Electromagnetic Immunity of Mobile Devices - Statistical Analysis

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***Abstract*—Mobile devices are an essential and integral part of our business and everyday lives. It is often argued that modern electronic equipment is more susceptible to electromagnetic interference than its older, lower specification counterparts. We have conducted electromagnetic susceptibility and immunity tests on different generations of mobile devices including mobile phones, tablets and smartphones. Obtained results demonstrate that the potential deterioration of electromagnetic immunity related to device generation depends on the type of device and the frequency of the disturbing signal.**

***Index Terms*—Electromagnetic compatibility, intentional electromagnetic interference (IEMI), susceptibility, immunity, mobile phones, smartphones, tablets.**

I. Introduction

In recent years, growing attention has been paid to the threat posed by high power microwaves (HPM) attacks against the operation of important electronic systems of critical infrastructure [1]–[3]. Several studies have presented the results of investigations focused on susceptibility of electronic components, devices and systems to intentional electromagnetic interference (IEMI) [4]–[10]. However, although a large variety of devices has been tested and covered in the available literature, the results for mobile phones, smartphones and tablets are scarce.

We have presented the results of HPM vulnerability tests on mobile devices in some of our previous works [11]–[14]. Since we conduct in-house experiments for a number of years already, our database includes measurement results for commercial mobile devices spanning the years from 1997 to 2016. In this paper we try to answer the following question: Are modern mobile devices more vulnerable to HPM than older ones?

Our approach is based on the statistical analysis of experimental data. We apply standard visualisation methods and compute correlation factors between electromagnetic immunity and the market launch year of the device. The launch year of the DUT is one of the possible characteristics representing generation of a device (another example could be for instance chip technology of its CPU unit).

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This paper is organized as follows. Section II describes our experimental setup, Section III presents the results of the statistical analysis of the measured data and finally Section IV summarizes the paper with conclusions.

II. Experimental setup

The vulnerability measurements of mobile devices have been carried out in an open TEM waveguide (Fig. 1) using pulse modulated HPM in the frequency range 0.1-3.4 GHz. At the position of the test objects field strengths up to several kV/m can be achieved, the pulse length and pulse repetition rate are 1 μs and 1 kHz, respectively. The pulsed field increased typically within a time of 20 s from a minimum to a maximum value in a saw-tooth like ramp. When a failure occurred during the field ramp, the corresponding field strength value was recorded for a given DUT.

Fig. 1. TEM waveguide for EMC tests in Fraunhofer INT

The measurements took place in a shielded hall. The tested mobile phones and smartphones were searching for a network connection. The function of the DUT was controlled by monitoring the behaviour of its display and the messages on it.

During the test run with mobile phones any changes in display quality and readability as well as unexpected notifications have been considered as failures. After each run the network connectivity was tested to evaluate the functionality of the communication transmitter.

For smartphones and tablets tests were more elaborated. To monitor these devices with a video camera during the tests, either a video was played, or the built-in slide show function was activated in an endless loop. Alternatively, a messenger application was opened in the test input mode, showing the virtual keyboard waiting for a text input. Any changes in the application functionality, e.g. video interruption or random text input as well as display quality degradation have been considered as failures. After each test run the network connectivity of the tested device was verified to check if it was not damaged during experiments.

The E-field of the impinging plane wave was oriented parallel to the long side of the mobile phone case. For tablets and smartphones, both horizontal and vertical orientation of the DUT have been tested, with the device's display facing the incoming plane wave (Fig. 2).

Fig. 2. Mobile devices tested in the open TEM waveguide.

III. Statistical Analysis

The analysis is based on the susceptibility data available for 38 mobile devices launched on the market between 1997 and 2016. We divide these devices into three categories:

- Legacy mobile phones (older devices from the years 1997–2008, 13 units).
- Tablets (larger devices, typically with no option for phone calls, launched 2011–2016, 10 units).
- Smartphones (newer mobile phones with larger screens and more features than the old ones, launched 2011–2016, 15 units).

The experimental data is not uniform for all DUTs. Generally, the devices have been tested in the frequency range 0.1–3.4 GHz. However, not all devices have been tested in the whole frequency range and the spectrum sweeps have been performed with different steps in each test campaign. To alleviate this problem a frequency clustering is used in this study: the tested frequency range is divided into 100 MHz wide clusters. Each cluster is represented by the maximal value of the electric field at which the DUT is still immune to the applied HPM signal. Therefore, electric field intensity representing each frequency cluster for a given DUT is the smaller of the two values: (i) electric field at which disturbance effects have been observed in the DUT, (ii) E-field strength corresponding to the ramp end when no HPM effects have been noticed.

The analysis presented in this work is performed in R, a free software environment for statistical computing and graphing [15].

Some examples of the electromagnetic immunity of the tested devices in function of the DUT launch year are shown in Figs. 3-5. Each point in the figure corresponds to EM immunity of a single DUT in a given frequency cluster. For easier trend recognition there are regression lines plotted on the scatterplots that represent all tested DUTs as well as each of the device classes. The scatterplot in Fig. 3 is supplemented by the histogram at the top of the figure that shows the number of the tested units launched in a given year. On the right-hand side of the figure there is a boxplot depicting all the data in the scatterplot through their quartiles.

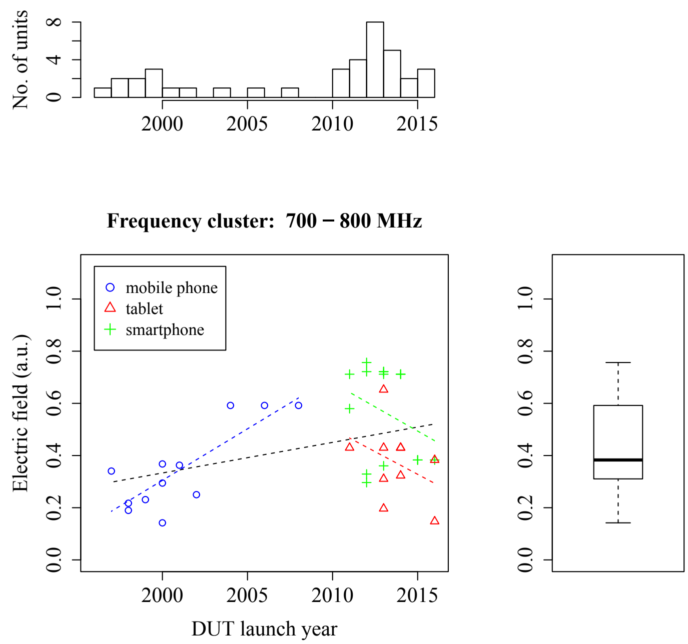

Fig. 3. DUT immunity as a function of the DUT launch year at frequencies 700–800 MHz. The dashed regression lines are added for all DUTs (black) and for each class of devices.

The regression lines included in Figs. 3-5 show clearly the trends in the plots. One can notice that the trends are generally frequency dependent. For instance, the immunity of all tested devices improves over the years in the frequency range 700–800 MHz (Fig. 3), whereas it is getting worse between 1600 and 1700 MHz (Fig. 4) and between 2100 and 2200 MHz (Fig. 5). Moreover, entirely different trends may be identified for various types of devices (see e.g. the trend for mobile phones vs the trends for tablets and smartphones in Fig. 3).

In order to quantify the relationship between the launch year and immunity of the DUTs, we computed correlation factor r between these two variables. Table I summarizes the data computed in each frequency cluster, for all tested devices as well as for the different device types.

The negative value of the correlation factor for all tested devices and for frequencies above 1 GHz indicates, in general, that the immunity of the mobile devices tends to decrease for

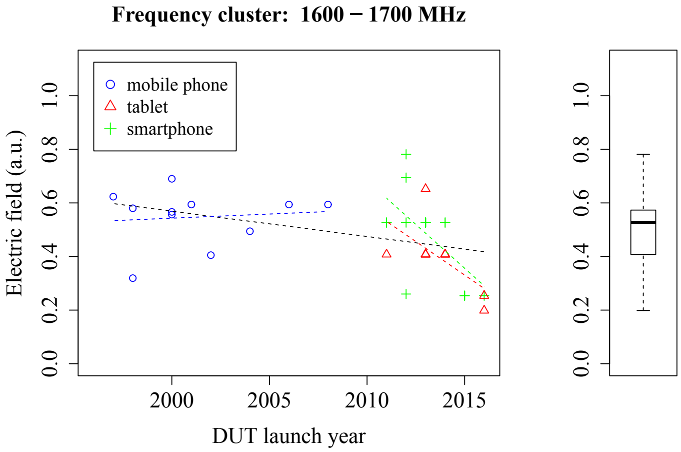

Fig. 4. DUT immunity as a function of the DUT launch year at frequencies 1600–1700 MHz. The dashed regression lines are added for all DUTs (black) and for each class of devices.

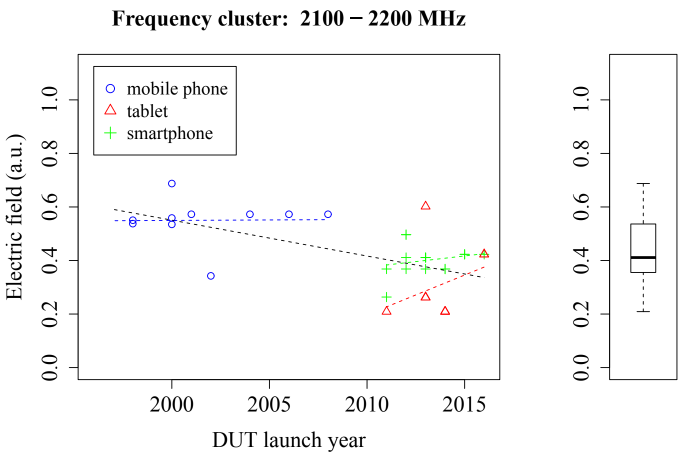

Fig. 5. DUT immunity as a function of the DUT launch year at frequencies 2100–2200 MHz. The dashed regression lines are added for all DUTs (black) and for each class of devices.

the newer devices in this frequency range. On the other hand, newer devices tend to be more immune to HPM for frequencies between 200 and 900 MHz, especially in the range 300-400 and 700–800 MHz.

Mobile phones, for instance, are generally characterized by the positive correlation between the launch year and immunity to EM disturbance. In 30 out of 33 frequency clusters r takes positive values. The negative r values for frequencies 1900–2100 and 3100–3200 MHz are close to zero so the trend is rather weak in this frequency bands. This means, in other words, that between the years 1997–2008 newer mobile phones became less susceptible and more immune to HPM disturbance (although this assumption does not hold for the mentioned, important 3G frequencies in the range 1900–2100 MHz).

For tablets from the years 2011-2016, the correlation factor is negative in 24 out of 33 frequency clusters. It means that newer tablets tend to be generally less immune to HPM disturbances. This trend is observed, however, up to about

TABLE I
CORRELATION FACTOR BETWEEN DUT LAUNCH YEAR AND DUT IMMUNITY.

Frequency [MHz]	Correlation factor r			
	All DUTs	Mobile phones	Tablets	Smartphones
100-200	-0.344	0.634	-0.238	-0.663
200-300	0.267	0.337	-0.299	-0.221
300-400	0.434	0.189	-0.167	-0.364
400-500	0.225	0.681	-0.176	-0.310
500-600	0.055	0.585	-0.247	-0.709
600-700	0.181	0.714	-0.343	-0.559
700-800	0.381	0.820	-0.367	-0.302
800-900	0.039	0.467	-0.425	-0.205
900-1000	-0.264	0.538	-0.562	-0.119
1000-1100	0.115	0.662	-0.257	-0.092
1100-1200	0.097	0.768	-0.201	-0.550
1200-1300	-0.090	0.700	-0.467	-0.320
1300-1400	-0.062	0.351	-0.245	-0.629
1400-1500	0.048	0.275	-0.339	-0.803
1500-1600	-0.082	0.553	-0.422	-0.161
1600-1700	-0.400	0.102	-0.633	-0.607
1700-1800	-0.102	0.492	-0.551	-0.442
1800-1900	-0.294	0.587	-0.106	-0.110
1900-2000	-0.521	-0.056	0.355	0.061
2000-2100	-0.641	-0.078	0.416	-0.029
2100-2200	-0.594	0.014	0.335	0.223
2200-2300	-0.501	0.558	0.439	0.332
2300-2400	-0.465	0.591	-0.042	0.073
2400-2500	-0.233	0.349	-0.011	-0.141
2500-2600	-0.250	0.190	0.008	-0.786
2600-2700	-0.232	0.506	-0.002	-0.701
2700-2800	-0.529	0.607	0.460	-0.674
2800-2900	-0.357	0.585	0.374	-0.789
2900-3000	-0.359	0.644	0.316	-0.762
3000-3100	-0.267	0.397	0.279	-0.711
3100-3200	-0.087	-0.005	-0.128	-0.789
3200-3300	-0.076	0.163	-0.165	-0.794
3300-3400	-0.015	0.613	-0.165	-0.786

1800 MHz, as for frequencies 1900–2300 and 2700–3100 MHz r is positive, whereas in the range between 2300 and 2700 MHz r values are small ($|r| < 0.1$).

The negative values of the correlation factor for smartphones (manufactured between the years 2011–2016) in 29 out of 33 frequency clusters indicate that, in general, newer smartphones are less immune to HPM than older ones. However, this property is not observed in the important 1900–2400 MHz frequency range, covering, among others, the 3G and ISM bands (the r value in the cluster 2000–2100 MHz is close to zero).

In order to further differentiate between the types of devices, we computed a median electromagnetic immunity for each class of devices in each frequency cluster. Fig. 6 shows the same scatterplot as Fig. 4 with the corresponding median values. The results in the frequency range 1.6–1.7 GHz indicate that the most immune are mobile phones, followed by smartphones. The least immune are tablets.

The results of this analysis are summarized in Tab. II. From all tested devices, tablets are characterized by the lowest immunity (in 29 out of 33 frequency clusters). The results for mobile phones and smartphones are comparable and frequency dependent. Smartphones are characterized by the highest immunity from the tested DUTs in 19 frequency

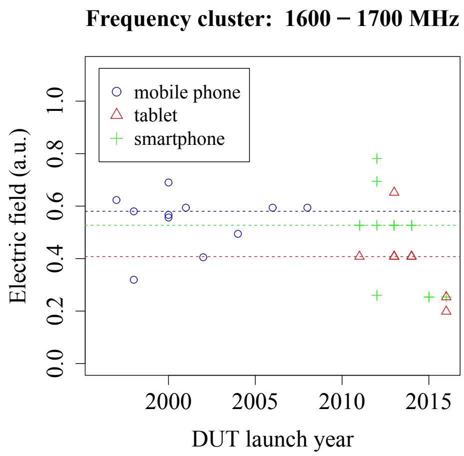

Fig. 6. DUT immunity as a function of the DUT launch year at frequencies 1600–1700 MHz. The horizontal dashed lines represent median values for each class of devices.

clusters (300–900 MHz, 1.1–1.6 GHz, 1.7–1.8 GHz, 2.4–2.7 GHz, 2.9–3.0 GHz and 3.1–3.4 GHz). In the remaining 14 clusters the most immune are mobile phones.

TABLE II
CLASSIFICATION OF DEVICE TYPES ACCORDING TO THE MEDIAN VALUE OF THE DUT IMMUNITY

Device type	**Median EM immunity value**		
	The highest	Intermediate	The lowest
Mobile phones	14/33	16/33	3/33
Tablets	0/33	4/33	29/33
Smartphones	19/33	13/33	1/33

IV. Summary and Conclusions

In this paper we try to answer the question if modern mobile devices are more vulnerable to HPM than older ones. In other words, if the continuous development of mobile phones, tablets and smartphones leads to their enhanced susceptibility to IEMI. Our results indicate that there is no straightforward answer to this question.

Electromagnetic immunity depends mainly on the frequency - below 900 MHz the newer devices are more immune than the old ones, whereas above 900 MHz they are less immune. Observing the results for traditional mobile phones commonly used before the era of smart devices and represented in our data set by units launched on the market up to the year 2008, their immunity improved over time in the whole tested frequency band 0.1–3.4 GHz. So, as a class of mobile devices, mobile phones improved their electromagnetic immunity.

On the other hand, the immunity of smartphones and tablets seems to deteriorate for the new generations of these devices, but this behaviour is frequency dependent. For instance, the newer tablets are more vulnerable to HPM below 1900 MHz and above 3100 MHz, whereas in the bands 1900–2300 and 2700–3100 their immunity improved. The brand-new smartphones are more susceptible to HPM than their predecessors up to 1.9 GHz and above 2.5 GHz - between these frequencies their immunity did not change or even improved.

The conclusion that can be drawn is that electromagnetic immunity of the modern mobile devices generally deteriorates, but not at all frequencies, especially it does not deteriorate at some frequencies related to front-door couplings. This may be related to the integration of advanced protection circuits in modern layout designs.

Another finding is that tablets are significantly less immune to HPM than (older) mobile phones and (newer) smartphones. It means that integration of a larger number of functionalities in a smaller volume, as is typically the case for smartphones when compared to tablets, does not have to mean higher susceptibility of the device.

In a future work we will attempt to identify other factors related to the electromagnetic immunity of the presented generations of mobile devices.

References

[1] O.-H. Arnesen, “Overview of the European project HIPOW,” IEEE EMC Magazine, Vol. 3(4), pp. 64-67, 2014.
[2] V. Deniau, “Overview of the European project Security of Railways in Europe Against Electromagnetic Attacks (SECRET),” IEEE EMC Magazine, Vol. 3(4), pp. 80-85, 2014.
[3] S. van de Beek et al., “The European project STRUCTURES: Challenges and results,” Proc. of the 2015 IEEE Int. Symp. on EMC, pp. 1095–1100, Dresden, Germany, 16-22 August 2015.
[4] D. Nitsch, M. Camp, F. Sabath, J.-L. ter Haseborg, and H. Garbe, “Susceptibility of some electronic equipment to HPEM threats,” IEEE Trans. on EMC, Vol. 46(3), pp. 380–389, August 2004.
[5] R. Hoad, N. J. Carter, D. Herke, and S. P. Watkins, “Trends in EM susceptibility of IT equipment,” IEEE Trans. on EMC, Vol. 46(3), pp. 390–395, August 2004.
[6] M. G. Backstrom and K. G. Lovstrand, “Susceptibility of electronic systems to high-power microwaves: summary and test experience,” IEEE Trans. on EMC, Vol. 46(3), pp. 396–403, August 2004.
[7] D. Mansson, “Susceptibility investigations and classification of civilian systems and equipment,” Ph.D. Dissertation, Uppsala Universitet, Sweden, 2008.
[8] F. Brauer, F. Sabath, and J.-L. ter Haseborg, “Susceptibility of IT network systems to interferences by HPEM,” Proc. of the 2009 IEEE Int. Symp. on EMC, pp. 237–242, Austin, USA, 17-21 August 2009.
[9] Y. Murata, T. Hoshina, and Y. Hatori, “Susceptibility of notebook computers to HPM,” Proc. of the 2014 IEEE Int. Symp. on EMC, pp. 549–553, Raleigh, USA, 4-8 August 2014.
[10] R. Przesmycki and M. Wnuk, “Susceptibility of IT devices to HPM pulse,” Int. J. of Safety and Security Eng., Vol. 8(2), pp. 223–233, 2018.
[11] C. Braun and H. U. Schmidt, “Effects of microwave irradiation on modern telecom devices - failure thresholds of five mobile phones,” Proc. of AMEREM 2002, p. 9, Annapolis, USA, 3-7 June 2002.
[12] C. Adami, M. Joster, M. Suhrke, and H. J. Tanzer, “HPEM tests of communication devices,” Proc. of AMEREM 2014, p. 39, Albuquerque, USA, 27-31 July 2014.
[13] C. Adami, M. Joster, T. Pusch, M. Suhrke, and H. J. Tanzer, “Generation dependence of communication device vulnerability to intentional electromagnetic interference,” Proc. of the 10th Future Security Conf., Berlin, Germany, pp. 347–354, 15-17 September 2015.
[14] C. Adami et al., “Generation dependence of ICT device IEMI vulnerability,” Proc. of the European Electromagnetics Symp. (EUROEM 2016), London, UK, 11-14 July 2016.
[15] R. www.r-project.org.