# Electromagnetic interference and environment

Frantisek Hruska

***Abstract*—**Electromagnetic fields have a big influences into environment. Aspects of electromagnetic inference cover very specific area. There are monitored in the field to the frequency of 100kHz. Electromagnetic interference is often electrically very powered e.g. in nearly power lines 50 Hz and influences functions of neighboring electrical instruments, data transmission in metallic cables as well as effects at living organisms. These influences are measured separately as electric field and as magnetic field. Significant there is understood of theory of these fields as well as using of modern software applications for modeling and simulation. Continuation of electromagnetic fields solves problems of electromagnetic wave in range of frequency above 100 kHz and until 60 GHz.

***Keywords*—** electric field, magnetic field, electromagnetic wave, interference, disturbing influences.

## I. Introduction

Electromagnetic interference (EMI ) is a process of emission and immission of electromagnetic field or electromagnetic radiation. Emission generates electromagnetic field or radiation from electric devices or electrical lines into free space. Immission is state of environment where is created field and accordance with concrete conditions this field affects other electrical equipment. Quality of electrical arrangement is given by electromagnetic compatibility ( EMC) namely by generating of electromagnetic field, i. e. electromagnetic interference and by immunity of electrical devices from this field , i. e. electromagnetic susceptibility. [2, 3]

Range of frequency for electromagnetic field is 0- 100 kHz and for electromagnetic wave is above 100 kHz namely till 60 GHz and higher.

Sources of EMI are established generally by electrical arrangement (generators, transformers, changers, switches) or electric devices (sources, consumers of LV, automation elements, light sources). Source of EMI can also be system producing electrostatic charge, atmosphere at thunderbolt. Next specific source of EMI is radio and television transmission and wireless communications and nets.

Coupling between elements of EMI is realized by cable as galvanic structure or in environment as capacitive or inductive structure. General view on EMI shows fig.1.

Problem EMI can be displayed universally as a negative way influencing correct function of electrical arrangement and instruments, when isn't well solved. In the history of expansion of techniques some accident implications can be found e.g. mistakes in the army, in the industry and other

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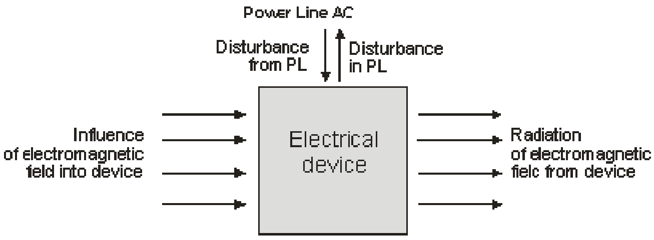



Fig. 1 Scheme of systems of intelligent buildings

## II. Theory of electromagnetic induction

Electric field can have character of stationary or alternate field. Unit is the V/m. Theory of electric direct field is described by interaction two charged elements accordance with fig.2 by the help of power effects.

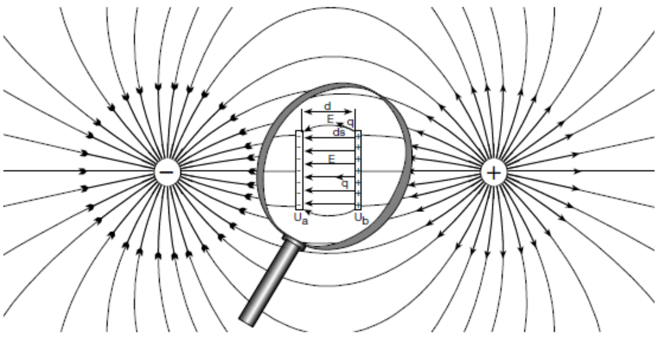


Fig. 2 Scheme of power effects of electric field

Power effecting between charges is :

$$F = \frac{1}{4\pi\varepsilon}\frac{Q_1 Q_2}{r^2} \tag{1}$$

where total permittivity ε is multiplication of permittivity of vacuum $\varepsilon_0$=8,854187818.10$^{12}$ (F/m) and of environment $\varepsilon_r$ , $Q_{1,2}$ are charges of elements and r is distance of ones.

Intensity of electric field is given by formula:

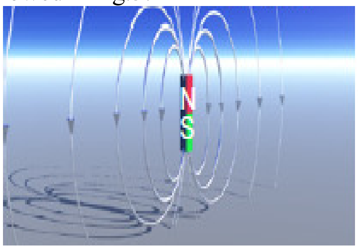
$$E = \frac{F}{Q_1} \tag{2}$$

The intensity of electric field on electrodes is given:

$$E = \frac{(U_a - U_b)}{d} \tag{3}$$

where is $U_i$ voltage potential and d is distance of electrodes.

Magnetic field of permanent magnet or around the line by current flow is showed in fig.3.

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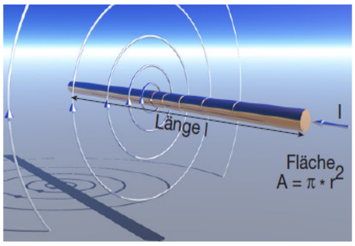


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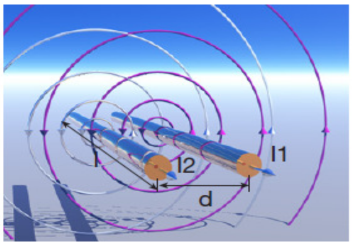



c)

Fig. 3 Pictures of magnetic fields (a-permanent magnet element, b-magnetic field around line of cable, c- magnetic field around two lines of cable)

Magnetic field is defined most frequently as magnetic inductance, B in unit Tesla or in the USA as Gaus. Electromagnetic inductance B for leader of longitude l is given by formula:

$$B = \frac{F}{I\ .l} = \frac{\mu I}{2\pi d} \qquad (4)$$

where is F applied power (N), I is passing current flow, L longitude of conductor, μ permeability of environment. Unit is Tesla or Gaus (T=1000G).

Field intensity for one conductor has formula:

$$H = \frac{I}{2\pi d} = \frac{B}{\mu} \qquad (5)$$

The power between two lines:

$$F = \frac{\mu I_1 I_2}{2\pi d} \qquad (6)$$

where is μ total permeability, $\mu_o$ permeability of vacuum 1,256.$10^{-6}$ (Vs/Am).

## III. Bindings between electrical devices

Bindings between electrical devices make EMI between source and receiver. Figure 4 shows the bindings.

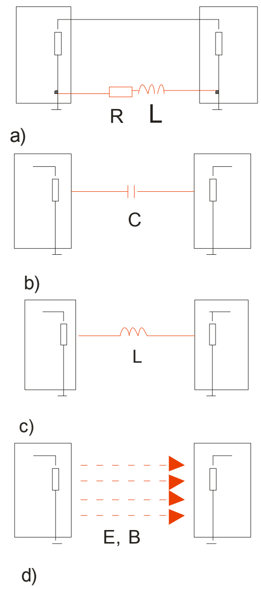
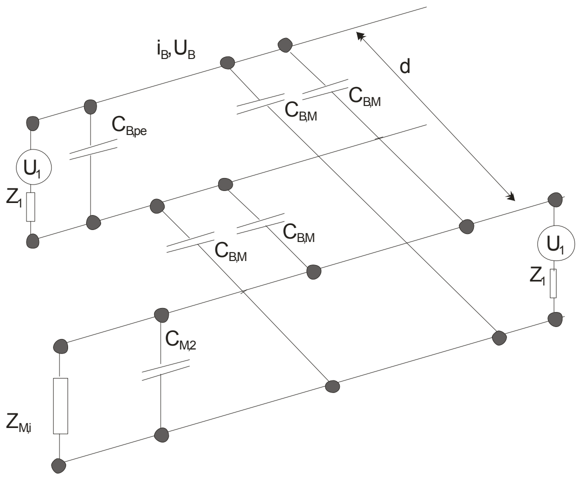



Fig. 4 Kind of bindings: a) galvanic, b) capacitive, c) inductance, d) by electric (E) and magnetic field (B).

### A. Capacitive bindings

Capacitive coupling is caused by existence of parasitic capacities between leaders (disturbing and disturbed) or between separate parts of loops or construction of arrangement. It is always at parallel leads of power, signal or data cables and lines, eventual at parallel leads of conductive tracks on printed circuit.




a)

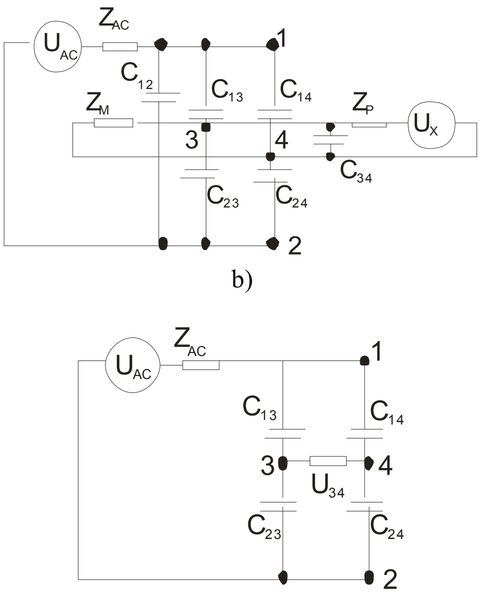



Fig. 5 Scheme of capacitive binding between source and receiver (a- electronic scheme, b- substitute scheme, c- simple substitute scheme)

After simplification of relations we can deduce formula for output interference voltage:

$$U_{34} = U_3 - U_4 = U_{12}.(\frac{Z_{32}}{Z_{132}} - \frac{Z_{42}}{Z_{142}}) \tag{7}$$

$$U_{34} = U_{12}.(\frac{Z_{32}}{Z_{13}+Z_{32}} - \frac{Z_{42}}{Z_{14}+Z_{42}}) \tag{8}$$

$$U_{34} = U_{12}.(\frac{1/C_{32}}{1/C_{13}+1/C_{32}} - \frac{1/C_{42}}{1/C_{14}+1/C_{42}}) \tag{9}$$

Calculation of capacity between lines is given if, the lines create pseudo - plate condenser by area $S=2r.l$, ( r is diameter of line, l is his longitude). We can write:

- According to Gauss law:

$$\oint \vec{E}.d\vec{S} = \frac{Q}{\varepsilon} = E\int_S dS = E.S \tag{10}$$

- Intensity of electric field:

$$E = \frac{Q}{\varepsilon.S} \tag{11}$$

- Voltage on capacitor:

$$U = \int_+^- E.ds = \int_+^- \frac{Q}{\varepsilon.S}ds = \int_0^d \frac{Q}{\varepsilon.S}ds = \frac{Q.d}{\varepsilon.S} = E.d \tag{12}$$

- Capacity of capacitor:

$$C = \frac{Q}{U} = \frac{Q.\varepsilon.S}{Q.d} = \frac{\varepsilon.2r.l}{d} \tag{13}$$

More accurately calculation we can do so, that we are thinking over potential on conductor A in point 1 as due of potentials from conductors A and B (see figure 7):

$$\Phi_2 = \Phi_{A2} + \Phi_{B2} \tag{14}$$

$$\Phi_2 = \frac{Q/l}{2\pi.\varepsilon}.\ln\left(\frac{1}{s-a}\right) + K_1 + \frac{-Q/l}{2\pi.\varepsilon}.\ln\left(\frac{1}{a}\right) + K_2 \tag{15}$$

$$\Phi_2 = \frac{Q/l}{2\pi.\varepsilon}.\ln\left(\frac{1}{s-a}\right) + K_1 + \frac{-Q/l}{2\pi.\varepsilon}.\ln\left(\frac{1}{a}\right) + K_2 \tag{16}$$

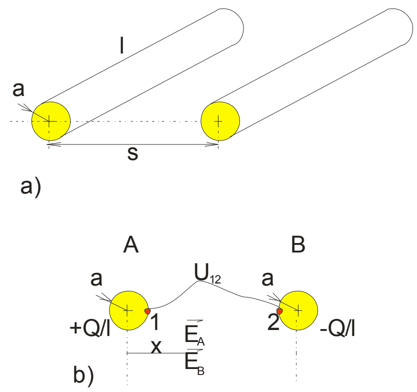



Fig. 7 Scheme of binding of two lines for calculation

Voltage between lines is differently of potential between points 1 and 2:

$$U = \Phi_1 - \Phi_2 \tag{17}$$

$$U = \frac{Q/l}{2\pi.\varepsilon}.\left[2.\ln\left(\frac{1}{a}\right) - 2.\ln\left(\frac{1}{s-a}\right)\right] \tag{18}$$

$$U = \frac{Q/l}{\pi.\varepsilon}.\ln\left(\frac{s-a}{a}\right) \tag{19}$$

Therefore is:

$$\frac{Q}{l} = \frac{C.U}{l} \tag{20}$$

so we can write:

$$\frac{C}{l} = \frac{\pi.\varepsilon}{\ln(s/a)} \tag{21}$$

result of electric field v point x has a formula:

$$E(x) = \frac{Q/l}{2\pi.\varepsilon}.\left(\frac{1}{x} + \frac{1}{s-x}\right) \tag{22}$$

and also is for voltage evaluating from electric filed:

$$U = \int_a^{s-a} E(x).dx \tag{23}$$

$$U = \int_{a}^{s-a} \left( \frac{Q/l}{2\pi.\varepsilon} . \left( \frac{1}{x} + \frac{1}{s-x} \right) .dx \right) \quad (24)$$

$$U = \int_{a}^{s-a} E(x).dx = \frac{Q/l}{\pi.\varepsilon}.\ln\left( \frac{s-a}{a} \right) \quad (25)$$

### *B. Inductive bindings*

Inductive bindings are found over magnetic field. Magnetic field can be rise by motion of charge or by alternation of electric field or by rise of magnetic inductance at current flow through line.

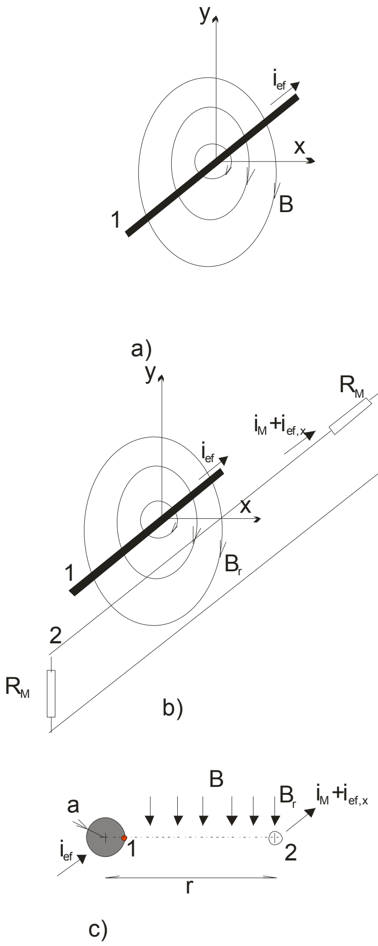



Fig. 8 Scheme of inductive binding of evaluation for calculation

Magnetic field defined by magnetic inductance B accordance with relation for distance x comes up about conductor with current flow $i_{ef}$ (with $U_{rms}$ and with frequence 50 Hz):

$$B_x = \frac{\mu.i_{ef}}{2\pi.x} \quad (26)$$

Induction flux is described Φ in flat S pays quadratic:

$$\Phi = B.S.\cos\phi \quad (27)$$

where is $B_{ef}$ effective value of alternate magnetic inductance by sine - wave frequence e.g . 50 cps (B.cosφ).

In distance r from conductor 1 there is loop of measuring circuit with conductor 2. Changes of magnetic field produces voltage $U_2$:

$$U_2 = -\frac{d\Phi}{d\tau} = B_{ef.r}.S_v \quad (28)$$

where is $S_v$ area of line 2, $B_{ef,r}$ is magnetic induction.

This induced interferential voltage is added to measuring voltage $U_M$ and presents changes $U_x$.

## IV. Connection with Measurement Loops

Scheme of generating of disturbing harmonic voltage and their incidence on measuring circle is showed in fig.9. Source of data signal has voltage $U_m$ and it is carried over signal in unit A2 with load resistance Ri of unit of signal processing and carry over signal give upon input device A2 load angle resistance Ri troop for signal processing. Power phasic lead uses electric current $I_{inter}$ about voltage $U_{inter}$. Power control interferential field functions over capacity coupling C1,C2 on signal lead. Magnetic interferential field B1 is transformed to the signal circuit. This harmonic disturbance forms disturbing series mode voltage $U_{SM}$ and common mode voltage near$_{CM}$.Influences of differences of earth current rises another disturbing harmonics tension , which adds to conformable voltage $U_{CM}$. On input device there are disturbing voltage superposed on voltage measuring signal $U_{la}$.

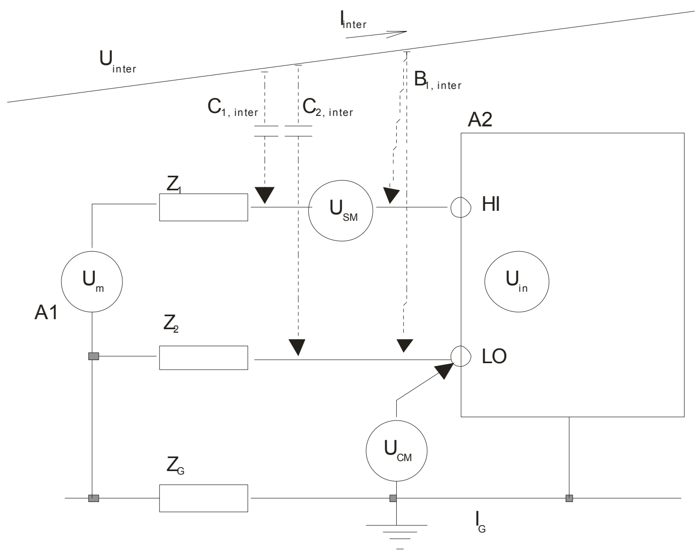



Fig. 9 Influence of interference voltage to measured signal

Factor of common mode disturbance CMRR (common mode rejection reduction) is defined by:

$$CMRR = 20.\log\frac{U_{CM}}{\Delta U_X} \tag{29}$$

where is $U_{CM}$ common mode voltage, $\Delta U_x$ change of input voltage from common-mode voltage

Factor of serial disturbance SMRR (serial mode rejection reduction) is:

$$SMRR = 20.\log\frac{U_{SM}}{\Delta U_X} \tag{30}$$

where is $U_{SM}$ voltage of serial disturbance, $\Delta U_x$ change of input measured voltage $U_{SM}$.

Very important aspect at composition of technical means there is electric parameters of binding periphery it is output and input of following element. At those structures correct voltage level, kind of voltage, correct output and input impedance of interconnected periphery and frequency characteristic have be realized. Diagram of all connection is showed in fig 10.

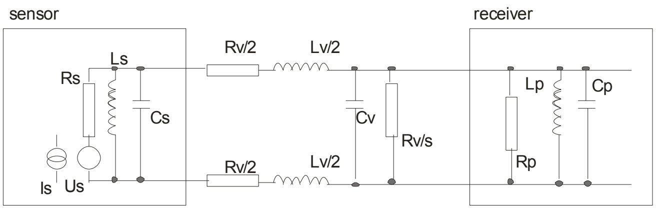



Fig. 10 Scheme of connection of sensor and receiver

In industrial conditions effects on system resources electric disturbing influences, there are first: harmonic disturbance (interference inductive, capacitive), transient disturbance (pulsed short - term and quick changing from atmospheric discharge and electrostatics) and fluctuating (earth current, changes of transitional resistances, drift of electronics, noise). Bindings of electromagnetic disturbance features general figure 5 and transient effect figure 6.

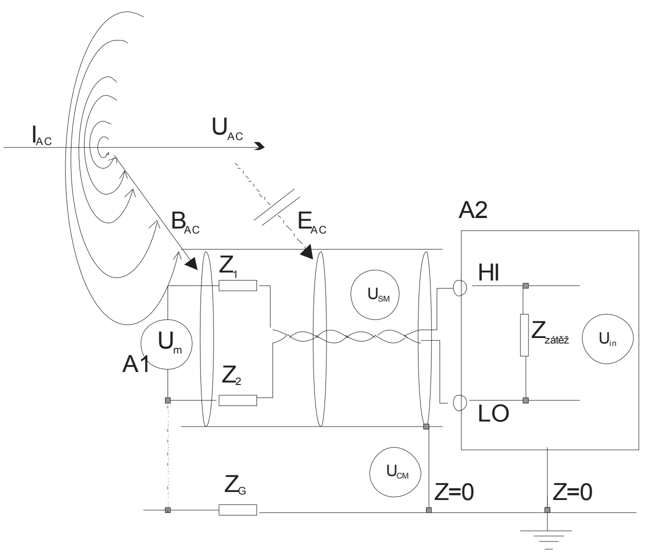



Fig. 11 Scheme of disturbance influence of electric and magnetic field and earth currents

## V. Transient influences

Transient is a change in the steady-state condition of voltage, current, or both. Transients are categorized as either impulse or oscillatory.

These transients typically have a fast rise time, a fairly rapid decay, and a high energy content, rising to hundreds and even thousands of volts. Their duration can be from a few microseconds up to 200 microseconds.

Oscillatory transient is sometimes called as a ring wave transient. This type of disturbance has a fast rise time, oscillations that decay exponentially, and lower energy content than impulse transients (250V to 2500V). The frequencies can have from a few hundred Hertz up to many mega-Hertz of frequency. [6]

### *A. Sources of transients*

Source of transient can be the most lightning strikes and faults and then switching. As a elecrostatic voltage there is generated charge on our clothes.

This weather-related phenomenon is often thought to be the principal cause of most transients because it is known to strike overhead power lines. So, it causes problems in facilities having solid-state electronic equipment. While this is only partly true, you still must protect against lightning. A lightning stroke, which averages about 25,000A at 30 million volts, produces high currents in lines that take a direct hit. Only the lightning voltage and the impedance looking into the system limit the current in these cases. He real situation shows fig. 12.

As you can see, lightning can produce extremely powerful, short-duration transients either by a direct strike or a near miss. Maximum lightning voltages on unprotected indoor low-voltage systems are proportional to residual voltages on the primary power system, when primary arresters operate. Lightning on power lines is diverted to ground by arresters, sparking over to conduct the build-up of energy before damage occurs.

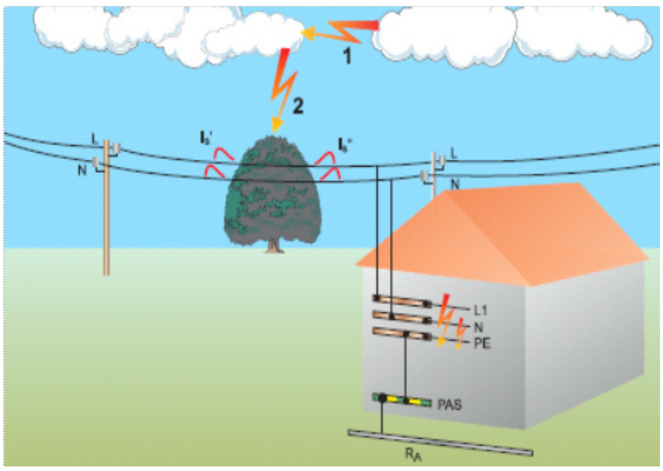



Fig. 12 Scheme of atmospheric transient influence

Switching of electric utility or onsite loads also causes transients of a magnitude depending on the instantaneous rate of change of current relative to time (di/dt).

Electrostatic deals with the phenomena and properties of stationary or slow-moving electric charges with no acceleration. Since classical antiquity, it has been known that some materials such as amber attract lightweight particles after rubbing. There are many examples of electrostatic phenomena, from those as simple as the attraction of the plastic wrap to your hand after you remove it from a package, to the apparently spontaneous explosion of grain silos, to damage of electronic components during manufacturing, to the operation of photocopiers. Electrostatics involves the buildup of charge on the surface of objects due to contact with other surfaces.

*B. Elimination of transient effects*

We can eliminate the problems of transient negative effects:

- Atmospheric effect with a specific equipment
- Static electric with connection the device with earth connection.

The base elements used to escape voltage or current by transient process there are gas tubes, varistors, zener diodes and suppressor diodes. The table 1 has contented its main parameters:

Table 1 Parameters of base elements of transient protection

| | Gas tube | Varistor | Zener diode | Suppressor diode |
|---|---|---|---|---|
| | | | | |
| Protected voltage | <12000 V | <2000 V | 2….200 V | 6…..220 V |
| Current in time 1 ms | 500 A | 120A | 10 A | 200 A |
| Max absorbed energy | 60 J | 2000 J | 0,1 J | 1J |
| Power loading | 800 W | 2 W | 50 W | 5W |
| Capacitance (pF) | <10 pF | < 40000 | <15000 | <15000 |
| Reacting time | >1000 ns | 25 ns | 10 ns | 0,01 ns |
| Application | rude | rude | fine | fine |

Equipment of over voltage protection is produced in different kind and wiring. It depends on place a kind of application. The application of the first degree (input switch-board od power line) has be used rude element, gas tube or with varistor. The example is showed in fig. 13. There are three group of tubes and varistors for ever power line L1, L2, and L3. The N wire is connected with PE wire with helping next group gas tube and varistor.

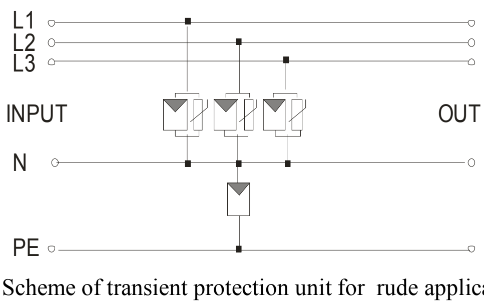



Fig. 13 Scheme of transient protection unit for rude applications

The protection unit for example for measuring loops or date communication line (LAN, RS485) uses regularly some fine elements. Scheme is in fig. 14 for a loop of analog signal (0-10V DC) and in fig. 15 for communication loop of coax cable.

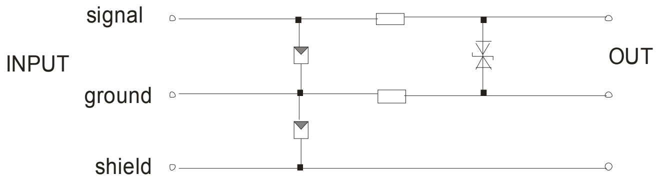



Fig. 14 Scheme of transient protection unit for analog signals

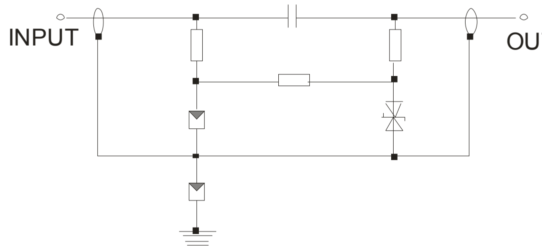



Fig. 15 Scheme of transient protection unit for coax cables

## VI. Measurement of Electromagnetic Fields

There is difference in metering of electromagnetic field of low frequence (up to the 100 kHz) and radiation of higher frequency (from 100 kHz to tens GHz).

Good experience is on devices of firm f GIGAHERTZ, Germany. It can be measured home devices, office techniques, supplies, lights, inductive machine and motors. [4]

( http://www.gigahertz solutions.de)

Apparatus measures intensity of alternate of electric field and magnetic induction. Measuring principle of electric field is indirect measurement of charge on measuring capacitor. Measurement of magnetic field is by the help of measuring coil.

Inductive methods of measurement of magnetic flow use Faraday law of electromagnetic induction, which describes inception of electromotive voltage on coil by time changing of magnetic flow of flat coil. Induced electromotive voltage $U_m$ equals with negative change magnetic inductive flow:

$$U_m = -N\frac{d\Phi}{d\tau} = -N.S\frac{dB}{d\tau} = -\mu.N.S\frac{dH}{d\tau} \qquad (31)$$

where is F magnetic induction flow through coil, N is number of winding, S area of coil, B magnetic induction, H field intensity, m permeability of coil.

Kernel of coil is produced from material with high permeability and then there is big growth of induced voltage Um.

Offer apparatus for filed LF is in range:

- 16Hz as far as 2kHz as narrowest range of frequency
- 5Hz as far as 100 kHz as middle LF range
- 5Hz as far as 1MHz as big range of frequency.

Other options of measurement are offered from the firm CHAUVIN ARNOUX [9] . They make use of principles of force measuring acting among charges and measuring cops for magnetic field. Measuring range is after type sensing head from 10Hz as far as 30 kHz or 5Hz as far as 400 Hz. Electric field is measured from 1 to the 30 000 Volt/m, magnetic field from 10 nT to the 1T.

The measurement of high frequencies is a special part. It is solved e.g. by NASA (for satellites). There are developed some special MEMS sensors KMY24 using Doppler´s principle [5, 7, 8]

## VII. Electrical Smog

Electronic smog is generated by electric, magnetic fields and electromagnetic radiation in space. The influence effects on organisms of all live subjects. Results of studies exist, they describe unhealthy influence over metabolism, heart activities, circulatory system, endocrinology system and central nervous system. [2,1]

Influence over activity on technical means above all electronic is known and is solved in frame of laws about electromagnetic compatibility.

First of all with expansion of techniques there is incidence of magnetic field and electromagnetic radiation of instrument using power electric voltage 50 Hz and from electromagnetic energy of frequencies from 100 Hz to orders of GHz fundamentally increased.

Main generator of electrical smog is electric voltage and electric current in ours proximity. These are e.g . cable electric lines in house in walls, outside lines HV and VHV on pylons, domestic apparatus in kitchen, lighting , apparatus TV, radio, PC, mobiles, cable of the Internet, power apparatus such as electric water heater, electric stove and kettle, wireless communication, in industrial halls electric motors and technological equipment.

The next table shows the data of magnetic and electrical fields measured in the town environment. The measurement was made in level of man body.

Table 2 Typical and peak values of electrical and magnetic fields for different areas

| Source | typical B (μT) | peak B (μT) | typical E (V/m) | peak E (V/m) |
|---|---|---|---|---|
| HV lines | 2 – 2,5 | 9 | 1000 | 7000 |
| Trolley line 13/11kV– 60/25 Hz | 3,5 | 30 | 350 | 700 |
| Transform-device | 1,5 – 2,5 | | | |
| Power line of 240/120 V | 0,5 – 1 | 10 – 20 | | |
| Supply line of family house | 0,1 | 0,4 | | |
| House grid | 0,05 – 0,1 | 0,5 – 1 | 1 – 5 | 10 |

Limits of stress of electrical and magnetic field for industry countries: (according to built biologist Maese, range of frequency 0-100kHz):

Table 3 Max values of electrical and magnetic fields for different areas

| | E, 50 Hz (V/m) | B, 50 Hz (nT) | E, DC (V/m) | B, DC (nT) |
|---|---|---|---|---|
| Standard DIN/VDE (citizen) | 7000 | 400000 | 10000 | 21200 |
| DIN/VDE (a man) | 5000 | 100000 | | |
| DIN/VDE (worker) | 10000-20000 | 500000-5000000 | 40000 | 67900 |
| Flat (standard) | 20-500 | 100-500 | 500-5000 | 1000-10000 |
| Flat recommend | 1-5 | 20-100 | 200-1000 | |
| Free environment | 0 | 0 | 20-200 | 45000-50000 |
| Storm | | | 2000-20000 | |

The standard values of magnetic and electrical fields have relevance to hygienic limits: the table 4.

Table 4 Limit values of electrical and magnetic fields for different abnormalities

| | Strong abnormality | Small Abnormality | without Abnormality |
|---|---|---|---|
| B, DC nT | 1000-10000 | 200-1000 | <200 |
| B AC nT | 100-200 | 20-100 | <20 |
| E AC V/m | 5-50 | 1-5 | <1 |
| | | | |

## VIII. Conclusion

Above the article describes the part of aspects of electromagnetic interference. Mainly there is the theory of its. Separately there is definition of electric field, magnetic field and then capacitive and inductive bindings of power lines and measuring lines.

In the future works there will be solved other aspects of electromagnetic interference and measured fields in several situations in environment. There will be studied the problems of electro smog too.

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