	28.1
30 MHz	26.8
35 MHz	24.9
40 MHz	23.3

Figure C.18
 Calibration Certificate for the AH Systems Model SAS-551 Passive Monopole (SN 193)

◀ C-19 ▶

◀ C-20 ▶



OBJECT

The spectrum analyzer is based on digital signal processing. Small frequency spans were measured at 100 MHz and 1 GHz settings using discrete Fourier transformation (DFT). The LO was also swept for larger frequency spans. A memory chip contains correction values for various frequencies and object settings. The stored values were taken into account automatically during the measurement.

METHOD OF MEASUREMENT

Calibration using the reference standard. The output power level of the synthesized CW generator was adjusted and calibrated using power sensors as reference standards. The frequency of the generator was calibrated using a frequency counter.

The reflection of the object was measured directly using a vector network analyzer (VNA) calibrated by means of a reference standard. The measuring equipment and the associated uncertainty were verified using a reference standard (verification kit).

CALIBRATION PROCEDURE

The object was connected to the signal source instead of the power sensors in order to calibrate it. Measurement of the RF frequency response was made with different settings of the measurement range. As a result, the measured values also include the effects due to the "input attenuator" and the "reference level". The calibration factor was calculated for various frequencies and settings from a comparison between the "actual level" and the "reference level". All the selection filters are digital filters. No calibration of the filters is necessary.

TRACEABILITY

The calibration results are traceable to the International System of Units (SI) in accordance with ISO/IEC 17025. The measuring equipment used for calibration is traceable through the reference standards listed below.

STANDARD	MANUFACTURER	MODEL	SERIAL	ID	CERTIFICATE	NEXT CALIBRATION DATE
REFLECTION COEFFICIENT	ROSENBERGER	RPV 45	107148	913	0118 DND-K-1910	2016-09
DOSE POWER SENSOR	R&B	RPV 24	107149	908	0104 DND-K-1910	2016-09
DOSE POWER SENSOR	R&B	RPV 25	107177	933	0284 DND-K-1910	2016-11
MISMATCH VECTOR 12.0	Rosenberger	--	01237	922-3	12966 DND-K-00201	2008-09
FREQUENCY COUNTER	Anritsu	FSR3238	170700137	923	13137 DND-K-00201	2009-09

Reference standard: not used for routine calibration

Figure C-20
Calibration Certificate for the Narda SRM-3006 Selective Radiation Meter –
Page 2



UNCERTAINTY

The reported expanded uncertainty U is based on a standard uncertainty multiplied by a coverage factor k = 2. The standard uncertainty is based on the measurement uncertainty of the reference standard carried out in accordance with the "Guide to the Expression of Uncertainty in Measurement" (GUM). The reported measurement uncertainty is derived from the uncertainty of the calibration procedure and the object during calibration, and makes no allowance for drift or operation under other environmental conditions.

MEASURING CONDITIONS

The following results were obtained after adjustment of the object under calibration. These values are within the setting ranges defined by the manufacturer.

RESULTS

1	FREQUENCY RESPONSE (IF):	passed
2	FREQUENCY RESPONSE (RF):	passed
3	OUT-OF-BAND RESPONSE:	passed
4	FREQUENCY ACCURACY	passed
5	NOISE SIDE-BAND (SSB):	passed
6	SPURIOUS (input related)	passed
7	SPURIOUS (residual)	passed
8	NOISE FLOOR:	passed
9	INTERMODULATION REJECTION (2 nd and 3 rd order):	passed
10	INPUT RETURN LOSS:	passed

Figure C-21
Calibration Certificate for the Narda SRM-3006 Selective Radiation Meter –
Page 3

Frequency in MHz	Fspan in MHz	RBW in kHz	Fcent in MHz	MR																U
				-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20					
500.1	26.75	30	500.1	-0.01	-0.01	-0.01	-0.01	-0.02	-0.03	0	-0.01	-0.01	-0.02	-0.03	-0.04	0.2				
600.1	26.75	30	600.1	0	0	0	0	-0.01	-0.01	-0.02	0	-0.01	-0.01	-0.02	-0.04	0.2				
700.1	26.75	30	700.1	0	0	-0.01	-0.01	-0.02	-0.03	-0.01	-0.01	-0.02	-0.02	-0.04	-0.04	0.2				
800.1	26.75	30	800.1	0	0	-0.01	-0.01	-0.02	-0.03	-0.01	0	-0.01	-0.02	-0.04	-0.05	0.2				
900.1	26.75	30	900.1	-0.01	-0.01	-0.02	-0.01	-0.02	-0.03	-0.01	-0.01	-0.01	-0.03	-0.03	-0.05	0.2				
1000.1	26.75	30	1000.1	-0.02	-0.03	-0.02	-0.03	-0.04	-0.05	-0.02	-0.03	-0.03	-0.04	-0.05	-0.06	0.2				
1100.1	26.75	30	1100.1	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.02	-0.02	-0.03	-0.04	-0.05	0.2				
1200.1	26.75	30	1200.1	-0.01	-0.01	-0.02	-0.02	-0.03	-0.03	-0.02	-0.02	-0.02	-0.03	-0.04	-0.05	0.2				
1300.1	26.75	30	1300.1	-0.01	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02	-0.02	-0.02	-0.03	-0.04	-0.05	0.2				
1400.1	26.75	30	1400.1	0.01	0.02	0.02	0.01	0.01	0	0.01	0.01	0	0	-0.01	-0.03	0.2				
1500.1	26.75	30	1500.1	0.03	0.03	0.03	0.02	0.02	0.01	0.03	0.03	0.02	0.01	0	0	0.2				
1600.1	26.75	30	1600.1	0.02	0.02	0.01	0.01	0.01	0	0.03	0.02	0.01	0	0	-0.01	0.2				
1700.1	26.75	30	1700.1	0.06	0.06	0.06	0.05	0.05	0.04	0.07	0.06	0.04	0.04	0.03	0.02	0.2				
1800.1	26.75	30	1800.1	0.02	0.02	0.02	0.01	0	0.01	0.01	0.01	0	0	-0.01	-0.04	0.2				
1900.1	26.75	30	1900.1	0.01	0	0	-0.01	-0.02	-0.02	0	0	-0.01	-0.01	-0.02	-0.04	0.2				
2000.1	26.75	30	2000.1	0.01	0	0.01	0.01	-0.01	-0.01	0.01	0.01	0	0	-0.02	-0.03	0.2				
2100.1	26.75	30	2100.1	0.02	0.01	0.01	0	-0.01	0	0.01	0.01	0.01	0	-0.01	-0.03	0.2				
2200.1	26.75	30	2200.1	0.01	0.02	0.01	0.01	-0.01	0	0.02	0.01	0	0	-0.01	-0.03	0.2				
2300.1	26.75	30	2300.1	0.02	0.02	0.01	0.01	0	0	0.02	0.02	0.01	0.01	-0.01	-0.01	0.2				
2400.1	26.75	30	2400.1	0.03	0.04	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.01	0	-0.03	0.2				
2500.1	26.75	30	2500.1	-0.01	-0.01	0	-0.02	-0.02	-0.02	0	0	-0.01	-0.02	-0.03	-0.04	0.2				
2600.1	26.75	30	2600.1	0.01	0	0.01	0	-0.01	0	0.02	0.01	0	0	-0.01	-0.03	0.2				
2700.1	26.75	30	2700.1	0.04	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03	0.02	0.02	-0.01	0.2				
2800.1	26.75	30	2800.1	0.05	0.05	0.04	0.03	0.03	0.04	0.05	0.05	0.04	0.03	0.03	0.02	0.2				
2900.1	26.75	30	2900.1	0.02	0.02	0.02	0.01	0	0.01	0.04	0.04	0.03	0.03	0.01	0	0.2				
2999.9	26.75	30	2999.9	0.01	0.02	0.03	0	0.01	0.02	0.03	0.03	0.01	0.02	0	-0.01	0.2				
3002.1	26.75	30	3002.1	-0.04	-0.02	-0.02	-0.01	-0.03	0	0.01	0.01	-0.01	0	-0.02	-0.03	0.2				
3100.1	26.75	30	3100.1	-0.02	-0.02	-0.02	-0.02	0	0	0.01	-0.01	0	-0.01	-0.03	-0.03	0.2				
3200.1	26.75	30	3200.1	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.03	0.02	0.02	0.02	0.01	-0.01	0.2				
3300.1	26.75	30	3300.1	0	0.01	0.01	0	0	-0.02	0.03	0.01	0.03	0.02	0.02	0	0.2				
3400.1	26.75	30	3400.1	0	0	-0.01	-0.02	-0.02	0.02	0.03	0.01	0.01	0.01	0	-0.02	0.2				
3500.1	26.75	30	3500.1	0.01	0.01	0	0	-0.01	-0.02	0.04	0.02	0.03	0.02	0.01	-0.01	0.2				

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Figure C23
Calibration Certificate for the Narda SRM-3006 Selective Radiation Meter
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APPENDIX

FREQUENCY RESPONSE (RF)

The generator was set to the Fspan. The object settings were Fspan, RBW, and Fcent.
The measurements were made at different settings of the measurement range MR. The nominal level of the generator was -32 dBm (for MR < -5 dBm) and -7 dBm (for MR > -5 dBm), respectively. The frequency response G was calculated as the difference of the actual generator level L_{actual} and the indicated level $L_{\text{indicated}}$ according to the following equation: $G/\text{dB} = (L_{\text{actual}} - L_{\text{indicated}})/\text{dBm}$

Frequency in MHz	Fspan in MHz	RBW in kHz	Fcent in MHz	MR																U
				-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20					
0.00901	0.002	0.01	0.01	0	0	0	0	-0.01	-0.01	0	0	0	0	-0.01	-0.01	0.2				
0.012	0.005	0.5	0.012	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0	0.01	0	0	0.2				
0.02	0.02	2	0.02	0.01	0	0	0	-0.01	-0.01	0.01	0.01	0	0	0	0	-0.01	0.2			
0.04	0.02	2	0.04	0	0	0	0	-0.01	-0.01	0	0	0	0	0	0	-0.01	0.2			
0.1	0.02	2	0.1	0	0	0	0	-0.01	-0.01	0	0	-0.01	-0.01	-0.01	-0.01	-0.01	0.2			
0.5	0.02	2	0.5	0	0	0	0	-0.01	-0.01	0	0	0	-0.01	-0.01	-0.01	-0.01	0.2			
2	0.02	2	2	0	0	0	0	-0.01	-0.01	0	0.01	0	0	0	0	0	0.2			
10	0.02	2	10	0.01	0.01	0	0	0	0.01	0.01	0.01	0	0	0	0	0	0.2			
20	0.02	2	20	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0	0	0	0	0.2			
30	0.02	2	30	0.01	0.01	0	0	0	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.2			
31.233	26.75	30	44.578	-0.11	-0.19	-0.15	-0.18	-0.26	-0.12	-0.14	-0.15	-0.29	0	-0.14	-0.21	0.2				
36.1	26.75	30	44.578	-0.03	-0.11	-0.07	-0.13	-0.17	-0.06	-0.08	-0.1	-0.17	-0.02	-0.1	-0.14	0.2				
40	0.02	2	40	0.01	0.01	0	0	0	0	0.01	0.01	0	0	0	0	0	0.2			
44.1	26.75	30	44.578	0.04	-0.01	-0.01	-0.03	-0.03	0.01	0	-0.01	-0.02	-0.04	-0.03	-0.06	0.2				
50	0.02	2	50	0.01	0	0	0	0	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.2			
52.1	26.75	30	44.578	0.03	0	-0.01	-0.05	-0.01	0	-0.01	-0.03	0	-0.11	-0.07	-0.07	0.2				
57.9948	0.02	2	57.9948	0.01	0	0	-0.01	-0.01	-0.01	0	0	-0.01	-0.01	-0.03	-0.05	0.2				
58.344	26.75	30	44.599	-0.02	-0.04	-0.07	-0.12	-0.05	-0.05	-0.05	-0.09	-0.05	-0.18	-0.15	-0.11	0.2				
60.1	26.75	30	60.1	0.02	0.01	0.01	0	-0.01	0	0.01	0.01	0.01	0	-0.01	-0.03	0.2				
160.1	26.75	30	160.1	0.02	0.01	0.01	0.01	0	0	0.02	0.01	0	0	-0.02	-0.02	0.2				
200.1	26.75	30	200.1	0	0	0	-0.01	-0.02	-0.02	0	-0.01	-0.02	-0.02	-0.03	-0.04	0.2				
300.1	26.75	30	300.1	0	0	0	0	-0.01	0	0.01	0	0	0	-0.02	-0.02	0.2				
400.1	26.75	30	400.1	0	0	-0.01	-0.01	-0.02	-0.02	0	-0.01	-0.01	-0.02	-0.02	-0.05	0.2				

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Figure C22
Calibration Certificate for the Narda SRM-3006 Selective Radiation Meter
Page 4

Calibration Certificate

Narda Safety Test Solutions hereby certifies that the referenced equipment has been calibrated by qualified personnel to Narda's approved procedures. The calibration was carried out within a certified quality management system conforming to ISO 9001.

Object
**Antenna, Three-Axis, E-Field,
27 MHz to 3 GHz**

Part Number (PIN)
3501/03

Serial Number (SN)
K-0242

Manufacturer
Narda Safety Test Solutions GmbH

Customer
Narda Safety Test Solutions GmbH

Date of Calibration
07-Oct-2010

Results of Calibration
Total results within specifications

Confirmation interval recommended
24 Months

Ambient conditions
**Temperature: (23 ± 3) °C
Relative Humidity: (20 to 60) %**

Calibration procedure
3000-8702-00A

Plüfingen, 07-Oct-2010

MANAGEMENT
SYSTEM



P. Gys
Person in charge
Gys

Head of Laboratory
J. v. Freuden

This certificate may only be published in full, without permission for the publication of an
approved extract has been obtained in writing from the Managing Director

Certified by DQS according to
ISO 9001:2008
(Reg. No. 099079 QAU01)

Frequency		Fspan		RBW		Fcent		MR													U	
in MHz		in MHz		in MHz		MHz		-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20			
3600.1	26.75	30	3600.1	0	0	-0.01	0	-0.02	0	-0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.02	0	-0.02	0.2		
3700.1	26.75	30	3700.1	-0.02	-0.02	-0.02	-0.02	-0.02	-0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0	-0.02	0.2		
3800.1	26.75	30	3800.1	-0.02	-0.01	-0.02	-0.02	-0.02	-0.04	0.01	0.02	0.01	0.01	0.01	0.01	0	-0.01	-0.03	0.2			
3900.1	26.75	30	3900.1	-0.01	-0.01	-0.02	-0.02	-0.02	-0.02	0	0.02	0.02	0.02	0.01	0.01	0.01	0.01	-0.01	-0.02	0.2		
4000.1	26.75	30	4000.1	-0.02	-0.01	-0.01	-0.02	-0.03	0.01	0.01	0.01	0	0	0	0	0	-0.02	-0.04	0.2			
4100.1	26.75	30	4100.1	0.02	0.01	0.01	0	0	0.04	0.05	0.05	0.04	0.03	0.01	0.02	0.2						
4200.1	26.75	30	4200.1	0.03	0.03	0.03	0.03	0.01	0.06	0.07	0.05	0.07	0.04	0.05	0.02	0.2						
4300.1	26.75	30	4300.1	0.03	0.04	0.03	0.03	0.01	0.04	0.06	0.06	0.06	0.04	0.03	0.01	0.2						
4400.1	26.75	30	4400.1	0	-0.01	-0.01	-0.01	-0.01	0.01	0.03	0.03	0.02	0.01	-0.01	-0.05	0.2						
4500.1	26.75	30	4500.1	-0.02	-0.03	-0.04	-0.04	-0.05	-0.02	0.01	0.01	0	-0.02	-0.04	-0.05	0.2						
4600.1	26.75	30	4600.1	0	0	0	0	-0.01	0	0.04	0.03	0.01	0	0.01	-0.03	0.2						
4700.1	26.75	30	4700.1	0.02	0.01	0.01	0	-0.01	0.01	0.04	0.03	0.03	0.01	0.01	-0.02	0.2						
4800.1	26.75	30	4800.1	-0.01	0	-0.02	-0.01	-0.03	-0.02	0.01	0	-0.01	-0.02	-0.06	-0.08	0.2						
4900.1	26.75	30	4900.1	-0.04	-0.03	-0.04	-0.06	-0.07	-0.05	-0.02	-0.03	-0.04	-0.05	-0.08	-0.09	0.2						
5000.1	26.75	30	5000.1	-0.03	-0.03	-0.04	-0.04	-0.05	-0.04	-0.01	-0.02	-0.04	-0.04	-0.05	-0.07	0.2						
5100.1	26.75	30	5100.1	-0.02	-0.02	-0.01	-0.01	-0.04	-0.02	-0.01	-0.01	-0.01	-0.03	-0.04	-0.09	0.2						
5200.1	26.75	30	5200.1	0	0	0.01	0	-0.03	0	0	0.01	-0.01	-0.01	-0.03	-0.05	0.2						
5300.1	26.75	30	5300.1	0.03	0.02	0.03	0.01	0	0.01	0.02	0.02	0.01	0.01	-0.02	-0.06	0.2						
5400.1	26.75	30	5400.1	0.01	0.02	0.01	0.01	-0.01	0	0.02	0	0	0	-0.03	-0.07	0.2						
5500.1	26.75	30	5500.1	0.01	0.01	0.02	0.01	0	-0.02	0.02	0.01	0	-0.01	-0.03	-0.06	0.2						
5600.1	26.75	30	5600.1	0.03	0.04	0.02	0.03	0.01	-0.02	0.02	0.02	0.02	0.02	0.01	-0.02	-0.04	0.2					
5700.1	26.75	30	5700.1	0.03	0.03	0.04	0.03	0.03	-0.01	0.03	0.01	0	0.02	0	-0.04	0.2						
5800.1	26.75	30	5800.1	0.03	0.04	0.04	0.03	0.02	0	0.02	0.01	0.01	0	-0.02	-0.04	0.2						
5900.1	26.75	30	5900.1	0.04	0.04	0.04	0.02	0.01	-0.02	0.01	-0.01	0	-0.02	-0.03	-0.06	0.2						
5986.1	26.75	30	5986.1	0.05	0.05	0.05	0.04	0.04	0	0.02	0.02	0.01	0	-0.01	-0.06	0.2						

Frequency Response G and Uncertainty U in dB

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Figure C-24
Calibration Certificate for the Narda SRW-3006 Selective Radiation Meter -
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Results

Frequency Response			passed
Frequency in MHz	E _a applied in V/m	Output voltage in dB(μV)	Antenna Factor in dB(1/m)
25	10.0	70.85	69.15
45	10.0	74.76	65.24
75	10.0	78.67	61.33
100	10.0	81.00	59.00
200	10.0	85.17	54.83
300	10.0	87.92	52.08
433	10.0	89.36	50.64
600	10.0	90.35	49.65
750	10.0	92.45	47.55
1000	10.0	92.69	47.31
1500	10.0	92.75	47.25
1800	10.0	91.69	48.31
2000	10.0	89.04	50.96
2250	10.0	87.31	52.69
2400	10.0	84.11	55.89
2700	10.0	82.34	57.66
3000	10.0		

Frequency Flatness (100 - 3000 MHz): 11.6 dB
 The Antenna Factor data is permanently stored in the antenna connector memory.
 The SRM basic unit uses this correction data to correct the display.

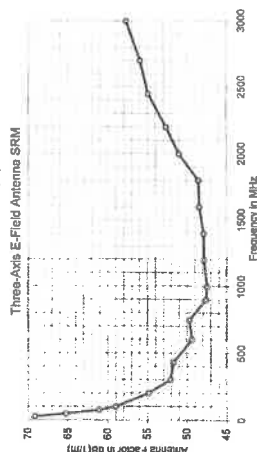


Figure C-28
 Calibration Certificate for the Narda 3501/03 Electric Field Antenna – Page 4

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Results

Rotational Ellipticity			passed
Frequency in MHz	Ellipse Ratio in dB		
25	+/-0.13		
45	+/-0.17		
75	+/-0.12		
100	+/-0.10		
150	+/-0.10		
200	+/-0.11		
300	+/-0.11		
433	+/-0.11		
600	+/-0.10		
750	+/-0.15		
1000	+/-0.17		
1500	+/-0.24		
1800	+/-0.37		
2000	+/-0.41		
2250	+/-0.83		
2400	+/-0.93		
2700	+/-1.35		
3000	+/-1.53		
	+/-1.37		
	+/-1.69		

Output Return Loss: passed

Figure C-29
 Calibration Certificate for the Narda 3501/03 Electric Field Antenna – Page 5

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