Testing designing an electrical device compliant with the electromagnetic compatibility directive

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Abstract. The goal of presented work was to build an electronic device in order to test the effectiveness of different EMC-improving solutions. Three EMC tests were done in order to check the created device compliance with the electromagnetic compatibility directive. Each of them was conducted for both industrial and non-industrial parameters (voltage and field strength), according to IEC PN-EN 61000 standards. Three tests were done: conductive immunity test in EM clamp, radiated immunity test in GTEM chamber, radiated emission test in GTEM chamber. Firstly, the device’s conductive immunity was examined. The set of possible solutions was created by examining existing designs, papers, books and producers’ recommendations. In result, different component configurations were chosen to determine the most EMC-effective one. Next, electromagnetic compatibility of proposed device configurations was tested in the GTEM chamber (radiated immunity and radiated emission). Tests results are presented on charts and analysed in order to verify if designed device face requirements of the electromagnetic compatibility directive. It was verify which of proposed electromagnetic compatibility improving solutions can solve problems with electromagnetic compatibility.

1. Introduction
Nowadays, manufacturers and distributors have to face many regulations, directives and requirements that their products have to meet or be compliant to. Some of them are state-regulated, other come from international entities like the European Union. The EMC directive (currently the directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014, later in this paper referred to as “the EMC directive”) is a legislative act that is not binding on its own. However most of the European Union member states have accommodated own laws, that are directly based on it. Guidelines to implementing the directive’s essential requirements are discussed in referenced sources [1, 2]. A lot of effort is spent on development of any types of devices that are used by a human because new materials and new technologies are opening brand new possibilities for designers and engineers [3,4]. They have the opportunity to apply new materials and new methodology to design devices and systems that, for example are more effective, have better properties and lower costs of production [5-8]. The new opportunities are also results of the possibility of smart materials application, so the materials that can change one or more of their properties during operations and this change can be controlled [9-11]. Modern systems include elements from different science areas, such as mechanics,
electronics and informatics. Such connection brings new possibilities and new effects, so those systems can be called mechatronic systems [12-17]. In spite of all of those benefits of modern engineering it is also important to take into account that designed technical system should also has a positive influence onto realization of the principles of sustainable development by both, the method of its production, as well as the whole product life cycle. The principles of sustainable development is understood as to ensure the development of the present generation, among others in terms of economic growth and meet its needs, while maintaining opportunities for further development and meet the needs of future generations. It is an idea that is committed to social justice through economic and environmental efficiency projects undertaken. In this light, the development of currently used technical devices that aim is to obtain their longer exploitation that will lower demand for raw materials and improve their use is the idea of the research work which results are presented in this paper.

A case of design and development process that concentrates on the electromagnetic compatibility are presented. The device chosen to serve as an example is a temperature sensor, designed and assembled on a PCB and programmed. Its electromagnetic immunity and emission was tested in a EMC laboratory placed in (the name of laboratory will be added in the final version of the paper). During the tests, the effectiveness of several EMC-improving solutions was checked. Most efficient ones were chosen and applied to the constructed device in order to achieve full compliance with the requirements of the EMC directive.

2. Temperature-sensing device — construction and operation principles

The goal was to build an electronic device in order to test the effectiveness of different EMC-improving solutions. A temperature-sensing device was chosen, because of the easy availability of cost-efficient silicon sensors. The apparatus consists of several elements soldered together on a PCB: an ATmega-8 microprocessor, an external EEPROM memory module, two digital temperature sensors DS18B20, three indicator LEDs, UART connector, which allows the device to be connected to a PC via FTDI232R module, and three bus connectors:

- I²C for EEPROM memory and optional LCD display,
- SPI for programming purposes,
- 1Wire for communication with the DS18B20 sensors.

The device is programmed to operate in three modes:

- Measurement - the microcontroller receives temperature values from two DS18B20s every 3 seconds and writes them to the external EEPROM memory for later recovery.
- Transmission - the microcontroller reads values, that were saved on the EEPROM module and transmits them through UART protocol to a FTDI232R component, which should be connected to a PC. This allows the user to receive and process the measurement data on a PC.
- View - the microcontroller reads data from the EEPROM module and displays it on an optionally connected LCD screen. This mode was used mainly for testing and debugging purposes, and the LCD display was not included in the final design.

The key feature of the microcontroller’s program is implemented in the measurement mode. It uses a native aspect of 1Wire communication with DS18B20 units — the CRC checksum algorithm. It allows the microcontroller to recognize which data frames received from the temperature sensors were altered due to electromagnetic interference (or other factors). Each time the EMI damage is reported, the microcontroller writes “0”, instead of the received values, to the EEPROM memory. These interference-indicating values can be distinguished from good quality readings, because both sensors are meant to measure the air temperature in a laboratory room (which, despite lacking AC, managed to maintain a stable temperature of 23 – 24 °C). Therefore, all values should remain constant with a slight deviation possible, due to nearby equipment heating up.

After deciding on a conception, an electric connections schematic was designed using the EAGLE 7.5.0 LIGHT CAD application. Simultaneously, the application for the microcontroller was written in C language. The C libraries presented in book [18] were used for 1Wire and I2C communication. Then
the device was assembled on a prototype board and tested to assure correct functionality. Moreover, preliminary EMC tests were conducted on the prototype. The purpose was to check the EMI’s effect on the prototype’s behaviour. Later in the paper it is compared to the assembled device’s performance. After these tests a PCB layout for the device was designed. The reason for which there are two temperature sensors present in the design needs elaboration. The device was subjected to three EMC tests. One of them was electromagnetic clamp. It induces interferences in a cable fed through it. Thus the wire needed to be connected to the device. To gather additional data, one DS18B20 sensor was placed at each end of the cable, and both of them were communicating with the microcontroller. Several good engineering practices were being taken into account while designing the PCB layout. Similar outlines are given by authors of referenced publications [19-22]. The ones that were considered are:

- Using filters mentioned in components’ datasheets. In this case the EEPROM memory needed one ceramic capacitor (100 nF) and the microcontroller needed one ceramic (100 nF) and one electrolytic capacitor (22 pF). These passive components ought to be mounted as close to the corresponding power pin as possible. Referenced source state, that distances larger than 1 cm are unacceptable [18].
- Using ground planes and power planes. It is considered best practice to use whole separate layers for ground and power signals. They provide paths of lesser resistance that regular copper paths. Moreover, these planes serve as noise shielding. However, this is only possible when dealing with multi-layer PCBs. Instead, we decided to use a single-layer PCB and “pour” the ground plane around remaining paths, thus creating partial shielding.
- Including a programming joint (SPI connector in this case) for easy access, flexibility and reprogrammability.
- Keeping the most commonly used connectors close to each other to avoid ground loop coupling. These are: power, SPI and 1Wire connectors.
- Anticipating soldering spots for additional components like an EMC filter, which was used in the final version of the device, and external oscillator, which was not.
- Allowing the chassis to be connected to the device’s ground in order to provide noise shielding and low-impedance paths both for signals and for interferences. The PCB creation was outsourced, but the component soldering was done by hand. The device in its final stage (after EMC testing and choosing the best component configuration) is shown in fig. 1. It includes aluminium chassis, a low-pass LC filter and 1Wire shielded cable.

![Figure 1. The device inside an aluminium casing.](image-url)

3. EMC testing and results
Electronical devices can be subjected to different tests to check their compliance with the EMC directive. These methods are described in a wide manner in publications [23-27].
Three EMC tests were done in order to check the created device compliance with the electromagnetic compatibility directive. Each of them was conducted for both industrial and non-industrial parameters (voltage and field strength), according to IEC PN EN 61000 standards. There tests were:

- conductive immunity test in EM clamp,
- radiated immunity test in GTEM chamber,
- radiated emission test in GTEM chamber.

3.1. Immunity tests
Firstly, the device’s conductive immunity was examined. The set of possible solutions was created by examining existing designs, papers [22, 25, 28], books [18-20,29] and producers recommendations [30-32]. In result, different component configurations were chosen to determine the most EMCeffective one:

A. The device on a prototype board without any additional EMC elements.
B. The device on a PCB without any additional EMC elements.
C. The device on a PCB with a snap ferrite on the cable (Wurth Elektronik No. 742735812, peak impedance 600Ω at 500 MHz).
D. The device on a PCB with cubic ferrite choke (Wurth Elektronik No. 74273001, peak impedance 280Ω at 100 MHz).
E. The device on a PCB with three ferrite beads (Wurth Elektronik No. 74275223, peak impedance 1500Ω at 100 MHz).
F. The device on a PCB with low-pass LC filter. The components are 10 μH coil and 470 pF capacitor. The parameters were tuned empirically for best interference suppression without unacceptable signal quality loss. We decided to construct a simple filter ourselves referring to advices mentioned in paper [33] instead of purchasing one like it is suggested in paper [34], because of cost efficiency and required dimensions.
G. The device on a PCB with shielded cable; shield connected to PCB ground. We used a four-wire, copper-braided cable.
H. The device on a PCB in aluminium chassis, with shielded cable, shield connected to PCB ground, chassis and external earth. PCB ground is connected to chassis by two sets of steel screws, bushings and nuts mounted to the right-side mounting holes on Fig. 1.
I. The device on a PCB in aluminium chassis, with shielded cable, shield connected to chassis and external earth but separated from PCB ground (copper around mounting holes on Fig. 1) with plastic nuts.

The EM clamp has a direction in which the interferences propagate. The A and B tests were done in both directions (towards sensor mounted on the PCB, and opposite). It turned out, that only when clamp was pointed towards the PCB, the interferences had effect on the device’s operation. This may be because the DS18B20 sensor’s manufacturer is obliged to immunize all his products according to the EMC directive. Therefore all latter test were done in the with EM clamp pointing toward the PCB. The C solution was mainly ineffective, probably due to frequency incompatibility, as the ferrite’s peak impedance lands at 500 MHz, and the test was conducted in the range of 150 kHz – 80 MHz.
The D and E solutions completely immunized the device to nonindustrial interference (3 V), but failed to do so for industrial interferences (10 V). However the ferrite beads were more effective than the cubic-shaped choke, because of their higher impedance.
The filter mentioned in F was as effective versus 3 V interference as ferrite chokes and even more effective against industrial-level, yet still did not grant full immunity.
Shielding the cable in G immunized the device to 3 V EMI, but failed to do so for 10 V. Moreover, it was less effective than D, E and F.
Adding aluminium chassis (H) improved the immunity, but the best effectiveness was achieved by connecting the cable’s shield to external earth through chassis, and separating it from the PCB ground (I). This is contradictory to what is stated in source [20]. It may have place because the tested device is
battery-powered. Thus it does not have own earthing included in the power supply and cannot sink interferences through it.

That configuration (I) of the device was then tested for radiated immunity in a GTEM chamber, both for industrial and non-industrial field intensity. It turned out to be immune to radiated EMI at tested parameters and as well. Selected test results are presented in fig. 2 to 11. Orange colour represents values read from the sensor placed on PCB, whereas blue stands for measurements from sensor at the far end of the cable.

In fig. 3 and 7 four solitary peaks can be seen. These peaks lay in the range of bad quality readings. Furthermore, their values are significantly different from the expected ones. That’s why it can be believed they were caused by a false positive result of the CRC check sum.

![Figure 2](image2.png)

**Figure 2.** The B variant, non-industrial interference voltage.

![Figure 3](image3.png)

**Figure 3.** The B variant, industrial interference voltage.
Figure 4. The C variant, non-industrial interference voltage.

Figure 5. D–I variants, non-industrial interference voltage.

Figure 6. The D variant, industrial interference voltage.
Figure 7. The E variant, industrial interference voltage.

Figure 8. The F variant, industrial interference voltage.

Figure 9. The G variant, industrial interference voltage.
3.2. Emission tests

Firstly, the device’s EM emission was tested in the GTEM chamber. Test results are presented in fig. 12 to 17. Firstly we decided to conduct additional test of A configuration with different processor clock values to see the emission results. As predicted, peaks corresponding to consecutive harmonic frequencies of the clock signal can be seen. Due to the sudden raise in allowed field strength at 230 MHz, increasing the clock frequency can lead to better compliance with emission requirements.

After that, B configuration was tested. The emission has decreased in comparison to A variant. Most probable explanation of that phenomenon is much lesser length of paths present on the PCB than on a prototype board.

Finally the I configuration was tested. However, the device placed inside the GTEM chamber couldn’t be properly earthed (with lowest impedance possible, e.g. with a copper braid). Instead, the device was tested twice: first without earthing, and secondly we earthed the device using a PE cable (2.5mm2). As predicted, the cable acted as an antenna and an increase in emitted field strength can be seen between fig. 16 and fig. 17.
Figure 12. The A variant, internal 8 MHz clock.

Figure 13. The A variant, external 12 MHz oscillator.

Figure 14. The A variant, external 16 MHz oscillator.
As presented above, despite poor earthing the I variant of the device is compliant with the EMC directive’s emission requirements, both for industrial and non-industrial environments.
4. Conclusions
This paper shows an example of an electronical device design and realisation process, that takes into consideration the EMC essential requirements. This approach was applied from the early stages of development by means of: designing the PCB according to Good Engineering Practices (GEP), proposing a selection of possible EMC-improving solutions and testing the effectiveness of proposed solutions.
As a result of those activities, the constructed device (configuration I) was proven to be compliant with the requirements of the EMC directive. The solution that was the most meaningful for both electromagnetic immunity and noise generation was assembling a proper earthing (connected to chassis) and separating it from the P electronical circuit.
It is believed that the approach (considering electromagnetic compliance on the early stages of design and development) leads to reduction of the amount of EMC-related problems that arise during tests, as it is stated in referenced publications [2,19-21]). Thus, it is recommended to always take into account the essential requirements of the EMC directive, when designing any device that applies to the directive’s scope.

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