Comparison of Different Exposure Situations to RF Radiation regarding Mobile Communications with Respect to 5G

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Abstract – **In the near future the demand of wireless communications will elevate tremendously. The rapid increasing number of mobile end devices will require a much higher data rate connection than nowadays e.g. to smart homes (Internet of Things, IoT) or to the Internet. The radiation power pattern of base stations and mobile end devices will completely change for the 5G Next Generation Mobile Network technology, which is expected to use frequency bands up to 100 GHz. The electro-magnetic exposure especially to human bodies will increase in the future, because most of the wireless Internet connections are realized in RF technology. In this contribution three different measurement campaigns are presented. The first shows the electromagnetic radiation regarding a base station over a period of several days. The second campaign figures out the electromagnetic radiation of a handheld mobile end device to a human head in an area with very poor reception values. The third measurement setup will show a comparison to the exposure of RF radiation caused by mobile communication in a vehicle. The results of the measurements campaigns where compared with current legal and health limits. All measured and calculated values regarding the base station and in the vehicle were in the frame of the legal exposure limits. The calculated legal exposure limits regarding the mobile device was exceeded twice in areas within very poor reception values. A much higher bandwidth in the near future is expected which also will correspond to higher electromagnetic exposure of human bodies that will lead to mandatory periodic measurements to comply with radiation limits.**

Keywords – **Mobile phone base station measurements; Legal limits electromagnetic radiation; Health electro-magnetic radiation limits, 5G Next Generation Mobile Networks**

I. INTRODUCTION

The data traffic of fixed and mobile electronical devices elevates significantly every month (see Fig. 1.). The strongest growth can be observed in the area of mobile devices where a usage of around 12 GB per month per active smartphone in Q3 2017 has been identified. This is an increase of around 50 percent since the end of 2015 [1]. The global mobile data traffic even had 63 percent growth from 2015 to 2016. In absolute numbers, the global mobile data traffic extended to 7.2 Exabytes per month. For 2021 Cisco predicts a mobile data transfer volume of 49 Exabytes per month [2]. Fig. 2. shows the exponential increase of mobile data traffic. More and more mobile end devices require a high data rate connection e.g. to a smart home (Internet of Things, IoT) or to the Internet and also in vehicles, which will be realized by 5G technology [3]. In Fig. 3. the increase of connected IoT devices in the coming years is presented.

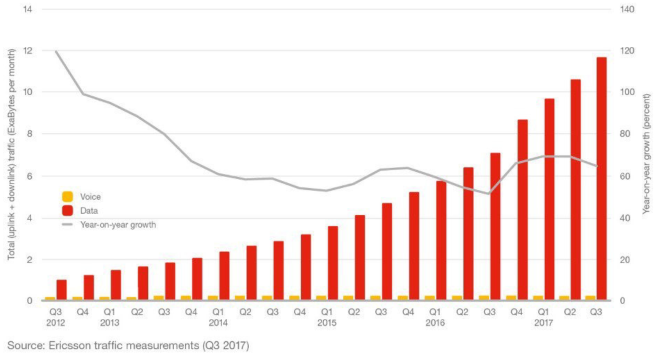

Fig. 1. Total global monthly data and voice traffic 2012 - 2017 [3]

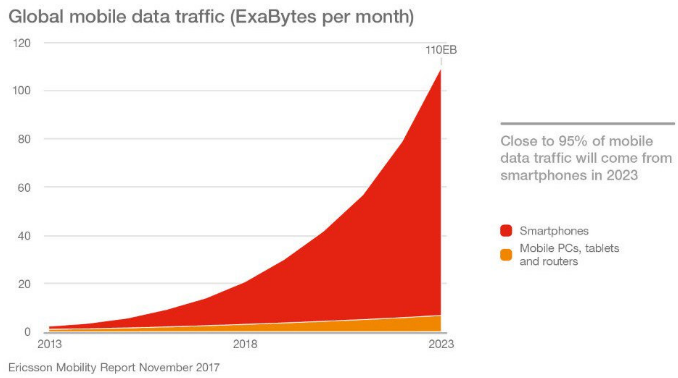

Fig. 2. Global mobile data traffic outlook [3]

To provide the needed high data rate and bandwidth to the 5G subscribers, new spectrum bands are required, which will offer the required bandwidth. The use of additional spectrum bands is not enough to achieve the proposed 5G targets. Another important step is the broadening of mobile base stations. In urban areas, where the majority of 5G subscribers will reside, a dense mesh of mobile base station has to be installed. This logically leads to an enormous increase of wireless data transfer. The rapidly increasing wireless data transfer causes more and more electromagnetic radiation that probably negatively influences human health. The World Health Organization (WHO) identified the health hazards

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associated with radio frequency (RF): The deposition of RF energy in the human body tends to increase the body temperature. In the frequency range of 300 Hz to 300 GHz, the induction of fields and current densities in excitable tissues is the most important mechanism for hazard assessment [4]. The electromagnetic fields produced by mobile phones are classified by the International Agency for Research on Cancer as possibly carcinogenic to humans [5], [6], [7]. A number of publications, like [8], deal with the status of the science and try to define rational limits and restrictions.

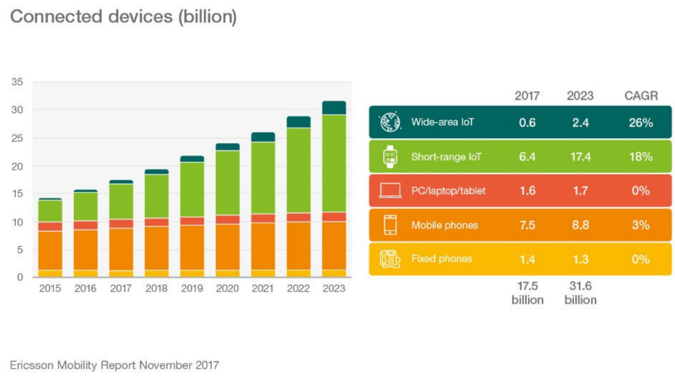

Fig. 3. Connected devices outlook [3]

The increased use of mobile networks is particularly evident in times of home quarantine, due to the high number of home offices caused by the COVID-19 crisis which is also reflected in higher power flux densities. In the light of the current circulating unsubstantiated and incomprehensible conspiracy theories and rumors regarding 5G, especially in social media, this publication is also intended to provide a comparative neutral basis of understanding based on real long term measurements with state of the art equipment for basic technical and physical understanding.

In this contribution three real RF measurement scenarios are presented and the results are evaluated with respect to the defined legal limits. The first scenario was a working place situated near to the antenna of a mobile base station. A measurement campaign over several days has been performed to receive reasonable measurement data to perform a high quality evaluation.

The second scenario deals with the radiation of a mobile device close to a human head, which was measured in a very poor reception area to force maximum transmission power.

The third scenario is a long term measurement and shows the radiation of mobile phone communication in a moving vehicle on motorways and inner city areas in Austria.

Section II. provides an overview of law and health issues. The test and measurement setup is descried in section III. The results and the comparison to the limits are summarized in section IV.

II. Law- and Health Issues

The directive 2013/35/EU of the European Parliament and the council 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) regulates the specific exposure limit values (ELVs) and action levels (ALs), which European member states bring into force by national laws by 1st of July 2016. In Austria the implementation of the directive came into force by the end of July 7th 2016. Electromagnetic fields in terms of this directive means static electric, static magnetic and time-varying electric, magnetic and electromagnetic fields with frequencies up to 300 GHz.

Where the exposure of workers to electromagnetic fields exceeds the ELVs, the employer shall take immediate action to reduce exposure below these ELVs. The physical quantities, ELVs and ALs, laid down in this directive are based on the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Basically there are divided two different direct effects in the human body caused by its presence in an electromagnetic field (biophysical effects), such as thermal effects and non-thermal (athermal) effects, where thermal effects are tissue heating through energy absorption from electromagnetic fields in the tissue. This paper is focusing on non-thermal effects, such as the stimulation of muscles, nerves or sensory organs. These effects might have a detrimental effect on the mental and physical health of exposed workers. Especially for workers who wear active or passive implanted medical devices, such as cardiac pacemakers, workers with medical devices worn on the body, such as insulin pumps, and pregnant workers, there are special regulations. This directive and the national Austrian regulation also references in these cases to European Council Recommendation [9]. In this recommendation reference levels of exposure are provided for the purpose of comparison with values of measured quantities where the compliance of all recommended reference levels will ensure respect of basic restrictions. The relevant reference levels of exposure are outlined in Table I.

Table I
Reference Levels for Electric, Magnetic and Electromagnetic Fields [9]

Frequency range	Reference levels			
	E-Field (V/m)	***H-Field (A/m)***	***B-Field (µT)***	S_{eq}[a] ***(W/m²)***
400 MHz — 2 GHz	$1.375 \cdot \sqrt{f}$ [b]	$0.0037 \cdot \sqrt{f}$ [b]	$0.0046 \cdot \sqrt{f}$ [b]	$\frac{f}{200}$
2 — 300 GHz	61	0.16	0.20	10

a. Equivalent plane wave power density

b. f as MHz

In addition to the reference levels, basic restrictions, given in Table II, are set in a way for uncertainties related to individual sensitivities, environmental conditions, and for the fact that the age and health status of members of the public vary.

TABLE II
BASIC RESTRICTIONS FOR ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS [9]

Frequency range	**Basic restrictions**		
	Whole body average SAR (W/kg)	***Localised SAR (head and trunk) (W/kg)***	***Localised SAR (limbs) (W/kg)***
100 kHz — 10 GHz	0.08	2	4

The specific energy absorption rate (SAR) is defined as the rate which energy is absorbed per unit mass of body tissue and is expressed in watts per kilogram (W/kg) [10].

III. TEST AND MEASUREMENT SETUP

In this chapter the measurement setup to check the compliance of the limits in Table I and Table II for a working place close to a mobile base station and for a mobile device is described. Also the measurement of exposure regarding mobile communications RF in a vehicle is shown.

A. Base Station Measurement Setup

An office employee complained about athermal health issues like dizziness and headaches. The workplace of the employee is situated in opposite to a mobile base station, see Fig. 4. In the office a long term measurement campaign was done to verify that the electromagnetic exposure does not exceed the limits. The antenna was positioned in head high of a typical writing desk workplace. The vertical distance between the antenna and the base station come to around 7 meters. A picture of the setup is shown in Fig. 5.

Fig. 4. Mobile base station in opposite of the office

The electromagnetic radiation caused by the mobile base station was measured over a timespan of a number of days. The maximum power spectrum and the power density at different frequencies versus time were recorded with a calibrated device.

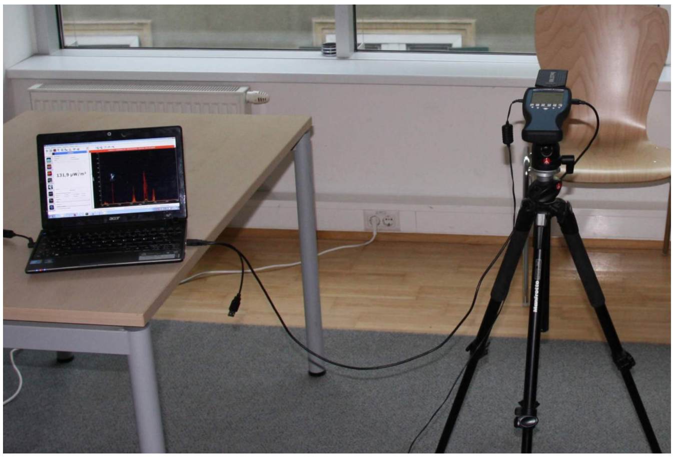

Fig. 5. Measurement setup in the office

B. Test Setup for a Mobile Device

The electromagnetic radiation of a common mobile phone was determined in an antenna measurement chamber. The measurement antenna was positioned directly on the device under test (DUT) to emulate the electromagnetic coupling during a normal telephone call. The door aperture angle of the measurement chamber was used to adjust the value of existing electromagnetic field, which was shown on the DUT's display at around -110 dB, close to a value gaining the connection loss to the mobile network (see Fig. 6.). According to [10] the transmitted power of the DUT will maximize, if the received power is very low. Under these conditions the maximum radiation caused by the mobile phone was measured.

Fig. 6. Antenna measurement chamber

C. Vehicle Measurement Setup

A vehicle can be considered as a Faraday cage in terms of electromagnetic radiation. In order to detect the exposure of persons in a vehicle, a long term measuring campaign over several hundred kilometres on motorways and inner city areas in Austria was performed. The measurement antenna was mounted on the passenger seat in the height of the scull (Fig. 7.).

Fig. 7. Measurement setup in a vehicle

IV. MEASUREMENT RESULTS

In this chapter the results of the base station, mobile device and vehicle measurement are presented, explained and finally compared to the legal limits.

A. Results of the Base Station Measurement

In Fig. 8. the maximum power flux density depending on the spectrum of all days is shown. A power flux density of almost $S_{max,Ant} = 1.2$ mW/m^2 was reached at around f = 1.2 GHz.

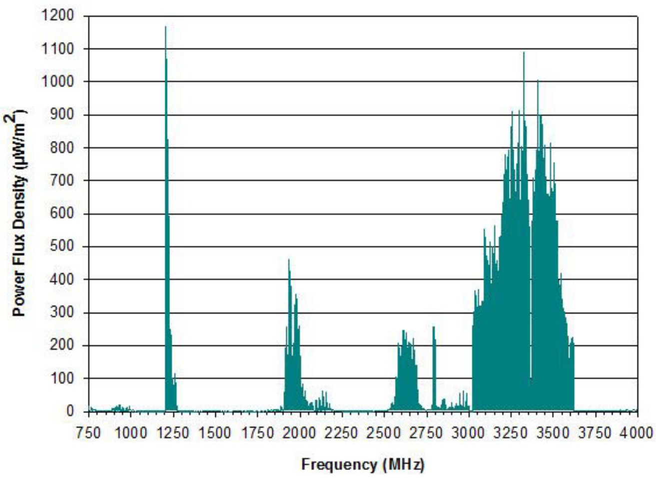

Fig. 8. Maximum power flux density of the base station versus frequency recorded over all days

The next figure presents the power flux density at f = 1.2 GHz depending on time of day. The maximum power density was reached between 07.30 a.m. and 01.30 p.m. (see Fig. 9.).

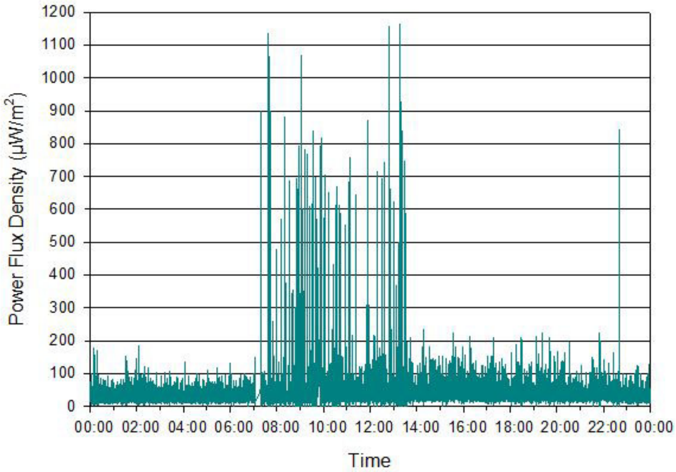

Fig. 9. Maximum power flux density of the base station at 1.2 GHz versus time of day

The magnetic field strength H can be calculated using

$$H = \sqrt{\frac{S}{Z_0}}\,, \qquad (1)$$

where S is the measured power flux density and Z_0 the characteristic impedance of vacuum. Assuming that $Z_0 = 120\pi\Omega \approx 377\Omega$ and $S_{max,Ant} = 1.2$ mW/m^2, the maximum magnetic field strength comes to $H_{max,Ant} = 1.78$ mA/m. By substituting the calculated value of $H_{max,Ant}$ into

$$E = Z_0 \cdot H\,, \qquad (2)$$

the maximum electric field strength reaches $E_{max,Ant} = 672.61$ mV/m. Inserting the frequency f = 1.2 GHz into Table I. the limits of the magnetic and electric field are $H_{lim,1.2GHz} = 128.17$ mA/m and $E_{lim,1.2GHz} = 47.631$ V/m. Both maximum values fall within the limits.

B. Results of the Mobile Device Measurement

The power flux density depending on the frequency caused by the mobile phone in the antenna measurement chamber during a normal phone call is presented in Fig. 10. a power flux density of around $S_{max,phone} = 217$ mW/m^2 was reached at around f = 1 GHz.

By means of equation (1) and the measured value $S_{max,Phone}$, the maximum magnetic field strength caused by the mobile device is $H_{max,Phone} = 23.60$ mA/m. Putting $H_{max,Phone}$ in (2), the calculated electric field strength reaches $E_{max,Phone} = 8.9775$ V/m. The legal limits of the magnetic and electric field at the frequency of f = 1 GHz are

$H_{lim,1GHz}$ = 117.00 mA/m and $E_{lim,1GHz}$ = 43.481 V/m. Again both maximum values fall within the limits.

In [11] practical studies on the issue of athermal effects of electromagnetic fields regarding mobile phones where done. The relation between SAR for a human head model and the input power of a typical mobile phone antenna were determined: 1 mW antenna input power results 17.667 mW/kg SAR average for the head. Using this relation a $SAR_{head,average}$ = 3.834 W/kg was calculated. The SAR value is almost twice as high as the legal SAR limit of 2 W/kg.

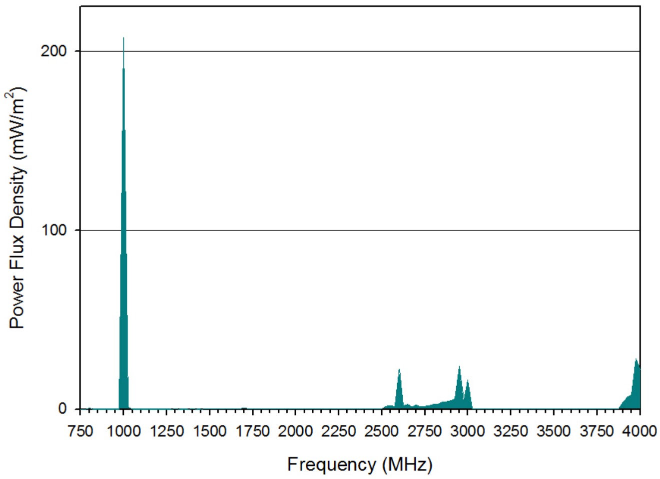

Fig. 10. Power flux density of the mobile phone versus frequency recorded during a normal telephone call

C. Results of the Vehicle Measurement

The power flux density depending on the frequency caused by the mobile phone communication in a vehicle is presented in Fig. 11. A power flux density of around $S_{max,vehicle} = 2.7\ mW/m^2$ was reached at around f = 2.9 GHz. The power flux density in the vehicle is around twice the power flux density of the measured base station.

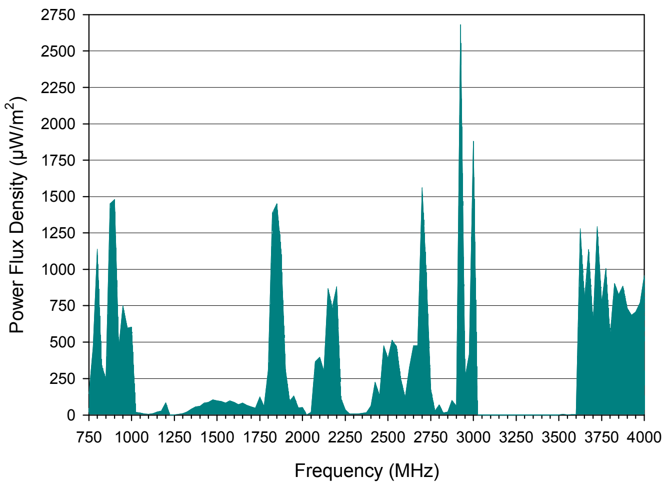

Fig. 11. Power flux density of mobile communication in a moving vehicle

By means of equation (1) and the measured value $S_{max,Vehicle}$, the maximum magnetic field strength measured is $H_{max,vehicle}$ = 2.7 mA/m. Putting $H_{max,vehicle}$ in (2), the calculated electric field strength reaches $E_{max,vehicle}$ = 1.009 V/m. The legal limits of the magnetic and electric field at the frequency of f = 2.9 GHz are $H_{lim,2.9GHz}$ = 160.00 mA/m and $E_{lim,2.9GHz}$ = 61.00 V/m. Again both maximum values fall within the limits.

D. Summary of the results

In Table III the measured and calculated results are compared to the legal limits. All measured and calculated results regarding the base station and in the vehicle are within the legal exposure limits. The calculated legal exposure limits of mobile devices were exceeded twice in areas within very poor reception values (see Table III).

TABLE III
SUMMARY OF RESULTS AND LIMITS

		Legal limits	Measurement
Base station	***E-Field (V/m)***	47.631	0.673
	H-Field (A/m)	0.128	0.002
Mobile device	***E-Field (V/m)***	43.481	8.8985
	H-Field (A/m)	0.117	0.024
	Localised SAR (head) (W/kg)	2	3.834
Vehicle	***E-Field (V/m)***	61	1.009
	H-Field (A/m)	0.16	0.0027

V. CONCLUSIONS

It has turned out that there is currently no exceeding of legal limits regarding the emissions of base stations and in vehicles. The presented measurement setup concerning the base station revealed that the E-Field reached a maximum of 0.673 V/m (legal limit: 47.631 V/m) and the H-Field a maximum of 2 mA/m (legal limit: 128 mA/m). The measurement in the vehicle showed that the E-Field reached a maximum of 1.009 V/m (legal limit: 61.00 V/m) and the H-Field a maximum of 2.7 mA/m (legal limit: 160 mA/m). The measurement campaign has emerged that the power flux density in the vehicle is around twice the power flux density of the measured base station.

The upcoming mobile radio standards like 5G are expected to use frequency bands up to 100 GHz and will have a much higher number and density of base stations. The bandwidths are expected to be 100 times higher than nowadays which will cause higher transmission power of base stations. From the mentioned facts it follows that it will be necessary to measure the radiation exposure of base stations in the future on a regular basis in order to ensure the legal limits and to reduce possible health hazards. Also it will be necessary to develop new measurement campaigns and/or technologies regarding the expecetd wide frequency spectrum of upcoming 5G technologies.

When measuring directly on an end device (simulating the use of a mobile phone directly on the human head tissue), it has turned out that the calculated SAR of 3.834 W/kg exceeds the legal limit of 2 W/kg. It has been shown impressively that the legal limit values can be exceeded greatly in areas with very poor reception values.

The free space loss for the power flux density is known as

$$F = \left(\frac{4\pi d}{\lambda} \right)^2 \tag{3}$$

where F is the free space loss in signal strength, d the distance from the transmitter and λ the wavelength.

By increasing the distance between a mobile end device and the head, e.g. by using a hands-free set or a headset can greatly reduce the human tissue exposure to electromagnetic radiation, especially when a mobile device is used in badly supplied areas and transmits with maximum power.

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