VULNERABILITY OF PERSONAL RADIATION METERS TO INTENTIONAL ELECTROMAGNETIC INTERFERENCE (IEMI)

Christian Adami[1], Wolfram Berky[2], Michael Joester[3], Michael Suhrke[4], and Thorsten Pusch[5]

[1] *christian.adami@int.fraunhofer.de*, [2] *wolfram.berky@int.fraunhofer.de*, [3] *michael.joester@int.fraunhofer.de*, [4] *michael.suhrke@int.fraunhofer.de*, [5] *thorsten.pusch@int.fraunhofer.de*

Fraunhofer Institute for Technological Trend Analysis INT, Dept Nuclear and Electromagnetic Effects, Appelsgarten 2, 53879 Euskirchen (Germany)

Abstract

In case of emergencies involving ionizing radiation, first responders will have to rely on robust measurement equipment for accurate risk assessment. Furthermore, radiation meters enable efficient control of illicit radionuclide traffic as well as effective radiation protection schemes in industrial environments. An increasingly relevant threat to routine operation of electronics consists in high-power microwave (HPM) radiation. Technological progress as well as information proliferation has brought a wide array of manageable equipment within reach of individuals. In order to assess the susceptibility of personal radiation detectors, i.e., the risk of faulty measurements or even damage being induced, several representative devices have been exposed to pulsed HPM. A variety of effects over frequencies ranging from 0.3 GHz to 3.4 GHz has been observed, their possible impact on typical usage scenarios will be analyzed in our study. The most severe effects include wrong readings of the radiation dose rate exceeding natural background by three orders of magnitude.

Keywords: IEMI, HPEM, HPM, rf, radiation detector, critical infrastructure.

1 INTRODUCTION

In recent years, the development of affordable technology as well as the availability of detailed knowledge in the World Wide Web regarding generation of high-power microwaves have reduced barriers for interested individuals or groups to perpetrate acts generally subsumed as intentional electromagnetic interference (IEMI). By irradiating electronic devices with continuous or pulsed radio frequency (rf) signals, routine operation may be temporarily hampered, sometimes requiring operator intervention, or even lasting damage may be induced. While there are quite a few cases already documented [1], the ever increasing reliance on complex electronics will aggravate the vulnerability of critical infrastructures in the future.

In the past, many efforts have been made to identify essential system components and to devise appropriate test procedures in order to assess thresholds of function failures up to damage symptoms regarding high-power microwaves (HPM) [2]. In addition, the impact of specific effects on single or composite systems in an operational context has been investigated, thus establishing a vulnerability assessment and mitigation strategies [3], [4].

In the context of our present work, we are focusing on sensitive measurement equipment used by authorities, law enforcement personnel and first responders. In such areas where reliable measurement devices are the only means to provide information about essential environmental factors not accessible to human perception, maintaining standard functionality is critical.

This holds especially true when considering radiation detectors: They are the only means to assess an invisible, but possibly life-threatening agent. Depending on the level of experience of the operating staff involved, an additional psychological hurdle of increased risk perception often related to ionizing radiation may exacerbate the unsettling effect of malfunctions such as gross misreadings of radiation levels. The latter may be even more difficult to judge if operators lack experience with signature readings of real radionuclide material.

Such highly elevated radiation readings could be observed during our test campaign, conducted within the project “Protection of Critical Infrastructures against High Power Microwave Threats” (HIPOW) [5], [6] which is part of the EU Seventh Framework Research Programme. It comprises a whole series of investigations regarding the vulnerability of electronic devices as part of critical infrastructures. In our tests, we submitted customary radiation detectors to high-power rf exposure. Measurements were performed at the facilities of the Fraunhofer Institute for Technological Trend Analysis INT (Euskirchen, Germany). There, HPM tests on diverse electronic devices used in critical infrastructure systems are performed on a regular basis in order to keep an overview of susceptibilities against IEMI and the respective failure patterns of each device category. Potential consequences in the wider system context are analyzed as well.

We will detail in the following the selection of test devices in Chapter 2, followed by a brief description of the test facility including the setup conceived for this campaign in Chapter 3. Specifics will be given regarding the irradiation scheme with microwave pulses, as well as an overview of test object surveillance. Based on the established susceptibility thresholds, possible consequences of device failure in various usage scenarios will be analyzed in Chapter 4. Essential malfunctions observed include wrong radiation measurements highly exceeding natural background.

2 SELECTION OF TEST OBJECTS

When narrowing down a selection of suitable test objects, their proliferation in organizations typically tasked with radiation measurements in their day-to-day operations has been taken into consideration. We concluded to investigate the following devices, all being widely used in various official contexts.

2.1 Characteristics of device No. 1

Device No. 1 is a small, battery-powered personal radiation meter of roughly cuboid shape and weighing below 200 g, the casing dimensions not exceeding 10 cm in any direction. It features a liquid crystal display (LCD) allowing for the actual gamma dose rate to be read off, in units of µSv/h. In addition, it includes a top-mounted LED indicating special instrument states, complemented by an acoustic alarm.

The device is used for detection and finding of radiation sources, predominantly during first responder operations. Other intended usage scenarios comprise border controls, customs or law enforcement activities. Technically speaking, it features a NaI(Tl) scintillation detector, complemented with a small-size photo-multiplier. By design, it allows for dose rates of a few hundredths of µSv/h to be captured. For our tests, we had two specimen of the same type at our disposal.

2.2 Characteristics of device No. 2

The second device is a personal electronic dosimeter of compact dimensions and cuboid shape, in total weighing below 60 g. The long side measures roughly 90 mm, the shorter end of about 50 mm width features an LC display allowing for the

accumulated dose to be shown. Next to the display, a warning LED is installed for the indication of alarm states.

The device is designed to be worn on person by staff of nuclear facilities or particle accelerators in the context of radiation protection regulations. Its sensitivity allows for dose rate levels from 0.1 µSv/h up to 10 Sv/h to be registered.

2.3 Characteristics of device No. 3

Finally, we submitted a portable radionuclide identifier to our test procedure. Device No. 3 weighs roughly 650 g and features an LC display covering the large flat surface of its oblong cuboid, but slightly tapered form. Since said LCD is mainly foreseen for complex user interaction including display of nuclide information in case of a detection event, a smaller always-on display is integrated into the front part of the device's tapered end. It allows for appraisal of the measured dose rates when the device is worn in a holster. By acoustic alarm signals and flashing display, operator awareness of special readings can be ensured. The device measures about 15 cm in length and slightly below 10 cm in width.

Typical application areas comprise border control checkpoints where the ability to actually identify radionuclides can complement information gained from fixed portal detectors which can only report certain thresholds being breached. The radiation detection technology employed is based on CZT semiconductor detectors.

3 TEST SETUP

3.1 The rf test site

In order to assess the vulnerability of the radiation meters over a frequency range of 260 MHz up to 3.4 GHz, we made use of the tapered open TEM waveguide at Fraunhofer INT [7] as shown in Fig. 1. It features the shape of an oblong, hollow pyramid turned on its side by 90 degrees and missing the left and right walls. The upper and lower sides consist of metal sheets sandwiching the so-called septum, a third triangular conducting plane close to the upper conductor. During tests, rf signals are injected at the entry point at the pyramids' tip, then propagating in good approximation as plane waves between the grounded lower conductor and the septum. At the pyramid's base of approximately 3 m x 3 m surface area, an absorber wall prevents potentially disturbing reflected waves propagating in reverse direction. In Fig. 2, a schematic overview of the setup is given.

Figure 1: Open TEM waveguide at Fraunhofer INT.

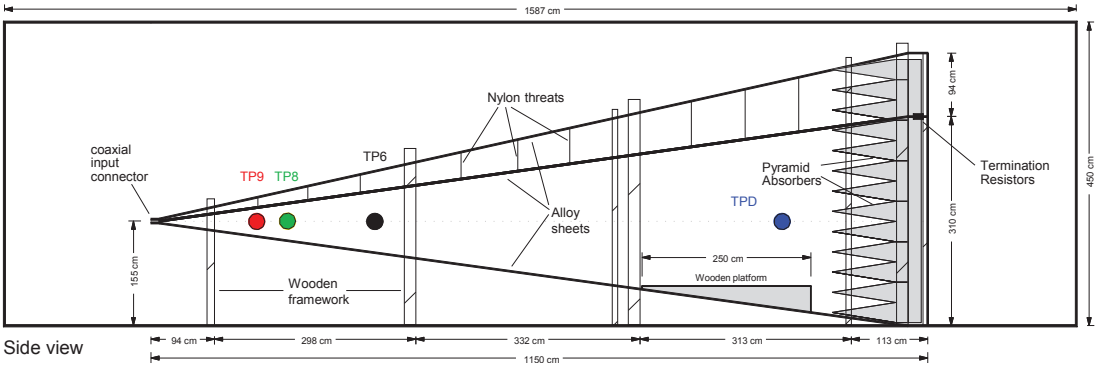


Figure 2: Schematic of the waveguide, including example test points.

Over the waveguide's length of roughly 10 m, an ever widening area in the middle of its transversal cross section features a suitably homogeneous vertical electric field. Thus, the device under test (DUT) can be submitted to well-defined exposure conditions. Small field imperfections still persist; they are unavoidable due to the geometry of the waveguide setup. In order to conform to generally accepted standard conditions [8], a rectangular area located in the central region of the waveguide cross section is chosen where the field characteristics are known to satisfy the standard criteria.

3.2 Surveillance of the test objects

For ensuring awareness of any failure states or dysfunction induced at the DUTs, we employed an rf-shielded camera system located on a tripod next to the waveguide structure. Its signals are transmitted via optical fiber to the control room outside the experimental hall. By observing the test device displays on a standard definition monitor, deviations from routine operation can be registered. The internal microphone of the camera allows for transmission of any sound alerts emitted by the devices.

3.3 Setup of the devices under test

During tests, the radiation meters have been propped up on a wedged Styrodur platform of a few centimeters thickness, located at the center of the lower waveguide conductor at about 3 m distance from the injection point. At this well-defined measurement position, calibrated field values collected during previous validation can be linked to the measured forward power of the rf amplifier. The setup is shown in Fig. 3; the colored camera casing on its tripod mount can be seen on the left.

Figure 3: Setup of the devices under test in the waveguide.

Four specimens of three different device types have been placed on the platform:

- Two personal radiation detectors (device No. 1), one standing vertically, one turned sideways by 90 degrees (thus aligning different internal structures with the applied vertical electric field).
- One personal electronic dosimeter (device No. 2), propped up on its narrow side with the display visible from the camera vantage point.
- One radionuclide identifier (device No. 3), the main display directed towards the impinging wave fronts. Since said LCD is powered down in absence of unusual events, a second, constantly active display is installed on the upper side of the device. In order to enable the observation camera to capture its content, a small dentist's mirror has been attached to the radiation detector's backside.

3.4 Target irradiation scheme

The rf system provides rectangular rf pulses of 1 µs length and a repetition rate of 1 kHz during routine operation. In order for the intended frequency range to be covered, a dozen plug-in modules can be operated in the rf generator main frame providing the high voltage required for operation. These inserts cover a bandwidth of 200 MHz to 400 MHz each, the available output power varying between 10 kW and 35 kW, depending on the frequency.

The measurement range from 260 MHz to 3400 MHz is sampled in steps of 10 MHz until reaching 1900 MHz, then continuing in 20 MHz steps. For a single measurement, the respective plug-in is tuned to the intended frequency and a power ramp of 10 s is started. Beginning at a minimum value of stable generator operation, the resulting field strength the DUT is exposed to rises in a roughly linear fashion. Fig. 4 illustrates the power ramp scheme.

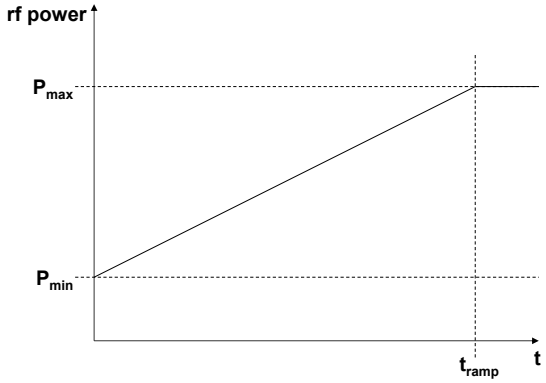


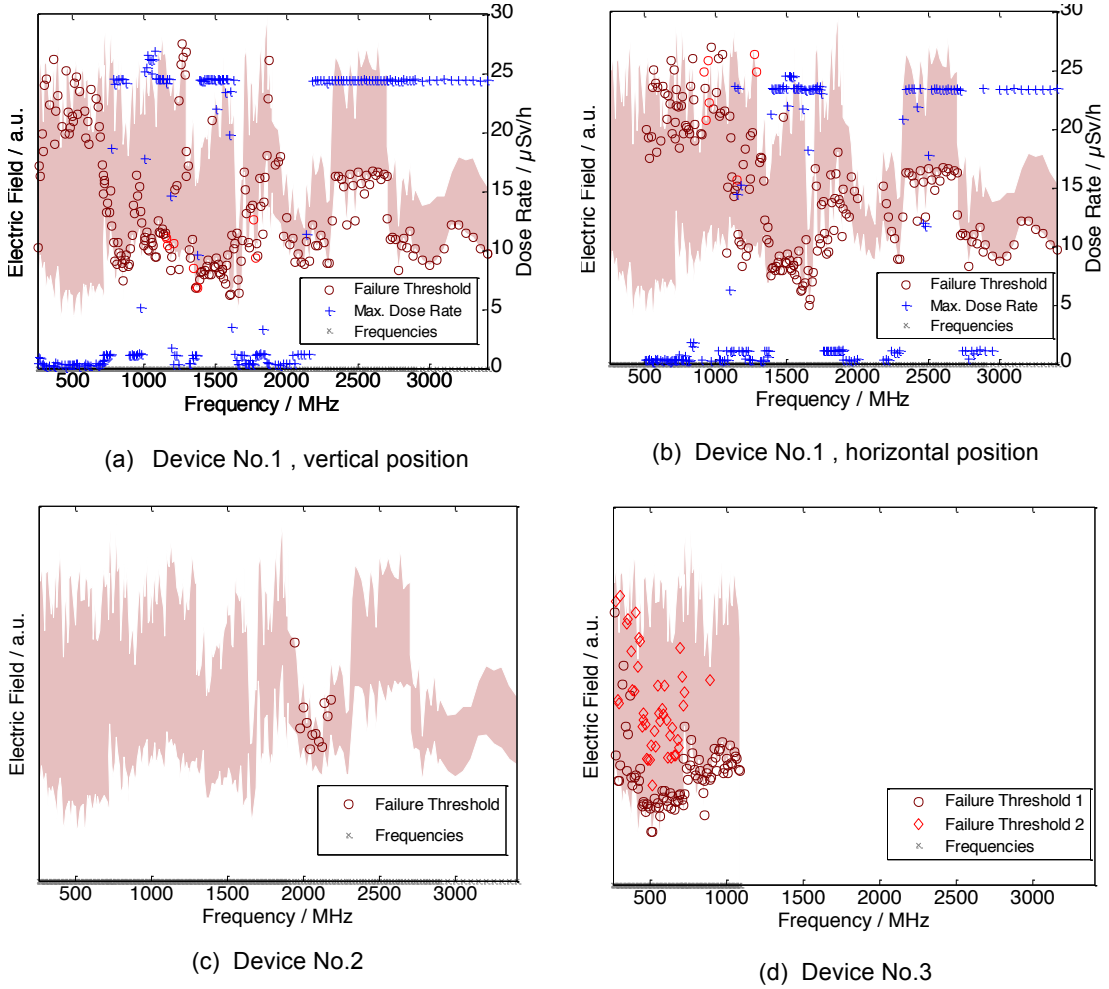
Figure 4: Rf power ramp for DUT failure threshold evaluation.

With such a scheme, the field threshold values for system disturbance can be evaluated at each of the test frequencies. As soon as device behavior as inspected via the camera system deviates from standard operation, the diode voltage generated by the signal power at injection is written down for later evaluation, together with a brief identifier of the respective failure state. Depending on the type of effect having occurred, a waiting period ensues if necessary, allowing the DUTs to return to their nominal state. During our tests of the radiation detectors, no obvious permanent damage has been observed, all devices returned to their normal state of behavior.

4 EFFECT ANALYSIS

4.1 Quantitative data preparation

During measurement, a voltage representing the rf forward power at injection is recorded at failure thresholds. After the test campaign, respective field values are attributed to said voltages, taking the exact properties of the whole measurement system into account. An overview of the resulting effect thresholds can be seen in Fig. 5, they are indicated by dark red circles.



(a) Device No.1 , vertical position

(b) Device No.1 , horizontal position

(c) Device No.2

(d) Device No.3

Figure 5: Failure thresholds of the devices under test, including dose rate readings if recorded. Dark red circles indicate the threshold for elevated dose rate readings. In subplots (a) and (b), bright red color coding of the markers reveals additional effects occurring during the ramp.

For device No. 1, the actual dose rate display was legible on the surveillance monitor and was included in the subplots (a) and (b). In the same plots, threshold values linked to particular occurrences like the LED flashing or an overload state being displayed are colored bright red. When the main display on device No. 3 switched on after initial alarm (secondary display flashing, acoustic signal), a second threshold value was recorded, indicated by bright red diamond symbols in subplot (d).

4.2 Behavior of the devices

Generally speaking, all DUT investigated have been observed to display elevated radiation levels at certain frequencies. We will detail the effects device by device.

4.2.1 Effects observed with device No. 1

Over most parts of the frequency range investigated, the device in question has shown elevated dose rates when exposed to pulsed rf fields above a certain threshold. The measured values scaled by at least one order of magnitude when compared to the natural background reading as observed in the lab. Between 1000 MHz and 1200 MHz, 1400 MHz and 1600 MHz and above 2200 MHz, the observed maximum dose rate even settled in at roughly 25 µSv/h, an increase of almost three orders of magnitude. These abnormalities hold true in roughly the same way for the second specimen, tilted by 90 degrees.

According to the data, susceptibility rises with the applied frequency. Above 800 MHz in vertical orientation and 1400 MHz in horizontal orientation, both specimens begin showing more and more abnormal readings already at comparatively small field values. Outlier values disappear altogether above 2200 MHz and 2400 MHz, respectively, while the elevated dose rate readings settle in at high values. This is in agreement with a general geometric consideration roughly matching critical wavelengths with device dimensions, both lying at a few centimeters in the present case.

4.2.2 Effects observed with device No. 2

The personal radiation meter has proven to be immune to the rf exposure over most frequencies. Any potential susceptibility threshold at these frequencies and pulse modulation parameters could thus be proven to lie at least higher than the maximum field strength obtainable from the rf equipment. Nonetheless, one notable exception became apparent between 2000 MHz and 2200 MHz. Within the regular 10 s of rf exposure, the dosimeter has shown increments of a few µSv in accumulated dose which would require days to register in a normal environment. In one case, an additional dose of about 60 µSv was recorded which typically would take about three months to accumulate.

4.2.3 Effects observed with device No. 3

Since, independently of rf exposure, problems arose regarding device operation which could not be resolved in time for meeting the measurement schedule, this detector only took part in measurements up to 1090 MHz. In that frequency range, it could be observed to react very early with acoustic alarm signals after starting the rf power ramp, regardless of the particular frequency chosen. Bright red circles in Fig. 5 (d) show field threshold values at which the main display was activated as well, showing additional warnings. Data analysis suggests that below roughly 800 MHz the susceptibility threshold is consistently lower when compared to the other DUTs.

Considering these results obtained from the regular test procedure, we did investigate whether the comparatively low-power rf emission of mobile wireless devices would suffice to hamper normal operation. We indeed could verify that when a regular mobile phone was placed close to the detector, an alarm could be set off when building up a connection. During that phase, the phone starts emitting with maximum power to reliably establish a link with the next base station.

4.3 Consequences for regular usage scenarios

4.3.1 Implications for device No. 1 operation

With regard to the border crossing and customs usage scenario device No. 1 fits in, artificial radiation dose rate readings induced by covert rf sources may well induce large delays in handling goods or travelers. A suitably compact rf source could be used to simulate ionizing radiation, prompting control personnel to pursue a time-consuming and ultimately fruitless search for illicit radioactive materials.

Apart from the caused delays themselves which may prove to be sufficient to further other goals of a prospective perpetrator, the above situation could prove especially problematic if the local personnel in charge decide to moderate normally stringent security protocols in order to cope with the accumulated workload. Trust into the reliability of the available measurement equipment may suffer considerable damage as well. In both cases, radioactive material may pass controls unimpeded afterwards.

In one of the other major use cases for the device, first responders may be trying to assess hazards at a disaster site potentially involving radioactive materials. If critical radiation levels are simulated via rf sources, incident command might revert to an overly cautious course of action, thus stalling de-escalation measures and foregoing chances of averting even larger damage.

4.3.2 Implications for device No. 2 operation

Personal radiation dosimeters are usually worn by employees known to be exposed to some additional level of radiation at their workplace, exceeding the general background. The operations of such a facility could be greatly slowed down or even come to a halt if operating personnel registers potentially hazardous radiation dose values during routine control. Due to the covert nature of an rf attack, the perpetrator may even be able to sustain the IEMI activities over a long period of time, thus undermining trust of company staff into protection measures in place. A sound feeling of being well-protected has been shown to be an important factor in guiding risk perception of experienced personnel [9]. If confidence declines, considerable economic damage could be the consequence.

4.3.3 Implications for device No. 3 operation

While the device has not been probed over the full intended frequency range, it has proven to feature quite a bit lower susceptibility thresholds when compared to the other devices under test. Especially the almost immediate reaction at the lower end of the power ramp could make the device a target for IEMI. Depending on the respective usage, scenarios as mentioned in connection with device No. 1 apply. In addition, when inadvertently worn on person next to a cell phone, false alarms may be confusing the operator.

5 CONCLUSION

All three devices under test could be led to abnormal function not easily appreciable as such for the respective operator. On the personal radiation meter, display of a dose rate elevated by up to three orders of magnitude could be induced. The electronic dosimeter was led to accumulate dose values over a few seconds which normally take months to register. At frequencies below 800 MHz, the radionuclide identifier has been observed to be especially susceptible in comparison with these two devices.

Rf field levels sufficient to provoke the above effects roughly range one order of magnitude above those of regular electromagnetic compatibility (EMC) immunity testing. With moderate HPM source design effort, these levels could be easily generated at a distance of several tens of meters.

The effects described could delay handling processes in customs and border control, possibly hampering security measures due to work overload. Essential first responder activities may be slowed down or even aborted due to exaggerated, rf-induced radiation measurement values, thus passing up the chance to timely de-escalate evolving disaster scenarios. Workers in elevated radiation environments could be led to distrust official risk assessment and safety control, critical workflow thus being compromised.

We deem it desirable that the above devices be ruggedized against IEMI by taking appropriate design measures, such entailing the potential benefits of a more robust and reliable operation. Possible countermeasures might include filtering and metal shielding, the thickness of the latter brought in line with the required device sensitivity.

ACKNOWLEDGEMENTS

We would like to gratefully acknowledge the local support for laboratory tests, as well as to thank those of our colleagues instrumental in supplying us with the test devices. In addition, the EU FP7 Grant No. 284802 provided financial support to our research which we are grateful for.

REFERENCES

[1] Sabath, F. (2011). *What Can Be Learned from Documented Intentional Electromagnetic Interference (IEMI) Attacks?* General Assembly and Scientific Symposium, 2011 XXXth URSI, August 13–20, 2011, pp.1–4.

[2] Backstrom, M.G. and Lovstrand, K.G. (2004). *Susceptibility of Electronic Systems to High-Power Microwaves: Summary of Test Experience*. IEEE Transactions on Electromagnetic Compatibility, Vol. 46, No. 3, pp. 396–403.

[3] Radasky, W.A., Baum, C.E., and Wik, M.W. (2004). *Introduction to the Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI)*. IEEE Transactions on Electromagnetic Compatibility, Vol. 46, No. 3, pp.314–321.

[4] Mansson, D., Backstrom, M., and Thottappillil, R. (2010). *Intentional EMI against Critical Infrastructures, a Discussion on Mitigation Philosophy*. APEMC, 2010 Asia-Pacific Symposium on Electromagnetic Compatibility, April 12–16, 2010, pp.134–137.

[5] HIPOW Project: *Protection of Critical Infrastructure against High Power Microwave Threats*, http://www.hipow-project.eu/hipow/ (visited June 2014).

[6] Arnesen, O.H., Suhrke, M., and Adami, C. (2013). *Protection of Critical Infrastructures against High Power Microwave Threats – HIPOW*, Proc. 8th Future Security, Berlin, Germany, September 17–19, 2013, p. 479.

[7] Schmidt, H.U. (1991). *Die Messanlagen des INT für Feldeinkopplungs-messungen im Mikrowellenbereich.* International EMP Symposium IESM-91, Mannheim, Germany, pp. 2.2–2.3.

[8] IEC 61000-4-20 Ed. 2.0 (2010). *Electromagnetic Compatibility (EMC) – Part 4-20: Testing and Measurement Techniques – Emission and Immunity Testing in Transverse Electromagnetic (TEM) Waveguides.* International Electrotechnical Commission.

[9] Perko, T. (2014). *Radiation Risk Perception: A Discrepancy between the Experts and the General Population*. Journal of Environmental Radioactivity, July 2014, Vol. 133, pp. 86–91.