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VERIFICATION OF A LOW-COST ELECTROMAGNETIC FIELD (EMF) TESTER FOR ELECTROMAGNETIC COMPATIBILITY (EMC) INVESTIGATIONS

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Electromagnetic compatibility (EMC) issues are increasingly prevalent in modern electronic devices. One contributing factor is the ongoing pressure to reduce production costs, which can lead to design compromises that negatively impact EMC performance. EMC measurements are often complex and typically require specialised facilities and instrumentation, such as anechoic chambers and spectrum analysers, to ensure accurate assessments. In this study, low-cost, handheld electromagnetic field (EMF) testers are presented as valuable tools for preliminary electromagnetic interference (EMI) investigations. Measurements indicate that these simple testers can serve as effective initial instruments for EMC assessments. However, accurate interpretation of measurement results is crucial. Adherence to general usage guidelines is essential, as misinterpretation may lead to an overestimation of EMC issues. For comprehensive analysis, particularly in identifying complex interference sources, more sophisticated measurement instrumentation remains necessary, such as a spectrum analyser and various types of antennas.

Keywords: *Electromagnetic compatibility (EMC), electromagnetic field (EMF) measurements, electromagnetic interference (EMI), EMC tester.*

1. INTRODUCTION

Electromagnetic compatibility (EMC) issues are becoming increasingly significant due to the growing complexity and density of electronic systems. This trend is further exacerbated by the continuous pressure to reduce the prices of electronic devices, often resulting in design compromises, such as inadequate shielding effectiveness. Additionally, the rising circuit density in modern electronics contributes to potential EMC problems, as EMC properties of devices may no longer meet acceptable levels. Consequently, it has become increasingly important to assess the EMC properties of devices, particularly their emission characteristics, as immunity properties are difficult to measure and often require specialised laboratory facilities or instrumentation – especially when various EMC standards are followed. Harmful and disruptive EMC interference has been reported from several different applications, e.g., [1]. Also, a relatively simple but practical solution has been presented to reduce these effects, e.g., [1], [2].

EMC measurements and investigations are typically complex and often necessitate specialised facilities such as anechoic chambers and other expensive measurement equipment, including spectrum analysers with various probes and antennas. The CE (Conformité Européenne) marking is intended to guarantee that all electrical devices and systems introduced to the market comply with prevailing EMC legislation. However, numerous surveillance campaigns conducted by regulatory authorities have revealed that devices and systems frequently do not fully meet EMC requirements or only partially comply. Furthermore, regulatory authorities often lack the resources to investigate the EMC properties of every new electrical system and device. Therefore, it is essential that informed consumers have the opportunity to conduct preliminary EMC assessments of purchased devices or systems.

The EMF tester is one of the clearest choices for EMC testing purposes. A variety of electromagnetic field (EMF) meters are available on the market, ranging from approximately 20 euros to several thousand euros. These devices exhibit significant variability in terms of features, functionality, and measurement accuracy. Comprehensive analyses of various EMF measurement tools have been presented in prior studies, e.g., [3]–[5]. While high-end meters offer advanced capabilities, their cost can be prohibitive for routine assessments. A self-made EMF tester was also built for EMC investigations, e.g., [6].

Our evaluation focused on the meter's performance in detecting and quantifying EMI (electromagnetic interference) emissions from various electronic devices and systems. The findings aim to determine the suitability of low-cost EMF meters for preliminary EMI investigations, particularly in scenarios where access to specialised laboratory facilities or instrumentations is limited. Chapter 2 outlines the measurement devices utilised in this study, providing detailed descriptions of the instruments and their specifications. Chapter 3 presents the measurement results, systematically organised to correspond with the research questions posed. Finally, Chapter 4 offers conclusions and interpretations of the results, discussing their implications and relevance to the field.

2. MEASUREMENT DEVICES

In this study, a low-cost EMF meter, priced around 80 euro, was selected for evaluation. The objective was to assess its effectiveness in measuring electromagnetic emissions from a diverse set of electronic devices and systems. Notably, some EMF meters in the market are available for as low as 20 euro; however, these often lack the necessary sensitivity and features required for comprehensive assessments. The selected EMF meter is capable of measuring magnetic fields (MF), electric fields (EF), and radiofrequency (RF) fields. Advanced models of EMF meters often incorporate three-axis measurement capabilities, allowing for the detection of field components (*E* and *H*) along the *x*, *y*, and *z* axes. The resultant field strength is typically computed as the vector sum of these components, providing a more accurate representation of the electromagnetic environment. The sum of these three-axis components is the following:

$$|E| = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

(for the electric field);

$$|H| = \sqrt{H_x^2 + H_y^2 + H_z^2}$$

(for the magnetic field).

The study utilised the PCE-EMF 30 electromagnetic field meter (Fig. 1), a compact and portable device designed for measuring electric fields, magnetic fields, and radio frequency later marked as (*S*) fields. The EMF meter's frequency range extends up to 10 GHz for RF and up to 3.5 GHz for both EF and MF. The PCE-EMF 30 features a built-in triaxial sensor, enabling simultaneous detection of field components along the *x*, *y*, and *z* axes. This triaxial measurement capability enhances the accuracy and reliability of the readings compared to single-axis models. The device is lightweight, with dimensions comparable to a standard mobile phone, making it highly portable and user-friendly for field measurements. Its integrated sensor design eliminates the need for external antennas, simplifying the measurement process. However, the manufacturer notes that the accuracy of the PCE-EMF 30 diminishes as the distance between the meter and the device under test (DUT) increases. Therefore, for optimal measurement accuracy, it is recommended to position the meter in close proximity to the DUT during assessments. Overall, the PCE-EMF 30 serves as a practical tool for preliminary electromagnetic compatibility investigations, offering a balance between functionality and affordability.

Fig. 1. The PCE-EMF 30 tester measures electric field strength at the top of the laptop touch pad and keyboards. It provides both instantaneous and peak values for magnetic, electric, and radio frequency fields. In this instance, the EF measurement is active.

It is well-established in electromagnetic theory that the strength of electric (*E*), magnetic (*H*), and radio frequency (*S*) fields diminishes significantly with increasing distance (*r*) from the source. This attenuation is primarily due to the inverse-square law, which states that the intensity of these fields is inversely proportional to the square of the distance from the source. Consequently, as the distance between the measuring device and the device under test increases, the measured field strength decreases rapidly. This principle is particularly relevant when using EMF meters for preliminary electromagnetic interference investigations, as accurate measurements require close proximity to the DUT to ensure reliable data. The relationship between field strengths and distance are presented below:

$H \propto \frac{1}{r}$ - unit μT;

$E \propto \frac{1}{r^2}$ - unit V/m;

$S \propto \frac{1}{r^2}$ - unit mW/m^2.

As mentioned, the strength of electromagnetic fields – electric (*E*), magnetic (*H*), and radio frequency (*S*) – diminishes significantly with increasing distance from their source. This attenuation is governed by the inverse-square law, where field strength decreases as the distance increases. In the near-field region, which is typically within one wavelength of the source, the electric and magnetic fields are predominantly reactive and decay rapidly with distance. As the distance increases, the measurement moves into the radiative near-field and eventually the far-field, where the RF field becomes more dominant and the electric and magnetic fields are orthogonal and in phase. Therefore, for accurate and reliable measurements, especially of weak fields, it is crucial to conduct assessments in close proximity to the device under test. The distance of the near-field (d_f) can be calculated as follows:

$$d_f = \frac{\lambda}{2\pi},$$

where λ is the wavelength. Thus, the distance of the near field depends on the frequency of the interfering signal.

3. MEASUREMENTS

The study identified several potential sources of electromagnetic interference by measuring the EMF emissions from various devices. Some of these sources are commonly recognised, such as overhead power lines and microwave ovens, while others were selected based on their known and predictable strong emissions, including switching power supply and laptop. A comprehensive list of the measurement sources, along with the corresponding distances from the DUT, is presented in Table 1.

During the measurements, it was observed that the recorded field strengths were highly sensitive to variations in the measurement distance. Even a slight change of a few centimetres in the distance between the EMF meter and the DUT resulted in a significant decrease in the measured field strength, often reducing it by more than half. This finding underscores the importance of maintaining consistent measurement distances to ensure accurate and reliable EMI assessments.

The study aimed to assess the efficacy of a commercially available EMF tester in identifying potential sources of EMI. The tester demonstrated its utility as a preliminary diagnostic tool, effectively detecting emissions from various devices. For instance, when evaluating a hot air blower, a device known to be an almost purely resistive load, the tester functioned as an indirect indicator of the device's operational status (= current consumption), confirming its active state without causing any interference. In this case, the values of the electric and magnetic fields provide information about the device's power consumption.

Table 1. RF, EF, and MF Levels Measured in Various Devices and Systems Using the PCE-EMF 30 Note: The reference column presents the previously reported RF, EF, or MF values for comparable devices and systems.

#	**Tested device/ system**	**RF (mW/m^2)**	**EF (V/m)**	**MF (μT)**	**Note**	**Reference**
1	400 kV overhead line	~ 0	> 2000	~ 10	At the distance of < 10 m, values are over the device's maximum range	>4 kV/m (depend on the distance from the line) [8], [9]; > 1 μT (depends on the distance from the line) [9]
2	Pad-mounted transformer	~ 0	~ 0	5.2	From the outside of the transformer cabin	
3	Railway overhead line	~ 0	450	~ 0	At the distance of < 5 m	>0.8 kV/m [10]
4	Mobile station	0.1	~ 0	~ 0	At the distance of 10 m	
5	Wi-Fi base station/ router	16.3	665	0.7	At the distance of 1 cm	max. 87 mW/m^2 at the distance of 0.5 m [11]
6	Microwave oven	40.4	105	22.2	At the distance of 5 cm	>10 μT at the distance of 61 cm [7]
7	Hot air blower (1000 W)	~ 0	235	3.3	Purely resistive load, at the distance of 1 cm (measured from the power cable)	
8	Hot air blower (2000 W)	~ 0	390	5	Purely resistive load, at the distance of 1 cm (measured from the power cable)	
9	Variable frequency drive, VFD (no load)	~ 0	630	1.3	Mini VFD (P_{non} = 750 W), at the distance of 1 cm	
10	Variable frequency drive, VFD (load)	~ 0	635	4.9	Mini VFD (P_{non} = 750 W, P_{load} = 50 W), at the distance of 1 cm	
11	Laptop	~ 0	310	63.7	At the distance of 1 cm	
12	Switching power supply	~ 0	820	11.2	At the distance of 1 cm, P = 30 W	
13	Mobile phone	4.1	150	0.6	At the distance of 3 cm	max. 1000 μT at the distance of 10 mm [12]

Conversely, when measuring emissions from overhead power lines, the tester indicated high electric field strengths. However, due to the significant distance between the tester and the DUT, the reliability of these measurements was compromised, aligning with the manufacturer's advisories on distance-related accuracy limitations. In addition, if the measurements are taken close to the overhead power lines (<10 m), the meter's maximum reading will be reached, as indicated in Table 1. However, in the study, the typical behaviour of the electric field beneath a power line was tested: the field was strongest at the centre, between the wires, and decreased with increasing distance from the power line [7]. The actual values were too unreliable due to the long distance between the measurement point and the source. The tester also successfully detected strong radio frequency fields from a Wi-Fi base station and a mobile phone, confirming its capability to identify common RF sources. Similarly, the microwave oven, a widely recognised source of RF, EF, and MF, was effectively monitored by the tester, as shown in Table 1.

Notably, the most intriguing results were obtained from a laptop and its associated power supply. The tester indicated relatively high levels of EF and MF emissions from both devices, prompting further investigation. To validate and further investigate these findings, the study employed a standard on-site EMC test setup. This setup included a near-field probe connected to a spectrum analyser, a configuration commonly used in EMC investigations. This approach enabled a more detailed frequency-domain analysis of the devices' emission properties, confirming the initial observations and providing a comprehensive understanding of their electromagnetic profiles. A similar measurement setup is used regularly in EMC investigations, e.g., [13]. A more detailed description of the measurement setup can also be found in [13].

Figure 2 presents the interference spectra obtained from spectrum analyser measurements. The lower panel illustrates the broadband interference signal emitted by the switching power supply, spanning a frequency range of 10 kHz to 150 MHz. The interference signal peaks at approximately 20 dB above the background signal level. The upper right panel shows the interference spectrum from the laptop, characterised by a strong and wideband signal. Notably, the signal spans a bandwidth of 50 kHz to 300 MHz and exhibits temporal variation across the frequency spectrum. In this case, the interference strength reaches around 25 dB above the background level at its maximum. The data shown in Fig. 2 were recorded using the "maximum hold" trace option (commonly referred to as the "Max Hold" option), which captured peak signal levels over time. As a result, this method may not fully reflect the dynamic behaviour of the interference signal. The upper left panel displays the background interference spectrum, which is free of strong interference signals, confirming that the interference is generated by the DUTs (the switching power supply and the laptop). During the spectrum analyser measurements, the near-field probe was positioned at a similar distance (~1 cm) as in the EMF tester measurements.

The observed traveling interference signal is attributed to the laptop's touchpad. While the EMF tester provides a preliminary indication of EMI presence, it lacks the precision to pinpoint the exact source of interference. In contrast, employing a spectrum analyser in conjunction with a near-field probe allows for more precise localization of the interference source. This combination facilitates detailed spatial mapping of the electromagnetic fields, enabling the identification of specific emission points. These findings underscore the utility of simple EMF testers as initial indicators of potential EMI sources, while highlighting the necessity of advanced instrumentation for comprehensive EMI analysis and source localization.

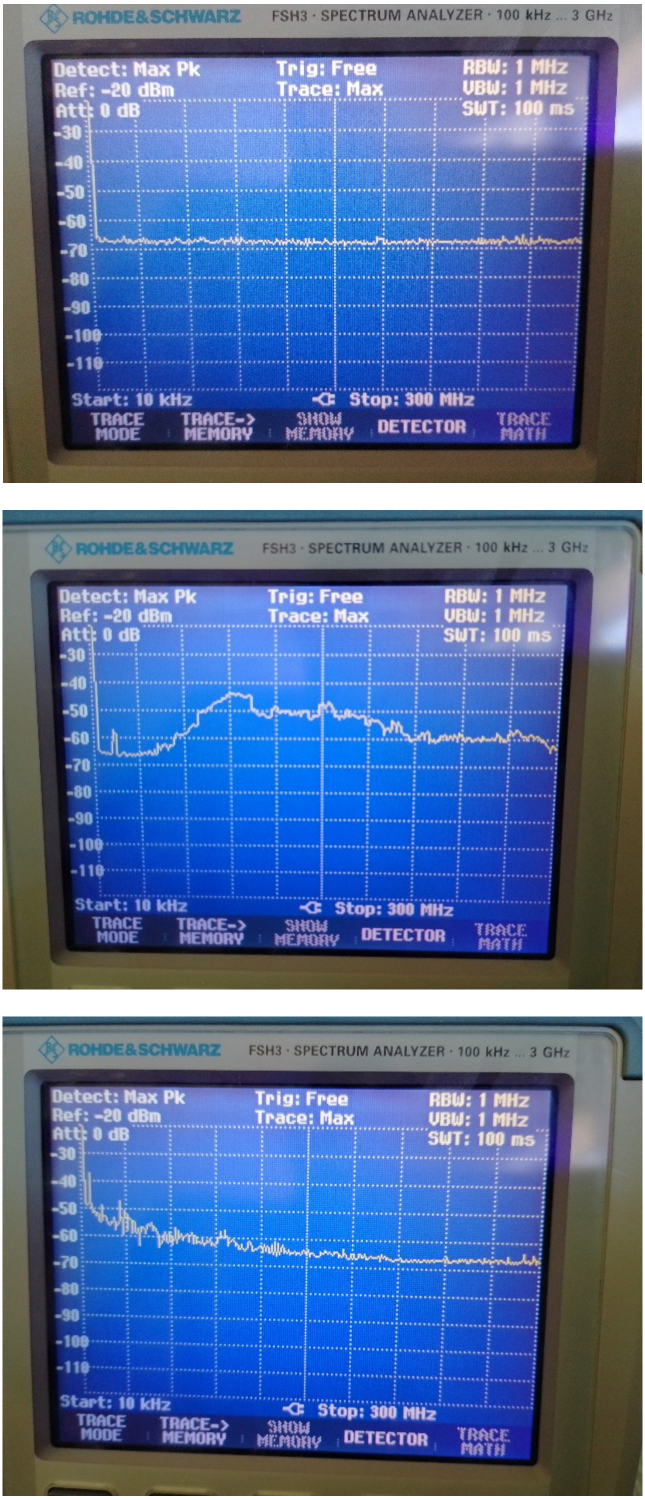

Fig. 2. On the upper left panel, the measured background interference spectrum. On the upper right panel, the measured interference signal from the laptop (laptop's touchpad) and on the lower panel, the measured interference signal from the switching power supply.

4. CONCLUSIONS

The simple, hand-held EMF tester serves as an effective initial tool for electromagnetic interference analysis, particularly suitable for consumer electronics and scenarios where measurements can be conducted in very close proximity to the device under test. In practice, the tester and DUT should ideally be in close physical proximity to ensure reliable measurements; measurements taken even a short distance away tend to be unreliable. Crucially, the interpretation of measurement results is paramount. The simultaneous presence of strong electric and magnetic fields from a consumer electronic device may indicate harmful, interfering emissions. However, the presence of only strong electric or magnetic fields alone does not necessarily signify problematic interference. More sophisticated analyses require additional instrumentation and measurement techniques.

The EMF tester represents a cost-effective option for preliminary EMI investigations, especially when the primary objective is to determine whether a device emits harmful interference. The EMF tester is an excellent choice for regular customers who are interested in the EMI behaviour of electronics. Selecting an appropriate tester is important, and it is strongly recommended to use a model with three-axis measurement capability for improved accuracy. Due to its limited features, the tester is not well-suited for professional EMC compliance testing but can be valuable as an on/off indicator in such contexts. As a proper first step in planning a suitable EMC measurement setup, it is recommended to review the measurement setup and instrument survey provided in [3].

Although straightforward to use, certain considerations must be observed. The distance between the tester and the DUT is critical, with measurements ideally conducted as close as possible to the DUT. Proper interpretation of results is essential; without it, the tester might merely serve as a load indicator rather than a reliable EMI detection tool. Additionally, the EMF tester can be effectively employed in educational settings, where practical laboratory exercises can be developed based on the findings and observations of this study. Example on educational exercise: a Bachelor-level students have to find a university building within a rather limited time period while facing as many interference sources as possible.

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