U.S. Department
of Transportation

Federal Transit Administration

Guidance on the Prevention and Mitigation of Environmental, Health and Safety Impacts of Electromagnetic Fields and Radiation for Electric Transit Systems

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For the
U.S. Department of Transportation
Federal Transit Administration
Office of Planning and Environment

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- (Green) Text providing background information
- (Yellow) Text describing activities or considerations where caution may be needed
- (Red) Text describing activities or considerations where restrictions may be needed

ACRONYMS

AC	Alternating Current
ANSI	American National Standards Institute
APTA	American Public Transit Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
CDRH	Center for Devices and Radiation Health
CENELEC	European Committee for Electrotechnical Standardization
DC	Direct Current
DOT	Department of Transportation
EF	Electric Field
EHC	Environmental Health Criteria
ELF	Extremely Low Frequency
EMC	Electromagnetic Compatibility
EMCCP	Electromagnetic Compatibility Control Plan
EMF	Electromagnetic Fields
EMF RAPID Program	Electromagnetic Field Research and Public Information Dissemination Program
EMI	Electromagnetic Interference
EMR	Electromagnetic Radiation
EPRI	Electric Power Research Institute
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GPS	Global Positioning Systems
HVAC	Heat Ventilation and Air Conditioning
ICNIRP	International Committee for Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronic Engineers
ITS	Intelligent Transportation Systems
LRV	Light Rail Vehicles
MF	Magnetic Field
MPE	Maximum Permissible Exposure
NEPA	National Environmental Policy Act
NIEHS	National Institute of Environmental Health Sciences
OCS	Overhead Catenary System
RF	Radio-Frequency
ROW	Right-of-Way
SAR	Specific Absorption Rate
SHE	Safety, Health, and Environmental
TCRP	Transit Cooperative Research Program
TPS	Traction Power System
TPSS	Traction Power Substation
TRB	Transportation Research Board
T&D	Transmission and Distribution
WAMATA	Washington Metropolitan Area Transit Authority
WHO	World Health Organization

Chapter I. BACKGROUND AND INTRODUCTION

I.A. Rationale for Guidance

Public concerns regarding the potential for adverse safety, health, and environmental (SHE) impacts of electromagnetic fields and radiation persist, often causing delays and extra cost for the National Environmental Policy Act (NEPA) process and project delivery.

This guidance focuses on approaches to preventing and reducing community environmental, health, and safety impacts from transit-generated electromagnetic fields (EMF) and electromagnetic radiation (EMR). The FTA recognizes that transit agencies, system planners, and designers need guidance on how to assess, prevent, and mitigate EMF and EMR impacts from new electric transit infrastructure.

Planners and designers must have flexibility in choice of technology and placement of traction power system (TPS) elements for efficient performance and safe operability, such as the traction power substations (TPSS) and the overhead contact- or catenary- system (OCS). Transit agencies need the tools to determine where electric transit systems and facilities can be safely located to avoid EMF and EMR hazards to the human and natural environment, what SHE impacts result from exposures to EMF and EMR, how to evaluate these impacts, and avoid, minimize, and mitigate exposures.

It is both consistent with environmental streamlining policies, and also cost-effective to address the EMF community impacts early in the transit project planning, since after-the-fact mitigation is usually more costly. Residents and workers in businesses near the transit system Right-of-Way (ROW) must be informed and involved in the siting and design decisions for new transit electric power and propulsion infrastructure.

This document provides electric transit planners with technical assistance and the resources necessary for assessing the SHE impacts from EMF and EMR due to electric transit power infrastructure and propulsion equipment and operations. Although exposure safety issues for electric transit workers and travelers are not specifically addressed in this Guidance, compliance with the human exposure safety consensus standards and guidelines referenced in Section IV will ensure the safety and health of all, including sensitive targets (wearers of electronic implants, hearing aids, and wheelchair users.)

I.B. What are electric transit system sources of EMF?

Results of the EMF Research and Public Information Dissemination Program (EMF-RAPID) include Department of Transportation (DOT) EMF data on typical electric transit and rail systems, some of which are reproduced in Figures 2 through 4. EMF levels are compared with transmission and distribution (T&D) power lines, and with school, commute, home and office sources.

Modern electric and non-electric transit systems all have power and propulsion subsystems (generators, electric motors, alternators, starter, inverter, braking, Heat Ventilation and Air Conditioning-HVAC), as well as electrically powered transmitters for communication, control, and navigation electronics. EMR exposures result from transportation technologies such as signaling, control and communications, Intelligent Transportation Systems (ITS), and Global Positioning Systems (GPS).

Electric transit systems include many sources of EMF and EMR with broad-band frequencies, and variable strength in space and time, as part of the wayside power and propulsion equipment, control and communications subsytem, and maintenance infrastructure, and in vehicles. EMF exposures to communities along the ROW are associated with power transmission and conditioning sources, including transformer substations, OCS, or a third rail.

The TPS consists of several subsystems for wayside power distribution and, conditioning (step-down transformers, AC to DC rectifiers and DC to AC inverters and choppers). The wayside distribution system is via an overhead catenary system and pantograph on top railcars, or using a third rail at 600-900 Volts and contact shoes. The current flows from the OCS to the transit vehicle and returns via the running rails and return cables to the negative substation terminal. Light rail vehicles (LRV) derive traction electric power for vehicles (as single units in "married pairs", or multiple units in longer consists) from an OCS, which is fed by TPSS along the ROW.

I.C. What are EMF, EMR, and electromagnetic interference (EMI)?

Electric charges produce electric fields due to voltage differentials, while magnetic fields are produced by moving charges or electric currents. An electric field is produced around the appliance when plugged in (even when not turned on). A magnetic field is produced when the appliance is turned on and the electrical current is flowing. Electric fields are shielded or weakened by materials that conduct electricity (e.g. trees, buildings, human skin), while magnetic fields pass through most materials and are difficult to shield. Therefore, magnetic fields are a greater potential concern for biological effects than electric fields, because they penetrate tissues without attenuation and are more difficult to shield. The EMR penetration depth in the human body or objects varies with EM frequency and wavelength ("skin depth"). The strength of both the electric and magnetic fields decreases with distance from the source, but how rapidly EMF falls off depends on its size, shape (compact, linear, double power line) and location (ground-level, overhead, underground).

The 2002 "*EMF Questions and Answers*"[1] provides background information on EMF, typical environmental levels of emissions and exposures from common home, work and transportation sources for other common, and research findings on potential EMF health concerns. The focus of public and scientific concern has been on biological and adverse health effects from power frequency magnetic fields. In spite of extensive research over many years, there is no agreed "dose metric" relevant to human health, although several have been proposed (time integrated, time averaged, maximum EMF, etc.)

The EM frequency spectrum, typical EMR sources in the urban environment, and their frequency, wavelength, and radiation energy are shown in Figure 1.

Time-varying EMF and non-ionizing EMR are associated with all electric power production, conditioning and transfer sources, such as electrical power generation and storage facilities, power lines, transformers, inverters, computer, communications and control equipment. These are common to electric transportation systems, as well as household appliances and office or workplace equipment.

Also, spark discharges due to imperfect contact between the pantograph on top of light rail vehicles and the OCS catenary wire are a common source of broad-band EMI. Undesirable EMI from electric transit operations is due to broad-band EMFs, which can affect electronic devices (computers) and electrical scientific and medical devices along the wayside, or near the TPSS. In turn, external EMF transmitters (like radio and TV stations and airport radars) could interfere with light rail communications and control. EMI due to power lines, airport or military radars, TV and radio transmitters and other electrical and electronic devices may pose safety hazards to the operation of rail transit vehicles and control and communications equipment. By preventing and reducing EMF levels, EMI impacts will also be prevented or mitigated.

Power lines and the OCS can induce undesirable "stray" currents in parallel metallic wires, rail transit tracks, metallic fences, underground communication cables, gas pipelines and conducting ground segments. This produces unwanted and potentially harmful EMI. This may cause contact- current shock and "RF burns" when people touch metallic fences and objects near, parrallel to power lines and OCS.

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[1]*EMF Questions and Answers.* 2002. www.niehs.nih.gov/emfrapid/booklet/home.htm

Figure 1. EM Spectrum with Typical EMR Sources, Frequency, Wavelength and Radiation Energy
At power frequency (60 Hz) EMF, the electric and magnetic fields can be considered separately, since the wavelength is very long.

Frequency (Hz)	Wavelength (m)	Energy (eV)
3	10^{8}	$1.25x10^{-14}$
30	10^{7}	$1.25x10^{-13}$
300	10^{6}	$1.25x10^{-12}$
$3x10^{3}$	10^{5}	$1.25x10^{-11}$
$3x10^{4}$	10^{4}	$1.25x10^{-10}$
$3x10^{5}$	10^{3}	$1.25x10^{-09}$
$3x10^{6}$	10^{2}	$1.25x10^{-08}$
$3x10^{7}$	10	$1.25x10^{-07}$
$3x10^{8}$	1	$1.25x10^{-06}$
$3x10^{9}$	0.1	$1.25x10^{-05}$
$3x10^{10}$	10^{-2}	$1.25x10^{-04}$
$3x10^{11}$	10^{-3}	$1.25x10^{-03}$
$3x10^{12}$	10^{-4}	$1.25x10^{-02}$
$3x10^{13}$	10^{-5}	0.125
$3x10^{14}$	10^{-6}	1.25
$3x10^{15}$	10^{-7}	12.5
$3x10^{16}$	10^{-8}	$1.25x10^{2}$
$3x10^{17}$	10^{-9}	$1.25x10^{3}$
$3x10^{18}$	10^{-10}	$1.25x10^{4}$
$3x10^{19}$	10^{-11}	$1.25x10^{5}$
$3x10^{20}$	10^{-12}	$1.25x10^{6}$
$3x10^{21}$	10^{-13}	$1.25x10^{7}$
$3x10^{22}$	10^{-14}	$1.25x10^{8}$
$3x10^{23}$	10^{-15}	$1.25x10^{9}$

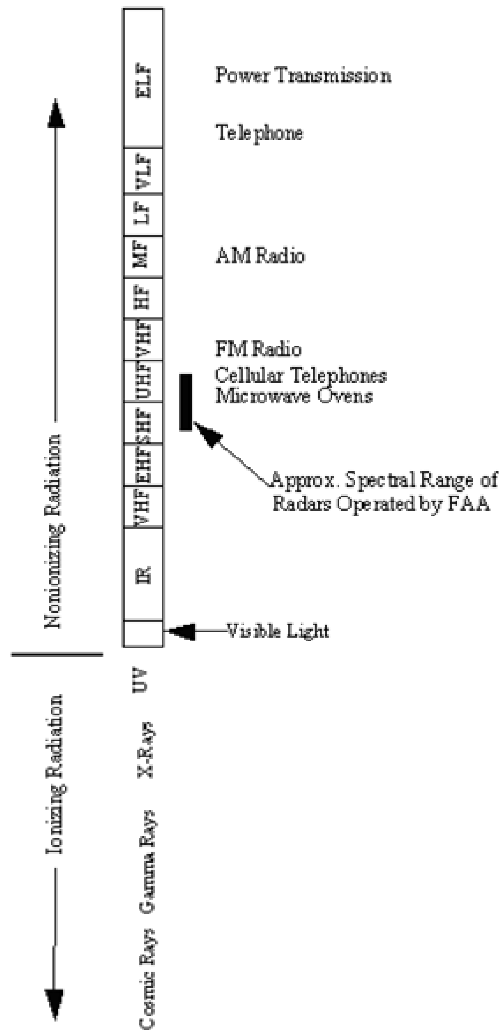

Table 1 shows the EMF terminology and units. Since typically environmental fields are highly variable in direction, frequency, time and space, the EMF levels measured are both time- and spatially- averaged.

Table 1. Units for Electric and Magnetic Fields. At low frequencies such as power line frequencies, magnetic flux units are more commonly used; so the magnetic field is expressed usually in mG (milliGauss) or microTesla (1 mG = 10 microTesla)

Term	Unit	Comment
Frequency	Hertz (Hz)	Number of times per second a wave goes through its maximum value
Electric Field Strength	Volts/meter (V/m)	Signified by "E"
Magnetic Field Strength	Amperes/meter (A/m)	Signified by "H"
Magnetic Flux Density	Tesla (T), or Gauss (G), where 10,000 G = 1 T	Signified by "B"

Chapter II. STATE OF THE SCIENCE REGARDING HEALTH EFFECTS OF EMF

II.A. What are the potential environmental EMF and EMR health effects?

Extremely Low Frequency (ELF) EMF from power lines and Radio-frequency (RF) radiation are non-ionizing, low-energy emissions unlike X-rays, and therefore not able to cause genetic damage in biological cells. In spite of three decades of scientific research on EMF and EMR adverse health effects, there are no proven health impacts due to long-term exposure to weak, environmental levels, although the public continues to fear potentially harmful biological and health effects due to long term exposures.[2]

Power frequency variable EMF basically induces electric currents in the human body; the electric fields are attenuated by several orders of magnitude by cell walls and skin, whereas magnetic fields penetrate without losing strength and are of greater concern. Adverse health impacts of long term (chronic) EMF exposures at low, environmental levels are not proven, nor well understood, but are widely feared. The most likely biological effect of changing external ELF/EMF is to induce electrical currents in the body, which must be compared in strength to normal human internal electrical activity. The bio-effects of RF radiation are due to partial or total body heating due to EM energy absorption, which causes tissue and organ heating at various frequency-dependent depths.

There is no clear evidence that specific illnesses may be linked to environmental levels of RF radiation below the Maximum Permissible Exposure (MPE) levels recommended by safety standards. Some claimed that "non-thermal" adverse health effects of RF exposure levels can result below the limits prescribed in current safety standards (e.g., brain cancers from cell phone use), so dosimetry and epidemiological research continues.[3]

II.B. What does research on EMF health and environmental impacts conclude?

In 2002, the International Agency for Research on Cancer (IARC) – a part of the World Health Organization (WHO) – included EMF as a Class 2B, potential human carcinogen, in its monograph evaluating carcinogens.[4] This classification reflected several epidemiology studies indicating attributing excess leukemia risk in children to elevated levels of EMF exposures.

Resources discussing RF human exposure safety issues of interest to the public and transit workers include the FCC Frequently Asked Questions on RF safety[5] and WHO EMF Research Program publications. The WHO experts have evaluated and summarized the environmental and health effects issues of EMR exposures in addition to the maximum exposure limits.[6]

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[2] See NIEHS EMF-RAPID studies posted at www.niehs.nih.gov/emfrapid/

[3] See Cell Phone facts and links at www.fda.gov/cellphones/ and EMF-RAPID and NIEHS NTP research on cell phones radiation at www.niehs.nih.gov/emfrapid/home.htm

[4] See 2002 list at http://monographs.iarc.fr/

[5] FCC Frequently Asked Questions on RF safety: www.fcc.gov/oet/rfsafety/rf-faqs.html

[6] The WHO Fact Sheet 183, "Electromagnetic fields and public health", discusses the potentially harmful levels and heating effects of radio-frequency fields and radiation human exposures, namely: that RF fields below 10 GHz (to 1 MHz) penetrate exposed tissues and produce heating due to energy absorption. The depth of penetration depends on the frequency of the field and is greater for lower frequencies. Absorption of RF fields in tissues is measured as a specific absorption rate (SAR) within a given tissue mass. The unit of SAR is watts per kilogram (W/kg). SAR is the quantity used to measure the "dose" of RF fields between about 1 MHz and 10 GHz. An SAR of at least 4 W/kg is needed to produce known adverse health effects in people exposed to RF fields in this frequency range. RF fields above 10 GHz are absorbed at the skin surface, with very little of the energy penetrating into the underlying tissues. The basic dose for RF fields exposure above 10 GHz is the intensity of the field measured as power density in watts per square meter (W/m2) or for weak fields in milliwatts per square meter (mW/m2) or microwatts per square meter

The WHO International EMF Project[7] has coordinated, evaluated and summarized scientific research on the environmental health effects of broad-band EMF exposures in its Fact Sheet 232, “Electromagnetic Fields and Public Health.”[8], The WHO EMF Project also compiled an EMF Research database and collected worldwide EMF standards conducted health risk assessments, examined prudent risk avoidance measures, and issued EMF risk communication guidelines. The WHO maintains an informative website on EMF and potential environmental health effects.[9]

- The WHO Environmental Health Criteria (EHC) documents summarizing the current knowledge and residual uncertainty regarding potential health effects from occupational and public environmental exposures to ELF/EMF, RF and static magnetic fields are:
- EHC 238 (2007), “Extremely- Low Frequency Fields”[10]
- EHC 232 (2006) “Static Fields”
- EHC 137 (1993) “Electromagnetic Fields (300 Hz- 300 GHz)”

These recent research reviews concluded that:

- There is no clear evidence so far, in spite of numerous studies, that specific illnesses may be linked to specific doses and frequencies of static fields, ELF EMF and RF radiation;
- Claimed “non-thermal” adverse health effects of RF exposure levels below the limits prescribed in current safety standards, (e.g., brain cancers from cell phone use) are still under active research for scientific verification and replication.[11]

Therefore, the WHO recommends low-cost precautionary measures to reduce EMF exposures in planning; design and engineering or electric facilities and equipment, similar to the ALARA (As Low as Reasonably Achievable) approach, and endorses public health risk communication with stakeholders.

The National Institute for the Environmental Health Studies (NIEHS) led a 5-year national interagency EMF Research and Public Information Dissemination (EMF-RAPID) program. DOT was an active research participant, and member of the EMF Interagency Committee. The final NIEHS report summary (1998) on potential – but still uncertain – EMF health effects[12] recognized a small, but unexplained excess risk of childhood leukemia linked to ELF/EMF average exposures in excess of 0.4 Microtel (or 4 milliGauss). Several scientific review articles on EMF epidemiology and biological effects were published in the NIEHS Environmental Health Perspectives journal.[13]

(µW/m2). Exposure to RF fields above 10 GHz at power densities over 1000 W/m2 are known to produce adverse health effects, such as eye cataracts and RF shocks and skin burns. At frequencies less than 100 MHz, RF burns or shock may result from charges induced on metallic objects situated near radars. Persons standing in RF fields can also have high local absorption of the fields in areas of their bodies with small cross sectional areas, such as the ankles“.

[7] Posted at www.who.int/peh-emf/project/EMF_Project/en/index.html

[8] June 2007 update posted at www.who.int/mediacentre/factsheets/fs322/en/index.html

[9] See posted WHO resources at “What is EMF” portal at www.who.int/peh-emf/about/WhatisEMF/en/

[10] EHC 237, 2007 posted at www.who.int/peh-emf/publications/elf_ehc/en/index.html

[11] See Cell Phone facts and links at www.fda.gov/cellphones/ and EMF-RAPID and NIEHS NTP research on cell phones radiation at www.niehs.nih.gov/emfrapid/home.htm

[12] See EMF postings at www.niehs.nih.gov/health/topics/agents/emf/

[13] Search recent review articles and editorials on EMF at www.ehponline.org

If transit operations raise already elevated urban EMF exposure levels, total EMF may greatly exceed background levels near schools and other sensitive sites. Population segments that may be particularly vulnerable to EMF and EMR exposure are of special concern to community health impact assessments. Such are: children (in homes, schools, or playgrounds near transit ROW or facilities), adults with impaired heat dissipation ability because RF exposures raise skin and core temperatures (such as pregnant women, diabetics, and people with high blood pressure). Vulnerable population segments to protect from environmental EMF also include individuals with:

- Medical electronic implants and external prosthetic devices susceptible to EMI;
- Metallic implants that could be magnetized or heated by RF radiation;
- Appliances that can be magnetized or can suffer from EMI with electronic controls, such as wheelchairs

EMF restrictions for medical device wearers are included in Table 3 (Chapter 4) below.

Chapter III. EMF FOR TYPICAL ELECTRIC TRACTION POWER SYSTEMS (TPS)

III.A. Guidelines for Design and Operation of Electric Transit TPS

There are several up-to-date resources describing the technology choices and design options for modern rail transit traction power systems:

- The American Railway Engineering and Maintenance-of-Way Association (AREMA) updates annually its *Manual for Railway Engineering*.[14] The AREMA Committee 12- Rail Transit prepares Chapter 12 with summary guide and procedures for the construction of track, structures, infrastructure (including utilities) and passenger design, and systems management. Chapter 11, on Commuter and Intercity Rail, also includes information on the power and propulsion subsystems.
- The American Public Transit Association (APTA) Rail Standards Task Force[15] produces the *APTA Manual of Standards and Recommended Practices for Rail Transit Systems.*
- The Transportation Research Board's (TRB) Transit Cooperative Research Program (TCRP) produced in 2000 the TCRP RPT-57, *Light Rail Track Design Handbook.* In Part D, Chapter 11-Transit Traction Power described in detail the complex electrical TPS components, such as: the overhead catenary system or third rail, TPSS, connecting cables, wayside distribution system, corrosion control system designed to redirect stray currents in tracks to a substation.

As these industry handbooks indicate, TPSS locations along the route are chosen using train performance modeling software to allow operation at peak power demand.[16] Other inputs are the geometry and geography of the proposed route, as well as local power utility demand to ensure reliable power supply for the substations. Only after the route has been chosen can the OCS design (single, double wire, system height) be optimized for track layout, including support poles, span length and tension to ensure constant contact with the vehicle pantograph. The substations locations and size, cables access, conduit systems and manholes must meet the constraints of electrical safety in the urban environment, and be shielded to minimize EMI with nearby conductors.

The safe operation and efficiency of electrically powered transit systems are the primary consideration in siting substations and wayside power distribution for light rail systems, and must meet the real estate constraints. Environmental impacts, including EMF impacts on the traveling public, are secondary considerations.

Several state legislatures and Public Utility Commissions (PUCs) have implemented limits on electric fields (EF) and magnetic fields (MF) for transmission power lines at ROW (center and edge, respectively).[17] Examples include: Florida: EF- 8 kV/m, 2 kV/m; MF: 150 mG (max load); Minnesota: EF- 8 kV/m; Montana: 7 kV/m (but 1 kV/m for highway crossings); New Jersey: 3 kV/m; New York: 11.8 kV/m (for public road crossings) to 7 KV/m (private road), but 1.6 kV/m for the edge of ROW and MF- 200 mG (max load); Oregon, 9 KV/m at ROW center. Transit system planners and operators, who might build track along power line ROW, should be aware of these restrictions for compliance, and consider minimizing incremental EMF contributions.

The Electric and Magnetic Fields Program of the California Department of Public Health Environmental Health Investigations Branch (EHIB), has developed guidelines to limit EMF exposure for schoolchildren

[14] AREMA. Manual for Railway Engineering. See postings at Online Store at www.arema.org.

[15] APTA Rail Standards Task Force. See postings at www.apta.com/about/committees/rstand.

[16] The Electric Power Research Institute (EPRI) developed CORRIDOR (Ver. 3 Manual)

[17] Source: "*Questions and Answers About EMF*"

(such as Fact-sheets and an EMF checklist for school buildings).[18] In addition, to protect children as sensitive targets, the California Department of Education has developed guidance[19] on setbacks for overhead and underground power transmission lines, ranging from 100 ft for 50-133 KV if overhead, to 25 ft for same voltage if buried, but increasing with voltage.

Similar guidelines were not required, but might apply to transit substations: The placement of electric transit and rail power substations is often contentious, because affected communities object to excessive EMF exposures (an Environmental Justice issue) and are concerned about potential safety and health hazards if children play near the transformers.

III.B. Typical EM fields from TPS and OCS for electric transit, compared to other EMF sources

Electric urban transit systems are one of the numerous and proliferating sources of environmental and occupational EM exposures, including: personal wireless data and voice (PDA, cellphones) and base station transmitters infrastructure, TV, radio and satellite broadcasting transmitters communication, navigation and positioning electronics for civil and military transportation fleets, and for emergency, medical and law enforcement, as well as the ITS in-vehicle devices and wayside infrastructure, which use GPS, RF or microwaves. For comparison, Earth's magnetic field is 50 microTesla. Common EMF levels under utility power lines are 20 microTesla magnetic fields, or several kV/m for electric fields. Average residential EMF levels in the U.S. are about 0.12 microTesla magnetic fields and several tens of V/m for electrice fields.

The main sources of EMF exposures for communities along the ROW are the catenary-running rail current loops, and the power rectification (inverters) substations. TPSS rectify AC power from the T&D network (typically at 11-12.5 KV) into Direct Current (DC) at voltages of 600-900 Volts, typically 750V DC. Therefore, the TPSS transformers have a DC side and an AC side with markedly different EMF characteristics. A "chopper" onboard the LRV (a mechanical cam system in earlier days, but electronic switches at present) provides the variable intensity AC current for propulsion.

The key feature of EMF from electrically powered transit is that it is complex and highly variable in space and time. Transit system EMF is also rich in the frequency spectrum due to multiple sources of power on-board and along the wayside, variable speed and current loading, and power transients. This variability is illustrated below in Figures 2a-c and 3 for a TPSS facility at Shady Grove, typical of the Washington Metropolitan Transit Authority (WMATA). The higher exposures result from peak passenger and vehicle current loads at rush hour, but the average exposure is typically below 10 MilliGauss (or 0.1 microTesla).

III.C. EMF data on electric rail and transit

Rapid transit and light rail systems in the United States run on DC electricity (600-750 V). DC-powered transit vehicles contain equipment that produces AC fields. For example, areas of strong AC magnetic fields have been measured on the Washington D.C. Metro subway cars close to the floor, during braking and acceleration, near equipment located underneath.

Figure 2a shows comparative EMF exposures intensity as a function of frequencies for typical electric transit vs. non-electric (diesel-powered) rail.

[18] California Department of Public Health. See resources on EMF health risk evaluation, communication and mitigation posted at www.dhs.ca.gov/ehib/emf/.

[19] See "Power Line Setback Exemption Guidance- May 2006 posted at http://www.cde.ca.gov/ls/fa/sf/powerlinesetback.asp

Figure 2a. Bar Chart Comparison of Maximum (bar top) and Averaged (line) Public Magnetic Field Levels Inside Transit Vehicles.

The EMF results from the current loop formed by the OCS or third rail and closed in the return rails, as well as from vehicle power and propulsion equipment.

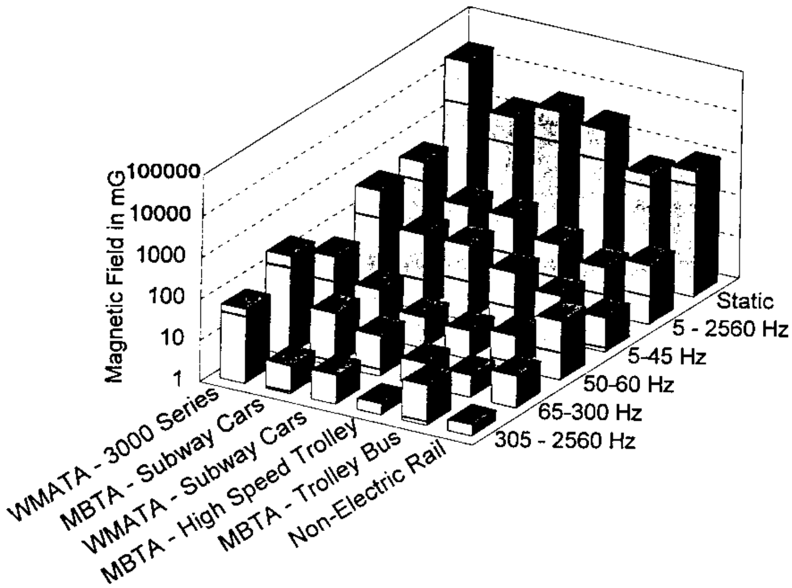


Figure 2b shows the WMATA public EMF public exposures in stations. The EMF exposure levels for wayside communities along transit ROW in stations are shown in Figure 2c and Table 2. Figure 2c also shows that the EMF levels near a WMATA TPSS at Shady Grove peak at rush hour, (about 25 mG average personal exposure) due to peak ridership and traction current loads. This illustrates the complexity and dynamic variability of EMF TPSS emissions over time, and in space and frequency domains.

Figure 2b. Range of Magnetic Field Levels in WMATA Stations Compared to Power Frequency Magnetic Fields Common EMF Sources Produce.

This figure illustrates the range of magnetic field levels in WMATA stations, at various distances from the platform edge, compared to typical levels of power frequency magnetic fields produced by common EMF sources, such as transmission and distribution lines and home appliances. Average public EMF exposures are comparable to those from T&D power lines and in the low range of that from home electric appliances.

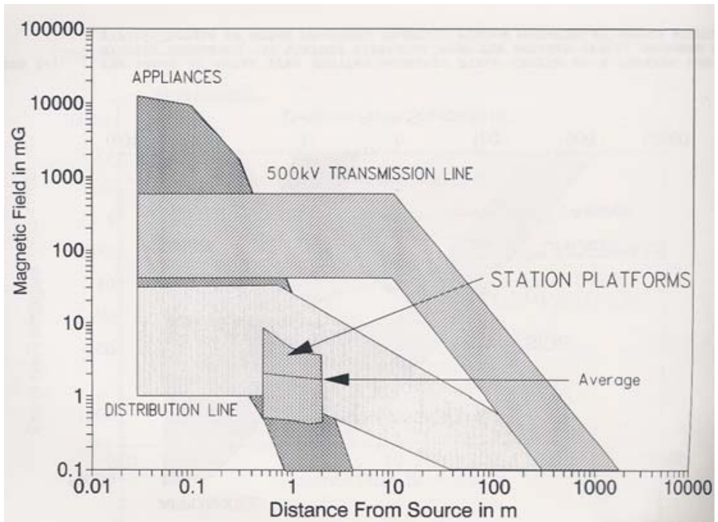


Figure 2c. Magnetic Field Levels Recorded Outside the WMATA Shady Grove TPSS

Magnetic field levels recorded outside the WMATA Shady Grove TPSS using a personal exposure EMDEX meter, as a function of time of day. EMF levels are higher at rush hour, reflecting peak power demand.

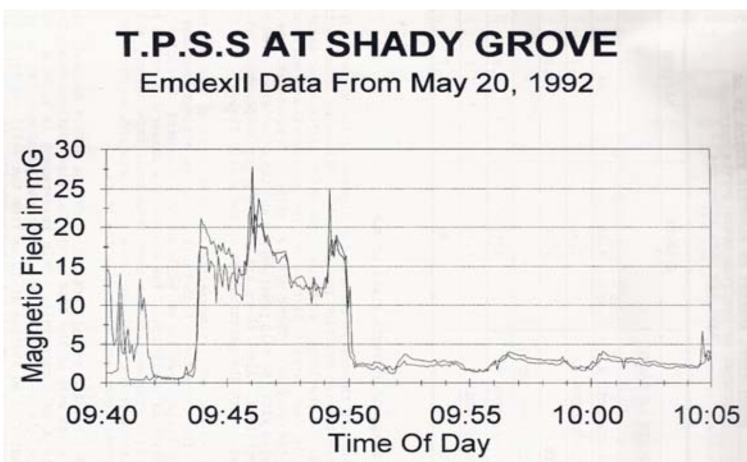


Figure 3. Comparative Magnetic Field Decay as a Function of Distance from Tracks for Typical Electric Transit vs. Inter-city Rail and Maglev
EMF intensity falls off rapidly with distance from the catenary or third rail, reaching levels of about 10 milliGauss within 10 m (30 ft) from the tracks. Typical environmental EMF levels of 1-3 mG are reached withing 60 m (180 ft) from the ROW.
Source: Volpe Center/FRA. Comparison of Magnetic and Electric Fields for Conventional and Advanced Electrified Transportation Systems. 1993.

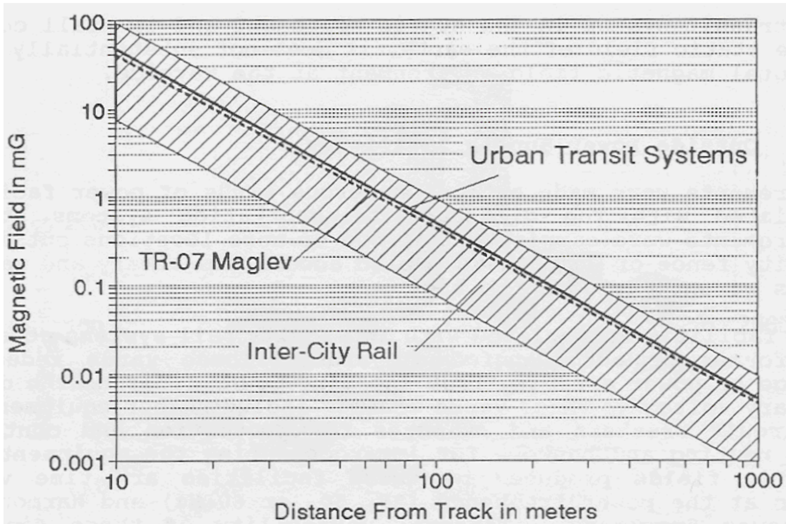
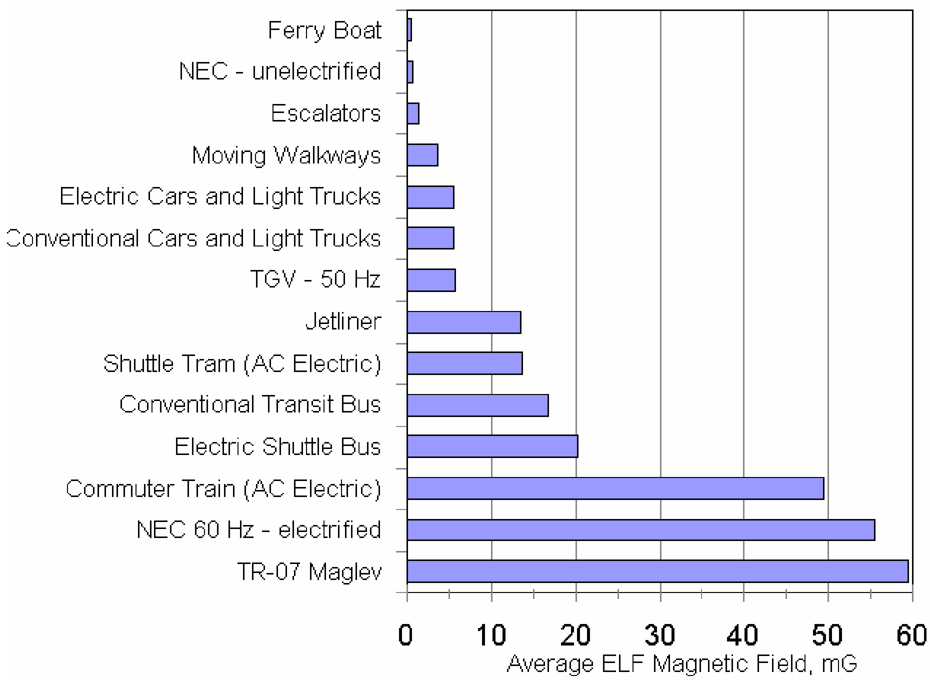


Table 2. Comparison of Average (and maximum) EMF Levels (in milliGauss) Inside the Power Supply Stations of MBTA Transit vs. Electric Rail
Source: DOT/FRA/Volpe Center. Comparison of Magnetic and Electric Fields for Conventional and Advanced Electrified Transportation Systems. 1993.

SYSTEM AND FACILITY	STATIC	5 - 45 Hz	50 - 60 Hz	65 - 300 Hz	305 - 2560 Hz	5 - 2560 Hz
NEC - CONTROL RM UPS VAULT	669 (1176)	1.9 (2.8)	37.4 (46.4)	18.3 (21.3)	37.2 (44.6)	56.4 (66.4)
TGV-A - GAULT ST. DENIS SUBSTATION	349 (358)	0.4 (0.9)	10.9 (34.3)	0.7 (2.1)	0.6 (1.5)	10.9 (34.7)
TGV-A - VENDOME RELAY ROOM	326 (464)	0.3 (0.5)	1.4 (2.8)	0.8 (1.8)	0.6 (1.1)	2.0 (3.0)
MBTA - TRACTION POWER STATION	841 (2750)	1.1 (18.4)	9.6 (110.7)	3.8 (78.4)	3.4 (55.8)	12.3 (133.1)

Figure 4. Comparative ELF/EMF Averaged Levels in Representative Transportation Systems and Facilities
Source: Volpe Center/Electric Research and Management, Inc. Comparative EMF in the Transportation Environment for EMF-RAPID. 1999.



The main sources of magnetic field exposure for passengers inside a bus are the overhead or wayside power lines.. EMF measurements made by the Volpe Center and Electric Research and Management, Inc.(ERM) for FRA on existing and emerging AC-powered commuter and high speed trains, such as the Amtrak Acela passenger rail on the NorthEast Corridor, New Jersey Transit Coastline, and Metro North commuter rail have shown that average 60-Hz magnetic field exposures for passengers and workers may exceed 50 MilliGauss (see Figures 3, 4 and Table 5). However, the public has accepted any excess EMF as a trade-off against economic and environmental benefits, as well as commuting convenience and time savings.

III.D. What should planners know about EMF impacts when siting traction power and propulsion systems?

The traction power design alternative for OCS, substations and track must be chosen for electrical safety and for reliable all-weather operation, so as to reduce operating costs and visual-impact. Although EMF community impacts are rarely considered (see Best Practices in Sec. V. b)., it is well known that a higher DC voltage (e.g., 900 V instead of 750 V DC) for the 3rd rail or catenary, means that peak currents can be lowered for the same traction power, and thus lower resulting EMF. Also at higher Voltage, the power distribution losses are lower as well.

The TPSS design and locations are usually chosen to provide efficient peak LRV performance, i.e. sufficient power (voltage, current) to the catenary at peak traffic loads and close headways, and good access for return current cables to the substations (under the tracks) and for maintenance. The local power utility must evaluate its capability to sustain peak-hour operation of the transit system, as well as network impacts at peak customer demand times.

The environmental impacts of TPSS and OCS infrastructure on the public are also considered, but are secondary to performance, safety and operability. For instance, grounding, lightning protection, and corrosion protection by minimizing potential hazards from ground return (stray) currents induced in nearby cables, metal fences, and gas distribution pipelines.

Recent technology trends for light rail are to use AC propulsion, rather than less efficient DC, which requires rectification from the AC distribution line to DC, and then on-board LRV "chopping" to AC power at frequencies that increase with acceleration and speed. Another recent trend is to increase the DC voltage (from 600 to 900 and above 1 kV), in order to lose less power along the line and use fewer substations to save cost. This helps lower the magnetic field, since higher voltage means lower current, hence lower magnetic fields (TPS system design options, issues and guidelines discussed below and in Refs. 1- 5).

Transit planners should be aware of typical EMF levels for power lines and substations in order to be able to compare transit system EMF levels, with those commonly encountered in home, office, factory workplaces and typical urban environments.

- **Power T&D lines** can be either overhead or underground. Overhead power lines produce both AC electric fields and magnetic fields at 60 Hz frequency, and their higher harmonics. EF intensity is proportional to the Voltage, and MF strength to the current intensity. Underground power lines produce lower electric fields above ground, but may produce magnetic fields above ground. Power transmission lines bring power at high voltage, over long distances from a generating station to electrical substations. Power distribution lines bring power from the substation to home, workplace and transit utilities.
- **Power Transmission lines:** At a distance of 300 feet and at times of average electricity demand, the magnetic fields from many lines can be similar to typical background levels found in most homes. The distance at which the magnetic field from the line becomes indistinguishable from typical background levels differs for different types of lines.
- **Power Distribution Lines:** Typical voltage for power distribution lines ranges from 4 to 24 kilovolts (kV). Electric field levels directly beneath overhead distribution lines may vary from a few volts per meter to 100 or 200 volts per meter. Magnetic fields directly beneath overhead distribution lines typically range from 10 to 20 MilliGauss for main feeders and less than 10 MilliGauss for laterals. Such levels are also typical directly above underground lines. Peak EMF levels, however, can vary considerably depending on the amount of current carried by the line. Peak magnetic field levels as high as 70 MilliGauss have been measured directly below overhead distribution lines and as high as 40 MilliGauss above underground lines. These may belong to the utility, but some may be added to supply power to the transit system.
- **Electric Power Substations:** The strongest EMF levels outside a substation is due to the power lines (cables) entering and leaving the substation. The strength of the EMF from equipment within the substations, 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.

Chapter IV. STANDARDS AND GUIDELINES FOR EMF AND EMR EXPOSURE SAFETY AND EMI/EMC PREVENTION AND CONTROL

Transit planners, builders, and operators should recommend and verify compliance with the best available and currently applicable EMF and RF human exposure safety standards, as well as adopt EMI/EMC control standards.

The EMF and RF human exposure safety standards and guidelines discussed below are voluntary and advisory, except for the FCC standard, which imposes legal requirements (enacted as 47 CFR 1.1307(b) in 1996) and has been enforced since Sept 2000. Although compliance with public and occupational recommended Maximum Exposure Limits is voluntary, it is widely accepted by government, industry and the public as a “best safety practice” for workplace safety and for health and environmental quality.

Current EMF/EMR safety standards prevent induced body currents in excess of normally occurring levels, and RF heating of the whole, body or partial body (limbs, head). Existing standards address only safety, not health, since they protect from short-term (acute) heating due to RF radiation exposures. These Standards do not address the potential for long-term (chronic) adverse health impacts due to low levels of RF radiation exposure.

Existing international RF (and also power frequency EMF) Human Exposure Safety standards were developed by the WHO International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998. Other U.S. and international standards and guidelines are summarized by the WHO EMF project.[20]

The U.S. exposure safety standards listed below differ somewhat from the WHO ICNIRP standard and amongst themselves in both approach and specific MPEs at the lowest and highest frequencies. The FCC standard for environmental emissions of radio-transmitters is the most protective. The American National Standards Institute (ANSI), which accepts the Institute of Electrical and Electronic Engineers (IEEE) as a competent consensus standards body, and the National Commission for Radiation Protection (NCRP) have exposure safety criteria.[21]

Standards are designed with a large safety margin to prevent potentially damaging induced body currents, and/or core temperature rises of 0.1 degrees Celsius. A one degree (10 times higher) temperature rise is considered harmful to cells, tissues and organs. The standards provide a sufficient margin of safety for both occupational and public exposures, including sensitive targets (pregnant women, children). Public or environmental MPE limits are typically 3- 5 times below those for occupational (controlled) levels.

National and international human exposure safety standards limiting public exposures to static (DC) ELF/EMF at power frequency magnetic and electric fields, and to Radio-frequency RF radiation (EMR) include:

- The ANSI/IEEE C95.6- 2002 standard[22] for EMF from 0- 3 KHz, includes environmental and public limits to DC (or static) and AC frequency EMF electric magnetic fields. A very important

[20] See http://www.who.int/peh-emf/standards/en/

[21] These limits are based on a determination that potentially harmful biological effects can occur at an SAR level of 4.0 W/kg, as averaged over the whole-body, but is measured for 1 cube of 1 gram of tissue (10 grams for ICNIRP standard). Appropriate and conservative safety factors apply to limits for whole-body exposure: a factor of 10, or 0.4 W/kg for "controlled" or "occupational" exposures. A larger “safety factor” of 5- 50 times lower than the harm threshold- or was adopted for "uncontrolled" or "general population" exposure namely 0.08 W/kg.

[22] IEEE C95.1 *" Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3KHz*"

aspect of this standard is to set limits that also prevent startle, shock and burns from contact currents, as shown in Table 6.

- The FCC regulatory limits for public (uncontrolled, or environmental) and occupational (controlled) exposures[23] are shown in Table 4 and Figure 5. [24]
- The ANSI/IEEE C95.1-2005 standard limits the radio frequency electric and magnetic fields and radiation to prevent short-term (acute) body heating; public and occupational exposures.[25]
- In 2005, the IEEE also adopted a recommended practice that provides guidance for safety programs to prevent or control exposure of workers or the public to potentially hazardous electromagnetic energy-producing devices, equipment and systems.[26]
- The WHO accredited the ICNIRP to develop similar exposure safety standards for static magnetic fields[27], and to time-varying electric, magnetic and electromagnetic fields.[28] In general, ICNIRP EMF exposure limits are more restrictive and conservative than IEEE limits, with a larger margin of safety provided for public environmental levels. The international EMF standards, which apply to imported transit systems and technologies, are stricter than IEEE US standards.
- The Occupational Safety and Health Administration resources on RF and ELF/EMF safety programs.[29]
- The American Conference of Governmental Industrial Hygienists[30] publishes occupational exposure limits – called Threshold Limit Values – for physical agents, including DC magnetic fields, ELF/EMF and radio-frequency radiation or EMR. Threshold Limit Values are updated annually based on current ANSI/IEEE consensus standards for occupational MPEs.
- The standards for EMI control and for electromagnetic compatibility (EMC) assurance are shown in Table 5 and are discussed in Chapter IV.

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[23] See References posted at www.fcc.gov/oet/rfsafety/

a) ET Docket 93-62 and Document # 96-326 *("Procedures for evaluating human exposures to RFR*")
b) Regulations in 47 CFR 1.1307(b); c) OET Bulletin 65,"*Guide for Evaluating Compliance with FCC RF Exposure Limits".*

[24] See FCC "Questions and Answers about Biological Effects and Potential Hazards of Radio-Frequency Electromagnetic Fields", Bulletin 56 (4th edition, Aug. 1999).

[25] IEEE "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz", 2005.

[26] IEEE C95.7, "*Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz*", 2005

[27]ICNIRP "*Guidelines on Limits of Exposure to Static Magnetic Fields*", Health Physics 66:100, 1994

[28] ICNIRP "*Guidelines limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)*" Health Physics 74:494, 1998.

[29] See www.osha.gov/SLTC/radiofrequencyradiation

[30] See www.acgih.org for the 2007 Threshold Limit Values and Biological Exposure Indices

Table 3. Summary of EMF Public Maximum Exposure Limits (MPE)

	Static (DC) Field	AC Power Frequency (60 Hz) Fields
IEEE C95.6 (2002) Reference Levels (external)	B_{dc}: 1.18 kG E_{dc}: 5 KV/m	B_{ac}: 9 G E_{ac}: 5-10 kV/m
ICNIRP (1998) Reference Levels (external)	$B_{dc:}$ 400 G E_{dc}: 25 KV/m Pacemaker: 5 G, 2 KV/m	B_{ac}: 0.83 Gauss E_{ac}: 4.2 KV/m 0.2 G, 2 KV/m

Table 4. EMR Limits for General Population

The FCC Regulations for EMR MPE limits for general population (public) vary with frequency and duration.

Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm^2)	Averaging Time (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f^2)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz * = Plane-wave equivalent power density

Table 5. List of EMI and EMC Standards

American Public Transportation Association, Standard for the Development of an Electromagnetic Compatibility Plan (EMCCP), APTA SS-E-010-98, 1998.
Association of American Railroads, Railway Electronics Environmental Requirements, AAR-5702, October 2002.
Association of American Railroads, Remote Control Locomotive Standard, Standard S-5507, November 2002.
Association of American Railroads, Specification for Remote Control Locomotive Communication Systems Operation at 220 MHz, Draft 2.1, November 15, 2003.
DOD Standard MIL-STD-461D Requirements for the Control of Electromagnetic Interference and Susceptibility, 1993.
DOD Standard MIL-STD-462D Department of Defense Test Method Standard for Measurement of Electromagnetic Interference Characteristics, 1993.
CENELEC Standard EN 50121:2000 Railway applications - Electromagnetic compatibility -- Parts 1-5
CENELEC Standard EN 50155:2001, Railway applications — Electronic equipment used on rolling stock.
ETSI EN 300 113-1 V1.4.1 European Telecommunications Standards Institute Electromagnetic Compatibility and Radio Spectrum Matters; Land Mobile Service; Radio Equipment Intended for the Transmission of Data (And/Or Speech) Using Constant or Non-Constant Envelope Modulation and Having an Antenna Connector; Part 1: Technical Characteristics and Methods of Measurement, 2002

Figure 5. FCC MPE Limits for Public RF Exposures

The strictest FCC MPE limits for public RF exposures apply in the frequency range 30-300 MHz, where the wavelengths are comparable to human limbs and body lengths, and therefore people are similar to antennae and absorb energy more efficiently ("body resonance").

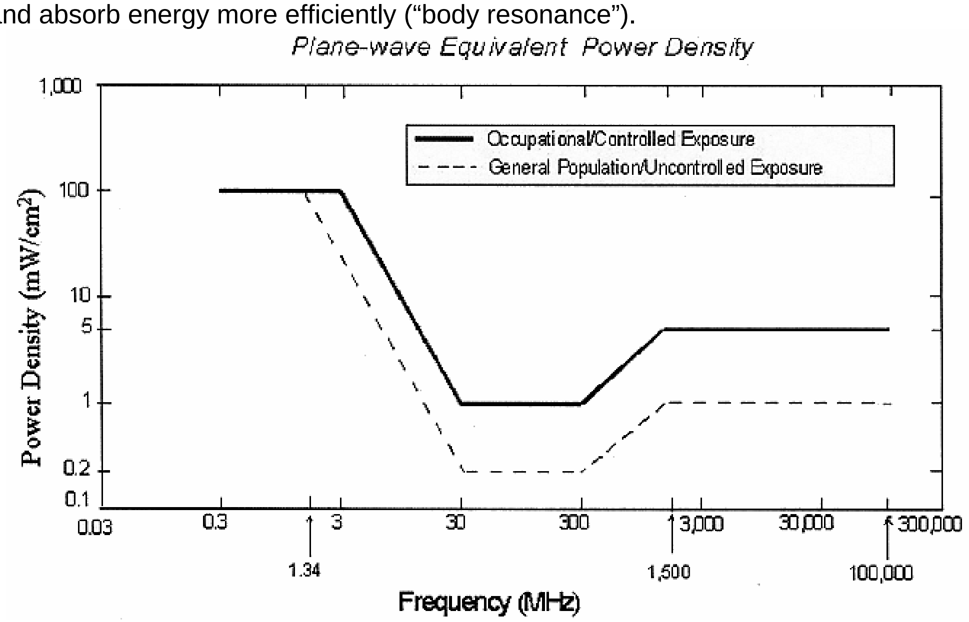

Table 6. IEEE C95.6 ELF/EMF MPE Limits for Contact and Induced Currents
Induced and contact currents, below and near power frequency, and harmonics that also apply to electric transit.

Condition	General public (mA, rms)	Controlled environment (mA, rms)
Both feet	2.7	6.0
Each foot	1.35	3.0
Contact, grasp[(a)]	-	3.0
Contact, touch	0.5	1.5

(a) Grasping contact limit pertains to controlled environments where personnel are trained to effect grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.
(b) Limits apply to current flowing between body and grounded object that may be contacted by the person.

Note that static fields are about 3 KiloGauss, while the MPE at 60 Hz is over 63 mT or 630 Gauss – over 1000 times above the peak EMF near a TPSS.

Chapter V. BEST PRACTICES FOR EMF PREVENTION, REDUCTION, AND MITIGATION

V.A. NEPA Integration with transit planning and design to reduce EMF

Engineering firms[31] that have successfully designed and built urban electric transit and rail systems, people movers and their traction power systems observe all applicable consensus safety standards, such as the NFPA 70-National Electrical Safety Code and several widely respected ANSI/IEEE Standards for substations and high voltage safety.[32]

Recent National Light Rail Conferences[33] sponsored by TRB described the improved technology options for light rail planning and design, which can also protect the environment, foster energy efficiency and reduce EMF and EMI impacts. These best practices include the LTK, Inc. Transit Electrification System (TES) model and the Siemens SITRAS-EMF 2.0 planning tool,, careful grounding, the elimination of DC stray currents, advanced AC switch gear and use of AC propulsion for improved energy efficiency, built-in-place TPSS to blend with nearby buildings in design-sensitive locations, and light rail without overhead wires.

Specific examples of Best Practice for Light Rail system in the planning and design phase are:

- The St. Louis MetroLink Washington University Mitigation Design Measures to prevent interference from LRV operations, OCS sparking and TPSS cabling with sensitive scientific equipment on campus (plan based on a 2002 Enertech report);
- The Sound Transit Link Light Rail Project[34] had to reroute the planned North Link Extension to the University of Washington campus, move stations and substation locations, and reduce magnetic fields by a factor of 100 using underground current loops so as to prevent EMI with medical and scientific laboratory instrumentation.

Since substations are usually located along the route points of maximum acceleration to supply peak currents, a best practice demonstrated is to use higher nominal DC voltages (over 1000 V vs. industry average 600-800) for substations, and thus reduce distribution line losses and require fewer substations, spaced at greater intervals. This reduces real estate acquisition costs and also reduces EMF. Another

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[31] LTK Engineering developed the *Traction Electrification System (TES)* simulation model. Siemens AG Transportation System Electrification developed the SITRAS-EMF 2.0 planning tool to calculate EMF for OCS systems. Other engineering firms that planned and designed urban light rail electric public transit systems and successfully deployed traction power systems include: HNTB, URS, ELCON Associates, Inc., L.K. Comstock & Co., RailWORKS Corporation, IMPulse, NC, Inc., Bombardier, and others.

[32] Substations and OCS safety consensus standards include: the NFPA 70- National Electrical Safety Code at www.nfpa.org, ANSI/IEEE Std. 80-2000 "*Guide to Safety in AC Substation Grounding*"; IEEE 399-1997 "*Recommended Practice for Power Systems Analysis*" (Brown Book) , IEEE 142-1991 IEEE "*Recommended Practice for Grounding of Industrial and Commercial Power Systems*"; ANSI/IEEE Std. 837-1989 "*Standard for Qualifying Permanent Connections Used in Substation Grounding*", IEEE/Std. 367-1979: IEEE "*Guide for the Maximum Electric Power Station Ground Potential Rise*", IEEE Std 665-1995 "*Standard for Generating Station Grounding*", IEEE Std. 1048-1990 IEEE "*Guide for Protective Grounding of Power Lines*", and IEEE Std. 644-1994, "*IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines*".

[33] See TRB Circular E-C058 (Proc. 9th National Light Rail Conference, 2003) section on Light Rail Electrification: a) "*Operational and Safety Considerations for Light Rail DC Traction Electrification System Design*" by K.D. Pham and R. S. Thomas; b) "*Built in Place Substations*" by R. Hastings et al.

[34] "*North Link Hi-Lo Mitigation EMI Re*port" by Ross Holmstrom for LTK Engineering Services, April 2006

best practice[35] example is perform a detailed utility analysis of power and equipment requirements to optimize TPSS siting and ensure electrical system safety.

The "*Power and Substation Fact Sheet*,"[36] which focuses on power substation safety rather than on environmental EMF, was prepared for light rail in Phoenix, AZ by Metro Light Rail and provides other best practices.

There are several examples of NEPA guidance and documents (EIS, EIR) that explicitly considered EMF reduction and can serve as model of industry best practice.

- The Valley Transit Authority (VTA) has prepared an Environmental Fact Sheet on preparing an EIS/EIR for a Major Transit Project which includes Electromagnetic Fields as an explicit item for environmental impact analysis.
- The Environmental Analysis of Electromagnetic Fields chapter in the Santa Clara VTA EIRs for the Silicon Valley Rapid Transit Corridor Final EIR (2003) and the Capitol Expressway Corridor (2005).[37]
- The NYCTA/MTA EIS for the 2nd Avenue Subway required relocation of substations and utilities, with consideration of safety, environmental EMF and EMI prevention.[38]
- The Seattle King County Sound Transit[39] explicitly includes consideration TPSS siting and EMF and environmental health in transit environmental documents

V.B. EMF modeling and measurement tools

A best practice is to compare the EMF and EMR for existing and planned electric transportation sources with the background levels from well accepted, common home, office and utility sources. For instance, EMF for advanced electric transit, rail and maglev with EMF from existing electric rail and transit systems that have long operated without any noticeable adverse long term environmental health effects (See Figure 4.

Modeling and prediction software must be used to characterize the EMF for substations, as a function of their design and operational parameters. Models can display the lateral magnetic and electric field levels versus distance, to verify compliance with safety standards. The Electric Power Research Institute (EPRI)[40] has sponsored the development of EMF modeling and measurement tools widely used by industry. The EMF modeling and prediction software includes: the EMDEX portable EMF measurement equipment with its associated data analysis software (EMCALC 2000), and the Enertech, Inc[41] EMF

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[35] Elcon Associates, Inc., 2003: "*Houston Metro Rail Utility Impact Study*" for Metropolitan Transit Authority of Harris County, TX.

[36] See www.MetroLightRail.org Fact sheet, Feb 2007

[37] See Environmental postings on the Bart to Silicon Valley light rail project of the Santa Clara Valley Transportation Authority (VTA) at htpps://www.communicationsmgr.com/projects/VTA/, e.g. EMF Chapter. 4 in the 2004 FEIR

[38] See NY City MTA NEPA documents posted at www.mta.info/capconstr/esas/documents, e.g., Chapter 14, Safety and Security of the 2006 "*50th Street Facility Revised SEA*" posted at www.mta.info/capconstr/esas/eafiles/ch_14.pdf

[39] Search for EMF in environmental documents at www.soundtransit.org

[40] See EPRI information on EMF modeling and environmental controls at www.epri.com EPRI sponsored the Enertech EMF Workstation modeling suite (EMF Expert, ENVIRO, EXPOCALC, Power Line Calculator and RESICALC), and of EMF measurement equipment with associated data recording, analysis and display software (EMDEX with EMCALC 2000).

[41] See postings on products and services for EMF modeling and measurement at www.enertech.net/html/company.html

Workstation modular software suite (EMF Expert, ENVIRO, EXPOCALC, Power Line Calculator and RESICALC). Other EMF modeling and simulation tools for transit power and propulsion system planning and optimization were developed by industry (See footnotes 31 and 34).

The American Conference for Governmental Industrial Hygienists also offers guidance developed by the National Institute of Occupational Safety and Health regarding EMF exposure measurement equipment and metrics.[42]

V.C. Electromagnetic Interference (EMI) Prevention and Control

EMI prevention requires measurements of EMF and EMR levels vs. frequency, time and distance, over the full dynamic range of light rail speeds and loading, and at multiple locations. EMF reduction may require:

- passive engineering controls (e.g., shielding with metallic materials at the TPSS source, or at the receptor, such a medical facility where EMI is observed);
- partial cancellation of magnetic field with a wire loop, in which an induced current creates a magnetic field of opposite direction;
- active shielding, that requires a power supply and feedback loop to control the induced current and magnetic field direction and magnitude;
- design modifications to place EMF sources (OCS or TPSS) further away or higher up, or to remove EMI-sensitive medical or research equipment;
- Other techniques used for urban LRVs (thicker, low resistance buried conductors, insulation, circuit breakers) to break up the current loops and thus limit the nuisance stray magnetic fields due to leakage ground currents and in conductors along the ROW.

EMI prevention and control is needed for both environmental health and for human and ope4rational safety assurance. Potential EMI with passive and Active Implantable Medical Devices (AIMD) is a special health and safety concern for electric transit workers and passengers, especially the elderly and disabled. Implanted and external medical electronic devices comply with EMC and EM immunity regulations issued by the Food and Drug Administration (FDA) Center for Devices and Radiation Health (CDRH).[43] However, the age and sources of implanted devices are so varied that the hazards are real, if not predictable.

Human exposure safety standards cited below have the strictest EMF limits for sensitive population segments, such as those who wear implanted medical electronic devices (heart pacemakers, defibrillators, insulin pumps, pain control) or use electric wheelchairs. As a precaution, transit authorities should post Caution or Warning signs in control centers, near TPSS, or in depots or maintenance yards[44] since body-worn or wayside RF radiation sources might interfere with cardiac pacemakers and other electronic medical devices (hearing aids, pain control, and insulin pumps). Another concern is that RF radiation could heat up internal metallic prosthetic devices (like clamps and metal pins), or external metallic objects in contact with skin (watches, belt buckles, wire-framed glasses, dental crowns) and cause RF burns.

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[42] See www.acgih.org for the "*NIOSH Manual for Measuring Occupational Electric and Magnetic Field Exposure" ,* Publication #99-077; and *"Assessing EMF in the Workplace: A Guide for Industrial Hygienists"* Publication #9853

[43] The CDRH advises medical device manufacturers to comply with ANSI C63.18-1997, "Recommended Practice for an on-site, test method for estimating radiated EM immunity of medical devices to specific RF transmitters." CDRH collects information in its MedWatch database of electronic medical device malfunction or failure incidents, including those due to EMI. CDRH advises that cell-phones not be worn close to heart pacemakers or defibrillators, but should be at distances that preclude unintentional EMI. Older pacemaker models could be adversely affected by cell-phones or other unintentional radiators close to the heart. See also EMI/EMC Program postings at http://www.fda.gov/cdrh/emc/

[44] RF Caution and Warning signage is specified in C95.2-1999, Standard "IEEE Standard for Radio-Frequency Energy and Current Flow Symbols."

To prevent EMI safety hazards from and with electric transit systems, the APTA Standard SS-E-010-98 requires the development of an Electromagnetic Compatibility Control Plan (EMCCP), which:

- Characterizes potential EMI sources and hazards to transit/rail operations;
- Considers low-cost, no-cost options, or best practices for EMI prevention, control and mitigation techniques. Examples are: posted warning signs to control access, fencing, and shielding of substations, or grade crossing access, as needed);
- Considers best practices in EMI susceptibility control procedures. Examples are: active or passive shielding, cathodic protection, surge protection, fail-safe circuit redesign, changed location of antennas or susceptible equipment, redesign of equipment, enclosures for equipment, etc.);
- Utilizes current EMC guidance and resources for transit electrification developed by EPRI, AAR and AREMA as discussed in Sec. V B.;
- Includes a safety analysis and failure analysis of the transit system;
- Addresses grounding or shorting hazards, prevents, controls or mitigates as needed stray currents (earth-return currents or induced currents in metallic structures and pipelines or along the return rails (where some fraction of the current finds its way back to substation or generating station through the earth for various regions and soil conditions), and the effects of different design and construction practices on these currents;
- Characterizes the frequency bands, spectral characteristics of ELF/EMF and RF generated noise by the pantograph-catenary contact under operating conditions;
- Characterizes along the right-of-way parameters (e.g., frequency spectrum, electric and magnetic field strengths, modulation system) for the wireless communications, control, and power and propulsion system (including auxiliary power for HVAC, emergency lighting and signage, public address, etc.).

Chapter VI. SUMMARY OF RECOMMENDED BEST PRACTICES

The best practices recommended below could cost-effectively reduce electric transit system EMF and EMR exposures in the early planning and design stage, to the public, and to transit users and workers. Green boxes indicate best practices that will yield background information; excessive caution is unnecessary if measured EMF levels are 10-100 times lower than limits. Yellow boxes indicate best practices recommended where caution may be needed, e.g. observed EMF levels are close to limits. Red boxes indicate best practices recommended where EMF restrictions may be needed, e.g., observed EMF levels exceed limits.

VI.A. Conduct baseline measurements before and after transit system construction and operation

EMF and EMR measurement surveys along the ROW and of locations where TPSS, inverters, 3rd rail, and OCS would be placed are recommended. If measurements are too costly, EMF and EMR data on similar transit systems and urban environments can be used, in combination with M&S tools, to predict environmental EMF levels as a function of distance from the ROW. The objective is to compare the pre-existing "before" background EMF levels, with expected "after" construction EMF. This allows the determination of incremental EMF contributions from the planned electric transit system.

Data will also permit identification of potential EMF or RF "hotspots" in publicly accessible areas (stations, streets, near utility substations, in vehicle) that might require mitigation.

VI.B. Use modeling and simulation tools to project EMF levels for all alternatives

The use of EMF modeling and measurement tools and resources (see Chapter V), is recommended to ensure that TPSS and OCS design, placement and transit system operations will not unduly expose the community to EMF in excess of existing environmental levels. This approach will prevent community concern and controversy.

VI.C. Document potential EMF and EMR exposure in NEPA process

It is important to document, as part of the NEPA planning process, the potential EMF and EMR exposures for various route and transit system design, or technology alternatives. This allows designers and planners to verify compliance with applicable EMF human exposure safety standards. Demonstrating compliance with the best standards for MPE can reassure abutting communities that environmental safety and health standards are preserved. Public MPEs can be considered "action levels:" Should MPEs be exceeded near substations, then mitigation options need to be weighed and implemented.

VI.D. Promote EMF prevention and reduction and EMI/EMC safety, planning, and design

The National Electrical Safety Codes (NECS) must be observed to protect the public and light rail system operators and maintenance workers. There is a clear distinction between ELF/EMF (power frequency and harmonics) and RF radiation emission characteristics of electric transit power, propulsion, signaling, and control and communications systems, from environmental and occupational human exposure levels. Exposures can be reduced and managed by using spatial separation to increase the distance from sources, engineering controls (such as power-down, or shielding), time or activity management (or limiting hours of work to limit exposure times, or on-off duty cycle), administrative controls (fences, enclosures, warning signs, alarms), and or Personal Protection Equipment for transit maintenance workers in high voltage areas like the OCS or 3rd rail or TPSS, include insulated gloves and grounding poles.

To prevent EMI safety hazards in operating light and heavy rail systems, it is recommended to utilize the EMC Handbook for light and heavy rail transit electrification.[45]

Another requirement is to develop an EMCCP as described in the APTA Standard SS-E-010-98 To ensure the safe operability of the transit system, it is recommended to verify that the EMCCP plan is implemented, and that no interference from or to the electric transit poses safety hazards. This is also important to ensure the access and mobility of workers and handicapped passengers using electric chairs, or electronic implant devices vulnerable to EMI. The EMCCP will guide transit power and propulsion, and the control and communication system engineering design so as to:

- Characterize potential EMI sources and limit radiated, conducted or inducted EMI hazards to transit system operations;
- Consider low-cost, no-cost options, or Best Practices (BP) for the EMI prevention, control and mitigation;
- Consider best practices (BP) in EMI susceptibility control procedures (fencing, active or passive shielding, cathodic protection, surge protection, fail-safe circuit redesign, changed location of antennas or susceptible equipment, redesign of equipment, enclosures for equipment).

VI.E. Evaluate and implement EMF reduction strategies to avoid costly mitigation

Given the uncertainty of actual health hazards from long term (chronic) EMF exposures, the WHO advocated adoption of precautionary policies, or “prudent avoidance” for EMF, to protect potentially vulnerable population segments. Low-cost “prudent avoidance” prevention and mitigation strategies to limit environmental EMF from electric transit might include: providing fencing and warning signs for substations to prevent public access; raising the height of the catenary, burying underground the cables to the TPSS or 3rd rail underground, and shielding them; administrative measures to limit exposure by reducing the duration of power and propulsion maintenance work for workers. Other engineering EMF mitigation measures include passive or active shielding of substations, or active wire shielding for the catenary or trolley wires.

VI.F. Design and implement a public consultation and risk communication plan on EMF, as part of the NEPA process.

Use of modeling and prediction tools permits planners to compare transit EMF levels at various substation and OCS or station locations with common home, office and environmental levels from power lines and common environmental EMF sources. It is important to highlight transit EMF levels in comparison with other common environmental, home and office sources in public outreach and communication, to stress the environmental, economic and travel time benefits of electric transit. Inclusion of EMF environment, health and safety issues in the public consultation and risk communication plan, and graphic EMF/EMR risk communication briefings have proven successful in facilitating public acceptance of electric transit.

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