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High-frequency Electromagnetic Field Measurement inside the Cars with Modern Embedded Wireless Technologies

***Abstract**. The main goal of the paper is the measurement of electromagnetic field distribution inside the two cars with modern embedded wireless technologies. Measurement was performed in standard urban environment in the cars with mobile phone Bluetooth connection for two cases by each car, without usage of the phone and receiving the call. Results of the measurements show, that in modern cars with more wireless technologies are many high frequency sources of electromagnetic fields. Although the values of these measured variables do not exceed the limit levels, it depends on the current state of the organism and the time of exposure.*

***Streszczenie.** Głównym celem niniejszej publikacji jest pomiar dystrybucji pola elektromagnetycznego wewnątrz dwóch samochodów. Pomiar został wykonany za pomocą nowoczesnych technologii bezprzewodowych Bluetooth. Doświadczenia zostały przeprowadzone w standardowym środowisku miejskim w samochodach z telefonem komórkowym Bluetooth dla dwóch: bez użycia telefonu i przy odbieraniu połączenia. Wyniki pomiarów pokazują, że w nowoczesnych samochodach z większą liczbą dostępnych technologii bezprzewodowych znajduje się wiele źródeł pól elektromagnetycznych o wysokiej częstotliwości. Pomimo, że wartości zmierzonych parametrów nie przekraczają poziomów granicznych, ich wpływ na organizm zależy to od aktualnego stanu organizmu i czasu ekspozycji. (**Pomiary pola elektromagnetycznego wysokiej częstotliwości w samochodzie wyposażonym w urządzenia komunikacji bezprzewodowej**).*

Keywords: Measurement, Electromagnetic field (EMF), Car, Received Power, Bluetooth technology,
Słowa kluczowe: pole elektromagnetyczne, samochód, odebrana moc, technologia Bluetooth.

Introduction

Safety, comfort, and cellular-based access technologies are one of the main challenges for all car manufacturers and at the same time an important condition for the buyer.
Technologies for the safety of passengers, traffic efficiency, passenger comfort, forwarding upcoming traffic information in a timely manner, and vehicular networking belong to the standard equipment of current cars. These technologies belong to the concept of Intelligent Transportation System (ITS).

The key parts of the ITS framework are GPS, Bluetooth, Dedicated Short Range Communication (DSRC), Vehicular Ad-Hoc Network (VANET), Vehicle-to-Vehicle (V2V) or Vehicle-to-Bicycle (V2B) communication, vehicle-to-infrastructure (V2I) connectivity based on Wi-Fi. In the near future, we anticipate the addition of sensors (e.g. biometric authentication system as protection from road accidents or unlocking the car) and sensors for the use of cars in the concept of the Internet of Things (IoT).[1][2][3]
Inside the cars are from 50 to 150 sensors. Due to the significant weight caused by the number of sensors wire the Intra-car Wireless Sensor Network (WSN) is installed. Intra vehicular WSN is an automotive architecture that allows the communications between electrical control units and sensors using wireless technology. The WSN use the same 2.4 GHz ISM frequency bands as Wi-Fi and Bluetooth do. Also, in this way increases the car's interior electromagnetic smog. [4]

Serve these technologies really for the protection of life and security? Is it safe to use these technologies for a long time? Recent studies indicate that exposure to radiofrequency radiation caused not only tissue heating at exposures above prescribed thresholds. The data point to increased occurrence of Schwannomas and malignant gliomas, as well as chromosomal DNA damage, Parkinson's Disease and Amyotrophic Lateral Sclerosis (ALS), acoustic neuroma, male and female infertility, individuals with nonspecific symptoms linked to electro-hypersensitivity, or microwave illness, etc. [5] [6] [7]. In 2011, an expert working group of the International Agency for Research on Cancer (IARC) categorized radio-frequency radiation emitted by cell phones and other wireless transmitting devices including cordless phones and Wi-Fi as a Group 2B ("possible") human carcinogen [8]. In this study [9] were taken readings inside a parked vehicle without a cell phone and were compared with the power density with cell phone using Bluetooth hands free device. Power density measurements were performed using a handheld portable power density measuring TES 593 electro- smog meter from TES Electrical Electronic Corp. The power density increased by 393% in case when cell phone and Bluetooth were use inside the car compared to case without cell phone and Bluetooth. The SAR value calculated from measured data is for 900 MHz 349 mW/kg and for 1800 MHz 514 mW/kg. The whole-body average SAR restriction for frequency range 10 MHz to 10 GHz is 80 mW/kg [10]. Another author's result obtained by simulations illustrated that the maximum SAR induced for mobile phone users in a vehicle is 5% higher than those in free space [11].

The transportation system is a source of the electromagnetic field, to which a large percentage of the population is exposed. The dosimetric analyses made in different countries in this area point out the increased levels of RF-EMF [12][13][14][15][16]. Although the measured data are still below the ICNIRP level [17], it is necessary to consider the amount of time spent in this environment of the transportation system, especially for children.

The main goal of this paper is the measurement of radio frequency electromagnetic field (RF-EMF) inside modern cars with lot of embedded wireless technology during the phone call and without a call, but with the Bluetooth device turned on. Measurements are performed using spectral analyser in the driver side inside the car. Measured electromagnetic field power in dBm is used for the calculation of field intensity and the results of the measurements were evaluated against the limits in the standards.

As the measure of RF-EMF exposure limits a specific absorption rate (SAR) is used. Because measuring SAR in living persons is impossible, the field strength (V/m) or the power density (W/m2) measured outside of the human body is instead used for regulating far-field RF-EMF. The ICNIRP recommends a field strength of 61 V/m or a power flux density of 10 W/m^2 [18].

Since ICNIRP bases its guidelines on proven adverse health effects and there is difference between a biological effect and an adverse health effects, for protective restrictions in sake of public health only adverse health effects are considered. Considered available experimental studies aimed for acute changes to wellbeing or symptoms have failed to identify any substantiated effects of exposure. However, a small portion of the population attributes non-specific symptoms to various types of radiofrequency EMF exposure; known as Idiopathic Environmental Intolerance attributed to EMF (IEI-EMF). Subsequent studies so far failed to identify a relation between radiofrequency EMF exposure and such symptoms in the IEI-EMF and healthy population as well, on the contrary, they suggest that "belief about exposure" and not exposure itself, is the relevant symptom determinant [18].

Bluetooth technology inside the cars

Automotive producents are annually increasing the safety measures and new technologies embedded in their new models of cars. We performed the measurement in two types of cars CAR1 (year 2015) and CAR2 (year 2019). CAR1 has Bluetooth technology, which is used to connect the phone to the phone interface in the vehicle. CAR2 has embedded more wireless technologies used beyond phone call establishment. Some phones are automatically detected and connected when the ignition is switched on if they have previously been connected to the car. Naturally, the Bluetooth feature on the phone must be turned on. When the phone is connected to the telephone interface, data is exchanged via one of the Bluetooth profiles. Automotive producents are annually increasing the safety measures and new technologies embedded in their new models of cars. Modern cars, such as the car in which we performed the measurement, have embedded many wireless technologies used beyond phone call establishment. Bluetooth technology is used to connect the phone to the phone interface in the vehicle. Some phones are automatically detected and connected when the ignition is switched on if they have previously been connected to the car. Naturally, the Bluetooth feature on the phone must be turned on. When the phone is connected to the telephone interface, data is exchanged via one of the Bluetooth profiles [18].

a.

b.

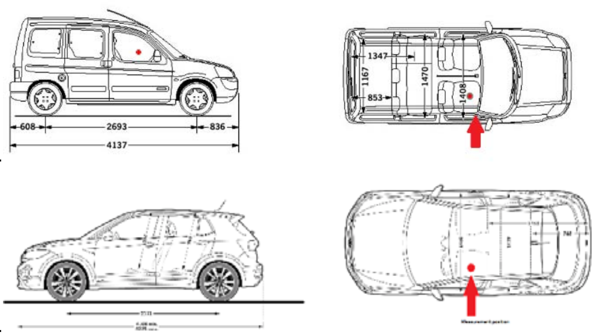


Fig.1. Dimensions of used cars (a. car 1 year 2015 and b. car 2 year 2019) and measurement position in the car- red point.

When activated via telephone, the Message-Access-Profile (MAP) and Phone-Book-Access-Profile (PBAP) are connected automatically to the Hands-free Profile (HFP). Even if the phone is connected to the Advanced Audio Distribution Protocol (A2DP), the Audio / Video Remote Control Protocol (AVRCP) will also connect automatically. Bluetooth communicates on a frequency of 2.45 GHz (between 2.400 GHz and 2.483.5 GHz). The manufacturer also provides Comfort-Telephony feature which is not available in all countries and depends on the car's equipment and usage of suitable mobile phone. The phone may be places and a cradle that connects the phone to the external antenna via a fixed interface in the centre console. This feature reduces level of radiation in the car and better reception quality.

Comfort-Telephony feature, however, is not activated in used car. The integrated Bluetooth® interface (for many models) enables wireless interaction with a compatible mobile phone. In addition, the mobile phone can be charged using the charging function. The functions of the mobile phone can be called up on the screen - incoming SMS messages are also displayed there. And driver can even use the control unit to choose the conversation partner quite safely and intuitively himself [19].

Estimation

For measuring EMF in a selected frequency range is used BK PRECISION 2650A spectral analyser together with TP - LINK TL - ANT 2408CL omni-directional microwave-band antenna. The suggested operating frequency range for this antenna is 2.4-2.5 GHz and by HPOL Beamwidth-horizontal polarization is 360 ° (Fig.2). During our measurements is the antenna horizontally oriented. Even if the optimum range for the 8dBi gain is declared only 2400 to 2500 MHz, we decided to show the values for frequency range 2100-2700MHz, just for illustration of the presence of many other RE-EMF bands inside the cabin.

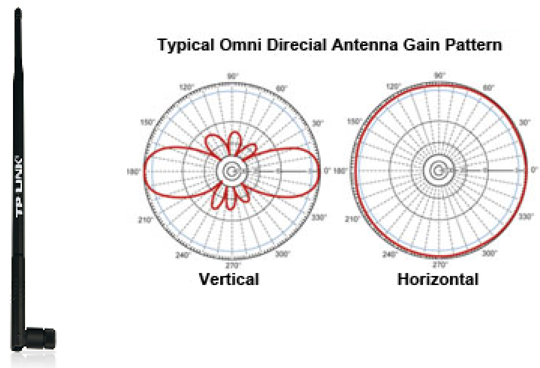


Fig.2. TL-ANT 2408CL omni-directional microwave-band antenna gain pattern.

The instrument works in mode which allows determining the maximum value for each frequency in the measurement interval of 7 seconds [20]. Measurements are conducted inside the cars, Fig. 1. for mentioned two situations: a) car is started without using cell phone and b) car is started with an on-going call. Measurements are performed in driver seat of the car at one position as depicted in Fig. 1. During measurement with on-going call the phone is placed at the dashboard compartment in centre panel otherwise it is switched off. Instead of the signal strength transmitted by an antenna, the real field intensity or power density at a given distance from a transmitter had to be learned.

When determining potential radiation specifications, field intensity or power density calculations are necessary for estimating electromagnetic interference (EMI) effects. The resulting absolute value of the electric field strength |**E**| at a given point is determined from equation for the received power. Each measurement is performed in all three axes because of polarisation of the wave. The measured power ratio G from the spectral analyser in dBm, for each measured antenna position in x, y, z direction is converted to the received power P. The values of power density S and then electric field strength E are calculated afterwards from the values of received power P. Field intensity (electric field strength) is a general term that usually means the magnitude of the electric field vector, commonly expressed in volts per meter [V/m]. At frequencies above 100 MHz, and particularly above one GHz, the power density (S) concept is used more often than the field strength. Power density and field intensity are related by equation

$$(1)\quad S = \frac{E^2}{Z_0} = \frac{E^2}{120\pi}$$

where S is power density in W/m^2, E is the RMS value of the field strength in V/m and 120π in ohms is the intrinsic impedance of free space. The resulting absolute value of the electric field strength |**E**| at a given point is determined by

$$(2)\quad |\mathrm{E}| = \sqrt{\mathrm{E}_x^2 + \mathrm{E}_y^2 + \mathrm{E}_z^2}$$

Where |**E**| is absolute value of electric field strength [V/m],E_x, E_y, E_z are measured absolute values of the electric field strength in x, y and z axis. All measurement points are at a height of 45 cm from the seat level, which is about the chest height of an average sitting person.,

Results

The measurements are performed during the day under standard urban environment. The power was measured in all three axes. The average values from all the measurements are calculated and the absolute value of the field strength above the driver seat inside the vehicle is evaluated. The field strength levels in case a) are relatively low, but it depends on frequency band and type of car. The maximum value occurs by CAR1 for frequency 2139MHz and CAR2 had the highest value of field strength by frequency 2674 MHz.

The rise in power in all wireless communication bands can be seen when the measurement is done during the phone call, case b). The electric field strength rises about four times in Bluetooth band (2400-2500MHz) and about twenty times in comparison of case a) by CAR2, which in addition to UMTS and GSM bands with more people inside the car with mobile phones or tablets, represents increase in RF-EMF exposure of persons in the cabin. Whereas the values are not exceeding limits for the public exposure the prolonged duration of calls adds to the total exposure of the person and possible development of biological effects of low-level RF-EMF.

Measured and calculated values of P, S and E for measured frequency range from 2100 – 2700 MHz are shown in Fig. 3 and Fig.4. According to the Bluetooth frequency spectrum used in cars and the omni directional dipole antenna frequency feature added, the emphasis is on the frequency range from 2400 MHz to 2500 MHz.

Table 1. Maximum values of measured emf for case a) CAR1

Frequency band [MHz]	P [nW]	S [nW/m2]	E [mV/m]
2100-2150	209.35	148805.0	236.85
2400-2500	22.43	36327.9	117.00
2650-2700	93.91	134329.0	225.00

Table 2. Maximum values of measured emf for case b) CAR1

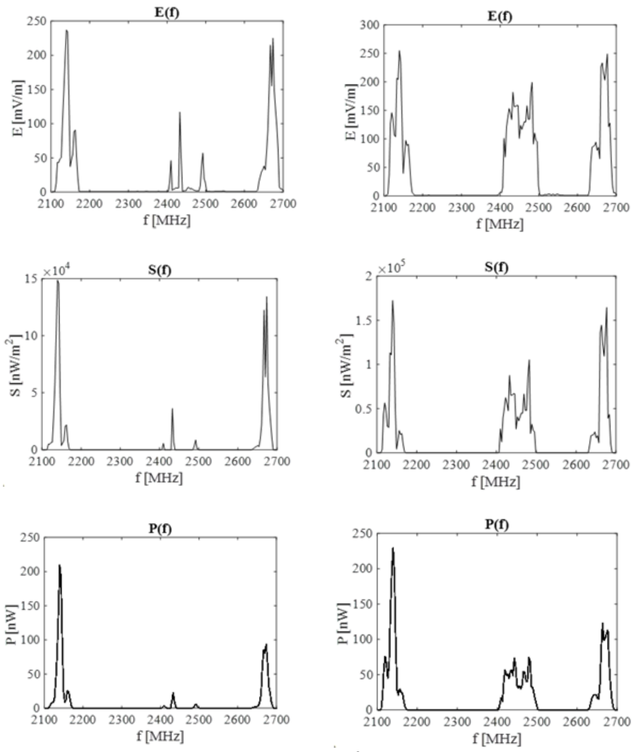
Frequency band [MHz]	P [nW]	S [nW/m2]	E [mV/m]
2100-2150	229.4	172431	254.96
2400-2500	73.91	105370	199.38
2650-2700	112.95	164528	249.00

Table 3. Maximum values of measured emf for case a) CAR2

Frequency band [MHz]	P [nW]	S [nW/m2]	E [mV/m]
2100-2150	6.27	4640.79	41.83
2400-2500	0.30	0.20	8.2
2650-2700	6.51	8869.00	57.82

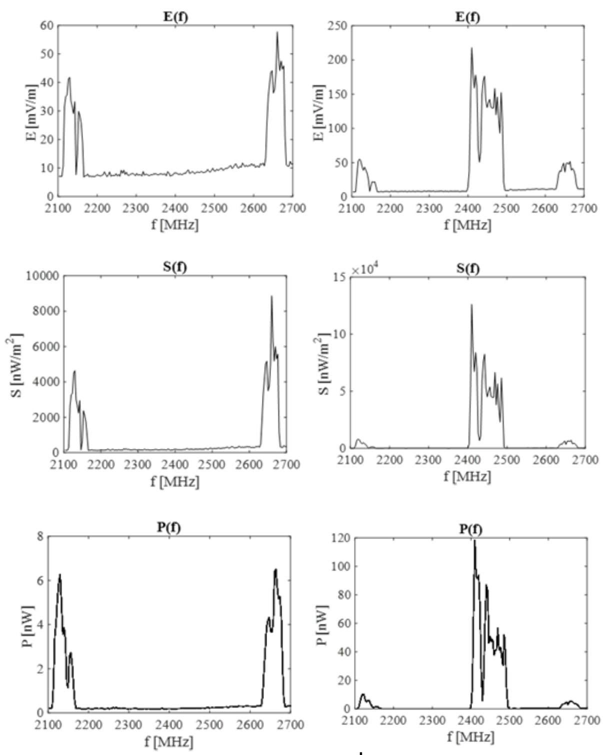
Table 4. Maximum values of measured emf for case b) CAR2

Frequency band [MHz]	P [nW]	S [nW/m2]	E [mV/m]
2100-2150	10.48	8101.19	55.26
2400-2500	118.64	126172.00	218.10
2650-2700	5.32	7111.31	51.70



a. b.

Fig.3. Measured values in CAR1 a.) turn off mobile phone. and b.) during phone call



a. b.

Fig.4. Measured values in CAR2 a.) turn off mobile phone. b.) during phone call

Maximum values for all present frequency bands are listed for case a) without mobile connected in car in table 1,3 and for case b) with ongoing call- in table 2,4.

Conclusion

The submitted article deals with the personal vehicle sources of EMF and potential exposure to radiation in two cars (release years 2015 and 2019), evaluating the measured and calculated effects of EMF levels and comparing them with exposure limits [18]. For both measured cars and both operation states in case of ongoing phone call the values are higher. The values in both cars varies significantly. Values in the older car are in most measured cases higher than in the newer car. The newer car has the highest values only in frequency range (2400-2500MHz) during the phone call. Although the values of measured and calculated quantities do not reach the limits, their effects may depend on the actual state of the organism and the time of exposure, since each organism is different, and subjective influences (headaches, insomnia, sleepiness) can cause subjective side effects. In order to study the dosimetry levels inside personal travel, further measurements and simulations need to be performed not only for the benefit of adults but also for the well-being of children as passengers. Nor have studies been done when any of the passengers in a modern car had a pacemaker or cochlear implant, which could depend on distance of wireless technology to implant [21] This article deals with pilot study of this problematic in our department and in the future will be used for next comparison with another types and numbers of cars. It is important to know, how these common vehicles users of car are affected, when they spend a long time of their life.

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