Alternative EMC measurements for teaching purposes

O. Väänänen
Senior Lecturer
Institute of Information Technology, JAMK University of Applied Sciences
Jyväskylä, Finland
E-mail: olli.vaananen@jamk.fi

J. Hannu
Chief Engineer
Microelectronics Research Unit, University of Oulu
Oulu, Finland
E-mail: jari.hannu@ee.oulu.fi

H. Jantunen
Professor
Microelectronics Research Unit, University of Oulu
Oulu, Finland
E-mail: heli.jantunen@ee.oulu.fi

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INTRODUCTION

Electromagnetic Compatibility (EMC) means the ability of a device to function properly in its intended environment without introducing intolerable electromagnetic interference in that environment [1]. EMC education is a part of electrical and electronic engineering curriculum in many Universities. Full-Compliance EMC measurements require special measurement environment and equipment that are not available in many Universities for teaching purposes.

This paper presents alternative measurement methods for demonstrating different EMC phenomena. These methods are simple and easy to realise with basic electronics measurement equipment in a normal teaching laboratory. The presented measurements are divided according to the EMC test standards. Each presented measurement and test method has been tested. Simple digital electronics boards and Raspberry PI computer have been used as example devices. This paper is based on a Licentiate thesis made by the main author during 2015-2016 [2].

It is important to underline that these measurement methods are not comparable to standard tests but these can be used to learn and better understand different EMC phenomena and design rules to make a device EMC compliant. These measurements can also help students to better understand general electromagnetics from engineering perspective. In addition to teaching purposes, these measurement methods are suitable to be used for the EMC troubleshooting and EMC Pre-Compliance testing in prototype phase or to check the effectiveness of design changes after failed standard measurement and before a retest.

1 EMC EDUCATION

1.1 Need for EMC education

Every electronics engineer will face EMC issues in product development work. Most electronic and electrical devices must fulfil the European Union EMC directive requirements. Common method to satisfy the fulfilment of directive requirements is to test the product according to the European Union harmonized standards.

In many Universities the electronics engineering curriculum includes an EMC course. Many times some kind of measurement exercises are included in the teaching laboratory; however, often these measurements have little to do with standard EMC tests. In many cases the measurements are simplified and concentrated on demonstrating different EMC coupling methods. Typical course contents can be found in the references [3, 4, 5]. Simple measurement methods to demonstrate EMC phenomena are presented in EMC Educational Manual published by IEEE EMC Society [6].

2 EMC MEASUREMENT METHODS FOR ENGINEERING EDUCATION

2.1 Measurement environment and devices needed

All measurements presented in this paper can be carried out with basic measurement equipment like spectrum analyser and oscilloscope. Different probes are needed but the students can build most probes as part of the learning process. The most expensive equipment needed for immunity tests is a high frequency signal generator. Spectrum analyser has traditionally been expensive equipment; however, cheaper models have recently entered the market. These basic models are suitable for measurement methods used for EMC teaching.

Because all measurements are carried out in a normal teaching laboratory, the radio frequency environment is not silent and a different approach for testing is needed compared to the standard measurements. For standard measurements an anechoic chamber is used for radiated measurements and tests. The anechoic chamber blocks the noise coming from the environment and absorbs and avoids reflections inside the chamber. In a teaching laboratory all broadcast channels and mobile networks are presented and affect the measurements.

The methods presented in this paper are mostly based on different EMC troubleshooting methods. Different EMC troubleshooting methods are presented and introduced in several EMC books like references [1, 7, 8, 9, 10]. These troubleshooting methods are also intended to be carried out without special EMC laboratory environment, which is also the situation in most small and midsize electronics industry companies.

2.2 Radiated emission

Standard radiated emission measurement is carried out with an antenna in the semi-anechoic chamber. Radiated emission test is perhaps the most typical EMC test. The requirements for controlled environment are the biggest challenge in the teaching environment when performing radiated measurements. The teaching laboratory is full of electromagnetic noise, for example from radio and television channels, mobile networks and all electronic devices presented in that laboratory. Standard type of measurement is not possible in the teaching laboratory, therefore a different approach is needed to present the phenomena. Alternative methods presented in this paper are high frequency current probe measurement from cables and near-field measurements with self-made near-field probes.

Current probe method

Cables are the main source of emissions from a device. Common mode currents radiate from cables easily, especially in cable's resonant frequencies. Even a few µA common mode current can generate so much electromagnetic noise that device does not meet the EMC standards requirements. [7]

Commercial current probes have been available on market for decades. If commercial current probes are not available for teaching, it is possible to construct with students their own current probe. Constructing students' own current probes helps the students to better understand the current probe measurement method.

A simple method for constructing the current probe is to use clamp-on ferrite. Wire wound several turns around the other half of the ferrite acts like a transformer's secondary winding. The basic structure of the current probe can be seen in *Fig 1.* The method for building the own current probes and characterizing its transfer impedance are presented in sources [11, 12]. In *Fig 2*. are presented two examples of self-made current probes. On the right, normal wire is used and the wire is soldered to the BNC connector. On the left, coaxial cable is used instead [12].

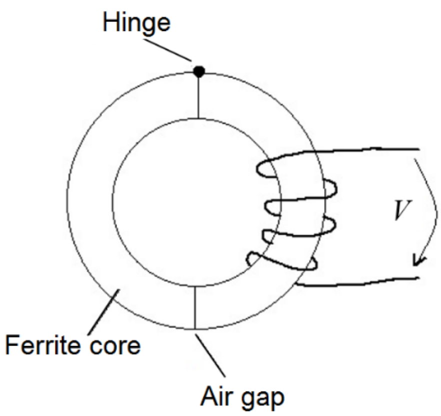

Fig. 1.

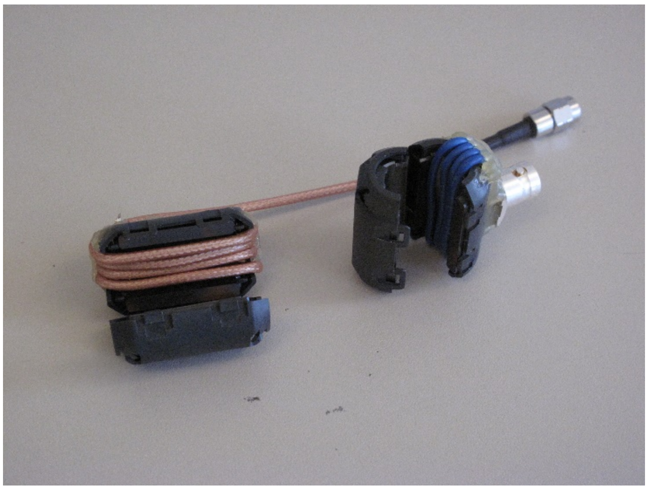

Fig. 2.

According to Henry W. Ott in his book Electromagnetic Compatibility Engineering, the current probe measurement is the most important Pre-Compliance EMC measurement to be carried out in the R&D laboratory. It should be done for all connected cables. Radiated emission from cable is directly proportional to the common mode current on that cable. [7]

To measure common mode current in amperes with the spectrum analyser requires the transfer impedance to be known for that frequency. Without knowing the transfer impedance it is still possible to use the current probe to make comparisons with different design solutions or, for example to test performance of different cables, connectors or ferrites.

For teaching purposes any kind of electronic device with cables connected can be used as an example device. For example, Raspberry PI computer has at least power cable and HDMI cable connected. With Raspberry PI it is very easy to demonstrate the effectiveness of clamp on ferrites to reduce common mode current on the power cable or on the HDMI cable.

Near-field measurement

The structure of a simple near-field probe is well known. Students can easily build their own near-field probes. Near-field probes can be used to estimate emissions from the device and to localize the source of emission. Near-field measurement results are not comparable to standard measurements; however, the effects of the modifications can be estimated. The difficulty in the near-field measurement is the repeatability. The distance and the orientation of the near-field probe affects the measured level a lot. The measurement should be fixed in some way. One possibility is to use some kind of frame to keep the distance and orientation of the probe always the same. If the probe distance and orientation can be kept same, it is possible to make comparison measurements with different device versions and compare different design solutions.

Fig. 3 illustrates the basic structure of near-field probes. On the left there is a magnetic near-field probe and on the right is an electric near-field probe. These kind of probes are very simple to construct by using semi-rigid coaxial cable. It is possible to use semi-rigid coaxial cable assembly with SMA-connectors on both ends of the cable. By cutting the cable into two parts it is easy to build a magnetic near-field probe from one part of the cable and an electric near-field probe from the other end of the cable. Both kind of near-field probes need to be insulated. In *Fig. 4* few self-made probes can be seen. On the left there is a small electric near-field probe made of semi-rigid coaxial cable still without insulation. The three other probes are for magnetic near-fields.

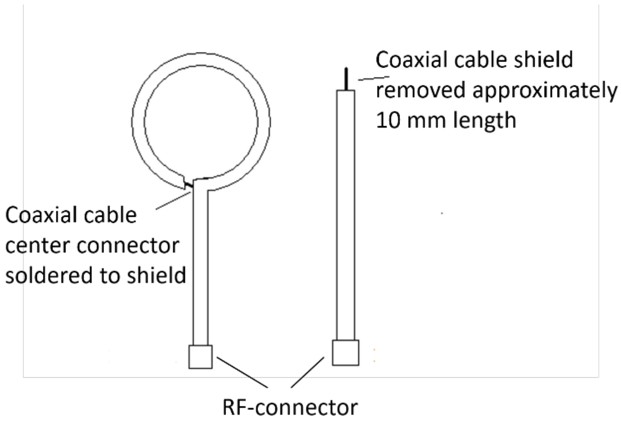

Fig. 3. Near-field probes construction

Fig. 4. Near-field probes

Two different PCB versions of almost same schematic were used as a case study. The PCBs were of the same kind as in reference [13]. The boards have the same functionality with a different layout and the second board has some extra capacitors added.

In the standard EMC radiated emission measurement (in frequency range 30 – 1000 MHz) the difference between two boards was up to 20 dB. The most problematic frequencies were 140 MHz and 220 MHz compared to standard requirements (CISPR 22). *Table 1* presents a comparison of the measurement results in 220 MHz frequency. The standard measurement is carried out according to CISPR 22 with quasi peak detector and the results presented are measured with horizontal antenna polarisation at 3- meter distance in fully anechoic chamber. The near-field measurement was made with the magnetic near-field probe. The spectrum analyser was set to max-hold setting and the whole board was scanned with the probe in exactly the same way for both boards. [2]

Table 1. Comparison of measurements

Measurement	Demoboard 1 [dBµV]	Demoboard 2 [dBµV]	Difference between board 1 and 2 [dB]
Standard measurement	55.73	39.08	16.65
Near-field measurement	48.55	32.51	16.04

The standard measurement and the near-field measurement levels are not comparable to each other. The near-field measurement levels are only comparable to each other. In this special case it can be seen that the difference between boards is very closely similar in both measurement methods. This should be treated with caution, however, it can give some indication.

The radiated emission measurement methods presented here are so simple and easy to realise that it is recommended to include this kind of measurement exercises to the EMC course content. With these measurements it is easy to demonstrate the effectiveness of different PCB layout design rules and other design solutions.

2.3 Conducted emission

Standard conducted emission measurements from power cables require the use of a Line Impedance Stabilization Network (LISN). [1] Without the LISN it is not possible to make exact measurements because the power supply impedance is not known. In general, the conducted emission measurement is not as difficult to realise as radiated emission measurement. The LISN is not so expensive and it is also possible to build the LISN for demonstration purposes. Instructions for building one's own LISN for demonstration and Pre-Compliance purposes can be found in from reference [10]. Special caution with electrical safety is needed if the self-made LISN is used.

Without the LISN it is possible to estimate conducted emissions with same kind of current probe method as used to estimate radiated emissions from cables. The only difference here is that the measurement is carried out in lower frequency. With the current probe it is easy to demonstrate the effectivity of common mode filter or cable ferrites to reject common mode noise current on the cable.

One simple exercise is to use LED lamps as an example and measure the common mode current from power cable with the current probe in frequency range 150 kHz – 30 MHz. LED lamps generate common mode noise on the power cable. It is also possible to make a measurement on a higher frequency when this measurement can be used to estimate radiated emission from the cable. [2]

Another simple example is to use Raspberry PI powered with general charger (mobile phone charger with micro-USB connector). As an example, two different chargers were tested with Raspberry PI and the common mode currents were measured with self-made current probe around the cable between charger and Raspberry PI. The measurement result can be seen in *Fig 5.* [2]

Both chargers were made by the same manufacturer (different models). The difference is biggest around 12.9 MHz frequency up to 12 dB. The effectivity of clamp-on ferrites to reduce low frequency common mode current was tested with charger 1 (yellow line in *Fig 5.*). In *Fig 6.* the green line represents charger 1 measurement without clamp-on ferrites on cable and the yellow line represents the same measurement with two clamp-on ferrites added. The cable was wound three times around the clamp-on ferrite. One ferrite was located on the powerline end and one on the Raspberry PI end. In this case the ferrites can reduce the common mode current over 20 dB from 13 MHz to 30 MHz. This is because two big ferrites were used and the cable was wound several times around one ferrite. The ferrites were not effective on lower frequencies because the ferrites were not characterized to such low frequencies. [2]

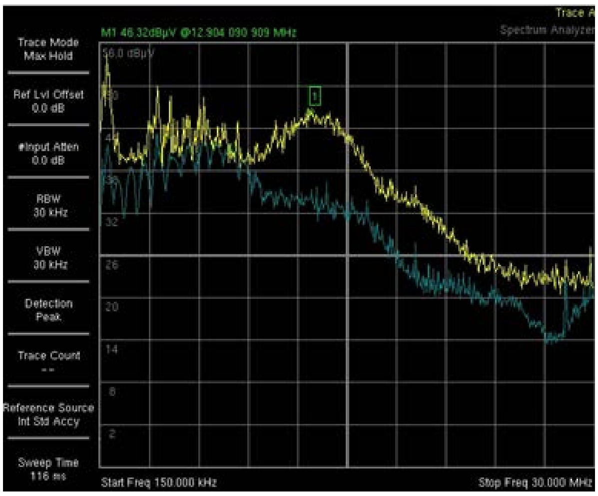

Fig. 5. Comparison of two different charger

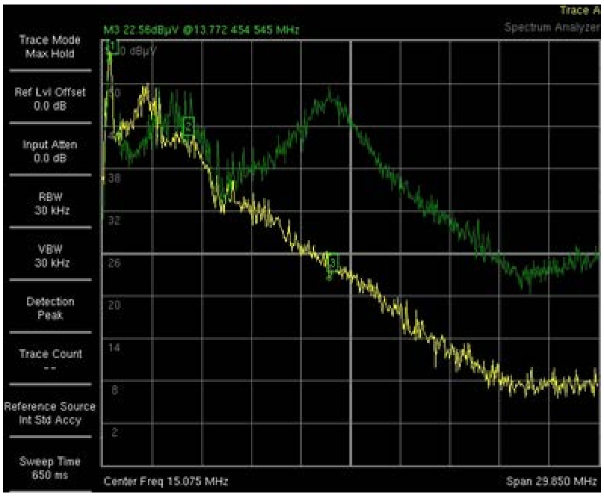

Fig. 6. Effectivity of clamp-on ferrites to reduce common mode current

2.4 Radiated immunity

Immunity tests are very difficult to realise without proper EMC test devices and environment. Radiated immunity test needs a fully anechoic chamber which avoid the created electromagnetic field to spread to the environment. It is illegal to create the needed disturbance field without electromagnetically screened room. Closed TEM and GTEM cells can be also used.

With the RF signal generator and the near-field probe, it is possible to create a local disturbance field directly to the PCB board. As the output power of the signal generator is very low, it is possible to use small RF power amplifier to create a higher level of field. With the use of the magnetic near-field probe a magnetic field is created. With changing the frequency and power level it is possible to find vulnerable frequencies. The test setup can be seen in *Fig 7.* [8]

The Raspberry PI was used as example and the magnetic near-field probe was supplied from the RF signal generator to create disturbance field. The RF signal generator output power was set to maximum 16 dBm with un-modulated signal. With the RF signal generator and the magnetic near-field probe the Raspberry PI was functioning properly. The frequency was stepped between 80 – 1000 MHz. Then the magnetic field generated was strengthened by using the magnetic field probe that was created by circulating coaxial cable several loops before soldering its centre wire to the shield (coil structure). The Raspberry PI was still functioning properly. Then a small low power RF amplifier was used to strengthen the output power of the signal generator. Now the power was at least 30 dBm that was fed to the magnetic field injection probe. When the magnetic field probe was set very close to the Raspberry PI's HDMI connector, the picture on the display disappeared in several frequencies. This happened for example in frequencies between 360 – 370 MHz and 430 – 480 MHz. The Raspberry PI seemed to be very immune to this kind of disturbance. [2]

2.5 Conducted immunity

For testing conducted immunity it is possible to use the same kind of current probe as used in the conducted emission measurement. The RF signal generator and possible RF power amplifier are needed with the current probe. High frequency noise is fed to the current probe and it couples the noise to the cable. With changing the frequency and power level it is possible to find vulnerable frequencies. The effect of different connectors and cables on vulnerability can be easily tested with this method. The test setup is presented in *Fig 8.* Ferrites in power supply end are used to direct disturbance toward equipment under test. The same setup can also be used for other cables than power cable. [8]

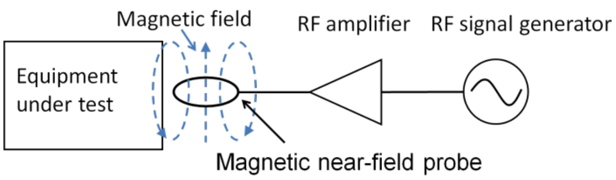

Fig. 7. Test setup for radiated immunity

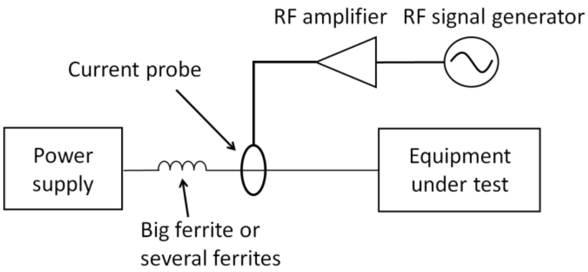

Fig. 8. Test setup for conducted immunity

The Raspberry PI was used as an example equipment again. The current injection probe was set around the HDMI cable and several frequencies between 1 – 80 MHz were tested. Even with the RF amplifier there was no effect on the Raspberry PI's functionality. Then the shield was removed from HDMI cable in approximately 7 cm length. Now the picture on display disappeared in several frequencies. Again, the Raspberry PI and its HDMI connection to display seem to be very immune to disturbance. [2]

2.6 Transient tests

Transient tests are difficult to realise without a proper transient generator. A piezoelectric element from a gas lighter can be used to generate fast voltage transient; however, its repeatability is very low [8]. Every time it generates slightly different transient, however, it is useful for teaching purposes.

The piezoelectric element can be used to demonstrate electrostatic discharge (ESD). Two wires coming from the piezoelectric element can be used to inject discharge directly to the device. One wire can be connected to the board ground and the other wire can be used to target the discharge. [2, 8] This method was tested with the Raspberry PI. ESD was exposed directly to the board and its processor. Several times the Raspberry PI was reset when discharge was exposed and finally, it was totally broken. [2]

Another method to expose device for voltage transient is to use a capacitive clamp. The capacitive clamp is easy to construct of two conductive plates. The piezoelectric element is connected directly to these plates and the equipment under test is located between these capacitor plates. [2]

No conclusions can be drawn from these transient tests because the level of the voltage transient is not known. The transient generated with the piezoelectric element is every time different and thus, the repeatability is very low. In transient tests the equipment under test can break and that should be taken into account in education.

3 DISCUSSION AND CONCLUSIONS

Measurement and test methods presented here are suitable for teaching purposes to demonstrate EMC phenomena and measurement methods. These methods help to understand the challenges of standard EMC tests. These kinds of methods are useful even when a proper EMC laboratory can be used because in industry only big companies have real EMC laboratory. The knowledge of these kinds of alternative test methods for troubleshooting is very useful for electronics engineers. The methods presented here can be used to develop measurement exercises for an EMC course.

All measurement methods could be further developed, and especially the development of more repeatable transient generator would make the transient test methods more suitable and realistic.

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