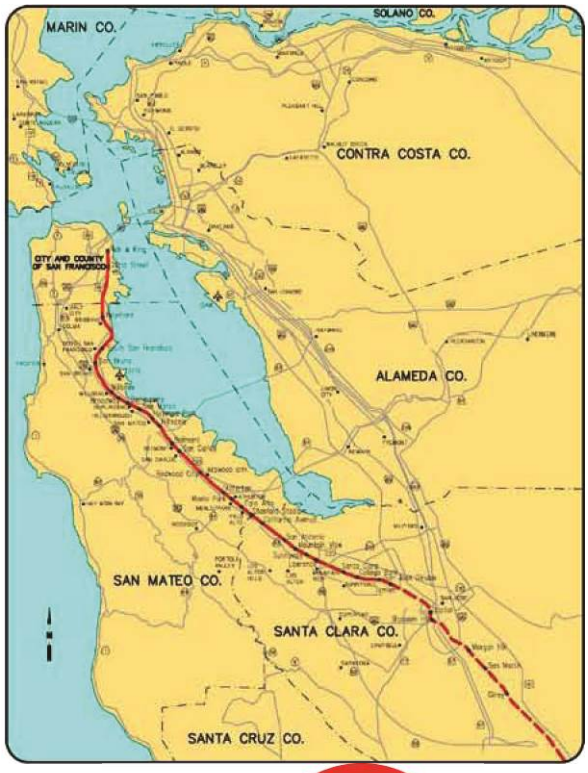
SAN FRANCISCO BAY AREA



Caltrain®

PENINSULA CORRIDOR JOINT POWERS BOARD

DESIGN BUILD
ELECTRIFICATION PROJECT

CONTRACT NO. 14-PCJPB-P-053
Pre-exisiting EMC Ambient Survey Results
CDRL 31517-001

REVISION 0

December 4, 2020

TURNER ENGINEERING CORPORATION

PGH WONG ENGINEERING INC.

Balfour Beatty Infrastructure Inc.

Revision History Record

Revision No.	Date	Reason for Revision
0	12/4/2020	Issued for Information

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References

Reference Table		
Publisher	**Document Number**	**Title**
BBII	CDRL 31515 – Final	EMI Outreach Program Plan – Revision 1, April 6, 2018
BBII	CDRL 31517 – Final	EMC Ambient Survey Procedure – Revisions 1, April 23, 2019
BBII	BBII-RFI-000804	BBII-RFI-000804 Pre-Existing EMC Ambient Survey Reduced Activity, August 22, 2020

List of Acronyms

Acronym	Definition
AC	Alternating Current
ACGIH	American Conference of Governmental Industrial Hygienists
BART	Bay Area Rapid Transit
BBII	Balfour Beatty Infrastructure Inc.
CalMod	Caltrain Modernization Program
CFR	Code of Federal Regulations
DC	Direct Current
EIR	Environmental Impact Report
EMC	Electromagnetic Compatibility
EMCP	Electromagnetic Control Plan
EMF	Electromagnetic Field
EMI	Electromagnetic Interference
EMU	Electric Multiple Unit
ESP	Electromagnetic Compatibility Ambient Survey Procedure
GHz	Gigahertz
Hz	Hertz
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronic Engineers
JPB	Joint Powers Board
kHz	Kilohertz
MHz	Megahertz
MPE	Maximum Permissible Exposure
OCS	Overhead Contact System
PCEP	Peninsula Corridor Electrification Project
PTC	Positive Train Control
RFI	Request for Information
RFP	Request for Proposal
ROW	Right-of-way
RSTP	Radiated Suggested Test Procedure
SFMTA	San Francisco Municipal Transportation Agency
SFO	San Francisco International Airport
SJC	Mineta San Jose International Airport
Tenco	Turner Engineering Corporation
TPS	Traction Power System
UPRR	Union Pacific Railroad
VAC	Voltage, Alternating Current
VHF	Very High Frequency
VTA	Santa Clara Valley Transportation Agency

1 Introduction

The Peninsula Corridor Electrification Project (PCEP) is a key element of the Joint Powers Board (JPB) Caltrain Modernization program (CalMod). CalMod will upgrade the performance, operations, capacity, and safety of the commuter rail system between San Francisco and San Jose. Caltrain will eventually operate in a blended system with California High-Speed Rail. The PCEP will deploy a 2x25 kV 60 Hz Traction Power System (TPS) and Overhead Contact System (OCS).

Balfour Beatty Infrastructure, Inc. (BBII) is the PCEP Design Build Contractor, in Contract No. 14-PCJPB-P-053, DB Peninsula Corridor Electrification Program (DB Contract). As part of its work, BBII established a PCEP Electromagnetic Compatibility (EMC) Program with the PCEP EMC Control Plan (CDRL #31510) that:

- Guides and coordinates the PCEP EMC design, analysis, test, documentation, and certification activities between all participants through all project phases and stages
- Performs work to achieve EMC with equipment and facilities of Caltrain passengers, workers, and neighbors identified in the EMC program
- Complies with applicable regulatory requirements, including EMC requirements in 49CFR 200-299, particularly Parts 236 and 238, for all PCEP systems
- Fulfills the PCEP EMC requirements in the DB Contract.

In the PCEP EMC Program, BBII is performing three sets of EMC Ambient Surveys:

1. Pre-existing EMC Ambient Survey
2. Revenue Service EMC Survey
3. One Year Monitoring EMC Survey.

The Pre-existing EMC Ambient Survey:

- Surveyed for sensitive receptors adjacent to the Caltrain right-of-way (ROW) including research facilities, universities, hospitals, and industrial facilities with sensitive equipment.
- Surveyed for potential electromagnetic interference (EMI) emitters that could interfere with sensitive Caltrain equipment.
- Measured ambient electric field levels from 10 kHz to 6 GHz and ambient magnetic field levels from static to 1000 Hz at 12 selected sites along the Caltrain ROW before power-up of the PCEP electrification system.

The Revenue Service EMC Survey will measure the same electric field and magnetic field levels, at the same locations, after electric multiple unit (EMU) trainsets begin running the Caltrain corridor in revenue service.

The One Year Monitoring EMC Survey will measure the same electric field and magnetic field levels, at the same locations, one year after Revenue Service EMC Survey.

If the Revenue Service EMC Survey or One Year Monitoring EMC Survey document PCEP emissions that are disruptive to sensitive receptors near the Caltrain ROW, BBII will:

- Propose EMI mitigations as necessary based on survey findings and measurements.
- Provide a report documenting survey findings, ambient electric and magnetic field measurements, and preliminary recommendations.

The PCEP will notify JPB if electromagnetic emissions field (EMF) exceed the IEEE, American Conference of Governmental Industrial Hygienists (ACGIH), or International Commission on Non-Ionizing Radiation Protection (ICNIRP) EMF exposure thresholds specified in CDRL #31510 EMCP.

Tenco developed and submitted an EMC Ambient Survey Procedure (CDRL 31517) describing the planned EMC Surveys. Tenco performed the Pre-existing EMC Ambient Survey per the EMC Ambient Survey Procedure, and prepared this Pre-existing EMC Ambient Survey Results, which is CDRL 31517-001. The Pre-existing EMC Ambient Survey Results provides the results, conclusions, and complete data and supporting information from the Tenco Pre-Existing EMC Ambient Survey.

1.1 Pre-existing EMC Ambient Survey Objectives

The objective of the Pre-existing EMC Ambient Survey is to determine the maximum and minimum existing ambient electromagnetic fields along the Caltrain ROW before power-up of the PCEP electrification system.

The objectives of this Pre-existing EMC Ambient Survey Results are to document and present:

- Maximum and minimum pre-existing ambient radiated and magnetic field levels along the Caltrain ROW
- Establish baseline EMF levels for the Revenue Service EMC Survey and One Year EMC Survey
- Describe measurements and locations
- Provide full results.

Tenco will reference this Pre-existing EMC Ambient Survey Results when performing the Revenue Service EMC Survey and One Year EMC Survey to:

- Measure at the same location
- Determine if Caltrain PCEP has increased the ambient EMF fields.

1.2 EMC Ambient Survey Requirements

DB Contract Vol 3, Part A, Section 1, Article 4.9.3.7 specifies that BBII shall conduct an EMI and EMC "investigation study along the electrification corridor for the following 4 types of electrical equipment and systems, and to suggest suitable mitigation measures if deemed necessary:

- Existing systems and equipment of the railroad (prior to electrification);
- New railway systems and equipment (installed as a part of the Project or thereafter);
- External systems or equipment, located outside the ROW but in close proximity to the tracks (up to 30 feet from the centerline of the near track, or within 30 feet from lateral power feeders); and
- External systems and equipment, located between 30 and 300 feet from the nearby track, or from lateral power feeders."

DB Contract Vol 3, Part A, Section 3, Chapter 26 specifies that the PCEP "systems equipment and facilities shall work with and not interfere with other systems equipment and facilities as well as with neighbor equipment and facilities".

DB Contract Vol 3, Part A, Section 9, Article 7 specifies that BBII shall survey the electromagnetic characteristics along the Caltrain ROW in the design phase, before construction begins, after full revenue service begins using the energized OCS and EMUs, and one year after full revenue service began.

DB Contract Vol 3, Part A, Section 9, EMF-2 states:

- "Conduct a due diligence assessment to identify potentially sensitive facilities along the project route (the Environment Impact Report (EIR) list of facilities was only a list of example facilities, not a comprehensive list of potentially sensitive facilities).

- Work with the JPB and make a good faith effort to coordinate with local cities, UCSF, France Telecom, Health Diagnostics, Valley Radiological, Palo Alto Medical Foundation, St. Jude Medical Center, Evans Analytical, Motorola and Intel (and any other facilities located adjacent to the ROW with sensitive equipment and requesting such consultation) to determine whether their facilities would be susceptible to EMI effects.

- Complete a pre-construction survey at each site identified as a potentially sensitive facility. During final design, the D-B shall evaluate the specific EMI levels associated with the electrified JPB system at the identified sensitive facilities and determine the appropriate controls necessary to avoid disruption of sensitive equipment prior to testing and commissioning of the system"

DB Contract Vol 3, Part A, Section 9, EMF-2 also requires:

- "Work with Union Pacific, SCVTA, BART and other rail operators during project design to ensure that signal systems and other sensitive electric equipment for other freight or passenger rail facilities are not disrupted by EMI from the PCEP OCS…"

1.3 Pre-Existing Ambient Survey Scope

The Pre-Existing EMC Ambient Survey scope is the measurement and recording of the ambient electromagnetic environment along the Caltrain ROW prior to construction. The Pre-existing EMC Survey provides baseline levels, so it is possible to determine the potential impacts of Caltrain with PCEP on:

- Stakeholders within 300 ft of the centerline of the track or the lateral power feeders
- Specified potentially facilities such as San Francisco International (SFO) and Mineta San Jose International (SJC) Airports; BART, Santa Clara VTA, and Union Pacific Railroad; and others

1.4 Overview of the Pre-existing EMC Ambient Survey Tasks

The Pre-existing EMC Ambient Survey work consisted of:

- Searched public databases for sensitive facilities and potential emitters along the Caltrain ROW.
- Performed a geospatial cluster analysis of locations to select 12 selected sites for taking measurements.
- Measured radiated electric field at the 12 selected sites along the Caltrain ROW.
- Measured magnetic field at the 12 selected sites along the Caltrain ROW.

The EMC Ambient Survey procedure provided the test method, test arrangement, and related technical information for the radiated electric field and magnetic field measurements.

Radiated Electric Field Measurements: Tenco performed radiated electric field measurements per the EMC Ambient Survey procedure and Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11, method RT/RE01A, "Broadband Emissions of Rapid Transit Vehicles - 140 kHz to 400 MHz" (RSTP). Tenco made measurements in the frequency range 10 kHz to 6.0 GHz, using an A.H. Systems Active Monopole Antenna, an A.H. Systems Bilogical Antenna, and a Keysight KT-9010A Signal Analyzer.

Magnetic Field Measurements: Tenco performed three-axis static and AC magnetic field measurements per the EMC Ambient Survey procedure using an AlphaLab three axis magnetometer and magnetic field probe, Tenco TransDAS data acquisition system. Tenco made magnetic field measurements in the frequency range from 0 Hz, static or Earth field, and from 54 to 1000 Hz in four bands centered at 60 Hz harmonics.

1.5 Survey Results Contents

This Pre-existing EMC Ambient Survey Results consists of the following sections:

Section 2, Results Overview: The Results Overview section summarizes the test schedule and scope, describes the most important results, and states conclusions.

Section 3, Selected Measurement Sites: The Selected Measurement Sites section describes the actual measurement locations relative to the Caltrain ROW. It provides maps showing the site and the Caltrain ROW. It also provides a detailed diagram and photographs for each site.

Section 4, Radiated Electric Field Measurement Results: The Radiated Electric Field Measurement Results section states the test purpose; states key pre-existing ambient radiated electric field emissions measurements and results; describes the measurement locations; describes the test equipment; and describes test procedure steps.

Section 5, Magnetic Field Measurement Results: The Magnetic Field Measurement Results section provides the corresponding information for the magnetic field measurements.

Appendix A and B: Appendices provide complete data for the Radiated Electric field and Magnetic Field measurements.

2 Results Overview

2.1 Conclusions and Summary Results

The Pre-existing EMC Ambient Survey measured ambient electric and magnetic field levels at 12 locations along the Caltrain ROW. The survey showed that electric and magnetic field levels along the Caltrain ROW are similar to levels typical for urban North America, considering broadband noise levels and transmission frequencies and levels. Existing electric and magnetic fields along the Caltrain ROW should not disrupt the safe and normal operation of Caltrain systems and facilities which are designed, built, and tested per PCEP EMC Control Plan (EMCP).

Caltrain PCEP rail systems, facilities, and locomotives that are designed, built, and tested per the Caltrain PCEP EMCP should be electromagnetically compatible with neighboring facilities and equipment along the Caltrain corridor.

The Revenue Service EMC Survey and One Year Monitoring EMC Survey will measure the magnetic field levels, at the same locations, after EMU trainsets begin running in revenue service. The test team will then compare the electromagnetic field emissions to Pre-existing EMC Ambient Survey, and check if the levels are still below the limits provided in the PCEP EMCP section 5.10, and established per the IEEE standards.

The timing of the Covid-19 pandemic and the schedule for Caltrain electrification caused the Pre-existing EMC Ambient Survey to be performed during the pandemic. During the pandemic, including at the time of the survey, California and the Bay Area had orders to restrict business and travel, and many businesses switched to remote work. BBII submitted RFI-000804 to explain that the electric and magnetic fields measured in the later tests may be higher than those measured in this Per-existing Ambient Survey, not because the PCEP caused an increase in Revenue Service levels, but because Convid-19 caused a decrease in pre-revenue service levels. JPB approved the survey dates.

2.1.1 Ambient Radiated Electric Field Results

Tenco performed a total of 168 radiated electric field measurement runs at the 12 selected sites, from September 28, 2020 to October 2, 2020. Section 3 describes the measurement locations. The test team measured radiated electric field in eight bands, B0 through B7, from 10 kHz to 6 GHz.

The Pre-existing EMC Ambient Radiated levels:

- Were similar at all measurement locations
- Showed normal high emissions levels at aeronautical communications, space communications, and TV broadcasting frequencies.

Table 2-1 summarizes and presents the radiated electric field results:

- For each frequency band, worst-case emitters, including amplitude and frequency of emission, location, conditions, and preliminary assessment of impact.
- For each frequency band, most quiet condition
- Notes on potential susceptible neighbors.

Section 4 provides detailed information and plots at each location.

TABLE 2-1
Radiated Electric Field Results Summary

Band	Frequency Range (Hz)	Results / Notes
B0	10 kHz – 160 kHz	* Sites 4, 10, and 12 are the noisiest sites, with highest ambient levels from 155 dB to 130 dB. * Site 9 is the quietest site, with lowest ambient levels from 120 to around 95 dB.
B1	150 kHz – 650 kHz	* Sites 7 and 8 are the noisiest sites, with ambient levels around 140 dB * Site 9 is the quietest site, with ambient levels around 105 dB.
B2	500 kHz – 3 MHz	* Sites 1, 4 and 12 are the noisiest sites, with ambient levels around 140 dB and several humps across the band * Site 9 is the quietest site, with lowest ambient levels around 110 dB Site 6 also has low ambient levels, around 115 dB
B3	2.5 MHz – 7.5 MHz	* Site 1, 4, 10 and 12 are the noisiest sites, with highest ambient levels around 135 dB. * Site 9 is the quietest site, with lowest ambient levels, around 100-110 dB.
B4	5 MHz – 30 MHz	* Site 10 is the noisiest site, with highest ambient levels around 145 dB * Site 9 is the quietest site, with the lowest ambient levels around 90-110 dB.
B5h	25 MHz – 325 MHz	* Site 6 is the noisiest site, with highest ambient levels around 95 dB. * Site 11 is the quietest site with lowest ambient levels, around 60-70 dB.
B5v		* Site 5 is the noisiest site, with highest ambient levels around 110 dB. * Site 11 is the quietest site, with lowest ambient levels around 65 dB.
B6h	300 MHz – 1.3 GHz	* Site 2 is the noisiest site, with highest ambient levels around 82 dB. Sites 5, 7 and 12 have similar high ambient levels * Site 1 is the quietest site, with lowest ambient levels at around 70 dB. Sites 3, 4, 6, 8,11have similar lowest ambient levels.
B6v		* Same as B6h band
B7h	1 GHz – 6 GHz	* Site 5 is the noisiest site, with highest ambient levels around 80 dB. * Site 1 is the quietest site, with lowest ambient levels around 72 to 68 dB. All sites except site 5 share the similar lowest ambient levels
B7v		* Same as B7h band

2.1.2 Magnetic Field Results

Tenco performed 41 magnetic field measurement runs at the 12 selected sites, from September 28, 2020 to October 2, 2020.

The test team measured ambient magnetic field levels along the ROW varied insignificantly at harmonics of 60 Hz. Variations in 60 Hz harmonics are typically caused by current flowing in overhead power lines.

The test team measured 0 Hz, or static magnetic fields, to see if disturbances in the static magnetic field occurred. Static magnetic field variations are typically due to large moving steel objects such as cars and freight trains.

The magnetic field results were typical for North American urban areas.

Figure 2-1 shows the highest measured 60 Hz field of 12 mG at Site 6 (565 Bragato Road) with power lines about 6 m above the measurement point. This magnetic field level is typical for under high voltage power lines, and far lower than the IEEE Std C95.1 exposure limit of 9.04 G.

Table 2-2 summarizes the Magnetic field results and presents from static to 1000 Hz, worst-case fields, at 60 Hz harmonics, including amplitude and frequency of emission, location, conditions, and preliminary assessment of impact.

TABLE 2-2
Magnetic Field Results Summary

Site	Frequency Bands					Results / Notes
	Static	60 Hz	180 Hz	360 Hz	720 Hz	
Site 1	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 2	Earth Level	5.62 mG	3.13 mG	< 1 mG	< 1 mG	Power line 8m overhead, and 5m away from measurement point.
Site 3	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 4	Earth Level	1.63 mG	0.92 mG	< 1 mG	< 1 mG	Power line 37 m away from measurement point.
Site 5	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 6	Earth Level	12 mG	7 mG	< 1 mG	< 1 mG	Power line 6 m above measurement point.
Site 7	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 8	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 9	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 10	Earth Level	1.86 mG	1.08 mG	< 1 mG	< 1 mG	Power line 20 m away from measurement point

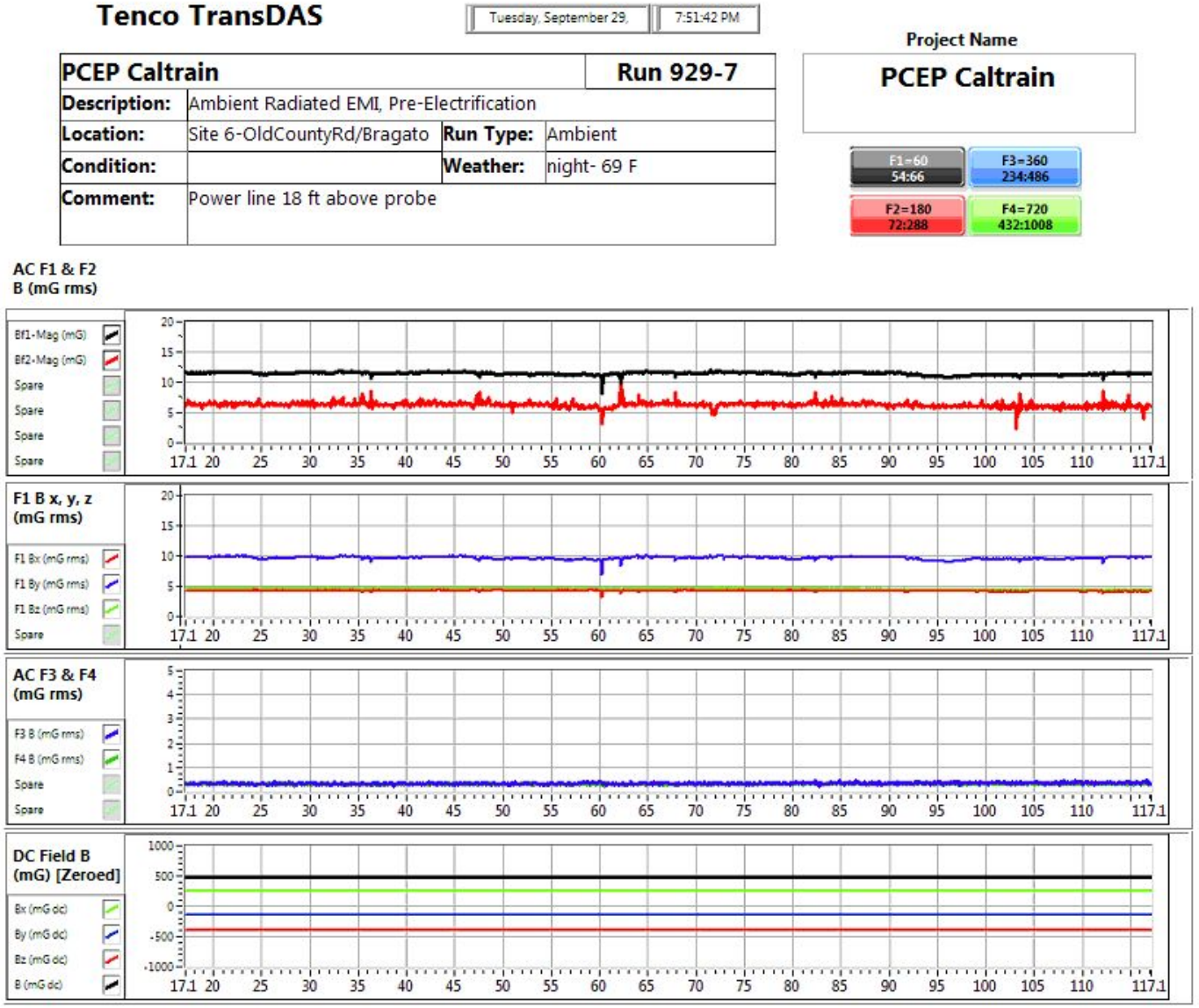
TABLE 2-2 Magnetic Field Results Summary						
Site	Frequency Bands					Results / Notes
	Static	60 Hz	180 Hz	360 Hz	720 Hz	
Site 11	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	
Site 12	Earth Level	< 1 mG	< 1 mG	< 1 mG	< 1 mG	

2.2 Survey Schedule

Tenco performed the ambient electric and magnetic field measurements per the Table 2-3 schedule.

TABLE 2-3 Pre-existing EMC Ambient Survey Schedule				
Mon 09/28/2020	Tues 09/29/2020	Wed 09/30/2020	Thurs 10/01/2020	Fri 10/02/2020
Setup and performed Radiated Electric field tests and Magnetic field tests at Site 1 and Site 10	Setup and performed Radiated Electric field tests and Magnetic field tests at Site 5, Site 6, and Site 9.	Setup and performed Radiated Electric field tests and Magnetic field tests at Site 7, Site 8, and Site 11.	Setup and performed Radiated Electric field tests and Magnetic field tests at Site 3 and Site 12.	Setup and performed Radiated Electric field tests and Magnetic field tests at Site 2 and Site 4. Remeasured magnetic field at Site 1 and Site 10.

FIGURE 2-1
Worst Case AC Field Level



3 Survey Locations

Tenco conducted measurements at the 12 selected sites along the Caltrain ROW. Locations included:

- Specific sensitive receptors adjacent to the ROW
- Worst case ambient EMF locations, such as under high voltage power lines or near significant emitters such as TV broadcast stations
- "Quiet" sites, where the BBII team expects low ambient EMF levels
- Where the BBII team expects worst case Caltrain EMF levels
- Locations with significant public interaction

3.1 Sensitive Receptors

BBII surveyed the PCEP corridor to identify possible sensitive receptors, as described in the EMC Survey Procedure (ESP), and per DB Contract Vol 3, Part A, Section 1, Article 4.9.3.7.

BBII assigned each sensitive receptor to a susceptibility category and environmental category considering the business type of the sensitive receptor and the location. Table 3-1 lists the sensitive receptor categories and identifiers.

TABLE 3-1
Sensitive Receptor Categories

Site Categories		Susceptibility Categories		Environment Categories	
1	Existing JPB systems and equipment	A	Routine	A	Quiet
2	New PCEP systems and equipment	B	Sensitive	B	Moderate
3	External systems or equipment, w/in 30 ft of track centerline	C	Very Sensitive	C	Noisy
4	External systems or equipment, 30 - 300 ft from track centerline	D	Extremely Sensitive	D	Very Noisy
5	Other sensitive facilities that may be affected by PCEP electromagnetic fields				

3.2 EMI Emitters

BBII surveyed the PCEP corridor to identify potential EMI emitters adjacent to the Caltrain ROW in the electric field range of 10 kHz to 6 GHz and magnetic field range of static to 1 kHz.

3.3 Electric and Magnetic Field Measurement Location

Tenco performed electric and magnetic field measurements at 12 selected sites along the PCEP corridor. The measurement sites are listed in the ESP, and cover the full range of sensitive receptor categories from Table 3-1 present in the PCEP corridor, as well as 2 quiet sites.

Figure 3-1 is an overview map. It shows:

- The 12 selected measurement sites shown as green diamonds
- Planned PCEP traction power facility locations shown as purple circles.

FIGURE 3-1
Survey Overview Map

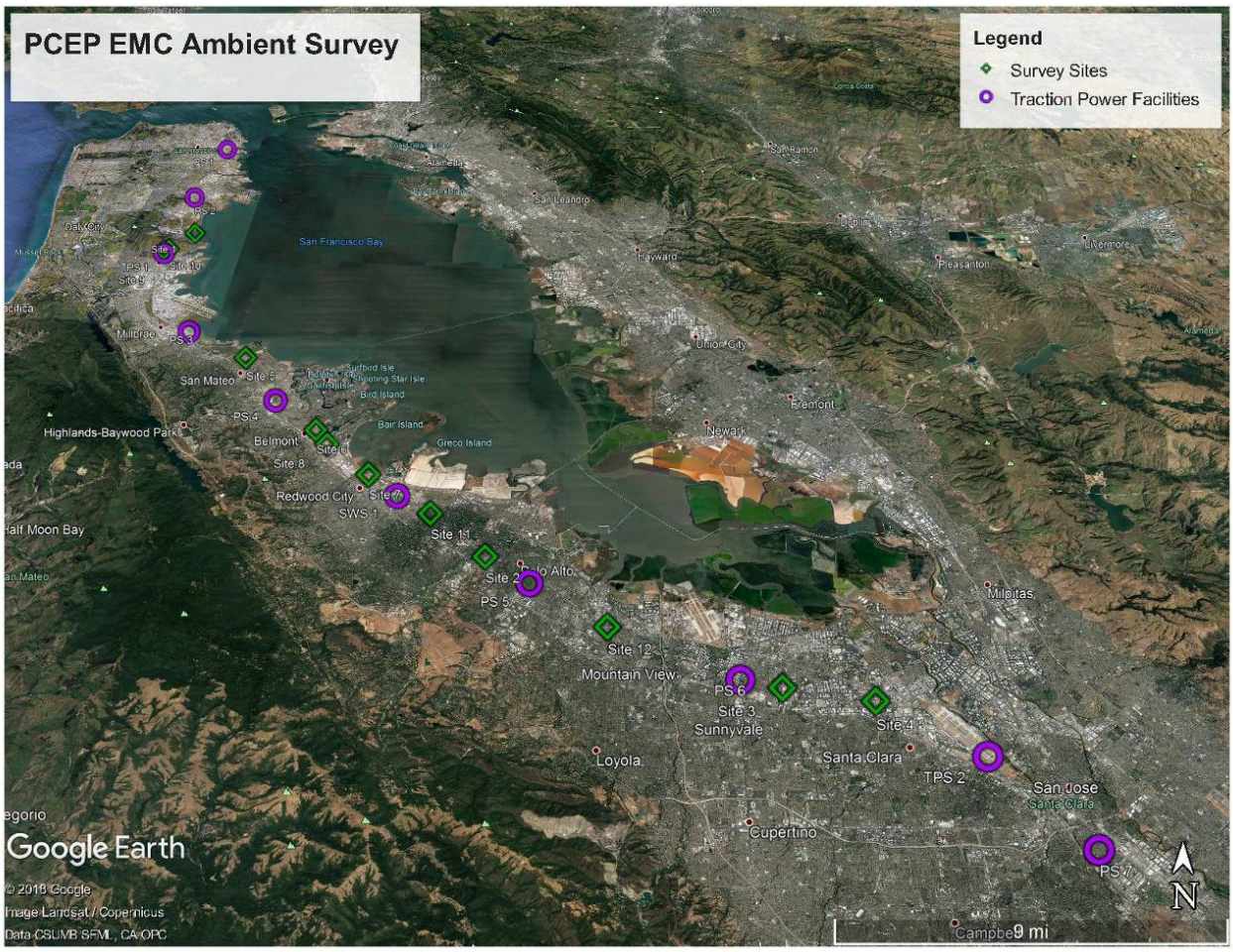


Table 3-2 lists the 12 selected measurement sites and their characteristics. Tenco measured the electric and magnetic fields at each of the 12 sites. Table 3-1 defines the Site, Susceptibility and Environmental category identifiers

TABLE 3-2
Selected Measurement Sites

ID	Location	Dist. from Track (ft)	No. Receptors in Area	Sensitive Receptor Categories Covered (Ref Table 3-1)			Caltrain Facilities
				Site	Susc.	Env.	
1	5000 Sierra Point Pkwy, Brisbane	100	12	4, 5	A, B, C	B	NA
2	Palo Alto Medical Foundation 795 El Camino Real, Palo Alto, CA 94304	75	1	5	C	B	Palo Alto Station, 1,500 ft
3	120 San Lucar Ct, Sunnyvale	50	5	4, 5	B, C	B	NA
4	2368 Walsh Ave, Santa Clara	30	21	5	A, B, C	B	NA
5	159 S B St, San Mateo	40	11	5	A, B, C	B	San Mateo Station, 50 ft
6	565 Bragato Rd, San Carlos	90	6	4, 5	A, B, C	B	NA
7	2401 Broadway, Redwood City	30	10	4, 5	A, B	B	SWS 1, 1200 ft Redwood City Station, 0 ft
8	700 El Camino Real, San Carlos	50	6	4, 5	A, B	B	San Carlos Station, 400 ft
9	590 Dubuque Ave, South San Francisco	50	7	3, 4, 5	A, B	C	TPS 1, 400 ft S San Francisco Station, 200 ft
10	Two Corporate Dr, South San Francisco	80	5	5	A, B	C	TPS 1, 500 ft S San Francisco Station, 1200 ft
11	98 McCormick Ln, Atherton	40	NA	NA	A	A	Quiet Site
12	2000 Crisanto Ave, Mountain View	40	NA	NA	A	A	Quiet Site

For each selected measurement site, the test team made the following measurements:

1. Used a passenger van to transport the measurement equipment to, and to provide shade and shelter at, the selected location
2. Parked in a safe location and set out traffic cones as necessary
3. Set up two or three measurement antennas connected by cable to equipment in the van set up a 120 VAC power connection
4. Performed measurements during daytime, between 8 am and 6 pm
5. Recorded data for up to 2 hours
6. Packed up and moved to the next location

The following subsections describe the actual measurement sites relative to the Caltrain ROW, including satellite images and photographs.

3.3.1 Site 1: 4000 Shoreline Ct, South San Francisco, CA

Measurement point: 7th parking spot south of Hilton, 30 m from Northbound track.

3.3.2 Site 2: 795 El Camino Real, Palo Alto, CA 94304

Measurement point: Palo Alto Caltrain Station / Palo Alto Medical Foundation parking spots #282 and #283, 30 m from Southbound track. The team performed the measurement with power lines located 8 m overhead, and 5 m away from the measurement point.

3.3.3 Site 3: 121 San Lucar Ct, Sunnyvale, CA 94086

Measurement point: EAG Laboratories rear parking lot, 21 m from nearest track

3.3.4 Site 4: 2450 Walsh Ave, Santa Clara, CA 95051

Measurement point: 11th parking spot north of track, 41 m from Northbound track
The team performed the measurement with power lines located 37 m away from the measurement point.

3.3.5 Site 5: San Mateo Caltrain Station west platform, San Mateo, CA 94401

Measurement point: Parking spots #215 and #216 north of station building, 11 m from Southbound track

3.3.6 Site 6: 221 Old County Rd, San Carlos, CA 94070

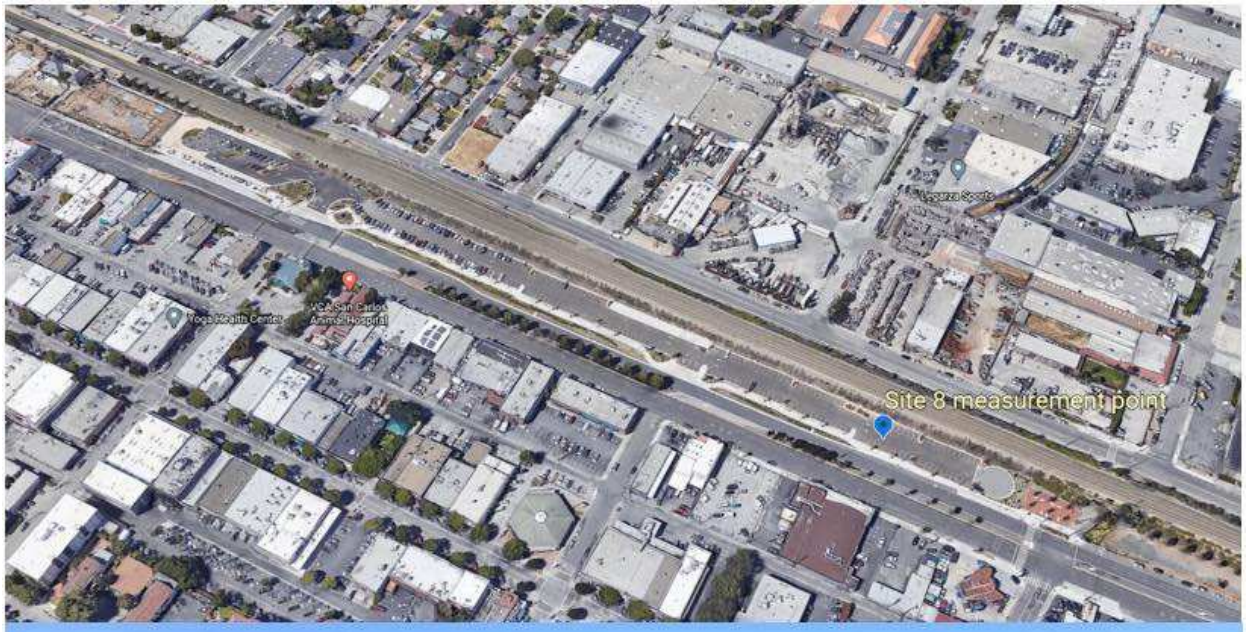
Measurement point: North corner of Old County Rd. and Bragato Rd. intersection, 25 m from Northbound track. The team performed the measurement with power lines located 6 m above the measurement point.

3.3.7 Site 7: 900B Middlefield Rd, Redwood City, CA 94063

Measurement point: Caltrain Right of Way – 8 m from Northbound track, 10 m east of Caltrain Crossing #754909K Signal House.

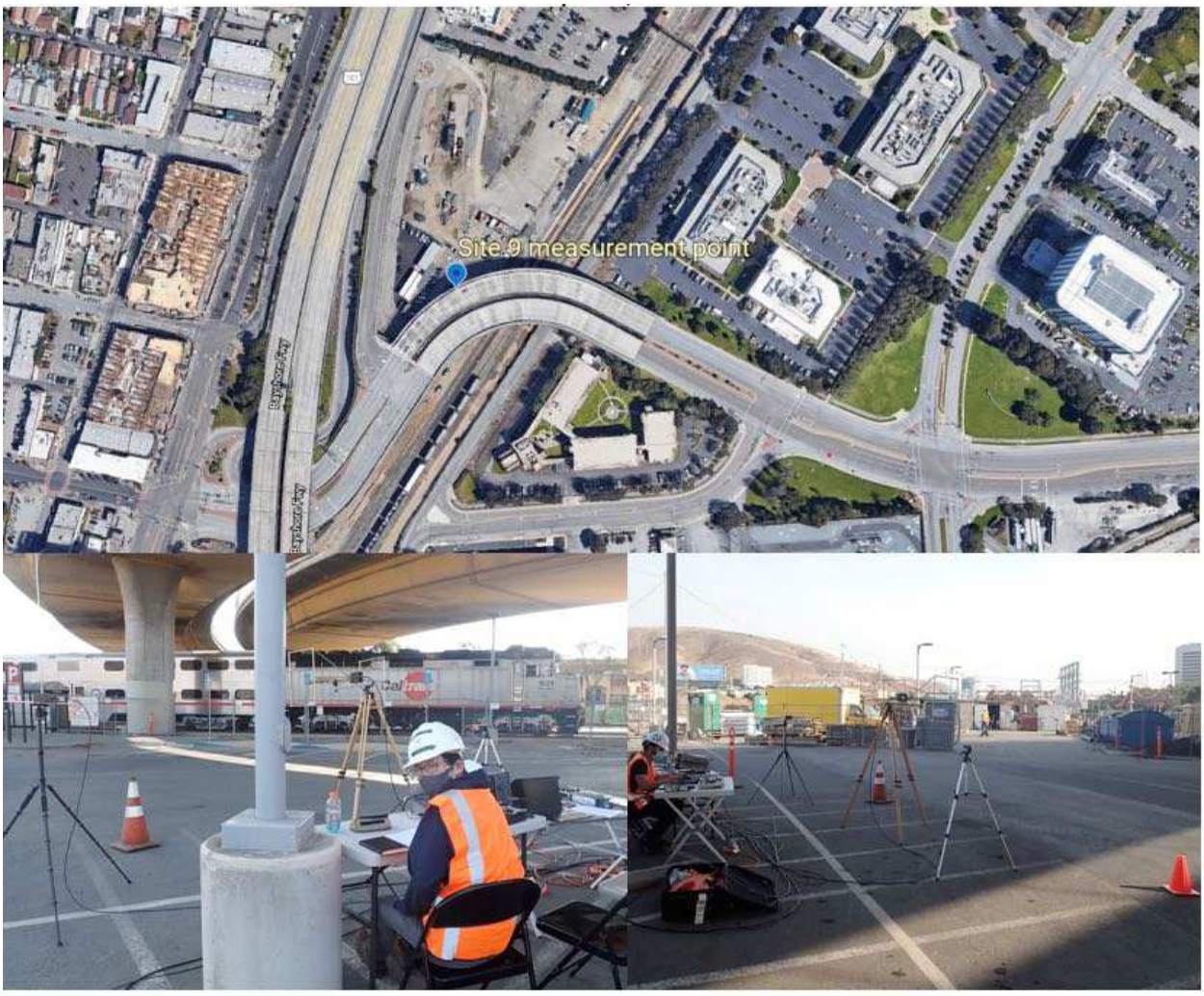
3.3.8 Site 8: 850 El Camino Real, San Carlos, CA 94063

Measurement point: South end of San Carlos Station parking lot, parking spot #133, 24 m from Southbound track.



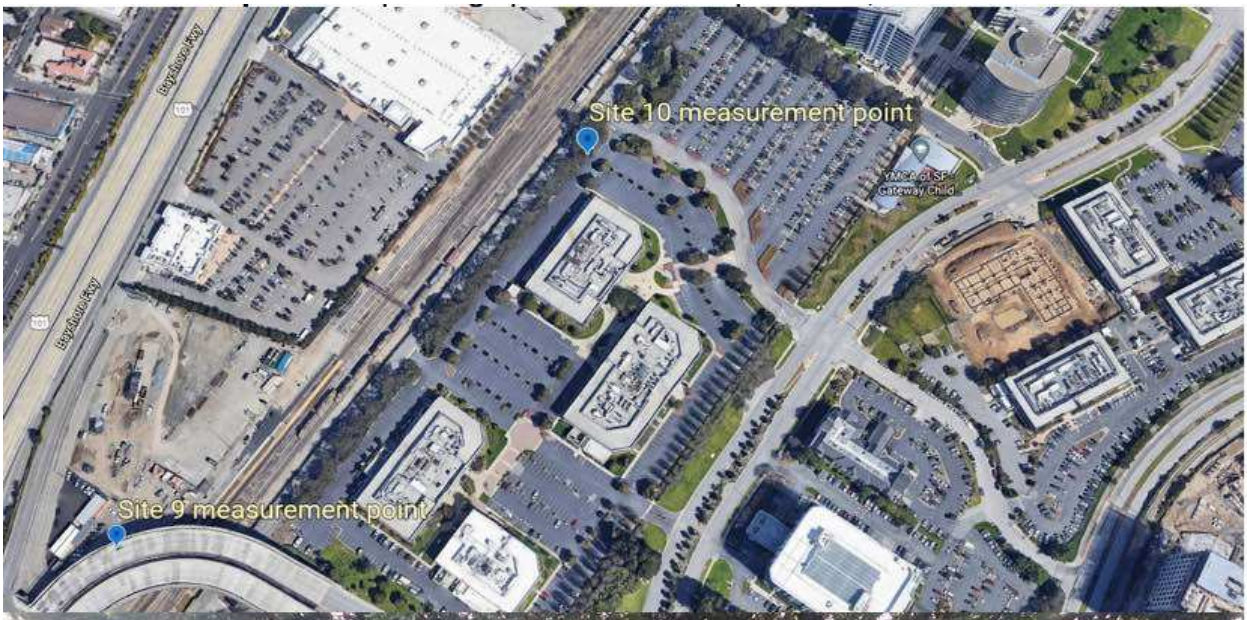
3.3.9 Site 9: 590 Dubuque Ave, South San Francisco, CA 94080

Measurement point: South San Francisco Station parking lot, next to lamp post under Grand Ave westbound overpass, 28 m from Southbound track.



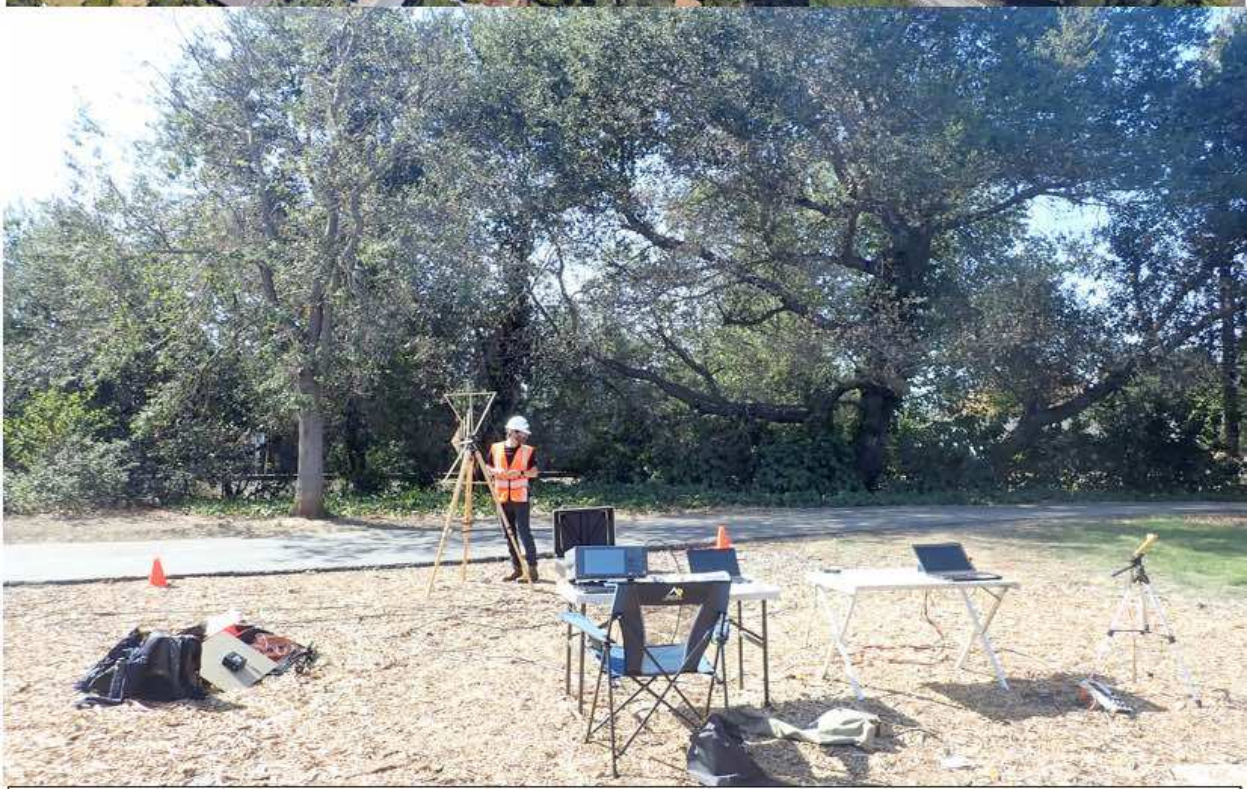
3.3.10 Site 10: 2 Corporate Dr, South San Francisco, CA 94080

Measurement point: 6th parking spot south of Corporate Dr, 26 m from nearest track. The team performed the measurement with power lines located 20 m away from the measurement point.



3.3.11 Site 11: 150 Watkins Ave, Atherton, CA 94027

Measurement point: 16 m from Northbound track.



3.3.12 Site 12: 2000 Crisanto Ave, Mountain View, CA 94040

Measurement point: Parking spots in front of Rengstorff Community Pool entrance, 42 m from Southbound track.

4 Radiated Electric Field Measurement Results

4.1 Purpose and Requirements

The purpose of the Pre-existing EMC Ambient Radiated Electric Field survey was to:

- Establish baseline electric field levels along the Caltrain ROW before power-up of the PCEP electrification system.

- Determine which frequencies and frequency bands are in use for communications and broadcasting along the Caltrain ROW, so the project can confirm that these frequencies do not conflict with planned Caltrain communication frequencies.

Tenco performed electric field measurements at each of the 12 selected locations along the Caltrain ROW. The following subsections provide summary test results and descriptions of measurement locations, test equipment, and test steps and runs. Appendix A provides complete test logs and test data.

4.2 Measurements performed

Tenco performed a total of 168 radiated electric field measurement runs at the 12 selected sites, from September 28, 2020 to October 2, 2020. The test team measured radiated electric field in bands B0 (10 to 160 kHz) through B7 (1 GHz to 6 GHz).

The test team kept a test log per the EMC Ambient Survey Procedure, providing the measurement number, measurement type and time, measurement description, comments for each run, and other relevant information. The test log is in Appendix A.

4.3 Test Results

As described in section 2.1.1, the Pre-existing EMC Ambient Radiated Electric Field levels:

- Were similar at all measurement locations.
- Showed typical high emissions levels at aeronautical communications, space communications, and TV broadcasting frequencies.

Table 2-1 summarizes the radiated electric field level results. This section provides further detail on the radiated electric field measurements, and highlights the most important test runs.

The Table 2-1 summary and the results in this section indicate that the ambient electric field conditions along the Caltrain ROW should not disrupt the safe and normal operation of PCEP rail systems and facilities.

In the following subsections, each page has two graphs:

- Nosiest site
- Quietest site.

Each radiated emission graph shows two traces:

- The top orange trace is the maximum peak hold electric field level
- The bottom bright blue trace is the minimum peak hold electric field level.

The test team made typical measurements for a 10 s period, so the maximum and minimum levels show the variation of the electric field within the 10 s measurement window.

On the graphs, where the maximum and minimum traces are vertically separated, this indicates a time-varying level of electric field during the measurement window. Where the maximum and minimum traces have the same peak value, this indicates a steady level of peak electric field.

A narrow peak with the same maximum and minimum peak value indicates a narrowband transmitter, such as radio, television, cellphone or other transmission frequency.

A broad hump indicates a broadband noise emission typical of high-power equipment other than radio transmitters.

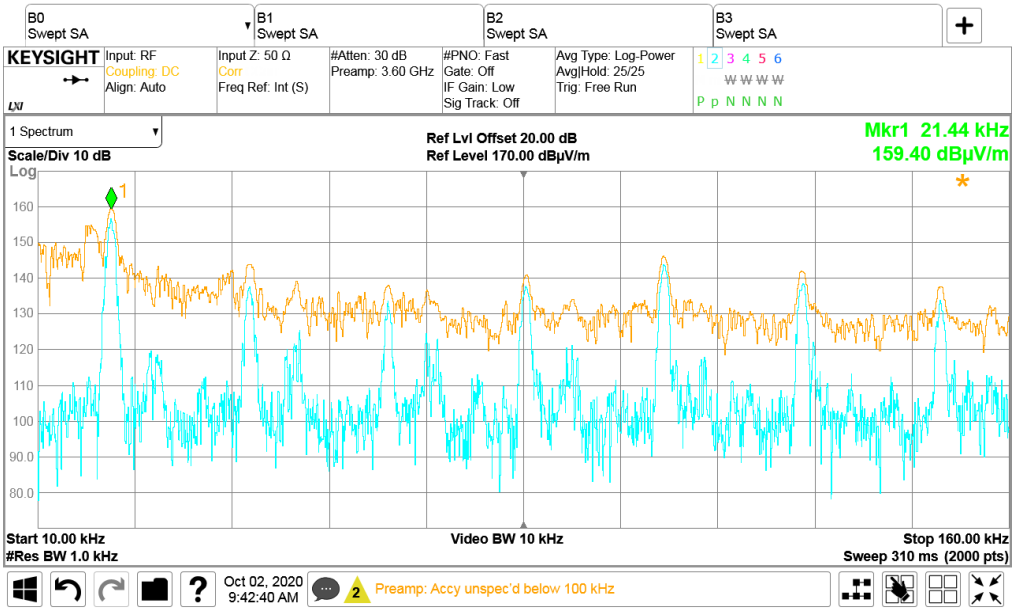
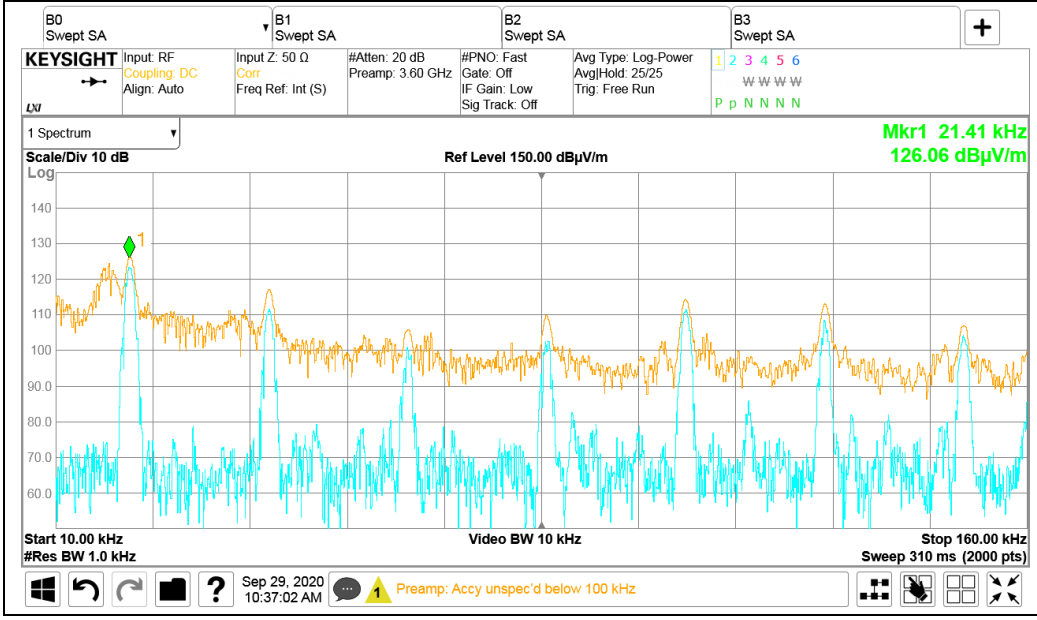
4.3.1 B0 Band, 10 kHz to 60 kHz

Figure 4-1 shows key radiated electric field test runs for B0 band:

- Run 1002-02: Site 4 is the noisiest site, with highest ambient levels up to 155 dB. Sites 10 and 12 have similar high ambient levels.

- Run 929-02: Site 9 is the quietest site, with lowest ambient levels from 120 to 95 dB.

FIGURE 4-1
Band B0 Results

Traces	Comment
Top – maximum peak hold Bottom – minimum peak hold	
	B0 Ambient **Noisiest Site**: 4 Run 1002-02 No emissions. Harmonics every 21 kHz.
	B0 Ambient **Quietest Site**: 9 Run 929-02 20 kHz harmonics slightly visible at about 125 dB intensity, about 20-30 dB lower than sites 1 and 10. Power from car battery through inverter.

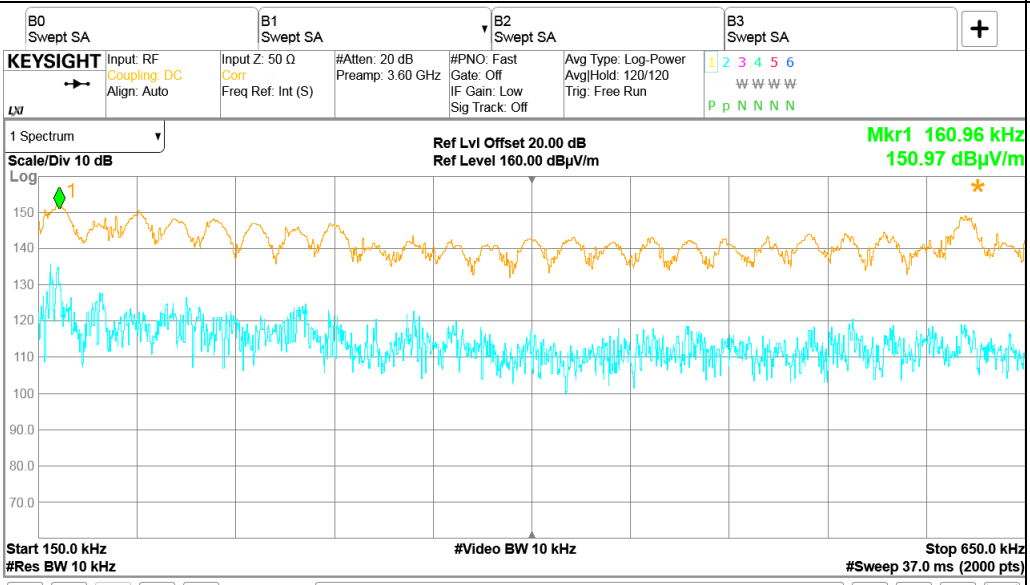
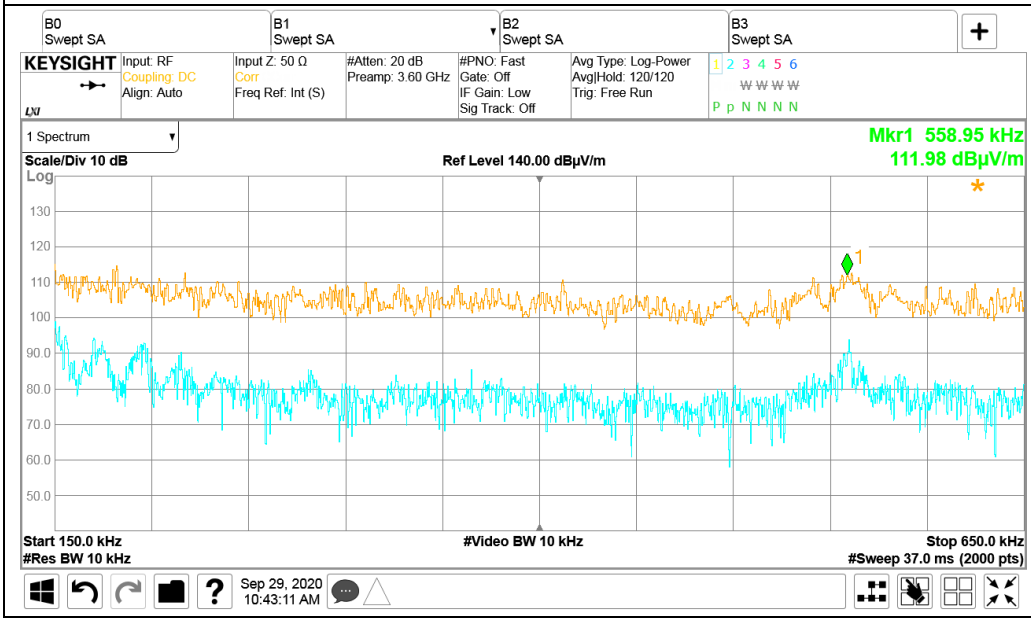
4.3.2 B1 Band, 150 kHz to 650 kHz

Figure 4-2 shows key radiated electric field test runs for B1 band:

- 930-29: Site 7 is the noisiest site, with highest ambient levels around 140 dB. Site 8 has similar high ambient levels.

- 929-03: Site 9 is the quietest site, with lowest ambient levels around 105 dB.

FIGURE 4-2
Band B1 Results

Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B1 Ambient **Noisiest Site**: 7 Run 930-29 Generator harmonics every 20 kHz. No notable emissions.
	B1 Ambient **Quietest Site**: 9 Run 929-03 Similar to Site 1 but 30 dB lower

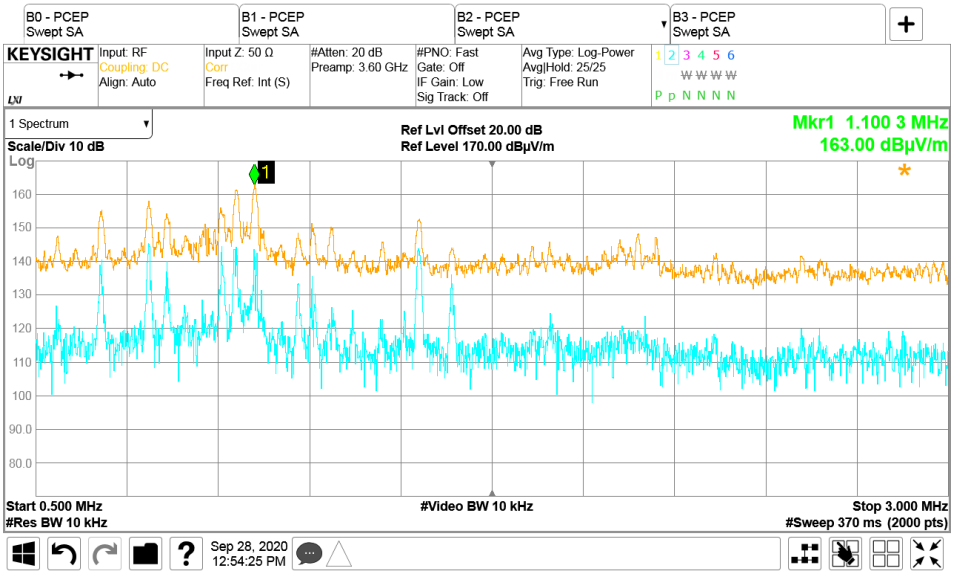
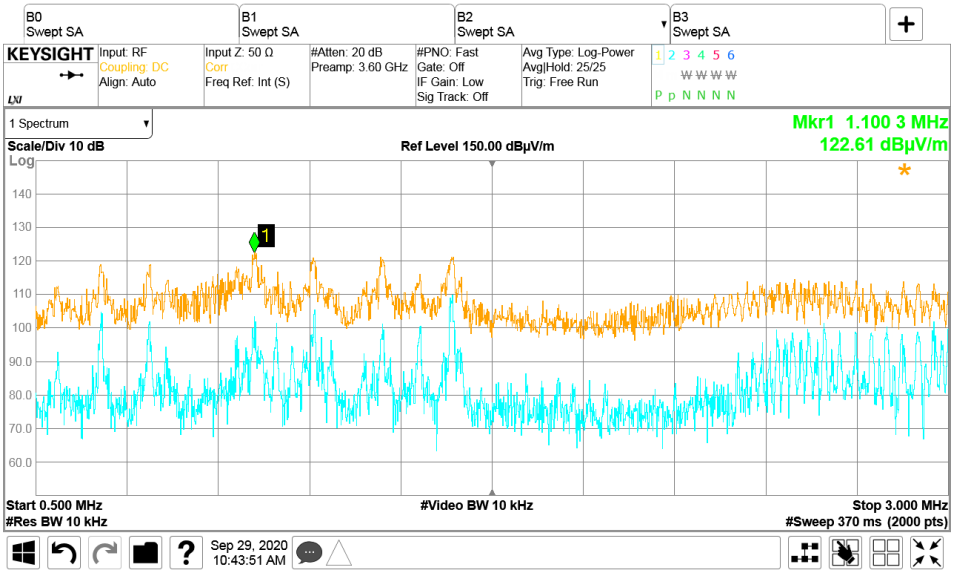
4.3.3 B2 Band, 500 kHz to 3 MHz

Figure 4-3 shows key radiated electric field test runs for B2 band:

- 928-04: Site 1 is the noisiest site, with highest ambient levels around 140 dB. Sites 4 and 12 have similar high ambient levels.

- 929-04: Site 9 is the quietest site, with lowest ambient levels around 110 dB. Site 6 has similar low ambient levels.

FIGURE 4-3
Band B2 Results

Traces	Comment
Top – maximum peak hold Bottom – minimum peak hold	
	B2 Ambient **Noisiest Site**: 1 Run 928-04 Max peaks at 1MHz, 1.05 MHz, and 1.1 MHz Peaks are AM broadcast radio.
	B2 Ambient **Quietest Site**: 9 Run 929-04 Similar to Sites 1 and 10 but about 20 dB lower

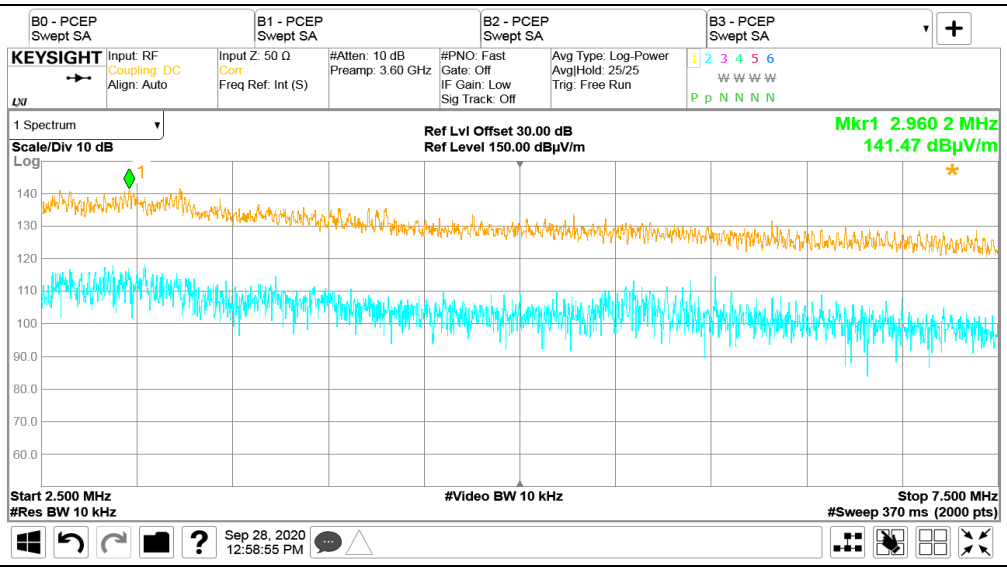
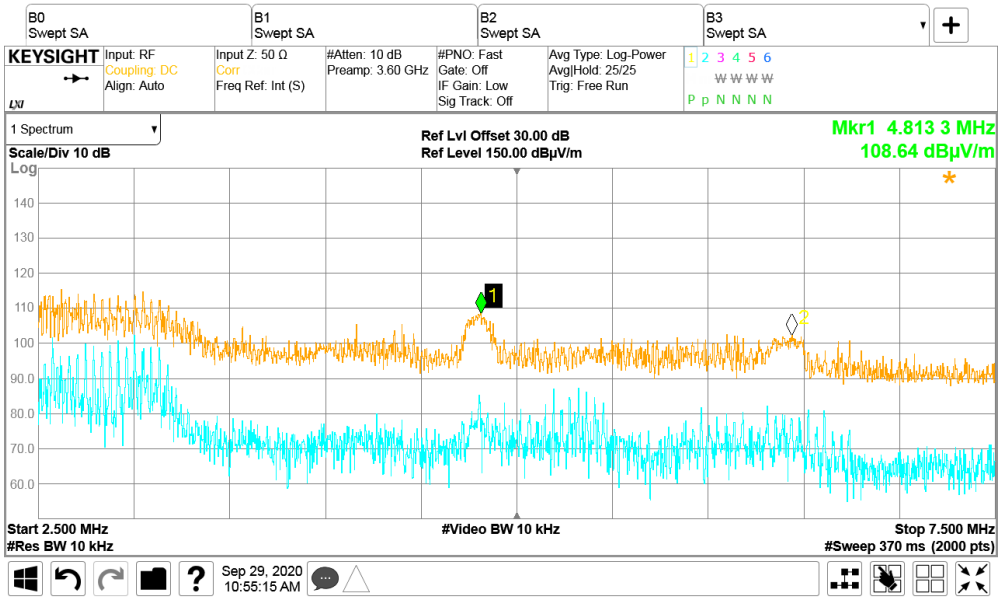
4.3.4 B3 Band, 2.5 MHz to 7.5 MHz

Figure 4-4 shows key radiated electric field test runs for B3 band:

- 928-05: Site 1 is the noisiest site, with highest ambient levels around 135 dB. Sites 4, 10 and 12 have similar high ambient levels.

- 929-05: Site 9 is the quietest site, with lowest ambient levels around 100 dB.

FIGURE 4-4
Band B3 Results

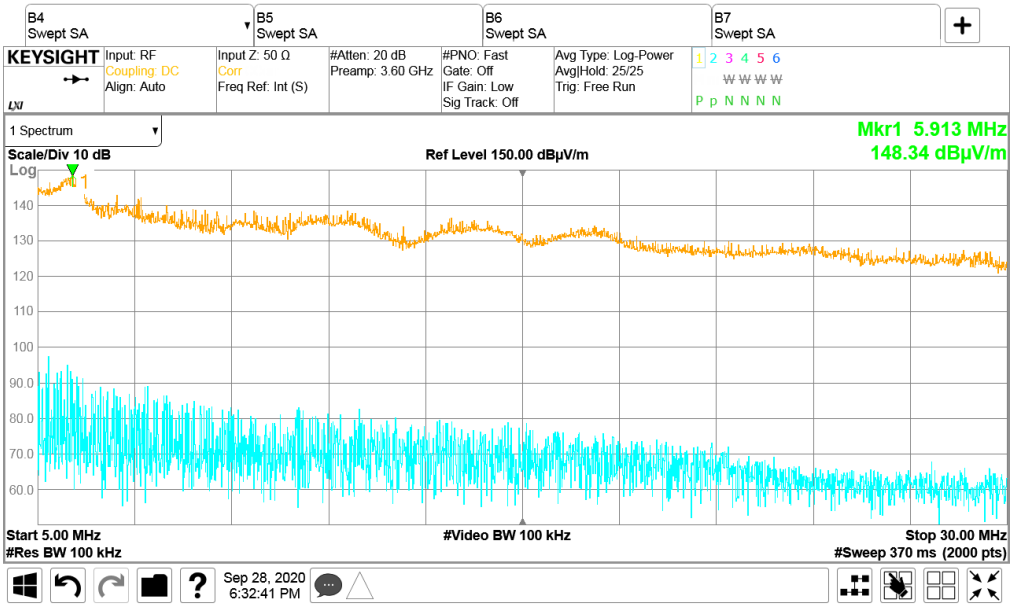
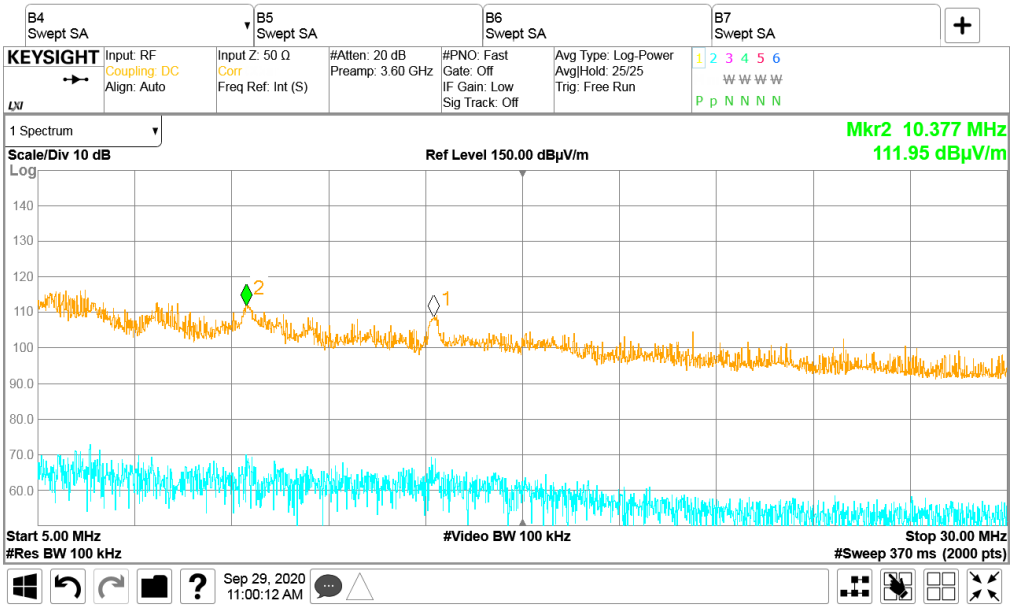
Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B3 Ambient **Noisiest Site**: 1 Run 928-05 Peaks at 2.96 MHz and 3.22 MHz
	B3 Ambient **Quietest Site**: 9 Run 929-05 Caltrain diesel electric MU trainset accelerating from rest. Emissions present at 6.4 MHz and 4.8 MHz with intensities across this band ranging from around 90 - 110 dB.

4.3.5 B4 Band, 5 MHz to 30 MHz

Figure 4-5 shows key radiated electric field test runs for B4 band:

- 928-18: Site 10 is the noisiest site, with highest ambient levels around 145 dB.
- 929-07: Site 9 is the quietest site, with lowest ambient levels around 90 - 110 dB.

FIGURE 4-5
Band B4 Results

Traces	Comment
Top – maximum peak hold Bottom – minimum peak hold	
	B4 Ambient **Noisiest Site**: 10 Run 928-18 Diesel locomotive passing. Max signal around 5.9 MHz
	B4 Ambient **Quietest Site**: 9 Run 929-07 Slight emissions present at 10.3 MHz and 15.2 MHz

4.3.6 B5 Band, 25 MHz to 325 MHz

Figure 4-6 shows key radiated electric field test runs for B5h band:

- 929-40: Site 6 is the noisiest site, with highest ambient levels around 95 dB.
- 930-09: Site 11 is the quietest site, with lowest ambient levels around 60 - 70 dB.

FIGURE 4-6
Band B5h Results

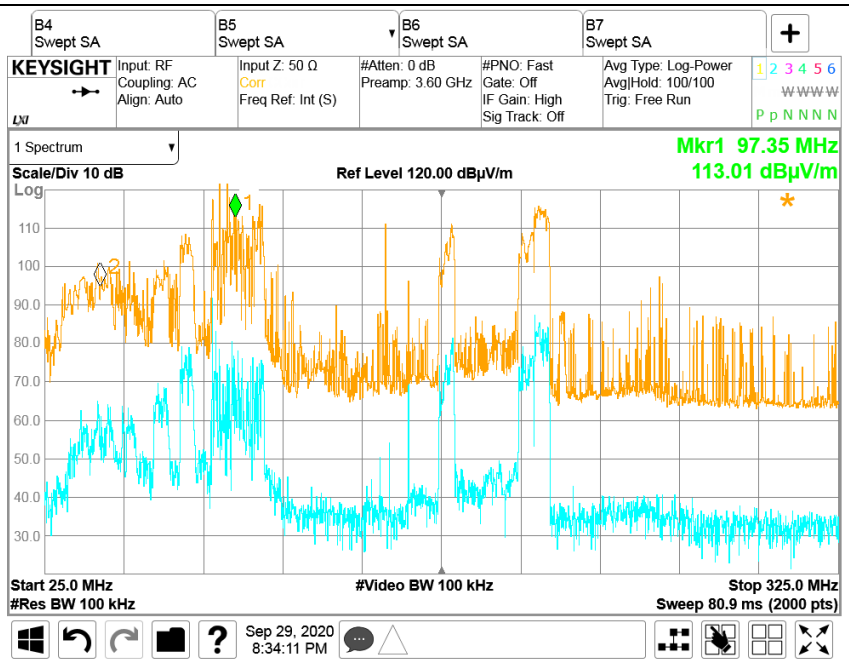
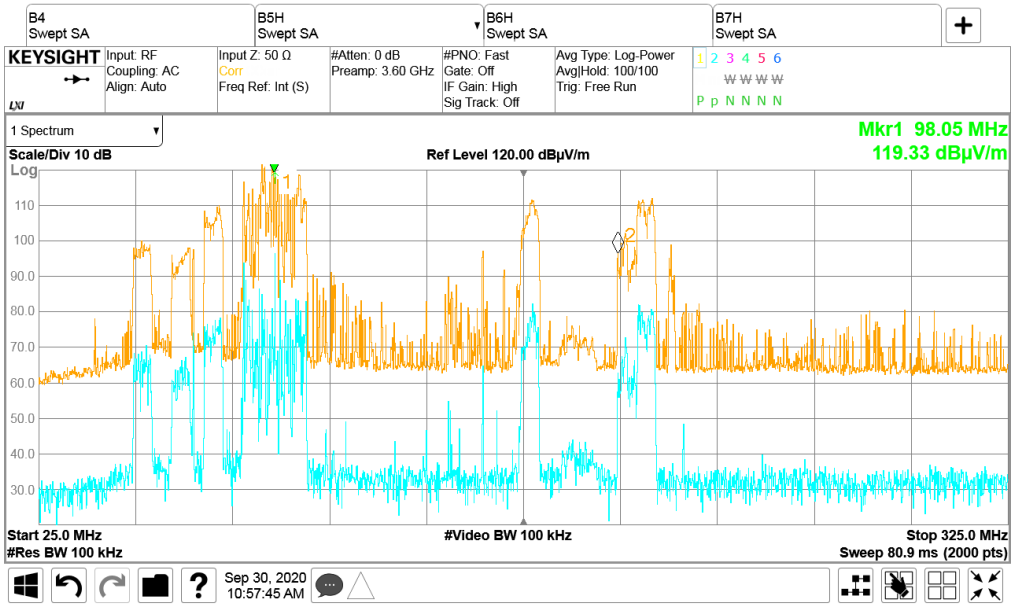
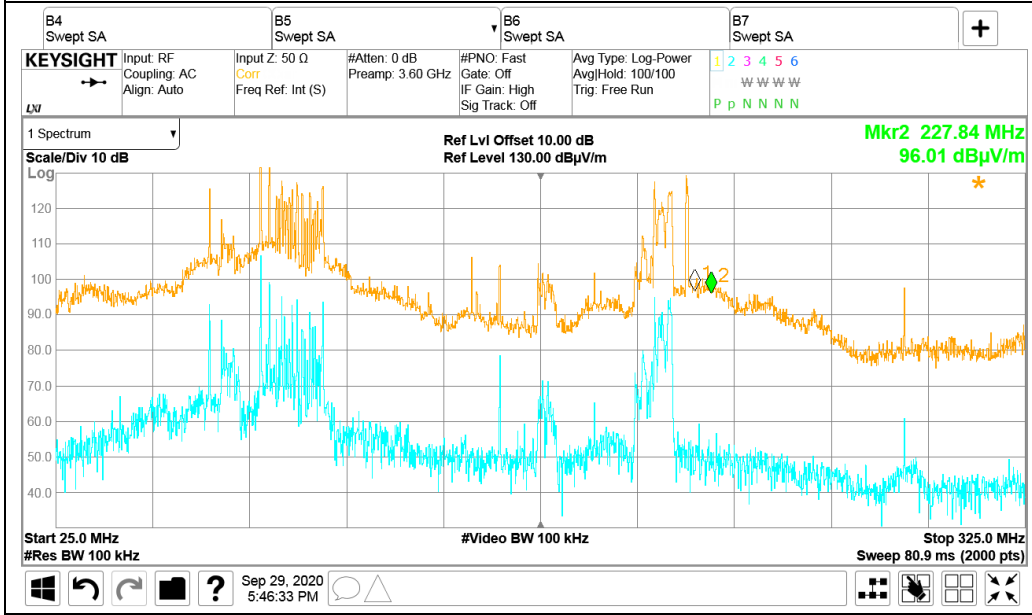
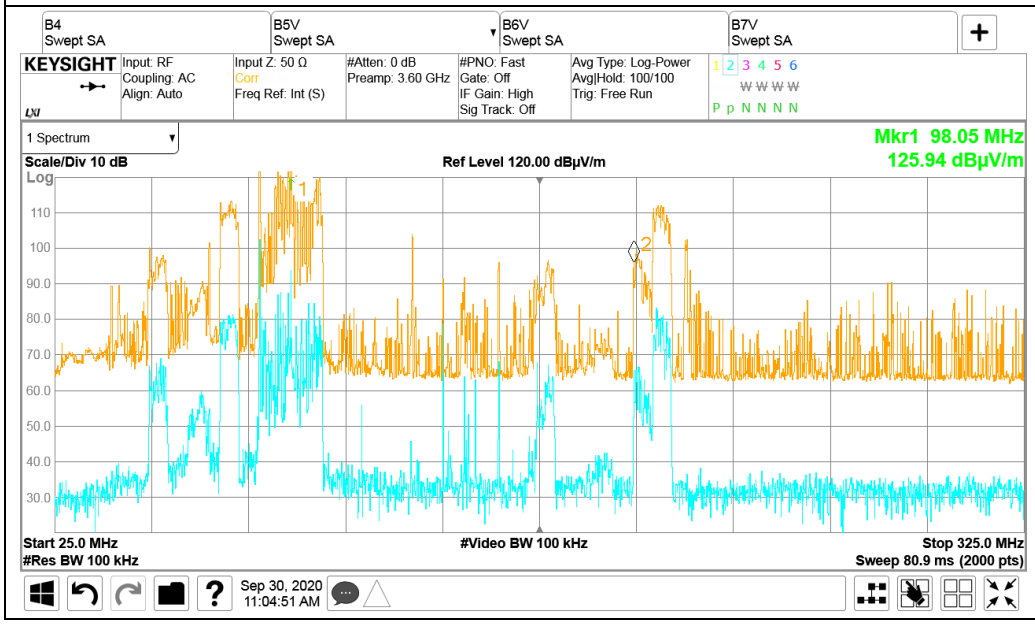
Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B5h Ambient **Noisiest Site**: 6 Run 929-40 Signal centered near 50 MHz Other signals across band from FM radio and TV broadcast.
	B5h Ambient **Quietest Site**: 11 Run 930-09 Slight emissions centered near 80 MHz, intensity near 80 dB. Other signals across band from FM radio and TV broadcast.

Figure 4-7 shows key radiated electric field test runs for B5v band:

- 929-24: Site 5 is the noisiest site, with highest ambient levels around 110 dB.
- 930-12: Site 11 is the quietest site, with lowest ambient levels around 65 dB.

FIGURE 4-7
Band B5v Results

Traces	Comment
Top – maximum peak hold Bottom – minimum peak hold	
	B5v Ambient **Noisiest Site**: 5 Run 929-24 Very similar to B5H Site 5. Caltrain MU trainset stopped in front of bilogic antenna for this run.
	B5v Ambient **Quietest Site**: 11 Run 930-12 Similar to Site 11 B5H.

4.3.7 B6 Band, 300 MHz to 1.3 GHz

Figure 4-8 shows key radiated electric field test runs for B6h band:

- 1002-20: Site 2 is the noisiest site, with highest ambient levels around 82 dB. Sites 5, 7 and 12 have similar high ambient levels.

- 928-09: Site 1 is the quietest site, with lowest ambient levels around 70 dB. Sites 3, 4, 6, 8, and 11 have similar low ambient levels.

FIGURE 4-8
Band B6h Results

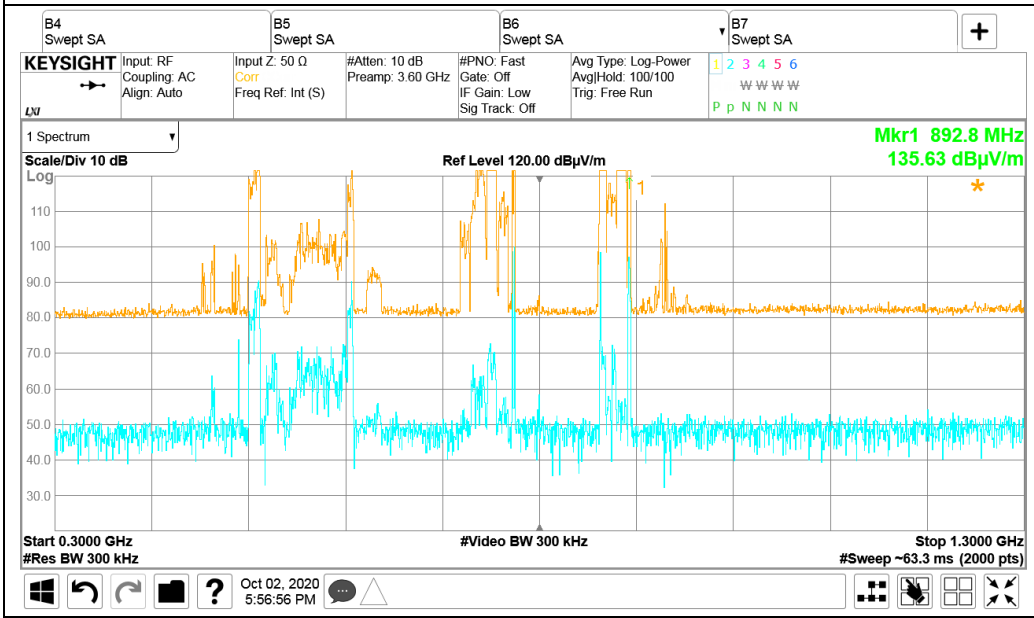
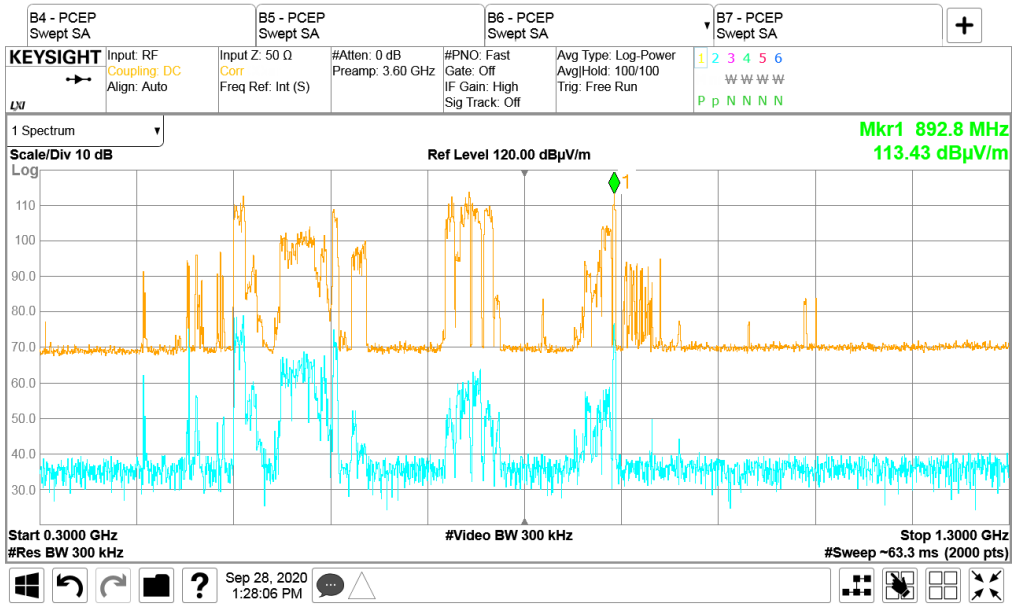
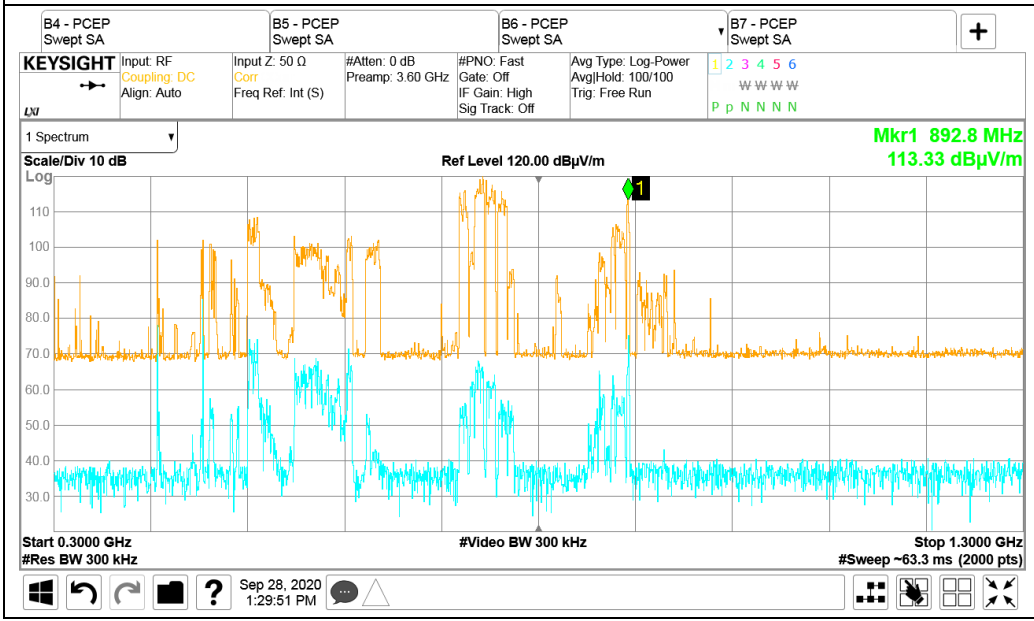
Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B6h Ambient **Noisiest Site**: 2 Run 1002-20 512 - 608 MHz broadcast TV. 800 and 900 MHz due to cellular phone
	B6h Ambient **Quietest Site**: 1 Run 928-09 512 - 608 MHz broadcast TV. 800 and 900 MHz due to cellular phone

Figure 4-9 shows key radiated electric field test runs for B6v band:

- 1002-23: Site 2 is the noisiest site, with highest ambient levels around 82 dB. Sites 5, 7 and 12 have similar high ambient levels.

- 928-10: Site 1 is the quietest site, with lowest ambient levels around 70 dB. Sites 3, 4, 6, 8, and 11 have similar low ambient levels.

FIGURE 4-9
Band B6v Results

Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B6v Ambient **Noisiest Site**: 2 Run 1002-23
	B6v Ambient **Quietest Site**: 1 Run 928-10 Similar to B6 horizontal

4.3.8 B7 Band, 1 GHz to 6 GHz

Figure 4-10 shows key radiated electric field test runs for B7h band:

- 929-23: Site 5 is the noisiest site, with highest ambient levels around 80 dB.
- 928-11: Site 1 is the quietest site, with lowest ambient levels around 72 – 68 dB. All sites except site 5 share the similar lowest ambient levels.

FIGURE 4-10
Band B7h Results

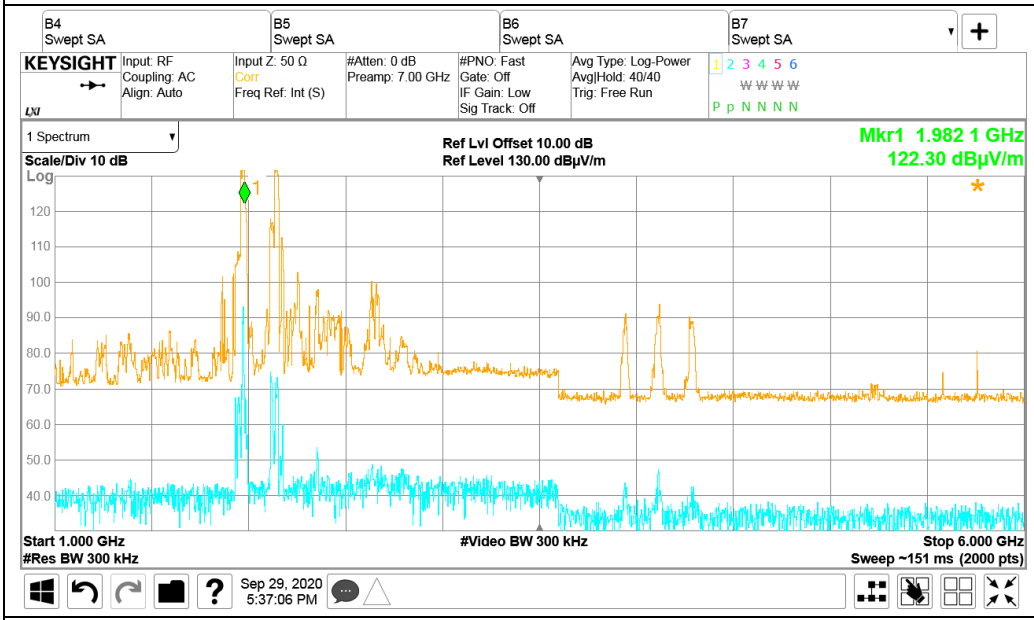
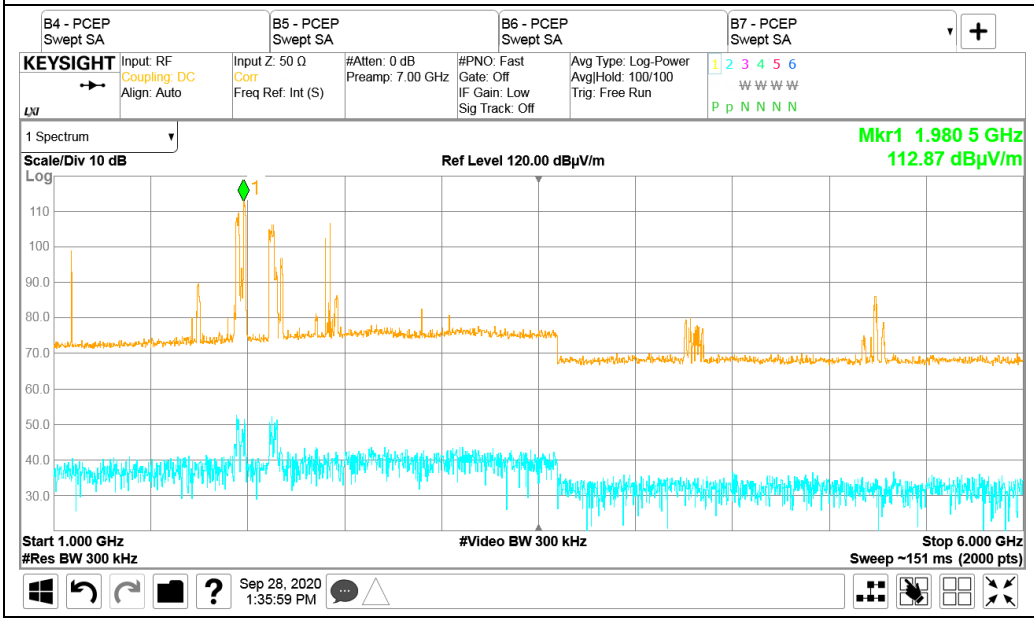
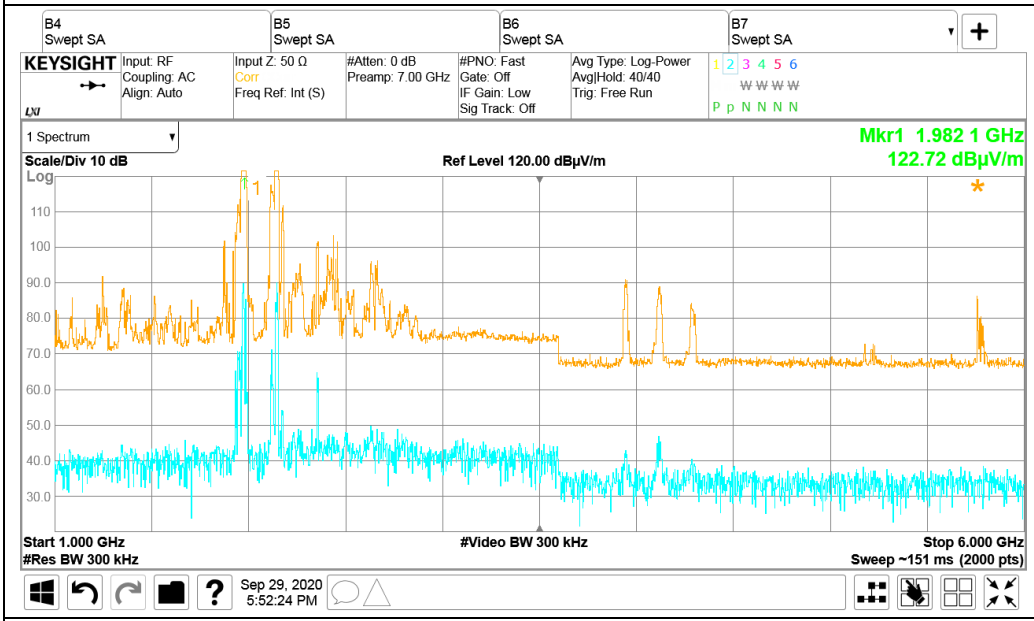
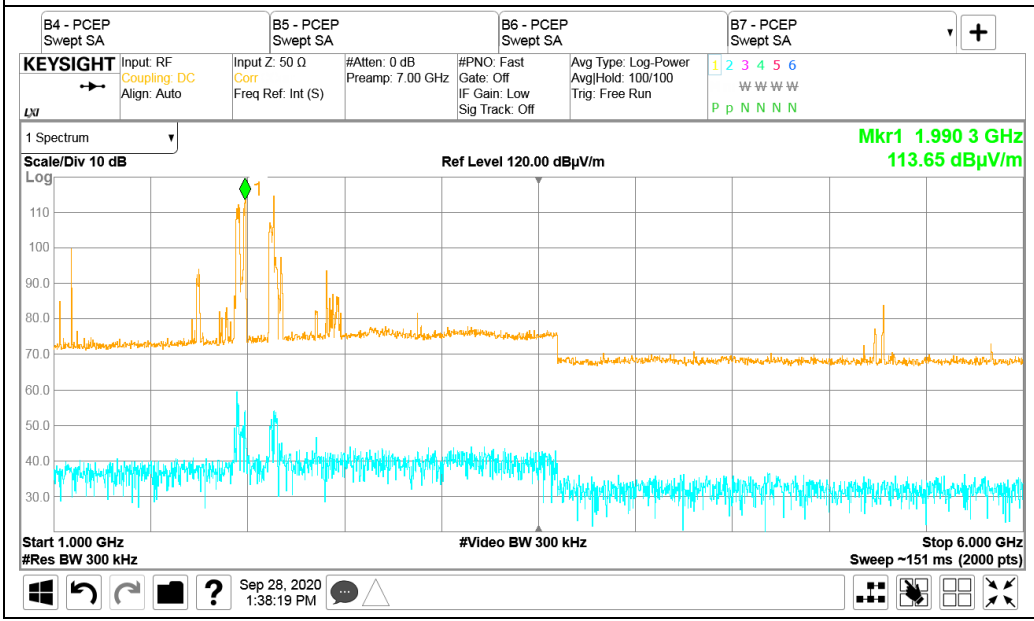
Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B7h Ambient **Noisiest Site**: 5 Run 929-23 Signals in this band due to cellphone, Wi-Fi, aeronautical and space communications
	B7h Ambient **Quietest Site**: 1 Run 928-11 Cluster of peaks between 1.9 GHz and 2.0 GHz

Figure 4-11 shows key radiated electric field test runs for band B7v band:

- 929-26: Site 5 is the noisiest site, with highest ambient levels around 75 dB.
- 928-12: Site 1 is the quietest site, with lowest ambient levels around 72 – 68 dB. All sites except site 5 share the similar lowest ambient levels.

FIGURE 4-11
Band B7v Results

Traces Top – maximum peak hold Bottom – minimum peak hold	Comment
	B7v Ambient **Noisiest Site**: 5 Run 929-26 Similar to B7H.
	B7v Ambient **Quietest Site**: 1 Run 928-12 Similar to B7 horizontal

4.4 Test Equipment and Calibration

4.4.1 Test Equipment

Figure 4-12 is a block diagram of the radiated electric field test setup. The test used an active monopole antenna and bilogical antennas to measure electromagnetic fields from the ambient environment at each site. The test used the monopole antenna for low frequency measurements from 9 kHz to 30 MHz (B0 Band to B4 Band), and the bilogical antenna for high frequency measurements from 25 MHz to 6.0 GHz (B5 Band to B7 Band).

The antennas were connected to a Keysight N9010B Spectrum Analyzer, which measured the electromagnetic field levels in each frequency band.

The test configuration followed the configuration in the EMC Ambient Survey Procedure, except for a change in antenna height noted in section 4.5. During each test run, the Spectrum Analyzer collected data in peak hold mode.

FIGURE 4-12
Radiated Electric Field Measurement Equipment Setup

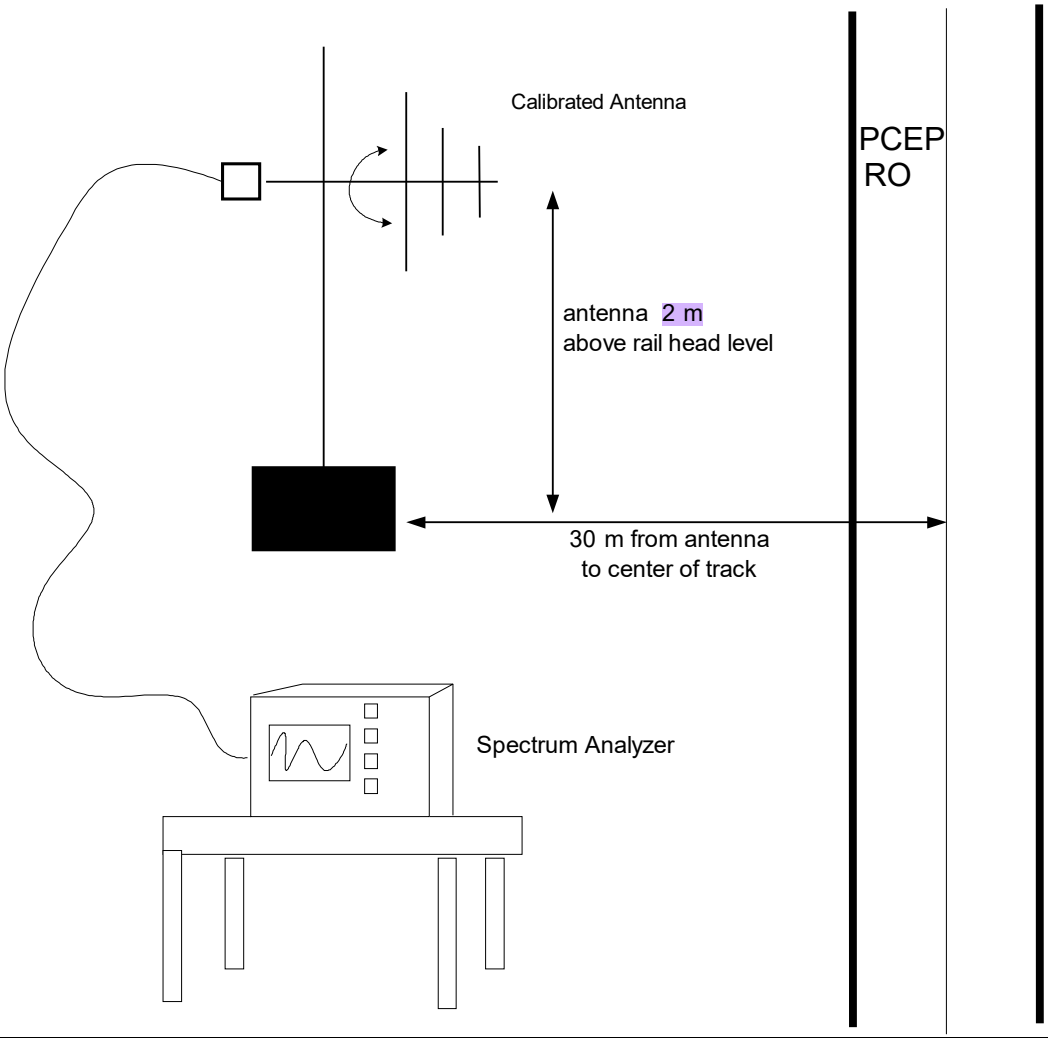


Table 4-1 lists the radiated electric field measurement equipment.

TABLE 4-1
Radiated Electric Field Measurement Equipment List

#	Item	Comment
1	Keysight KT-9010A-507/P07/EDP 10 Hz – 7 GHz EXA Signal Analyzer with KT-N6141A/2TP EMI Measurement application or equivalent	For measuring EMI field intensity between 10 Hz and 6 GHz.
2	Keysight PC Software, KT-N6141A/2TP EMI Measurement application or equivalent	For transfer of data from Spectrum Analyzer to PC
3	Inkjet Printer, or equivalent	For plotting emission spectra. Compatible with spectrum analyzer.
4	A.H Systems SAS-550-1: Active Monopole Antenna or equivalent, 10 kHz to 60 MHz	Calibrated antenna for Bands 0 – 4
5	A.H. Systems SAS-521F-7: Bilogical Antenna or equivalent, 25 MHz to 7 GHz	Calibrated antenna for Bands 5 – 7
6	Adjustable Antenna Tripod	To support antennas
7	Laptop computer	For control of printer and storage of survey data results
8	AC Power Source	AC line, generator, or car battery inverter.

The EMC Ambient Survey Procedure describes the major test equipment items in more detail.

4.4.2 Test Bands

Tenco performed broadband emission measurements from 10 kHz to 6 GHz using active monopole and bilogical antennas, for horizontal and vertical electric fields as appropriate.

The test team divided the measurement band into eight smaller test bands, listed in Table 4-2.

The test engineers used the active monopole antenna to cover the range from 10 kHz to 30 MHz, in five measurement sub-bands. Per the UMTA procedure, Tenco measured with the active monopole oriented vertically. The active monopole antenna is omnidirectional, so a single measurement will record fields in all compass directions.

The test engineers used the Bi-logical antenna to cover the range from 30 MHz to 6 GHz, for both horizontal and vertical polarization.

TABLE 4-2
Radiated Electric Field Measurement Bands

ID	Band Frequency Range	Antenna	Antenna Orientation	Resolution Bandwidth
B0	10 kHz – 160 kHz	Active Monopole	Vertical	1 kHz
B1	150 kHz – 650 kHz	Active Monopole	Vertical	10 kHz
B2	500 kHz – 3 MHz	Active Monopole	Vertical	10 kHz
B3	2.5 MHz – 7.5 MHz	Active Monopole	Vertical	10 kHz
B4	5 MHz – 30 MHz	Active Monopole	Vertical	100 kHz
B5h	25 MHz – 325 MHz	Bilogical	Horizontal	100 kHz
B5v	25 MHz – 325 MHz	Bilogical	Vertical	100 kHz
B6h	300 MHz – 1.3 GHz	Bilogical	Horizontal	300 kHz
B6v	300 MHz – 1.3 GHz	Bilogical	Vertical	300 kHz
B7h	1 GHz – 6 GHz	Bilogical	Horizontal	300 kHz
B7v	1 GHz – 6 GHz	Bilogical	Vertical	300 kHz

4.4.3 Calibration

The test team performed the following steps to verify proper operation of the radiated electric field test equipment:

- Turned on spectrum analyzer and let it warm up for 30 minutes
- After warm up, calibrated the spectrum analyzer as described in the user's manual
- Verified cable loss matches calibration record.
- Verified antennas are operating properly.

4.5 Test Procedure Steps

The test team followed the steps in the EMC Ambient Survey Procedure to measure ambient radiated electric field at each site. The test team positioned the active monopole antenna 1.4 m above ground and the bilogical antenna 1.6 m above ground at all 12 selected measurement sites in section 3.3. These revised heights were selected to ensure that the same height could be used at all locations, regardless of local terrain variations.

Otherwise, there were no significant deviations from the procedure steps and test runs.

The test setup for data collection is in EMC Ambient Survey Procedure Section 4.6.4.

5 Magnetic Field Measurement Results

5.1 Purpose and Requirements

Magnetic fields resulting from DC and AC currents can disrupt sensitive electronic and scientific equipment including early technology pacemakers. The PCEP EMCP and IEEE standards require that human exposure to electromagnetic fields in and around the PCEP line must comply with:

- IEEE Std C95.6-2002, Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz.

- IEEE Std C95.1-2005, Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

The IEEE Standard C95.6 Maximum Permissible Exposure (MPE) for controlled environments in which employees work is 27.1 G. This limit applies to areas that are not open to the public. For the general public and in particular at 60 Hz, the frequency of the traction power system, the IEEE Std 95.6 Table 2 provides an MPE limit of 9.04 G. This applies in all areas onboard and near the rolling stock.

Accordingly, the purpose of the Pre-existing EMC Ambient Magnetic Field survey was to:

- Establish baseline ambient magnetic field levels along the Caltrain ROW before power-up of the PCEP electrification system.

- Determine that the pre-existing magnetic field levels along the Caltrain ROW is below the standard limits.

Tenco performed magnetic field measurements at each of the 12 selected sites along the Caltrain ROW. The following subsections provide summary test results and descriptions of measurement locations, test equipment, and test steps and runs.

Appendix A provides complete test logs and test data.

5.2 Measurements performed

Tenco performed 41 magnetic field test runs at the 12 selected sites, from September 29, 2020 to October 2, 2020.

The test team recorded static magnetic field magnitude and in 4 frequency bands every test run. Table 5-1 shows the frequency bands used during the magnetic field tests.

TABLE 5-1
Magnetic Field Test Measurement Bands

Band	Frequency Range
DC (static)	0 Hz
F1	54 – 66 Hz
F2	72 – 288 Hz
F3	234 – 486 Hz
F4	432 – 1008 Hz

5.3 Measurement Results

All magnetic field test results were well below the IEEE limits, as expected, since the test team only measured the ambient.

The Revenue Service EMC Survey and One Year Monitoring EMC Survey will measure the magnetic field levels, at the same locations, after EMU trainsets begin running in revenue service. The test team will then compare the electromagnetic field emissions to pre-PCEP operations, and make sure the levels are still below the IEEE limits.

As noted in section 2.2, the test team observed minimal static magnetic field fluctuation during all test runs. For each site, the static field levels were identical to or very close to the earth level, which is about 483 mG in San Francisco.

The test team observed maximum AC magnetic field of 12 mG at 60 Hz. These levels are very low compared to the to the IEEE limits of 9.04 G.

This section provides detailed results from the magnetic field measurements. Each test run figure in this section has 4 graphs:

- Graph 1: Vector Magnitudes for AC frequency bands F1 (60 Hz) and F2 (72 to 288 Hz)
- Graph 2: F1 (60 Hz) x, y, and z axis field strength magnitude
- Graph 3: Vector Magnitudes for AC frequency bands F3 (234 to 486 Hz) and F4 (432 to 1008 Hz).
- Graph 4: Static (0 Hz) Magnetic field strength magnitude

Figure 5-1 shows run 929-M07, the maximum AC magnetic field measurement with 12 mG at 60 Hz and 7 mG at 180 Hz. These levels are far below the IEEE maximum exposure limit of 9.04 G for the general public. Run 929-M07 was at Site 6, with power lines located 6 m above the measurement point.

Figure 5-2 shows run 1002-M14, the next highest AC magnetic field measurements, with 5.62 mG at 60 Hz, and 3.13 mG at 180 Hz. These are also far lower than the IEEE maximum exposure limit of 9.04 G. Run 1002-M14 was at Site 2, with power lines located 8 m overhead, and 5 m away from the measurement point.

Figure 5-3 shows run 1002-M11, the third highest AC magnetic field measurement, with 1.86 mG at 60 Hz, and 1.08 mG at 180 Hz vs. a limit of 9.04 G. Run 1002-M11 was at Site 10, with power lines located 20 m away from the measurement point.

As noted in section 2.2, the test team measured the higher magnetic field levels near high voltage power lines. Those levels are higher due to AC currents in utility power cables.

FIGURE 5-1
Run 929-M07 – Maximum AC Magnetic Field Run

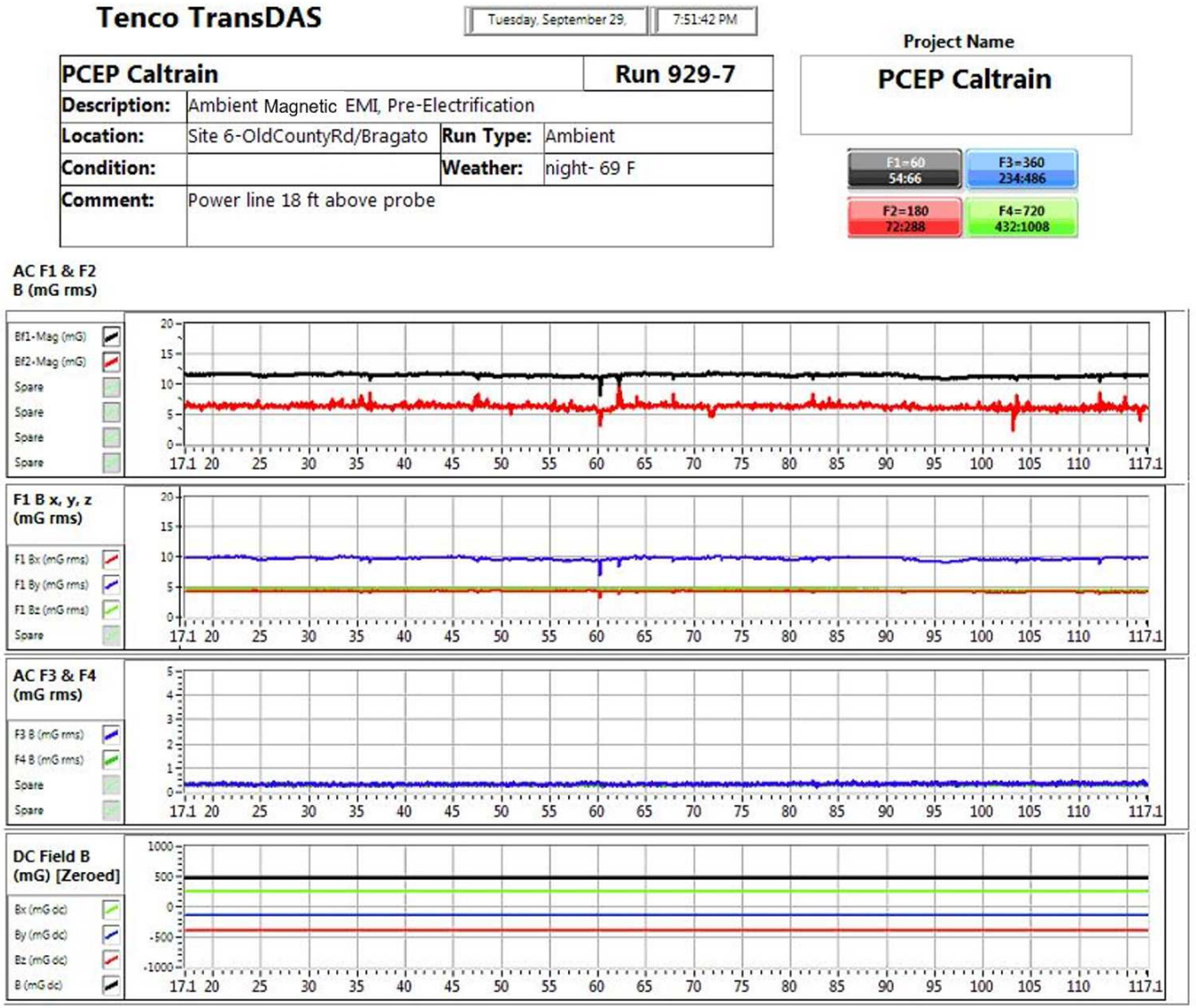


FIGURE 5-2
Run 1002-M14 – Notable AC Magnetic Field Run

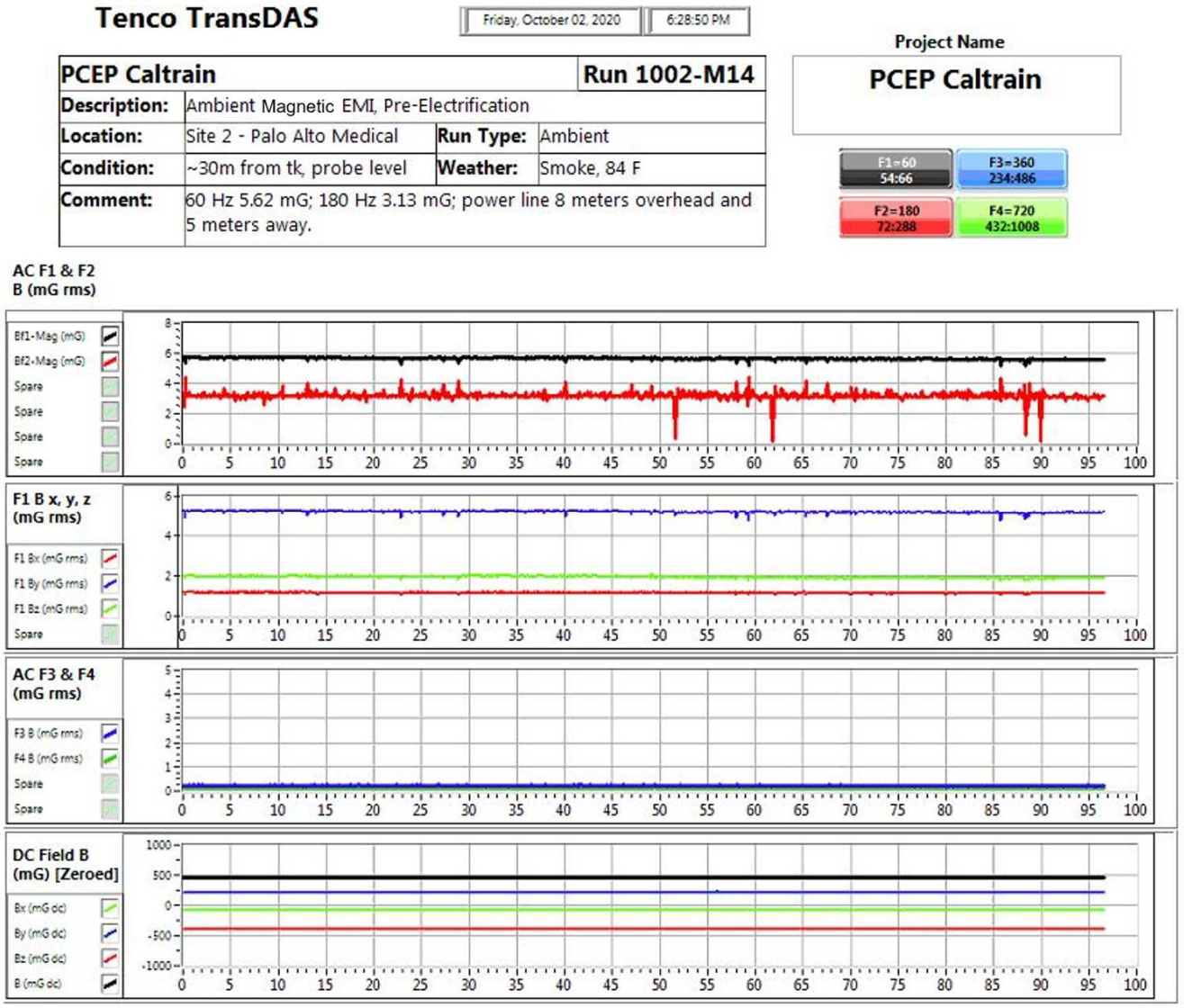
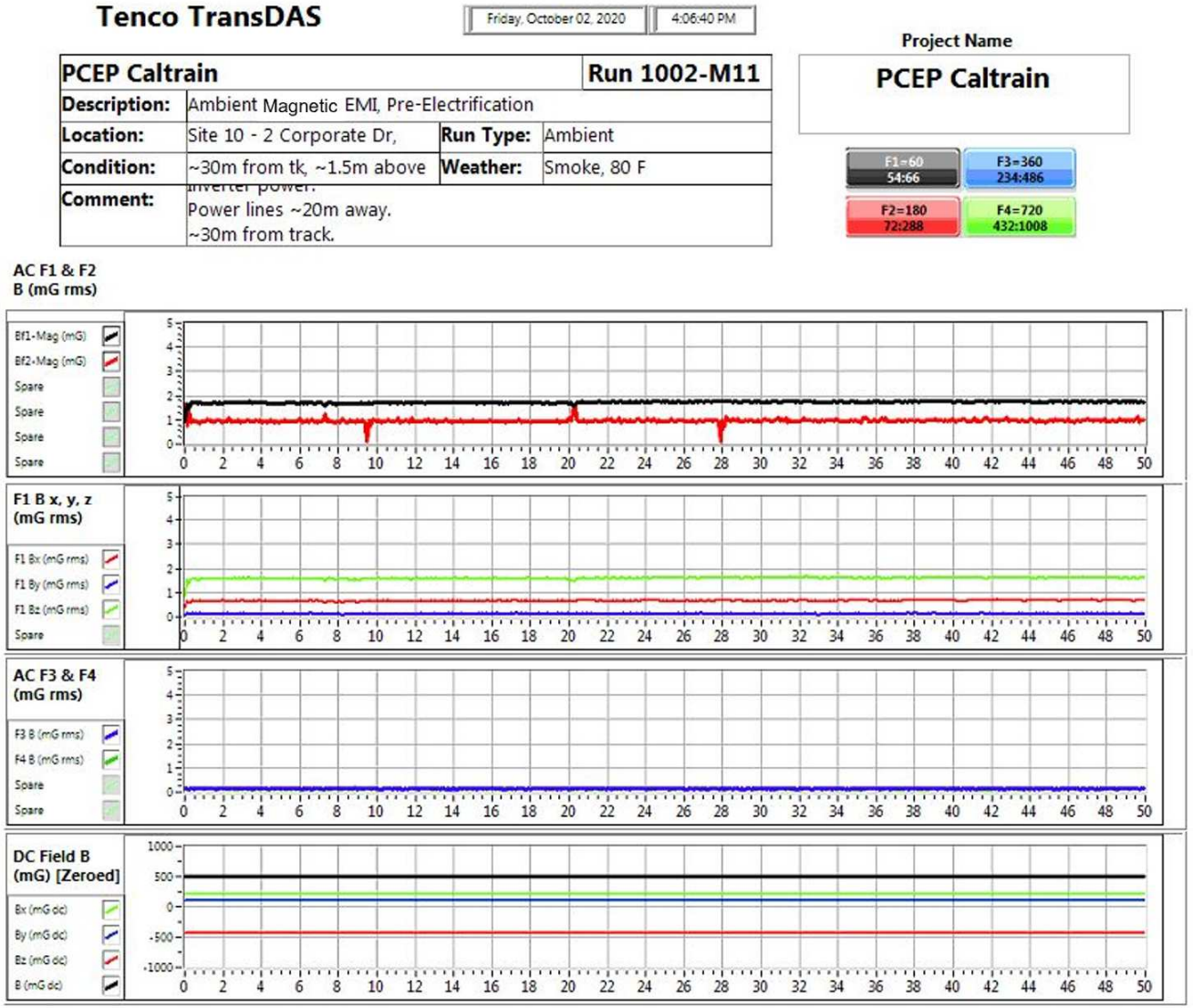


FIGURE 5-3
Run 1002-M11 – Notable AC Magnetic Field Run

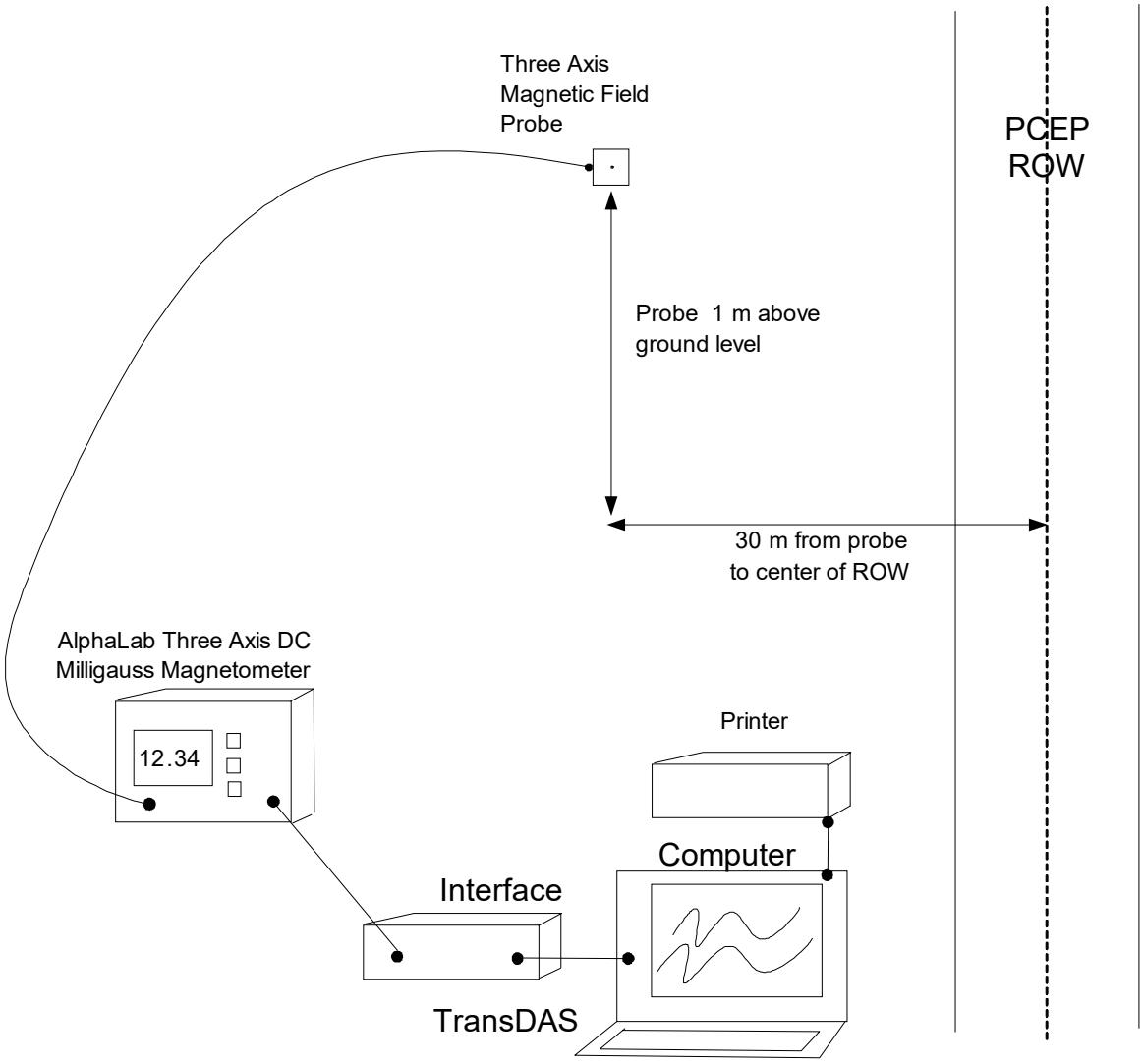


5.4 Test Equipment and Calibration

Figure 5-4 shows the test equipment setup for the magnetic measurements.

The magnetic field probe is generally positioned 1 m above the ground and about 30 m from the center of ROW per the EMC Ambient Survey Procedure. The purpose is to find and record the strongest magnetic field strengths, vectors, and magnitudes, and changes related to ambient conditions.

FIGURE 5-4
Magnetic Field Measurement Equipment Setup



5.5 Test Procedure Steps

The test team followed the steps in the EMC Ambient Survey Procedure to measure ambient magnetic field at each site. There were no significant deviations from the procedure steps and test runs. The test set up for data collection is in EMC Ambient Survey Procedure Section 5.6.4.