Exercise 3.

Electromagnetic Compatibility (EMC)

Aim of the measurement

Measurement of conductive, inductive and capacitive coupling.

Test of power line filter.

Keywords

EMC, conductive coupling, inductive coupling, capacitive coupling, line filter.

References

[1] L. Schnell: *Technology of electrical measurements. John Wiley & Sons, 1993.*

[2] Schurter AG: *Power entry modules with line filters*

Measurement instruments:

Oscilloscope	Agilent 54622A
ARB generator	Agilent 33220A

Test panel

No VIK-II-03 for demonstrating of different couplings. See Fig. 10.

Line filter: Type CD11.4599.151.

Theoretical background of the measurement

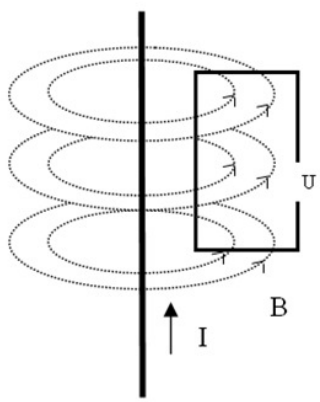
During the exercises we use the following procedure

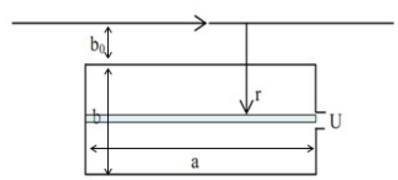
- We prepare the physical model of the measurement task
- Based on the model, we estimate the value of the later measured parameters
- Based on the results of the estimation, we choose a measurement procedure and instrument
- After the measurement we compare the measured and the estimated values
- In case of a difference is observed, we search for mistakes in the model or in the procedure

In the followings we sum up the simplest physical models for the measurement tasks.

Inductive coupling

The simplest model of inductive coupling is the rectangle formed loop parallel to a conductor of infinite length. In this case the time varying current flowing in the conductor induces time varying magnetic field in the loop which, based on Lenz's law, induces voltage in the loop. Therefore current is flowing in the closed circuit. The induced voltage in the loop is equal to the time derivative of the flux in the loop. Based on the relation of the following Fig.1., in case of sinusoidal current source, the induced voltage is directly proportional to the amplitude of the source current, and the constant of proportionality is called mutual inductivity. During the calculation of the induced voltage we took into consideration that the magnetic field has cylindrical symmetric property.





$$U = j\omega\Phi = j\omega \int_{b_0}^{b_0+b} B(r)\, a\, dr = j\omega \int_{b_0}^{b_0+b} \mu_0 H(r)\, a\, dr = j\omega \int_{b_0}^{b_0+b} \mu_0 \frac{I}{2\pi r}\, a\, dr = j\omega \frac{\mu_0 I\, a}{2\pi} [\ln r]_{b_0}^{b_0+b}$$

Fig. 1. Model of the inductive coupling

The measurement is carried out on the EMC-M block on the upper part of the test panel visible on Fig. 10. The current inducing the *I* disturbance signal flows in the outer loop, the interference voltage is measured on the two inner loops. The enclosed area of the inner loops are different, thereby we can measure how the geometry influences the coupling. The coupling is calculated between the four sides of the outer loop and the enclosed areas of the inner loops using the simple model on Fig. 3-1.

During the measurement the outer excitating coil is deemed to be four separate wires. The voltage drop on the inner loop is calculated as the correct signed superposition of the four standalone excitations. The electronic substitution for the measurement is given by the combination of the four excitations, as visible on the following figure.:

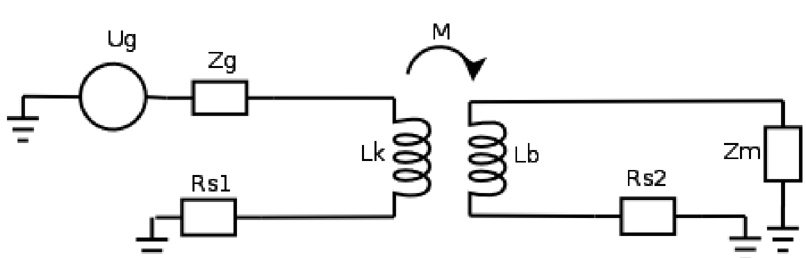


Fig. 2. Substitution of the inductive coupling for the measurement

Where

Ug - is the idle voltage drop of the generator

Zg – is the output impedance of the generator

Lk, Lb – are the inductivity of the outer and inner loop respectively

Rs1, Rs2 – are built in resistors on the panel

Zm – is the input impedance of the voltage meter

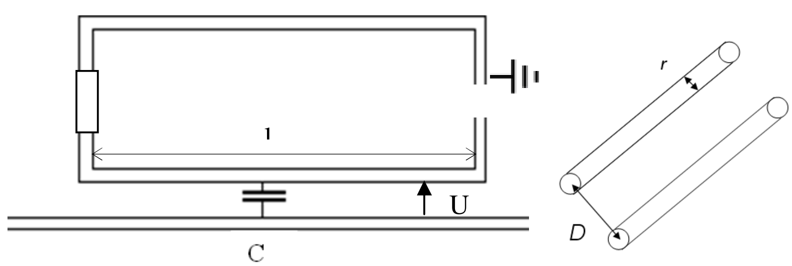
M – is the resultant mutual inductivity

Pay attention!

During the measurement care must be taken, that the measured coupling method is the dominant!

Capacitive coupling

In the case of capacitive coupling, electric field is generated between the wires, due to the voltage drop between the different parts of the electric circuit. This voltage drop causes the flow of displacement current, so the arrangement behaves as a capacitor. The magnitude of the current depends on the voltage drop, so the phenomenon will be decisive at higher levels of voltage. For the physical model the existing capacitance should be determined using the arrangement on the following figure. Capacitors exist between the other wires of the inner loop, but the marked one gives the dominant part of the coupling.



$$C = \frac{\pi \varepsilon_0 \varepsilon_r}{\ln \frac{D}{r}},$$

Fig. 3. Model of the capacitive coupling

The field lines of the parallel wires with rectangular cross-section, that can be seen above, resemble to the field line distribution of the well-known Lecher wire. For the estimation we should use the relation for the length per unit of capacitance (F/m) of the Lecher wire. Underneath the printed circuit lines, dielectric with finite thickness, above them air can be found. Using the above mentioned relation for calculations, capacitance is smaller in air and greater with dielectric filling out the whole space, than in reality. The best upper estimation is the arithmetic average of the two calculations.

The measurement is carried out on the EMC-C block on the center of the test panel visible on Fig.10. The voltage drop, that causes the disturbance signal, can be measured between the closest wires of the outer and inner loops. The disturbance voltage is measured in the two inner loops. The coupling capacitor should be calculated for the 'l' length, shown on Fig.3. On the right side loop of the EMC-C block on Fig.10. the effect of the separated grounded shielding can be examined.

The electric substitution can be seen on the following figure:

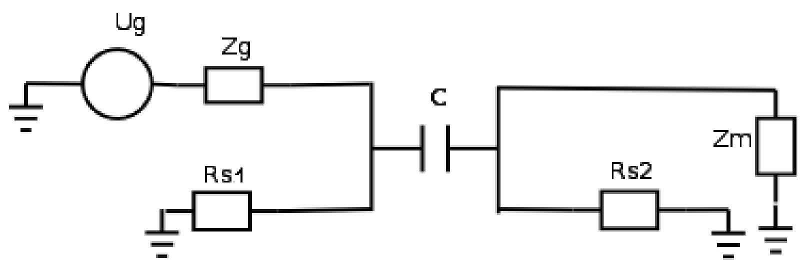


Fig. 4. The measurement substitution of the capacitive coupling

Where

Ug – is the idle voltage drop of the generator

Zg – is the output impedance of the generator

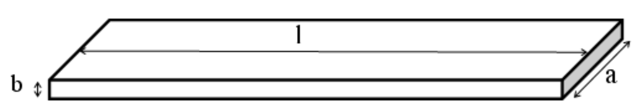
Rs1 Rs2 – are the built in resistors on the panel

Zm – The input impedance of the voltage meter (The instrument is connected to the measure point by a cable!)

C – is the coupling capacitance

Galvanic coupling

In case of galvanic coupling the two circuits share a common wire. This can be a shared ground or power line. The physical model of the coupling impedance is a resistor.



$$R = \rho \frac{l}{a \cdot b}$$

Fig. 5. Model of the galvanic coupling

The measurement is carried out on the EMC-G block of the test panel seen on Fig.10. The source of the disturbance is the shared wire between the inner and outer loops on the left side. The inner loop on the right side has no such part. The disturbance voltage is measured in the two inner loops. During the measurement of the loop on the left side the measuring points cannot be grounded.

The electric substitution can be seen on the following figure.:

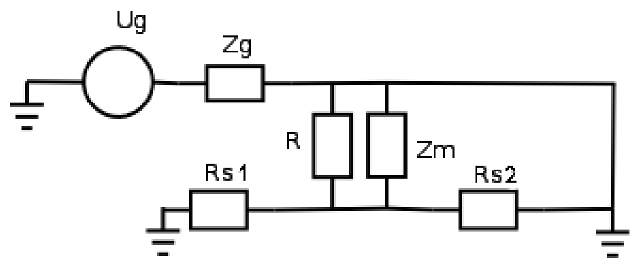


Fig. 6. The measurement substitution of the galvanic coupling

Where

Ug – is the idle voltage drop of the generator

Zg – is the output impedance of the generator

Rs1 Rs2 – are the built in resistors on the panel

Zm – The input impedance of the voltage meter (The instrument input can not be grounded!)

R – is the coupling resistor

Pay attention!

During the measurement care must be taken, that the measured coupling method is the dominant!

Power network filters

Inside an electric device disturbance signals are present due to the coupling methods explained before. The most common case is when the disturbance appears on the power supply lines, which propagates through the power network to the other connected electric devices as well. The power network filters were developed to prevent this exact phenomenon. In case of the most common single-phase supply method, three cables should be filtered (line, neutral, ground), due to the fact that disturbance currents can flow on the normal supply lines (line-neutral), and on the ground as well.

Disturbances can always be separated into a differential mode, i.e. symmetric (line & neutral), and a common mode, i.e. asymmetric (line + neutral & ground) component. Therefore the network filters can be given for two cases.

The schematic of the filter can be seen on the following figure.

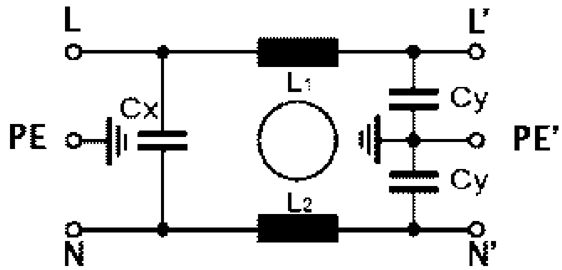


Fig. 7. The schematic of the network filter

L1, L2 coils are reeled on a shared ferrite core and the course is set in a way, that the symmetric currents do not magnetize the core. Therefore the ferrite do not saturate due to the currents flowing during normal operation mode. From this we can conclude that only L1 - L2 = Lsz inductivity affects the symmetric currents, which is a result of inaccuracy during manufacturing. Based on this, the model is the following:

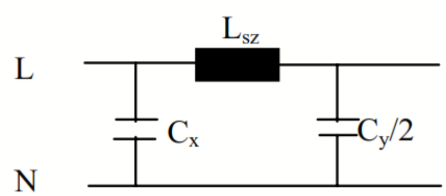


Fig. 8. Symmetric model of the network filter

Model for the asymmetric disturbances:

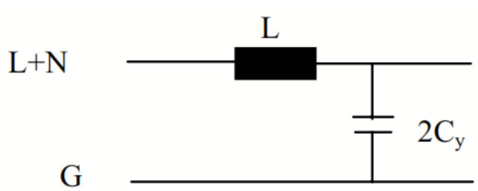


Fig. 9. Asymmetric model of the network filter

In this case Cx capacitances has no effect, since they are short circuited and L = L1 = L2

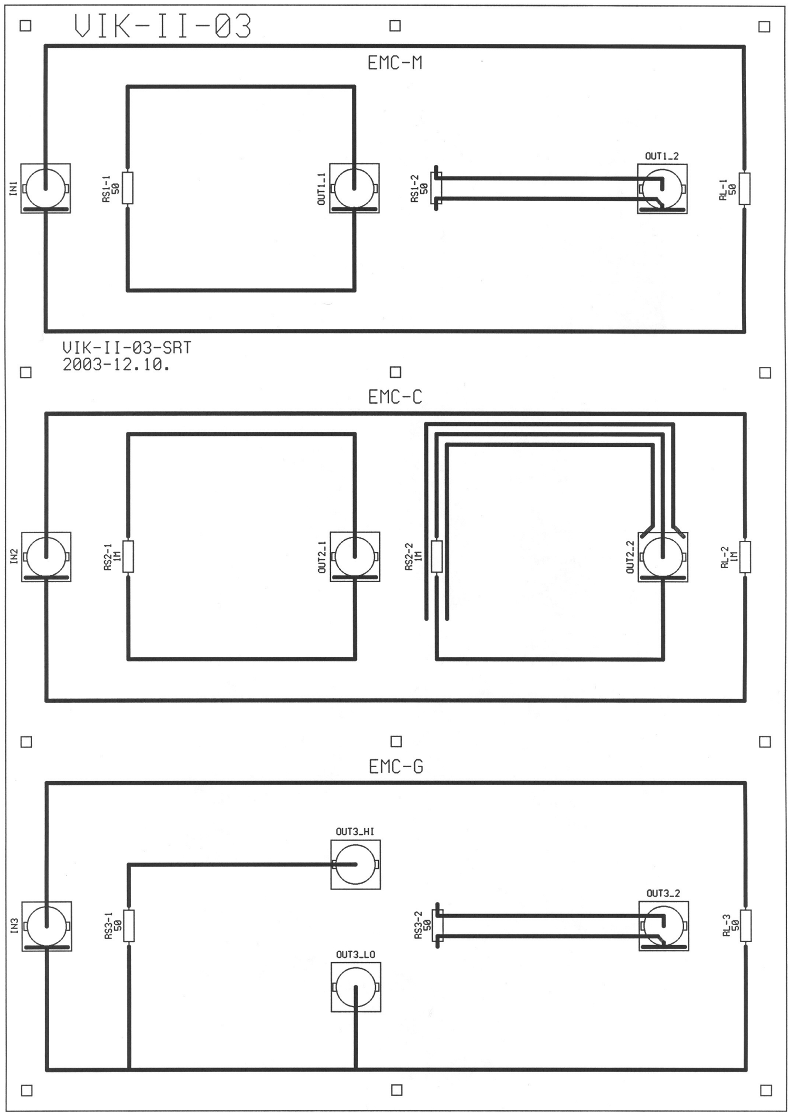


Fig. 10. Test panel No VIK-II-03

Laboratory exercises

1. Measurement of inductive, capacitive and conductive coupling

1.1. Calculate the mutual inductances between the loops for the two configurations! (See EMC-M in Fig. 10!)

1.2. Measure the inductive coupling at 10 MHz!

1.3. Calculate the stray capacitances between the tracks for the two configurations! (See EMC-C in Fig. 10!)

1.4. Measure the capacitive coupling at the optimal frequency!

1.5. Calculate the conductive coupling between the two loops for the two configurations! (See EMC-G in Fig. 10!)

1.6. Measure the conductive coupling at the optimal frequency!

The copper foil is 52…58 µm thick, width of track is 1mm ± 10%. The PCB is 1.6 mm thick, relative permittivity is 4.7.

2. Test of the line filter

2.1. Using Reference [2], calculate the stray inductance of the line filter for symmetrical signals at 1 MHz!

2.2. Calculate and measure the damping of the line filter for asymmetrical signals at 0.1 and 1 MHz!

Note, that the damping of the built-in impedance matching unit is 4 dB!