Taiwan Railways Administration
68 Units of Electric Locomotive Project

Toshiba Electric Locomotive Factory EMI Type Test Report

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Revision History		
Date	**Rev.**	**Change**
April 16, 2024	0	Initial release
April 29, 2024	0.1	Added trace labels to RE figures and RE Appendix

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1 Introduction

Toshiba Infrastructure Systems & Solutions Corporation (TISS) is supplying the Taiwan Railways Administration (TRA) with 68 new electric locomotives. TISS is designing, building, integrating, and testing the locomotives. Turner Engineering Corporation (Tenco) is providing electromagnetic compatibility (EMC) testing and other engineering services for the Electric Locomotive (EL) project.

TRA specified EMC requirements in Section 6.5 of the TRA Procurement of 68 Electric Locomotive Specification (Technical Specifications or TS). In response to the Technical Specifications and TRA direction, TISS developed an EMC Control Plan (EMCCP) governing all EMC test activities on the project.

Per the EMCCP and the TRA requirements, TISS and Tenco performed the Factory Electromagnetic Interference Type Tests (FETT) to document that the EL electromagnetic interference (EMI) emissions conform with TRA TS limits. This Factory EMI Type Test Report (FETR) provides the results of the FETT which TRA, TISS, and Tenco performed from November 8, 2023 through January 26, 2024.

1.1 Overview of the Factory EMI Type Test

TISS and Tenco performed the FETT tests of radiated emissions, conducted emissions, onboard magnetic field emissions, and DC return current to demonstrate that the EL electromagnetic emissions conform to TRA TS limits.

This FETR provides complete results of the FETT that TRA, TISS and Tenco performed on the first TRA EL E501 at Qidu Depot, and on the TRA mainline track between Sanyi and Houli Stations in Taichung City, Taiwan.

TISS, and Tenco performed the FETT tests from November 8, 2023 through January 26, 2024, per the TRA-approved Factory EMI Type Test Procedure Rev 5.0.

The Factory EMI Type Test Procedure (FETP) provides test methods, test arrangements, and related technical information for performing the FETT, as well as the methods and format for measuring, recording, and documenting the test results.

In overview, TRA, TISS, and Tenco performed the following EMI tests on the first EL E501:

- Radiated Emissions Tests (RET), measuring electromagnetic fields from the EL 10 m from the track centerline, from 150 kHz to 1 GHz. Tenco measured in propulsion, braking, coasting, and with the locomotive stationary, at up to 50 km/h.

- Conducted Emissions Tests (CET), measuring propulsion and auxiliary power supply current, negative return current, and main circuit voltage. Tenco measured under normal and failure propulsion system conditions, in powering and braking, at up to 50 km/h.

- DC Return Current Test (DCRCT) measuring the DC component of the line current after the Vacuum Circuit Breaker was closed for 1s.

- Onboard Magnetic Field Emissions Tests (OMFT), measuring DC, 60 Hz, and wideband magnetic fields up to 800 Hz at TRA-specified locations in the EL. Tenco measured at maximum propulsion current, in powering and braking, at up to 130 km/h.

1.2 Objectives of the Factory EMI Type Test Report

The objective of the FETT is to demonstrate that the EL conducted, radiated, and onboard magnetic field emissions conform to TRA TS limits.

The objective of this FETR is to provide TRA and TISS management with complete EL FETT results.

1.3 Scope

The scope of this FETR is the test results from TISS EMI tests at Qidu Depot on November 8 to 14, 2023, and on the TRA mainline on January 22 to January 26, 2024. This FETR provides test results for the TISS EL with car number E501.

The FETR excludes all other equipment and activities outside the TISS EL scope. Elements outside the scope include:

- Emissions from the TRA traction power system or the overhead contact wire system

- Emissions from the signal, power, communications, and other equipment in use on or near the TRA rail lines.

1.4 Factory EMI Type Test Requirements

The EL must be electromagnetically compatible with the TRA traction power distribution railway signals, and communication systems.

1.4.1 Conducted Emissions Test Requirements

The EL conducted emissions must meet TRA requirements for psophometric current in TS 6.4 (4) which requires that interference noise current (Psophometric Weighted) of the maximum horsepower output of the locomotive and 25kV electric line voltage shall not be more than 10 A maximum; the maximum interference value within 10% variation of the running speed is also not to exceed 12 A.

1.4.2 Magnetic Field Emissions Test Requirements

The onboard EL magnetic field must be less than the time-varying magnetic field limits specified in TS 6.5.3-(4).

1.4.3 Radiated Emissions Test Requirements

The EL radiated emissions must conform to the limits in EN 50121-3-1.

1.4.4 DC Return Current Test Requirements

The DC component of the line current must not exceed 2.6 A after the Vacuum Circuit Breaker (VCB) is closed for 1 s as specified in TS 8.9.4-(7).

1.5 Reference Information

Table 1-1
Reference Documents

ID	Publisher	Title
EN 50121-3-1:2017	CENELEC	Railway applications – Electromagnetic compatibility, Part 3-1: Rolling stock – Train and complete vehicle
ICNIRP 2010	ICNIRP	ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1Hz – 100 kHz)
Technical Specifications	TRA	Specification for TRA 68 Units of Electric Locomotive
EMCCP	TISS	TRA EL EMC Control Plan, Rev 4.0, July 4, 2022
FETP	TISS	Factory EMI Type Test Procedure Rev 5.0

1.6 Acronyms and Abbreviations

Table 1-2 shows the FETR acronyms and abbreviations.

Table 1-2
Acronyms and Abbreviations

Acronym	Definition
A	Amperes
AC	Alternating Current
APS	Auxiliary Power Supply
APU	Auxiliary Power Unit
ATP	Automatic Train Protection
CE	Conducted Emissions
CENELEC	European Committee for Electro technical Standardization
CET	Conducted Emissions Test
CI	Converter-Inverter
dB	Decibel
dBuA/m	Decibel Microamperes per Meter
dBuV/m	Decibel Microvolts per Meter
DC	Direct Current
DCRCT	DC Return Current
EL	Electric Locomotive
EMC	Electromagnetic Compatibility
EMCCP	Electromagnetic Compatibility Control Plan
EMI	Electromagnetic Interference
EN	Euro Norm
EPA	Environmental Protection Administration
FETP	Factory EMI Type Test Procedure
FETR	Factory EMI Type Test Report
FETT	Factory EMY Type Test
FFT	Fast Fourier Transform
FM	Frequency Modulation
G	Gauss
HEP	Head End Power
Hz	Hertz
ICNIRP	International Committee on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
I-pso	Psophometric-Weighted Current
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
km/h	Kilometers per hour
MFE	Magnetic Field Emissions

Table 1-2
Acronyms and Abbreviations

Acronym	Definition
MFT	Magnetic Field Emissions Test
mG	Milligauss
MGM	Milligauss Meter
MOTC	Ministry of Transportation and Communications
MP	Measurement Point
MPE	Maximum Permissible Exposure
MPU	Main Power Suply Unit
OCS	Overhead Contact System
OMFT	Onboard Magnetic Field Emissions Test
RE	Radiated Emissions
RET	Radiated Emissions Test
RF	Radio Frequency
RMS	Root Mean Square
ROW	Right of Way
Tenco	Turner Engineering Corporation
TISS	Toshiba Infrastructure Systems & Solutions Corporation
TOD	Train Operator Display
TPSS	Traction Power Substation
TRA	Taiwan Railways Administration
TS	Specification for TRA 68 Units of Electric Locomotive
UHF	Ultra High Frequency
V	Volts
VCB	Vacuum Circuit Breaker
VVVF	Variable Voltage Variable Frequency
W	Watts

1.7 Contents of this Report

This FETR consists of the following sections.

Section 2, Conclusion and Summary Results: The Conclusion and Summary Results section provides a summary of the test results and test conclusions.

Section 3, Electric Locomotive Configuration Under Test: The EL Configuration Under Test section specifies the EL equipment configuration information relevant to EMI.

Section 4, Factory EMI Test Track: The Factory EMI Test Track section describes the as-tested track configuration used for the test track section of the mainline between Houli and Sanyi Stations and for the depot tests at Qidu Depot. This section lists modifications to the track configuration from that specified in the FETP.

Section 5, Radiated Emissions Factory EMI Type Test Results: The Radiated Emissions Factory EMI Type Results section states the purpose and requirements of the Radiated FETT, and provides test results from key test runs.

The section describes the full set of test runs performed by the test team and provides test variables for each run including frequency band, operating mode, direction, speed, and notes on the run purpose or condition. It describes the test equipment configuration and provides a list of test equipment with model numbers, connection diagrams, and calibration methods. Calibration includes both instrument and setup calibration.

Section 6, Conducted Emissions Factory EMI Type Test Results: The Conducted Emissions Factory EMI Type Test Results section follows the same format as the Radiated FETT section.

Section 7, DC Return Current Factory EMI Type Test Results: The DC Return Current Factory EMI Type Test Results section follows the same format as the Radiated FETT section.

Section 8, Onboard Magnetic Factory EMI Type Test Results: The Onboard Magnetic Factory EMI Type Test Results section follows the same format as the Radiated FETT section.

Appendix A: Appendix A presents the certification record of test equipment and the equipment calibration certificates.

Appendix B: Appendix B presents complete FETT Radiated Test Data. It provides a test equipment list and calibration information, site descriptions, and key test notes. It includes a test log or test directory for all test runs as well as test run print outs. The test log/directory includes Test Date, Test Team, Location, and Train Configuration, and specific test run information including Test Run Number, Test Type, Time, Description, and Results.

Appendix C: Appendix C presents the FETT Conducted data, similar to Appendix B.

Appendix D: Appendix D presents the FETT DC Return Current data, similar to Appendix B.

Appendix E: Appendix E presents the FETT Onboard Magnetic data, similar to Appendix B.

2 Conclusion and Summary Results

The EL met all TS requirements and passed all FETT tests. The following subsections summarize the results.

2.1 Overview of Test Results

Radiated Emissions: The FETT showed that the EL radiated emissions comply with TRA requirements. The test team observed some EL radiated emissions in the ranges 150 to 500 kHz, 40 to 60 MHz, and 160 to 200 MHz, but they were all below TRA limits.

Conducted Emissions: The FETT showed that the EL conducted emissions comply with TRA requirements. The test team recorded a maximum psophometric-weighted current of 3.34 A, significantly below the TRA limit of 10 A.

DC Return Current Test: The DC component of the line current was below the limit of 2.6 A after the VCB had been closed for 1 s. The maximum duration for which the DC return current was above 2.6 A after closing the VCB was 0.2 s.

Onboard Magnetic Field: The FETT showed that the magnetic field inside the EL complies with the TRA requirements.

The maximum TISS EL magnetic field measured inside the locomotive was:

- Static Magnetic Field (DC): 462.7 milligauss (mG)
- Power Frequency (60 Hz): 28.4 mG
- Lower Band Below Power Frequency (10 Hz to 45 Hz): 60.6 mG
- Broader Lower Band (75 Hz to 800 Hz): 12.0 mG

The highest measured magnetic field level at 60 Hz was 28.4 mG measured at the driver's seat in the front cab. This measurement is far below the EPA of the Executive Yuan limit of 833.3 mG at 60 Hz.

2.2 Test Sequence

Tables 2-1 and 2-2 show the sequence of FETT on the Depot and Mainline test tracks. Table 2-2 includes the Factory EMI Type Test schedule highlighted gray for reference.

Table 2-1
FETT Depot Track Test Schedule

Sun 11/5	Mon 11/6	Tue 11/7	Wed 11/8	Thu 11/9	Fri 11/10	Sat 11/11
			Location Scouting	Health Check	Equipment Setup	
Sun 11/12	**Mon 11/13**	**Tue 11/14**	**Wed 11/15**	**Thu 11/16**	**Fri 11/17**	**Sat 11/18**
	Equipment Setup in Qidu Depot	DC Return Current Test	Commissioning Tests	Commissioning Tests	Commissioning Tests	

Table 2-2
FETT Mainline Track Test Schedule

Sun 1/21	Mon 1/22	Tue 1/23	Wed 1/24	Thu 1/25	Fri 1/26	Sat 1/27
	Safety Training Equipment Setup on Locomotive	Conducted Emissions Test	Conducted Emissions / Onboard Magnetic Emissions Tests	Radiated Emissions Tests	Radiated Emissions Tests	
Sun 1/28	**Mon 1/29**	**Tue 1/30**	**Wed 1/31**	**Thu 2/1**	**Fri 2/2**	**Sat 2/3**
	Commissioning Tests	Commissioning Tests	Commissioning Tests			

2.3 Radiated Emissions Test Results Summary

The FETT tests showed that the EL radiated emissions comply with TRA requirements.

The radiated emission tests detected some EL radiated emissions in the ranges 40 to 60 MHz and 160 to 200 MHz of Band B5, but these were below TRA limits. These radiated emissions were highest during powering and braking runs with the bilogical antenna oriented vertically.

The test team measured emissions in the range 150 to 500 kHz in Band B1 whenever the EL pantograph was raised, irrespective of the location or operating mode of the locomotive. These emissions exceeded ambient measurements taken when the pantograph was lowered by over 10 dB. However, given that the test team observed these emissions even when the locomotive was not in front of the antennas with the pantograph was raised, it is likely that they were radiated from the OCS and not from the locomotive itself.

2.4 Conducted Emissions Test Results Summary

All conducted emissions were under the TRA limit for psophometric-weighted interference noise current (I-pso) of 10 A.

The highest measured I-pso was 3.34 A for Test Type C3a run 123-03. During this test, the locomotive braked with minimal effort from 20 km/h to 6 km/h. The average I-pso was higher for braking runs at 1.2 A than for powering runs at 0.69 A.

2.5 DC Return Current Test Results Summary

The DC component of the line current was below the limit of 2.6 A after the VCB had been closed for 1 s. The maximum duration for which the DC return current was above 2.6 A after closing the VCB was 0.2 s.

2.6 Onboard Magnetic Field Emissions Test Results Summary

The Onboard Magnetic FETT runs were mainline magnetic TransDAS-1 through TransDAS-15. The tests showed that the magnetic field levels inside the TISS EL were significantly below the TRA limits in both cabs. The highest measured magnetic field level at 60 Hz was 28.4 mG at location B in the front cab, far below the EPA of the Executive Yuan limit of 833.3 mG at 60 Hz.

The maximum TISS EL magnetic field measured inside the locomotive was:

- Static Magnetic Field (DC) to 462.7 mG
- Power Frequency (60 Hz) to 28.4 mG
- Lower Band Below Power Frequency (10 Hz to 45 Hz) to 60.6 mG
- Broader Lower Band (75 Hz to 800 Hz) to 12.0 mG

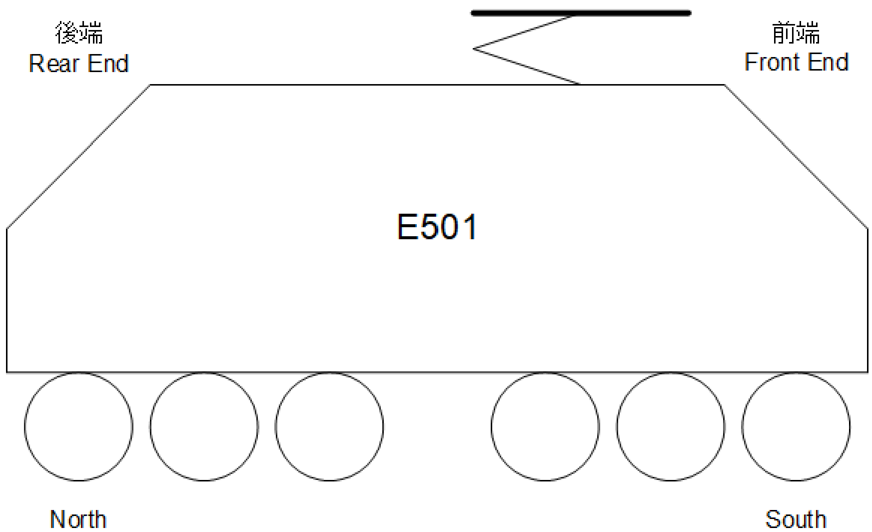
The tests showed that the magnetic field levels inside the TISS EL are low compared to the applicable TRA Onboard Magnetic Field Test Limits shown in Figure 8-2 during maximum acceleration and braking.

This FETR focuses on the 60 Hz magnetic field levels due to the low TRA limit compared to the rest of the 0 to 800 Hz frequency range. While the 10 to 45 Hz band had higher magnetic field readings, considering the much higher limit in this range, these readings are not as significant as the 60 Hz readings.

3 Electric Locomotive Configuration Under Test

The test team performed the FETT on a single Toshiba locomotive with the identifier E501. The locomotive was oriented as shown in the figure below during the mainline FETT.

Figure 3-1
As-tested Toshiba Locomotive E501



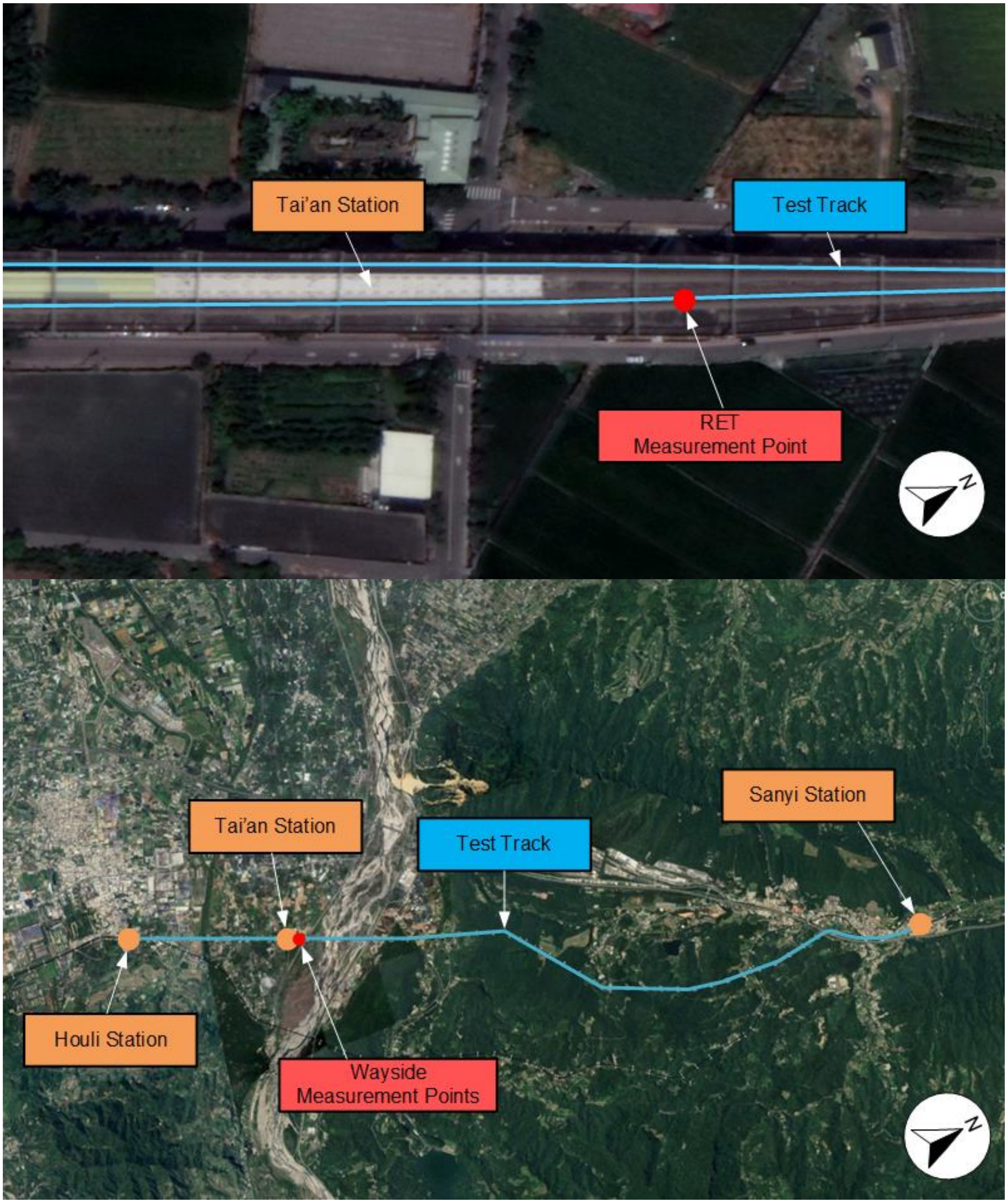
TISS performed the FETT with the Auxiliary Power Unit (APU) and Head End Power (HEP) on, unless otherwise specified in the test log.

4 Factory EMI Test Track

4.1 Mainline Test Track

TISS performed radiated emissions, conducted emissions, and magnetic field emissions tests on a test track section of the mainline on the normal southbound track between Sanyi and Houli stations north of Taichung. The test team performed the wayside tests just north of Tai'an Station near OCS pole 169/34. The FETT Site Plan in Figure 4-1 below shows wayside measurement points as well as the full test track between Sanyi and Houli stations.

Figure 4-1
Taichung Mainline Site Plan



4.2 Depot Test Track

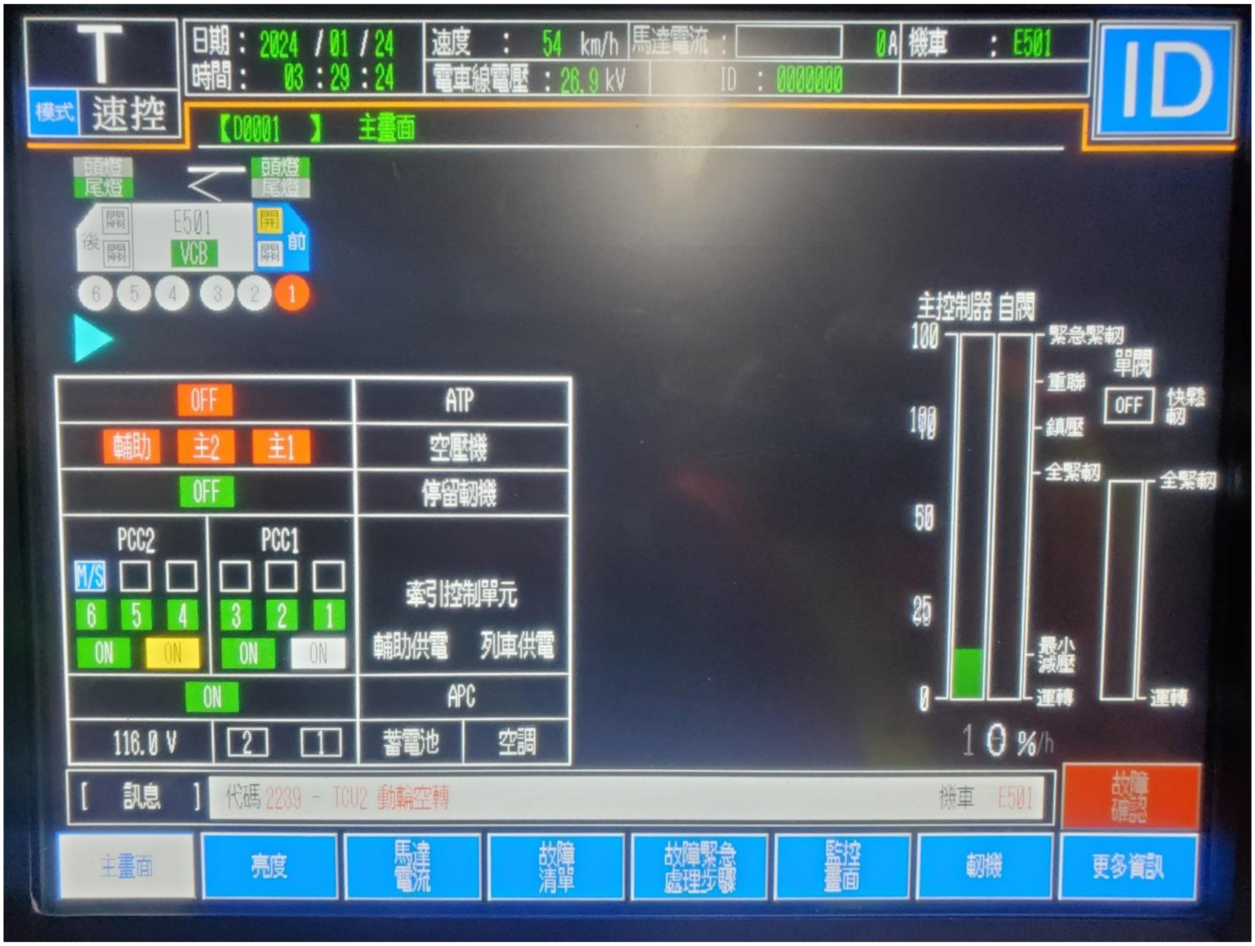
TISS performed DC Return Current tests on the Qidu Shop W14 track and on the northernmost track in Qidu Yard. The track Figure 4-2 below shows the Qidu Depot Site Plan.

Figure 4-2
Qidu Depot Site Plan

4.3 Line Voltage

The test team performed all tests at the 25 kV nominal line voltage provided by the mainline traction power substations. Since the tests were after revenue service with no other loads on the traction power substations, the line voltage was at the high end of the normal range, around 27 kV, in all tests. See Figure 4-3, top middle, which shows the typical voltage of 26.9 kV.

Figure 4-3
Train Operator Display – Typical Line Voltage



5 Radiated Emissions Factory EMI Type Test Results

5.1 Purpose and Requirements

Electrically powered railcars such as the TISS EL can generate broadband radiated electromagnetic emissions. If these emissions exceed the immunity of sensitive electronic equipment near the railroad right of way (ROW), the emissions can interfere with the normal operation of radio, television, and telephone communications equipment as well as other sensitive electronic equipment.

The purpose of the radiated emissions test (RET) was to measure:

- EL radiated emissions
- The ROW ambient radio environment

Per the FETP, the radiated emissions are acceptable if they are below TRA limits, or if they are not more than 10 dB above the ROW ambient radio environment.

Tables 5-1 and 5-2 and Figures 5-1 and 5-2 show the TRA radiated emission limits, taken from EN50121-3-1. Table 5-1 and Figure 5-1 show the stationary RE limits, in Decibel microvolts per meter (dBµV/m) versus log frequency. Table 5-2 and Figure 5-2 show the low-speed RE limits. The figures and tables show the limits for a measurement distance of 10 m.

Table 5-1
Stationary Electric Locomotive RE Limits at 10 m

Frequency (MHz)	E-Field Limit (dBµV/m)
0.15	106.5
30	56.5
30	60
1000	50

Table 5-2
Low-Speed Electric Locomotive RE Limits at 10 m

Frequency (MHz)	E-Field Limit (dBµV/m)
0.15	121.5
30	71.5
30	90
1000	65

Figure 5-1
Stationary Electric Locomotive RE Limits at 10 m

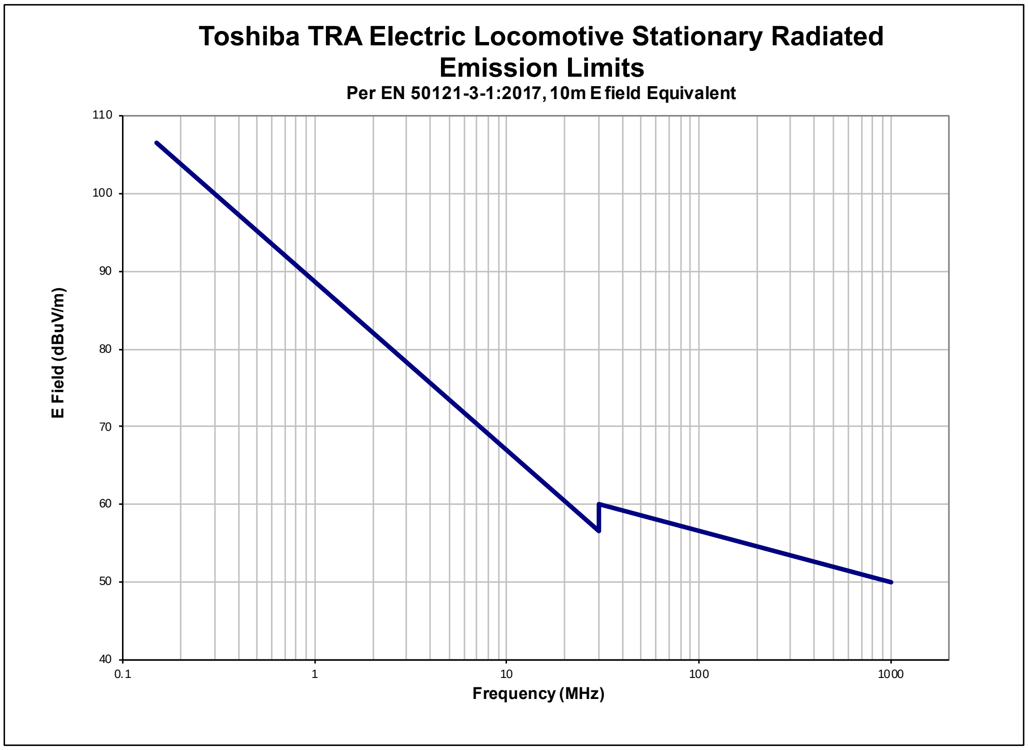
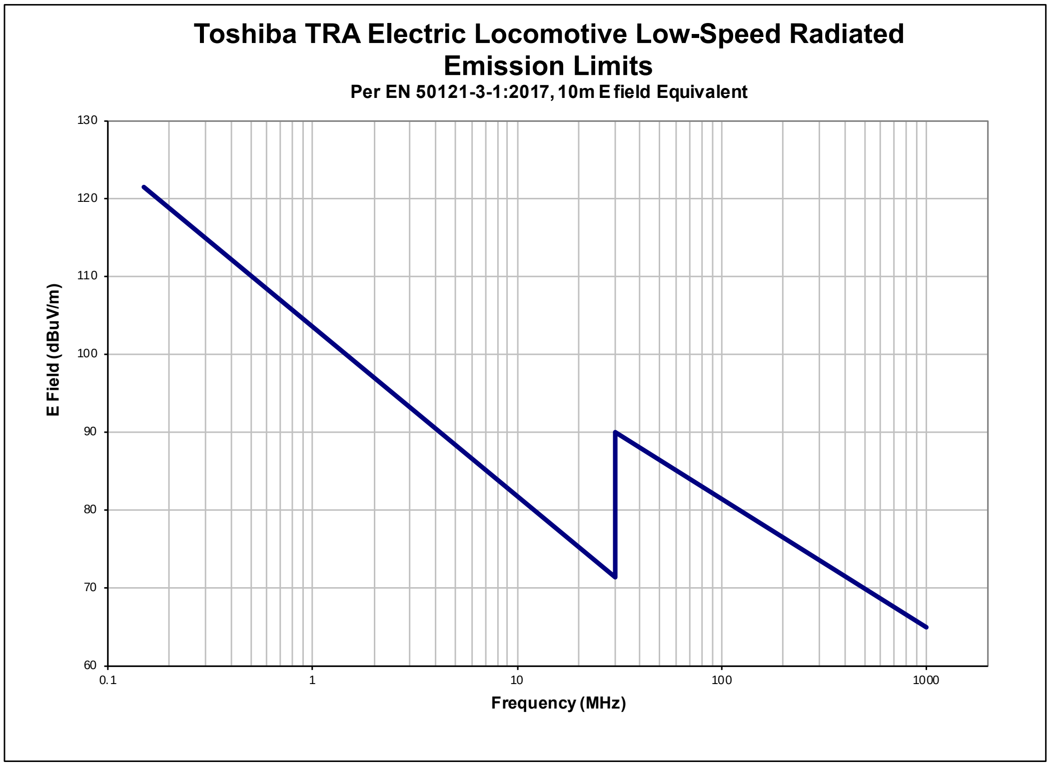


Figure 5-2
Low-Speed Electric Locomotive RE Limits at 10 m



5.2 Measurements Performed

TISS and Tenco performed 96 radiated measurements of the ambient environment and the E501 test EL at a test track section of the mainline north of Tai'an Station. The test runs covered the full range of operating conditions up to 50 km/h, per the test list in the FETP. The test team made the measurements 10 m from the centerline of the test track, 2 m above the railhead. Section 5 and Appendix B of this FETR provide complete information above the RE tests and results.

The test team kept a test log per the FETP, providing the frequency band, test type, locomotive operating activity, comments, and other relevant information for each test run.

5.3 Test Results

5.3.1 RET Results Summary

The FETT tests showed that the EL radiated emissions comply with TRA requirements.

The radiated emission tests detected some EL radiated emissions in the ranges 40 to 60 MHz and 160 to 200 MHz of Band B5, but these were below TRA limits. These radiated emissions were highest during powering and braking runs with the bilogical antenna oriented vertically. See Section 5.3.2.5 for further details.

The test team measured emissions in the range 150 to 500 kHz in Band B1 whenever the EL pantograph was raised, irrespective of the location or operating mode of the locomotive. These emissions exceeded ambient measurements taken when the pantograph was lowered by over 10 dB. However, given that the test team observed these emissions even when the locomotive was not in front of the antennas with the pantograph was raised, it is likely that they were radiated from the OCS and not from the locomotive itself. See Section 5.3.2.1 for further details.

5.3.2 Results for each Frequency Band

5.3.2.1 Band B1, 150 kHz to 650 kHz

Tenco observed radiated emissions in Band B1, 150 to 500 kHz that were slightly above ambient measurements taken when the pantograph was lowered. However, these emissions were also observed when the locomotive had the pantograph raised and was not in front of the antenna. This suggests that the low-frequency emissions were radiated from the OCS and were not radiated by the locomotive.

Figure 5-3 shows powering run 126-25. This shows the worst-case emissions in Band B1, 150 to 500 kHz.

Figure 5-4 shows ambient run 126-05, taken with the locomotive away from the measurement point with the pantograph lowered. This shows repeating peaks every 20 kHz.

Figure 5-5 shows ambient run 126-77, taken with the locomotive away from the measurement point with the pantograph raised. This run has no repeating peaks and a higher noise floor when compared to the pan-down ambient measurement in Figure 5-4. This measurement was taken while the locomotive was away from the measurement point moving south between Tai'an and Houli stations.

Tenco observed that emissions in ambient runs where the pantograph was raised as seen in Figure 5-5 were higher than ambient runs with the pantograph lowered as in Figure 5-4. This is likely the result of increased radiated emissions from the OCS when the pantograph is raised. The emissions seen in the powering run in Figure 5-3 do not exceed those from the pan-up ambient measurement in Figure 5-5.

The Band B1 measurements therefore showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

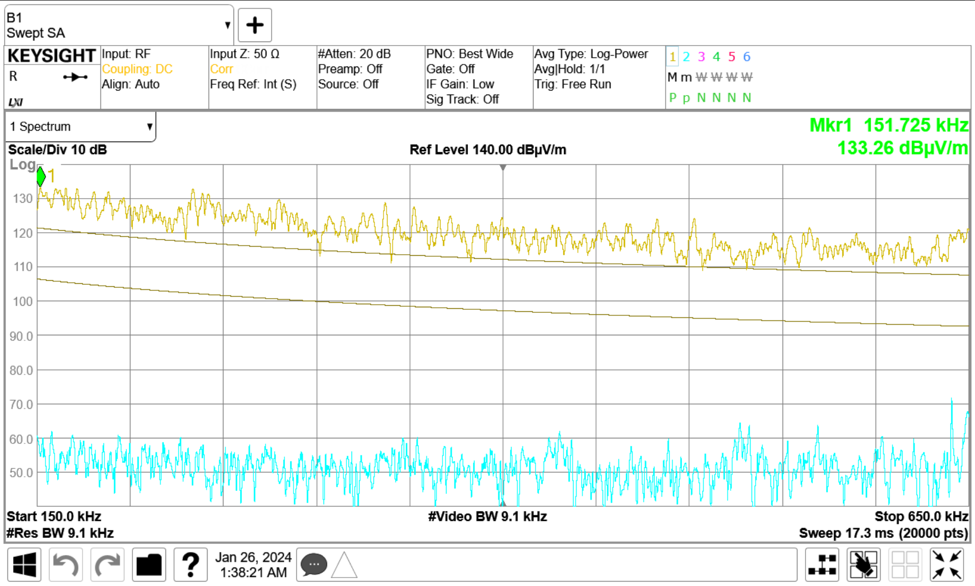
Figure 5-3 **Run 126-25, B1 Powering**				
Test ID	**Band**	**Description**	**Traces**	**Comment**
126-25	B1	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Similar to Ambient

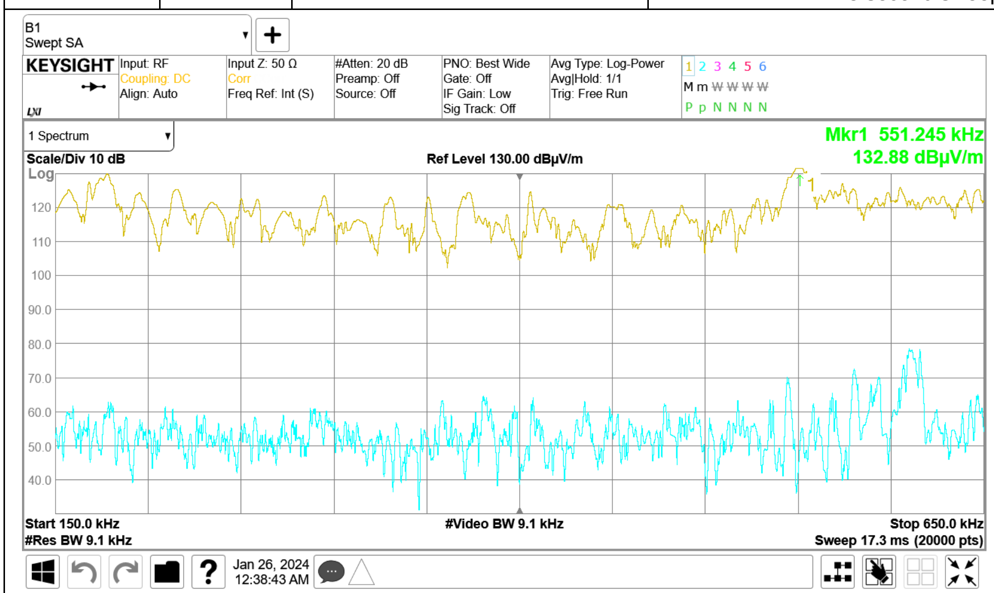
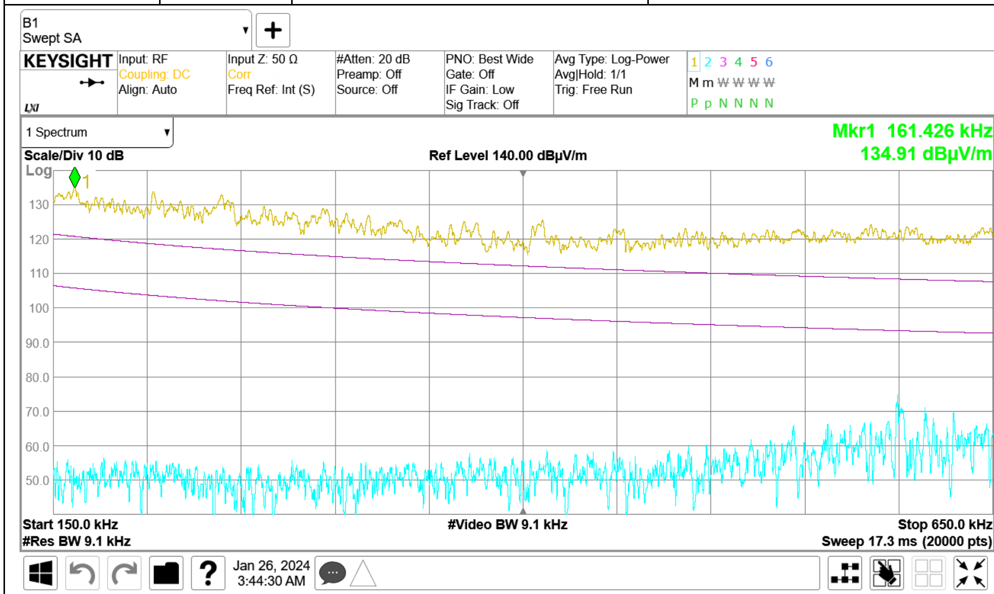
Figure 5-4 **Run 126-05, B1 Ambient, Pantograph Lowered**				
Test ID	**Band**	**Description**	**Traces**	**Comment**
126-05	B1	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Ambient above limits Broad peaks between 150 and 450 kHz every 18 kHz

Figure 5-5
Run 126-77, B1 Ambient, Pantograph Raised

Test ID	Band	Description	Traces	Comment
126-77	B1	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 60 second sweep duration	
				Ambient above limits 60s Ambient with pantograph raised

5.3.2.2 Band B2, 500 kHz to 3 MHz

There were no significant EL emissions in Band B2.

Figure 5-6 shows ambient run 126-06 while Figure 5-7 shows powering run 126-28.

Figure 5-7 is very similar to the ambient run in Figure 5-6 and does not show any EL radiated emissions. Measurements in other modes, including standing and braking, were similar to the ambient measurement in Figure 5-6 and did not show any EL radiated emissions.

The Band B2 measurements showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

Figure 5-6
Run 126-06, B2 Ambient

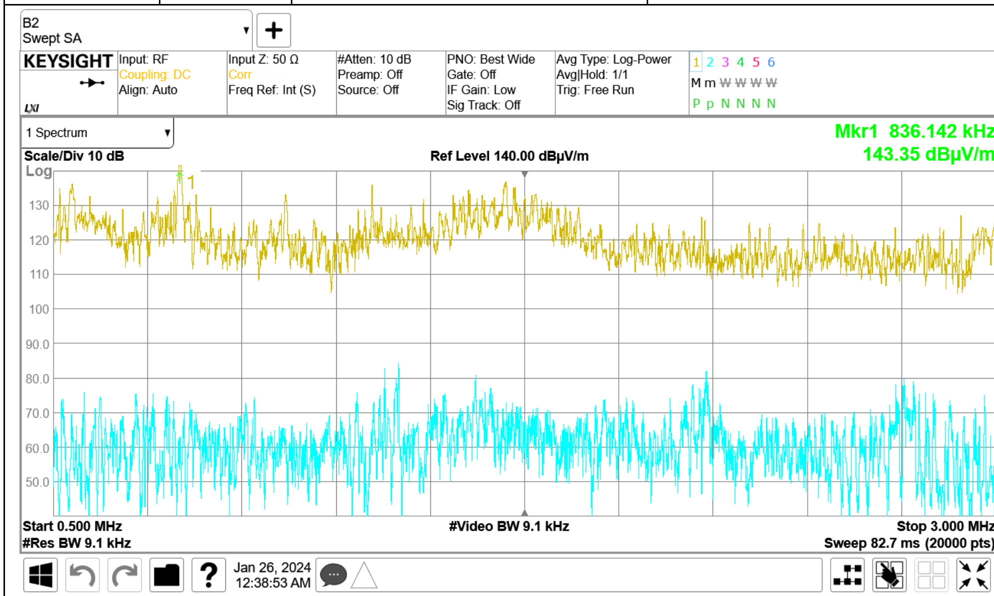
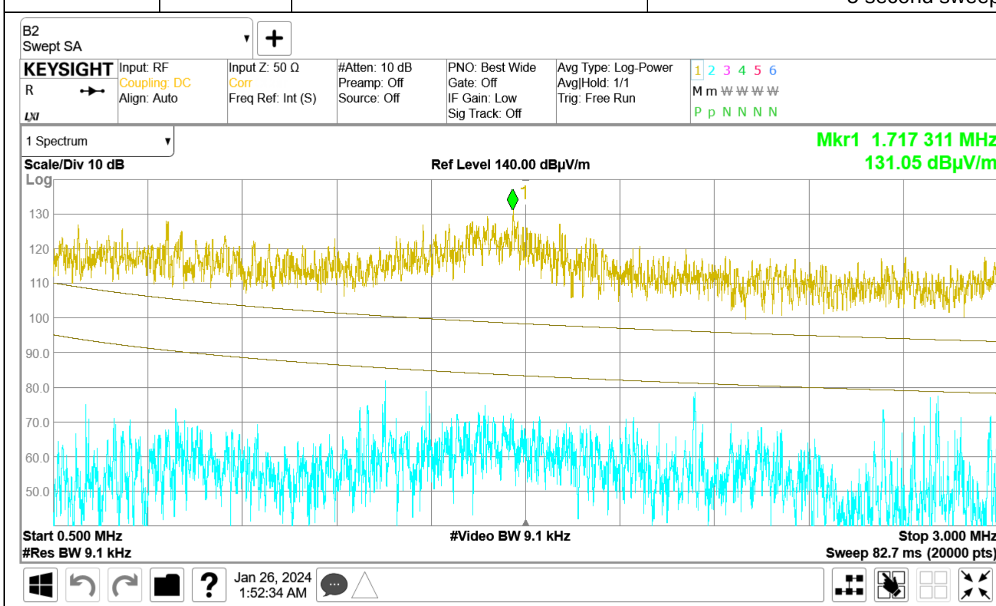
Test ID	Band	Description	Traces	Comment
126-06	B2	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Ambient above limits Narrow peak at 838.6 kHz with, broad peak between 1.25 and 2.0 MHz

Figure 5-7
Run 126-28, B2 Powering

Test ID	Band	Description	Traces	Comment
126-28	B2	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Similar to Ambient

5.3.2.3 Band B3, 2.5 MHz to 7.5 MHz

There were no significant EL emissions in Band B3.

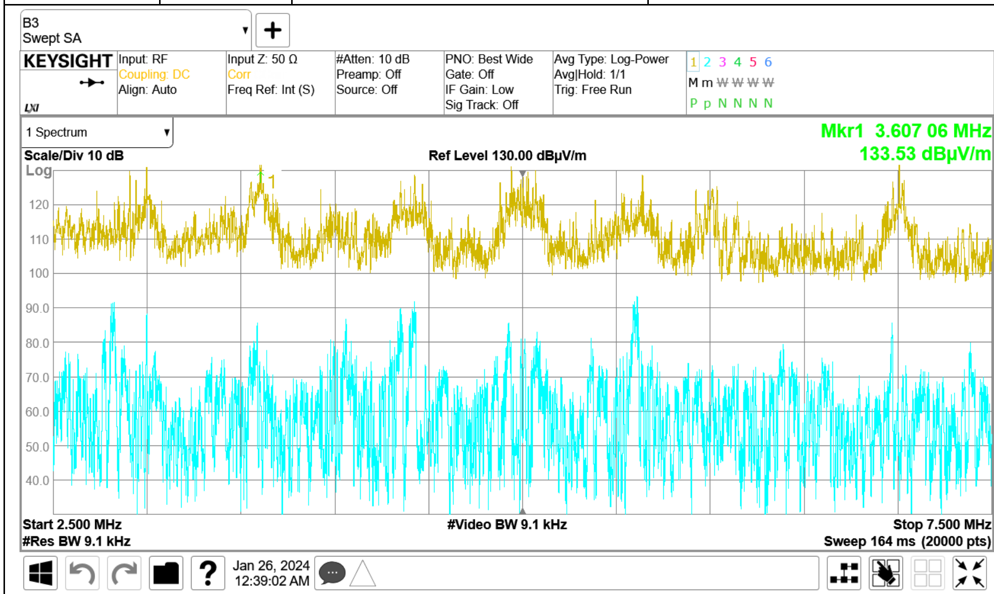
Figure 5-8 shows ambient run 126-07 while Figure 5-9 shows powering run 126-30.

Figure 5-9 is very similar to the ambient run in Figure 5-8 and does not show any EL radiated emissions. Measurements in other modes, including standing and braking, were similar to the ambient measurement in Figure 5-8 and did not show any EL radiated emissions.

The Band B3 measurements showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

Figure 5-8
Run 126-07, B3 Ambient

Test ID	Band	Description	Traces	Comment
126-07	B3	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	

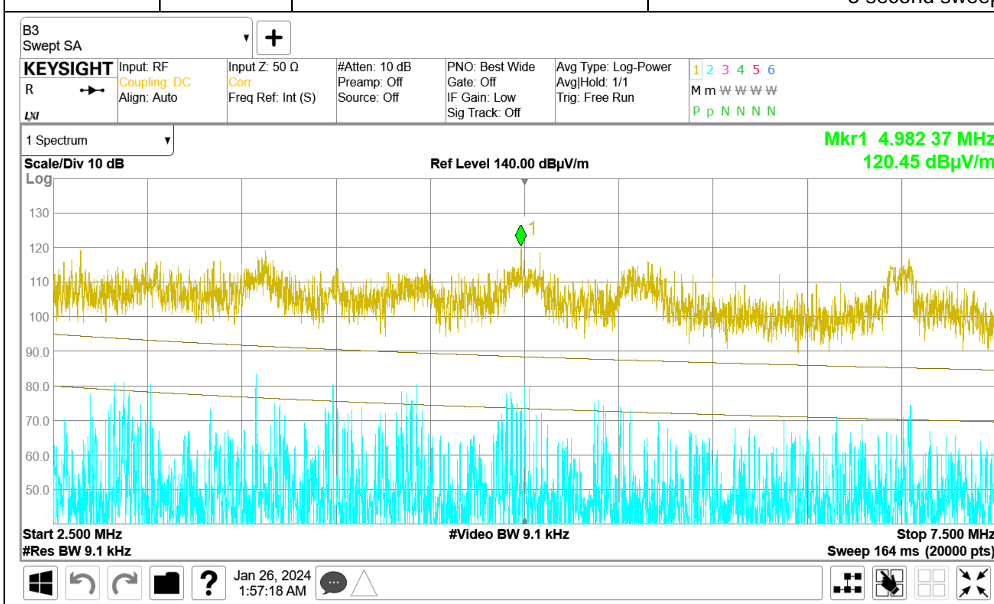


Comment: Ambient above limits

Broad peaks at 3.6 MHz, 4.4 MHz, 5.0 MHz, 5.6 MHz, 7.0 MHz

Figure 5-9
Run 126-30, B3 Powering

Test ID	Band	Description	Traces	Comment
126-30	B3	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	



Comment: Similar to Ambient

5.3.2.4 Band B4, 5 MHz to 30 MHz

There were no significant EL emissions in Band B4.

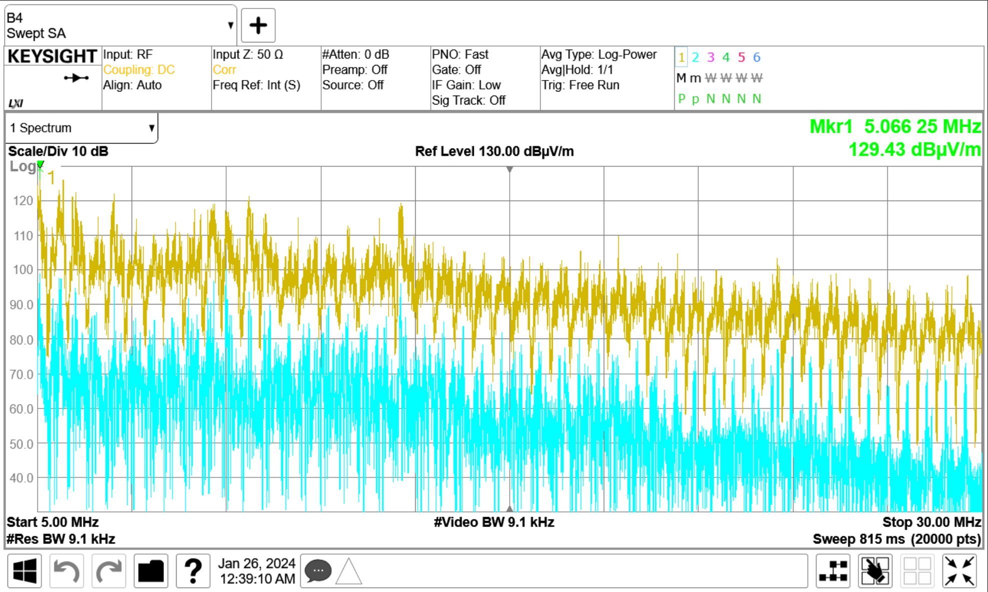
Figure 5-10 shows ambient run 126-08 while Figure 5-11 shows powering run 126-31.

Figure 5-11 is very similar to the ambient run in Figure 5-10 and does not show any EL radiated emissions. Measurements in other modes, including standing and braking, were similar to the ambient measurement in Figure 5-10 and did not show any EL radiated emissions.

The Band B4 measurements showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

Figure 5-10
Run 126-08, B4 Ambient

Test ID	Band	Description	Traces	Comment
126-08	B4	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	

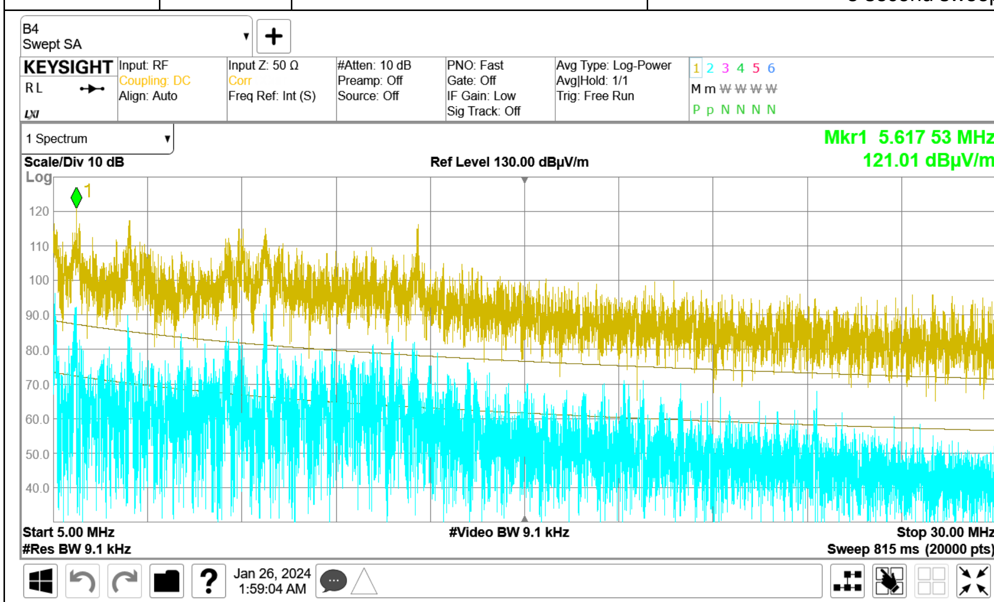


Ambient above limits

Peaks in range 10 to 15 MHz

Figure 5-11
Run 126-31, B4 Powering

Test ID	Band	Description	Traces	Comment
126-31	B4	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	



Similar to Ambient

5.3.2.5 Band B5, 30 MHz to 330 MHz

Tenco observed locomotive emissions in Band B5 from 40 to 60 MHz and 160 to 200 MHz. The emissions in this band were below TRA limits.

Figure 5-12 shows ambient run 126-69 taken with the bilogical antenna in the vertical position. Tenco observed that the Band B5 ambient was generally the same with the antenna in the horizontal and vertical positions, except that the peaks at 183 and 190 MHz were stronger with the antenna in the vertical position.

Figure 5-13 shows powering run 126-53. Figure 5-13 shows that the EL radiated emissions in the ranges 40 to 60 MHz are more than 10 dB above the ambient, however, the emissions do not exceed the TRA low-speed limits in this range. The emissions between 40 and 60 MHz were not present when the bilogical antenna was in the horizontal orientation. The emissions between 160 and 200 MHz were present when measured with the antenna in either orientation.

The Band B5 measurements showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

Figure 5-12
Run 126-69, B5 Ambient

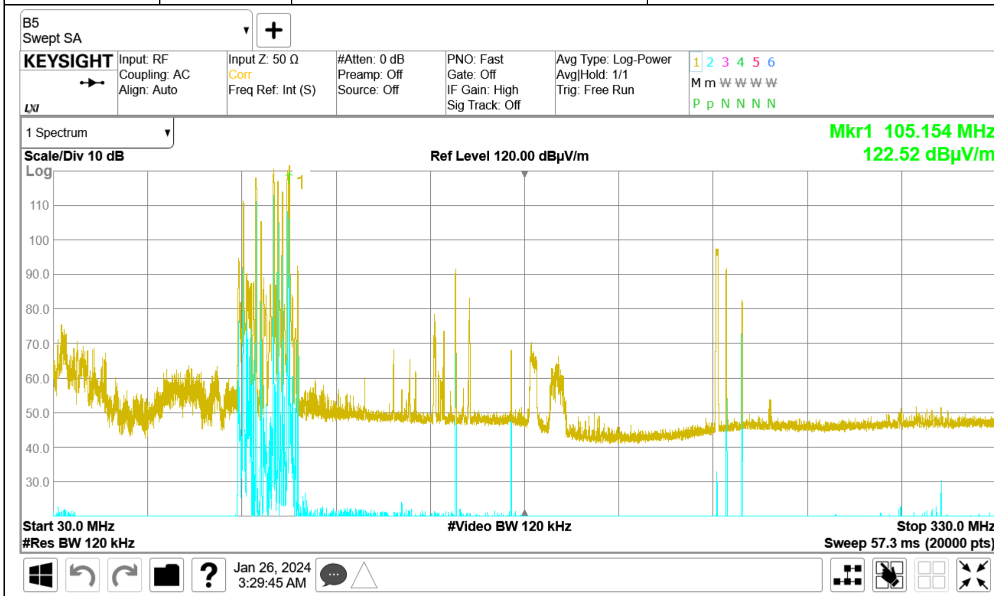
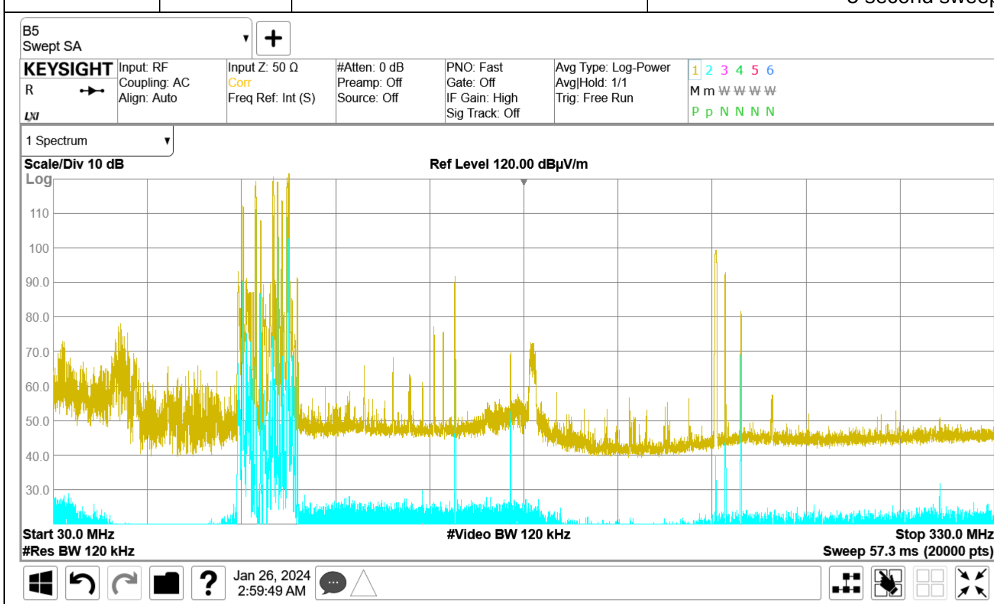
Test ID	Band	Description	Traces	Comment
126-69	B5	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 60 second sweep duration	
				High amplitude signals up to 123 dB in range 90 - 110 MHz Narrow peaks in ranges 150 - 180 MHz and 240 - 270 MHz Two broad 70 dB peaks between 180 and 200 MHz.

Figure 5-13
Run 126-53, B5 Powering

Test ID	Band	Description	Traces	Comment
126-53	B5	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Broad peak with amplitude of 70 dB around 50 MHz The most significant emissions are seen in this lower end of B5v Powering and Braking runs

5.3.2.6 Band B6, 300 MHz to 1 GHz

There were no significant EL emissions in Band B6.

Figure 5-14 shows ambient run 126-70 while Figure 5-15 shows powering run 126-54. Tenco identified the 106 dB narrowband peak at 435 MHz seen in Figure 5-14 as the handheld radio used by the test team.

Figure 5-15 is very similar to the ambient run in Figure 5-14 and does not show any EL radiated emissions. Measurements in other modes, including standing and braking, were similar to the ambient measurement in Figure 5-14 and did not show any EL radiated emissions.

The Band B6 measurements showed that the EL radiated emissions comply with the applicable TRA requirements in this band.

Figure 5-14
Run 126-70, B6 Ambient

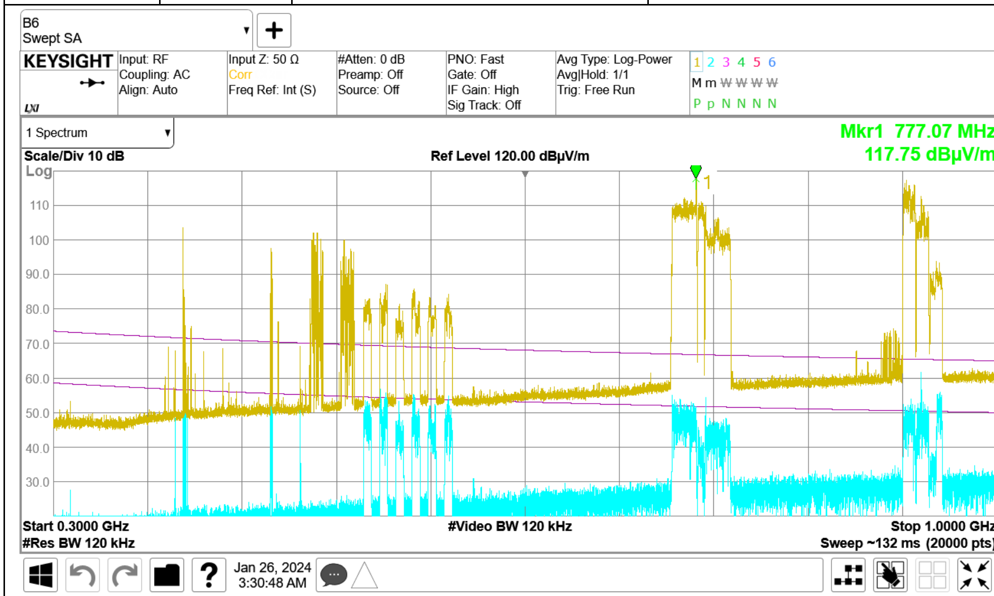
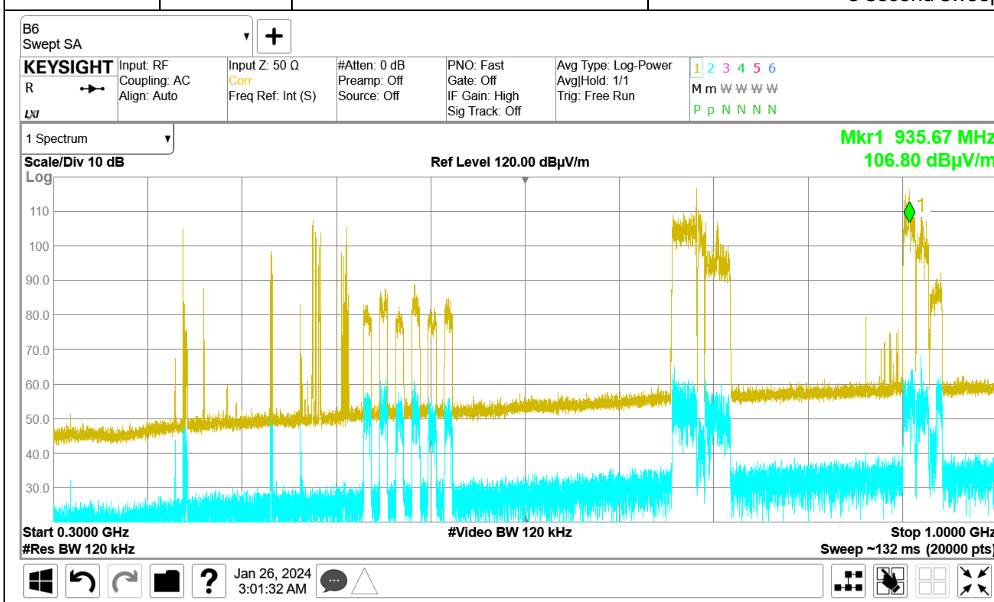
Test ID	Band	Description	Traces	Comment
126-70	B6	R1 - Ambient	Top – maximum peak hold Bottom – minimum peak hold 60 second sweep duration	
				Ambient Reflection High amplitude signals in ranges 370 - 600 MHz, 755 - 825 MHz, and 930 - 960 MHz.

Figure 5-15
Run 126-54, B6 Powering

Test ID	Band	Description	Traces	Comment
126-54	B6	R4 - Powering	Top – maximum peak hold Bottom – minimum peak hold 5 second sweep duration	
				Similar to Ambient

5.3.3 Test Variables

The test team performed test runs for the EL configurations and operating modes described below.

Direction: The test team performed test runs in forward and reverse directions.

Operating Modes: The test team performed tests using the full range of operating modes and speeds.

Speed: The test team performed test runs with the EL standing, accelerating, and braking at speeds of 40-60 km/h.

Auxiliaries: The test team performed most test runs with normal auxiliaries. Additional R2 test runs were performed with the EL standing with minimal and maximal auxiliary load.

Line Voltage: The test team performed tests at the 25 kV nominal line voltage provided by the mainline traction power substations.

5.3.4 Test Run Types

The test team performed the following types of test runs, measuring radiated fields under different operating modes of the EL as appropriate.

R0: Calibration

The test team performed the spectrum analyzer calibration with a 50 Ohm resistor each time the test equipment was set up to establish the noise baseline.

R1: Ambient

The test team performed ambient measurements with the EL standing at Tai’an station about 30 m away from the antenna and with the pantograph fully lowered. The test team recorded emission levels at all frequency sub-bands and antenna polarizations from 150 kHz to 1 GHz.

R2: Electric Locomotive Standing

The test team performed this test with the EL standing and locomotive centerline aligned with the antennas. The test team measured radiated emissions at all frequency sub-bands and antenna polarizations from 150 kHz to 1 GHz, per Table 5-3.

R3: Electric Locomotive Coasting

The test team performed this test with the EL coasting at 10km/h past the antennas. The test team only recorded radiated emissions data while the locomotive was passing in front of the antennas. The test team measured radiated emissions at all frequency sub-bands and antenna polarizations from 150 kHz to 1 GHz, per Table 5-3.

R4: Electric Locomotive Powering

The test team performed this test with the EL powering at maximum effort past the antennas. The test team only recorded radiated emissions data while the locomotive was passing in front of the antennas. The test team measured radiated emissions at all frequency sub-bands and antenna polarizations from 150 kHz to 1 GHz, per Table 5-3.

The test team performed the R4 test in the forward and reverse directions for bands B1 to B4, as specified in the FETP, and determined that direction had no effect on radiated emissions.

R5: Electric Locomotive Braking

The test team performed this test with the EL braking at maximum effort past the antennas. The test team only recorded radiated emissions data while the locomotive was passing in front of the antennas. The test team measured radiated emissions at all frequency sub-bands and antenna polarizations from 150 kHz to 1 GHz, per Table 5-3.

5.3.5 Test Bands

The test team performed broadband emission measurements from 150 kHz to 1 GHz. The test team divided the measurement bands into six smaller test bands as listed in Table 5-3. The active monopole antenna covered the range from 150 kHz to 30 MHz in four measurement sub-bands. The bilogical antenna covered the range from 30 MHz to 1 GHz in two measurement sub-bands, each with both horizontal and vertical orientation. Table 5-3 lists these sub-bands.

Table 5-3
Radiated Emissions Test Bands

ID	Frequency Range	Antenna	Antenna Orientation	Resolution Bandwidth
B1	150 kHz to 650 kHz	Active Monopole	Vertical	9.1 kHz
B2	500 kHz to 3 MHz	Active Monopole	Vertical	9.1 kHz
B3	2.5 MHz to 7.5 MHz	Active Monopole	Vertical	9.1 kHz
B4	5 MHz to 30 MHz	Active Monopole	Vertical	9.1 kHz
B5h	30 MHz to 330 MHz	Bilogical	Horizontal	120 kHz
B5v	30 MHz to 330 MHz	Bilogical	Vertical	120 kHz
B6h	300 MHz to 1 GHz	Bilogical	Horizontal	120 kHz
B6v	300 MHz to 1 GHz	Bilogical	Vertical	120 kHz

The test team changed the resolution bandwidth for bands B1 to B4 from 9 kHz as specified in the FETP to 9.1 kHz due to limitations of the Spectrum Analyzer.

5.4 Test Equipment and Calibration

5.4.1 Test Equipment

The test configuration generally followed the configuration in the FETP, except that the printer, keyboard, and mouse were not used during the test. Additionally, the Spectrum Analyzer used was the Keysight N9010B-507-P07 rather than the N9010B-503-P03 specified in the FETP.

Figure 5-16 is a block diagram of the radiated emissions test setup and Figure 5-17 shows photos of the test setup.

Figure 5-16
Radiated Emissions Test Configuration

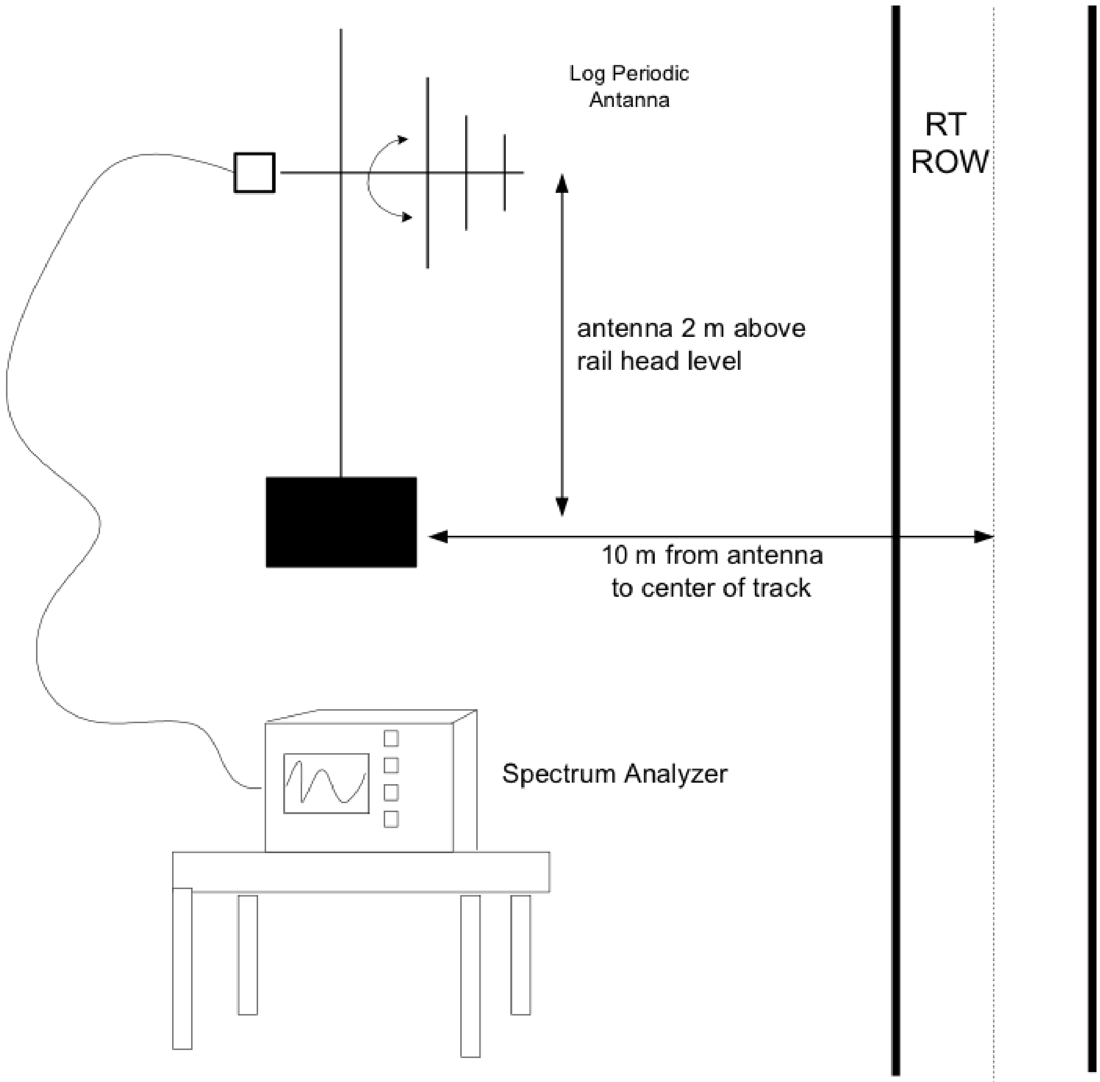
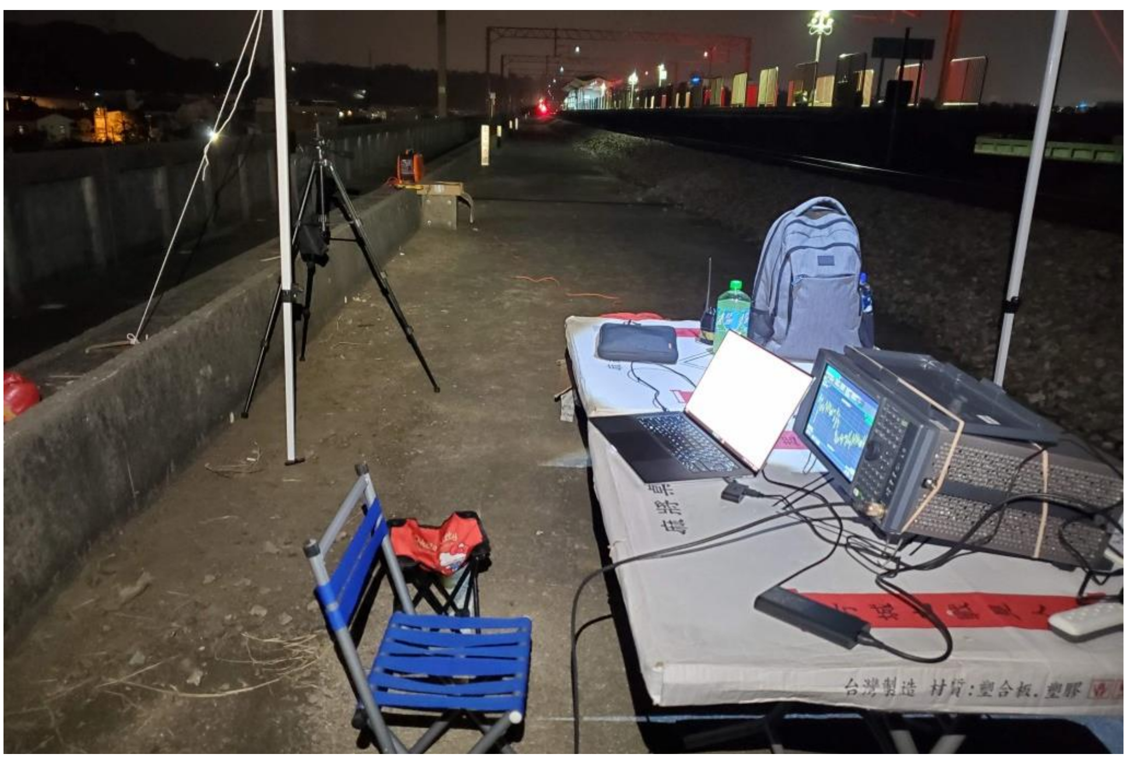


Figure 5-17
TISS Radiated Emissions Test Setup

Test Antennas at Measurement Point, north of Tai'an Station



Test Equipment on Wayside

Table 5-4 below lists the test equipment used for the RET.

Table 5-4
RET Equipment List

No.	Item	Purpose	Serial No.
1	Adjustable Antenna Tripod	To support antennas	-
2	Laptop Computer	For control of Spectrum Analyzer and storage of test data results	-
3	AC Power Source and extension cables	To power Spectrum Analyzer and other test equipment	-
4	Tables, Chairs, and Tent	Workspace for wayside measurement	-
5	Lighting	Visibility at workspace	-
6	Handheld Radios Hora U-11 UHF FM Transceiver CCAJ18LP1850T4	Communication between locomotive driver and wayside test team	105974139
7	RF Spectrum Analyzer 10 Hz to 3.6 GHz Keysight N9010B-507-P07	For measuring EMI field intensity between 10 Hz and 3.6 GHz	MY57110397
8	Active Monopole Antenna 9 kHz to 60 MHz A.H. Systems SAS-550-1B	Calibrated antenna for Bands 1 to 4	854
9	Bilogical Antenna 25 MHz to 7 GHz A.H. Systems SAS-521F-7	Calibrated antenna for Bands 5 to 6	225
10	RG8x Coax	Connecting Active Monopole Antenna to Spectrum Analyzer	TEC2-087
11	RG214 Coax SAC-211	Connecting Bilogical Antenna to Spectrum Analyzer	160

5.4.2 Calibration

The test team performed the following steps to verify proper operation of the RET equipment:

- Turn on the spectrum analyzer and let it warm up for 5 minutes.
- After warm up, calibrate the spectrum analyzer as described in the user’s manual.
- Verify cable loss matches calibration record.
- Verify antennas are operating properly.

5.5 Test Procedure Steps

TISS and Tenco documented correct operation for all instruments.

RET measurements were made using the peak hold averaging mode on the spectrum analyzer while the EL passes the test location or while ambient measurements are being made.

The test staff used Min/Max Hold or Quasi-peak detector functions to distinguish broadband and narrowband emissions and continuous versus discontinuous emissions.

For each frequency sub-band, TISS and Tenco tested the locomotive for the following test operating conditions:

- R0 Calibration
- R1 Ambient
- R2 EL standing at MP
- R3 EL coasting past MP
- R4 EL powering past MP
- R5 EL braking past MP

TISS and Tenco frequently repeated the ambient measurement R1 to document variations in the radiated ambient.

6 Conducted Factory EMI Type Test Results

6.1 Purpose and Requirements

The purpose of the Conducted FETT is to demonstrate that the TISS EL conducted emissions comply with the TRA limit of 10.0 A for the psophometric-weighted current. The conducted emissions test (CET) requirements are stated in Section 1.4.1 of this FETR.

6.2 Measurements Performed

TISS performed 26 conducted emissions test runs on the test track section of the mainline between Sanyi and Houli stations in Taichung City from January 23 through January 24, 2024. The test team measured harmonic components of the main circuit current and voltage in the full range of operating conditions, from low speed up to 50 km/h per the test run list in the FETP.

The test team kept a test log per the FETP providing the test type, locomotive configuration, run description, comments for each run, and other relevant information. The CET test log and results are in Appendix C of this report.

6.3 Test Results

6.3.1 CET Results Summary

All conducted emissions were under the TRA limit for psophometric-weighted interference noise current (I-pso) of 10.0 A.

The highest measured I-pso was 3.34 A for Test Type C3a run 123-03. During this test, the locomotive braked with minimal effort from 20 km/h to 6 km/h. The average I-pso was higher for braking runs at 1.2 A than for powering runs at 0.69 A.

6.3.2 Qualification Test Results

Table 6-1 provides the CET test results showing I-pso for each test type.

Table 6-1
CET Mainline Test Results

Propulsion State	Type	Mode	Speed (km/h)	Purpose/Special Conditions	I-pso / Run ID
Braking Regen Brake	C1a	Max Brake	50 to 0	Nominal	1.08 / 123-01
	C1b			1 MPU Fail	1.82 / 123-04
	C1c			1 APU Fail	0.99 / 123-07
	C1d			1 MPU and 1 APU Fail	0.96 / 123-10
	C2a	50% Brake	30 to 0	Nominal	1.48 / 123-02

Table 6-1
CET Mainline Test Results

Propulsion State	Type	Mode	Speed (km/h)	Purpose/Special Conditions	I-pso / Run ID
	C2b			1 MPU Fail	0.88 / 123-05
	C2c			1 APU Fail	0.74 / 123-08
	C2d			1 MPU and 1 APU Fail	0.88 / 123-11
	C3a	Min Brake	20 to 0	Nominal	3.34 / 123-03
	C3b			1 MPU Fail	0.72 / 123-06
	C3c			1 APU Fail	0.62 / 124-01
	C3d			1 MPU and 1 APU Fail	1.22 / 123-12
	C4	Emergency Brake	20	Worst Case CI config from C1 to C3	0.77 / 124-14
Powering	C5a	Max Accel	0 to 40	Nominal	1.55 / 124-11
	C5b			1 MPU Fail	0.61 / 124-08
	C5c			1 APU Fail	0.63 / 124-02
	C5d			1 MPU and 1 APU Fail	0.55 / 124-05
	C6a	50% Accel	0 to 30	Nominal	0.72 / 124-12
	C6b			1 MPU Fail	0.59 / 124-09
	C6c			1 APU Fail	0.69 / 124-03
	C6d			1 MPU and 1 APU Fail	0.51 / 124-06
	C7a	Min Accel	0 to 20	Nominal	0.67 / 124-13
	C7b			1 MPU Fail	0.56 / 124-10
	C7c			1 APU Fail	0.75 / 124-04
	C7d			1 MPU and 1 APU Fail	0.44 / 124-07

6.3.3 Test Variables

The test team performed test runs for the locomotive configurations and operating modes listed below. The test team evaluated results during the first test runs to determine the modes and conditions under which the EL makes worst-case emissions, considering propulsion and braking.

Length and Loading: TISS and Tenco performed all test runs with a single EL. The EL was only loaded with test equipment and test personnel.

Direction: The test team performed test runs in forward and reverse directions.

Operating Modes: The test team measured conducted emissions while the EL was powering, braking, and emergency braking.

Converter-Inverters: The test team performed tests with the following CI conditions:

- Nominal: 6 MPU's active, 2 APU's active, 2 HEP's active
- 1 MPU Fail: 5 MPU's active, 2 APU's active, 2 HEP's active
- 1 APU Fail: 6 MPU's active, 1 APU's active, 2 HEP's active
- 1 MPU and 1 APU Fail: 5 MPU's active, 1 APU's active, 2 HEP's active

Speed: The test team performed test runs at up to 50 km/h.

Location: TISS and Tenco performed the CET at the Taichung Mainline Test Track.

Line Voltage: The test team performed tests at the 25 kV nominal line voltage provided by the mainline traction power substations. Since the tests were after revenue service with no other loads on the traction power substations, the line voltage was at the high end of the normal range, around 27 kV, in all tests.

6.4 Test Equipment and Calibration

6.4.1 Equipment Setup

Figure 6-1 shows the test equipment setup for the CET. The FFT Analyzer was connected to two current sensors and one voltage sensor.

6.4.2 Test Equipment

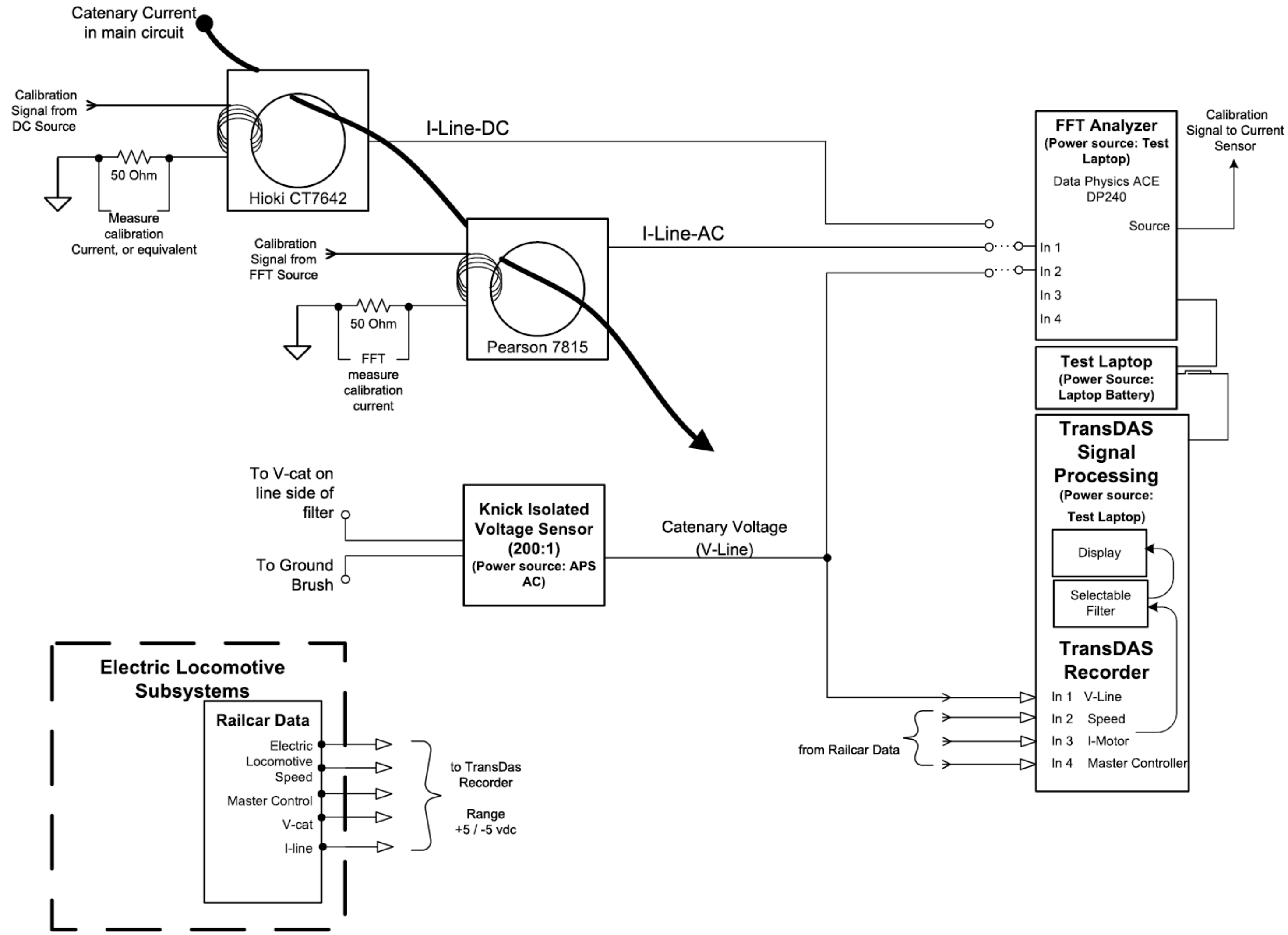
Table 6-3 lists the CET test equipment.

Table 6-2
CET Equipment List

No.	Item	Purpose
1	Tenco TransDAS Data Acquisition Computer or Strip Chart Recorder	For capturing and printing stripchart-type time-based records of locomotive performance, and for monitoring selected AC components.
2	110 VAC Isolation Transformer	To provide AC power and eliminate ground current loops.
3	Uninterruptible Power Supply	To provide instrument AC power when the auxiliary power supply (APS) is not running.
4	Four Channel FFT Dynamic Signal Analyzer and Digital Data Recorder Data Physics DP240 or equivalent	For measuring and recording emission signals, typically FFT spectra. (CET) For measuring and processing AC components of magnetic fields (MFT)
5	AC/DC Current Probe Hioki CT7642	For measuring AC and DC current components.
6	AC Current Probe Pearson 7815	For measuring AC current components.
7	Isolated Voltage Transducer with Sensor Knick P52100 or equivalent	For monitoring AC and DC components of line voltage.
8	Digital Voltmeter Fluke 115	For monitoring AC and DC voltages.

The test equipment is described in greater detail in the FETP.

Figure 6-1
CET Equipment Setup



6.5 Test Procedure Steps

6.5.1 Conducted Emissions Test Steps

Tenco followed these steps for the CET:

1. Set up the test equipment per Figure 6-1. Confirm that the Pearson 7815 AC Current Sensor is not susceptible to pickup from currents outside its measurement window. Connect the Pearson 7815 to the TransDAS and the FFT Analyzer. Record the test equipment configuration.

2. Use a test signal to calibrate the Pearson 7815 output as displayed by the TransDAS and the FFT Analyzer. Record the end-to-end frequency response of the Pearson 7815 when used with the TransDAS and FFT Analyzer.

3. Set the FFT analyzer frequency resolution low enough to capture sweeping inverter harmonics. TISS and Tenco will use 3 different frequency resolutions during the test, shown in Table 6-4. TISS and Tenco will generally use frequency resolution #1 to perform most test runs, frequency resolution #2 to check the amplitude of fixed harmonics, and frequency resolution #3 to record emissions across the entire audio frequency range, and to check worst-case emissions.

Table 6-3
FFT Analyzer Frequency Resolution Settings

ID	Frequency Range	Resolution Lines
1	0 to 1.6 kHz	400
2	0 to 800 Hz	400
3	0 to 10 kHz	3200

4. Set up the EL for running on the test section, with all equipment energized as indicated in the test list.

5. Record EL general configuration; Traction firmware configuration; APS configuration; EL loading condition; any simulated signals; and test track layout.

6. Record traction power substation (TPSS) locations and track number. Confirm calibration of sensors and equipment.

7. Measure EL CE for the listed test runs. Note in the test log the CI's configuration for each test run, the consist length and makeup, and record the HEP and APU loads.

    a) Display and record CE with the DP240 FFT analyzer. Use TransDAS to document the acceleration / deceleration cycle and other EL signal measurements. Confirm peak emissions do not exceed maximum settings for the AC current sensor.

    b) Determine worst-case CE from each run, and compare to the limits calculated in Section 6.5.2. Repeat tests as necessary to highlight frequencies where CE is close to or above the scaled CE limits. Determine whether each run type conforms to limits. Determine whether run is a worst-case run for later repetition. Record data and results.

8. Check that all run types have been performed, and that compliance has been checked for each frequency range for each run type.

6.5.2 Conducted EMI Pass / Fail Criterion

TRA defines EL CE limits in TS 6.4 (4) which requires that the "interference noise current (Psophometric Weighted) of the maximum horsepower output of the locomotive and 25kV electric line voltage shall not be more than 10 A maximum; the maximum interference value within 10% variation of the running speed is also not to exceed 12 A.

TISS and Tenco calculated I-pso as follows:

$$\text{I-pso} = \frac{1}{P800} \times \sqrt{\sum (\text{Pf} \times \text{If})^2}$$

Where:

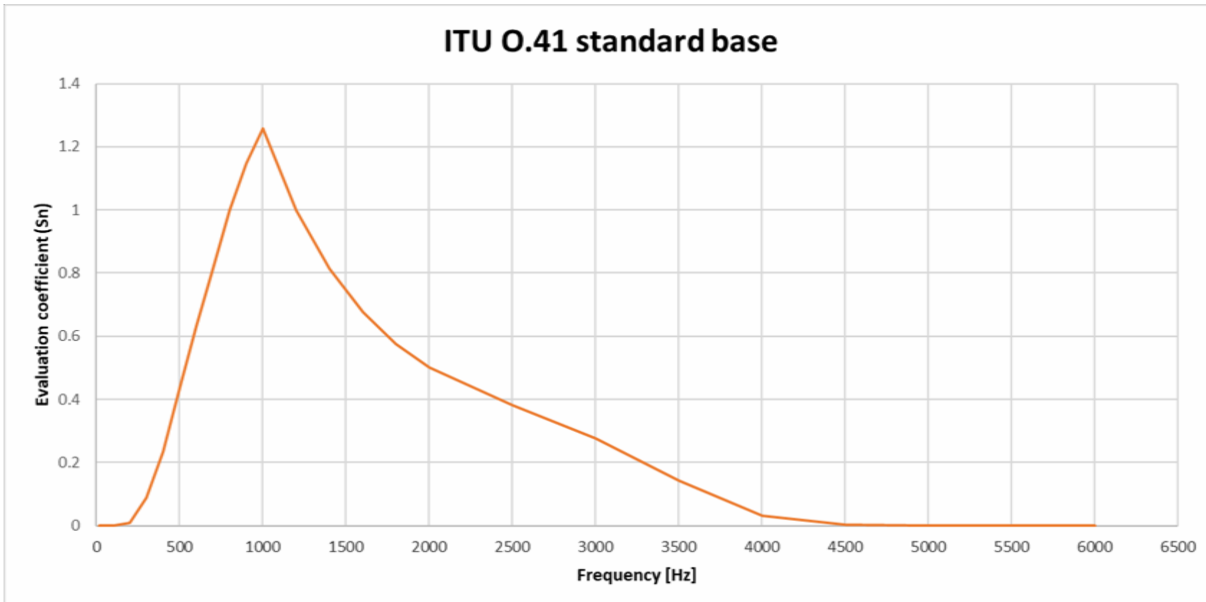
- I-pso is the psophometric current
- If is the current component at frequency f in the traction current
- P800 is the psophometric weighting factor at a frequency of 800 Hz
- Pf is the psophometric weighting at other frequencies.

The weighting factor at 800 Hz, P800, has a value of 1.

The values of Pf are specified in ITU-T O.41, "Protection of telecommunications against harmful effects from electrical power and electrified railway lines." The calculation applies the weighting factor to each the current at each harmonic in proportion to its disturbing effect relative to 800 Hz.

Figure 6-2 shows the Table 1/O.41 of ITU-T O.41 weighting values.

Figure 6-2
Psophometric Weighting Factor



7 DC Return Current Factory EMI Type Test Results

7.1 Purpose and Requirements

The purpose of the DC Return Current Test (DCRCT) is to demonstrate that the DC component of the line current does not exceed 2.6 A after the Vacuum Circuit Breaker (VCB) is closed for 1.0 s as per TS Section 8.9.4-(7). The DC Return Current Guidelines are stated in Section 1.4.4 of this FETR.

7.2 Measurements Performed

TISS and Tenco performed 3 measurements of the return current after the VCB was closed. The measurements were performed on November 14, 2023 at Qidu Depot with the EL stationary.

7.3 Test Results

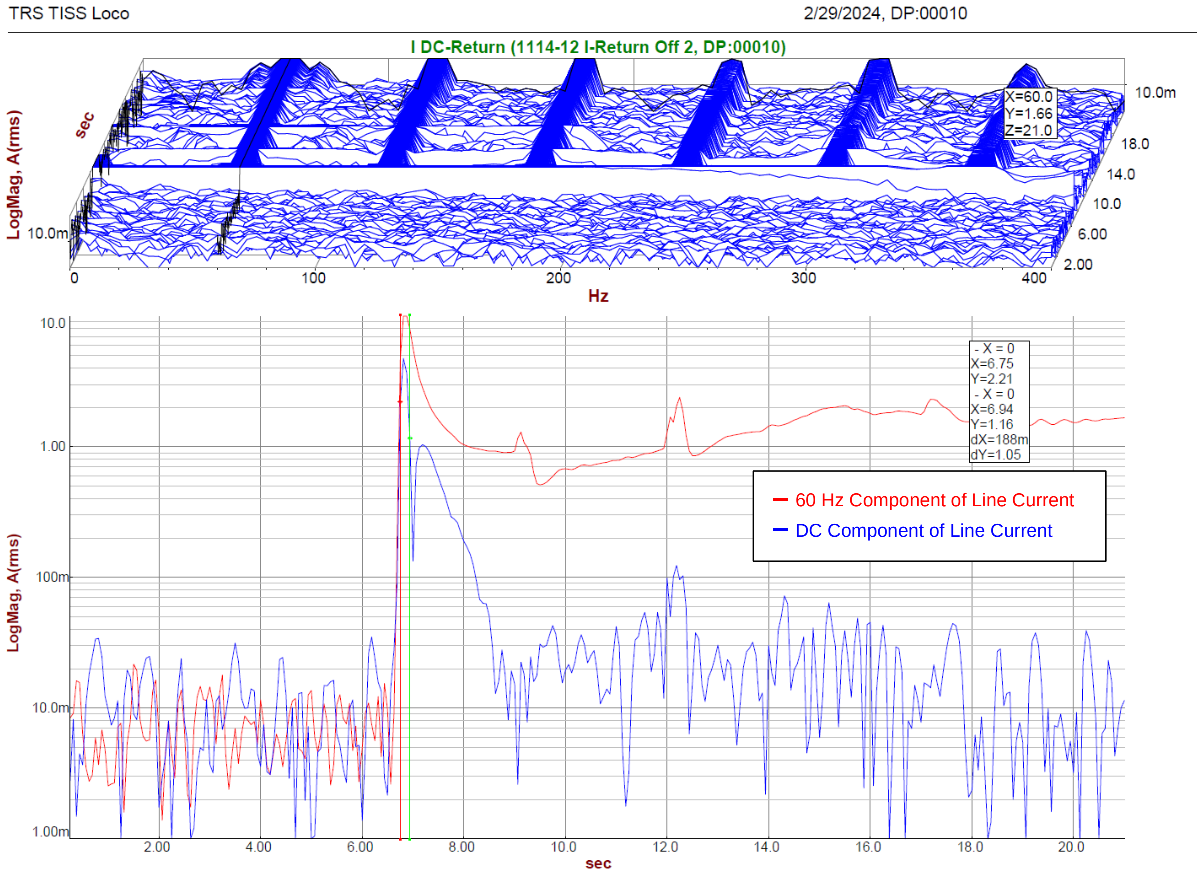
7.3.1 DCRCT Results Summary

The DC component of the line current was below the limit of 2.6 A after the VCB had been closed for 1.0 s. The maximum duration for which the DC return current was above 2.6 A after closing the VCB was 0.2 s.

7.3.2 Qualification Test Results

Figure 7-1 below shows the worst-case DC Return Current with the current exceeding 2.6 A for a duration of 0.2 s after the VCB was closed.

Figure 7-1
Worst-Case DC Return Current, Run 1114-12



7.4 Test Equipment

Figure 7-2 shows the DC current sensor setup for the DCRCT. Table 7-1 lists the test equipment used for measuring the DC component of the line current.

Figure 7-2
DC Return Current Test Configuration

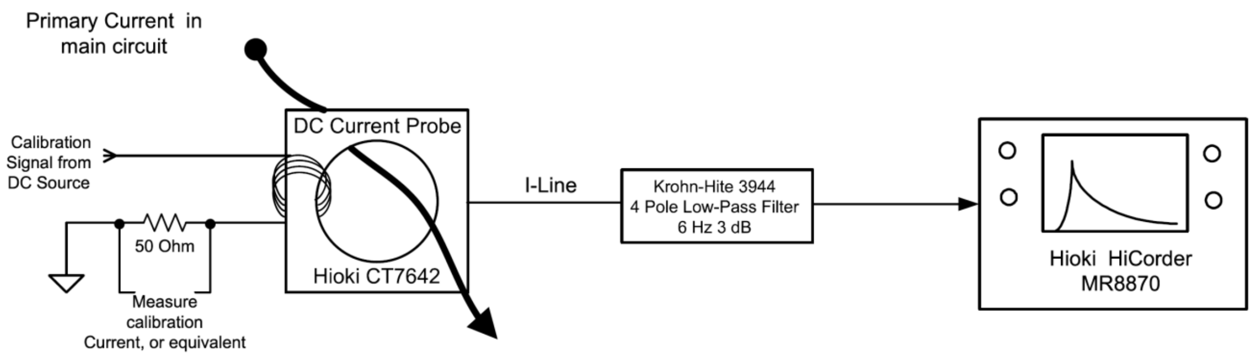


Table 7-1
DC Return Current Test Equipment List

#	Item	Purpose
1	Hioki CT7642 AC/DC Current Probe	For monitoring DC return current component
2	Krohn-Hite 3944 Low Pass Filter	Channel 1 to filter out AC components. Channel 2 to amplify 60 Hz component and suppress higher harmonics.
3	Hioki MR8870 2-channel Memory HiCorder. Digital Oscilloscope/Recorder	For measuring and recording DC and AC components of line current.
4	Printer, Brother MFC-J870DW, HP930 Deskjet Printer, or equivalent.	For plotting DC return current spectra.

7.5 Test Procedure Steps

TISS followed these steps for the DCRCT:

1. Set up the test equipment per Figure 7-2.
    a. Confirm that the Hioki CT7642 is not susceptible to pickup from currents outside the CT clamp
    b. Connect the Hioki 7642 output to the Krohn-Hite filter inputs on Channels 1 and 2
    c. Set the Krohn-Hite filter Channel 1 to 6 Hz, 3 dB point, Butterworth filter with 24 dB attenuation per octave, 20 dB input gain 20 dB output gain
    d. Set the Krohn-Hite filter Channel 2 to 3 kHz, 3 dB point, and 20 dB output gain
    e. Connect respectively the Krohn-Hite filter output Channel 1 and 2 to the Hioki MR8870 HiCorder input Channel 1 and 2
    f. Set the Hioki MR8870 HiCorder to 10 ms/div on the time scale, and 10 mV per division on both channels

2. As described in Section 9.1.2 of the FETP, use a DC test signal to calibrate the Hioki CT7642, the Krohn-Hite filter, and display it on the Hioki MR8870 Channel 1. Repeat this step with a 60 Hz AC test signal on the Hioki MR8870 Channel 2

3. Set the EL in standstill position on the test track, with the VCB open.

4. Record EL general configuration; Traction software configuration; APU and HEP software configuration; EL loading condition; any simulated signals; and test track layout. HEP will be operated with no load condition.

5. Record TPSS (Traction Power Substation) locations and track number. Confirm calibration of sensors and equipment.

6. Turn ON the VAC and Blower equipment, and perform the following:
    a. Make sure all conditions are met to close VCB.
    b. Start recording on the Hioki MR8870 HiCorder
    c. Close VCB
    d. Continue recording for 30 s
    e. Open VCB
    f. Stop recording, save data and results

7. The VCB closing time will be determined by the sudden rise in 60 Hz current on Channel 2 of the Hioki MR8870 recording.

8 Onboard Magnetic Factory EMI Type Test Results

8.1 Purpose and Requirements

The purpose of the Onboard Magnetic FETT is to demonstrate that the magnetic field inside the TISS EL complies with the applicable TRA guidelines. The Onboard Magnetic Field guidelines are stated in Section 1.4.2 of this FETR.

Per the FETP, the magnetic field emissions (MFE) are acceptable if they are below TRA limits.

The TS does not establish magnetic field Maximum Permissible Exposure (MPE) limits for humans onboard the EL.

The World Health Organization recommends the application of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. The appropriate ICNIRP document is the ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz – 100 kHz), 2010.

The IEEE Std C95.6 limits and ICNIRP guidelines are consistent with EN 45502-2-1 Section 27.6, which defines the magnetic field immunity of active implantable medical devices.

The EL magnetic field MPE limits for the general public at 60 Hz is 833.3 mG according to the Environmental Protection Administration (EPA) of the Executive Yuan.

Figure 8-1 provides the EPA of the Executive Yuan limits and the standards limits described above. It shows that some standards are more restrictive than others.

TISS and Tenco will apply the most restrictive limits during the Onboard MFT, and apply the limits shown in Figure 8-2.

Figure 8-1
Magnetic Field EMI – TRA TS Limits & Standard Limits

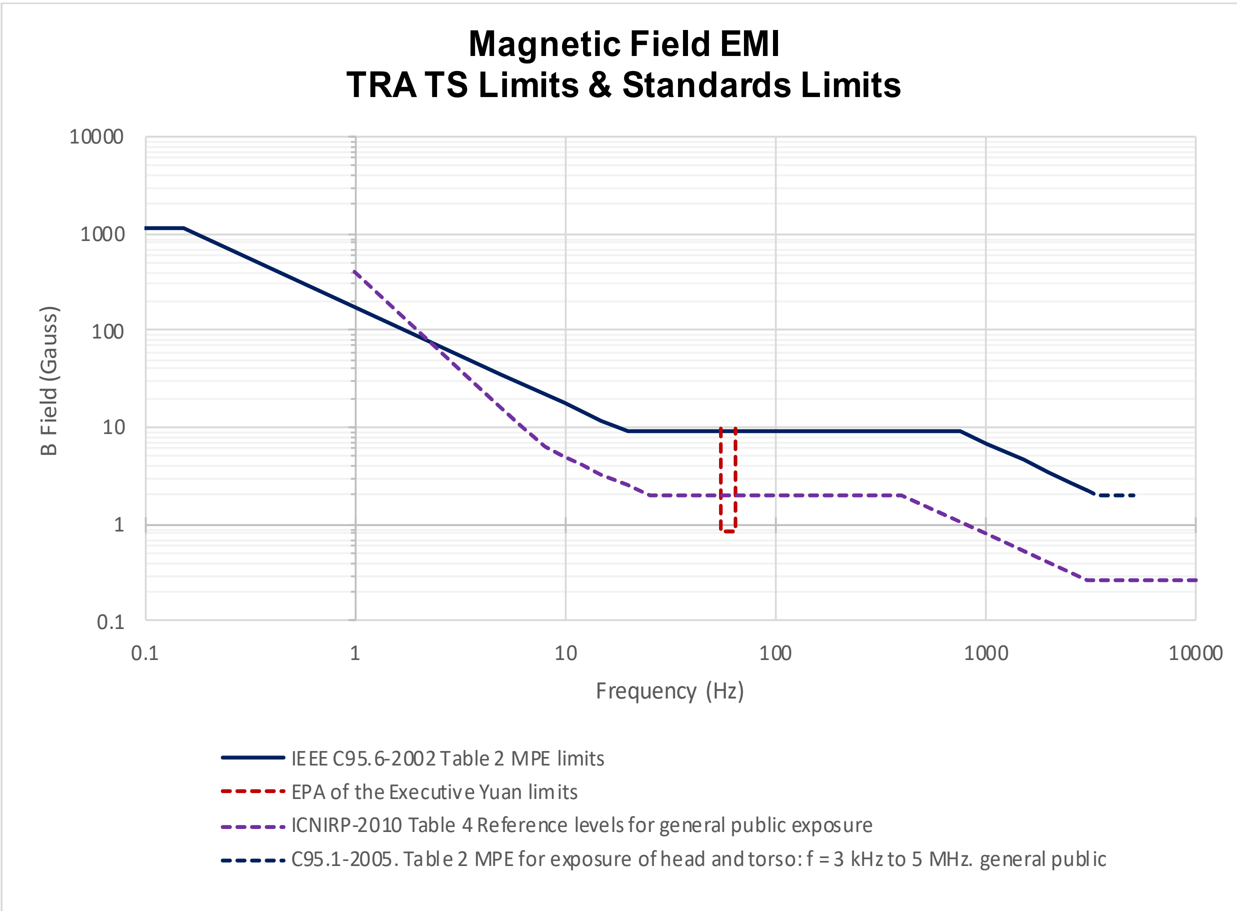
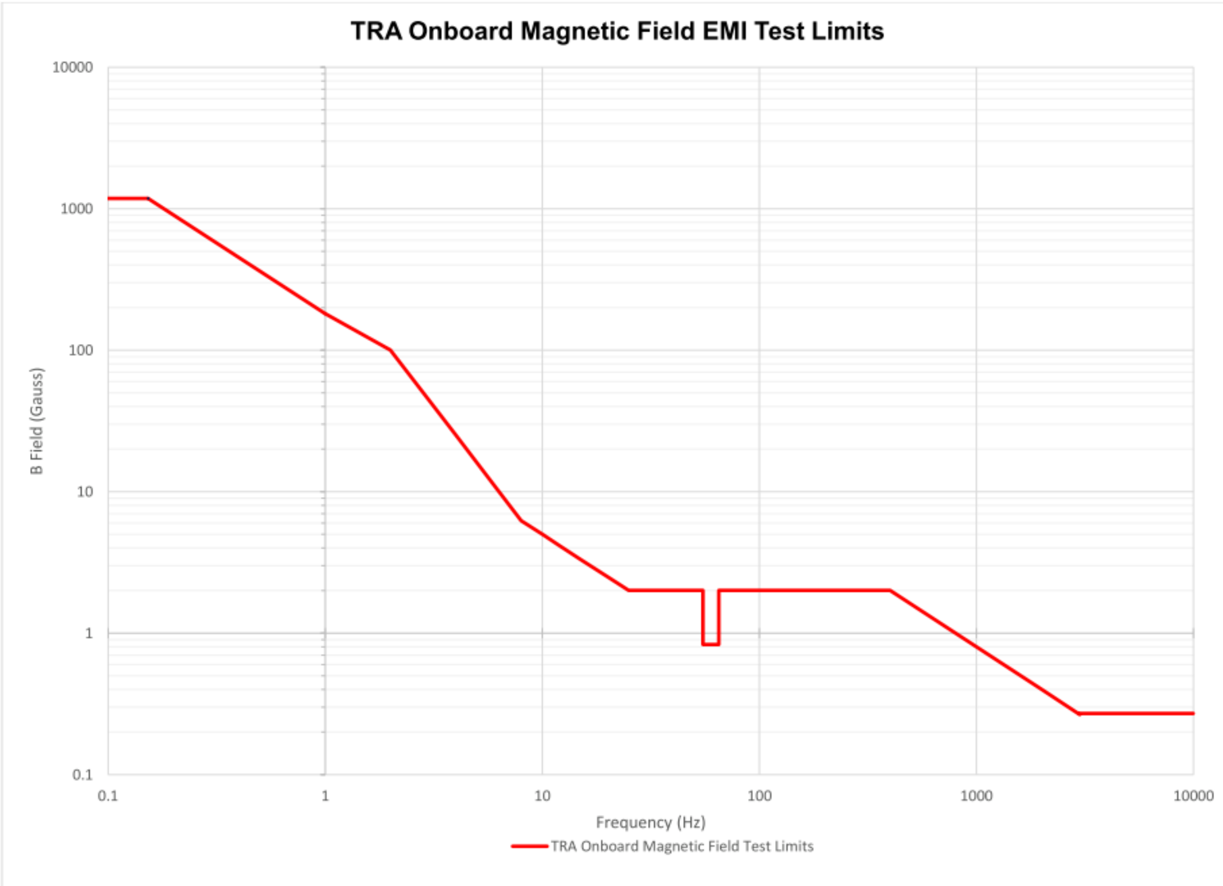


Figure 8-2
Onboard MFT Limits



8.2 Measurements Performed

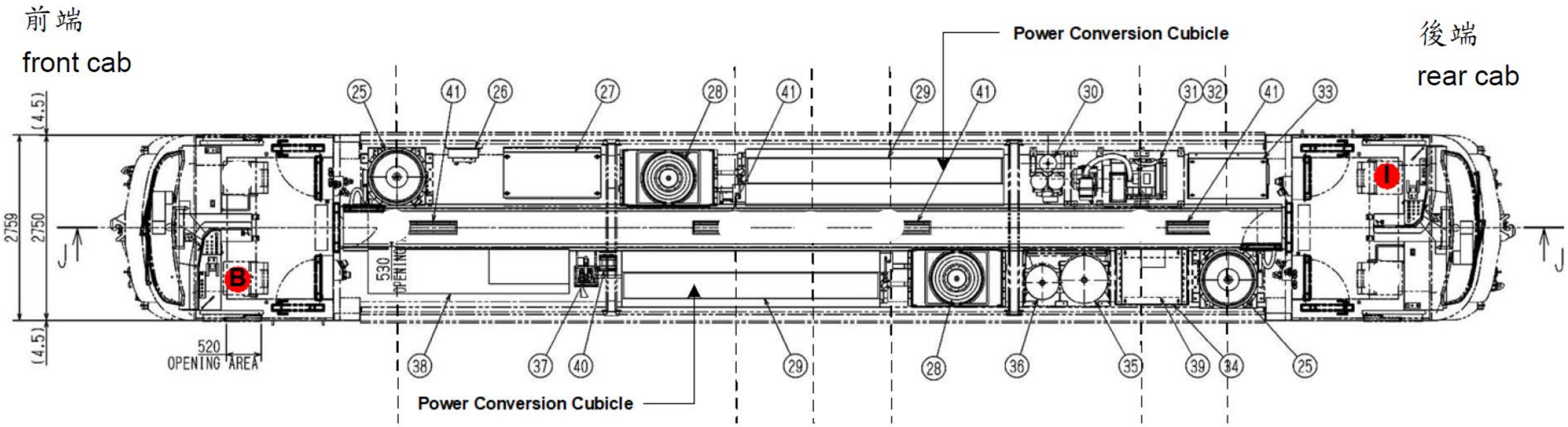
TISS and Tenco performed onboard magnetic field tests inside the TISS EL while the EL was running to determine the worst-case locations on the EL.

The test team took measurements while the TISS EL accelerated to 130 km/h, during the time when the train was drawing maximum current. The test team took measurements with the magnetic probe 0.9 m above the floor at the driver's seat.

Figure 8-3 shows the locations measured by the test team.

The test team used the data acquisition and display system TransDAS to record the magnetic field during the duration of a train run. TransDAS is described in detail in the FETP.

Figure 8-3
Onboard Magnetic Field EMI Test Locations



TISS and Tenco performed 2 magnetic field test runs onboard the E501 TISS EL on the test track section of the mainline in Taichung between Houli Station and Sanyi station, on January 24, 2024. The tests covered maximum acceleration up to 130 km/h followed by maximum brake per the test list in the FETP. Appendix E provides complete information about the Onboard Magnetic tests and results.

The test team kept a test log per the FETP, providing the test type, locomotive configuration, run description, comments for each run, and other relevant information. The test log is in Appendix E. TISS made a video recording of each test run.

8.3 Test Results

8.3.1 OMFT Results Summary

The Onboard Magnetic FETT runs were mainline magnetic TransDAS-1 through TransDAS-15. The tests showed that the magnetic field levels inside the TISS EL were significantly below the TRA limits in both cabs. The highest measured magnetic field level at 60 Hz was 28.4 mG at location B in the front cab, far below the EPA of the Executive Yuan limit of 833.3 mG at 60 Hz.

The maximum TISS EL magnetic field measured inside the locomotive was:

- Static Magnetic Field (DC): 462.7 mG
- Power Frequency (60 Hz): 28.4 mG
- Lower Band Below Power Frequency (10 Hz to 45 Hz): 60.6 mG
- Broader Lower Band (75 Hz to 800 Hz): 12.0 mG

The tests showed that the magnetic field levels inside the TISS EL are low compared to the applicable TRA Onboard Magnetic Field Test Limits shown in Figure 8-2 during maximum acceleration and braking.

This FETR focuses on the 60 Hz magnetic field levels due to the low TRA limit compared to the rest of the 0 to 800 Hz frequency range. While the 10-45 Hz band had higher magnetic field readings, considering the much higher limit in this range, these readings are not as significant as the 60 Hz readings.

8.3.2 Qualification Test Results

Figure 8-4 shows the front cab onboard magnetic field measurement while Figure 8-5 shows the rear cab measurement.

Figure 8-4
Front Cab Onboard Magnetic Field Measurement, Run TransDAS-1

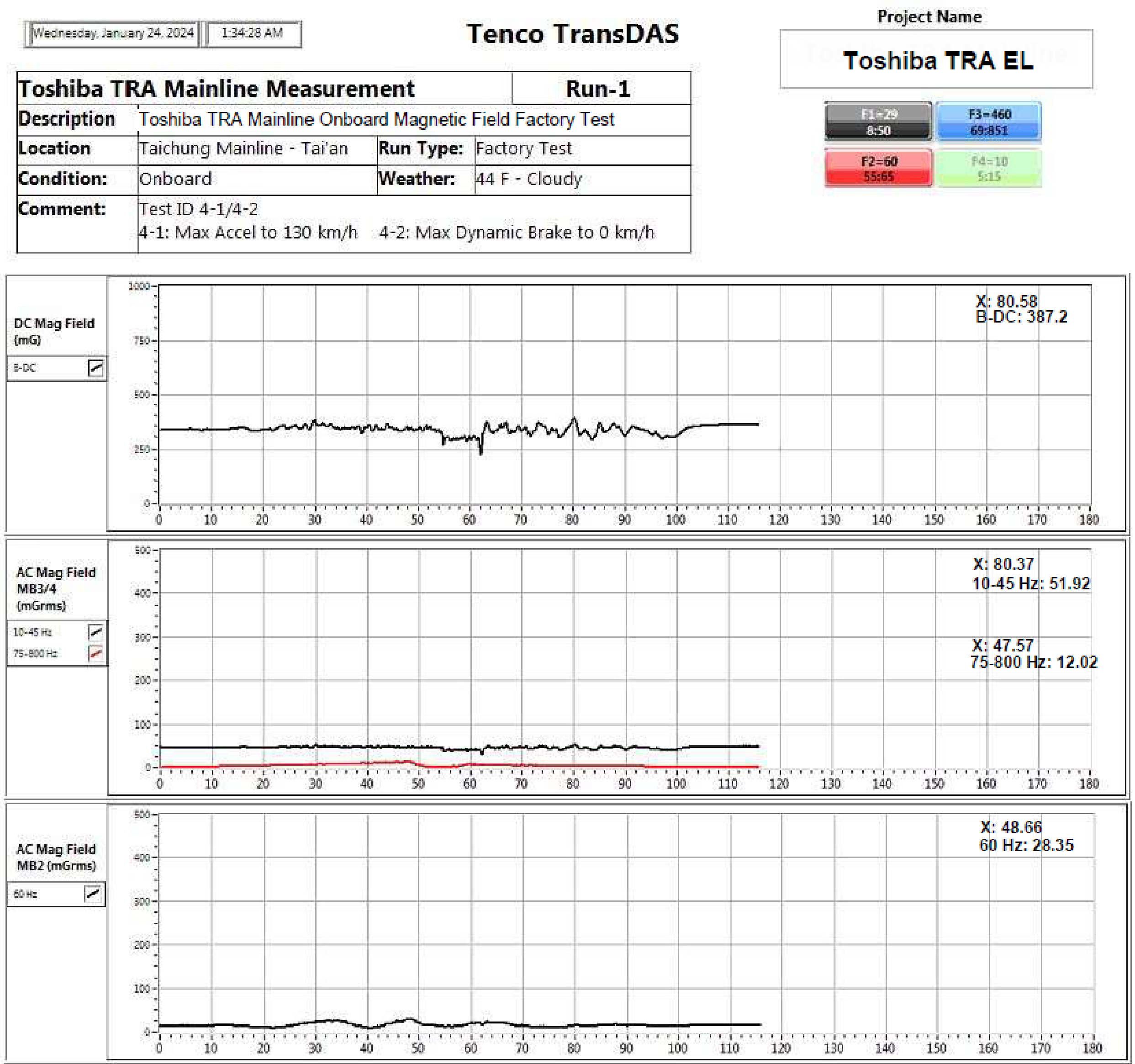
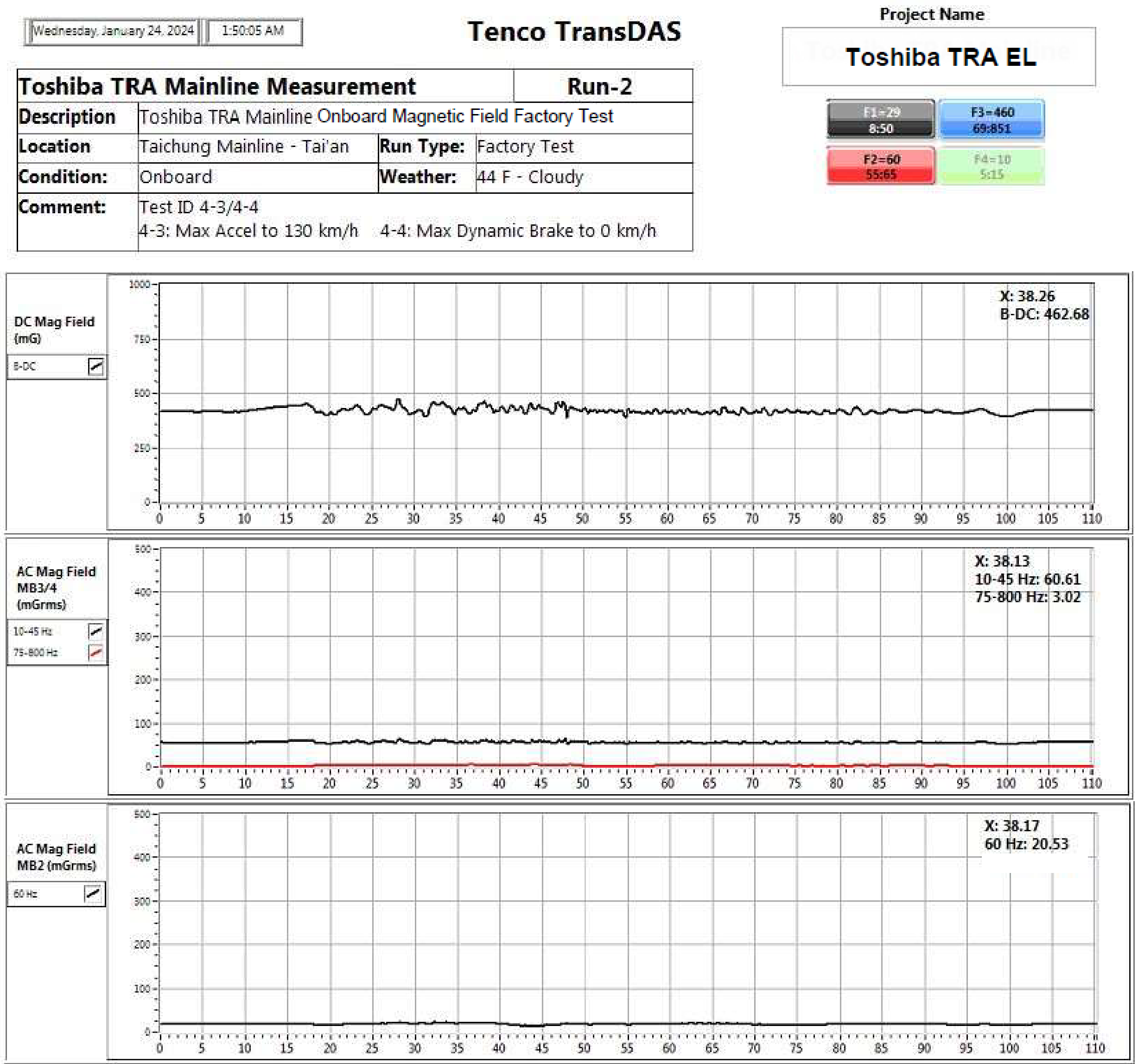


Figure 8-5

Rear Cab Onboard Magnetic Field Measurement, Run TransDAS-2



8.3.3 Test Variables

The test team performed test runs for the TISS EL configurations and operating modes below. The test team evaluated results during the first test runs to determine the modes and conditions under which the TISS EL makes worst-case emissions, considering propulsion and braking. Further tests focused on worst-case modes and conditions.

Length and Load: TISS and Tenco performed all test runs with a single EL. The EL was only loaded with test equipment and test personnel.

Direction: The test team performed test runs in forward and reverse directions.

Operating Modes: The test team measured magnetic fields in powering and braking.

Speed: The test team performed test runs at up to 130 km/h.

Auxiliaries: The test team performed test runs with TISS EL auxiliaries at normal power.

Line Voltage: The test team performed tests at the 25 kV nominal line voltage provided by the mainline traction power substations. Since the tests were after revenue service with no other loads on the traction power substations, the line voltage was at the high end of the normal range, around 27 kV, in all tests.

8.3.4 Test Bands

Since rail traction power systems only emit electromagnetic fields as static and low power frequency fields, TISS and Tenco performed the OMFT only in the range of 0 to 800 Hz, as there are no significant MFE above 800 Hz. The traction current inverters, which are typically the main source of the magnetic field, are Variable Voltage Variable Frequency (VVVF) type, so there is not a particular frequency to focus on to measure their contribution to the magnetic field.

The TransDAS calculated and displayed the vector sum of the three axes of magnetic field, in each frequency band in Table 8-1.

TISS and Tenco performed measurements that covered that range in bands MB1, MB2, MB3, and MB4, so that the earth's static magnetic field in band MB1 and the power currents in band MB2 do not block the measurement of the fields in bands MB3 and MB4.

Table 8-1 Magnetic Field Measurement Bands		
#	**Band**	**Comment**
MB1	DC	Static magnetic field
MB2	60 Hz	Power frequency
MB3	15 Hz to 45 Hz	Low band below power frequency
MB4	75 Hz to 800 Hz	Broader lower band

8.4 Test Equipment and Calibration

8.4.1 Test Equipment

Figure 8-6 shows a block diagram of the Onboard Magnetic FETT equipment. The test used a three-axis Milligauss Meter to make measurements of the magnetic field at different locations onboard a TISS EL.

Table 8-2 lists the test equipment used in the Onboard Magnetic FETT.

The Milligauss Meter was connected to the Tenco TransDAS, a data acquisition system that provides signal processing and strip chart functions. TransDAS graphically displays the values measured by the Milligauss Meter. The test configuration generally followed the configuration in the FETP. The TransDAS ran constantly during each run, usually for about 60 s. AC power was supplied by a TISS EL 110 VAC outlet.

Figure 8-6
Onboard Magnetic Field EMI Test Configuration

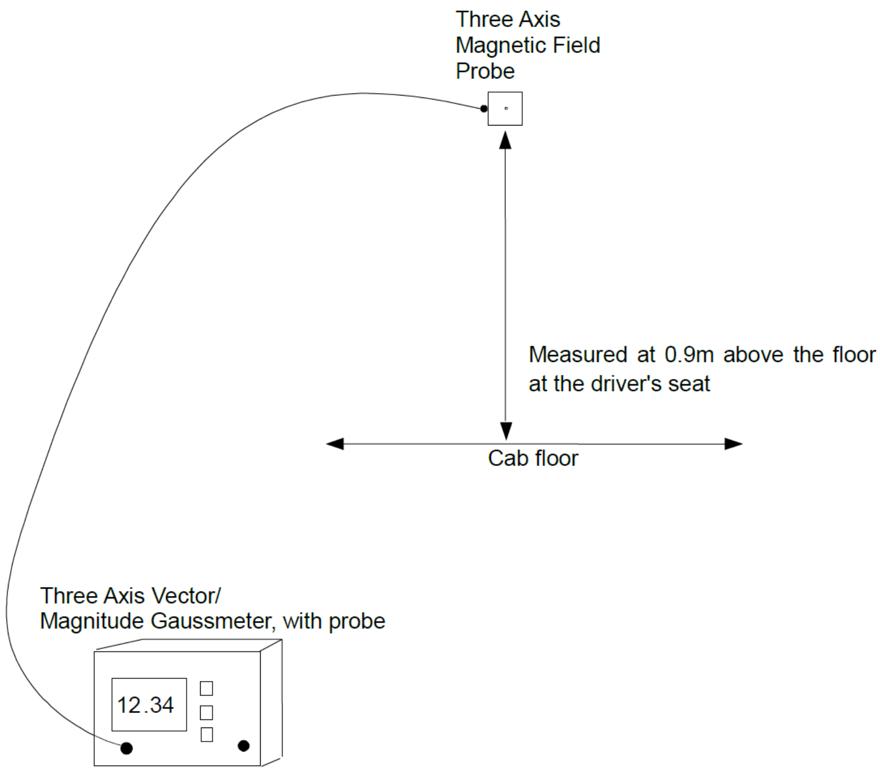


Table 8-2
Magnetic Field Train EMI Type Test Equipment List

#	Item	Supplied By	Comment
1	AlphaLab Three Axis Milligauss Meter	Tenco	For measuring magnetic field
2	TransDAS Data Acquisition Computer	Tenco	For capturing and printing stripchart-type time-based records of locomotive performance
3	Laptop computer	Tenco	To control test equipment and storage of test data results
4	AC Power Source	TISS	TISS EL AC Supply

8.4.2 Equipment Calibration

Each time the equipment was set up, Tenco performed a calibration to verify the proper operation of the Milligauss Meter, as follows:

1. Turn on the Milligauss Meter and let it warm up for 10 minutes.

2. Calculate and enter the zero-correction factors for the Milligauss Meter into the TransDAS or by using the MGM adjustment dials.

3. After warm-up, check the Milligauss Meter responds as expected when drawn close to a current carrying conductor.

8.5 Test Procedure Steps

TISS and Tenco followed these steps for the OMFT:

1. Set up the test instrumentation at the first test location. Set or hold the magnetic field probe in the first position for onboard measurement.

2. On the Gaussmeter, select the appropriate amplitude range. Prepare TransDAS and FFT Analyzer.

3. Start the TransDAS and FFT Analyzer recording and begin powering the EL for the test run. Stop the TransDAS and FFT Analyzer recording when the EL comes to a stop.

4. For each test, record the test number, conditions, time, and date. Use the test results sheet to record all applicable test data indicated.

5. Move the magnetic field probe to a new test location and repeat steps 2 through 4.

9 Appendices

Appendix A – Test Equipment Calibration Records

Appendix B – Radiated Emissions Test Results

Appendix C – Conducted Emissions Test Results

Appendix D – DC Return Current Test Results

Appendix E – Onboard Magnetic Field Test Results