HANDOUT FOR

RF Interference Emission and Susceptibility Measurement (EMC)

Building V2, Floor VII, Room #721
Antenna and EMC Laboratory

BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF ELECTRICAL ENGINEERING AND INFORMATICS

Department of Broadband Infocommunications and Electromagnetic Theory
H-1111 Budapest, Goldmann György tér 3.
V2 épület VI. emelet
tel.: (+36 1) 463 15 59, fax : (+36 1) 463 32 89

Elaborated by:
László Szűcs

2002

Table of Contents

1. The Purpose of the Measurement

The purpose of the measurement is to learn the fundamental notions of EMC measuring technology by performing some basic measurement procedure. During the experiment primarily interference emission and susceptibility related tasks will be completed. The emitted and conducted disturbances of a PC will be investigated, as well as the susceptibilities of a monitor and a digital scale.

2. The Devices Used

Personal computer
Digital scale
Wideband antenna 30 MHz-1000MHz
LISN
TEM cell
Near-field probe
Spectrum analyzer
Measuring receiver
RF generator

3. The Fundamental Notions of Electromagnetic Compatibility (EMC)

The general model of electromagnetic interference is:

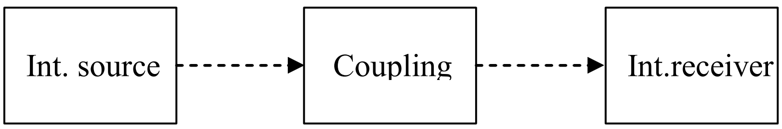

Figure 1.1

Interference sources can be either natural or artificial. For example, natural sources are lightening and other atmospheric phenomena, and cosmic radiation. Disturbances originating from a properly operating or malfunctioning electromagnetic device and emitted to the environment are considered as artificially generated signals. This latter group comprises e.g. high voltage power lines, radio and TV transmitters, high current switches, motors, rectifiers, gas discharge tubes, etc. Practically every electronic device emits spurious components. These, however, become interfering signals only if they disturb the operation of another equipment.

The coupling path may transfer the disturbing signal to the receiver in different ways. The coupling modes can be analyzed collectively by solving the Maxwell equations at various boundary conditions. The following classification is closer to the realistic circumstances:

The disturbing signals may be transferred to the receiver by

- galvanic coupling
- capacitive coupling
- inductive coupling
- conducted electromagnetic wave
- radiated electromagnetic wave

The disturbing signal may enter the interfered device via the wire providing contact with the external world, or directly as electromagnetic near- or far-field. The former case is designated as conducted, while the latter one as radiated interference.

The disturbances can be reduced on all the three parts of the model. Decreasing the spurious level of the source, increasing the attenuation of the coupling path or increasing the resistance of the receiver against the interfering signals all lead to a decreased disturbance. Naturally not all of these procedures can always be applied, since we do not have the opportunity to reduce the level of natural disturbances, and, on the other hand, it is also not elegant to reduce e.g. the receive sensitivity of a radio interfered by a tram passing nearby.

In the following the different coupling paths will be investigated:

Galvanic coupling:

Galvanic coupling occurs when the signal and the disturbance currents flow thru the same impedance. Such an example is when the impedance of a common earth conductor is not negligible.

Capacitive coupling:

Capacitive coupling occurs between units and wires that are placed next to each other. This mode of coupling is typical for cases when the interacting devices operate with small currents but with relatively high voltages, and can be considered as equipotential regions, i.e. both their size and the distance between them does not exceed one tenth of the wavelength of the disturbance signal. Such interference may be generated, for example, in wires located in the vicinity of high frequency – high voltage devices.

Inductive coupling:

Inductive coupling occurs in geometrical arrangements identical to the previous one, but in case of high currents, when the magnetic filed of the current in one of the circuits induces currents in the other device. This kind of coupling can often be found near high power switching mode power supplies.

Conducted electromagnetic wave:

If the wires are still close to each other but their lengths exceed one tenth of the wavelength, then they behave as coupled transmission lines. Coupling in this case can be described by the mutual impedances as laid down in the literature using complicated equations. In today's increasingly faster computers such couplings may occur even on the printed circuit boards.

Radiated electromagnetic wave:

If the conductors are located in each other's far field, then coupling is generated by radiated electromagnetic waves. In this arrangement both the electric and magnetic field strengths are inversely proportional to the distance. Coupling can be determined exclusively by knowing the radiating properties of the transmitting and receiving wires. The formulae obtained in the theory of linear antennas may used for the estimation of the field generated by the wires.

4. Disturbance Sources

The telecommunications, broadcasting, radar and remote sensing devices emit electromagnetic waves during their normal operation, which induce voltages and currents in the disturbed equipment.

Table 1 summarizes the typical field strengths generated by some devices:

DISTURBANCE SOURCE	DISTANCE	FIELD STRENGTH
Broadcast transmitter	2 km	1 V/m
CB radio	5 m	10 V/m
Cellular telephone	1m	0.1-1 V/m
Cellular telephone	0.1m	1-30V/m
Radar	1 km	100V/m

The disturbances caused by defective operation are usually smaller than the above indicated values, and can be reduced by the proper design of the device.

5. Filtering of Conducted Disturbances

The filters can be divided into two classes on the basis of their operating principle:

- reflective type, and
- absorbing type filters.

The reflective filters exhibit highly unmatched impedance on the disturbance frequency, reflecting back the interfering signals to their source. It is hard to determine the effectiveness of these filters, because the impedances of both the network and the device to be protected vary on a large scale. Most often filters similar to the following circuit are used:

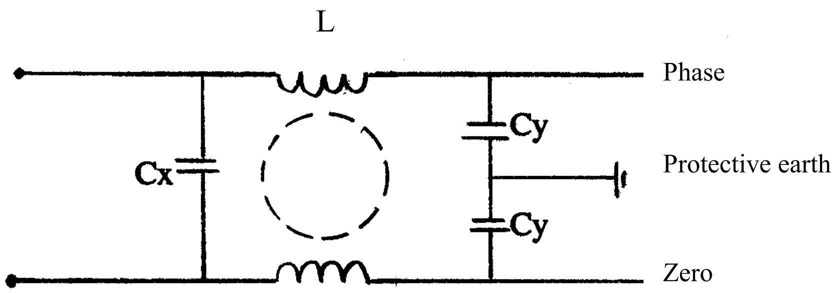

Figure 3.1

The C_x capacitor ensures the filtering of the balanced signals, while the current compensated L choke and the C_y capacitors suppress the unbalanced ones. The two windings of the L choke are directed in such a way that the currents of normal operation compensate each other's magnetic effect, preventing the core from saturation.

It can be observed in the circuit diagram that there is current flow via the C_y capacitors to the protective earth in case of normal operation. The magnitude of the permissible current is laid down in electric shock protection standards, setting stipulations for both the value and the breakdown strength of the capacitance.

By cascading several filters with different frequency bands such a filter can be obtained which is suitable for a wider range, and, in addition, it is less sensitive for the terminations.

The absorbing filters contain a lossy dielectric or magnetic material on the disturbance frequency. These materials convert the interfering signals into heat, and their operation is less dependant on the terminations. A well-usable version of these kind of filters is a mains wire constructed of cables featuring low-pass nature, which contains a jacket around the wires made of a lossy material.
Cables fitted with standard mains connectors containing reflective filters and overvoltage protection elements within the connectors themselves are already available.

6. Reduction of Radiated Interference

The propagation process of disturbance signals was introduced above. It was shown that interference can also be transferred without a galvanic connection. Such disturbances can be eliminated or suppressed by shielding. To evaluate shielding, the circumstances of the generation and propagation of the radiated disturbance signals must be analyzed. We identified the following coupling modes:

- capacitive coupling
- inductive coupling
- conducted electromagnetic wave
- radiated electromagnetic wave

Shielding attenuation is specified by the electric or magnetic field strengths occurring on the two sides of the shielding material:

$$S_e = 20 \log \frac{E_1}{E_2} \text{ ; dB,}$$

$$S_h = 20 \log \frac{H_1}{H_2} \text{ ; dB.}$$

The shielding attenuation depends on the resultant effect of three factors:

$$S = R + A + B$$

where R - is the return loss of the entry and exiting boundary planes of the shielding substance,

A - is the absorption attenuation in the shielding material,

B - is the effect of multiple reflections occurring between the two boundary planes of the shielding material (plate).

The return loss — as implied in its name — depends on the extent of the reflection of the electromagnetic waves. Its magnitude depends on how much the ratios of the electric and magnetic filed strengths of the electromagnetic fields outside and inside the material differ from each other. If the difference is big, the return loss is also big.

The absorption attenuation is the degradation of the magnitude of electromagnetic wave propagating in the shielding material due to the resistive losses of the substance.

The effect of multiple reflections must be taken into consideration because reflection occurs not only when the electromagnetic wave penetrates the shielding but also when it leaves the material. Obviously, if the return loss or the absorption attenuation are sufficiently high, the effect of multiple reflections is negligible.

For the cases mentioned in the introduction the following design considerations apply, which have also been proven in practice:

In case of capacitive coupling, very good shielding can be made of metals which have high conductivity. The size and shape of the shielding plate must be chosen in such a way that most of the electric filed lines end on the surface of the metal surface.

In case of inductive coupling the shielding must be made of a ferromagnetic material that features high permeability. For magnetic near fields this is the only substance that can be taken into consideration, which provides acceptable attenuation. The dependence of the ferromagnetic properties of the shielding on the direction, frequency and magnetic induction may cause problems is this case. Designing of such shielding requires good professional skills.

In case of conducted electromagnetic waves the combination of the above two methods must be applied. Often increasing the distance between the wires leads to a simpler and more effective solution in such cases.

For radiated electromagnetic waves, the ratio of the electric and magnetic field strengths in the air is 377 Ohms. A proper shielding can be made of wires that feature good conductivity, but special care must be taken on the implementation. Exclusively closed metal boxes assembled with adequate galvanic connections provide such an attenuation that corresponds to the properties of the material. Openings on the box and cables fed thru degrade the shielding attenuation by several magnitudes.

7. Device Design Principles

The emitted disturbance level and susceptibility of the devices is laid down in standards. The stipulated levels were specified in such a way that the level designated as compatibility band in the figure below provides sufficient protection in most of the practical cases.

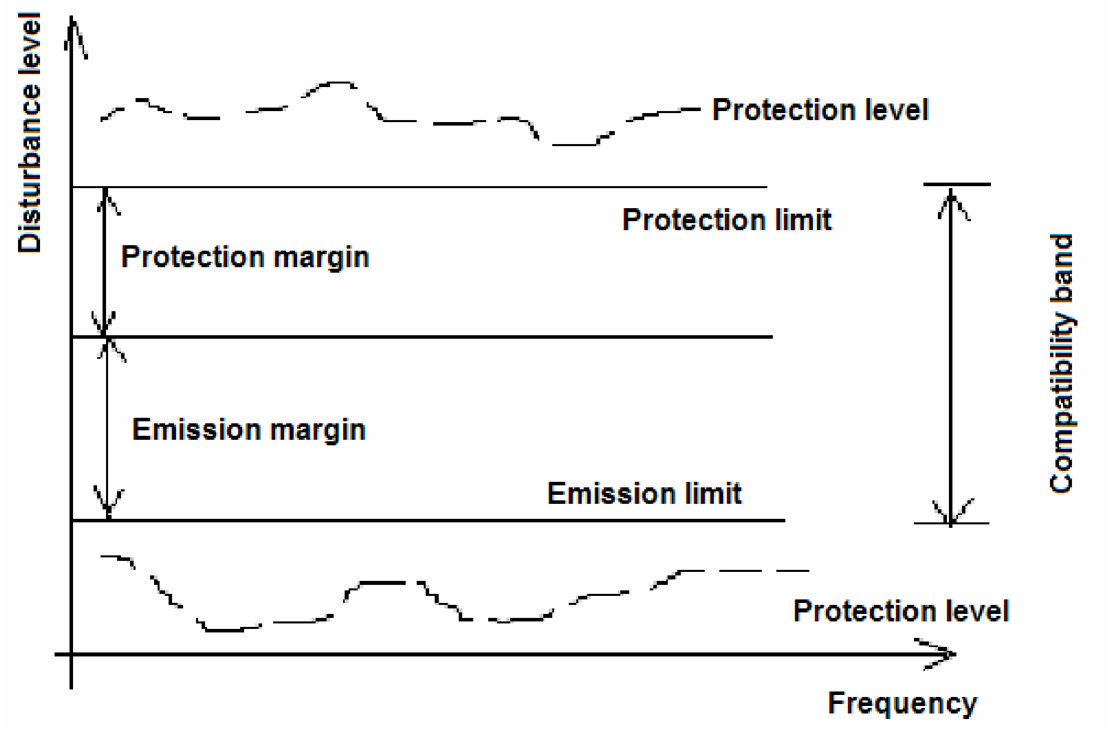

Figure 5.1

8. EMC Measurements

EMC measurements can be generally classified into two groups:

-disturbance susceptibility measurements

-disturbance emission measurements

Conducted and radiated disturbances can be investigated in both cases.

In case of susceptibility measurements a standard signal is fed to the device under test (DUT) with a proper coupling unit, and the changes of the DUT's operation is observed. In case of disturbance emission measurements the magnitude of the interfering signal (current, voltage, field strength) is measured by a frequency selective device.

A fundamental problem during EMC measurements is that the waveform (disturbance) to be investigated is completely unknown. Depending on the waveform, the different detectors (PEAK, RMS, AVERAGE, Quasi Peak – QP) indicate highly different values. For example, in case of periodic impulse signals the indicated values are as follows:

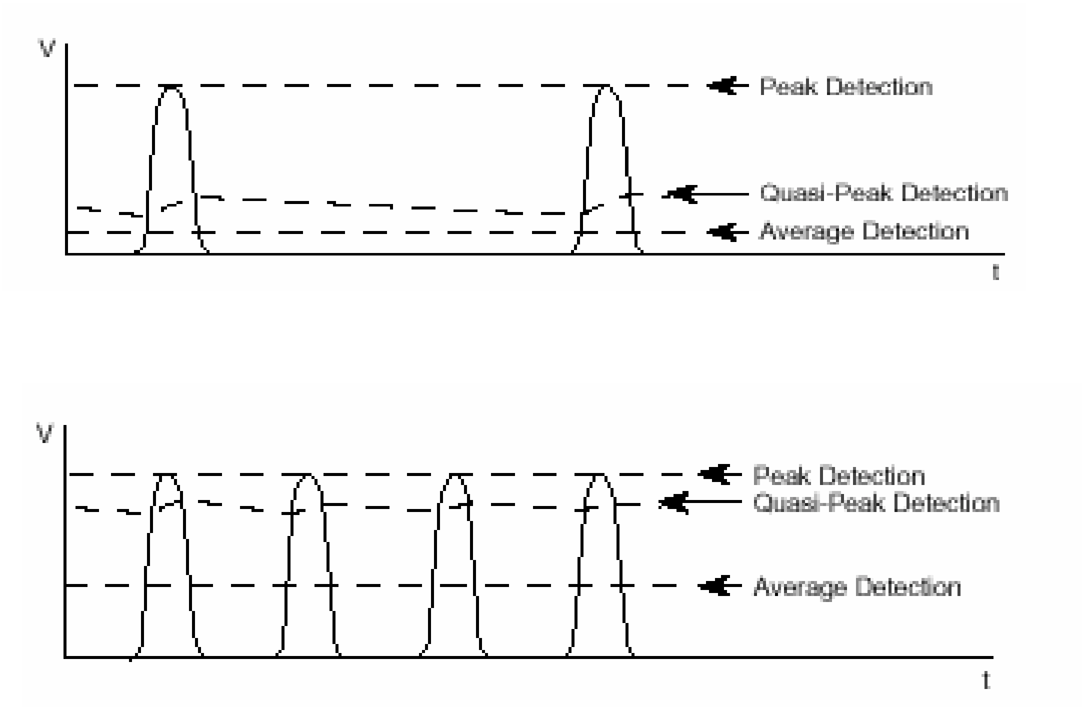

Figure 6.1

Quasi-Peak (QP) detection is performed by a circuit depicted in the figure below:

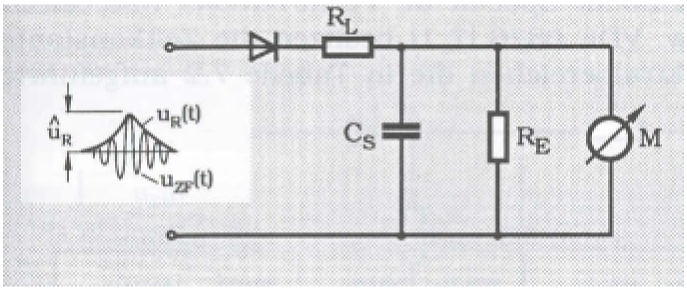

Figure 6.2

	9 kHz-150 KHz	150 kHz-30 MHz	30 MHz-1 GHz
Bandwidth	**200 Hz**	**9 kHz**	**120 kHz**
Time constant of the QP detector	**45/500 ms**	**1/160 ms**	**1/550 ms**

The standards specify limit values for two types of detectors (QP and average) to overcome the above problem. The DUT must comply with both limits.

Homework:

1. Repeat what you have learned about transmission lines (characteristic impedance, reflection coefficient, standing wave ratio, etc.).
2. Repeat what you have learned about wave propagation (the field of a resonant dipole, near field, far field, free space attenuation, etc.).
3. Study the operating principle of the QP detector.
4. Determine how the values indicated by the peak and QP detectors are related to each other for sinusoidal signals.

Self-test Questions

1. What is the definition of path attenuation?
2. Write down the equation of free space attenuation.
3. What is the definition of antenna gain?
4. What is the near and far field of an antenna?
5. How is the voltage reflection coefficient defined?
6. How is the voltage standing wave ratio defined?
7. What is the EMC compatibility band?
8. What is a current compensated choke?
9. What coupling modes exist in EMC tests?
10. What is the fundamental principle of the QP detector?
11. How do the disturbance signals reach the disturbance receiver?
12. When do disturbances propagate by galvanic coupling?
13. When do disturbances propagate by capacitive coupling?
14. When do disturbances propagate by inductive coupling?
15. When do disturbances propagate as conducted electromagnetic waves?
16. When do disturbances propagate as radiated electromagnetic waves?
17. What is the definition of shielding attenuation?
18. What is the shielding attenuation dependent on?
19. How do reflection type disturbance filters operate?
20. How do absorption type disturbance filters operate?

Obligatory Tasks

1. Study the EMC devices with the supervisor teacher. Get acquainted with the most important controls, as well as with the automatic and manual operating modes.
2. Get acquainted with the EMC measurement accessories (antennas, near filed probes, current transformers, TEM cell, etc.).
3. Investigate the radiated and conducted disturbance emission of a DUT.
4. Having removed the housing of the DUT, estimate the shielding attenuation by a repeated measurement.
5. Identify the most significant interference sources within the DUT using near filed probes.
6. Measure the immunity of a DUT against radiated and conducted disturbances.

Optional Tasks

7. Repeat the conducted interference measurements after inserting a network filter.

8. Compare the measured values with the limit levels of the standards and evaluate the result.