Metrolinx Electrification Project

Metrolinx Contract No. RQQ-2011-PP-032
Metrolinx Project No. 109503

UP EXPRESS EMC REPORT

Document Reference No. PB 991
March 27, 2014

Submitted to

METROLINX
An agency of the Government of Ontario

Submitted by

PARSONS BRINCKERHOFF

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1.0 Purpose

The purpose of this document is to identify the applicable electromagnetic field (EMF) and electromagnetic interference (EMI) procedures and provide measurements and analyses based on the site survey performed along the UP Express corridor from Union Station to Terminal 1 at Toronto Pearson International Airport to determine the impact of the EMI/EMF and to propose mitigation strategies if necessary to ensure Electromagnetic Compatibility (EMC).

2.0 Scope

The EMC report will –

1. Identify neighbouring facilities along the corridor that are likely to have EMI-susceptible electrical equipment, such as hospitals and scientific research facilities
2. Identify existing EMI-susceptible equipment within the Metrolinx right-of-way
3. Identify the EMC and EMI site survey procedures
4. Estimate and analyze the maximum background extremely low frequency (ELF) electromagnetic fields at those facilities and equipment by adding the railway emissions to the baseline emissions measured in the EMF survey
5. Propose the necessary actions to be undertaken to mitigate the EMI in facilities or equipment for items 1 and 2.

The railway system within this EMC assessment scope is comprised of the power supply, signalling, grounding and communication systems which are connected by the running rails and the trains.

3.0 Background

This section covers the nature of electromagnetic fields (EMF), industry standards for human exposure to these fields, the concept of electromagnetic interference (EMI) between electrical equipment, and industry requirements for the mitigation of interference.

3.1 EMF

Electric and magnetic fields are invisible lines of force that surround any electrical device. Power lines, electrical wiring, communication broadcasting antennas and electrical equipment all produce EMF. Electric fields are produced by voltage and increase in strength as the voltage increases. The electric field strength is measured in units of volts per meter (V/m).

Electric fields have the following characteristics –

- Metal conduits and encasements effectively attenuate electric fields
- The strength of the electric field decreases as the distance from the source increases
- Ground and buildings could significantly attenuate electric fields
- When the intensity of electric field changes, it induces magnetic field in a zone of the electric field influence.

Magnetic fields result from the flow of current through wires or electrical devices and increase in strength as the current increases. Magnetic fields are measured in units of gauss (G) or Tesla (T).

Magnetic fields have the following characteristics –

- Metal conduits and encasements of electric current sources effectively attenuate magnetic fields
- The strength of the magnetic field decreases as the distance from the source increases
- Ground and buildings do not significantly attenuate magnetic fields
- When the intensity of magnetic field changes, it induces electric current in a metallic loop located in a zone of the magnetic field influence.

3.1.1 Sources

Radiofrequency (RF) and extremely low frequency (ELF) are the two main forms of EMFs. **Figure 3-1** illustrates the main railway system EMFs and the following subsections describe these EMFs.

3.1.1.1 RF EMF

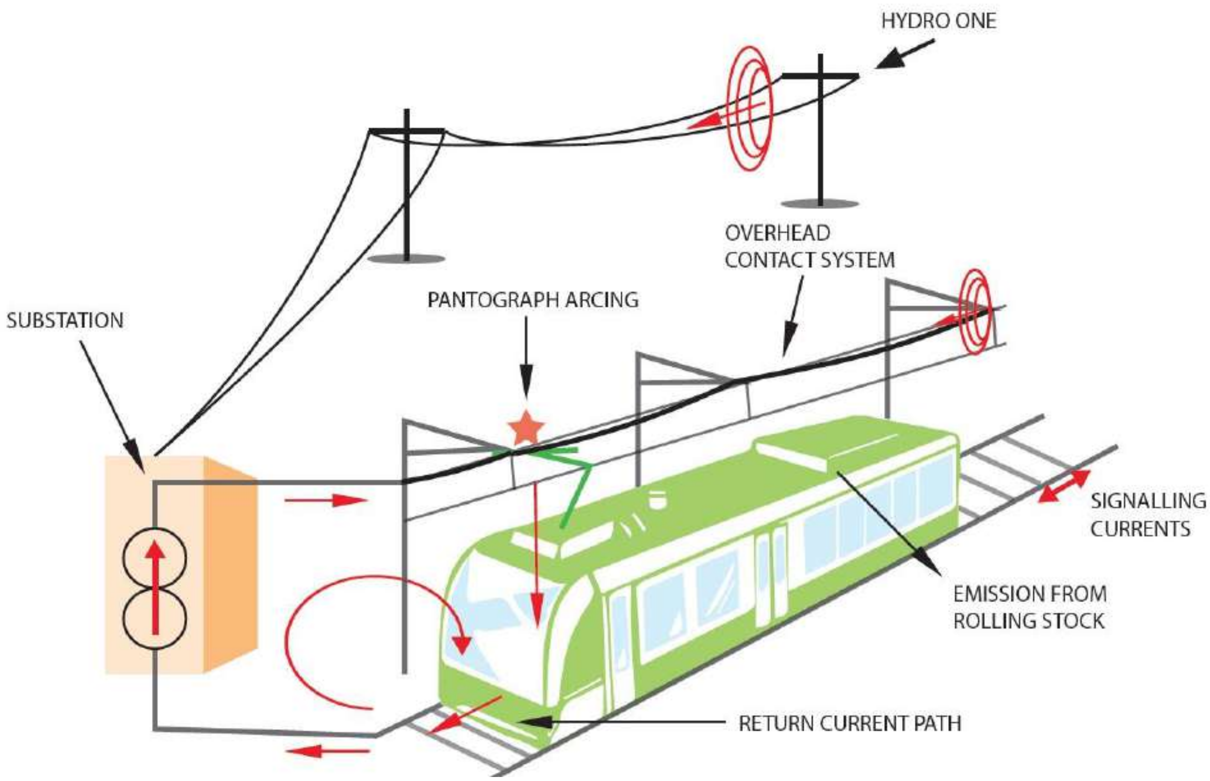
RF fields (approximately 3 kHz to 300 GHz in frequency range) result predominantly from the train and overhead contact system (OCS) interaction. Sources of RF noise include micro-arcing associated with the OCS/pantograph interaction, corona discharges from the surface of OCS insulators, and the railway system non-linear, harmonic producing loads. These fields are not permanent, are localized, transient in nature, and only occur for the duration of a train’s passage.

There are also RF emissions from railway-licensed radio sources that will have emission levels regulated by FCC, Health Canada (*Safety Code 6*) and Industry Canada.

3.1.1.2 ELF EMF

The frequency range of ELF EMF is from dc to approximately 400 Hz, and in North America is predominately associated with the generation, distribution, transmission, and use of 60 Hz electricity. As such, the predominantly 60 Hz frequency is called the 'fundamental frequency'. Many man-made sources of ELF EMF exist, including power lines, substations, appliances, electric motors and generators. The most significant source of EMF at the railway system environment is the OCS, emanating 60 Hz electric and magnetic fields.

Figure 3-1 Railway EMF Sources



60 Hz magnetic fields can be illustrated using the right hand rule. If an electric current passes through a straight wire (i.e., overhead line), and the thumb points in the direction of the conventional current (from positive to negative), the fingers point in the direction of the magnetic field (see **Figure 3-2**). Electric fields for wires (i.e., overhead lines), on the other hand, radiate perpendicular to the line (see **Figure 3-3**). Lateral decrease of the electric and magnetic fields may be assumed to attenuate linearly with distance.

Figure 3-2 Right Hand Rule for Magnetism

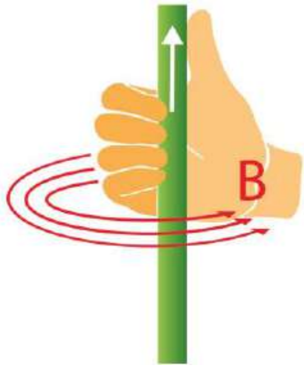
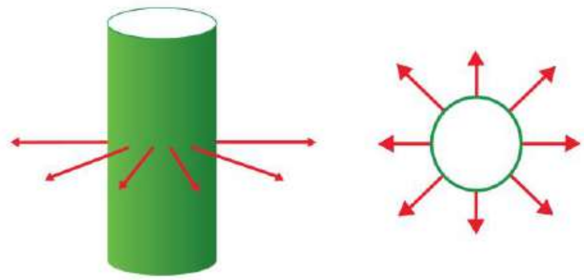


Figure 3-3 Electric Field Orientation for Power Lines



3.1.2 Human Exposure

Human exposure to electromagnetic fields can be divided into exposure to RF and ELF.

3.1.2.1 RF EMF

Licensed radio sources for the railway system will have radio frequency (RF) emission limits as per Industry Canada and Health Canada's *Safety Code 6: Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz*. The limits will ensure human exposure to these fields does not pose a threat to human health.

Microwave radiation is in the range from 300 MHz to 3 GHz. Electrified railways are not considered to be a source of microwave radiations and therefore microwave radiations are not discussed in this report.

The railway transient RF EMF emanation occurring for the duration of train passage does not pose a human health risk since it is not a permanent field (ie, the field only occupies the electromagnetic environment for the duration of the train passage). Non-permanent fields do not cause significant thermal effects on human body tissue.

3.1.2.2 ELF EMF

The railway ELF EMF will be permanent since the OCS will always be energized under normal operating conditions. There are currently no Canadian-specific standards that regulate power line frequency EMF limits. However, there are three main organizations in North America that have introduced standards that limit power line frequency electromagnetic field exposures from a human health risk per5spective –

- The International Commission on Non-Ionizing Radiation Protection (ICNIRP) through their *Guidelines for limiting exposure to time-varying electric and magnetic fields, 1 Hz to 100 kHz*
- The Institute of Electrical and Electronics Engineers (IEEE) through *IEEE C95.1 Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz*
- The American Conference of Governmental Industrial Hygienists (ACGIH).

In combination, these standards set limits for occupational and public settings as well as for workers who have pacemakers. From a health risk perspective, the 60 Hz fundamental frequency electric and magnetic field exposure limits are per the tables below.

Table 3-1 Exposure Limits for Fundamental Frequency Electric Fields

	ICNIRP (kV/m)	IEEE (kV/m)	ACGIH (kV/m)
Occupational	8.3	20	25
Public	4.2	5[1]	n/a
Workers with Medical Implants	n/a	n/a	1

Table 3-2 Exposure Limits for Fundamental Frequency Magnetic Fields

	ICNIRP (mG)	IEEE (mG)	ACGIH (mG)
Occupational	10,000	27,100	10,000
Public	2,000	9,040	n/a
Workers with Medical Implants	n/a	n/a	1,000

3.2 EMI

Electromagnetic interference is defined as the degradation of performance of a device, equipment or system caused by an electromagnetic disturbance.

Sources of electromagnetic interference include –

- The propulsion system's high voltage and high current operational mode emissions
- Train signalling systems and their associated computer operating codes
- Train control system emissions
- Track to train control circuits
- Right-of-way electromagnetic field emission sources.

Electromagnetic interference involves three elements –

- **Sources** generate electromagnetic fields or energy such as the overhead contact system and the Electric Multiple Unit (EMU)
- These sources may interfere with electrical **receptors** such as railway and substation electrical components or third party devices such as electron microscopes, magnetic resonant imaging devices or antennas
- Potential interference is transmitted through a **coupling path** through a conductor such as an electric power line or ground wire, or through the air by induction or radiation (often referred to simply as radiation). Coupling paths can be complex, involving both conducted and radiated elements.

These disturbances can be mitigated through various technical measures to achieve electromagnetic compatibility to ensure that all electrical and electronic devices can co-exist and function satisfactorily. These mitigation measures are presented in **Sections 10.0** and **11.0**.

[1] Maximum permitted: 10 kV/m under power line rights-of-way.

3.2.1 Impact of Electrified Railway on Equipment

ELF and RF EMF emanating from the railway system may interfere with the proper operation of third party and Metrolinx equipment. EMC is mainly a concern for EMI sensitive sites as discussed below.

3.2.1.1 EMI Sensitive Sites

EMI sensitive sites are often equipped with electrical devices susceptible to EMI, for example –

- Airport navigational aid and communication systems
- Radars
- Medical imaging equipment
- MRIs
- Scientific instruments that utilize charged beams or high precision magnet systems
- Electron microscopes
- Electron beam lithography systems
- Focussed ion beams
- Systems requiring a very stable magnetic field, such as magnetic field imaging devices and nuclear magnetic resonance spectrometers.

Per *IEEE 241*, the following facilities are considered to be EMI sensitive sites and may require a degree of control of electromagnetic energy –

- Research and development laboratories for low-noise circuitry work
- Research and development laboratories using high-energy radio-frequency devices
- Special computer facilities
- Test and measurement laboratories
- Hospital and other biomedical research and treatment rooms
- Railway signalling and communication systems
- Airport navigational aid and communication equipment.

3.2.1.2 ELF EMI

The alternating currents and voltages associated with the traction power supply and OCS of an electrified railway system may interfere with nearby communications systems, Wi-Fi networks, including railway communication and signalling systems. ELF EMF is normally the predominant source of interference in the form of magnetic induction. Specifically, alternating current flowing in the OCS, including its harmonics, generates a magnetic field that induces a voltage in nearby communication conductors and equipment in EMI sensitive sites.

For inductive coordination between the OCS and communication conductors, the clearance requirement between the OCS and communication conductors will be as per the Ontario Electrical Safety Code requirement, which will ensure that the inductive interference from the OCS to nearby communication lines is minimized. **Section 10.0** provides the currently identified equipment in EMI-sensitive sites neighbouring the UP Express corridor for both Metrolinx and third parties and provides steps to ensure EMC.

Electromagnetic compatibility between the UP Express electrification systems and the current and future Wi-Fi networks in close proximity of the railway (Zone 1 and Zone 2 as defined in **Section 5.0**) would be ensured during the detailed design to prevent any interference. To ensure compatibility, Wi-Fi networks compliance to *IEEE 802.11* for the specific Wi-Fi frequency bands would be mandatory.

3.2.1.3 RF EMI

Intentional radiators (licensed radio sources) pertaining to Metrolinx and third parties may cause interference with each other due to frequency overlap between radio applications. RF noise from the OCS/pantograph interaction may cause interference with nearby RF receivers. It should be noted that the RF noise from the OCS/pantograph interaction will be limited as per *EN 50121* via field verification and interference with nearby RF receptors will be minimized.

As well, the nonlinear loads in the rolling stock produce harmonic voltages and currents which will introduce harmonic EMFs in the RF range. These harmonics are normally limited to values set forth in industry standards and are not significant.

3.2.1.4 Equipment Impact on Electrified Railway

The frequency management plan that will be executed by Metrolinx during the detailed design stage will identify and avoid any frequency overlaps between the railway RF receivers and third party RF intentional radiators. The radios pertaining to the railway system will use the frequency allocated to railway radio devices by Industry Canada. Other third party radio devices in the vicinity of the railway system have different frequencies of operation assigned to them by Industry Canada and normally do not interfere with railway radios and vice versa.

Furthermore, since railway equipment will be immunized per *EN 50121* and no significant background electromagnetic radiation at the UP Express corridor has been measured and estimated during the site survey, it is not expected that nearby third party equipment will interfere with the proper operation of the railway equipment.

4.0 Reference Documents & Standards

The following reference documents and standards pertain to the EMC requirements for the UP Express electrified railway.

4.1 Documents

- Project Contract RQQ-2011-PP-032
- Electrification Performance Specifications (EPS) allow Metrolinx to determine the performance type requirements for electrification of any GO transit corridor. Also, these specifications identify standards, set performance requirements, and capture known constraints of existing conditions in the rail corridors –
  - EPS-01000 – Traction Power Supply system
  - EPS-02000 – Traction Power Distribution System
  - EPS-03000 – Grounding and Bonding
  - EPS-04000 – Electromagnetic Compatibility
  - EPS-05000 – Signal System Compatibility
  - EPS-06000 – Operations and Maintenance
  - EPS-07000 – Maintenance Facilities
  - EPS-08000 – SCADA System
  - EPS-09000 – Operations Control Centre (OCC)
  - EPS-10000 – System Integration
  - EPS-11000 – System Assurance
  - EPS-12000 – Safety and Security.

4.2 Standards

The following is a list of standards with which manufacturers of the traction electrification railway equipment must comply. They cover the emission and immunity limits, and test methodologies for measuring electromagnetic emissions.

In North America, electromagnetic compatibility and immunity are addressed through a number of commissions and associations such as AREMA, APTA, IEEE, CSA, FCC, Industry Canada and IEC.

American Railway Engineering and Maintenance (AREMA)

- AREMA Committee 38 – Part 11.5.2 addresses electromagnetic immunity and emissions standards for Signalling Equipment.

American Public Transportation Association (APTA)

The APTA electromagnetic compatibility program addresses the requirements for the development of a program for all rail equipment and track sided equipment delivered to the railroad to achieve safe operations.

- APTA SS-E-005-98 – Standard for Grounding and Bonding
- APTA SS-E-010-98 – Standard for the Development of an Electromagnetic Compatibility Plan.

Canadian Standard Association (CSA)

These standards covers design considerations in various areas of railway electrification including interference with railway signalling circuits and communication circuits.

- CSA C22.3 No. 8-M91 – Railway Electrification
- CAN3-C108.3.1-M84 – Canadian Standard for Limits and Measurement Methods of Electromagnetic Noise from AC Power Systems, 0.15-30 MHz
- CAN/CSA-C22.3 No. 3 – Canadian Standard for Electrical Coordination between power supply and communication conductors
- CSA C22.3 No. 6 – Principles and Practices of Electrical Coordination between pipelines and electric supply lines
- Canadian Electrical Code, part 1
- The Ontario Electrical Safety Code.

Federal Communications Commission (FCC)

FCC electromagnetic compatibility standards address how to control EMI interference outlined in Part 15 of the FCC rules, which specify that any spurious signal greater than 10 kHz is subject to regulation.

The following standards pertain to FCC requirements for human exposure to electromagnetic fields:

- FCC OET-65 Evaluating Compliance with FCC guidelines for human exposure
- FCC OET-65c Evaluating Compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields.

Industry Canada

Electromagnetic Compatibility Standards from Industry Canada cover the Canadian requirements for electromagnetic field emission limits, spectrum allocations and measurements. All intentional radiators used in Canada should comply with Industry Canada requirements.

European Standards (EN)

Since electrified railways are typical in the European Union, these are used as well-developed design standards that are followed in Canada/North America electrified railways. The *EN50121* series of standards were produced by CENELEC (European Committee for Electrotechnical Standardization) as a means of managing EMC across the whole railway industry. These standards provide a management framework, product standards and best practice to cover all aspects of EMC within a large distributed installation. The basic emission levels were set from emission measurements made across a number of railways. Recent reviews of these standards have confirmed their validity to reflect best practice within the railway industry. Compliance with these standards will ensure that UP Express electrification meets best practice guidelines for general emissions and immunity of equipment and systems within the traction electrification design/build project.

The following reference standards are preferred but not exclusive for application to different environments, subsystems and functional electrical/electronic equipment.

- EN 50121: Railway Applications – Electromagnetic Compatibility
  - Part 1:2006 Railway Applications. Electromagnetic Compatibility – General
  - Part 2:2006 Emission of the whole railway system to the outside world
  - Part 3.1:2006 Railway stock – Train and complete vehicle
  - Part 3.2:2006 Rolling stock – Apparatus
  - Part 4:2006 Emission and immunity of the Signaling and Communications apparatus
  - Part 5:2006 Emission and immunity of the fixed power supply installations and apparatus
- EN 61000: Electromagnetic Compatibility
  - Part 6-1:2007 Immunity for residential, commercial and light industrial environments
  - Part 6-2:2005 Immunity for industrial environments
  - Part 6-3: 2007 Emission standard for residential, commercial, and light industrial
  - Part 6-4: 2007 Emission standard for industrial environments
  - Part 3-2: 2006 Limits for harmonic current emissions (equipment input current less than or equal to 16 A per phase)
  - Part 4-3 Radiated susceptibility test
  - Part 4-6 Conducted immunity test
  - Part 4-8 Power frequency magnetic test
- EN 50155: 2007 Railway Applications. Electronic equipment used on rolling stock
- EN 50238: 2003 Railway Applications. Compatibility between rolling stock and train detection systems
- EN 50343: 2003 Railway Application – Rolling Stock. Rules for installation of cabling
- EN 50357: 2001 Evaluation of human exposure to electromagnetic fields from devices used in Electronic Article Surveillance (EAS) Radio Frequency identification, and similar applications
- EN 50364:2010 Limitation of human exposure to electromagnetic fields from devices operating in the frequency range 0 Hz to 10 GHz, used in Electronic Article Surveillance (EAS), Radio Frequency identification, and similar applications
- EN 50500: 2008 Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure
- EN 50081-1: 1992 Generic emissions standard for residential, commercial and light industrial environments
- EN 50081-2 Generic emissions standard for industrial environment
- EN 55022: 2010 Limits and methods of measurement of radio disturbance characteristics of information technology equipment (also known as CISPR-22)
- EN 55011: 2007 Industrial, Scientific and Medical (ISM) radio frequency equipment – Radio disturbance characteristics – Limits and methods of measurement (also known as CISPR-11)
- EN 55013: 2001 Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment
- ETSI EN 300 339 V1.1.1-1998-06 Electromagnetic compatibility and Radio spectrum Matters (ERM)

– General Electromagnetic Compatibility (EMC) for radio communications equipment

Health Canada

- Safety Code 6 – Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz.

Institute of Electrical and Electronic Engineers (IEEE)

IEEE electromagnetic compatibility standards define the unintentional generation, propagation, and reception of electromagnetic energy, the associated unwanted effects, and the correct operation of different equipment involving electromagnetic phenomena in their operation.

- IEEE 1100-2005 – Recommended Practice for Powering and Grounding Electronic Equipment
- IEEE 518-1982 – Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
- IEEE 519-1992 – Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE 141-1993 – Recommended Practice for Electric Power Distribution for Industrial Plants
- IEEE 241-1990 – Recommended Practice for Electric Power Distribution for Commercial Buildings
- IEEE 1159-2009 – Recommended Practice for Monitoring Electric Power Quality
- IEEE 1308-2001 – Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters – 10 Hz to 3 kHz
- IEEE C95.1-2005: Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3kHz to 300 GHz
- IEEE C95.6-2002 – Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 – 3 kHz
- ANSI/IEEE C63.12 – The American National Standard for Electromagnetic Compatibility Limits
- IEEE 802.11 – Wireless Local Area Networks.

International Electrotechnical Commission (IEC)

IEC electromagnetic compatibility standards define the terminology and description of the electromagnetic phenomena, the electromagnetic environment, measurement and testing techniques, and guidelines for installation and mitigation.

- IEC 60255-26 Electrical relays – Part 26: Electromagnetic compatibility requirements for measuring relays and protection equipment
- IEC 60479 Effects of current on human beings and livestock – Part 1 General aspects
- IEC 61000-5 Electromagnetic Compatibility (EMC) – Installation and mitigation guidelines
- IEC 61000-5-2 (EMC) Part 5: Installation and mitigation guidelines – Section 2: Grounding and cabling.

- IEC 61000-6-1: Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments
- IEC 61000-6-2: Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
- IEC 61000-6-3: Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
- IEC 61000-6-4: Electromagnetic compatibility (EMC) – Part 6-4: Generic standards - Emission standard for industrial environments
- IEC 61000-6-5: Electromagnetic compatibility, immunity for power station and substation environment.

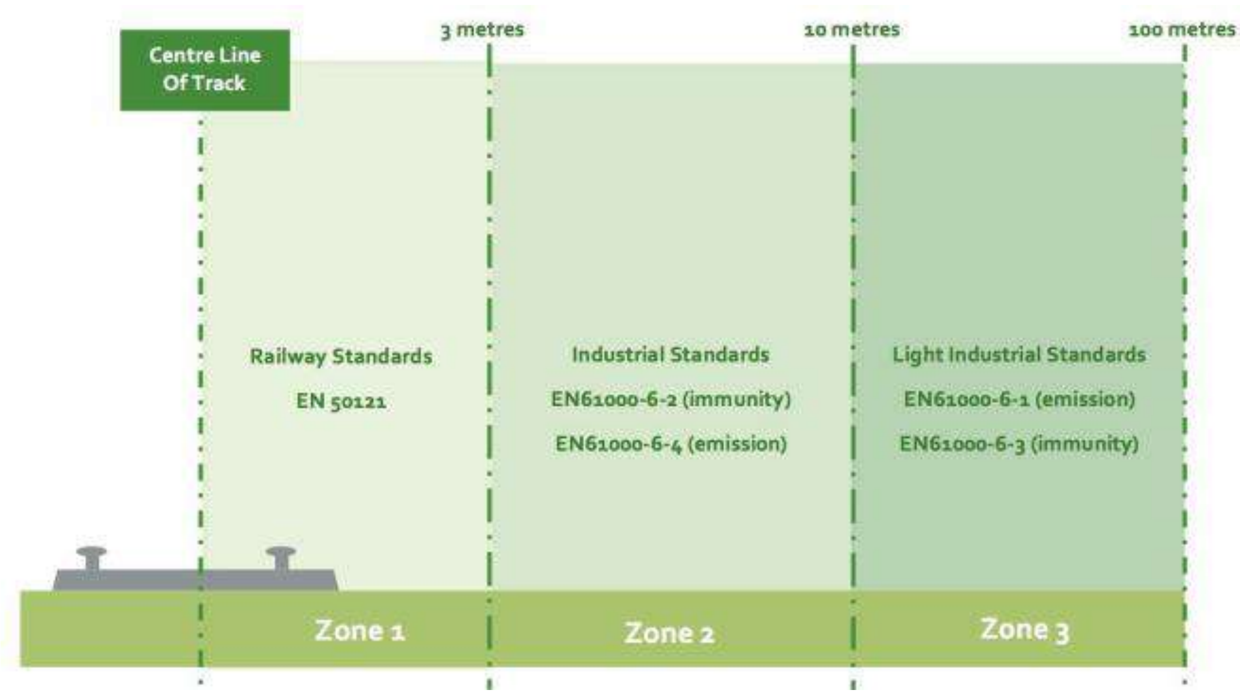
5.0 Electromagnetic Site Survey

An electromagnetic site surveying along the UP Express corridor was performed to measure and estimate background electromagnetic fields at the railway right-of-way and compare the values to human exposure limits set in industry standards. Furthermore, the survey identified equipment and facilities that may be susceptible to electromagnetic radiation from an electrified railway, and actions to prevent interference to these equipment and facilities are recommended.

There were three investigation zones in the site survey –

- **Zone 1** Existing Metrolinx and the neighbouring right-of-way railway systems and equipment up to 3m (10') from the centreline of the outermost track.
- **Zone 2** Metrolinx and external third party systems and equipment, located on the right-of-way and outside the right-of-way but in close proximity to the tracks up to 10m (33') from the centreline of the outermost track.
- **Zone 3** External third-party EMI-sensitive sites (such as laboratories, hospitals, and airports) located between 10m and 100m (33' and 330', respectively) from the outermost track.

Figure 5-1 EMI Investigation Zones & Applicable Standards



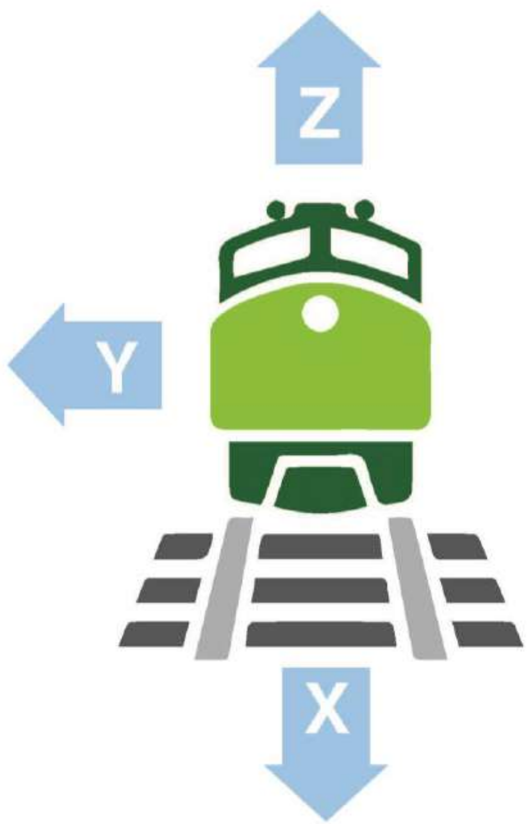
5.1 EMF Site Survey Procedure

The EMF site survey was performed to evaluate human exposure to power line frequency (60 Hz) electric and magnetic fields, which are the predominant EMFs in the electrified railway environment. The survey results (ie, background electromagnetic field level measurements) have also been used for the EMI assessment.

During the EMF site surveying phase, the survey personnel measured ELF magnetic field levels along the UP Express corridor. Measurements were performed at the outermost track at a height of 1m (3'3") above tracks to capture both the background emission at the railway and the magnetic fields induced by track currents.

The measurements were taken at three axes with magnetic field orientation per **Figure 5-1**.

Figure 5-2 Railway Magnetic Field X, Y & Z Component Orientation



Measurements were documented at every milepost and at areas where there was a significant (more than 10 mG) magnetic field level. **Appendix E** outlines the magnetic field values measured along the UP Express corridor.

Special attention was paid to the magnetic field levels at areas of the UP Express corridor with nearby overhead transmission lines, since transmission lines within Zone 3 (both parallel and perpendicular to the railway corridor) are the most significant sources of ELF EMF along the UP Express corridor. These areas are discussed further in **Section 6.0**.

A Walker Scientific ELF-60D magnetometer was used to measure the background magnetic field levels throughout the UP Express corridor. The unit frequency operation is from 40 to 400 Hz and is capable of measuring the power line (60 Hz) frequency and the associated third (180 Hz) and fifth (300 Hz) order harmonics. Please refer to **Appendix D** for the calibration certificate and product data sheet.

5.2 EMI Site Survey Procedure

The EMI survey was performed to identify Metrolinx and third party facilities and equipment that are susceptible to the electrified railway system EMI, along with necessary steps for immunization.

Prior to the field survey, an EMI desktop analysis was performed to identify equipment and facilities along the UP Express corridor that fall within Zones 1 and 2 and EMI sensitive facilities that fall within Zone 3. The analysis was based on available data, designs, property information, aerial photos, business directories and city maps. The results of the analysis were input into the site survey to provide the surveyors with a starting point and baseline information on nearby facilities that may be possible receptors of EMI.

The site surveying was conducted by visually identifying and listing equipment and facilities within 100m of the outermost track that were suspected of being susceptible to railway EMI. Special attention was paid to identifying EMI sensitive facilities within Zone 3. The results of the investigation are summarized in **Section 10.0**.

6.0 Electromagnetic Site Survey Measurements & Estimates

The 60 Hz electromagnetic fields were measured and estimated along the UP Express corridor for human exposure to EMF and electrical equipment EMI assessment and are provided in this section.

6.1 EMF

For the purpose of assessment of human exposure to 60 Hz electric and magnetic fields, magnetic field levels were measured along the UP Express corridor and are summarized in **Appendix E**. Subsequently, the maximum estimated 60 Hz electric and magnetic field emanation from the UP Express railway (specifically, 1 kV/m and 160 mG, respectively) was superimposed on the measured background EMF to arrive at the worst-case (highest anticipated EMF) public exposure. This section will discuss these estimates for the corridor and the traction power facilities (TPFs), passenger stations, and the maintenance facility.

6.1.1 Corridor

Table 6-1 provides the maximum conservative estimate for the fundamental frequency (60 Hz) electric and magnetic field level on the UP Express corridor.

Table 6-1 Fundamental Frequency Magnetic & Electric Field Strength

Corridor	Electric Field Limit		Magnetic Field Limit (at max load)	
	Within the Right-of-Way	Edge of Right-of-Way	Within the Right-of-Way	Edge of Right-of-Way
UP Express	9 kV/m	9 kV/m	250 mG	250 mG

The values in the table were estimated by adding the highest EMF level measured/estimated on site (specifically, at areas in the vicinity of high voltage transmission lines) with the maximum expected EMF emanation from the railway system. Since this estimate is conservative, the actual field levels are expected to be much lower. The values in **Table 6-1** are below IEEE requirements for public exposure to power line frequency EMF. As such, human health effects due to EMF are not expected.

6.1.2 Facilities

In general, the strongest source of EMF at a substation, paralleling station, passenger station or maintenance facility comes from the power lines entering and leaving the facility.

6.1.2.1 TPFs

The power lines entering the 175 City View TPS are within the jurisdiction of Hydro One, and the typical electric and magnetic field emanations from those lines are 2 kV/m electric and 57.5 mG magnetic directly under the high voltage transmission lines at peak, which is below industry standards for human exposure.

There will also be underground ducts exiting the TPS and PS feeding the OCS, with peak fields directly above the feeder at 40 mG and 200 V/m. The strength of the EMF from equipment within the TPF such as transformers, reactors, and capacitor banks, decreases rapidly with increasing distance. Beyond the substation fence or wall, the EMF produced by the substation equipment is typically indistinguishable from background levels.

The area within the TPF sites is considered an occupational setting (ie, workplace). The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of potential risks and to take appropriate precautions. In contrast, the general public is comprised of individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals. Moreover, individual members of the public cannot reasonably be expected to take precautions to minimize or avoid exposure. These considerations underlie the adoption of more stringent exposure restrictions for the public than for the occupationally exposed population.

6.1.2.2 Passenger Stations & Resources Road Maintenance Facility

Weston, Bloor and Union Stations and the RRMF are expected to be exposed to the same maximum EMF as the corridor (**Table 6-1**) – that is, below industry standard human exposure limits.

6.2 EMI

Electromagnetic compatibility of the railway system and supporting facilities will be ensured via compliance with the emissions and immunity requirements of relevant EMC industry standards as described below.

6.2.1 Corridor

Compliance with *EN 50121* will ensure that the railway system components at the UP Express corridor, including power supply system, signalling, communication, and the rolling stock are immune to electromagnetic interference and do not interfere with the operation of electrical equipment in nearby facilities. Furthermore, the railway signalling system should comply with the emissions and immunity limits and test procedures set forth in the *AREMA Communications and Signalling Manual Part 11.5.2.*

6.2.2 Facilities

The facilities supporting the electrified railway must comply with industry EMC requirements. TPFs have their own specific standards for emissions and immunity, while the passenger stations and maintenance facility should comply with generic EMC standards.

6.2.2.1 TPFs

TPF emission and immunity requirements will be per *EN 50121 part 5*, *CAN3-C108.3.1-M84* and *IEC 61000-6-5* to ensure that the equipment in these facilities is immune to EMI and does not interfere with the proper operation of nearby electrical equipment.

6.2.2.2 Passenger Stations & Maintenance Facility

The passenger stations and Maintenance Facility will comply with the emission and immunity requirements of generic standards *EN 61000-1*, *EN 61000-2*, *EN 61000-3*, *EN 61000-4* and/or *IEEE C63.12* to ensure EMC.

7.0 Rolling Stock

Rolling stock emanates RF EMF by interaction with the OCS through its nonlinear loads and through the intentional radiators used in rolling stock (ie, radios).

As well, the rolling stock distorts the background ELF EMF as it moves by and radiates ELF EMF through the use of 60 Hz electricity. However, unlike the OCS, rolling stock emissions are intermittent and correspond to a train's presence, and therefore are not considered to be a significant source of ELF EMF.

7.1 OCS/Pantograph & Harmonics Transient RF EMF

Rolling stock emanates RF electromagnetic fields by the interaction of rooftop pantographs with the OCS producing micro-arcing. The resulting RF EMF is transient in nature and occurs only for the duration of a train's passage. The non-linear loads of the rolling stock produce harmonic voltages and currents and harmonic electromagnetic fields in the RF range. This resultant RF emission is spread throughout the electromagnetic spectrum and should be field verified against the limits of *EN 50121-2*, so that the rolling stock does not produce excessive characteristic noise to nearby RF receivers.

7.2 Train & Components

The electromagnetic compatibility of the trains will be per the emission and immunity requirements of *EN 50121-3-1*, whereas the electrical and electronic apparatus used in the rolling stock will have emission and immunity requirements per *EN 50121-3-2*. Furthermore, the electromagnetic compatibility between the rolling stock and the train detection system will be per *EN 50238*.

Train components subject to EMC analysis include –

- Traction and brake system including traction and brake control electronics, inverters, etc.
- Auxiliary power supply including auxiliary power converter
- Heating, ventilation and A/C system.

7.3 Intentional Radiators

Intentional radiators used in the rolling stock will comply with Industry Canada emission limits and spectrum allocation requirements to prevent interference with nearby RF receivers. Frequency allocation for the intentional radiators in the rolling stock will be per the requirements of the system level frequency management plan and will be the responsibility of the rolling stock supplier and design/build contractor. Normally, third party intentional radiators operate at frequencies allocated by Industry Canada for those particular applications and these radios do not operate or overlap with railway radio operating frequencies. As such, there will be no interference.

7.4 Harmonics Control

The EMU rolling stock will not exceed certain limits of harmonic current and voltage versus frequency to limit the EMFs produced by these harmonics. The electrical coordination between the power supply and rolling stock technologies will be per *EN 50388* for harmonics control. *IEEE 519* can also be used to establish harmonic voltage and current limits.

8.0 Electrification System

The electrification system emission and immunity levels will be per *EN 50121* to attain EMC with neighbouring facilities. The following section describes specific emission control of the electrification system to prevent EMI with equipment in neighbouring facilities.

8.1 OCS & TPFs

The OCS and TPFs predominantly emanate 60 Hz electric and magnetic fields. Furthermore, there will be corona discharge (arcing) on the surface of the OCS and TPF insulators producing RF EMF.

8.1.1 ELF

The estimated maximum magnetic and electric fields emanating from the OCS and TPF will be 160 mG and 1 kV/m respectively, and the combined emission of the railway system and nearby transmission lines will be below the limits in **Table 6-1**. Human exposure to these fields will not result in potential human health effects and most electrical and electronic equipment are immune to these fields.

However, EMI sensitive facilities within Zone 3 (ie, 100m) may be affected by EMI and may therefore need to be evaluated and potentially immunized during the detailed design stage. **Section 11.0** discusses the EMI sensitive sites within Zone 3 and the steps necessary to mitigate potential interference with the electrical and electronic equipment within these sites. Immunization is attained by controlling the sources of emission and/or immunizing equipment from EMI per the emission and immunity limits of applicable EMC standards.

8.1.2 RF

The partial discharge (ie, corona) from the surface of OCS and TPF insulators will emanate RF EMF, which may interfere with the proper operation of nearby RF receivers such as radios, and radar and communication towers. *EN 50121-2*, *CSA/CAN3-C108.3.1-M84* and *EN 50121-5* RF emission limits and measurement methods will be utilized to prevent excessive electromagnetic noise originating from these power lines, substations and paralleling stations.

Please note that the limits set forth in the aforementioned standards will not be breached unless there is an abnormal condition such as damaged or polluted insulators. In this situation, repairing, replacing or cleaning the insulators will resolve any high RF emanations.

9.0 Analysis

The measured and estimated electric and magnetic fields were analyzed with regard to human exposure to EMF and potential interference with electrical and electronic equipment.

9.1 EMF

As mentioned, the highest magnetic fields at the UP Express corridor were measured directly underneath the Hydro One transmission lines at approximate Mileposts 0.7, 5.7, 11.1 and 12.2 (please see **Figures 9-1** to **9-4**), and the magnetic field measurements under the power lines were 20 mG, 24 mG, 58 mG and 59 mG, respectively. The conservatively estimated combined maximum electric and magnetic fields from the railway system and these transmission lines will be within the values of **Table 6-1**. The electric and magnetic fields along the UP Express corridor after electrification will be below industry standard human exposure limits (see **Tables 3-3** and **3-4**).

Figure 9-1 Hydro One Transmission Lines at UP Express Corridor (Milepost 0.7)

Figure 9-2 Hydro One Transmission Line Crossing the Railway (Milepost 5.7)

Figure 9-3 Hydro One Transmission Lines Crossing the Railway (Milepost 11.1)

Figure 9-4 Hydro One Transmission Line Crossing
the Railway (Milepost 12.2)

9.2 EMI

The estimated electric and magnetic fields along the UP Express corridor are not expected to interfere with electrical and electronic equipment in the vicinity of the corridor.

9.2.1 ELF

60 Hz magnetic fields are normally a concern for sensitive research, scientific and medical equipment that operate on electromagnetic waves, such as electron microscopes in laboratories and MRI scanners. This equipment is normally located in the EMI sensitive sites discussed in **Section 3.2**.

It should be noted that this sensitive equipment is already shielded and immunized from ELF EMF. For example, MRI systems in hospitals are placed in a shielded room to prevent EMF from entering and interfering with their proper operation. This is due to the fact that there are overhead lines already existing near EMI sensitive sites that emanate ELF EMF as well as the fields produced by the electrical wiring of the EMI sensitive site itself. As such, provisions for immunity against these fields have already been considered during their engineering design.

However, some of the existing immunizations may not be adequate. EMI sensitive sites have been identified in **Section 10.0** along with the necessary steps to evaluate and mitigate EMI effects if necessary.

9.2.2 RF

The radios in the electrified railway system are in compliance with Industry Canada's frequency allocation plan and emission limits. All other licensed RF devices, intentional radiators and receivers are also Industry Canada-compliant. Compliance with Industry Canada frequency allocation and emission limits ensures that there is no frequency overlap between radio applications used in Canada. It should be noted that all off the shelf licensed radios in Canada comply with Industry Canada requirements and will not use the radio operating frequencies assigned to the railway system.

Furthermore, the transitory RF emission from the OCS and pantograph interaction is below the *EN 50121* limits and will be perceived as background characteristic noise for the RF receivers in the vicinity of the railway (ie, the railway RF emission will not degrade the performance of nearby RF receivers). This RF noise is, however, a concern for the navigational aid and communication receivers at Toronto Pearson International Airport. Further analysis and field testing is needed during the detailed design stage to ensure that the railway system does not interfere with the aforementioned airport equipment. If it does, immunization undertakings need to be implemented to mitigate the EMI. **Sections 10.0** and **11.0** provide additional details on these undertakings.

10.0 Mitigation Measures

Table 10-1 summarizes the results collected during the EMI inventory investigation and provides the immunization/emission control mitigation recommendations. Specifically, the 'Comments' column provides additional details for the EMI mitigations and in some instances engineering activities recommended to be undertaken during the detailed design stage.

Table 10-1 EMI Inventory Checklist

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
1.37, 10.57, 12.27	Receptor: Third party facilities Neighbouring the UP Express TPFs	n/a	Existing & Future	Various	Zone 3	Beyond the TPF fence or wall, the EMF produced by the substation equipment is typically indistinguishable from background levels. RF emissions from TPFs should be compliant with *CAN3-C108.3.1-M84* to prevent RF noise to nearby RF receptors. Subject to compliance with the aforementioned standard, facilities neighbouring the TPFs will not be affected by TPF EMI.
0.58, 0.7, 1.59, 2.0, 2.46, 2.55, 3.45, 4.8, 5.37, 5.5, 5.65, 6.12, 6.94, 7.17, 7.2, 7.43, 7.5, 7.69, 7.8, 8.2, 8.25, 8,45, 8.6, 8.63, 8.95, 9.5, 10.42, 11.07, 11.73, 11.76, 12.13, 12.32, 12.37, 12.77,	Toronto Hydro power line crossings	n/a	Existing & Future	TH	Zone 2	The Ontario Electrical Safety Code and Canadian Standard on Overhead Systems (*CSA C22.3 No. 1*) require that if open line wires and conductors are crossing a power line, the highest voltage is to be routed at the top. Based on the above, the Toronto Hydro power lines at the locations identified in this chart will be affected by the UP Express 2x25kV OCS as described in the above referenced code and standards. As a result, the Toronto Hydro power lines should be relocated and buried below the railway tracks. A separation between the OCS and Toronto Hydro power lines would be in all instances (existing and future) more than 1m. According to *CSA C22.3 No. 1* and *No. 7*, no EMI is

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
12.8, 13.06, 13.3, 13.5, 13.6						anticipated to the Toronto Hydro power lines in their current and future configurations.
4.7	Receptor: Neighbouring non-electrified railways, West Toronto Diamond	n/a	Existing & Future	CP	Zone 2	Signalling equipment of those railway systems should be compliant with AREMA *C&S Manual Part 11.5.2* and/or *EN 50121 Part 4*. The **UP Express Signalling Compatibility Preliminary Design Report** provides more details on immunization and compatibility of CP-owned signalling and railway equipment.
All	Receptor: GO Transit, CN, CP and VIA non-electrified rolling stocks	n/a	Existing & Future	CN/CP/VIA Rail	Zones 1 & 2	The rolling stock should be verified for compliance with *EN 50121 Part 3*. For existing equipment, the equipment manufacturer should be consulted regarding the EMI threat to the rolling stock electrical and electronic equipment to ensure rolling stock electromagnetic compatibility.
King, Queen, & St Clair Overpasses	Overpasses with TTC tracks under the railway	TTC Street Car Tracks	Existing	TTC	Zone 2	The TTC tracks are grade-separated from the UP Express railway lines. In addition, the TTC tracks are not running in parallel and in close proximity to the future UP Express electrified tracks. It was observed that there is, in all instances. More than 1 metre of separation between the TTC traction power and communication lines (including fiber optics, copper, twisted pairs, triads, and coax, underground or overhead) and the OCS. According to *CSA C22.3 No. 1* and *No. 7*, no EMI is anticipated to the TTC power and

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						communication lines. Since the EMF at the UP Express railway system edge of the right-of-way is not expected to exceed 250 mG and 9 kV/m, and TTC streetcar and subway systems and rolling stock should comply to *EN-50121-3-1* and be immune to conducted interference levels as defined in *EN 50121-3-2*, no EMI related effects are expected to the TTC equipment and communication lines due to UP Express electrification.
Bathurst, Dundas & Spadina bridges	Bridges with TTC tracks above the railway	TTC Street Car Tracks	Existing	TTC	Zone 2	The TTC tracks are grade separated from the UP Express railway lines. In addition, the TTC tracks are not running in parallel and in close proximity to the future UP Express electrified tracks. It was observed that there is, in all instances, more than 1m of separation between the TTC traction power and communication lines (including fiber optics, copper, twisted pairs, triads, and coax, underground or overhead) and the OCS. According to *CSA C22.3 No. 1* and *No. 7*, no EMI is anticipated to the TTC power and communication lines. Since the EMF at the UP Express railway system edge of the right-of-way is not expected to exceed 250 mG and 9 kV/m, and TTC streetcar and subway systems and rolling stock should comply to EN-50121-3-1 and

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						be immune to conducted interference levels as defined in *EN 50121-3-2*, no EMI related effects are expected to the TTC equipment and communication lines due to UP Express electrification.
GO Bloor Station	TTC subway tracks in the TTC tunnel below the railway	TTC Subway Tracks	Existing	TTC	Zone 2	The TTC tracks are grade separated from the UP Express railway lines. In addition, the TTC tracks are not running in parallel and in close proximity to the future UP Express electrified tracks. It was observed that there is, in all instances, more than 1m of separation between the TTC traction power and communication lines (including fiber optics, copper, twisted pairs, triads, and coax, underground or overhead) and the OCS. According to CSA C22.3 No. 1 and No. 7, no EMI is anticipated to the TTC power and communication lines. Since the EMF at the UP Express railway system edge of the right-of-way is not expected to exceed 250 mG and 9 kV/m, and TTC streetcar and subway systems and rolling stock should comply to EN-50121-3-1 and be immune to conducted interference levels as defined in the Standard EN 50121-3-2, no EMI related effects are expected to the TTC equipment and communication lines due to UP Express electrification.

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
All	Receptor: UP Express signalling and communication equipment	n/a	Existing & Future	Metrolinx	Zone 1 & 2	Signalling and communication equipment should be compliant with *AREMA C&S Manual Part 11.5.2* and/or *EN 50121 Part 4*. Please refer to the signalling equipment list in the **UP Express Signalling Compatibility Preliminary Design Report** for additional details.
All	Receptor & Source: UP Express railway equipment	n/a	Future	Metrolinx	Zone 1 & 2	To attain EMC with neighbouring facilities, the railway system will be procured and tested to comply with Metrolinx Electrification Specifications. Specifically, full compliance to the *EN 50121* series of standards for the emission and immunity limits to achieve EMC with neighbouring facilities and equipment is necessary.
1.37, 10.57, 12.27, 10.35	Receptor & Source: the TPF sites and the Maintenance Facility	n/a	Future	Metrolinx	Zone 1, 2 & 3	RF emissions pertaining to the TPF and RRMF (specifically, the tri-gen) should be as per *CAN3-C108.3.1-M84 (R2009) – Canadian Standard for Limits and Measurement Methods of Electromagnetic Noise from AC Power Systems, 0.15-30 MHz* to minimize potential RF interference with neighbouring facilities. To control immunity and emission, the TPF is to comply with IEC *61000-6-5* (immunity) and *ANSI/IEEE C63.12* (immunity and emission), and the Maintenance Facility is to comply with *ANSI/IEEE C63.12* or *IEC 61000*. There is no third party EMI susceptible

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						equipment identified within 10m of the electrified tracks and there is no third party sensitive facility identified within 100m of the outermost Maintenance Facility track. Therefore, no EMI mitigation to third party property and equipment would be required.
All	Receptor: Existing snow clearing devices	Hovey Hell Fire 900 & 400, Condor T4000	Existing & Future	Metrolinx	Zone 1	AREMA compliance has been verified by Parsons Brinckerhoff. For Metrolinx records, an official written statement from the product manufacturer should be obtained confirming that these devices are immune to the electrified railway system and are *EMI/AREMA 11.5.2* compliant. Please refer to the **UP Express Signalling Compatibility Preliminary Design Report** for the list, location, and configuration of the snow clearing devices.
All	Receptor: Existing track switch machines	Alstom GM 4000 dual control, 110 V dc power operated	Existing & Future	Metrolinx	Zone 1	In general the existing switch machines are fully immune to the electrified railway environment. However, for Metrolinx records, an official written statement from the product manufacturer should be obtained confirming that these devices are immune to the electrified railway system and are *EMI/AREMA 11.5.2* compliant. Please refer to the **UP Express Signalling Compatibility Preliminary Design Report** for the list, location, and configuration of the switch machines.

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
All	Receptor: Signalling and communication bungalows	n/a	Existing & Future	Metrolinx	Zone 2	The existing Metrolinx wayside signalling and communication equipment on the UP Express railway corridor will be fully replaced once the Georgetown South signalling project is fully commissioned. The new USRC signalling and communication equipment will be fully compatible and immune to the electrified railway environment and comply with AREMA *C&S Manual Part 11.5.2* and *EN 50121 Part 4*. The rest of the new signaling equipment for the UP Express will be upgraded to be fully compatible with the electrified railway. Please refer to the **UP Express Signalling Compatibility Preliminary Design Report** for the signalling equipment compatibility design.
0.6	Receptor: Canada Lands computer room near the CN Tower	n/a	Existing	Canada Lands	Zone 2	Estimated railway ELF EMF will be within the limits of **Table 6-1**. Therefore, it is unlikely that the railway system emissions would interfere with the computer room. However, because there are sensitive computers and electronics within the facility according to *IEEE 241*, general immunization measures as discussed in this report should be applied. To provide more specific immunization assessment, access to the site to examine the existing immunization scheme of the sensitive electronic equipment would be required during the detailed design stage to

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						determine the necessity of additional immunization requirements.
0.7	Source: Hydro One Transformer Station	n/a	Existing	Hydro One	Zone 3	UP Express will be emanating up to 160 mG and 1 kV/m of maximum 60 Hz EMF into the existing electromagnetic environment. It is not anticipated that the neighbouring Hydro One transformer station equipment will be affected by the railway electrification system, since the transformer station is not considered an EMI sensitive facility per *IEEE 241*. Transformer station design always considers EMC due to the fact that these facilities are subject to high levels of EMI from power lines and electrical equipment within the facilities.
0.7, 5.7, 11.1, 12.2	Source: Hydro One transmission lines	n/a	Existing	Hydro One	Zone 1	It is not anticipated that the neighbouring Hydro One transmission lines and equipment will be affected by the railway electrification system, since these facilities are not considered EMI sensitive facilities as per *IEEE 241*. Furthermore, the railway system will not be affected by the transmission lines since the railway equipment will be immunized as per the *EN 50121* and AREMA requirements. UP Express will be emanating up to 160 mG and 1 kV/m of maximum 60 Hz EMF into the existing electromagnetic environment. Specifically, the railway signalling system is

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						particularly susceptible to transmission line magnetic field emanation and should be immunized and tested as per *AREMA 11.5.2* and protected from RF and ELF EMI.
All	Source & Receptor: Neighbouring third party and Metrolinx communication cables (receptor) with regard to the OCS and Hydro One overhead power lines (source)	n/a	Future	Metrolinx & various Third Parties	Zone 1 & 2	Clearance requirements to mitigate EMI from power lines to communication cables (including copper, twisted pars, triads and coax) should be per the Ontario Electrical Safety Code requirements. Specifically, the OCS clearance to neighbouring third party communication cables should be per *Section 75* of the Code. Overhead communication cables pertaining to the railway system should also comply with these clearance requirements.
All	Source & Receptor: Neighbouring third party and Metrolinx communication cables (receptor) with regard to the TPF underground ducts and underground power cables (source)	n/a	Future	Metrolinx & various Third Parties	Zone 1 & 2	Clearance requirements to reduce EMI from underground power cables to communication cables (copper, twisted pars and triads and coax) should be as per *CSA C22.3 No. 7: the Canadian Standard on Underground Systems*. Specifically, the TPF underground cable clearance to neighbouring third party communication cables should be as per the aforementioned standard. Underground communication cables pertaining to the railway system should also comply with these clearance requirements.
All	Source & Receptor: Hydro One Smart Meters	n/a	Existing & Future	Hydro One	Zone 1 & 2	Hydro One should verify that the neighbouring Smart Meter emissions and

Facility/ Location Approx. Milepost/ GPS (if applicable)	System/Equipment Name EMI Receptor and/or Source of EMF	Manufacture Equipment Model (If Applicable)	Existing or/and Future	Ownership	Zone of Influence (if applicable)	Comments EMC Assessment/Immunization and/or Emission Control Recommendations – to be commenced during the detailed design stage
						immunity is as per *ANSI/IEEE C63.12*, *IEC 61000* or an equivalent EMC standard in order to attain EMC with the railway system.
All	Receptor: Track circuits	n/a	Future	Metrolinx	Zone 1	Differential mode voltage control to reduce interference to track circuits: rail to rail voltage test, insulated joint, impedance bond, surge arrestor, and ballast maintenance as part of the railway maintenance scheme.
All	Receptor: UP Express railway personnel and the public	n/a	Future	Metrolinx	Zone 1	Common mode voltage control for personnel safety against electromagnetic field induced voltage electric shock hazard: rail to ground voltage test, to be incorporated as part of the railway maintenance scheme as stated in this report.
15	Receptor: Toronto Pearson International Airport navigational and communication systems	n/a	Existing	NavCan GTAA	> Zone 3	A paper study followed by field testing and verification will be performed to ensure EMC between the railway system and the airport navigational aid and communication equipment.
15	Receptor: Toronto Pearson International Airport security scanners	n/a	Existing	GTAA	> Zone 3	It is not expected that the airport security scanners will be affected by the ELF and RF EMF since they are more than 100m away from the railway outermost track (ie, outside the zones of influence).
15	Receptor: Toronto Pearson International Airport cable people movers (CPM)	n/a	Existing	GTAA	Zones 1, 2 & 3	A paper study followed by field testing and verification is recommended to ensure the neighbouring CPM operates satisfactorily within the railway system electromagnetic environment.

11.0 Next Steps & Future Considerations

The EMC engineering activities will continue throughout the detailed design, construction, commissioning, and revenue phases. Important future EMC tasks are described in this section.

11.1 Detailed Design

11.1.1 Immunity & Emissions Compliance

This report provides an overview of the preliminary EMI and EMF assessment for the UP Express corridor including the airport spur. **Section 10.0** provides a commentary on the proposed future work and studies that will need to be carried out during the detailed design phase to confirm potential EMI effects and to determine mitigation measures to be implemented, where necessary.

The Pearson International Airport has been identified as an EMI-sensitive area. During the UP Express electrification implementation, detailed EMI/EMF analyses should be performed taking in to account the communicating, navigation, surveillance (CNS) system performance specifications per the current International Civil Aviation Organization (ICAO) Annex 10 (Aeronautical Telecommunication - International Standards & Recommended Practices).

EMI impacts on NavCan communications, generated by the electrified UP Express communication, navigation, and surveillance (CNS) facilities will be addressed in the EMI/EMF assessment and the EMC Analysis Report which will be developed as part of the detailed design phase.

11.1.2 Frequency Management Plan

The frequency management plan will be implemented by Metrolinx during the detailed design phase. This plan is needed to capture the operating frequencies at the system engineering level from all intentional radiators in the vicinity of the railway. The frequency management plan will cover both railway emissions and background emissions. The plan will identify and avoid any frequency overlap between radio applications, any misallocations with respect to the national radio frequency allocation plan (Industry Canada), and the major EMI risks related to an excessive characteristic noise in the reception band of the communication system. Mitigations will be performed by Metrolinx as needed and as per the frequency management plan recommendations.

11.2 Construction

Compliance requirements with *EN 50121*, *IEEE C63.12*, *AREMA Signalling and Control Manual 11.5.2*, *IEC 61000* and other relevant EMC standards will be specified to product manufacturers. The manufacturers are to provide compliance test results and supporting documentation to Metrolinx during the project construction phase.

11.3 Commissioning

During the UP Express electrification commissioning phase, it should be field tested and verified that the overall ELF and RF emissions emanating from the UP Express electrified railway system as a whole (including emissions from all the electrified tracks, OCS, TPFs, RRMF, and EMU trains) are within the limits of applicable industry standards. Specifically, RF limits per *EN 50121*, *CAN3-C108.3.1-M84*, Health Canada's *Safety Code 6* and other relevant EMC standards such as *IEEE C63.12* and *IEC 61000*, and ELF EMF limits tested as per *EN 50500*, *IEEE 644* and compared against **Tables 3-3**, **3-4** and **6-1**.

11.4 Revenue Phase

The following tests and maintenance procedures are recommended to mitigate EMI to track circuits and increase personnel safety due to EMI induced common mode voltage –

1. Common mode voltage control for personnel safety as follows –
   - Maximum rail to ground voltages should be measured periodically. Excessive values per each section of the track (between insulated joints) should be investigated and mitigated as needed.
2. Differential mode voltage control to reduce interference to track circuits as follows –
   - Rail to rail voltages should be measured periodically. Values are not to exceed track circuit manufacturer recommended maximum voltage level per each section of the track (between insulated joints). Deviations should be investigated and corrective measures undertaken as needed.
   - Insulated joints to be tested as per product manufacturer recommendations. Defective insulated joints to be replaced or repaired.
   - Surge (lightning) arresters to be tested as per product manufacturer recommendations. Defective arresters to be replaced or repaired.
   - Proper ballast maintenance to be performed per the supplier's recommendation.

APPENDIX A – ABBREVIATIONS & ACRONYMS

ac	Alternating Current	**ICAO**	International Standards & Recommended Practices
ACGIH	American Conference of Governmental Industrial Hygienists	**IEC**	International Electrotechnical Commission
ANSI	American National Standards Institute	**IEEE**	Institute of Electrical and Electronics Engineers
AREMA	American Railway Engineering and Maintenance-of-Way Association	**k**	kilo
ARL	Air Rail Link	**kV**	kilo-Volt
CNS	Communication, Navigation, Surveillance	**M**	mega
CEC	Canadian Electrical Code	**mG**	Mili-Gauss
CPM	Cable People Mover	**MP**	milepost
dB	Decibels	**MTO**	Ministry of Transportation Ontario
dc	Direct Current	**Mx**	Metrolinx
EA	Environmental Assessment	**NF**	Negative Feeder
ELF	Extremely Low Frequency	**OCS**	Overhead contact system
EMC	Electromagnetic compatibility	**PD**	Preliminary design
EMF	Electromagnetic field	**PS**	Paralleling Stations
EMI	Electromagnetic interference	**RF**	Radio Frequency
EMU	Electric Multiple Unit	**ROW**	Right-of-way
EN	European Standard	**TPF**	Traction Power Facilities
EPRI	Electric Power Research Institute	**TPS**	Traction Power Substations
FCC	Federal Communication Commission	**TPSS**	Traction Power Supply System
FM	Frequency Modulated	**US**	Union Station
G	Gauss	**USRC**	Union Station Rail Corridor
GTAA	Greater Toronto Airport Authority	**UP**	Union Pearson
HV	High Voltage	**V**	Volts
Hz	Hertz	**V/m**	Volts per Meter

APPENDIX B – DEFINITIONS

Arcing
Discharge of current through air.

AREMA
The acronym for American Railway Engineering and Maintenance-of-Way Association. AREMA is the organization that represents the engineering function of the North American railroads.

Cable People Mover
A fully automated, grade-separated mass transit system. It is composed of a train being pulled by cables attached to motors.

Catenary
An assembly of overhead wires consisting of, as a minimum, a messenger wire, carrying vertical hangers that support a solid contact wire which is the contact interface with operating electric train pantographs, and which supplies power from a central power source to an electrically-powered vehicle, such as a train.

Corona
Discharge of current through air, creating a plasma of ionized air.

Duct Bank
A duct bank is an assembly of electrical conduits that are either directly buried or encased in concrete. The purpose of the duct bank and associated conduit is to protect and provide defined routing of electrical cables and wiring. It also provides a physical separation and isolation for the various types of cables.

Traction Power Facility
A traction substation, paralleling station, or switching station.

ELF – Extremely Low Frequency
For the purpose of this report, ELF covers the frequency range from dc to 400 Hz, which is predominately the power line frequency (60 Hz) and the associated harmonics (normally 10% of the fundamental frequency).

EMC
Electromagnetic compatibility is the ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

EMI
Electromagnetic interference is a disturbance that affects an electrical circuit due to either electromagnetic induction or radiation from an external source.

EMU (Electric Multiple Unit)
Multiple unit train consisting of self-propelled carriages, using electricity as the motive power.

Environment
Surrounding objects or region which may influence the behaviour of the system and/or may be influenced by the system.

Equipment
Equipment is a finished appliance or combination of appliances commercially available as a single functional unit, either liable to generate EMI or liable to be affected by EMI.

Isokeraunic Activity

Indicating or having equal frequency or intensity of thunderstorm activity

Fault
A short circuit is the current flow without any resistance.

Fundamental Frequency
Power line frequency (specifically, 60 Hz in North America and 50 Hz in Europe) including the third and fifth order harmonic frequencies.

Ground
A conducting connection, whether intentional or accidental, by which an electric circuit or electrical equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth. Note: It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting ground currents to and from earth (or the conducting body).

Grounding
Connecting to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to limit the build-up of voltages to levels below that which may result in undue hazard to persons or to connected equipment.

Harmonics
A frequency component of a periodic wave that is an integer multiple of the fundamental frequency.

High Voltage
For the purpose of this document, voltages above 600 Volts will be considered high voltage.

Hydro
The electric power company (often a public utility) that engages in the generation, transmission, and distribution of electricity. For example, Toronto Hydro and Hydro One.

Hydro One
Hydro One Incorporated delivers electricity across the province of Ontario. Hydro One has four subsidiaries, the largest being Hydro One Networks. They operate 97% of the high voltage transmission

grid throughout Ontario.

Immunity
The ability of equipment to perform as intended without degradation in the presence of an electromagnetic disturbance.

kV
Abbreviation for kilovolt and equal to 1000 volts.

Low Voltage
For the purpose of this document, voltages 600 Volts and below will be considered low voltage.

Magnetometer
A magnetometer is a measuring instrument used to measure the strength and, in some cases, the direction of magnetic fields.

Maintenance Facility
A mechanical facility for the maintenance, repair, and inspection of engines and railcars.

Mitigation Measure
Actions that remove or alleviate, to some degree, the negative effects associated with the implementation of an alternative.

Negative Feeder
A feeder running parallel to the tracks and catenary, energized at 25 kV but 180 degrees out of phase with the catenary. The resultant catenary to negative feeder voltage is 50 kV.

Neighbouring
Within 100m of the UP Express outermost track.

Noise
Unwanted electrical signals that produce undesirable effects in the circuits of the control systems in which they occur.

Pantograph
Device on the top of a train that slides along the contact wire to transmit electric power from the catenary to the train.

Paralleling Station (PS)
An installation which helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration. The negative feeders and the catenary conductors are connected to the two outer terminals of the autotransformer winding at this location with the center terminal connected to the traction return system. The OCS sections can be connected in parallel at PS locations.

Performance Standards
General specifications and criteria that define the parameters and requirements of a particular system.

Potential Effect
A possible or probable effect of implementing a particular alternative.

Preliminary Design
The design of a proposed project (including a cost estimate) to a level that demonstrates that the project is buildable within the given parameters of the design scope.

Radio-Frequency
Approximately the frequency range 3 kHz to 300 GHz.

Shield
As normally applied to instrumentation cables, refers to a conductive sheath (usually metallic) applied, over the insulation of a conductor or conductors, for the purpose of providing means to reduce coupling between the conductors so shielded and other conductors that may be susceptible to, or which may be generating, unwanted electrostatic or electromagnetic fields (noise).

Shielding
Shielding is the use of a conducting and/or ferromagnetic barrier between a potentially disturbing noise source and sensitive circuitry. Shields are used to protect cables (data and power) and electronic circuits. They may be in the form of metal barriers, enclosures, or wrappings around source circuits and receiving circuits.

Additionally shielding is used to protect overhead transmission lines or OCS from incidents of lightning, in regions of high Isokeraunic activity. Shield wire is located above the exposed current carrying wires to provide a 45 degree angle of protection. In sensitive applications, the angle is reduced to 30 degrees for more conservative design.

Signal System
The rail signal system is a combination of wayside and on board equipment and/or software to provide for the routing and safe spacing of trains or rail vehicles.

Spur
Is a railroad track that diverges from the main track to service a specific location or industry.

Substation or Traction Substation
Electric Traction Facility that transforms the utility supply voltage of 230 kV to 50 kV and 25 kV for distribution to the trains via catenary and negative feeders.

Transmission Line
Transmission lines electrically interconnect generating power plants and electrical substations located near demand centers for bulk transfer of electrical energy over long distances, at a high voltage generally 115 kV or higher. Transmission of power at high voltage is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. Transmission lines, when interconnected with each other, are called transmission network or electric grid.

Zone of Influence
Within 100m of the outermost track, where electromagnetic interference from the railway system is significant.

APPENDIX C – REFERENCE DOCUMENTS

Source Documents

The documents in the following table represent the key inputs to the overall design process. These documents are not industry standards but are documents developed either during past studies, by Metrolinx/GO Transit for existing operations, or by Parsons Brinckerhoff during earlier stages of the design. The documents are not listed in a specific order and all are considered relevant and are discussed in the report.

Ref #	Document Title	Owner
1	An Overview of Common Sources of Environmental Levels of Radio Frequency Fields	EPRI
2	ANSI/IEEE C63.12: The American National Standard for Electromagnetic Compatibility Limits.	IEEE
3	APTA SS-E-010-98, Standard for the Development of an Electromagnetic Compatibility Plan	APTA
4	AREMA Signalling and Communications (S&C) Manual	AREMA
	EN 50121 series – Railway system EMC series	EN
5	EN 50121-1:2000 – Railway applications – Electromagnetic Compatibility – Part 1: General	EN
6	EN 50121-2:2000 – Railway applications – Electromagnetic Compatibility – Part 2: Emission of the whole railway system to the outside world	EN
7	EN 50122-1: Railway applications – Fixed installations – Electrical safety, earthling, and the return circuit – part 1: Protective provisions against electric shock.	EN
8	EN 50238 – Compatibility between rolling stock and train detection systems	EN
9	CSA C22.3 No. 8M91, Railway electrification	CSA
10	CAN3-C108.3.1-M84 (R2009) – Canadian Standard for Limits and Measurement Methods of Electromagnetic Noise from AC Power Systems, 0.15-30 MHz	CSA
11	CSA C22.3 No. 1-10 – Canadian Standard for Overhead Systems	CSA
12	CSA C22.3 No. 7-10 – Canadian Standard for Underground Systems	CSA
13	EMI/RFI Generation from Light Rail Transit Systems Report for the Los Angeles Metro Crenshaw/Lax Transit Corridor, April 2013	Los Angeles Metro
14	Directive 2004/40/EC of the European Commission for health and safety requirements regarding the exposure of workers to EMF	EC
15	Recommendation 1999/519/EC of the European Commission on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)	EC
16	IEC 61000 series – Electromagnetic compatibility	IEC
17	IEC 61000-5 - Electromagnetic Compatibility (EMC)-Installation and Mitigation Guidelines.	IEC
18	IEC 61000-6-1: Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments	IEC
19	IEC 61000-6-2: Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments	IEC
20	IEC 61000-6-3: Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments	IEC
21	IEC 61000-6-4: Electromagnetic compatibility (EMC) – Part 6-4: Generic standards - Emission standard for industrial environments	IEC

Ref #	Document Title	Owner
22	IEC 61000-6-5: Electromagnetic compatibility, immunity for power station and substation environment	IEC
23	IEC 61000-6-6: Electromagnetic compatibility (EMC) - Part 6-6: Generic standards - HEMP immunity for indoor equipment	IEC
24	IEC 60479 - Effects of Current on Human Beings and Livestock – Part 1 General Aspects	IEC
25	IEC 60255-26 - Electrical relays – Part 26: Electromagnetic compatibility requirements for measuring relays and protection equipment	IEC
26	IEEE 241-1990 – Recommended Practice for Electric Power Distribution for Commercial Buildings	IEEE
27	IEEE 644-1994 – Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines	IEEE
28	IEEE 1308-2001 – Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters – 10 Hz to 3 kHz	IEEE
29	IEEE C95.1: Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3kHz to 300 GHz	IEEE
30	IEEE C95.6 – Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 – 3 kHz	IEEE
31	FCC OET-65 - Evaluating Compliance with FCC Guidelines for Human Exposure	FCC
32	FCC OET-65c - Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, FCC Office of Engineering and Technology Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01)	FCC
33	Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz - Safety Code 6 (2009)	Health Canada
34	Magnetic Field Shielding Design Guide	EPRI
35	The Ontario Electrical Safety Code 25th Edition	Electrical Safety Authority
36	Power System and Railroad Electromagnetic Compatibility Handbook, 2006	EPRI
37	RQQ-2011-PP-032: Environmental Assessment for the Electrification of Airport Rail Link	Metrolinx
38	EMI Inventory Procedure – Airport Spur	Parsons Brinckerhoff
39	EMF Survey Procedure – Airport Spur	Parsons Brinckerhoff
40	EMI Inventory Procedure - UP Express and USRC	Parsons Brinckerhoff
41	EMF Survey Procedure - UP Express	Parsons Brinckerhoff
42	UP Express & USRC EMC Control Plan	Parsons Brinckerhoff
43	UP Express EMF Control Plan	Parsons Brinckerhoff
44	EPS-03000 Electrification Performance Specification Grounding and Bonding	Parsons Brinckerhoff
45	EPS-04000 Electrification Performance Specification Electromagnetic Compatibility	Parsons Brinckerhoff

APPENDIX D – MAGNETOMETER CALIBRATION CERTIFICATE & DATA SHEET

Certificate of Calibration

The calibration of this instrument was controlled by documented procedures as outlined on the attached calibration report(s) using equipment traceable to N.I.S.T.

PARSONS BRINCKERHOFF, INC.

Calibration Report: X20629 Instrument Model: ELF 60D

Report/Sales Order Number: X20629 Serial Number: K72370110607

Customer Asset Number: Date Calibrated: June 28, 2012

Number of Calibration Reports Attached: 1 Re-calibration Due: June 28, 2014

LE USA
WALKER SCIENTIFIC, INC.
4280 Giddings Road • Auburn Hills, MI 48326 U.S.A.
Telephone: (248) 340-7040 • FAX: (248) 340-7045

Signature 6-28-2013
Date

LE USA
WALKER SCIENTIFIC
4280 GIDDINGS ROAD AUBURN HILLS, MI 48326
PHONE 248-340-7040 FAX 248-340-7045

ELF Field Monitor
Calibration Data

PARSONS BRINCKERHOFF, INC.
Customer

Report Number **X20639**
Model **ELF 60D**
Serial Number **K72370110607**
Calibration Date **6/28/2013**
Temperature **22C**
Humidity **46%**
Technician **Jacob Hohner**

Range	Standard	Value Before Calibration	Value After Calibration	% Deviation	In Tolerance (Y/N)
Low	170 mG	**172**	**170**	**<1%**	**Y**
High	8.00 G	**8.03**	**8.00**	**<1%**	**Y**

In Cal ≤1%

Instrument Calibration Standards Used - NIST Traceability			
Instrument Mfr.	Model	S/N	CAL Due Date
Agilent	34401A	MY41007301	08/20/13
Eico	HF-20	41711	N/A
Test Fixture	N/A	TF0001	N/A

ELF calibrated per " LS-WS Gaussmeter procedure # 6" REV 1.2007.6ELF

FIELD MONITOR COMPARISON CHART

MODEL #	ELF-40D	ELF-45D	ELF-50	ELF-50D	ELF-55D	ELF-60D	ELF-66D	VLF-80D	ELF-90D
Certified & Traceable to NIST	NO	NO	YES	YES	YES	YES	YES	YES	NO
Range (in Gauss)	1mG to 1999mG	0.1mG to 199.9mG	1mG to 51.2G	1mG to 19.99G	1mG to 19.99G	0.1mG to 19.99G	0.1mG to 19.99G	0.01mG to 199.9mG	0.1mG to 1999mG
Bandwidth	30Hz to 300Hz	30Hz to 300Hz	50Hz or 60Hz	50Hz or 60Hz	50Hz or 60Hz	40Hz to 400Hz	40Hz to 400Hz	12Hz to 50kHz	40Hz to 400Hz
Number of Axes	Single Axis	Single Axis	Single Axis	Single Axis	Single Axis	Single Axis	Single Axis	Single Axis	Triaxial w/Single Axis Option
Analog Output	NO	NO	NO	NO	NO	YES 200mVFS	YES 200mVFS	YES See (4)	NO
Internal Sensor (I) External Sensor (E)	I	I	I	I	I	I	E	E	I
Digital Display (D) Bargraph Display (B)	D 3/8"	D 3/8"	B N/A	D 1/2"	D 1/2"	D 7/10"	D 7/10"	D 1/2"	D 3/8"
Audible Tone w/Earplug	NO	NO	NO	NO	YES	YES	NO	NO	NO
Low Battery Indicator	NO	NO	YES	YES	YES	YES	YES	YES	YES
Optional AC Adaptor	NO	NO	NO	NO	NO	YES	YES	NO	NO
"Out of Range Indicator"	NO	NO	NO	NO	NO	NO	YES	YES	YES
Accuracy (See Notes)	(1) ±1%	(1) ±1%	±1%	(2) ±1%	(2) ±1%	(3) ±1%	(3) ±1%	(2) ±1%	(5) ±1%
Power Source	9V Battery	9V Battery	9V Battery	9V Battery	9V Battery	9V Battery	9V Battery	9V Battery	9V Battery
Battery Life	100 hours	100 hours	20 hours	50 hours	45 hours	40 hours	45 hours	100 hours	30 hours
Weight	4.9 oz.	4.9 oz.	8.0 oz.	8.0 oz.	8.0 oz.	15.0 oz.	15.0 oz.	15.0 oz.	7.0 oz.
Case Dimension	4.7"L 2.4"W 1.0"D	4.7"L 2.4"W 1.0"D	5.75"L 3.5"W 1.5"D	5.75"L 3.5"W 1.5"D	5.75"L 3.5"W 1.5"D	7.0"L 4.0"W 2.0"D	7.0"L 4.0"W 2.0"D	5.9"L 3.15"W 1.18"D	5.9"L 3.2"W 1.2"D
Warranty	90 Days	90 Days	180 Days	180 Days	180 Days	180 Days	180 Days	1 Year	90 Days

NOTES: (1) ±1%, ±1 Digit, Typical at 50Hz or 60Hz, ±30% Within Badwidth (30Hz to 300Hz) (2) ±1%, ±1 Digit, at 50Hz or 60Hz
(3) ±1%, ±1 Digit, at 50Hz or 60Hz, ±5% Within Bandwidth 40Hz to 400Hz)
(4) Two Analog Outputs (A) 60Hz RMS Value 200mVFS; (B) Wieband (12Hz to 50kHz) 3 Volts Peak to Peak
(5) Accuracy, Each Axis, 1% ±1 Digit Typical at 50Hz or 60Hz (over100 counts); ±2 Digits Typical at 50Hz or 60Hz (less than 100 counts).

APPENDIX E – MEASURED UP EXPRESS ELECTROMAGNETIC FIELD VALUES

The following table outlines measured magnetic field values measured along the UP Express corridor that includes the airport spur line. The EMF measurements have been taken in accordance with the EMF Survey Procedures for UP Express, including the airport spur.

Section 1 – Union Station to Strachan Avenue (South Side)

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
MP 0	0.2, 0.2, 0.1	0.3	East end of Union Station train shed
MP 0	0.1, 0.3, 0.2	0.4	Middle of Union Station train shed
MP 0	0.5, 0.4, 0.2	0.7	West end of Union Station train shed
N 43 38 36.8 W 79 23 2.2	0.6, 0.5, 0.5	0.9	
N 43 38 36.6 W 79 23 3.6	0.1, 0.3, 0.2	0.4	
N 43 38 36.3 W 79 23 5	0.6, 0.5, 0.5	0.9	Near switch machine
MP 0.25	0.3, 0.4, 0.3	0.6	
N 43 38 36.2 W 79 23 8.2	0.4, 0.1, 0.2	0.5	Near wayside high voltage enclosure
N 43 38 34.9 W 79 23 12	0.4, 0.3, 0.3	0.6	
MP 0.4	0.5, 0.5, 0.5	0.9	
N 43 38 35.5 W 79 23 19.1	0.4, 0.4, 0.4	0.7	
MP 0.5	0.4, 0.4, 0.4	0.7	
N 43 38 31 W 79 23 33.3	0.9, 0.7, 0.5	1.2	
N 43 38 29.3 W 79 23 38.7	0.4, 0.4, 0.4	0.7	
MP 0.75	0.4, 0.4, 0.5	0.8	
N 43 38 29.5 W 79 23 45.6	0.4, 0.3, 0.4	0.6	
N 43 38 28.1 W 79 23 48.8	0.4, 0.4, 0.4	0.7	
N 43 38 26.6 W 79 23 54.6	0.4, 0.4, 0.4	0.7	
N 43 38 25.8 W 79 24 1.6	0.4, 0.4, 0.4	0.7	
N 43 38 25.4 W 79 24 5.6	0.3, 0.4, 0.3	0.6	
N 43 38 25.1	0.3, 0.4, 0.4	0.6	

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
W 79 24 8.9			
N 43 38 24.5 W 79 24 15.9	0.4, 0.4, 0.4	0.7	Underneath temporary overhead distribution line
N 43 38 24.4 W 79 24 28.4	0.4, 0.4, 0.4	0.7	Near Strachan Ave

Section 1 – Union Station towards Strachan Ave (North Side)

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
N 43 38 40.6 W 79 22 39.3	0.4, 0.4, 0.3	0.6	
N 43 38 41.4 W 79 22 34.6	0.3, 0.4, 0.1	0.5	
MP0.25	0.2, 0.3, 0.1	0.4	
MP 0.3	0.3, 0.1, 0.7	0.8	
N 43 38 48.6 W 79 22 23.6	0.3, 0.3, 0.3	0.5	
N 43 38 44.7 W 79 22 20.3	0.3, 0.3, 0.3	0.5	
MP 0.5	0.3, 1.3, 0.5	1.4	Y component is higher than the other components. This suggests that there are likely induced currents in the track, creating additional magnetic fields around the tracks, detected at the Y direction by the magnetometer.
N 43 38 46.1 W 79 22 14.3	0.2, 2.6, 0.9	2.8	Y and Z components are high, suggesting induced current in track.
N 43 38 46.5 79 22 13.4	0.2, 2.6, 0.3	2.6	Y component is high at Jarvis Street, suggesting induced current in track. At rail level on all tracks, the magnetic field was measured ranging from 11.1 mG to 18 mG.
N 43, 38, 48.2 W 79, 22, 6.4	0.3, 6.6, 0.8	6.7	Y and Z components are high, suggesting induced current in track.
MP 0.7	0.6, 7.1, 3.8	8.1	At hydro substation north outermost track. Y and Z components are high, suggesting induced current in track.
MP 0.7	0.5, 6.8, 3.2	7.5	Near substation wall. Y and Z components are high, suggesting induced current in track.
MP 0.7	13.8, 0.1, 13.3	19.2	Directly underneath power transmission line feeding substation

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
MP 0.75	0.1, 1.1, 4	1.8	At closest track to the transmission line. There were neighbouring transmission lines parallel to the tracks.
N 43 38 50.5 W 79 21 53.7	0.3, 1.1, 3.7	3.9	Transmission lines on left side going towards Strachan Ave. At track levels, Y and Z components increased to 7.8 and 4.4 mG respectively, suggesting induced current in track. The induced current in track is likely resulted in from the transmission line magnetic fields.
N 43 38 51.1 W 79 21 48.4	1, 6.7, 3.5	7.6	Y and Z components are high, suggesting induced current in track.
MP 1	0.3, 4.3, 2.7	5.1	Induced current in tracks exists due to high Y and Z components of the magnetic field.

Section 2 – Strachan Ave to HWY 427

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
MP 1.6	0.3, 0.3, 0.3	0.5	
MP 1.9	0.3, 0.3, 0.3	0.5	
MP 2.9	0.3, 0.3, 0.3	0.5	
MP 3.9	0.3, 0.3, 0.3	0.4	Nearby overhead distribution line (north side)
MP 3.96	0.3, 0.3, 0.3	0.5	At Bloor station, nearby overhead distribution line
N 43 39 44.4 W 79 27 18.1	0.2, 0.3, 0.7	0.8	Near small substation
N 43 39 45 W 79 27 18.7	0.3, 0.3, 0.4	0.6	Near 3 phase overhead distribution line
N 43 39 47.2 W 79 27 22.6	4.5, 1, 0.7	4.7	Near 3 phase overhead distribution line
N 43 40 34.2 W 79 28 7.9	10.3, 12.5, 17.2	24	Underneath overhead transmission line crossing the tracks.
MP 6.1	1.3, 1.1, 1.4	2.2	Underneath overhead distribution line crossing tracks
MP 6.7	0.1, 0.3, 0.2	0.4	
N 43 41 33 W 79 29 52	0.2, 0.1, 1.6	1.6	Underneath overhead distribution line crossing tracks
N 43 41 39.5 W 79 30 4.8	0.2, 0.2, 0.2	0.3	Underneath overhead distribution line at Jane St. bridge crossing railway

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
N 43 41 56.4 W 79 30 38.7	0.3, 0.3, 0.3	0.5	Near Weston Station, under overhead distribution line crossing railway
N 43 42 24.7 W 79 32 0.7	1, 0.8, 0.3	1.3	Underneath overhead distribution line crossing railway
N 43 42 23.2 W 79 33 5.5	0.2, 0.3, 0.3	0.5	Underneath overhead distribution line crossing railway
N 43 42 22.8 W 79 33 53.8	41, 21.3, 35.4	58.2	Maximum value measured underneath three overhead transmission lines
N 43 42 21.7 W 79 34 38.5	4.1, 0.1, 1.4	4.3	Underneath overhead distribution line crossing railway
N 43 42 21.2 W 79 35 10.6	58, 7, 9.1	59.1	Maximum value measured underneath a three level overhead transmission line
N 43 42 20.8 W 79 35 25.9	0.3, 0.2, 0.2	0.4	Near parallel overhead distribution lines, near HWY 427
N 43 42 19.1 W 79 36 54.4	3, 0.3, 0.4	3.0	Near overhead distribution lines parallel and perpendicular to the railway

Section 3 – HWY 427 to Terminal 1 (Airport Spur)

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
N 43 42 15.6 W 79 36 52.4	0.1, 1, 0.2	1.0	Near parallel overhead distribution line
N 43 42 12 W 79 36 50.8	0.1, 0.5, 0.1	0.5	
N 43 42 8.1 W 79 36 46.6	0.2, 0.1, 0.1	0.2	
N 43 42 9.6 W 79 36 47.9	0.1, 0.2, 0.1	0.2	
N 43 42 2.3 W 79 36 39.9	0.2, 0.1, 0.1	0.2	
N 43 41 56.2 W 79 36 37.1	0.1, 0.1, 0.1	0.2	
N 43 41 53.5 W 79 36 36.1	0.1, 0.1, 0.1	0.2	
N 43 41 40.4 W 79 36 43	0.2, 1.1, 1.5	1.9	Near parallel overhead distribution line
N 43 41 39.9 W 79 36 43.4	0.1, 2.4, 0.8	2.5	Near parallel overhead distribution line
N 43 41 38.2 W 79 36 44.2	0.2, 1.3, 1.9	2.3	Near parallel overhead distribution line

GPS Location/Milepost	Flux Density (X, Y, Z) Components respectively (mG)	Resultant Flux Density Magnitude (mG)	Comments
N 43 41 33.9 W 79 36 45.6	0.2, 0.2, 0.9	0.9	Near overhead lines feeding underground raceway
N 43 41 30.4 W 79 36 46.5	0.2, 0.1, 0.4	0.5	
N 43 41 28.6 W 79 36 47	0.2, 0.1, 1.1	1.1	
N 43 41 24.3 W 79 36 47.8	0.7, 0.2, 0.3	0.8	Near underground raceway feeding overhead distribution line
N 43 41 15.3 W 79 36 48.5	0.2, 0.2, 0.1	0.3	
N 43 41 15.3 W 79 36 51.2	0.2, 0.3, 0.2	0.4	
N 43 41 9.1 W 79 36 56.4	0.3, 0.3, 0.2	0.5	
N 43 41 4.6 W 79 36 56.1	0.3, 0.2, 0.2	0.4	
N 43, 41, 1.6 W 79 36 52.3	0.3, 0.3, 0.3	0.5	
N 43 41 0.4 W 79 36 50.6	0.3, 0.3, 0.3	0.5	West platform of T1
N 43 40 59.7 W 79 36 49.8	0.3, 0.3, 0.3	0.5	West platform of T1
N 43 40 58 W 79 36 47.6	0.3, 0.3, 0.3	0.5	West platform of T1
N 43 40 58.3 W 79 36 47.6	0.3, 0.3, 0.3	0.5	Inside T1
N 43 40 56.6 W 79 36 44.6	0.2, 0.3, 0.3	0.5	TPA Terminal
N 43 40 59.1 W 79 36 47.8	0.2, 0.2, 0.2	0.3	East platform of T1
N 43 41 0.3 W 79 36 48.7	0.2, 0.2, 0.3	0.4	East platform of T1
N 43 41 0.3 W 79 36 49.6	0.2, 0.2, 0.2	0.3	East platform of T1