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Electromagnetic Field (EMF) Effects on Human Body Based on ICNIRP Guideline in Railway Environments

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ABSTRACT

Growing of new railway infrastructure in Malaysia poses challenges in terms of electromagnetic field (EMF) interferences. This radiation comes across wired and wireless transmitters/receivers, electrical/electronic devices, and systems. Electromagnetic Field (EMF) Effects on Human Body Based on ICNIRP Guideline in Railway Environments has been measured was conducted from 9 KHz to 6 GHz using three (3) different antennas (Loop, Tri-Log and Horn) and analysed. Four (4) railway stations have been identified as the worst-case location and the results have been compared with the ICNIRP guideline limit. Based on the results, the Electric-Field (E-field) result from the measurements is below than ICNIRP's permissible limit. The percentage reaching ICNIRP level from measured E-field is more than 20%.

1. Introduction

Recently, the Malaysian government, through the 12th Malaysia Plan (12MP) 2021-2025 has emphasised improving transport infrastructure as part of the development structure of the country. In addition, connectivity, and transformation technologies like 5G and Internet of Things (IoT) are introduced to critical infrastructures, power grids, transport systems (including railways) and hospitals. There will be a growing need for new railway infrastructure in Malaysia to support this economic expansion. However, the drawback of this technological advancement of the new system integration must be coupling or integrated, with a new configuration that poses challenges in terms of electromagnetic field (EMF) interferences. This radiation comes across wired and wireless transmitters/receivers, electrical/electronic devices, and systems. Such electromagnetic (EM) waves

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are well prone and tend to cause heating in the exposed part of the human body very rapidly and cause serious injuries, like severe burns when the radio frequency (RF) waves energy is very strong.

This has developed deep concerns among the public about the human health implications due to no law enforcement and guideline for EMF compliance in the railway environment in Malaysia. However, the only existing law is governed by the Malaysian Communications and Multimedia Commission (MCMC) on the Commission Determination on the Mandatory Standard for Electromagnetic Field Emission from Radiocommunications Infrastructure (MS EMF) - Determination No. 5 of 2021 which covers on the Radio Frequency (RF)-Electromagnetic Field (EMF) used in telecommunications. The limits adopted in the MS EMF are based on the International Commission on Non-Ionising Radiation Protection (ICNIRP) Guidelines which is recognised by the World Health Organisation (WHO). "ICNIRP aims to provide advice on protection against adverse health effects from both short- and long-term exposures to NIR and uses the WHO's definition of health: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity by International Commission on Non-Ionizing Radiation Protection [1]".

Therefore, the railway environment could be a harmful EMF area because of the proximity to public and/or maintenance workers. Sources of the EMF could be the driving motors, intentional transmitter (antennae), railway third rail, electronic devices, high-voltage (HV) AC power cables, and train control system. EMF can be divided into two (2) sources:

i. EM wave from an ambient railway system (radiated emission) and intentional transmitter from rolling stock and a nearby railway station.
ii. Magnetic field (H-field) from HV AC cables, HV DC Cable and railway traction system.

Many applications, such as 5G technologies, Wi-Fi, Bluetooth, mobile phones, and base stations ranging from 100 kHz to 300 GHz was covered by "The International Commission on Non-Ionising Radiation Protection (ICNIRP) Guidelines [2]". "ICNIRP's RF guidelines derive, motivate, and define a revised safety concept based on a set of Basic Restrictions (BR) and Reference Levels (RL) to maintain safe exposure to RF EMF by Jeschke *et al.,* [3]". "Numerous studies have been done to analyse the electromagnetic field (EMF) near railway station platforms was also conducted by Dan *et al.,* [4]" and authors concluded that the radiation level was below the specification EMF limit. However, since the study was conducted in the near field region, inaccuracy results occurred, and it was suggested to improve in future work [4]". While "Sadaimitsu *et al.,* [5] presented the importance of analysing EMF based on the ICNIRP guidelines. Authors highlighted that both hearing aid and pacemaker user should be taken into consideration in the EMF study nearby railway system [5]". "Notwithstanding the usefulness of the electromagnetic frequency base stations that transmits the wireless radio frequency signals that boost the network carriage capacity, there exist several negative health implications on the citizens living close to the locations where the base stations are erected, especially when they are not modulated by Kazaure *et al.*, [6]" and author agreed that research has to be done to states and investigate the levels of compliance. In addition, "Ismail *et al.*, [7] highlighted the emergence of wireless structures everywhere provides a sense of insecurity to the citizens of the world on the effect of the radiation coming from those structures on them and the environment [7]." "Magnetic field exposure has been a major concern for the protection of live-line workers over electric field exposure because the intensity of the magnetic field is high on a highly loaded conductor and it is difficult to reduce the exposure, whereas electric field exposure can be reduced by wearing a conductive suit by Shiina *et al.,* [8]*".* Therefore, it is important to measure and analyse the EMF level in the railway environment in Malaysia for future reference has been identified as research gap for this research.

Based on the study of the research gap, multiple locations have been identified to be included in a site survey along with the railway alignment has been done. The approach of the site survey is to identify the potential sources and receptors of interference in railway areas. Identification of the potential EMF sources and receptors is done from a desktop study of the railway route map as well as a visual survey. For the desktop study, the railway route is compared to updated maps to identify the EMF sources and receptors. For the visual survey, a physical visit has been conducted to the railway station's location, and an investigation for any identifiable EMF sources and receptors.

An Electromagnetic Compatibility (EMC) Site Survey was conducted which identifies some of the possible Electromagnetic Interference (EMI) sources and EMI sensitive facilities along the proposed railway alignment based on information gathered through maps and preliminary visual survey along the railway alignment. No access to the actual location of the stations was made available during that time. With the up-to-date location of stations being made known, it is proposed that measurement is not necessary at sites listed if their distances being greater than 100 m from the nearest station. "Galán-Jiménez *et al.,* [9] mentioned that a maximum EMF limit of 6 [V/m] is imposed for the radiation from BSs in residential zones. Moreover, a minimum distance of 100 meters between a BS and a sensitive place is enforced in many cities of the country, such as Rome [9]". Hence, at more than 100 m, the electric fields radiated by equipment are reduced by more than 40 dB compared to at 1 m, resulting in the fields do not causing intolerable interference to the facility at the sites listed in Table 1.

Table 1
List of possible EMI sources and EMI sensitive facilities along the proposed railway alignment

Locations	Remarks/findings/observations
A	Measurement is recommended at the Kwasa Damansara Station for ambient EMF baseline data due to its proximity to the MRT Sungai Buloh Putrajaya (MRT1).
B	The emission due to MRT1 system and other sources should be assessed at the Sungai Buloh Station. Measurement is recommended near the Sungai Buloh Station for ambient EMF baseline data.
C	Ambient EMF baseline data is recommended near the Sungai Buloh Depot to assess the baseline ambient EMI level.
D	The medical center is located about 65 m from the proposed railway station. Measurement is recommended near the DDMC for ambient EMF baseline data.
E	The nearest distance between the proposed railway station to the boundary of the substation is about 40 meters. Measurement is recommended at the nearest point on the proposed railway alignment for ambient EMF baseline data.
F	The proposed railway station is located near KTM Station. Possible EMI due to the KTM station. Measurement is recommended near the Kepong Sentral Station for ambient EMF baseline data.
G	Measurement is recommended at the proposed railway station due to the presence of telco base stations on top of commercial buildings nearby.
H	Measurement is recommended at the proposed railway station due to the presence of telco base stations on top of commercial buildings nearby.
I	The 132 kV TNB transmission line is a potential source of interference at the proposed railway station. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
J	The proposed railway station is located near KTM Station. Possible EMI due to the KTM station Measurement is recommended near the proposed railway station for ambient EMF baseline data.
K	The proposed railway station is located near Kentonmen military camp. Intentional transmitters are expected to be in the camp. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
L	The proposed railway station will pass within 51 m of the Sentul Polis HQ. Measurement is recommended at the Police Station for ambient EMF baseline data.
M	The proposed railway station nearest building is located about 148 m from the HKL Station. The Measurement is recommended near the Institut Radioterapi dan Onkologi for ambient EMF baseline data.

Table 1
List of possible EMI sources and EMI sensitive facilities along the proposed railway alignment

Locations	Remarks/findings/observations
N	The proposed railway station is located near the Ampang Park LRT Station. Possible EMI due to these stations. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
O	Measurement is recommended at a selected location of the commercial area near the proposed railway station for ambient EMF baseline data.
P	Measurement is recommended at a selected location of the commercial/residential area near the proposed railway station for ambient EMF baseline data.
Q	The proposed railway station is located near the TRX MRT1 Station. Possible EMI due to the station. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
R	The proposed railway station is located near the Chan Sow Lin LRT Station. Possible EMI due to these stations. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
S	The future HSR station can be an EMI source. Measurement is recommended near the Bandar Malaysia South station for ambient EMF baseline data.
T	Measurement is recommended at the proposed railway station due to the presence of telco base stations near the area.
U	The proposed railway station is located near the Sungai Besi LRT Station. Possible EMI due to the LRT station. Measurement is recommended near the proposed railway station for ambient EMF baseline data.
V	The proposed railway alignment will run within 46 m of the Sungai Besi Toll Plaza. Measurement is recommended near the Sungai Besi Toll Plaza for ambient EMF baseline data.
W	Measurement is recommended near the Bomba station due to its proximity to the proposed railway station box.
X	Ambient EM baseline data is recommended near the Serdang Depot to assess the baseline ambient EMI at this location.
Y	The TNB lines can potentially be an EMI source along the proposed railway alignment. Measurement is recommended at a location along the line nearest to the TNB lines.
Z	Measurement is recommended at the proposed railway station due to the presence of telco base stations on top of commercial buildings.
AA	Measurement is recommended at the proposed railway station due to its proximity to a Giant hypermarket, hotels and commercial areas.
AB	Measurement is recommended at the proposed railway station due to the presence of telco base stations on top of commercial buildings.
AC	The 275/132 kV TNB lines crossing over the proposed railway alignment can potentially be an EMI source. Measurement is recommended beneath or as nearest possible to the TNB lines.
AD	The KLIA Express/Transit station can both be sources of EMI. Measurement is recommended near the proposed railway station.

The facilities considered are the worst-case scenario, with a high volume of public usage due to proximity to an interchange station or another adjacent line of railway, facilitate a radio base station, or are close to a mobile base station. The sites identified during the survey stage have been measured to compare with the ICNIRP level. Figure 1 shows an example of the selected location for the EMF measurement due to the several interchanges with different railway operators. In addition, the sites have been selected due to the proximity of the mobile base transmitter to the railway station. There are four (4) locations from 30 sites survey that have been identified as high potential EMF emission and radiation. The measurement has been conducted at four (4) locations in a worst-case environment.

Fig. 1. Example of selected location of EMF's measurement

2. Methodology

The EMF measurements were conducted between 100 kHz to 6 GHz at four (4) locations compared with the ICNIRP Guidelines level. The measurement methods outlined in this study are based on the principle of detecting the maximum EM fields (E-field and H-field) at a particular location for a frequency range between 100 kHz to 6 GHz as stated in Table 2. The EN55011 is used only as guidance on two (2) aspects; the height of the antenna and the minimum four (4) measurements in orthogonal directions, north (N), east (E), south (S), west (W). However, the existences of potential radiators are identified during site survey, the measurement direction shall also include northeast (NE), southeast (SE), southwest (SW), and northwest (NW). The rest of the methods are based on the best practices and pragmatic approaches that are commonly implemented in performing EMF site surveys. The list of equipment used for the measurements is listed in Table 2. All the equipment is calibrated by an accredited test lab in accordance with ISO 17025:2005. "Paonessa *et al.,* [10] mentioned that a loop antenna is the common solution for the detection of magnetic field strength in the low frequency range (150 kHz to 30 MHz) while for the upper frequency range two antennas are used: a biconical antenna for the 30 MHz-300 MHz range and a log-periodic antenna for the 300 MHz-1 GHz range [10]".

Table 2
Measurement's frequencies range

Frequency range	Resolution bandwidth of SA	Scan rate of SA (ms)	Antenna type
100 kHz to 150 kHz	1 kHz	300	Loop
150 kHz to 1.15 MHz	10 kHz	37	Loop
1 MHz to 10 MHz	10 kHz	370	Loop
10 MHz to 20 MHz	10 kHz	370	Loop
20 MHz to 30 MHz	10 kHz	370	Loop
30 MHz to 230 MHz	100 kHz	42	Tri-log
200 MHz to 500 MHz	100 kHz	63	Tri-log
500 MHz to 1 GHz	100 kHz	100	Tri-log
1 GHz to 6 GHz	1 MHz	15	Horn

The standard uncertainty, $ui(y)$ is calculated by dividing the individual uncertainty contribution with its probability distribution. The combined uncertainty, $uc(y)$ is obtained by taking the square root of the sum of the square of the individual uncertainty, Eq. (1). Expanded uncertainty is calculated by multiplying the combined uncertainty by the coverage factor, k. The coverage factor, k, is set as 2 for a confidence level of 95%. The calculation of Standard Uncertainty, $u_i(y)$ as Eq. (2) and Expanded Standard Uncertainty, is $u_i{}^2(y)$ as Eq. (3) below. The combined uncertainty of the whole measurement systems is contributed by antenna factor (A), spectrum analyser (B), cable loss (C), mismatch (D), and repeatability (E) as stated in Eq. (4). The expanded combined uncertainty as Eq. (5).

$$uc(y) = \sqrt{\sum_{i=1}^{m} u_i^2}\,(y) \tag{1}$$

$$u_i(y) = \frac{Uncertainty}{Probability\ Distribution} \tag{2}$$

$$u_i{}^2(y) = u_i\,(y) \times u_i(y) \tag{3}$$

$$\text{Combined Uncertainty}, u_c(y) = \sqrt{A^2 + B^2 + C^2 + D^2 + E^2} \tag{4}$$

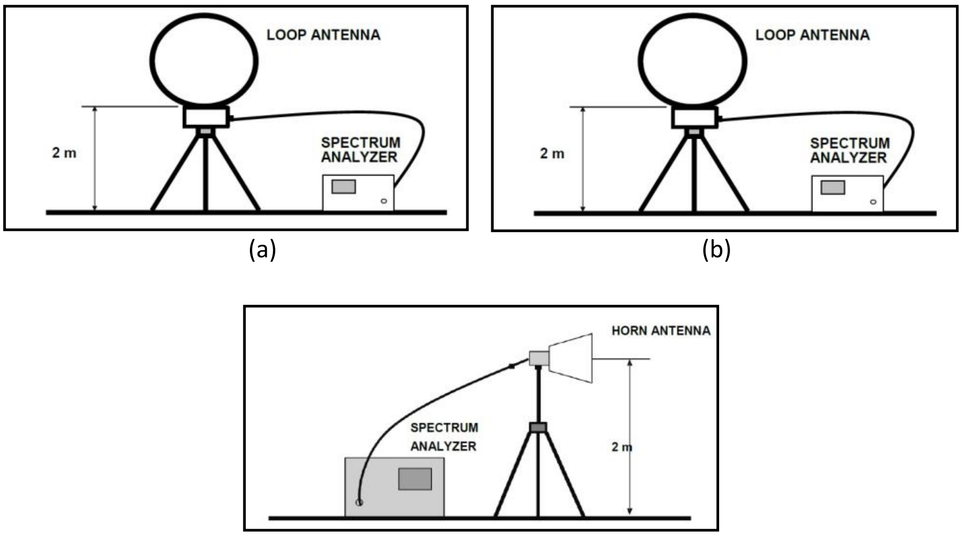
$$\text{Combined Uncertainty}, u_c(y) = \sqrt{A^2 + B^2 + C^2 + D^2 + E^2} \tag{5}$$

The expanded combined uncertainty for loop, tri-log and horn antenna have been calculated with a value of 1.88, 2.11 and 2.76 respectively as stated in Table 3.

Table 3
Calculation of system uncertainty

No.	Contribution	Probability distribution	Uncertainty (dB)			Standard uncertainty, $u_i(y)$			Expanded standard uncertainty, $u_i{}^2(y)$		
			Loop	Tri-log	Horn	Loop	Tri-log	Horn	Loop	Tri-log	Horn
1.	Repeatability	2.00	0.1000	0.1000	0.1000	0.0500	0.0500	0.0500	0.0025	0.0025	0.0025
2.	Spectrum analyser	2.00	0.6000	0.8000	0.9000	0.3000	0.4000	0.4500	0.0900	0.1600	0.2025
3.	Cable loss	1.00	0.3000	0.5000	1.0000	0.3000	0.5000	1.0000	0.0900	0.2500	1.0000
4.	Antenna factor	2.00	1.0000	1.0000	1.0000	0.0500	0.0500	0.0500	0.2500	0.2500	0.2500
5.	Mismatch	1.4142	0.9500	0.9500	0.9500	0.6718	0.6718	0.6718	0.4513	0.4513	0.4513
Combined uncertainty, $u_c(y)$									0.94	1.0554	1.38
Expanded combined uncertainty (dB)									1.88	2.11	2.76

Figure 2(a) shows the measurement set-up for the loop antenna connected to a spectrum analyser. The same measurement set-up is applicable for other antennas such as Tri-log and horn antenna as shown on Figures 2(b) and 2(c).

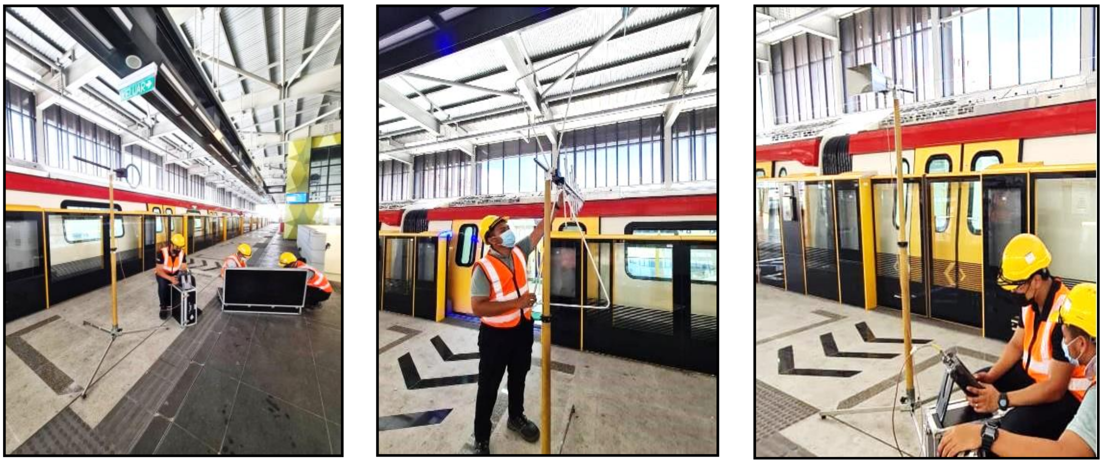


(a) (b)

(c)

Fig. 2. Test set-up for (a) Loop antenna (100 kHz to 30 MHz) (b) Tri-log antenna (30 MHz to 1 GHz) (c) Horn antenna (1GHz to 6 GHz)

The measurement was conducted near the railway platform for the worst-case condition with the approximate distance between the center of the track and the measurement location is less than three (3) meters. In addition, references have been made according to EN50121-3-2 which stated any railway devices located within three (3) meters may interfere with other apparatus inside the railway environment or increase the total emissions for the railway's highest emission. "Trackside equipment had been assessed according to EN50121, but the assessments did not take into account the equipment's close proximity to the track i.e. less than 3m, as mentioned in EN50121-4 mentioned by Morant *et al.,* [11]". Figures 3(a), 3(b) and 3(c) shows the example of measurement set-up using loop antenna, tri-log antenna, and horn antenna near the railway platform respectively.



(a) (b) (c)

Fig. 3. Example of measurement set-up using (a) Loop antenna (b) Tri-log antenna (c) Horn antenna

During the measurement, Peak Detector and Max-Hold functions of the spectrum analyzer are used to ensure that maximum field strengths are detected. The Max-Hold function will be maintained for at least six (6) minutes before the data is stored. The measurement quantity to be obtained from the measurement is either a magnetic field, $H\ dB\mu V/m$ or an electric field, $E\ (dB\mu V/m)$. These quantities can be derived based on the voltage detected at the spectrum analyzer, $V_{SA}(dB\mu V)$, electric antenna factor, $AF_E(dB\ m)$, magnetic antenna factor, $AF_M(dB\ m)$ and cable loss, $(L\ dB)$. The relationships are given as Eq. (6) and Eq. (7).

$$Magnetic\ Field, H\ (dB\mu V/m) = V_{SA}(dB\mu V) + AF_M(dBm) + L(dB) \quad (6)$$

$$Electric\ Field, E\ (dB\mu V/m) = V_{SA}(dB\mu V) + AF_E(dBm) + L(dB) \quad (7)$$

The measurement has been conducted for both antenna polarisations vertical (V) and Horizontal (H) in four (4) directions of north (N), south (S), east (E), and west (W) while in the existences of potential radiator, the measurement direction also conducted in additional four directions of northeast (NE), southeast (SE), southwest (SW), and northwest (NW) as stated in Table 4.

Table 4
Summary of electromagnetic measurements

Frequency range	Field component	Antenna	Polarisation/measurement directions
100 kHz to 150 kHz	Magnetic	Loop antenna	V-EW, V-NS, H
150 kHz to 30 MHz	Electric	Loop antenna	V-EW, V-NS, H
30 MHz to 1GHz	Electric	Tri-log antenna	H-W, H-N, H-E, H-S V-W, V-N, V-E, V-S
1 GHz to 6 GHz	Electric	Horn antenna	H-W, H-N, H-E, H-S V-W, V-N, V-E, V-S

3. Results

The ambient measurement data will be stored automatically by the spectrum analyser in the form of voltage versus frequency. The data will then be transferred to the computer for conversion of the voltage to electric field versus frequency based on the equations given. The final data will then be presented in graphical form for evaluation on the severity of the electromagnetic environment at that location.

A series of ambient measurements for the selected sites as stated in Table 1 have been carried out. The measurement for each site was recorded and stored in Excel files. The measurement results display the electric field, E (in $\mathrm{db\mu V/m}$) versus frequency (MHz) range as shown in Figure 4 and Figure 5. This result was obtained from the horn antenna that operated from 1 GHz to 6 GHz. The result indicates the highest recorded emission of electric field, E near to the railway platform below the permissible limit by ICNIRP in Figure 4 and Figure 5 for location D and H respectively. "ICNIRP RF EMF exposure limits are given in terms of basic restrictions, which relate to physical quantities inside the body, and in terms of reference levels, which are external field quantities derived from the basic restrictions by Colombi *et al.,* [12]". The ICNIRP Guidelines only indicate the limit up to 2GHz and no limit is applicable for 2 GHz to 300 GHz as stated in the ICNIRP. Therefore, the recorded measurements shown in Figure 4 and Figure 5 only cover up to 2 GHz.

The peaks above the noise floor indicate the existence of intentional and unintentional radiation at the location of measurement. The identified intentional radiators were commercial radio transmitters for mobile coverage near to the measurement location. Based on measurement results recorded, four (4) worst-case readings of all data were identified by picking up the electric field peak closer to the ICNIRP limit. "ICNIRP has set standards for exposure to RF radiation from BTS to minimize health problems due to radiation exposure. Health problems due to exposure to RF radiation cannot be felt instantly by Imansyah *et al.*, [13]". The ICNIRP guidelines limit are in $v\ m^{-1}$ unit and shall be converted to $dB\mu v/m$ for result comparison. The result has been compared with the converted ICNIRP level. Based on the measurement results, there is no electric field peak recorded that has exceeded the minimum ICNIRP level as listed in Table 5.

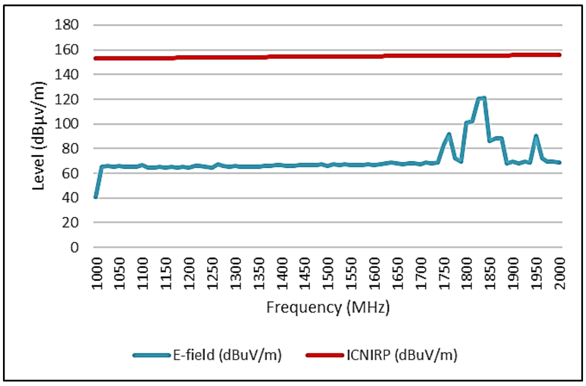


Fig. 4. Measurement result for location D

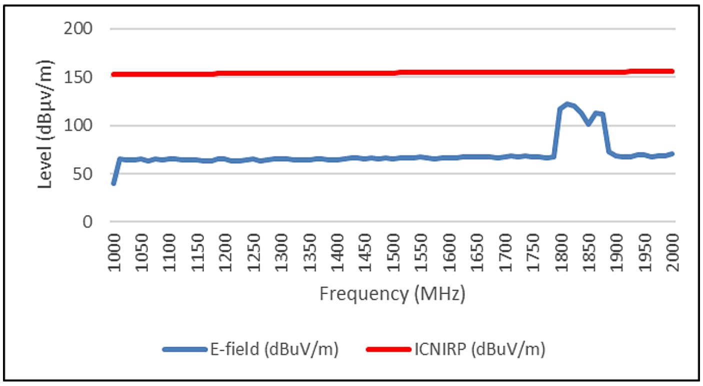


Fig. 5. Measurement result for location H

Table 5
Maximum E-field for each location

No	Location	Frequency (MHz)	Maximum E-field (dBµV/m)	Polarization	Direction	ICNIRP limit (dBµV/m)
1.	D	1838	120.20	Vertical	East	155.41
2.	J	1825	119.60	Vertical	East	155.38
3.	H	1813	122.01	Vertical	North	155.35
4.	G	2625	113.46	Vertical	South	155.76

Based on results as recorded in Table 5, the result is then calculated and compared to ICNIRP Guidelines as Eq. (8). Table 6 shows the percentage of measured reading compared with the ICNIRP level. The percentage reaching the ICNIRP level is very low at 21.46% for location H. The same results also obtained by "Gourzoulidis *et al.,* [14]. The intensities of electromagnetic fields on the whole and on every specific region are below the national limits".

$$\text{Percentage of maximum peak versus ICNIRP level } (\%) = \left(\frac{ICNIRP\ Limit - Maximum\ Electric\ Field}{ICNIRP\ Limit}\right) \times (100\%) \quad (8)$$

Table 6
Percentage of measured reading compared with the ICNIRP level

No	Location	Frequency (MHz)	E-Field (dBµV/m)	ICNIRP level (dBµV/m)	Percentage of maximum peak versus ICNIRP level (%)
1	D	1838	120.20	155.41	22.65%
2	J	1825	119.60	155.38	23.03%
3	H	1813	122.01	155.35	21.46%
4	G	2625	113.46	155.76	27.16%

4. Conclusions

The aim of this studies to ensure that the exposure to the EMF accordance to ICNIRP Guidelines for railway industry in Malaysia does not bring harm to public as concerned while using the public transport or to the operator for the service and maintenance. "We could consistently demonstrate that all exposure levels were far below reference levels proposed by ICNIRP (International Commission on Non-Ionizing Radiation Protection). Exposure levels were of the same order of magnitude in all cities. Consistently in all cities, exposure was highest in public transports (train) and lowest in residential areas (central and non-central residential areas) by Urbinello *et al.,* [15]". This is also concluded by Hussin *et al.,* [16] "it can be said that radiation levels present at all measured locations at Satellite Earth Station were very low and in compliance with the exposure limit as stated in the MCMC Mandatory Standard for workers and members of the public. This suggests that the Radio Frequency emission at Cyberjaya Earth Station, Kuantan Earth Station and Melaka Earth Station is relatively safe [16]*".* ''The exposure to RF radiation within the WHO building is very low compared to other measurements, for example our measurements inside the Stockholm Central station where people both are passing through but also are there for hours each day such as security and police staff, cafe workers, shop workers, janitors, information counter people, etc. by Hardell *et al.,* [17]". Lack of enforcement in laws for railway applications to protect the public customers that use the railway services and operators that are operating the railway alignment are justified based on this research. In conclusion, it is understood that the maximum level of magnetic and electric field present at site is below the severity levels specified in the ICNIRP Guidelines.

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References

[1] International Commission on Non-Ionizing Radiation Protection. "A Description of ICNIRP'S Independent, Best Practice System of Guidance on the Protection of People and the Environment from Exposure to Non-Ionizing Radiation." *Health Physics* 122, no. 5 (2022): 625-628. https://doi.org/10.1097/HP.0000000000001561

[2] International Commission on Non-Ionizing Radiation Protection. "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)." *Health Physics* 118, no. 5 (2020): 483-524. https://doi.org/10.1097/hp.0000000000001210

[3] Jeschke, Peter, Carsten Alteköster, Kjell Hansson Mild, Michel Israel, Mihaela Ivanova, Klaus Schiessl, Tsvetelina Shalamanova, Florian Soyka, Rianne Stam, and Jonna Wilén. "Protection of workers exposed to radiofrequency electromagnetic fields: a perspective on open questions in the context of the new ICNIRP 2020 guidelines." *Frontiers in Public Health* 10 (2022): 875946. https://doi.org/10.3389/fpubh.2022.875946

[4] Dan, Dipankar, and Satyajit Chakrabarti. "Electromagnetic environment in modern railway system." In *2015 13th International Conference on Electromagnetic Interference and Compatibility (INCEMIC)*, p. 116-121. IEEE, 2015. https://doi.org/10.1109/incemic.2015.8055860

[5] Sadamitsu, Shinichi, S. W. Leung, W. K. Lo, and W. N. Sun. "Practical considerations of human exposure in railway systems." In *2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility (EMC/APEMC)*, p. 28-31. IEEE, 2018. https://doi.org/10.1109/isemc.2018.8393732

[6] Kazaure, Jazuli S., Ugochukwu O. Matthew, Nwamaka U. Okafor, and Ogobuchi Daniel Okey. "Telecommunication network performances and evaluation of radio frequency electromagnetic radiation: health effects of the RF-EMR GSM base stations." *International Journal of Information Communication Technologies and Human Development (IJICTHD)* 13, no. 3 (2021): 16-37. https://doi.org/10.4018/IJICTHD.2021070102

[7] Ismail, Aiman, Norashidah Md Din, Md Zaini Jamaluddin, and Nagaletchumi Balasubramaniam. "Electromagnetic assessment for mobile phone base stations at major cities in Malaysia." In *2009 IEEE 9th Malaysia International Conference on Communications (MICC)*, p. 150-153. IEEE, 2009. https://doi.org/10.1109/MICC.2009.5431485

[8] Shiina, Takeo, Takahiro Kudo, Daijiro Herai, Yuko Kuranari, Yoichi Sekiba, and Kenichi Yamazaki. "Calculation of internal electric fields induced by power frequency magnetic fields during live-line working using human models with realistic postures." *IEEE Transactions on Electromagnetic Compatibility* 63, no. 6 (2021): 1812-1819. https://doi.org/10.1109/TEMC.2021.3083057

[9] Galán-Jiménez, Jaime, and Luca Chiaraviglio. "Measuring the impact of ICNIRP vs. stricter-than-ICNIRP exposure limits on QoS and EMF from cellular networks." *Computer Networks* 187 (2021): 107824. https://doi.org/10.1016/j.comnet.2021.107824

[10] Paonessa, Siriana, Walter Picariello, Luca Bocciolini, Carmine Zappacosta, Stefano Di Pascoli, Bernardo Tellini, and Massimo Macucci. "Analysis of the electromagnetic emission of a railway vehicle according to the EN 50121-3-1

standard: a case study." In *2020 International Symposium on Electromagnetic Compatibility-EMC EUROPE*, p. 1-6. IEEE, 2020. https://doi.org/10.1109/EMCEUROPE48519.2020.9245630

[11] Morant, Amparo, Åke Wisten, Diego Galar, Uday Kumar, and Stefan Niska. "Railway EMI impact on train operation and environment." In *International Symposium on Electromagnetic Compatibility-EMC EUROPE*, p. 1-7. IEEE, 2012. https://doi.org/10.1109/EMCEurope.2012.6396847

[12] Colombi, Davide, Bo Xu, David Anguiano Sanjurjo, Paramananda Joshi, Fatemeh Ghasemifard, Carla Di Paola, and Christer Törnevik. "Implications of ICNIRP 2020 exposure guidelines on the RF EMF compliance boundary of base stations." *Frontiers in Communications and Networks* 3 (2022): 744528. https://doi.org/10.3389/frcmn.2022.744528

[13] Imansyah, Fitri, Leonardus Sandy Ade Putra, and Eka Kusumawardhani. "Measurement and Analysis of Radiation Levels from Base Transceiver Station in Sambas." *Journal of Information Systems and Telecommunication (JIST)* 5 (2021): 1. https://doi.org/10.52547/jist.9.36.1

[14] Gourzoulidis, G., P. Tsaprouni, N. Skamnakis, C. Tzoumanika, E. Karastergios, A. Gialofas, E. Kalampaliki, A. Achtipis, C. Kappas, T.G. Maris, E. Karabetsos. "Occupational exposure to electromagnetic fields–The situation in Greece." *Physica Medica* 32 (2016): 276. https://doi.org/10.1016/j.ejmp.2016.07.609

[15] Urbinello, Damiano, Wout Joseph, Leen Verloock, Luc Martens, and Martin Röösli. "Temporal trends of radio-frequency electromagnetic field (RF-EMF) exposure in everyday environments across European cities." *Environmental Research* 134 (2014): 134-142. https://doi.org/10.1016/j.envres.2014.07.003

[16] Hussin, Mohamad Fahmi, Mohd Shaiful Asri Sulian, Mohamad Huzaimy Jusoh, and Ahmad Asari Sulaiman. "Radio frequency radiation at satellite earth station for occupational safety and health." In *2015 IEEE 11th International Colloquium on Signal Processing & Its Applications (CSPA)*, p. 174-179. IEEE, 2015. https://doi.org/10.1109/CSPA.2015.7225641

[17] Hardell, Lennart. "World Health Organization, radiofrequency radiation and health-a hard nut to crack." *International Journal of Oncology* 51, no. 2 (2017): 405-413. https://doi.org/10.3892/ijo.2017.4046