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3D printers − are they electromagnetically compatible?

***Abstract**. The paper presents the results of a study of the conducted and radiated electromagnetic emissions of selected 3D printer models, which are related to the EMC Directive and the permissible limits in harmonised standards. The measurements carried out showed that both 3D printers tested did not comply with EMC requirements in terms of radiated emissions*

***Streszczenie.** W artykule przedstawiono wyniki badania emisji elektromagnetycznej przewodzonej i promieniowanej wybranych modeli drukarek 3D, które odniesiono do Dyrektywy EMC i dopuszczalnych limitów w normach zharmonizowanych. Przeprowadzone pomiary wykazały, że obie testowane drukarki 3D nie spełniają wymagań związanych z kompatybilnością elektromagnetyczną w zakresie emisji promieniowanej. (**Drukarki 3D – czy są kompatybilne elektromagnetycznie?**)*

Keywords: 3D printers, electromagnetic compatibility, electromagnetic emission measurements.
Słowa kluczowe: drukarki 3D, kompatybilność elektromagnetyczna, pomiary emisji elektromagnetycznej.

Introduction

Equipment is subject to mandatory conformity assessment with the essential requirements before it is placed on the market or put into service [1, 2]. Conformity assessment of appliances should be carried out for all operating conditions for which it is intended. In the case of a device that can be manufactured and used in various configurations, its conformity assessment should be carried out for all representative configurations compatible with its intended use.

3D printing enables the generation of physical objects from three-dimensional computer models. Such objects are most often used for prototyping, as well as to produce various components or small models. 3D printing technology is becoming more and more advanced, allowing the use of more durable and advanced materials. This makes it possible to print highly complex and functional objects. A 3D printer, like any electrical device, converts electrical energy into target functioning. At the same time, when operating in a specific electromagnetic environment, it emits electromagnetic disturbances, which, depending on the coupling path, can propagate in a conducted or radiated form.

As a starting point with regard to standards for disturbance emissions, two acts provide general guidelines for emissions in residential environments (PN-EN 61000-6-3) [6] and industrial environments (PN-EN 61000-6-4) [7]. 3D printers are equipment which, by standardisation, simultaneously fall under the product group of IT equipment (PN-EN 50561-1:2013-12) [8] and are also subject to the requirements for general-purpose instruments, electric tools and similar equipment (PN-EN 55014-1) [9]. These types of products can operate in any environment, so it was assumed that the observed disturbance levels would be referenced to both standards, and the conclusions would refer to operation in a residential environment, so that the product would meet the more stringent radiated and conducted disturbance emission requirements. The article does not analyse studies of the immunity of 3D printers to electromagnetic fields.

Tests were carried out on radiated disturbances emitted by equipment in a GTEM 1000 cell in the frequency range from 30 MHz to 1 GHz, and conducted disturbances with a frequency change from 150 kHz to 30 MHz. First came the Sapphire Pro model from Shenzhen Twotress, made in China, and then the i3 MK3S+ from Prusa Research made in the Czech Republic. In addition, the former printer had metal side covers that are approximately 1mm thick.

Radiated emission testing

For radiated disturbance studies, the GTEM cell was used as an alternative measurement environment to the open array test site (OATS) [3-10]. The method of measuring emissions in the GTEM cell takes into account a mathematical model of the radiation of the equipment under test (EUT) in the form of a system of three equivalent mutually orthogonal dipoles. Knowing the moments of the equivalent dipoles for each frequency, the values of the field strength radiated by the EUT in free space or above a reference surface are determined numerically. Following the standardisation recommendations [10], the measurement of the emissivity of devices is reduced to the measurement of the power at the entrance of the cell for the positions of the device under test in the three orthogonal axes, assuming that emission in all directions is measured in this way. At the end of the measurement, the resultant value of the electric field strength is calculated, which, after applying the conversion algorithm from GTEM to OATS, gives the equivalent of a measurement on an open measuring area. The value of the maximum electric field strength for the OATS conditions is then determined from the formula [10]

$$E_{\max} = 20\cdot\log(g_{\max}) + 20\cdot\log\left(\left|\frac{\eta_0 k_0}{2\pi e_{0y}}\right|\right) + \\ + 10\cdot\log\left(\frac{S^2}{Z_C}\right) + 120\ \ [\mathrm{dB}\,(\mu\mathrm{V/m})] \quad (1)$$

where: $g_{\max}$ – coefficient related to the geometry of the test equipment (EUT) and the antenna in the open air test site (OATS), η_0 – wave impedance in free space ($120\pi\,\Omega$), $k_0 = 2\pi/\lambda$ – wave coefficient in 1/m, λ – wavelength in m, Z_C – characteristic impedance of the waveguide in Ω, e_{0y} – normalised field factor in $\Omega^{0,5}$□m^{-1}, S^2 – sum of the squares of the voltages U_{p1}, U_{p2}, U_{p3} measured at the output port of the GTEM cell for the three orthogonal positions of the tested object in V.

The sum of the squares of the voltages expressed in dB(μV) is given by [10]

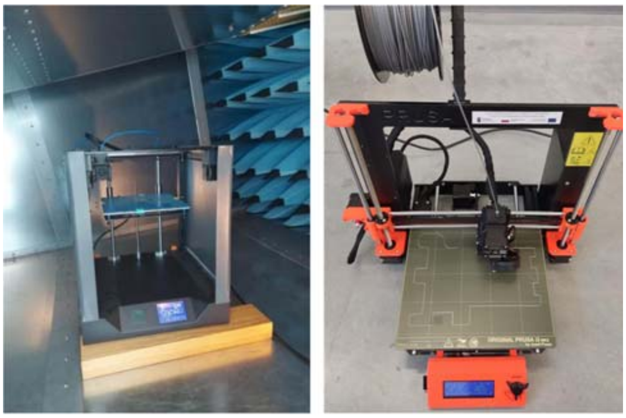
$$S^2 = 10^{\frac{U_{p1}|_{dB}-120}{10}} + 10^{\frac{U_{p2}|_{dB}-120}{10}} + 10^{\frac{U_{p3}|_{dB}-120}{10}} \quad (2)$$

Gauss Instruments TDEMI 1G Real time TDEMI System and the GTEM 1000 cell were used for the tests (Fig. 1).

The tests of the 3D printers (Fig. 2). were performed according to the guidelines of the PN-EN55014 standard [9], over the full frequency range from 30 MHz to 1 GHz, using a quasi-peak detector and a bandwidth of 120 kHz. Both printers were tested in accordance with their intended use in a domestic environment − Class B [9].

In the first phase of the tests, a background measurement was carried out to compare the disturbances obtained during the tests in the stand-by and running phases of the printers (Figs. 3, 4). In the next step, the radiated interference of the printers was measured during the stand-by phase (Figs. 5, 9) and during actual operation (printing) (Figs. 7, 11) at a distance of 3 m. Next, the radiated emissions of the printers were examined at a distance of 10 m, for the same operating parameters, that is, during standby (Figs. 6, 10) and printing (Figs. 8, 12) phases.

Fig.1. The GTEM 1000 cell with the TDEMI 1G high frequency generator



a b

Fig.2. The Sapphire Pro printer (No. 1) placed in the GTEM 1000 cell (a) and a view of the Prusa i3 MK3S+ 3D printer (No. 2) (b)

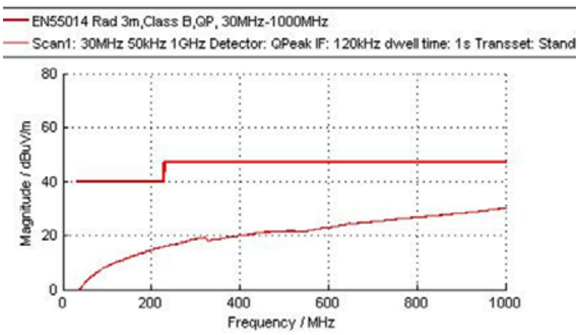


Fig.3. Result of the measurement of the radiation background emission at a distance of 3 m

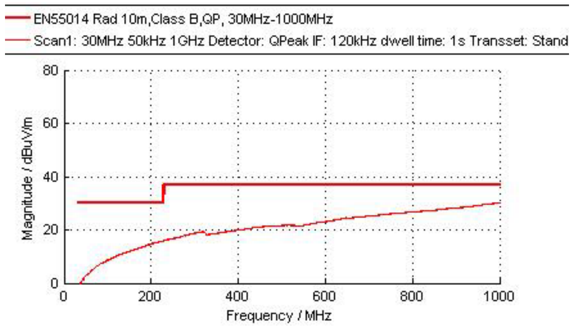


Fig.4. Result of the measurement of the radiation background emission at a distance of 10 m

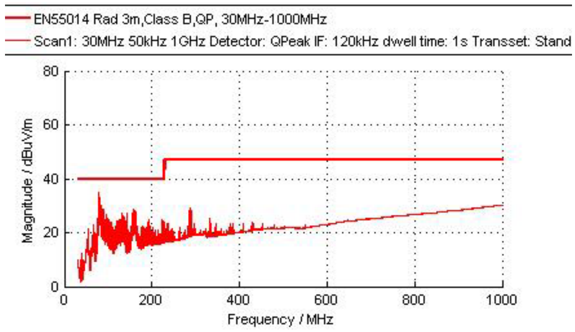


Fig.5. Result of the measurement of radiated emission by printer No. 1 on standby, at a distance of 3 m

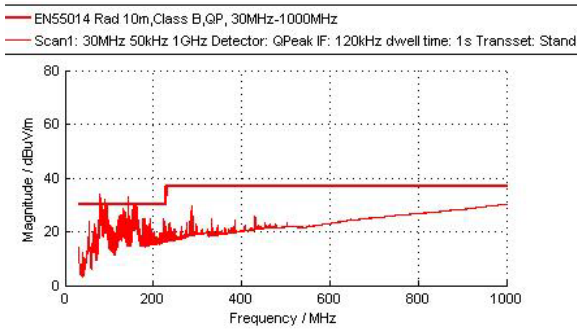


Fig.6. Result of the measurement of radiated emission by printer No. 1 on standby, at a distance of 10 m

From the characteristic curve displayed (Fig. 5), it can be seen that the permissible disturbance level was not exceeded in the entire measurement band at a distance of 3 m for printer No. 1, which was in standby mode. However, at a distance of 10m, for printer No. 1, in standby mode, there are exceedances of radiated emissions of a maximum of 3 dB(μV/m) above the permissible limit, in the frequency range 80 MHz÷150 MHz (Fig. 6).

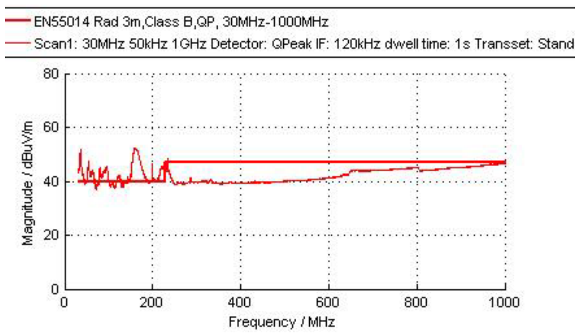


Fig.7. Result of the measurement of radiated emission by printer No. 1, during printing, at a distance of 3 m

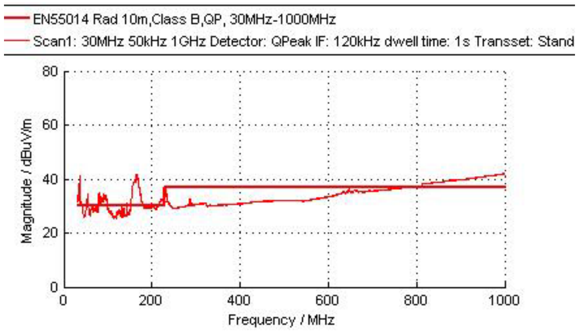


Fig.8. Result of the measurement of radiated emission by printer No. 1, during printing, at a distance of 10 m

For printer No. 1, exceedances of the radiated emission limits in the frequency range 30 MHz÷220 MHz at a distance of 3 m occur during printing (Fig. 7). The highest electric field strength value of 52 dB(μV/m) occurs at 180 MHz, where the permissible limit was exceeded by 12 dB(μV/m). When measuring the disturbance during printing at a distance of 10 m, it can be observed (Fig. 8) that the permissible limit was exceeded by 12 dB(μV/m) in the frequency range 30 MHz÷180 MHz with the highest disturbance of 43 dB(μV/m) at 180 MHz and above 800 MHz.

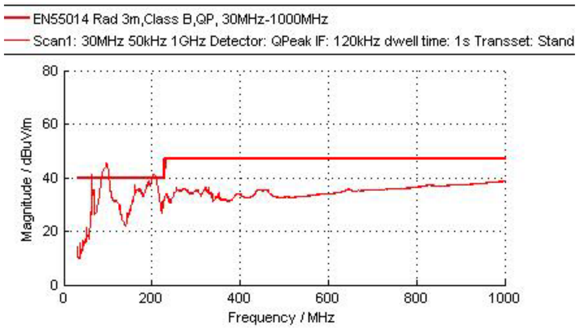


Fig.9. Result of the measurement of radiated emission by printer No. 2 on standby, at a distance of 3 m

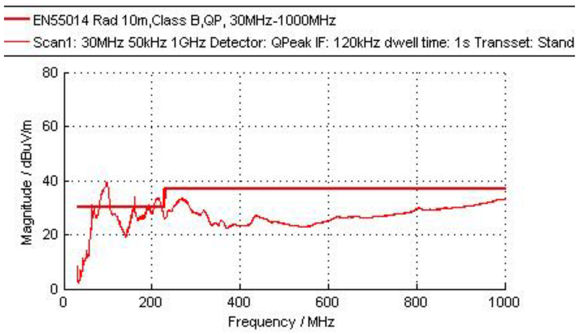


Fig.10. Result of the measurement of radiated emission by printer No. 2 on standby, at a distance of 10 m

In the case of printer No. 2 in standby mode, at a distance of 3 m, it can be seen from the characteristic shown (Fig. 9) that the permissible disturbance level is exceeded in the frequency range 30 MHz÷210 MHz, with a maximum exceedance of 4 dB(μV/m) occurring at 80 MHz. Printer No. 2 in standby mode, at a distance of 10m (Fig. 10) causes disturbances in the frequency range 70 MHz÷220 MHz. The maximum exceedance of 10 dB(μV/m) above the limit occurs at 90 MHz.

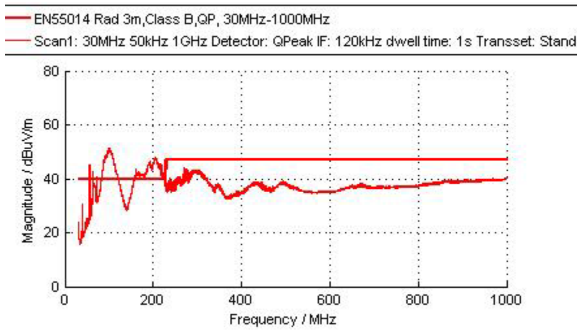


Fig.11. Result of the measurement of radiated emission by printer No. 2, during printing, at a distance of 3 m

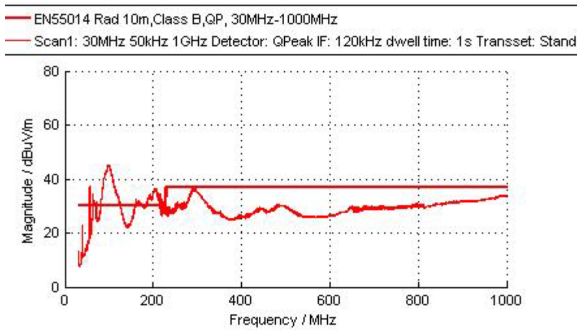


Fig.12. Result of the measurement of radiated emission by printer No. 2, during printing, at a distance of 10 m

For printer No. 2 during printing (Fig.11), radiated disturbances above the permissible limit occur in the frequency interval 50 MHz÷220 MHz, at a distance of 3 m, the maximum value of 51 dB(μV/m) was registered at 90 MHz, which is an exceedance of the permissible limit by 11 dB(μV/m). The characteristic curve for Printer No. 2 during printing (Fig. 12) shows that the acceptable level of disturbance was exceeded in the frequency range 50 MHz÷200 MHz at a distance of 10 m, while the highest disturbance of 46 dB(μV/m) occurs at 90 MHz.

Conducted emission testing

The emission tests were carried out on a test bench, a diagram of which is shown in Figure 13. The main apparatus used in the tests was an ESCI3 measuring receiver from Rohde Schwarz, together with a NNB41 single-phase artificial network. Measurements were carried out on a test bench with earthed equipotential planes (aluminium sheets) and a grounded artificial network. Measurements were carried out with an average (AV) and maximum value detector, at settings compliant with CISPR standards - bandwidth 120 kHz, step size 40 kHz, measurement time 10 ms. Operation of the measurements and interference meter was carried out from a computer with EMC32 software.

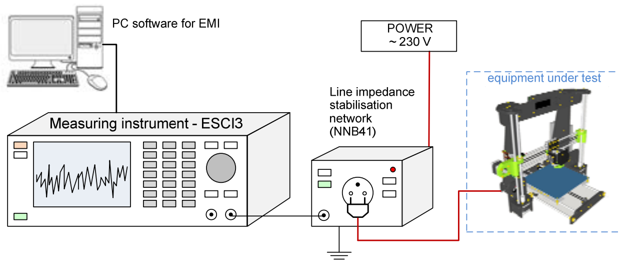


Fig.13. Structure of the measuring system for conducted disturbance analysis

After the printer under test had been placed on the test bench, the disturbance background level was measured before it was put into operation. The measurement results are shown in Figure 14 (green curve). The measured disturbance background level is at a very low level. The next stage of the tests was scanning in the mode of connecting the printer to the power supply − but without running the control modules (blue in Fig. 14). Here, too, no limit exceedances were found. The third stage of the preliminary tests was scanning the spectrum while the printer was being set up and warmed up (magenta in Fig. 14). No exceedances were found here either. The next stage of testing was already carried out in the printer's normal operation, i.e. − printing. The measurement results are shown in the graphs – (Figs. 15 and 16).

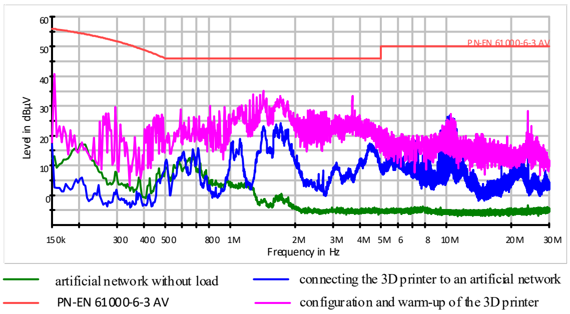


Fig.14. Identification of the conducted disturbance level at the 3D printer site, measurement of the emission level of the artificial network and the 3D printer connected to it

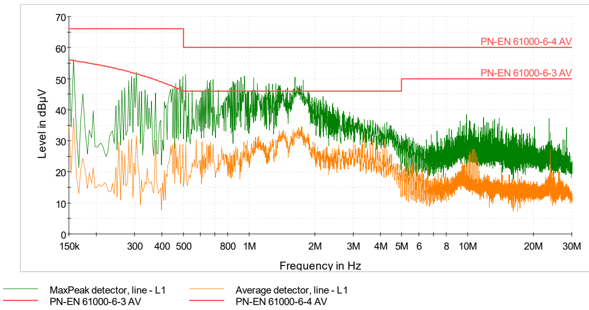


Fig.15. Conducted disturbance measurement results, line L1, Prusa i3 MK3S+ printer

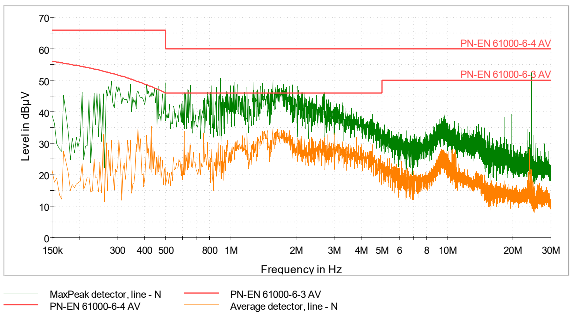


Fig.16. Conducted disturbance measurement results, line N, Prusa i3 MK3S+ printer

Conclusions

The emitted levels of conducted disturbance from the printers are low and do not exceed acceptable limits for both industrial and residential environments. In contrast, both 3D printers tested in the operating state do not meet the EMC requirements for radiated emissions. In the standby state, the Sapphire Pro printer also fails to comply with the standard.

The maximum measured quasi-peak value of radiated disturbance reached 52 dB(µV/m) and an exceedance level of 13 dBµV/m was recorded for the Sapphire Pro printer at a distance of 3 m in the operating state.

It can be assumed that the printers tested met acceptable requirements when they entered the market. The tested printers were subjected to tests after a certain period of their use. With continued application, it is possible that the level of radiated disturbance emissions will change.

A more complete picture of changes in the level of interference emissions from 3D printers could be obtained by enlarging the number of devices tested, together with the specific conditions of their use.

The cause of broadband disturbances generated by 3D printers are supply voltage converters. One method of eliminating these is to use a properly designed enclosure, unfortunately this is not often used as it can complicate the assembly process and increase the cost of manufacturing the device. The same is true for the use of electroplating, which requires an additional step in the process.

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REFERENCES

[1] Act of Parliament of 13 April 2016 on conformity assessment systems and market surveillance, *Dz.U.* 2019 poz. 544. (in Polish)
[2] Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility, *Official Journal of the European Union*, L 96/79J
[3] Eltera P., et al., EMC Measurement with GTEM Cell, *Journal of Applied Technical and Educational Sciences*, (2019) vol. 9, no. 4, pp. 112-128
[4] Gerth H., et al., New Advances on Correlating TEM Cell and OATS Emission Measurements, *IEEE Transactions on Electromagnetic Compatibility*, (2010), vol. 52, no. 1, pp. 11-20.
[5] Fujii K. et al., 2-6 Site Validation of the Open-Area Test Site and the Semi-Anechoic Chamber, *Journal of the National Institute of Information and Communications Technology*, (2016), vol. 63 no. 1. pp. 127-134
[6] PN-EN IEC 61000-6-3:2021-08, Electromagnetic compatibility (EMC) -- Part 6-3: Generic standards -- Emission standard for equipment for residential environments
[7] PN-EN IEC 61000-6-4:2019-12, Electromagnetic compatibility (EMC) -- Part 6-4: Generic standards - Emission standard for industrial environments
[8] PN-EN 50561-1:2013-12, Power line communication apparatus used in low-voltage installations – Radio disturbance characteristics – Limits and methods of measurement – Part 1: Apparatus for in-home use
[9] PN-EN 55014-1:2021, Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 1: Emission
[10] EN 61000-4-20:2011E, Electromagnetic compatibility (EMC) – Part 4-20. Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides