Near Field Radio Frequency Radiation Hazard on Military Armoured Vehicle - Approach to a Dose Assessment

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ABSTRACT

The level of radio frequency (RF) electromagnetic field emitted from a military armoured vehicle antenna was investigated to identify possible adverse health effect on personnel, especially in the near field region. Both E-Field and H-Field radiations levels emitted from antenna were recorded by emphasising on the main areas of crew working station. To date, open literature on military vehicle and equipment RF radiation hazard safety assessment has limited numbers of discussion especially on RF source distance, location and mode of power transmission. In this investigation, RF levels from two radio antennas were measured, high frequency (HF) and very high frequency (VHF) with the low and high-power transmission. Measurements were taken in two distinct locations namely; commander and gunner respectively with three different conditions; open hatch, close hatch and open hatch with standing crews which representing the normal and combat situations. The measured E-Field and H-Field levels were then assessed for compliance with occupational reference levels of Military Standard 464C, The Institute of Electrical and Electronics Engineers (IEEE) for Military Workplace standards and International Commission on Non-Ionising Radiation Protection (ICNIRP) guidelines. The occupational standard was exceeded on commander and gunner area at certain condition; nevertheless, the rest of the conditions complied within the occupational standard.

Keywords: Military armoured vehicle; high frequency; very high frequency; E-field and H-field; radio frequency radiation.

INTRODUCTION

The electromagnetic (EM) radiation become hazardous to human health if the exposure received is excessively high. An antenna placed aboard an armoured vehicle with ranging the spectrum of high frequency (HF) and very high frequency (VHF) potentially exposes the crew with radiation hazards respectively with radio frequency (RF) energy. Only a few studies on EM radiation hazards to armoured vehicle crew was found to date.

The danger of radiation hazards occurs due to the RF energy absorbed which transformed into the movement of molecules in the human body. As discussed by the World Health Organisation (WHO), friction between rapidly moving molecules results in temperature rise period. Significant heating may lead to tissues damage if the access heat is dissipated accordingly [1]. A lot of interesting facts have been discovered from open access literature on EM radiation emitted from military radar, antenna and the personnel

operating radio equipment. However, RF radiation hazards are not clearly defined from these studies due to a different standard of RF exposure level. The acceptable exposure limits for occupational specified by different standardisation bodies for various frequency ranges summarised in Table 1.

The objective of this study is to describe the measured RF exposure on Armoured Vehicle 8 Wheels (AV8W). The exposure information is then used to approach total exposure and dose assessment. Total RF exposure collected pertaining with the operation tenure of armoured vehicle crew and the transmitting patterns. The dose assessment calculated for daily and annual RF dose for the exposed armoured crew on AV8W. The scope of this paper bounding into selected armoured vehicle crew working station with ordinary operational conditions and uniform transmitting patterns of HF and VHF.

Table 1. A summary of exposure limits.

| Body	Metric	Frequency	Occupational values	Remarks
Military Standard 464C	Electric Field Strength	2 MHz – 30 MHz	103 V/m	HF
		30 MHz -150 MHz	74 V/m	VHF
ICNIRP	Electric Field Strength	1 MHz – 10 MHz	610/f V/m	HF
		10 MHz – 400 MHz	61 V/m	HF / VHF
	Magnetic Field Strength	1 MHz – 10 MHz	1.6/f A/m	HF
		10 MHz – 400 MHz	0.16 A/m	HF / VHF
IEEE Standard 95. 1-2345-2014	Electric Field Strength	1 MHz – 30 MHz	1842/f V/m	HF
		30 MHz – 100 MHz	61.4 V/m	VHF
	Magnetic Field Strength	1 MHz – 30 MHz	16.3/f A/m	HF
		30 MHz – 100 MHz	0.163 A/m	VHF

MATERIALS AND METHODS

The measurement on RF radiation hazard from communication equipment mounted on Armoured Vehicle 8 Wheels (AV8W) has been done concerning the advice from Malaysian Army and Science & Technology Research Institute for Defence (STRIDE) to provide a safe working environment. In this study, Military Standard 464C [2] and IEEE Standard for Military Workplaces [3] are used where both of these standards protect military personnel against the exposure to electromagnetic fields in the various frequency ranges, between 0.01 MHz to 18 GHz and 0 Hz to 300 GHz respectively. For critical crew locations located in the near-field region, the International Commission on Non-Ionising Radiation Protection (ICNIRP) guidelines [4] for E-Field and H-Field measurement has been used as the main references standards guidelines.

**Description of Armoured Vehicle 8 Wheels (AV8W)**

The AV8W multirole combat vehicles in various configurations have been operative since 2014 by Malaysian Army. Designed with a length of 8 m, width 3 m, weight up to 30

tonnes and crew consisted of 8 personnel able to perform modern military operational requirements in any nature of the conflict.

Each of these vehicles is equipped with HF and VHF radio sets where the antennas of these sets are mounted on the turret as shown in Figure 1(a). In this study, only two AV8W locations measurements had taken place, namely commander and gunner due to its locations close to both antennas — the measurement took place with three conditions; close hatch, open hatch and standing crew open hatch as illustrated in Figure 1(a) to Figure 1(c).
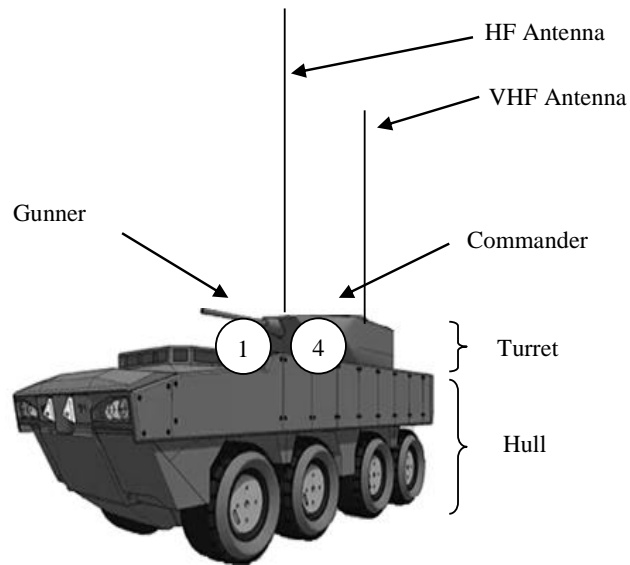
(a) AV8W close hatch condition with measurement spots (1 and 4).
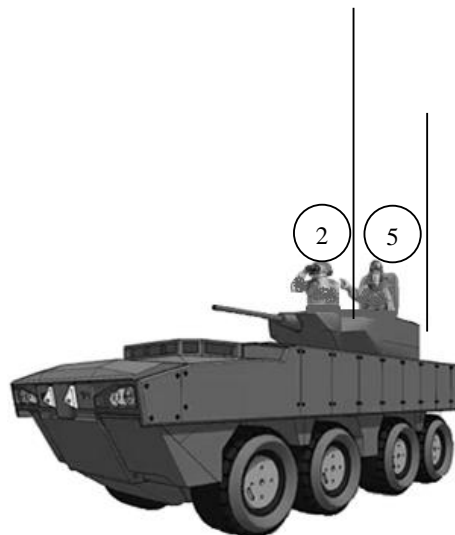
(b)AV8W open hatch condition with measurement spots (2 and 5).
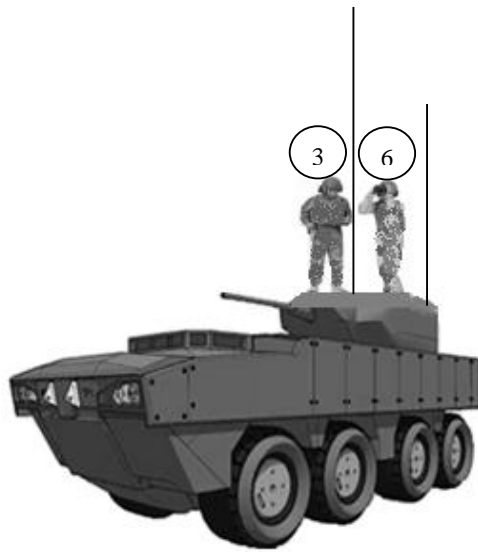
(c) AV8W standing crew open hatch condition with measurement spots (3 and 6).

Figure 1. AV8W multirole combat vehicles in various configurations.

High Frequency (HF) and Very High Frequency (VHF) Antenna

RF radiations from both antennas were measured at six different spots on AV8W. The measurements were performed at frequency range 5MHz – 25MHz for HF and 30MHz – 80MHz for VHF with an increment of 5MHz and 10MHz in each step respectively. Both antennas were transmitted with varied transmission time, the highest estimate being 5min/h. During the operation or combat environment, both HF and VHF sets are used concurrently. However, for this study, RF radiations was measured with only from one antenna at a time in a stationary condition. RF radiations from both antennas were measured at six different spots and conditions as shown in Figure 1. The measurements were performed at a frequency range of 5MHz to 25MHz for HF and 30MHz to 80MHz for VHF in 5 MHz and 10 MHz step respectively. Both antennas transmitted varying transmission times with the highest was 5min/h. The transmission power to the HF antenna varied from 1W to 125W and 0.5W to 50W to the VHF antenna.

Measurement Device

Two types of measurement device were used for the measurement. Rohde & Schwarz (R&S) FSH8 Spectrum Analyser with TSEMF-B3 Typical Isotropic Antenna used for E-Field measurement. This device measures any sources in the frequency ranges from 9 kHz to 8 GHz. Narda SRM-3006 was another measurement device used to measure H - Field. This device can detect the magnetic field any frequency ranges from 9 kHz to 6 GHz. Both measurement devices were placed at various spots as shown in Figure 1. The distances from the measurement device to both antennas were either in a horizontal line or if the measurement device was lower than the antenna, the distance was measured in a direct line to the antenna base. The actual distances from both antennas to the measurement spots are shown in Table 2. Distance from both antennas to standing crew

condition is not given in this study. All measurement devices were calibrated before their use.

Table 2. Distances to the VHF and HF antenna and measurement spots on AV8W.

Location	Condition	Distance from antenna (m)		Spots Number
		VHF	HF	
Gunner	Close hatch	1.8	1.5	1
	Open hatch	1.64	1.22	3
	Standing crew	-	-	5
Commander	Close hatch	1.4	1.8	2
	Open hatch	1.28	1.6	4
	Standing crew	-	-	6

Exposure Calculation: Linear and Spatial Average

Linear and spatial average exposure calculation suggested by Baste et al. [5] has been applied in this paper. The measurement spots were grouped to a location on the AV8W as shown in Figure 1(a) to (c). Exposure at each location was calculated as both linear in Eq. (1) and spatial in Eq. (2) Exposure, averaged over the actual number of measurement spots in the specific location. Linear average is calculated related to effects depending on E-Field; the spatial average is used by ICNIRP because of the thermal effects of RF electromagnetic field (EMF).

$$\text{E-linear}_{\text{equipment}} = \left(\frac{1}{\text{no.of spots}}\right) \sum E \tag{1}$$

$$\text{E-spatial}_{\text{equipment}} = \sqrt{\left(\frac{1}{\text{no.of spots}}\right) \sum E^2} \tag{2}$$

Annual Accumulative Dose Assessment

In this study, deployment of armoured vehicle crews in the United Nation (UN) mission becomes a relevant benchmark to calculate the dose assessment on AV8W. Estimated with eleven months per year active tenure of deployment, two cycles active patrol duty per day (2 hours per cycle), three days patrol duty per week and minimum transmission time 10 minutes varied on different spots were considered. Estimated RF exposure duration amongst the armoured vehicle crews summarised in Table 3. In order to make the dose assessment related with a period of deployment, spatial average methods have been applied as shown in Equation 3.

$$\text{Exposure Dose} = \tag{3}$$
$$\sum_{\text{equipment}} \left(\text{E-spatial}_{\text{equipment}} \times 24h \times \text{transmission time}_{\text{equipment}}\right)$$

This method calculated exposure dose by multiplying spatial average with transmission time and then summed up over the equipment. Each location was calculated separately. To obtain the annual exposure dose, the value was multiplied with mission

time, which gives an annual time average dose in V h/m. The annual exposure dose is given by exposure dose $\times 365 \times$ (active patrol time/12 months). The calculated result with this method is given in Table 10.

The similar method applied by Baste et al. [5], takes ICNIRP guidelines consideration and performed a calculation as Equation 4. In this study, the reference level for occupational exposure is E reference value (HF) = 610/frequency and the E reference value (VHF) = 61 V/m for frequency range 1 – 80 MHz [4]. To get an annual indication of dose, these values were multiplied by mission time, where annual exposure dose (ICNIRP) = exposure dose (ICNIRP) $\times 365 \times$ (active patrol time/12 months), which resulted in annual dose in the proportion of ICNIRP and the result given in Table 10.

$$\text{Exposure Dose (ICNIRP)=} \hspace{4cm} (4)$$

$$\sum_{\text{equipment}} \left[\left(\frac{\text{E-Spatial}_{\text{equipment}}}{\text{E-Spatial}_{\text{reference value (equipment)}}} \right)^2 \times 24h \times \right.$$

$$\left. \text{transmission time}_{\text{equipment}} \right]$$

Table 3. Estimated RF exposure duration time amongst armoured vehicle crews.

Tenure of deployment	Exposure time (minutes)
Daily	20
Weekly	60
Monthly	240
Yearly	2640

RESULTS AND DISCUSSION

Results from the E-Field measurements on the gunner and commander location with different spots and frequencies are shown in Table 4 and 5 respectively. For each of the HF and VHF antenna, the mean exposure (E *mean*) over the frequency range for each measurement spot was calculated. The measurement from HF in the frequency range of 5-25 MHz with low and high-power transmission resulted in value from 0.005 to 0.69 V/m. The measurement results from VHF in the frequency range of 30 – 80 MHz were higher than the HF for most of the spots, varied from 0.005 to 252 V/m.

The H-Field measurements have been done except for spot no. 3 and 6, due to measurement device safety precautions. The measurements result varied from 10.02×10^{-6} to 23.94×10^{-3} A/m and are shown in Table 6 and 7 respectively.

Total Exposure Assessment – HF and VHF Antenna

As regards to estimating the total amount of exposure from gunner and commander location on AV8W, the summation of exposures was calculated with both linear (from Eq. (1)) and spatial average (from Eq. (2)) as given in Table 8 and 9. The highest value has been found at commander location, where the linear and spatial average was equal to 23.2 V/m and 40.18 V/m respectively, from low power transmission and high power transmission was equal to 301.7 V/m and 521.5 V/m. The annual exposure dose values at both locations on AV8W as shown in Table 10.

Table 4. E-field measurements from HF and VHF antenna at gunner spots, transmitted with low and high power on AV8W.

| Transmission | E-field measurement at gunner (V/m) | | | | | |
| | HF (Low power) | | | HF (High power) | | |
MHz	Spot 1	Spot 2	Spot 3	Spot 1	Spot 2	Spot 3
5	0.006	0.01	0.62	0.006	0.02	0.46
10	0.007	0.02	0.66	0.005	0.03	0.67
15	0.005	0.04	0.53	0.005	0.04	0.70
20	0.006	0.04	0.36	0.005	0.03	0.11
25	0.007	0.01	0.28	0.014	0.01	0.66
	VHF (Low power)			VHF (High power)		
30	0.007	0.005	4.57	0.014	0.010	62.0
40	0.005	0.005	14.3	0.030	0.043	131
50	0.008	0.021	6.47	0.125	0.214	147
60	0.009	0.026	3.83	0.063	0.193	52.1
70	0.007	0.008	8.03	0.080	0.088	94.7
80	0.007	0.022	5.50	0.070	0.073	75.5
E mean	0.074	0.207	45.2	0.417	0.751	565

Table 5. E-field measurements from HF and VHF antenna at commander spots, transmitted with low and high power on AV8W.

| Transmission | E-field measurement at commander (V/m) | | | | | |
| | HF (Low power) | | | HF (High power) | | |
MHz	Spot 4	Spot 5	Spot 6	Spot 4	Spot 5	Spot 6
5	0.006	0.01	0.23	0.006	0.02	0.43
10	0.005	0.07	0.39	0.006	0.02	1.02
15	0.006	0.23	0.26	0.034	0.05	0.36
20	0.005	0.05	0.13	0.092	0.01	0.21
25	0.005	0.05	0.40	0.101	0.01	0.69
	VHF (Low power)			VHF (High power)		
30	0.007	0.6	6.23	0.035	8.3	78.2
40	0.005	1.2	21.4	0.017	16.9	246
50	0.010	2.3	3.10	0.053	34.9	51.7
60	0.018	0.9	18.8	0.108	16.2	252
70	0.014	3.6	5.83	0.160	66.1	80.0
80	0.011	1.2	2.53	0.033	18.1	31.4
E mean	0.092	10.2	59.3	0.645	160	742

Table 6. H-field measurements from HF and VHF antenna at gunner spots, transmitted with low and high power on AV8W.

Transmission MHz	H-field measurement at gunner (A/m)					
	HF (Low power)			HF (High power)		
	Spot 1 ($\times10^{-3}$)	Spot 2 ($\times10^{-3}$)	Spot 3	Spot 1 ($\times10^{-3}$)	Spot 2 ($\times10^{-3}$)	Spot 3
5	0.16	0.83	-	0.18	0.69	-
10	0.15	0.59	-	0.83	0.46	-
15	0.07	0.26	-	0.07	0.32	-
20	0.05	0.19	-	0.07	0.28	-
25	0.06	0.15	-	0.06	0.25	-
	VHF (Low power)			VHF (High power)		
30	0.52	2	-	6.9	19.65	-
40	0.62	2.37	-	8.52	22.39	-
50	0.63	3.3	-	9.41	24.79	-
60	0.43	2.74	-	7.02	25.8	-
70	0.32	1.75	-	4.29	20.46	-
80	0.22	1.38	-	3.14	17.29	-
H mean	3.23	15.56	-	40.49	132.38	-

Table 7. H-field measurements from HF and VHF antenna at commander spots, transmitted with low and high power on AV8W.

Transmission MHz	H-field measurement at commander (A/m)					
	HF (Low power)			HF (High power)		
	Spot 4 ($\times10^{-6}$)	Spot 5 ($\times10^{-3}$)	Spot 6	Spot 4 ($\times10^{-6}$)	Spot 5 ($\times10^{-3}$)	Spot 6
5	30.35	0.35	-	32.7	0.311	-
10	14.64	0.33	-	14.4	0.218	-
15	9.30	1.36	-	8.2	1.372	-
20	10.02	0.41	-	13.0	0.323	-
25	6.46	0.11	-	8.8	0.177	-
	VHF (Low power)			VHF (High power)		
30	21.50	2.48	-	683.5	20.65	-
40	19.35	3.36	-	2610.3	22.127	-
50	54.59	4.69	-	742.9	23.943	-
60	36.34	2.72	-	1435.9	23.427	-
70	32.95	2.63	-	992.8	21.067	-
80	159.14	1.53	-	2823.3	19.46	-
H mean	394.64	19.97	-	9365.8	133.08	-

Table 8. Exposure calculation: linear and spatial average for HF and VHF low power transmission at gunner and commander location on AV8W.

Range	Gunner				Commander			
	Linear* (V/m)	Linear# (V/m)	Spatial* (V/m)	Spatial# (V/m)	Linear* (V/m)	Linear# (V/m)	Spatial* (V/m)	Spatial# (V/m)
HF	0.87	0.075	1.5	0.106	0.62	0.22	1.07	0.31
VHF	14.27	0.065	24.7	0.091	22.59	4.93	39.12	6.98
Total Exposure	15.14	0.141	26.3	0.197	23.2	5.15	40.18	7.29

*All spots   #Exclude spot no. 3 and 6

Table 9. Exposure calculation: Linear and spatial average for HF and VHF high power transmission at gunner and commander location on AV8W.

Range	Gunner				Commander			
	Linear* (V/m)	Linear# (V/m)	Spatial* (V/m)	Spatial# (V/m)	Linear* (V/m)	Linear# (V/m)	Spatial* (V/m)	Spatial# (V/m)
HF	0.92	0.08	1.6	0.12	1.01	0.17	1.77	0.25
VHF	187.77	0.5	325.22	0.71	300.06	80.45	519.73	113.8
Total Exposure	188.69	0.58	326.82	0.83	301.07	80.62	521.5	114.05

*All spots   #Exclude spot no. 3 and 6

Table 10. HF and VHF antenna with annual exposure dose values at gunner and commander location on AV8W.

	Annual exposure dose (V h/m)			
Location	Gunner		Commander	
Spots	Low Power	High Power	Low Power	High Power
All spots	202×10^6	2519×10^6	309×10^6	4020×10^6
Exclude spot no.3 and 6	1.5×10^6	6×10^6	56×10^6	879×10^6
	ICNIRP- Low Power	ICNIRP- High Power	ICNIRP- Low Power	ICNIRP- High Power
All spots	693×10^3	110×10^6	1622×10^3	280×10^6
Exclude spot no.3 and 6	20.39	601	52×10^3	13×10^6

RF radiation dose assessment methods creating new challenge to armoured vehicle RF radiation exposure study due to various factors which may probably affect the results. In a study carried out by Baste et al. [5] recorded RF radiation exposure ranges 5.5×10^3 V h/m to 152×10^3 V h/m as a result from calculated annual ship dose on the different locations and tenure of sailing. This study was similar to the methods of calculating continuous RF radiation hazard onto crew onboard of a ship which was based on annual mission time for different periods and dose on different locations within the ship.

The measurements were made in near-field region and changes in distance to the RF source can affect the values of both E Field and H Field, required investigation both fields are taken into account [4, 9]. However, not all conditions have measured H-Field due to device restriction. Thus the relative connection between E-Field and H-Field in exposure near field is not achievable.

In this study, the values measured from both antennas during the open and close hatch condition complied with the ICNIRP and others standard guidelines. However, some values are exceeding the limits; especially on commander standing crew open hatch condition with the highest value of 742 V/m. As a result, this value contributing the most extreme RF radiation exposure level. The higher E-Field value probably influenced by the factors such as the antennas distances to personnel position, vehicle dimensions, windows, material, and ground surrounding [6,7]. Others study on military vehicle RF radiation levels carried out by Alcaras and Frere [8] shown the E-Field results range 1200 V/m from the 125 W HF transmission and 200 V/m from 50 W VHF transmission respectively. The RF radiations levels were measured 1 m from both antennas.

Summation values of exposure, HF and VHF seemed realistic with these methods due to the condition of the crew and the radio system on AV8W and specified tenure of deployment in the mission. Hence, the RF radiation dose assessment approach probably yielded a satisfactory indication of exposure level.

CONCLUSION

The measurements and calculated of RF radiation exposure emitted by the HF and VHF antenna aboard AV8W have been performed at a selected location normally occupied by the crew. Various range of RF radiation values from measurement was demonstrated as a result of the different mode of transmission power, the tenure of mission deployment, location and condition of the crews. Hence, dose assessment values significantly influenced by these factors. Since this measurement was conducted in the open area test site, the results may probably influence by man-made surrounding factors. Ideal and absorbance measurement place need consider in further research of armoured vehicle development for more accuracy of RF radiation exposure result.

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