Assessment of the Local Levels of Exposure to Electromagnetic Field and Radio Frequency

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Abstract— Today, electromagnetic fields (EMFs) and radio frequencies (RFs) exist in most inhabited areas, whether urban or rural. However, there are still some conflicting beliefs as to the degree of hazard associated with the sources of these fields and frequencies. In this work, the levels of exposure to EMFs and RFs are evaluated for the city of Amman, Jordan. Other cities may have different results depending on the size of the city which affects power requirements and the type and size of the cell towers used. The sources that are investigated include high voltage (HV) cables, electric substations, electric vehicles (EVs), hybrid electric vehicles (HEVs), home appliances, communication towers, Wi-Fi, etc. The proper measuring devices and procedures have been used to obtain the data. The measured values, which are compared to the published international standards and conclusions, are made based on these measurements. One interesting finding is that salvage EVs emit much more EMF than clean title EVs, which warrant more scrutiny on the quality of maintenance performed on these vehicles.

Keywords— Cell tower, electric vehicle, electromagnetic frequency, high voltage, hybrid electric, radio frequency, vehicle.

I. INTRODUCTION

The aim of this work is to provide a definite answer for the safe distances away from EMF and RF sources, and to define the potential hazards of these sources. Contour maps of the EMF and RF levels around selected common sources will be constructed. For RF, the measurements will be taken using RF strength meter, with display resolution of 0.1 μA/m and 0.1 W/m^2. For EMF, an EMF field radiation tester will be used, with a range of 0.1–(2)10^6 μT or 1–(20)10^6 mille gauss (mG). The danger posed by EMF in Jordan was assessed by Hamdan [1], where he suggested exposure limits to avoid or minimize the risk of EMF. However, his work was not extended to the effects of EVs or HEVs as these vehicles were not common at the time of the study. Gajšek et al. [2] reviewed assessment studies done in Europe on the exposure of the public to EMF. They found that outdoor EMF can go up to 2 mG. Indoors, high values of 1 mG have been measured close to some domestic appliances. In addition, they recorded EMF in HEVs in the range of 0.3-24 mG, whereas EMF in EVs was found at 1 mG. They showed that EMF in EVs is the same as personal exposure in some residential areas. However, no distinction has been made between clean-title and salvage EVs or HEVs. In this work, both clean-title and salvage cars will be tested.

II. RADIO FREQUENCY (RF)

The classification of RF limits according to the conservative bioinitiative report [3] is shown in table 1. Some of the main RF sources will be addressed in this work; these sources include smart phones, Wi-Fi, MiFi, Bluetooth and cell phone towers.

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TABLE 1
RF RISK LEVELS

Unit	No Concern	Slight Concern	Severe Concern	Extreme Concern
μW/cm²	< 0.000,01	0.000,01 - 0.001	0.001 - 0.1	> 0.1

A) Cell Phones

Studies have demonstrated the potential risks of holding cell phones close to the head; the effects include migraines, obscured vision, cerebral pain, malignancies, tumors, melanoma, diminished melatonin and memory misfortune [4]. The readings obtained for a typical smart phone are shown in Table 2.

B) Wi-Fi, MiFi and Bluetooth

Wi-Fi, MiFi and Bluetooth emit RF in the low-gigahertz frequency. Contingent upon the level and the length of exposure, the risks can run from sleeping disorder and cerebral pains to tumors [5]. The average readings taken for various devices are listed in Table 2.

C) Cell phone tower

Cell phone towers transmit high-frequency radio waves, or microwaves, that can extend to 45 miles. These microwaves can meddle with the body's particular frequencies, causing an assortment of potential health issues, such as headache, memory loss, infertility and cancer [6]. One of these towers is shown in Fig. 1, while a reading is being taken. Many readings have been taken at various distances. As a result, contour map of RF density distribution for the tower is constructed as shown in Fig. 2. All the distances shown are in meters. "E" is the most risky region. However, moving outward to "D", "C", "B" and "A" decrease the risk, while "A" is the safest region. It is worth noting that the contour map shows irregular contours instead of circles. This may be due to obstacles as well as interference from other sources.

Fig. 1. Reading RF for a cell phone tower

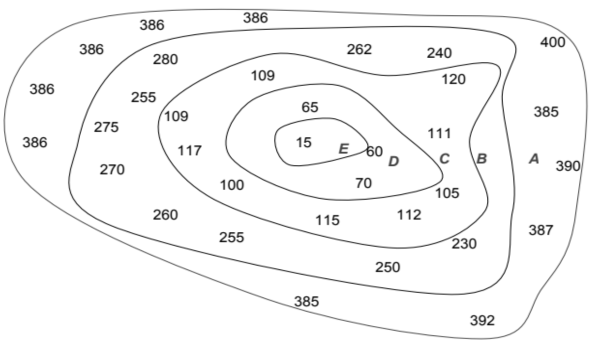

Fig. 2. RF distribution around the cell phone tower

D) RF Safe Distances

The readings taken around the aforementioned sources are summarized in table 2. The highest RF level was found around mobile base stations or cell phone towers, where the adjacent cell tower reading is way above the extreme concern region. When such a tower is placed above a building, the highest effect was found on the upper floor, even with closed windows. In middle floors, RF readings drop to safe levels only if the windows were closed. In the ground floor, RF readings become safe even with open windows. In the street in front of the building, the RF readings are not safe until reaching the safe distance mentioned in table 2 (350 m). It is noted that the measured safe distance is only 17% higher than the standard safe distance, which could be due to the different type of equipment.

The Federal Communications Commission (FCC) regulated acceptable safe distances for cellular phones based on a specific absorption rate (SAR) of 1.6 W/kg [7]. The Wi-Fi, MiFi and Bluetooth adjacent readings are in the extreme concern region. The measured safe distances for these devices are within two meters. It is noted that microwave ovens exceed the safe distance requirements of other typical household items.

TABLE 2
SAFE DISTANCES FROM RF SOURCES [7], [8]

Frequency Source	Adjacent reading, $\mu W/cm^2$	Standard safe distance, m	Measured safe distance, m
Cell tower	0.723	300	350
Smart phone	6.0	1.0	1.5
Wi-Fi router	0.13	1.5	2
MiFi	0.313	0.7	1.5
Bluetooth	0.2	0.65	0.81
Microwave oven	0.6	3.0	3.6

III. EMF

As stated by WHO [1], the minimum EMF level to potentially disturb the biological mechanisms in the human body is 10 mV/m. Epidemiological studies conducted by Mizrach and Cherry [1] found abnormal incidence of childhood leukemia in houses close to electrical substations or power lines. Masateru [1] showed a positive association between exposure above 0.4μT and the risk of childhood brain tumors. A survey [1] of electric power workers found that there is a greater incidence of depression among those who worked near electrical substations. Different bodies have set guidelines restricting exposure to EMF; the limits set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) [9] are 5 KV/m for electric field (E) and 150 mG for magnetic field (B). An epidemiologic study found that if the human is exposed to more than 0.4 μT, the risk of leukemia and brain tumor will be 95% [10]. In this work, some of the common EMF sources such as power pylons, transmission lines, electric substations, grid low- voltage (LV) links, home appliances, EVs and HEVs will be tested. The classification of EMF limits according to Bioinitiative report [3] is shown in Table 3.

TABLE 3
EMF RISK LEVELS [3]

Unit	No Concern	Slight Concern	Severe Concern	Extreme Concern
mG	< 0.2	0.2-1	1-5	> 5

A) Electric Grid Elements

Many investigations have demonstrated that living near HV parts of the power transmission system expands the risk of disease [11]. In this work, the measured electric grid elements include power pylons, substations (Fig. 3) and grid LV cables. A power pylon is a steel tower used to hold an overhead HV cable, whereas a substation houses a transformer to step down the voltage for power distribution. We gauged the EMF for few pylons, substations and LV cables. The contour map of the EMF intensity distribution around a substation is shown in Fig. 4. The risk decreases as we go from D through C and B; and the least risk is found at region A. All distances are in meters. However, it is noted that the EMF distribution is asymmetric due to the obstacles, especially metallic materials, existing around the substation.

Fig. 3: Reading EMF on the fence of a substation

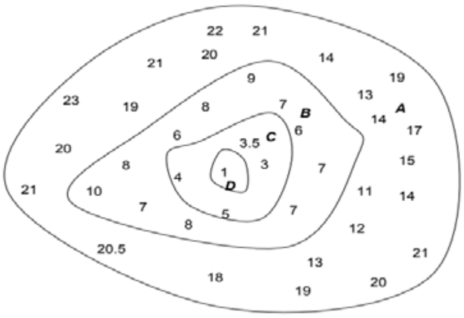

Fig. 4. EMF distribution around a substation

B) Appliances and Equipment

Several appliances and equipment such as vacuum cleaners, refrigerators, electric heaters (Fig. 5) and welding machines (Fig. 6) are tested. The results are shown in table 4. Some of these devices such as hair dryers must be kept close to the body during usage, while others such as washing machines can be kept away from the body. Therefore, in the first category, the adjacent reading is the critical parameter, while in the second category, the safe distance is the critical parameter.

Fig. 5. Reading EMF for an electric heater

Fig. 6. Reading EMF for a welding machine

C) EMF Readings and Safe Distances

The average EMF readings and safe distances are listed in table 4. It is noted that for all the tested home appliances, the safe distance is within 1.5 meters. In most cases, the measured safe distances are higher than the standard ones. The reason could be the difference in type and capacity of each device.

TABLE 4
EMF READINGS AND SAFE DISTANCES [1]

Frequency Source	Adjacent reading, mG	Standard safe distance, m	Measured safe distance, m
Power pylon	4180	213	220
Substation	380	20	20
LV line	190	10	10
Welding machine	90	0.5	1.5
Microwave oven	15	0.5	1.4
Washing machine	2.2	0.5	1.2
Vacuum cleaner	13.2	0.7	1.1
Blender	50	0.3	0.7
Refrigerator	1.1	0.3	0.5
Electric heater	3.8	0.3	0.3
Hair dryer	200	0.1	0.05

D) EVs and HEVs

Since EVs and HEVs carry HV batteries and components, it is expected that both emit extremely low frequency (ELF) electromagnetic radiation (EMR). Thus, the safety of these vehicles must be investigated. Shockingly, little research on this issue has been funded [12]. Even if EMF estimations do not exceed ICNIRP rules, passengers may still be at risk [13]. A major source of EMF in EVs and HEVs is the battery [14]. Most of the common types of EVs and HEVs in the local market have been tested. The results are shown in table 5. Depending on the car condition, the results are divided into two categories: clean title and salvage. It is noted that clean title cars have the lowest EMF emissions, while salvage cars emit the highest EMF. A more detailed EMF-speed relationship for a clean title Ford Focus is shown in Fig. 7; EMF stays well below the safe limit for all speeds up to 80 km/h, while the difference between front and rear is small. On the other hand, EMF emissions for salvage Ford Focus is shown in Fig. 8, where the EMF level exceeds the safe limit, especially in the front. The results in Table 5 show that all clean title EVs and HEVs are safe; and all salvage EVs and HEVs are unsafe.

TABLE 5
MEASURED EMF IN DIFFERENT EVS AND HEVS

Make	Model	Year	Condition	Speed (km/h)	Max EMF (mG)
Ford	Focus	2013	Clean title	80	0.2
Mercedes	Smart	2016	Clean title	80	0.28
Nissan	Leaf	2013	Clean title	80	0.3
Tesla	Model S	2017	Clean title	80	0.3
Ford	Focus	2014	Salvage	80	0.9
Tesla	Model S	2016	Salvage	80	1.7
Nissan	Leaf	2016	Salvage	80	1.9
Mercedes	Smart	2017	Salvage	80	2.2
Chevrolet	Volt	2015	Salvage	90	3

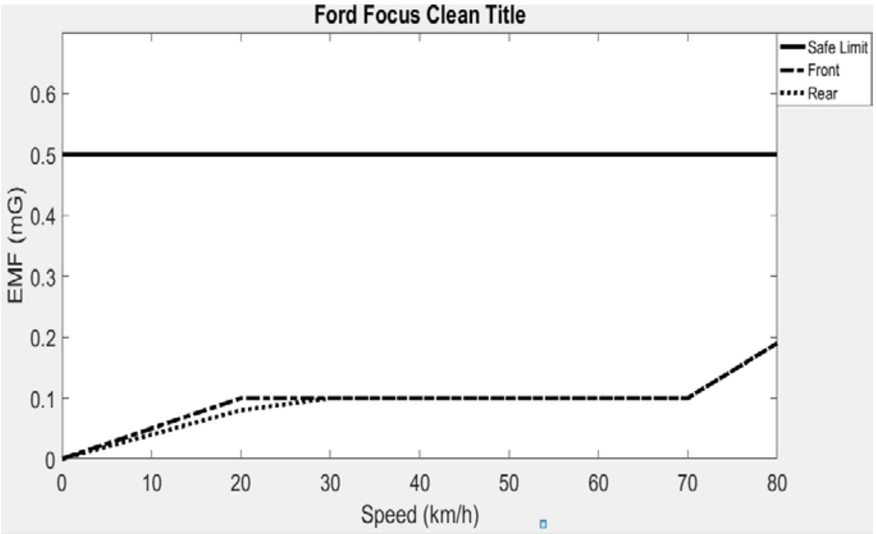

Fig. 7. Measured EMF in front and rear seats for Ford Focus- clean title

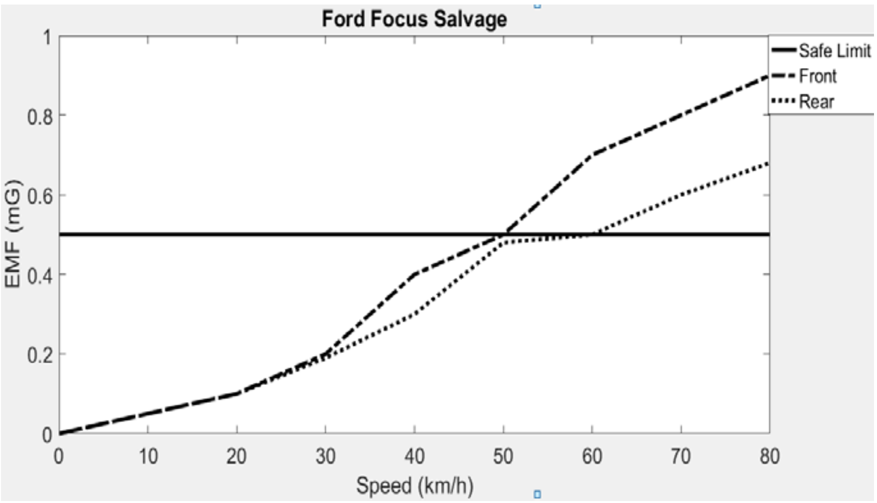

Fig. 8. Measured EMF in front and rear seats for Ford Focus- salvage

IV. CONCLUSIONS

RF and EMF emissions in various locations have been measured and recorded. Based on the results of this study, it is recommended that people mitigate the effects of RF and EMF by staying as far as possible from their sources. The safe distances provided in this work should serve as guidance in this regard. In the meantime, once under exposure, the time of the exposure should be as short as possible. The measured RF and EMF values in this work are specific to the types of devices tested; and due to the variability of types and sizes of RF and EMF sources, these values may differ.

EMF emissions in EVs and HEVs were dependent not only on the make and model of the car, but also on whether it is clean title or salvage. A clean title car means it has not suffered from an accident, while a salvage car means it was involved in a crash before being fixed later. It seems that the electrical insulations or shields were not reinstalled properly in some salvage cars; therefore, their EMF levels are unsafe. Nevertheless, all tested clean title cars were found safe. It is worth noting that we have a certain degree of control over the distance to keep away from many frequency sources. However, when it comes to EVs and HEVs, the option of keeping a longer distance from the source is clearly not available. Therefore, there is a minimum amount of inevitable EMF emissions. It is clear in Fig. 7 and Fig. 8 that the amount of RF increases with the speed of the car. Therefore, as a future work, it is recommended to test both clean title and salvage EVs and HEVs at speeds higher than 80 km/h.

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