MAGLEV

EMI ASSESSMENT

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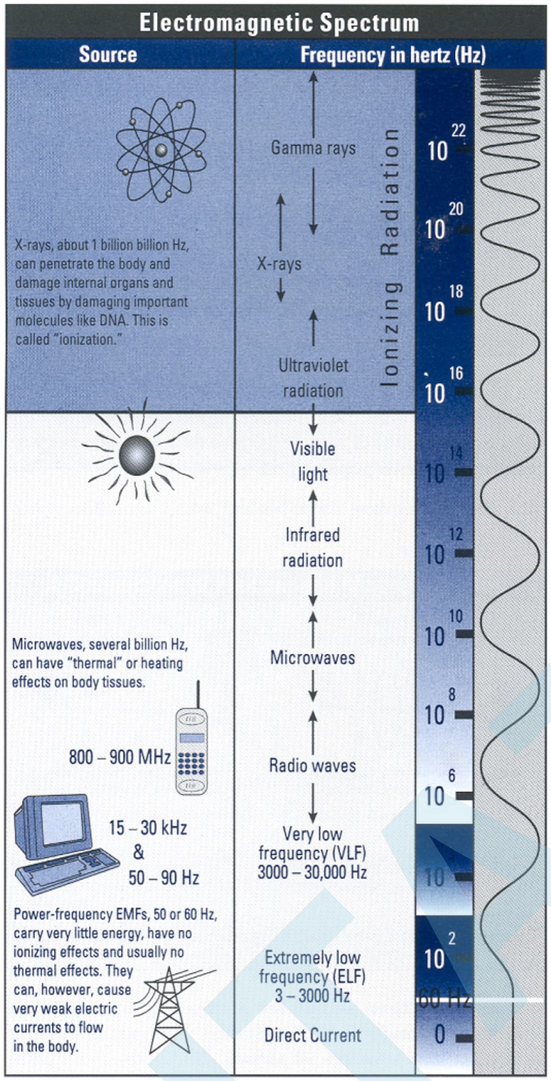
1.0 Introduction & EMF Basic Theory



Electrified transportation systems such as the Transrapid TR08 MAGLEV, subways, trains, and trolleys operate by transferring electrical energy into an electromotive force that propels a passenger vehicle either forward or reverse on a fixed track. As electrical energy is consumed, electric and magnetic fields known as EMFs (electromagnetic fields) are produced in the process emanating into the passenger cars and surrounding environment from the propulsion, electrical supply (i.e., third rails, overhead catenary cables, high voltage feeders and substations) and on-board communication systems.

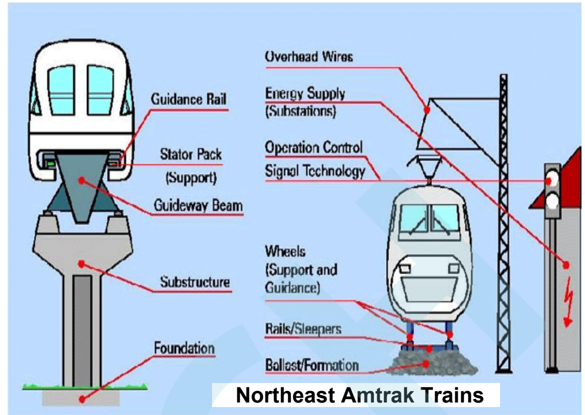
The Electromagnetic Spectrum shows the distribution of electromagnetic fields (EMFs) according to frequency and energy. In the ionizing region, the electromagnetic radiation is very destructive breaking the chemical bonds of RNA and DNA nucleic acids. The term *electromagnetic radiation* applies only to ionizing sources with sufficient energy to strip electrons from atoms and molecules damaging electronic components, cells and tissues.

Electromagnetic fields in the non-ionizing radiation region do not have the necessary destructive kinetic energy to strip electrons breaking chemical bonds -- these include visible and infrared light, microwave and radiofrequency (RF) sources, very low frequency (VLF), extremely low frequency (ELF) and static/quasi-static DC sources. Thermal heating, cooking and death can occur when in close proximity to high power microwave and RF emissions in the 300 kHz to 300 GHz ranges.

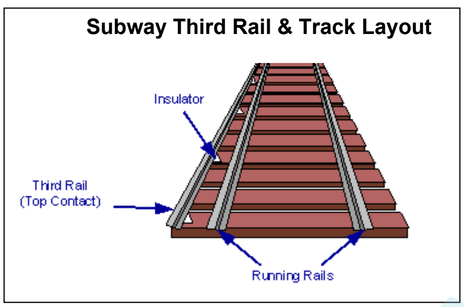
In response to this potential hazard, the Federal Communications Commission (FCC) issued Bulletin 65 in 1997 to establish maximum permissible exposure (MPE) limits for technically trained staff working in controlled occupational areas near antennas and transmitters, and a more stringent MPE limit for the general public in uncontrolled environments and for hand-held cell phones.

Older model cell phones operate in the region of 850 MHz while the newer personal communications service (PCS) phones in the 1,900 MHz band. Antenna output power can range from 600 milliwatts (mW) to over 3 watts for hand-held analog/digital cell phones and mobile transceivers. Although the FCC requires cell phones to comply with a maximum Specific Absorption Rate (SAR) of 1.6 watts per kilogram (1.6 W/kg), SAR testing methods are for the most part intentionally confusing, especially as published by the manufacturers, contributing to the exposure risk controversy and public fear regarding safety.

Electric power and transportation systems operate in the extremely low frequency (3 Hz to 3000 Hz) and sub-extremely low frequency (0 – 3 Hz) bands at the bottom of the electromagnetic spectrum. The two major electric power and distribution systems of the world run on two different fundamental frequencies: 60 Hz in the Western Hemisphere (i.e., North and most of South America) and 50 Hz in the Eastern Hemisphere (i.e., Europe, Asia, Africa, Oceania, etc.).



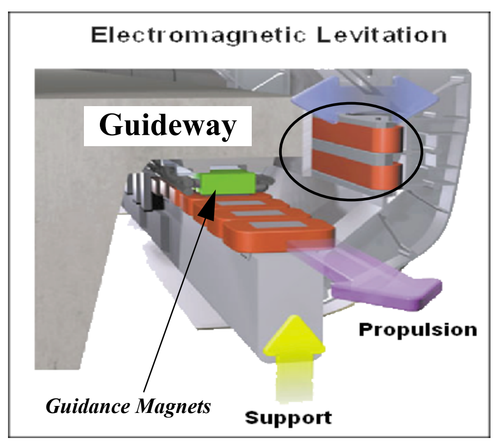
The Northeast Amtrak railway system from Washington to New Haven applies traction power to the trains via electrified overhead wires (catenary cables) operating at two different frequencies: 25 Hz from Washington to New York City and 60 Hz from New York City to Boston. The Transrapid TR08 MAGLEV operates with a time-varying 0 to 300 Hz electric current applied to the synchronous longstator linear motor installed in both the guideway and vehicle for propulsion and braking.



Metropolitan subway systems, especially in the Northeast, use direct current (DC) between the third-rail and two tracks to provide traction power to the subway cars. For example, the New York City and Boston subways run on 600 VDC while the newer Washington, D.C. system a 750 VDC system. In the United Kingdom, the London Underground subway is 630 VDC. Remarkably, the subways of New York, Boston and London are over 100 years old.

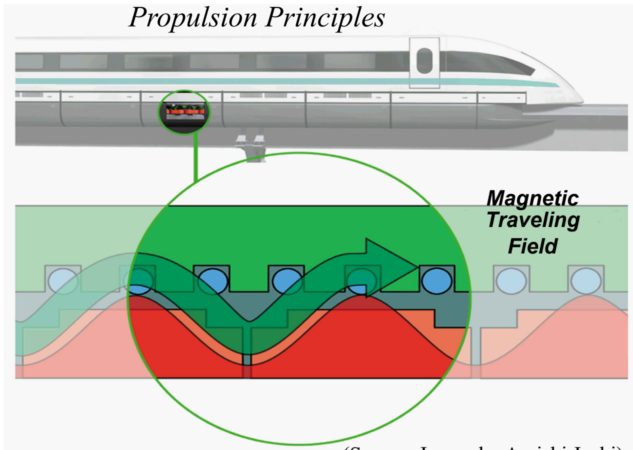
1.1 Transrapid TR08 MAGLEV Levitation & Propulsion System

The Transrapid TR08 MAGLEV system is a *synchronous longstator linear motor* with conventional electromagnets integrated into guideways and vehicles to generate an attractive magnetic force. During propulsion, *levitation magnets* pull the vehicle towards the stator packs from below to hover above the guideway while *guidance magnets* maintain a precise centreline above the guideway in motion.



As the vehicle moves along the guideway, the energized *levitation* and *guidance* magnets installed along the entire length on both sides of the vehicle and sections of the energized stator packs under the guideway emanate static/quasi-static DC and ELF magnetic fields into the passenger compartments and surrounding environment. Magnetic field emissions are negligible near guideway, except when vehicles pass, and inside passenger compartments stopped at a station.

By changing the frequency (0 to 300 Hz) of the applied alternating current to the synchronous longstator linear motor, vehicle acceleration and velocity is varied by the *magnetic traveling field* that propels the levitated trains forward and backward. To reduce vehicle speed and stop, the linear motor is configured to also produce a generator effect. On-board batteries provide all power to the vehicles – when in motion the batteries are charged by the generator effect of the linear motor.



(Source: Image by Amishi Joshi)

Electric power from the local utility is distributed by MAGLEV substations to switching control panels located adjacent to and beneath the guideways. Finally, a centralized MAGLEV command center controls and manages the switching control panels, signals, guideways and communicates to vehicles via a 38-40 GHz radiofrequency (RF) data link.

1.2 Fundamental - Electric & Magnetic Fields

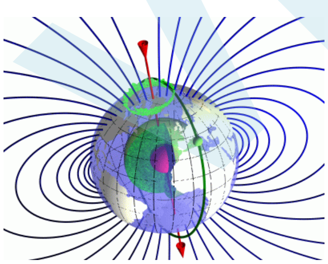
Electricity whether supplied by a small battery, transmission line, or electrical outlet has a voltage and current. Voltage (specified in volts) is the potential difference between electric charges and the source of electric fields **E** measured as electric field strength in volts-per-meter (V/m).

For example, under the mid-span of a 500 kV transmission line, the *electric field strength* is 7 kilovolts-per-meter (kV/m) three feet above the ground; more than enough to illuminate a hand-held fluorescent tube. Good reason not to play sports beneath high voltage transmission lines. Fortunately, grounded conductive object such trees, buildings, and metal conduits easily attenuate (reduce) electric fields, thereby providing a shielding effect.

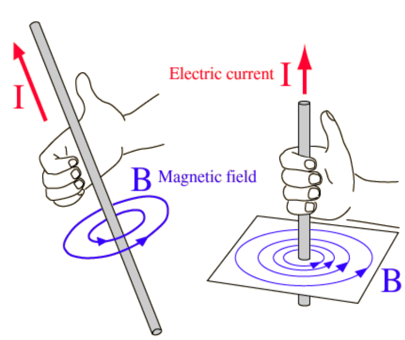
Current (specified in amperes) is the rate electric charges flow past a given point and the source of magnetic fields **H** measured in amps-per-meter (A/m). When an emanating *magnetic field* **H** permeates (passes through) a medium such as free space, building or person, it converts to another term known as *magnetic flux density* **B** measured in Gauss as follows:

$\mathbf{B}_{\textbf{magnetic flux density}} = \mu \mathbf{H}_{\textbf{magnetic field}}$ where μ is the permeability of the medium

To simplify the descriptive text in this report, Gauss (G) and milligauss (mG), which are used in the United States as units of *magnetic flux density,* will also apply to the term *magnetic field*.



Static DC magnetic fields from direct current (DC) sources are normally unidirectional (fixed) and relatively constant over time like the earth's geomagnetic field (see *right-hand rule* example on next page). The resultant geomagnetic field is 670 mG at the north and south poles, around 550 mG at the middle latitudes and Pittsburgh, and 330 mG at the equator. Core samples of the deep Atlantic mid-ocean ridges revealed alternating North-South magnetic rock bands indicating reversal of the earth's magnetic poles every 200,000 years.



A static DC and time-varying AC current I (in amps) on a wire generates a circular magnetic field according to the *right-hand rule: if the* *fingers of the right hand are placed around the wire so that the thumb points in the direction of current flow, the fingers will point in the direction of the magnetic field produced by the wire.* Using a simple formula $\mathbf{B_{mG} = 2(I_{amps})/r_{meter}}$ it is possible to calculate the magnetic field level at selected distances from the wire.

High current sources such as lightning, transmission and distribution lines, transformers, electric and MAGLEV trains, secondary feeders, switchgears, busways, electrical panels, motors, and electric heaters produce elevated and high magnetic fields**.** Time-varying ELF magnetic sources can induce electromagnetic interference (EMI) in CRT computer monitors (i.e., screen jitter), diagnostic medical equipment and scientific instruments depending on the susceptibility to EMI and magnitude of the source. *Magnetic fields* from static/quasi-static DC and AC ELF sources are difficult to shield and easily permeate (penetrate) nearly all materials including people, trees, buildings, concrete, equipment, and most metals except those composed of permeable ferromagnetic alloys (i.e., low-carbon steel, silicon-iron steel, nickel-iron, cobalt-iron, etc.) and thick, highly conductive (i.e., copper and aluminum) materials as shown below

AC ELF Magnetic Shield	DC Magnetic Shield	RF Shield
		

Procedures for recording, assessing and comparing the electromagnetic field (EMF) and electromagnetic radiation (EMR) generated by high-speed TR07 MAGLEV vehicles with other rail systems are presented in several technical documents published in 1993 by the FRA (see references). Recently, the FRA released the *Electromagnetic Field Characteristics of the Transrapid TR08 MAGLEV System*. These publications present available EMF data on existing transportation systems, including the proposed TR08 MAGLEV, as well as a discussion of applicable standards and guidelines for EMF and EMR human exposure safety.

Currently, there are no national standards for static/quasi-static DC or extremely low frequency (ELF) magnetic field exposure in the United States. Two voluntary standards published by the American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission of Non-Ionizing Radiation Protection (ICNIRP) recommend maximum permissible exposure (MPE) for the general public and those with cardiac pacemakers and implants. Human exposure to EMF/EMR radio-frequency (RF) sources are regulated by the FCC's OET Bulletin 65 *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields* for the General Population/Uncontrolled environments.

Section 2, Transrapid TR08 MAGLEV System EMF Assessment

In August 2001 the electric and magnetic field characteristics from the Transrapid TR08 MAGLEV System were recorded at the Transrapid Test Facility (TVE) (see Figure 2.1-1) near Emsland, Germany, for the Federal Railroad Administration (FRA) by Electric Research & Management, Inc. and published in *The Electromagnetic Field Characteristics of the Transrapid TR08 MAGLEV System* (DOT-VNTSC-FRA-02-11) in May 2002. The EMF analysis and assessments discussed in Sections 2 and 3 are based exclusively upon the recorded EMF data and technical information presented in the May 2002 report. Section 2.1 discusses basic procedures and methods used to record the EMF characteristics of the Transrapid TR08 MAGLEV System. The next three sections present selected EMF data recorded inside TR08 MAGLEV passenger cars while moving and stationary (section 2.2), on the platform as cars pass and stop at the station (section 2.3), and from the guideway (section 2.4) and switching cabinets (section 2.5).

2.1 EMF Characteristics - Procedures & Methods

The specific details regarding the instruments and data collection protocols used to record the electric and magnetic field characteristics are beyond the scope of this report. As discussed in the introduction, electromagnetic fields (EMF) of various frequencies normally emanate from electrified transportation and electric power systems. Since the Transrapid TR08 MAGLEV System is located in Germany, the electrical power operates at 50 Hz (when deployed in the United States it will be 60 Hz). In order to evaluate the potential EMF impact on passengers and the surrounding environment, it was necessary to record a wide spectrum of electric and magnetic fields at the Transrapid Test Facility (TVE). *Table 2.1-1, Recorded Electric & Magnetic Field Parameters,* shows the Frequency Band, EMF field (magnetic or electric), Bandwidth (frequency range of recorded data) and Data Range (possible lowest and highest recorded levels) of the instruments deployed to record EMF data during the tests:

Table 2.1-1, Recorded Electric & Magnetic Parameters

Frequency Band	EMF	Bandwidth	Data Range
Static & Quasi-Static DC	Magnetic	0 Hz – 3 Hz	0.01 mG - 10,000 mG
Extremely Low Frequency (ELF)	Magnetic	3 Hz - 3,000 Hz	0.01 mG - 10,000 mG
Extremely Low Frequency (ELF)	Electric	3 Hz - 3,000 Hz	1 V/m - 70 kV/m
Very Low Frequency (VLF)	Magnetic	3 kHz – 30 kHz	0.5 mG - 2,000 mG
Low Frequency (LF)	Magnetic	30 kHz - 300 kHz	0.5 mG - 2,000 mG
Radiofrequency (RF) fields	Electric	80 MHz -40 GHz	1V/m - 300 V/m

The first two magnetic frequency bands, static/quasi-Static DC and Extremely Low Frequency (ELF), from 0 Hz to 3000 Hz, contain the most important EMF data and information. The ambient average 500 mG geomagnetic fields of the earth at the TVE site are compared to the recorded static/ quasi-static DC emissions inside the TR08 passenger car when moving and stationary, on the platform as the TR08 passes and stops, and near the guideway as the TR08 travels. The critical EMF information is contained in the Extremely Low Frequency (ELF) band from 3 Hz to 3000 Hz. This includes the local German utility frequency of 50 Hz and the complex magnetic emission profile that emanates from the control/distribution systems beneath the TR08 passenger car floor, levitation and guidance magnets along the sides of each car and the stator packs mounted in the guideway all of which are part of the s*ynchronous longstator linear motor*.

The magnetic field levels were negligible in the 3 kHz – 30 kHz Very Low Frequency (VLF) and 30 kHz - 300 kHz Low Frequency (LF) bands inside the TR08 passenger car, at the station platform, near the guideway and switching cabinet. Electric field strength levels in the 3 Hz – 3000 Hz Extremely Low Frequency (ELF) band were generally low and due to nearby electrical power sources on-board the TR08 cars (2.5 – 5.5 V/m) measured at chest height and the platform 1-meter from stationary and passing TR08 cars (3 V/m – 32.9 V/m). Finally, the RF electric field strength levels were low inside the passenger compartments (1.2 V/m – 5 V/m) and negligible on the platform 1-meter from the passing TR08.

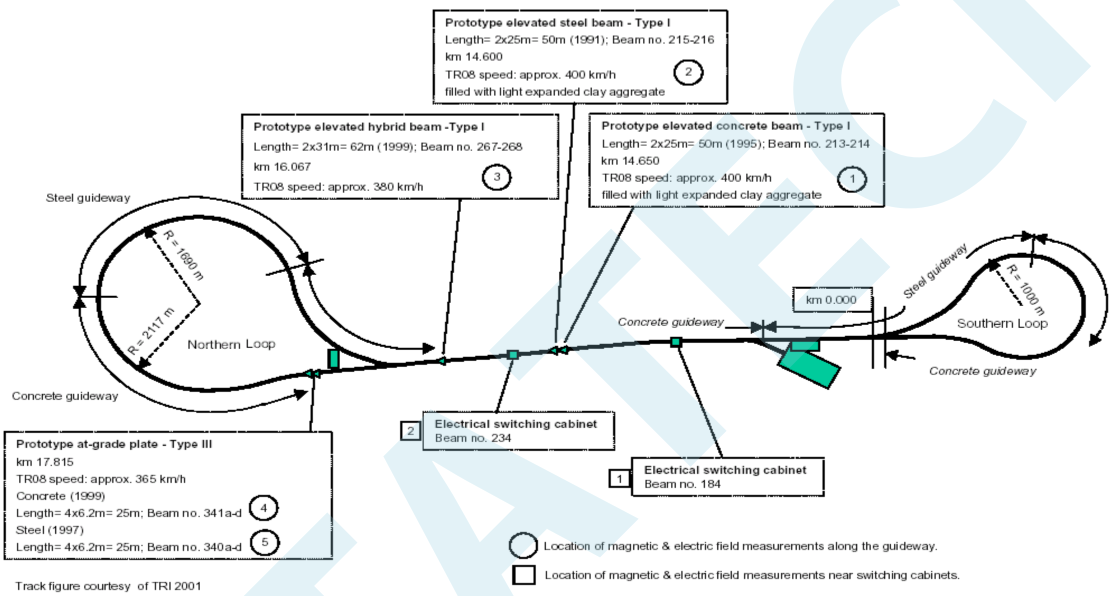
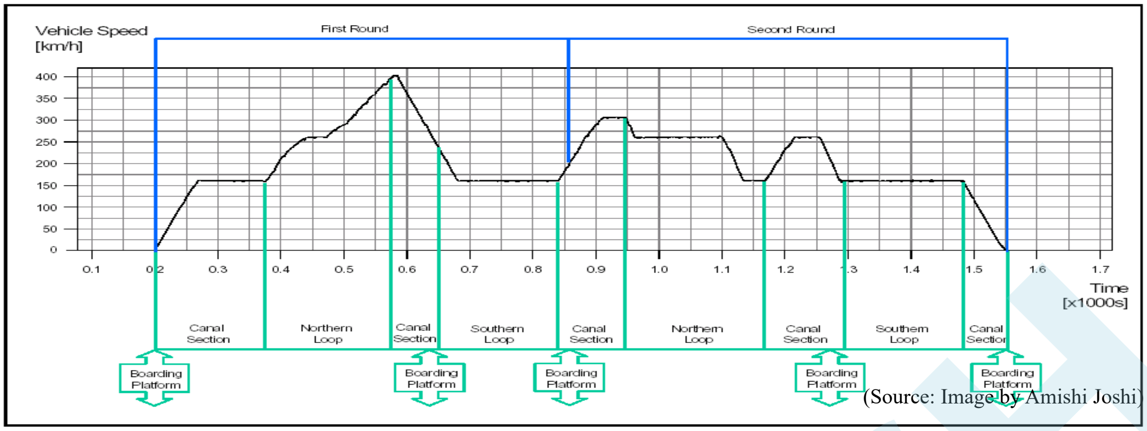


Figure 2.1-1. Transrapid Test Facility (TVE)

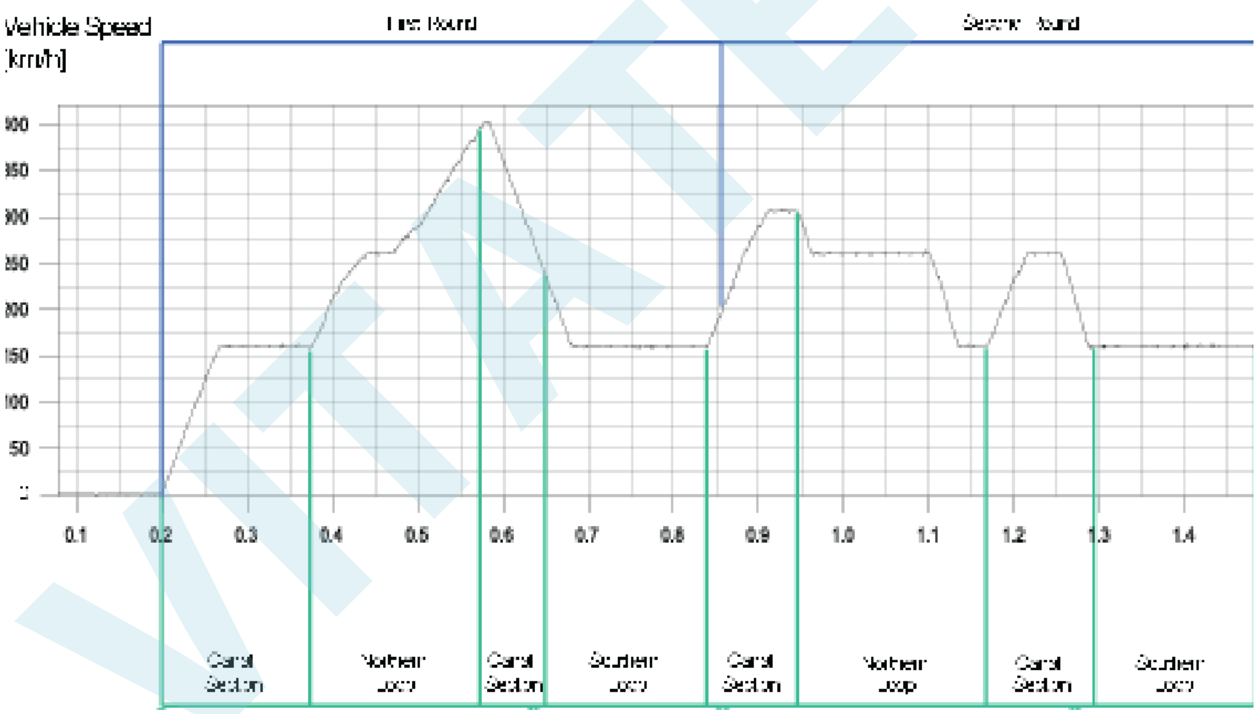
EMF data was recorded inside the TR08 passenger vehicles, on the platforms, along the at-grade and elevated guideways, and near the electrical switching cabinets at the Transrapid Test Facility (TVE) near Emsland, Germany, shown below in Figure 2.2-1:

The TVE test facility has a 31.5 km (19.5 mile) guideway (elevated and at-grade sections) of several construction types (steel, concrete, and hybrid) with two loops at each end. One trip is two complete runs of the entire track length with TR08 Passenger Vehicle operating speeds ranging from 150 km/h (99.2 mph) to over 400 km/h (249 mph) as presented in Figure 2.2-2 below:



Source: Transrapid International (TRI)

Figure 2.1-2. Typical Speed Profile of TR08 at the Transrapid Test Facility



2.2 TR08 Passenger Vehicle On-Board Static/Quasi-Static DC & ELF Magnetic Field Data

Electric and magnetic field emissions were recorded inside the TR08 passenger vehicles at 14 locations while stationary and moving along the guideway. A test mannequin representing a seated or standing passenger was deployed to record EMF data equipped with sensors located at the head, chest, waist, leg and ankle as shown below in Figure 2.2-1.

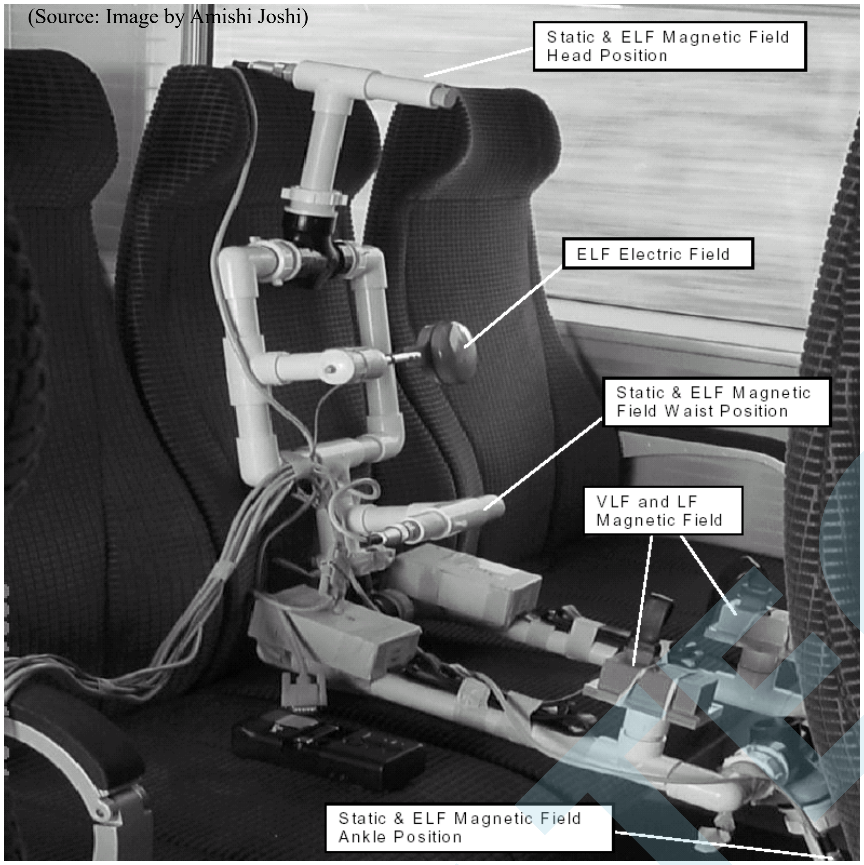


Figure 2.2-1. Test mannequin seated in TR08 vehicle with sensors

According to the test plan electric and magnetic field data was to be recorded around a two-lap trip of twenty minutes with data sampling every 15 seconds. Several unforeseen difficulties at the TVE test site interfered with EMF data collection including unsuccessful vehicle starts, delays departing the station, unexpected stops while moving along the guideway, extending planned travel times, and passing the station before stopping.

Another problem was maintaining the standard speed profile (see Figure 2.1-2) planned for all test trips as data was recording. Fortunately, similar average vehicle speeds were achieved on most trips. There appeared to be no correlation between TR08 speed, guideway current, passenger load and the magnetic field levels in the passenger vehicles, except during acceleration and deceleration when increased current is required to change the velocity of the vehicles. Data suggests lower field levels may occur inside the vehicle when loaded with passengers.

To simply analysis of the magnetic field levels within the TR08 passenger cars while stationary (not levitating) and moving, three selected locations in each car (Lead, Middle and Trailer) are presented and discussed. Locations 1, 3 and 4 were selected in the Lead Car (see Figure 2.2-3) to show magnitude variation laterally from centerline to bulkhead.

(Source: Image by Amishi Joshi)

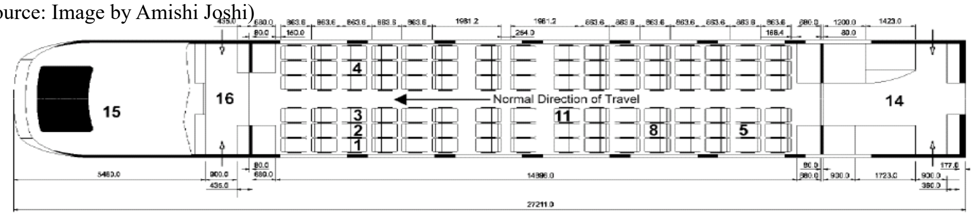


Figure 2.2-2. TR08 – Lead Car Data Locations

When stationary (not levitating) the head and waist static/quasi-static DC magnetic fields (0 Hz) at seats 1, 3 and 4 are in the normal geomagnetic range (400 mG – 600 mG) of the earth's magnetic field with elevated levels near the floor from large ferromagnetic components and DC currents in the control/distribution systems beneath (see Table 2.2-1 below). Stationary ELF magnetic fields (2 – 3002 Hz) at the same locations were low and according to the 48 – 62 Hz component spectral data (not shown) due to power frequency sources such as the lighting, air conditioning and other electrical power equipment either inside the car or at the station (see Table 2.2-1 below).

Table 2.2-1. Stationary TR08 Lead Car Magnetic Fields (* - Data not available)

Train Stationary – Lead Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0 – 3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Seat 1	**Seat 3**	**Seat 4**			**Seat 1**	**Seat 3**	**Seat 4**
Head	Mean	501	648	400	**Head**	Mean	1.19	1.15	1.33
	Range	*	*	*		Range	*	*	*
Waist	Mean	334	478	310	**Waist**	Mean	1.07	2.36	2.50
	Range	*	*	*		Range	*	*	*
Ankle	Mean	612	1012	438	**Ankle**	Mean	0.71	2.54	3.52
	Range	*	*	*		Range	*	*	*

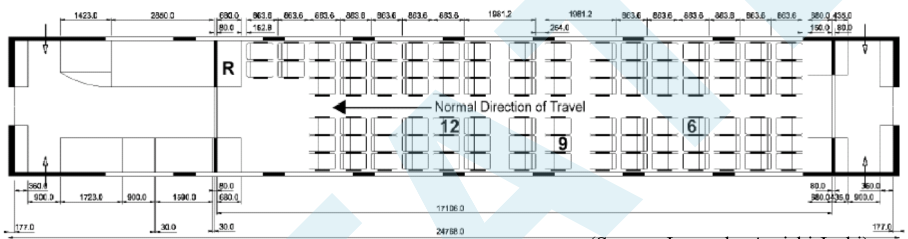
Moving TR08 passenger vehicles emanate a spectrally complex emission profile with wide fluctuations (see ranges) in the static/quasi-static DC and ELF magnitudes as the Lead Car levitate, accelerate, travel, decelerate and stop along the guideway as shown in Table 2.2-2 on the next page.

Table 2.2-2. Moving TR08 Lead Car Magnetic Fields

Train Moving – Lead Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0-3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Seat 1	**Seat 3**	**Seat 4**			**Seat 1**	**Seat 3**	**Seat 4**
Head	Mean	539	553	506	**Head**	Mean	35.2	26.4	26.8
	Range	325-852	369-1158	157-611		Range	7.1-108.1	3.7-87.4	2.1-80.3
Waist	Mean	429	376	522	**Waist**	Mean	45.4	37.6	37.1
	Range	150-845	124-1084	219-817		Range	8.4-123.5	5.1-123.8	3.4-135.3
Ankle	Mean	1105	905	919	**Ankle**	Mean	93.6	58.5	67.6
	Range	575-2168	512-2035	273-1520		Range	27-236.1	7.3-190.6	6.6-245.7

Near the floor by the ankle sensors, the mean static/quasi-static DC magnetic fields ranged from 905 to 1105 mG with peak emissions exceeding 2,000 mG at seats 1 and 3. The mean ELF emissions at the ankle were 37 to 45 mG with peaks exceeding 200 mG. At the waist and head, the static and ELF mean/peak magnetic levels decay to less than 50%, which is normal since magnetic field strength decreases as a function of distance from the source.

Middle Car data locations 6, 9 and 12 are shown in Figure 2.2-4 where spots 9 and 12 were above the battery compartments and power distribution system, respectively.



(Source: Image by Amishi Joshi)

Figure 2.2-3. TR08 – Middle Car Data Locations

Static/quasi-static and ELF levels (mean and peak) in the Middle Car when stationary (not levitating) and moving were less compared to the Lead Car (see Tables 2.2-3 and 2.2-4). Obviously, the type of control and power distribution equipment beneath the floor of each car contributes to the magnetic emissions profile beside the levitation and guidance magnets along the sides and the guideway mounted stator packs. Statistically it would have been more valid to record a fixed array of data points at set distances throughout each car, although very difficult and costly to perform without deploying multiple test mannequins.

Table 2.2-3. Stationary TR08 Middle Car Magnetic Fields (* - Data not available)

Train Stationary – Middle Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0-3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Seat 6	**Seat 9**	**Seat 12**			**Seat 6**	**Seat 9**	**Seat 12**
Head	Mean	391	417	522	**Head**	Mean	0.41	0.37	0.35
Waist	Mean	541	291	476	**Waist**	Mean	0.87	0.53	0.37
Ankle	Mean	620	337	502	**Ankle**	Mean	9.48	0.74	1.39

Table 2.2-4. Moving TR08 Middle Car Magnetic Fields

Train Moving – Middle Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0-3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Seat 6	**Seat 9**	**Seat 12**			**Seat 6**	**Seat 9**	**Seat 12**
Head	Mean	619	525	535	**Head**	Mean	22.1	21.5	21.2
	Range	395-826	306-648	139-699		Range	2.2-56.6	0.4-48.8	2.8-66.1
Waist	Mean	565	443	392	**Waist**	Mean	32.3	32.5	28.2
	Range	394-823	131-627	214-602		Range	3.4-72.4	0.5-106.7	4.4-86.3
Ankle	Mean	797	579	452	**Ankle**	Mean	65.3	80.3	54.0
	Range	412-1324	218-917	185-840		Range	10.2-147.	0.8-213.7	8.2-212.2

In the Trailing Car spot 10 is above the battery compartment and spot 13 over power distribution systems (see Figure 2.2-5); whereas, spot 7 is similar to spots 4 and 6 in the Lead and Middle Cars.

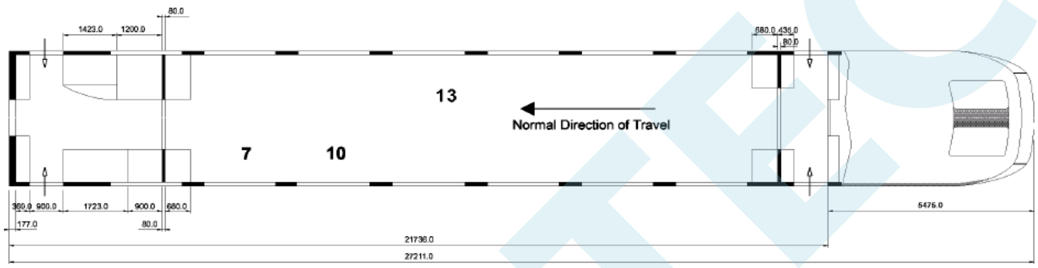


Figure 2.2-4. TR08 – Trailer Car Data Locations

Levels (mean and peak) in the Trailer Car when stationary (not levitating) and moving were similar to the Middle Car and less than the Lead Car (see Tables 2.2-3 and 2.2-4). As discussed on the previous page -- Statistically it would have been more valid to record a fixed array of data points at set distances throughout each car.

Table 2.2-5. Stationary TR08 Trailer Car Magnetic Fields (* - Data not available)

Train Stationary – Trailer Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0-3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Spot 7	**Spot 10**	**Spot 13**			**Spot 7**	**Spot 10**	**Spot 13**
Head	Mean	482	541	556	**Head**	Mean	0.44	0.28	0.39
	Range	*	*	*		Range	*	*	*
Waist	Mean	374	390	398	**Waist**	Mean	1.06	0.37	0.64
	Range	*	*	*		Range	*	*	*
Ankle	Mean	455	406	515	**Ankle**	Mean	6.95	1.08	1.59
	Range	*	*	*		Range	*	*	*

Table 2.2-6. Moving TR08 Trailer Car Magnetic Fields

Train Moving – Trailer Car Magnetic Field Levels in Milligauss – mG									
Static/Quasi-Static DC Magnetic (0-3 Hz)					**ELF Magnetic Fields (2-3002 Hz)**				
		Spot 7	**Spot 10**	**Spot 13**			**Spot 7**	**Spot 10**	**Spot 13**
Head	Mean	586	610	580	**Head**	Mean	22.8	24.4	19.1
	Range	366-792	201-1003	486-874		Range	1.2-54.8	0.2-92.5	2.2-65.5
Waist	Mean	515	504	382	**Waist**	Mean	32.9	36.8	26.1
	Range	226-783	50-927	281-782		Range	1.7-91.6	0.3-122	3.2-111.7
Ankle	Mean	699	692	452	**Ankle**	Mean	65.4	60.2	34.9
	Range	298-1279	206-1195	315-967		Range	7.5-169.2	0.4-203.8	5.2-84.9

Static/quasi-static DC and ELF data was recorded in the Operator's Position while the TR08 Vehicles were stationary and moving; however, that information, although important, was not presented since the objective is assess the potential impact of EMF exposure to the public and environment from the proposed TR08 MAGLEV system.

Figure 2.2-5 shows the waist height ELF magnetic field spectral plot from 3 Hz to 300 Hz of a seated passenger at location 2 in the Lead Car (see Figure 2.2-2) during a 1600 second (26.7 minute) trip. When the car is stationary, a small 50 Hz ridge is visible from 0 to about 250 seconds due to the nearby electric power sources. Three failed attempts to depart the station (see peaks) are also distinguishable in the first 400 seconds. Approaching the maximum 400 km/hr (249 mph) at 700 seconds (see speed/time insert chart) the maximum frequencies were 110 Hz and 220 Hz. As the car accelerates, travels at a fix velocity and decelerates, the magnetic field emissions increase and decrease accordingly in magnitude and complexity. Remarkably, all of the spectral emissions are within a narrow band from 0 Hz to 300 Hz, which is the operating frequency of the electric current applied to the synchronous longstator linear motor installed in both the guideway and vehicle for propulsion and braking.

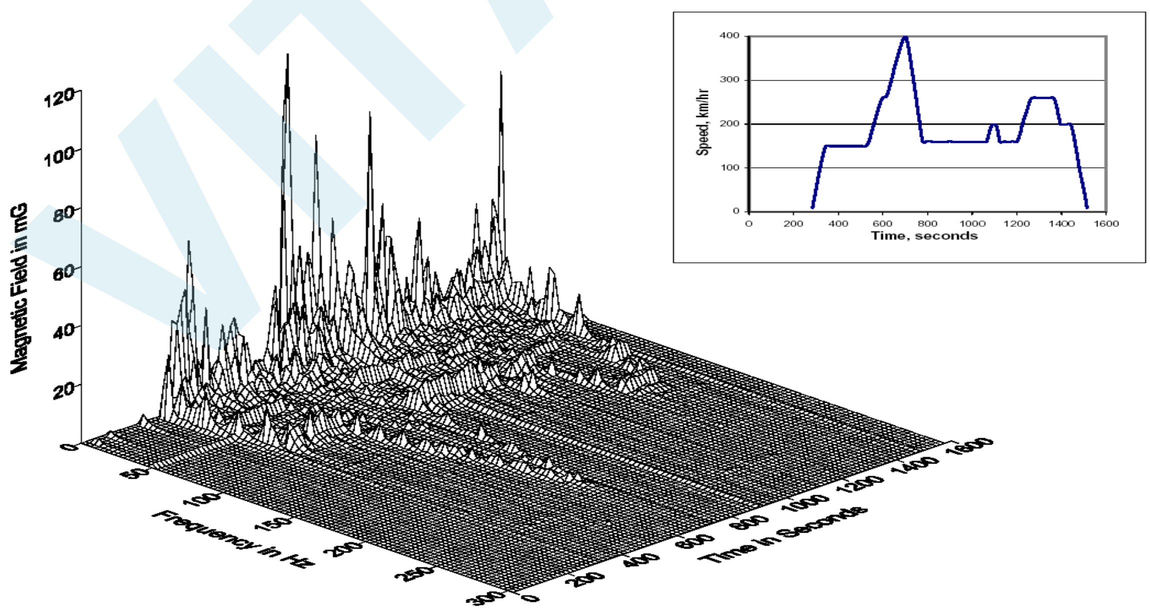


Figure 2.2-5 Waist high ELF magnetic field expanded 3 Hz – 300 Hz spectral plot

2.3 Station Static/Quasi-Static DC & ELF Magnetic Field Data

For safety, future stations will probably have protective moveable doors and walls to separate waiting passengers from high-speed passing and levitating trains. Such doors and partitions would naturally attenuate the electric fields (i.e., ELF, LF and RF), but have minimal effect on the magnetic field emissions when moving and levitating. To assess the magnetic emission profile on the station platform at the head, waist and ankle heights, data was recorded every three seconds as the train passed and stopped with the test mannequin standing at 1-m and 1.9-m from the platform edge as shown in Figure 2.3-1. Problems plagued the 1-m data collection at the platform when on the fourth pass the TR08 missed stopping at the station, so the car had to reverse and travel slowly back into the station to complete the stop and data collection.

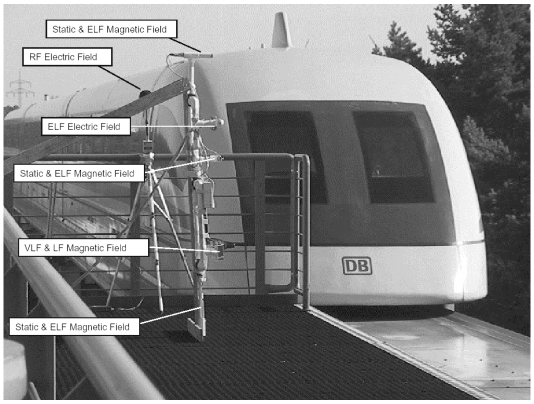


Figure 2.3-1. Test mannequin standing on platform

Static/quasi-static DC and ELF magnetic emission data was recorded on the station platform 1- and 1.9 meters from the edge when the TR08 cars were Running Elsewhere, Passing Station and Stopping at Station as shown in Tables 2.3-1 and 2.3-2 below. The static/quasi-static DC mean and peak magnetic field levels were within the 400 – 600 mG ambient background levels at the site during all three conditions (elsewhere, passing & stopping). When Stopping at Station the static /quasi-static DC magnetic fields were slightly higher compared to Running Elsewhere and Passing Station, but still within the ambient background levels at the site (see Table 2.3-1).

Table 2.3-1. Station – Static/Quasi-Static DC Magnetic Fields Magnetic Fields

Station – Static/Quasi-Static DC Magnetic Field Levels Magnetic Field Levels in Milligauss – mG							
		1 meter from TR08			**1.9 meter from TR08**		
		Running Elsewhere	Passing Station	Stopping At Station	Running Elsewhere	Passing Station	Stopping At Station
Head	Mean	517	517	533	581	574	593
	Range	515-519	515-519	477-619	577-582	542-582	559-633
Waist	Mean	502	502	519	556	546	577
	Range	501-504	500-504	472-559	553-558	515-558	517-637
Ankle	Mean	456	456	519	433	425	468
	Range	453-457	453-457	411-642	431-434	396-435	406-539

Although DC currents and equipment beneath the floor and sides (levitation/guidance magnets) of the TR08 cars produce elevated static/quasi-static DC magnetic fields when in motion, these fields appear as time-varying ELF magnetic fields when passing at high-speeds the test mannequin on the platform. The synchronous longstator linear motor in the guideway and the moving cars generate the ELF magnetic field sources relative to the test mannequin on the platform. Obviously, when the TR08 is Running Elsewhere, the platform ELF magnetic levels are very low (see Table 2.3-2) and due exclusively to nearby 50 Hz electrical power sources. At the 1-m distance there were problems synchronizing the data collection when the cars were Passing Station. Apparently, data was either recorded too early or too late since there is a nearly a factor of 10 between the 1-meter mean Stopping at Station and Passing Station levels (see Table 2.3-2).

Levels are higher at the ankles nearest the guideway and car levitation/guidance magnetic emission sources decaying as a function of distance by 40-50% at head height and at slightly higher decay rates laterally from the cars to the 1.9 m spot on the platform. The ELF magnetic emissions recorded at various heights on the platform station within 1-meter of the cars is very similar in magnitude to those recorded inside the passenger cars when stopped at the station and probably also similar when passing.

Table 2.3-2. Station – ELF Magnetic Fields Magnetic Fields

Station - 2 to 3002 Hz ELF Magnetic Field Levels Magnetic Field Levels in Milligauss – mG							
		1 meter from TR08			**1.9 meter from TR08**		
		Running Elsewhere	Passing Station	Stopping At Station	Running Elsewhere	Passing Station	Stopping At Station
Head	Mean	0.6	2.7	24.4	0.5	10.2	10.3
	Range	0.6-0.6	1.0-6.5	3.1-108.3	0.5-0.5	0.7-54.1	2.1-57.4
Waist	Mean	0.7	3.0	30.5	0.5	13.3	11.9
	Range	0.6-0.7	1.2-6.8	3.8-140.1	0.5-0.6	0.6-63.7	2.5-67.5
Ankle	Mean	0.8	3.6	43.7	0.6	17.2	15.6
	Range	0.7-0.8	1.7-7.3	6.4-204.1	0.6-0.6	0.6-82.9	4.2-94.1

Section 2.4, Guideway Static/Quasi-Static DC & ELF Magnetic Field Data

Static/quasi-static DC and ELF magnetic fields were recorded at five guideway locations around the TVE site as shown in Figure 2.1-1. Data was recorded at three elevated guideway locations (noted as circled 1, 2 & 3) representing steel, concrete and hybrid construction types and two at-grade sites (noted as circled 4 & 5). Field characteristics at each location were measured during two TR08 passes with data recorded for 300 milliseconds (mS) every 3 seconds up to 5 minutes. Due to operational problems, it was not possible to achieve identical TR08 speeds for each data run and only one of seven passes of data was recorded as the TR08 passed the elevated guideway.

As the TR08 moves along the at-grade and elevated guideways, the ambient geomagnetic field was only perturbed by 2% and less 5 meters away including under the elevated guideway, and less than 1% at 20 meters away. However, these quasi-static DC and ELF magnetic field emissions will cause EMI issues beyond 35 meters with sensitive research instruments such as ion beam electron microscopes (i.e., TEMs, SEMs, STEMs, FIBs, E-Beam, etc.), MRIs, NMRs and other EMI sensitive diagnostic and research tools as shown in Table 2.4-1 on the next page.

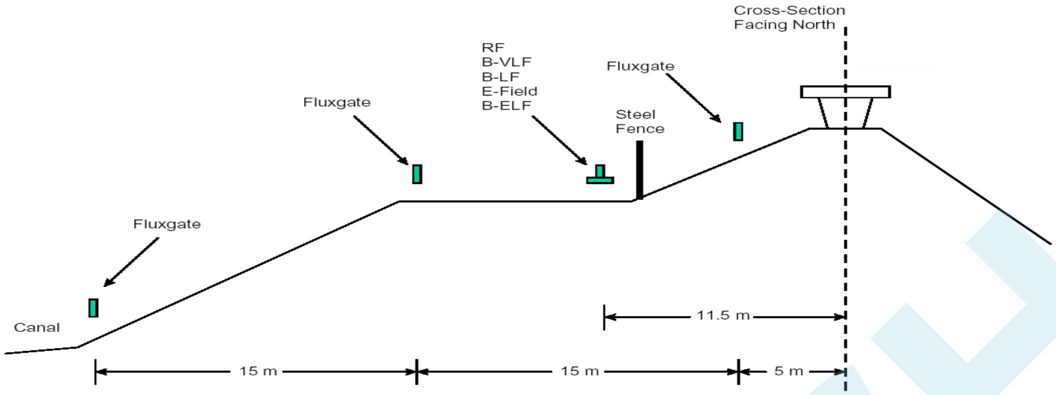


Figure 2.4-1. At-Grade guideway sensor placements

Static/quasi-static DC and ELF fluxgate measurements were recorded (see Figure 2.4-1) 1-meter above grade at 5 m, 11.5 m, 20 m and 35 m away from the guideway centerline. All sensors were placed 11.5 m from the centerline outside the steel safety fence because access inside was prohibited when the TR08 was operational.

Table 2.4-1 summarizes the at-grade average (mean) and peak (max) magnetic emissions at five distances from the centerline as the TR08 made four passes with a column showing the Potential ELF Electromagnetic Interference (EMI) caused by moving TR08 cars based on distance.

Table 2.4-1. At-Grade Average (mean) & Maximum (peak) levels as TR08 Passes

Distance To Centerline	At-Grade Guideway Average (mean) as TR08 Passes	At-Grade Guideway Maximum (peak) as TR08 Passes	Potential ELF Electromagnetic Interference (EMI)
5 m	116 mG	127 mG	YES
11.5 m	21 mG	27 mG	YES
20 m	8.4 mG	10.4 mG	YES
24.1 m	5 mG	6.5 mG	YES
35 m	2.5 mG	3.2 mG	YES

Electromagnetic induction (source of electromagnetic interference – EMF) occurs when quasi-static DC and time-varying ELF magnetic fields couple with any conductive object including wires, electronic equipment and people, thereby inducing circulating currents and voltages. In unshielded (susceptible) electronic equipment (computer monitors, video projectors, computers, televisions, LANs, diagnostic instruments, magnetic media, etc.) and signal cables (audio, video, telephone & data), electromagnetic induction generates electromagnetic interference (EMI), which is manifested as visible screen jitter in displays, hum in analog telephone/audio equipment, lost sync in video equipment and data errors in magnetic media or digital signal cables.

Generally, for AC 50 Hz electrical power sources the minimum EMI threshold is 1 uT (10 mG) RMS in unshielded electronic equipment, especially 14" to 17" Cathode Ray Tube (CRT) color computer monitors displaying *screen jitter* and analog signal cables; however, the AC 50/60 Hz EMI threshold for high-resolution 17" to 21" CRT color monitors is only 0.5 uT (5 mG) rms. It should be noted that liquid crystal displays (LCDs) are not susceptible (do not display *screen jitter)* when exposed to static/quasi-static DC and time-varying AC ELF magnetic emissions (no apparent EMI threshold limit for LCDs). Use the following formula to convert from peak-peak to root-means-square (RMS) where needed:

$$B_{rms} = \frac{Bp-p}{2\sqrt{2}} = \frac{Bp}{\sqrt{2}}$$

In hospitals, clinics and medical research facilities electrophysiology instruments such as EEGs, ECGs, and EMGs are susceptible to AC ELF EMI noise at 0.1 uT (1 mG) RMS. Vitatech recommends a maximum of 0.1 uT (1 mG) RMS for most NMRs and MRIs although some NMRs can tolerate up to 0.5 uT (5 mG) as specified by the manufacturer. A summary of DC & AC ELF EMI thresholds by unit of peak-to-peak are presented in Table 2.4-2 below:

DC & AC ELF EMI Peak-to-Peak (RMS) Typical Research Tool EMI Thresholds
1400 nT p-p (500 nT RMS) high resolution CRT monitors & audio/video analogue cables
300 nT p-p (100 nT RMS) magnetic imaging & electrophysiology (MRIs, NMRs, EEGs, EKGs, etc.)
80 nT p-p (29 nT RMS) typical electron imaging tools (SEMs, E-Beams Writers, FIBs, etc.)
30 nT p-p (10 nT RMS) improved performance electron imaging tools (SEMs, E-Beams, FIBs, etc.)
10 nT p-p (3.5 nT RMS) high performance electron imaging tools (TEMs, STEMs, EEGs, etc.)
Conversions: 1000 nT = 10 mG   100 nT = 1.0 mG   10 nT = 0.10 mG

Table 2.4-2, DC & AC ELF EMI Thresholds

The DC EMI thresholds in units of Gauss RMS for CRTs, Implantable Devices, credit cards, magnetic media, video / audio tapes and hard drives are listed in Table 2.4-3 below:

DC EMI Thresholds – Implantable Devices & Erasing Magnetic Media
0.75 Gauss RMS CRT Monitors Screen Shift Threshold & Electronic Instruments
5.0 Gauss RMS Cardiac Pacemakers & Implantable Devices (Must Post Warning Signs)
10.0 Gauss RMS Credit Cards & Magnetic Media (Must Post Warning Signs)
300 Gauss RMS Low Coercivity Mag-Stripe Credit Cards / Key Cards, Computer Diskettes
1000 Gauss RMS Audio/Video Tapes (VHS, U-matic, 1-inch, Betacam, etc.)
2800 Gauss RMS High Coercivity Mag-Strip Credit Cards
5000 Gauss RMS Hard Drives (1.8-, 2.5-, 3.5-, 5.25-inch, etc.)
Conversions: 1 Gauss = 1000 mG   10,000 Gauss = 1.0 Tesla

Table 2.4-3, DC EMI Thresholds – Implantable Devices & Erasing Magnetic Media

The European international 50 Hz magnetic field electronic and electrical equipment immunity standard, IEC 61000-6-1.2005-3, Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments recommends a maximum of 3 A/m RMS (Level / Class 2 – households, offices, etc.) magnetic field strength which converts to 37.7 mG RMS (note: multiply A/m by 4π to convert to magnetic flux density). In Europe, UK and other countries around the world except the United States, electronic and electrical equipment must be tested and CE certified to the IEC 61000-4-8 EMC Part 4-8 Testing and measurement techniques – Power frequency magnetic field immunity test for residential and commercial locations, industrial installations and power plants and medium and high voltage substations. IEC 61000-4-8 tests and certifies with a CE stamp one of five (5) classifications of Level / Class (x) according to the EMC environmental requirements shown in Table 2.4-4 below:

The IEC 61000-4-8 Level / Class 2 threshold of 37.7 mG RMS is 3.7 times higher than the 10 mG RMS level recommended for commercial buildings and long-term human occupancy (residential, etc.) in New York City, around the U.S. and in several European countries. CRT monitors do not operate in 37.68 mG RMS environments displaying screen jitter (waving back-and-forth); however, in the last decade most CRT monitors have been replaced by LCD monitors which are EMI immune to levels exceeding 1000 mG RMS without displaying screen jitter. But many electronic, computer, audio/video, control and communication equipment would experience EMI issues at 37.68 mG RMS unless there is a CE mark specifying compliance with IEC/EN 61000-4-8 Level 2 EMC standard. European electronic equipment manufacturers' are legally required test, verify and document compliance to the IEC/EN EMC standards in the Operator's Manual, but U.S. manufactures' are only required to meet FCC compliance for EMI/RFI immunity (Note: no FCC EMI immunity requirement for U.S. 60 Hz magnetic fields).

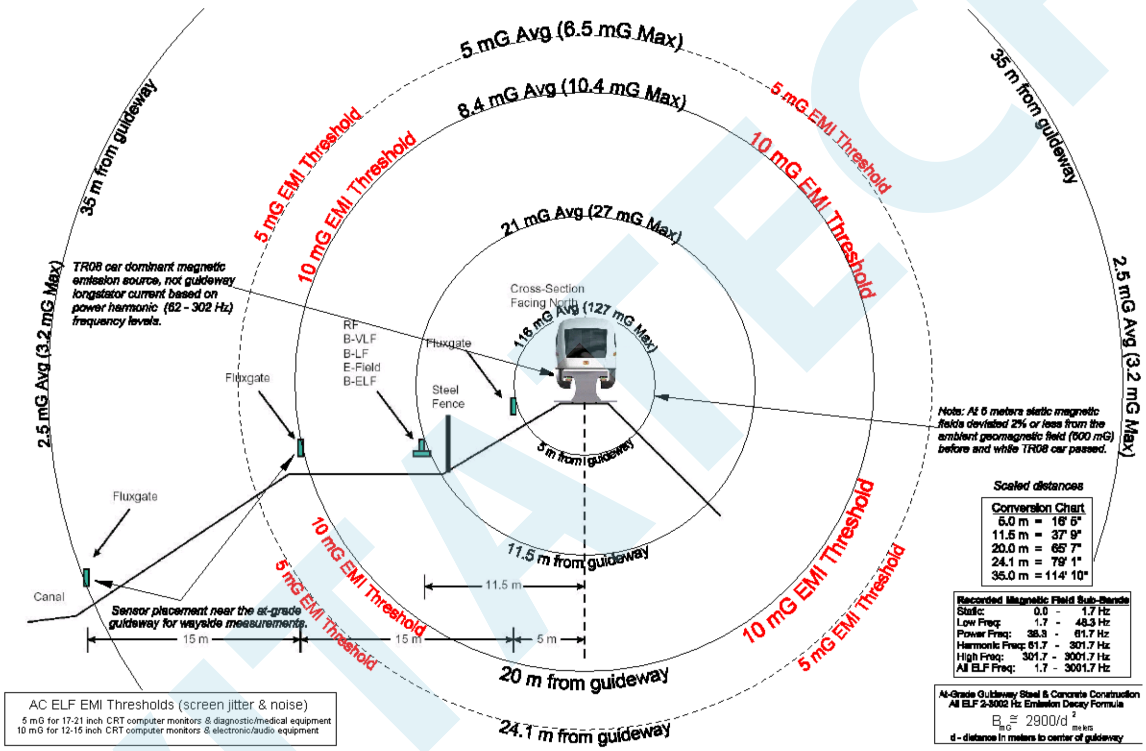


Figure 2.4-2. TR08 Passing ELF Magnetic Emission Decay At-Grade Guideway - Steel & Concrete Construction

Figure 2.4-2 on the previous page presents the at-grade ELF magnetic field data showing the mean (average) and peak (max.) levels at fixed radial distances from the centerline as the TR08 made four passes along the guideway. A moving TR08 has a symmetrical (bilateral) emission profile with static/quasi-static DC and ELF magnetic fields of nearly equal magnitude emanating from each side of the car and guideway section. Although Figure 2.4-2 shows circular isolines of equal magnitude below and above the moving at-grade TR08, data could not be recorded below (no access) or above any moving TR08 cars to support such uniformity – this was included to simplify the model. An ELF emission decay rate formula is shown to calculate the magnetic field level at a selected distance (d in meters) from the at-grade guideway when a TR08 car passes.

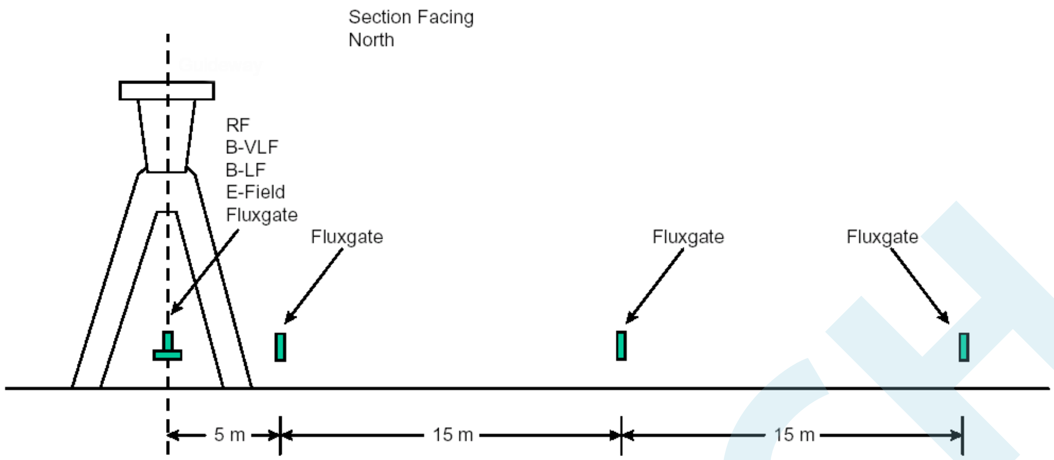


Figure 2.4-3. Elevated guideway sensor placements

Sensors were positioned under (0 m) the elevated guideway and adjacent to the centerline at 5 m, 20 m and 35 m away as shown in Figure 2.4-3. At each location the fluxgate sensor was positioned 1-m above grade. Only during a single pass out of seven attempts was the TR08 adjacent to the sensors to properly record data. Therefore, sufficient data were not available to calculate the average (mean) and maximum (peak) statistics for the elevated guideways.

Elevated guideway TR08 single pass magnetic field levels are shown in Table 2.4-5 at four distances from the centerline with a column showing the Potential ELF Electromagnetic Interference (EMI) caused by the moving TR08 cars based on distance.

Table 2.4-5. Elevated Guideway Single TR08 Pass Levels

Distance To Centerline	Elevated Guideway Single TR08 Pass	Potential ELF Electromagnetic Interference (EMI)
0 m	122.7 mG	YES
5 m	71.12 mG	YES
20 m	10.17 mG	YES
35 m	3.07 mG	YES

The at-grade ELF magnetic field data showing the mean (average) and peak (max.) levels at fixed radial distances from the centerline were overlaid on the single pass elevated guideway data in Figure 2.4-4 (next page). As in the at-grade model, a symmetrical (bilateral) magnetic emission profile emanates from each side of the moving TR08 car and guideway section. The elevated guideway 10 mG EMI threshold is 20 m from the centerline – similar to the at-grade guideway (see figure). Therefore, EMI problems will occur with CRT computer monitors and sensitive electronic equipment including research/diagnostic tools as presented in Tables 2.4-3 and 2.4-4 from beneath the elevated guideway to over 35 meters away on either side as the TR08 cars approach and pass. The elevated guideway 5-mG EMI threshold for high-resolution

CRT monitors and selected medical/scientific instruments is estimated to be between 24.1 (79 ft.) - 30.7 meters (~100 ft.).

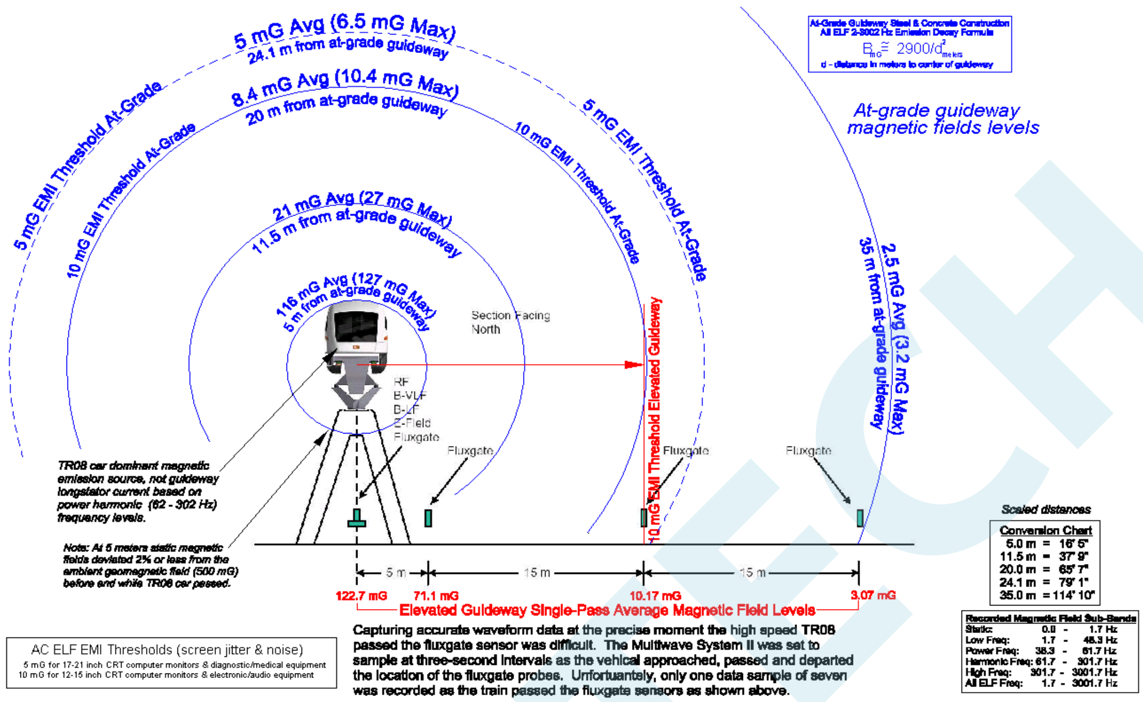
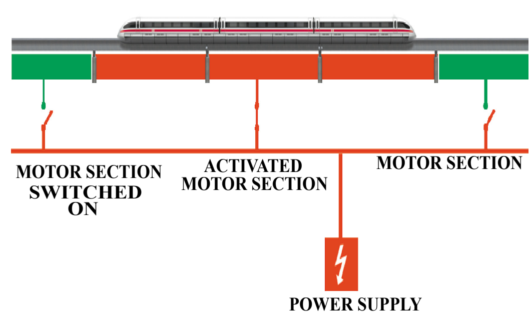


Figure 2.4-4. TR08 Passing ELF Magnetic Emission Decay Elevated Guideway - Steel & Concrete Construction

2.5 Switching Cabinet Static/Quasi-Static DC & ELF Magnetic Field Data

The levitating TR08 vehicles are pulled along by the *synchronous longstator linear motor,* which has stator packs mounted in sections under the guideway. Switching cabinets, located along each section of the guideway, supply power to the stator packs propelling the TR08 vehicle forward or reverse when accelerating or decelerating. Switching cabinets are feed from inverter stations around the site and only energized when a TR08 car is traveling in a section of the guideway controlled by the cabinet as shown in Figure 2.5-1. When a switching cabinet and associated guideway are not energized, the magnetic field emissions are negligible in that area.

Five sets of data were recorded from the switching cabinets at two locations under the elevated guideway (see Figure 2.2-1). Three data sets were from the redesigned cabinets. In order to isolate the car/guideway fields from the switching cabinet emissions, sensors were placed at 5, 20 and 35 meters lateral (perpendicular) and 3.5 m north of the switching cabinets (see Figure 2.5-2) as TR08 cars Figure 2.5-1. Energized guideway sections approached and departed.



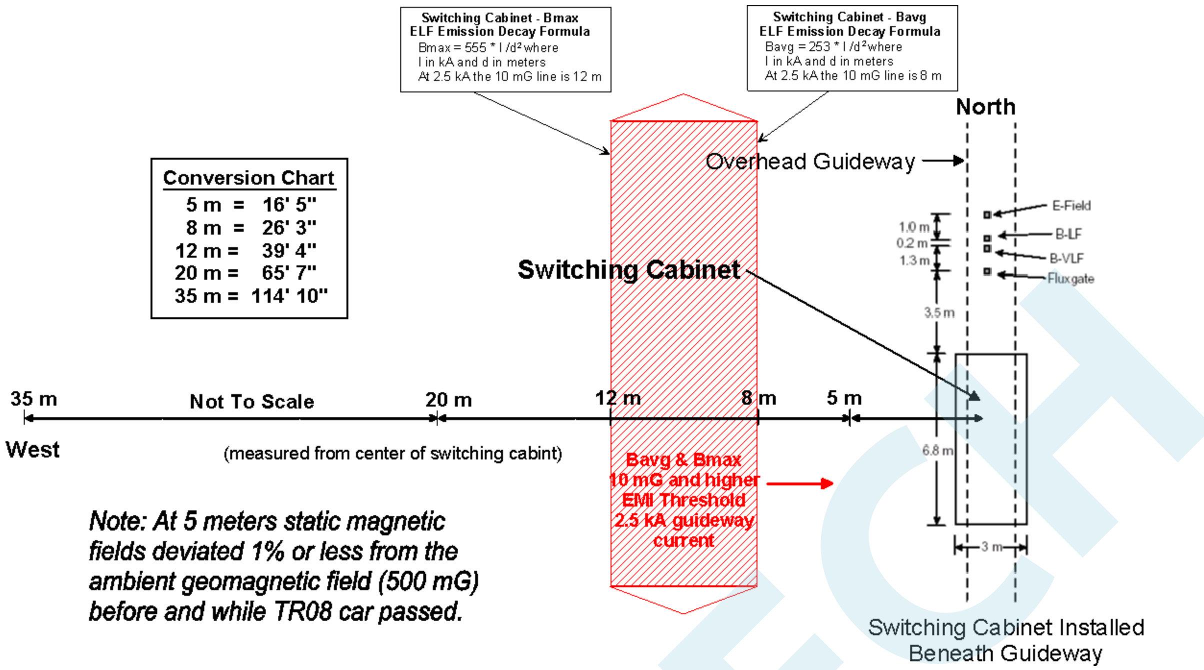


Figure 2.5-1. Switching cabinet sensor placement

The static/quasi-static DC magnetic fields had a very minimal impact (1% and less) on the ambient geo-magnetic fields as the switching cabinets were energized and de-energized. ELF magnetic fields around the switching cabinets were nearly sinusoidal with the frequency proportional to the TR08 car speed. ELF magnetic field levels were recorded during three constant speeds at four sensor locations as the TR08 cars approached and passed the switching cabinets. Table 2.5-1 shows the levels around the redesigned (new) switching cabinet when the TR08 car is traveling at 120 km/hr. Two ELF Emission Decay Formulas (see Figure 2.5-1) were extracted from the
recorded data to predict the Bavg (average) and Bmax (maximum) magnetic field levels at a selected lateral distance, d in meters, from the new switching cabinet based on guideway current (in kiloamps – kA). Using the Bavg and Bmax formulas, the 10 mG EMI threshold region was calculated based on a guideway current of 2.5 kA to be 8-12 meters west of the switching cabinet as the TR08 approached and departed the energized guideway section (Note: passing TR08 and guideway EMI emissions are significantly higher as discussed in section 2.4). Table 2.5-1 shows the recorded ELF magnetic fields at four distances from the switching cabinets when the TR08 Car is traveling 120 km/hr.

Table 2.5-1. Switching cabinet emissions at 120 km/hr

New Switching Cabinet Levels - TR08 Car Traveling at 120 km/hr		
	TR08 Approaching	**TR08 Departing**
	Range of Field Levels	Range of Field Levels
North of Cabinet 3.5 m	2.8-7.0 mG	16-0.3 mG
West of Cabinet 5 m	5.0-24.5 mG	28.0-0.9 mG
West of Cabinet 20 m	0.4-1.0 mG	1.1-0.07 mG
West of Cabinet 35 m	0.15-0.4 mG	0.4-0.06 mG

ELF magnetic emissions ranged from 0.9 mG to over 28 mG at 5 m west of the switching cabinet as the TR08 car approach and departed; whereas, levels 3.5 m north of the switching ranged from 3-8 mG approaching and 16-1 mG departing. North/south emissions from the switching cabinets under elevated guideways or adjacent to the at-grade guideways should not be considered a potential EMI problem since public access to such areas will be restricted.

Table 2.5-2. Switching cabinet emissions at 200 km/hr

New Switching Cabinet Levels - TR08 Car Traveling at 200 km/hr		
	TR08 Approaching	**TR08 Departing**
	Range of Field Levels	Range of Field Levels
North of Cabinet 3.5 m	0.2-0.7 mG	6.0-0.21 mG
West of Cabinet 5 m	0.2-1.5 mG	8.0-0.21 mG
West of Cabinet 20 m	0.1-0.15 mG	0.9-0.09 mG
West of Cabinet 35 m	0.07-.10 mG	0.2-0.07 mG

A rather odd inconsistency occurred: the magnetic field levels around the switching cabinets at high speeds (200 km/hr and 294 km/hr) shown in Tables 2.5-2 and 2.5-3 were less compared to the slower 120 km/hr operating speed data in Table 2.5-1. This was explained by “the differences in vehicle speed and time required to travel the length of one section of longstator”. Regardless of the cause for these differences, it would be prudent to use the 120 km/hr data and ELF Emission Decay Formulas to define a 10 mG EMI region 8 to 12 meters lateral (normal) from the switching cabinets where potential EMI problems may occur depending on the longstator currents and TR08 operating speeds.

Table 2.5-3. Switching cabinet emissions at 294 km/hr

New Switching Cabinet Levels - TR08 Car Traveling at 294 km/hr		
	TR08 Approaching **Time: 30 seconds**	**TR08 Departing** **Time: 30 seconds**
	Range of Field Levels	Range of Field Levels
North of Cabinet 3.5 m	0.3-2.0 mG	6.0-1.0 mG
West of Cabinet 5 m	1.0-10.0 mG	11.0-3.0 mG
West of Cabinet 20 m	0.09-0.2 mG	1.2-0.15 mG
West of Cabinet 35 m	0.08-0.14 mG	0.5-0.06 mG

As the TR08 approaches an elevated guideway with a switching cabinet below, a magnetic field projects a lateral (normal) ELF magnetic field that increases from nearly zero to the 10 mG EMI threshold 8- to 12-meters from the centerline when energized. When the TR08 begins to pass, the 10 mG EMI threshold pushes out another 8- to 12-meters to 20 meters measured from the centerline of the guideway, then suddenly the reversal occurs as the TR08 departs and the ELF magnetic fields levels drop to nearly zero when the switching cabinet is finally de-energized. Depending on the TR08 speed, this rather extensive ELF magnetic emission expansion and contraction event occurs rather quickly --- 60 to 120 seconds.

This completes the Section 2, Transrapid TR08 MAGLEV System EMF Assessment.

3.0 POTENTIAL MAGLEV HEALTH ISSUES FOR OPERATORS / STAFF

Several years ago Vitatech was contacted regarding a potential health issue causing lethargy and fatigue in the engineers and conductors operating a Transrapid TR08 MAGLEV type train. Apparently, the high DC magnetic fields emanating from the *synchronous longstator linear motor* propulsion system can magnetize individual red blood cells that form small chains or groups called a Rouleaux Formation. Although this process is not precisely understood, it is believed that high DC magnetic fields can induce magnetization of the iron containing hemoglobin proteins within individual red blood cells causing chains and grouping as shown below:

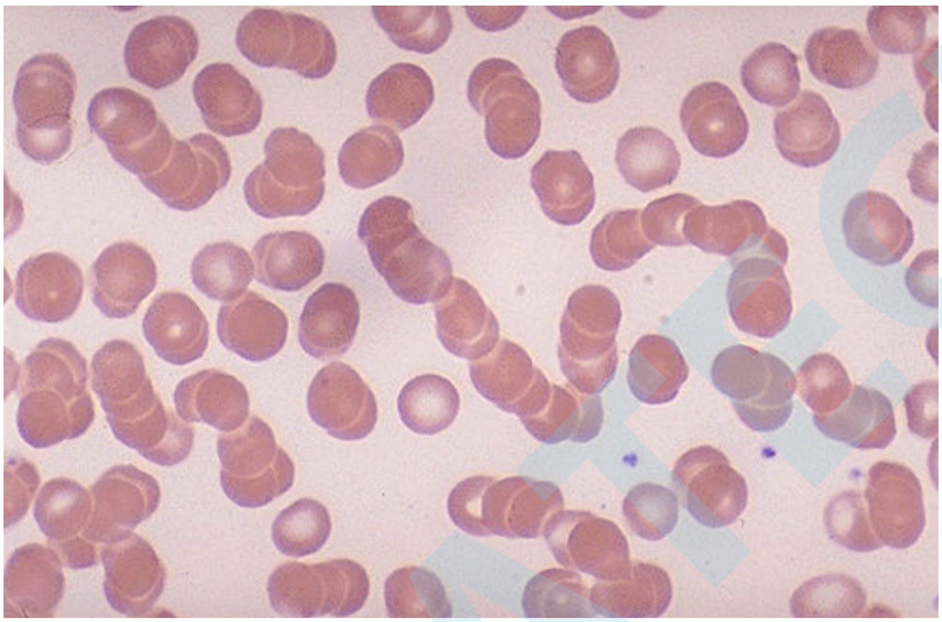


Figure 3.0-1, "Rouleaux Formation" long chains of red blood cells

Rouleaux Formation is a blood condition wherein red blood cells stick together in a configuration similar to a stack of coins. Typically, four to ten RBC stack together, although larger or smaller stacks are possible. In some instances, Rouleaux Formations can slow the circulation of blood within a lumen (i.e., tubular structure, such as an artery or intestine) of the human body. This slowing can result in limited physiological function and in some situations medical problems. In addition, Rouleaux is sometimes accompanied by cellular aggregation, i.e., the random or substantially random "clumping" or adherence of red blood cells and/or multiple distinct Rouleaux Formations.

The high DC magnetic fields may impart a net dipole moment to individual red blood cells. The induced magnetization in the red blood cells is believed to be an underlying cause of Rouleaux Formation. This phenomena may also occur when working in close proximity to extremely high static, quasi-static, and transient DC magnetic field sources.

3.1 Degaussing Treatment – Appears To Relieve Symptoms

Currently the only effective treatment is whole body degaussing which is a process of decreasing the unwanted dipole magnetization of red blood cells. Apparently, after each shift the MAGLEV operators are exposed to a whole body degaussing magnetic field to reduce the magnetically-induced Rouleaux red blood cell aggregation. As such, whole body degaussing typically results in a small remnant magnetic field remaining in the degaussed red blood cells. Information is not available regarding the efficacy of the degaussing treatments and long-term health effects from remnant magnetization on the red blood cells. Additional study is recommended to address these concerns.