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Laboratory Measurements of Electromagnetic Field inside Motorcycle Helmet with installed Bluetooth Communicator

***Abstract**. The main objective of the paper is to evaluate the electromagnetic field (EMF) within the motorcycle helmet with a Bluetooth communicator. Under laboratory conditions, the measurement was carried out using two helmets with integrated Bluetooth communicator set in intercom mode. The distance of the helmet was set to 500 mm without communication, the same distance with communication and the distance set to 2500 mm with continuous communication and BK PRECISION 2650A spectral analyzer together with Rohde & Schwarz used as a measurement set-up.*

***Streszczenie.** Głównym celem pracy jest ocena pola elektromagnetycznego wewnątrz kasku motocyklowego z komunikatorem Bluetooth. W warunkach laboratoryjnych pomiar przeprowadzono z wykorzystaniem dwóch kasków z wbudowanym komunikatorem Bluetooth ustawionym w trybie interkomu. Odległość pomiaru ustawiono na 500 mm bez komunikacji z kasku, taką samą odległość z komunikacją z kasku oraz odległość ustawioną na 2500 mm z komunikacją ciągłą. Jako stanowisko pomiarowe wykorzystano analizator widma BK PRECISION 2650A firmy Rohde & Schwarz. (**Laboratoryjne pomiary pola elektromagnetycznego wewnątrz kasku motocyklowego z zainstalowanym komunikatorem Bluetooth**).*

Keywords: electromagnetic field (EMF), motorcycle helmet, Bluetooth communicator, electric field strength.
Słowa kluczowe: pole elektromagnetyczne, kask motocyklowy, komunikator Bluetooth, natężenie pola elektrycznego.

Introduction

Motorcycle riding is very common and popular leisure time activity and is even more widely used as a major commuting alternative. Increased interest in the motorcycle riding is the reason of great improvement of motorcycle gear and development of safety means for both rider and pillion. The essential portion of all the equipment is a helmet. Since the introduction of wireless technology into motorcycle equipment, motorcycle riders around the world enthusiastically welcomed the prospect of easier contact and other advantages of helmet communication. For different riding activities, from motorcycle touring to regular commuting, a helmet communication system provides more protection and comfort. Many helmet communicators with various mounting styles and different sets of functions are available on the market. Helmet communication systems have several advantages that make the experience of motorcycle riding safer, smoother, and much more enjoyable. There is a large amount of work focused on wireless communication systems which are implemented in a helmet. These studies described the different prototypes of communication devices with multiple features. Spelta C. et al referenced a system which consists of a vehicle-to-driver and a vehicle-to-environment communication mechanism and is based on a smartphone core and on a wireless Bluetooth medium. [1] A communication system of a helmet was designed by Patil S. et al [2] and this system also strives to decrease the chances of a motorcycle being stolen by integrating additional security features such as helmet-put-on. In case of a motorcycle being stolen, remedial measures such as tracking and identification can be taken. Divyapushpalakshmi M. et al [3] purposed a novel helmet with smart functions. A vibrating sensor, GPS and GSM module are integrated in order to inform about the accidents and SIM module is applied for sending a message about a detected accident with an exact location, which can reduce the death rate in road accidents. The mobile communication can be done via Bluetooth module with a speaker. Chandran S. et al [4] monitored the value received from accelerometer saved in a helmet which detects an accident by analysing values and sends an emergency notification to contact with Global Positioning System location. There is another helmet communicator which was introduced as a cost effective and user-friendly protection system for the rider's safety. In addition to the mentioned accident detection and communication protocols, it also contains the alcohol detector which is a gas sensor to detect the presence of alcohol in the rider's breath, to determine his sobriety and IR sensor, which recognises if the person is wearing the helmet or not. [5, 6, 7]

Based on these designs, there are a lot of helmet communicators available on the market. In these models, the noise from the surroundings is eliminated and the voice sensing is actively protected. Since every helmet has a common Bluetooth communicator inside the helmet near human tissue, this paper studies the strength of the electric field, produced by a communicator. The device can typically be combined simultaneously with multiple devices and allows a rider to have hands-free telephone conversations when driving, allows riders to communicate within a specified area of proximity, as in an intercom system, allows music streaming and radio listening, provides links to the GPS navigation system. However positive the effect of using the Bluetooth communicator in the helmet is, the reality of electromagnetic field radiation is still present in the immediate vicinity of the human brain, the most sensitive known living tissue. Because artificial electromagnetic waves produced by electronic devices are usually polarized compared to natural electromagnetic radiation and can create interference effects and cause oscillation in living tissues of free-charged or polar molecules, the caution of the usage is in place. Recommendations and exposure limit values for low-frequency electromagnetic fields (EMF-s) and microwaves are set to protect people from health effects based on the known thermal effects. However, it remains unambiguous whether weak EMF-s pose a health hazard in the case of long-term exposure. [8], [9]

International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set guidelines for restricting exposure to electromagnetic fields in the range from 100 kHz to 300 GHz for the safety of humans exposed to radiofrequency electromagnetic fields (RF). Many applications such as 5 G technology, WiFi, Bluetooth, mobile phones, and base stations are covered by these exposure restrictions. For the Bluetooth communicator, the frequency is 2400MHz and the recalculated maximum of electrical strength E is 67 V/m and the power density S is 12 W/m2. [10]

The ICNIRP recommendations are based on confirmed adverse health effects. However, there is a distinction between an adverse health effect and a biological effect. Therefore, only adverse health effects and no other non-specific effects identified by some as caused by EMF exposure have been regarded for protective restrictions for the sake of public health.

Measurement and simulation

All the measurements are performed under laboratory conditions. We are using two helmets with SRC□System™ Bluetooth communication device using multiple Device Connectivity ("MDC") with Bluetooth® compatible devices (cell phone, motorcycle, navigation device etc.) integrated to the collar upholstery of helmet. It offers parallel connectivity to intercom with up to two other SRC System™ headsets, Bluetooth enabled mobile phone / GPS device and A2DP enabled MP3 Player or A2DP Adapter. [11]

For measuring EMF in a selected frequency range BK PRECISION 2650A spectral analyser together with Rohde & Schwarz antenna RS E 10 for near field measurement directly on the communicator and TP - LINK TL - ANT 2408CL omnidirectional microwave-band antenna with gain 8 dB for the measurement in the middle of the helmet is used. The instrument settings allow determining the maximum value for each frequency in the measurement interval of 7 seconds. Measurements are conducted inside the helmet with SRC System™ headset, Fig. 1. [11]

Fig.1. Communicator, helmet, antenna set, spectral analyser [11]

As mentioned, two communication arrangements are modelled by placing helmets at a distance *d* of 500 mm in a row for model of communication between rider and pillion, Fig. 2. Arrows are indicating the location of the communicator inside the helmet. The communication mode of the intercom is established, and the communication is silent or active from the partner side for the entire time of measurement inside the driver/partner helmet. For measurement, the frequency spectrum set is from 2250 to 2650 MHz. [11]

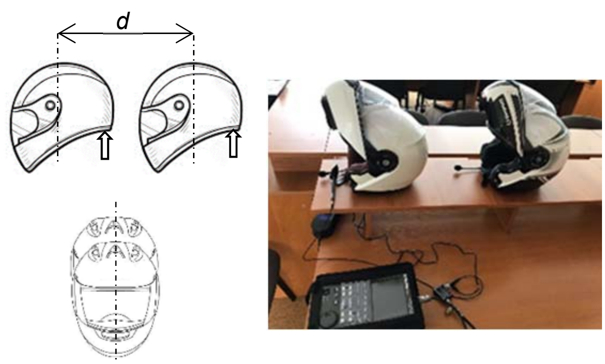

Fig.2. Measuremet arangement [11]

During the measurement, the 7 sec maximum values of the signal strength received by an antenna are saved. Field intensity or power density calculations are necessary for estimating electromagnetic interference (EMI) effects, when determining potential radiation hazards (personnel safety), or in determining or verifying specifications. The resulting absolute value of the electric field strength *E* at a given point is determined from equation for the received power

$$P = \frac{E^2}{480\pi^2}\frac{c^2}{f^2}\,G \qquad (1)$$

where *P* is received power in mW, *G* is measured power ratio from the spectral analyser in dBm, *f* is frequency in Hz and *c* is the speed of light in ms^{-1}. Then are from the value of received power calculated the values of power density *S* and then RMS of electric field strength **E**. 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. At frequencies above 100 MHz, and particularly above one GHz, power density S value is more often used than field strength. Power density and field intensity are related by equation

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

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 characteristic impedance of free space. [11].

For the further investigation, the model of measured arrangement is developed. The bipolar antenna and simplified spherical model of human hear are considered. A simplified three-layer spherical model of head consisting of averaged brain tissue, bone and skin is used, Fig. 3.

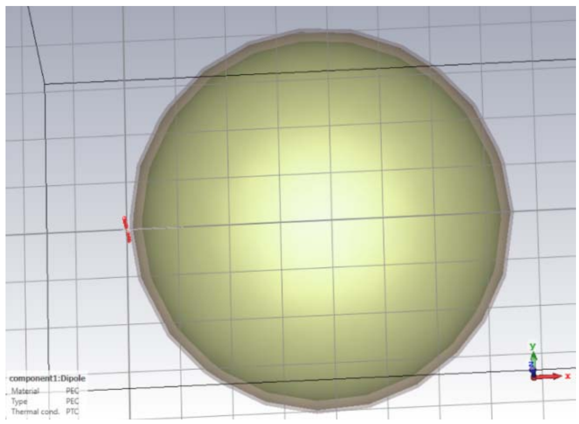

Fig.3. Simulation model arrangement

The dielectric properties of tissues are taken from database [12]. Due to its simplicity, a model of the dipole antenna is used for modelling of helmet communicator. The position of the antenna is in similar distance to the orb as the position inside the helmet it is chosen to 5mm. In order to perform calculation, the MV&RF&Optical module solver in time domain is chosen. As mentioned above, the model contains the source of electromagnetic field dipole antenna and three-layered simplified sphere representing head. The tissue properties are calculated and set for frequency 2.4 GHz, which is the operational frequency of device used in measurement. The model of dipole antenna consists of two cylinders of perfect electric conductor fed by a discrete port located in the middle of the longitudinal cylinder axis. We use discrete port with a reference impedance of 50 Ω, excited by a Gaussian shaped excitation signal with a frequency of 2.4 GHz. Due to postprocessing calculations a line is placed across the centre of orb head model. The line is oriented to be on the shortest distance flowline between the centre of the sphere and the dipole antenna.

Measurement and simulation results

The measurements are performed for near field - case a.) and far field - case b.). The electric field is measured in the case a.) by the Rohde & Schwarz antenna and in case b.) using TP - LINK TL - ANT 2408CL omnidirectional antenna. The values from all the measurements are calculated and the maximum absolute value of the field strength is evaluated. Compared to current exposure limits, the field strength levels for both scenarios are relatively low. Maximum values acquired in the silent condition for all measured frequencies while the device is on, but no continuous transmission are in table 1 and for transmission modelled as pillion-rider speaking are in table 2.

The measurement in case a.) is performed directly on the surface of the communicator cuff along the part where the antenna is situated. For the measurement performed using near field probe the increase of measured received power from the silence to the voice communication is obvious. The value rises about 57 times in Bluetooth band for the transmission case when talking to the pillion. The electric strength value rises about 6.7 times up to 807.8 mV/m.

Table 1. Maximum values of measured EMF for case a.)

Operation of device	P [nW]	S [nW/m2]	E [mV/m]
silence	35.78	37530	118.9
talking to pillion	2041	1731000	807.8

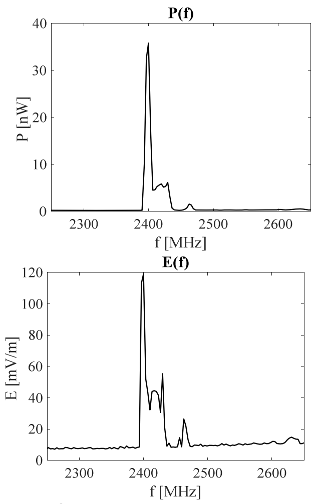

Fig.4. Case a.) - near field measurement, silence

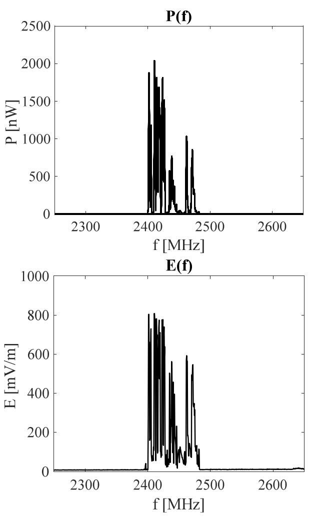

Fig.5. Case a.) - near field measurement, rider to pillion communication

When the measurement is performed using omnidirectional probe - case b.), the increase of measured received power from the silence to the voice communication is also present, however, as expected, the values are lower. The value of received power rises about 21 times in Bluetooth band. The electric strength value rises about 4.5 times up to 331.1 mV/m.

Table 2. Maximum values of measured EMF for case b.)

Operation of device	P [nW]	S [nW/m2]	E [mV/m]
silence	15.88	14470	73.85
talking to pillion	338.6	301400	331.1

As it is obvious from the graphs depicting measured and calculated values the Bluetooth communicator in the helmet achieves maximum performance in all cases at a frequency about 2400MHz. In both cases a.) and b.) higher values of all evaluated quantities – received power, field strength and power density were achieved during the talking to pillion where a higher value was measured with near field probe.

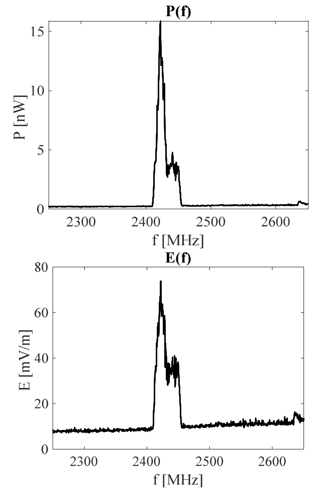

Fig.6. Case b.) - far field measurement, silence

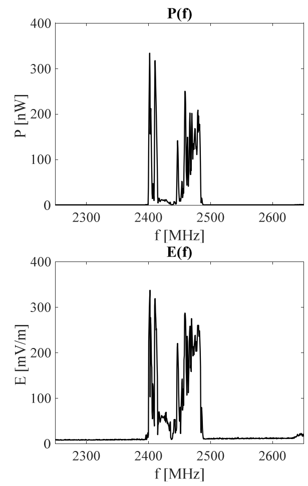

Fig.7. Case b.) - far field measurement, rider to pillion communication

The numerical simulation of the spatial EMF distributions in surrounding and on the surface of the orb head model are calculated for the bipolar antenna at distance 5mm from it.

The electric field distribution inside the orb head model is shown for the maximum values of electric field strength on cutting plane perpendicular to the dipole antenna centre, Fig. 8. The figure shows that maximum values of electric field strength vector is situated near the surface of the orb as expected. The graph of electric strength maximum values along the curve from the antenna towards the centre of the head model are shown as well. For the close distance of 5mm the maximum value of electric field strength is 0.689 V/m in the distance 6.78 mm from the antenna, which is the skin tissue near bone.

a.

b.

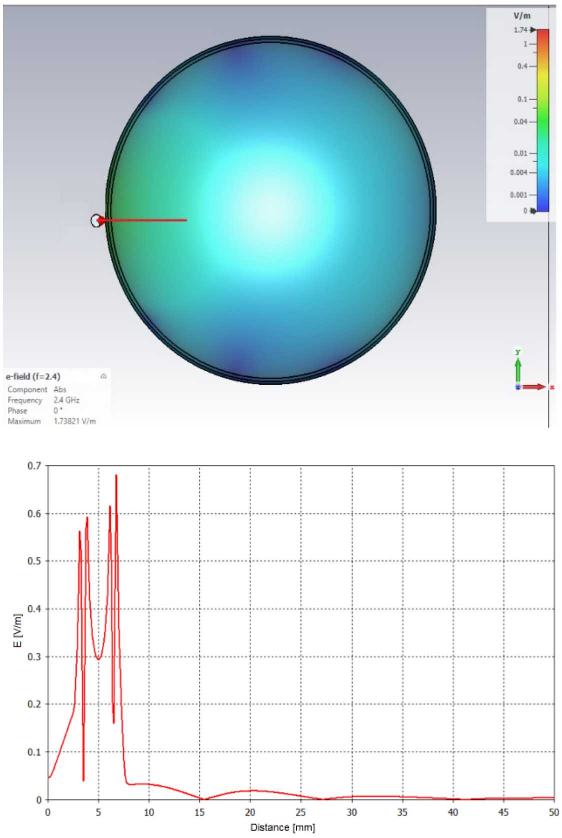

Fig.8. Electric field strength a. spatial distribution and b. distribution along the red curve

Conclusion

In this article, we presented our EMF calculation and estimation of the received power, field strength and power density of the Bluetooth communicator inside the motorcycle helmet during rider and pillion communication simulated by positioning the two helmets at a near distance of 50cm and simulating the simple head model exposed to a 5 mm close distance transmitter of 2.4 GHz. For the measurement of the near field and far field within the helmet, two types of probe were used as the distance of the near field antenna was less than 1 cm from the transmitting unit and the distance of the near field antenna was more than 20 cm from the cuff. During the silence on both sides and while receiving the signal talking from the partner side, the EMF was measured during the established intercom link. The numerical simulation of electric field strength inside the three-layered model of human head have shown that the absolute value of electric field strength has the maximum inside the skin tissue. Parameters of the simulation were adjusted to achieve similar field distribution as obtained by measurement. Although the field strength and power corresponding values are less than the limits set by ICNIRP, values in hundreds of mV/m have riders very close to the most vulnerable body tissue - the brain - directly at the head. Since research studies have not offered a definitive response to the likelihood of adverse effects of long-term exposure to low-level EMF sources, further analysis of this subject is needed. Whereas it is virtually difficult to prevent exposure to EMF in daily life in the civilized world at present, the long-term use of such instruments demands prudence, essentially, when it comes to one's brain, [12].

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