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UNCONVENTIONAL CABLE CONSTRUCTION POSSIBILITIES FOR ELECTROMAGNETICALLY COMPATIBLE APPLICATIONS

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Key words: Electromagnetic compatibility (EMC), electromagnetic shielding measurements on selected cables, transfer impedance.

Electromagnetic compatibility (EMC) is one of the most important phenomena from complex systems' reliability point of view. Omission of its requirements might possibly result in catastrophic consequences in medium to large scale manufacturing companies. High-frequency cable networks must comply with electromagnetic shielding regulations. Shielding must not only allow energy emission exceeding the prescribed value, but it must adequately protect the cables from external electromagnetic radiation. Shielding efficiency of signal and power cables as well is one of the most important parameters. Cable shielding or shielding guarantees the electrical properties and EMC and also embodies human health protection against electromagnetic radiation. Prescribed limits for electromagnetic radiation in buildings, or other interfering effects of transmission, distribution and signal networks are affected by the type and various components of cables used. Paper describes obtained transmission properties of cables made of unconventional construction materials.

1. INTRODUCTION

The shielding efficiency (IEC 96-0-1), especially of coaxial cables, was a very important topic in the 1970s and 1980s before the expansion of fiber-optic signal transmissions mostly because of the cable television network construction. In the early 1980s the importance of EMC arose, forcing the establishment of maximum emission criteria for all devices and equipment on the market. The attention weakened by the advent of optical cables with their undeniable advantages in the field of EMC.

The electromagnetic radiation impact on environment gradually become an extremely monitored factor. Concerns about the electromagnetic radiation of mobile networks as overall increase in EMI in densely populated areas grows, too. We dealt with these concerns more seriously for the first time during the era of the former Czechoslovakia, especially in terms of quantification of electromagnetic radiation and its impact on the human health in 1978. At that time, there was a demand to create recording devices, similar to radiation dosimeters, for radar operators. From the beginning of mobile phones expansion, there was an obvious and relatively strong electromagnetic coupling between phones and other electrical devices and receivers. The importance of EMC evinced special attention. Upon the European Parliament and Council Directive No. 2004/108/EC EMC applies to all electrical products manufactured or distributed within the EU.

Our workplaces at the Faculty of Electrical Engineering and Information Technology of the Slovak University of Technology in Bratislava and at the former Research Institute for Cables and Insulation Materials, today's company VUKI, a.s., are focused on cables and their accessories for more than half a century with special attention to electromagnetic compatibility.

2. SHIELDING EFFICIENCY

Cable shielding efficiency belongs to important technical parameters. In telecommunication technology attenuation of the near-end and far-end crosstalk were evaluated for really long time in history. It highlighted the twisted pair effect to minimize crosstalk between signals in neighbouring pairs in cables. Later on, shields in the form of common foil with attached wires were gradually added. For more mechanically resistant cable constructions braiding or wrapping with metal non-ferromagnetic tape (Cu) and ferromagnetic copper-plated tape (FeCu) are used.

Optimization of technical parameters enabled massive implementation of data networks using UTP, STP and FTP cables, as well as derived new types and designations. Nowadays, the EMC is highly actual for power and high-voltage cables as well. EMC project include required cable parameters, concept of their recommended and unsuitable laying – signal and power cables – as shown in project of 3rd and 4th block of Nuclear Power Plant Mochovce (NPP MO 3,4).

Shielding is relatively the most sophisticated topic within coaxial cables. The outer conductor, called shielding, forms the so-called coaxial pair with the inner conductor. The signal is transmitted in the space between them by TEM (transverse electromagnetic mode), from the waveguide technology point of view. The insulation is made of dielectric, most often solid or foamed polyethylene.

As known, at higher frequencies (above 50 to 100 MHz), due to the skin and proximity effect, only the surface of the inner conductor and the inner tubular part of the outer conductor participate in signal propagation. Therefore, only 0.030 mm thick copper metal layer is sufficient to enclose the electromagnetic field in the coaxial cable completely by these and higher frequencies. Practically the shielding can be formed applying a Cu layer to a PET (polyethylene terephthalate) film. A thickness of 0.045 mm for Al (aluminum) firmly connected with a PET foil, is also suitable. Conversely, for lower frequencies the thickness needs to be significantly increased to eliminate radiation.

3. SHIELDING EFFICIENCY MEASUREMENT

As mentioned, EMC is one of the main parameter of today's cables and wires. Cable test methods are given by several standards [1, 2]. The principle is based on measuring the coupling between an interfering and transferring cable, the signal attenuation in transferring cable or in the surrounding environment.

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Let's take a closer how to perform such a measurement. The tested cable is connected to a signal generator with adjustable frequency from a few Hz to hundreds of MHz. The cable sample during the measurement must be terminated by a characteristic impedance in order to avoid reflection forming which could significantly affect the measurement result. Figure 1 presents a schematic sketch of the transfer impedance measurement using triaxial method.

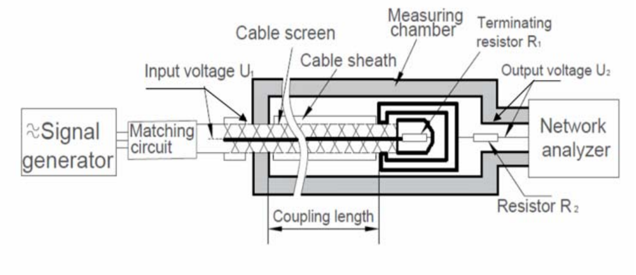

Fig. 1 – Connection for measuring transfer impedance Z_t .

Using triaxial test method the signal generator is connected to the inner circuit at the near end of cable and the outer circuit is connected to the network analyzer at the far end. In this connection is the influence of the capacitive coupling suppressed by the short circuits in the primary and secondary circuit. The method is very sensitive and suitable to measure also low values of the transfer impedance (values 1 μΩ/m and less). Its advantage is in sample's preparation simplicity, disadvantage is in the lower measured bandwidth.

If the measured cable is of symmetrical construction and consists of more cores under common cable shield, all cores are connected and a system similar to the construction of a coaxial cable is formed. The modified tested cable is terminated in the shielded chamber using termination impedance to avoid reflections.

The measuring chamber is made of electrically conductive material and simulates the surroundings of the measured cable as shown in Fig. 2. The source of interference is the measured cable's shielding, i.e. the signal that is not absorbed in shielding. The measuring chamber and the shielding of the interfering cable form a coaxial system again, which is connected to a selective voltmeter after suitable impedance adjustment. The active length of the measured cable emits signal-interference into the measuring chamber, is decisive for determining the value of transfer impedance.

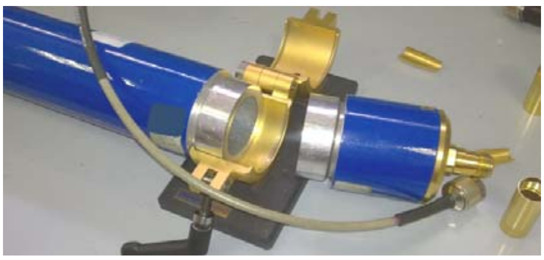

Fig. 2 – Apparatus for transfer impedance test using triaxial method.

Frequency change determines which part of signal emitted from tested cable enters the impedance adjusted measuring system which evaluates the transfer impedance. The measurement result is the frequency dependence of the transfer impedance *Zt*. It enables EMC project requirements comparison to obtained results and decide if it fulfills given criterion.

4. CABLE TYPES' EMC REQUIREMENTS

As mentioned, the EU Directive No. 2004/108/EC of electromagnetic compatibility has been in force since the end of 2004 for all electrical products manufactured or distributed in the EU [3]. It means, that all new systems must be designed and developed in compliance with EMC rules, and if the system is to be operated as electromagnetically compatible, all its elements shall, individually and in conjunction, guarantee the EMC.

Designers hold the responsibility for selection and placement of appropriate elements in projected device and for its interactions with surroundings as well. Moreover, experience is vital for a correct design, because wrong implementation of EMC measures might lead to failures or interference with other devices and failure's cause is hard to identify.

Tested cables, used in the construction of a nuclear power plant according EMC concept NPP MO3,4, are marked with the following abbreviations

Medium voltage (MV) cables	WH
Low voltage (LV) cables	WB, WL, WC, WD, WM
Communication cables	WR
Signal cables	WT
Coaxial cables	WK

Cables'transfer impedance requirements for selected frequencies are based on relevant EMC concept in Table 1 and 2. EMC immunity requirements are based on shielding impedance (*Zt*) values, which must be lower than the values in the table (values are given only for cables that provide signal transmission and may be disturbed or may disturbed the other cables due to poorly design).

Table 1

Max. Zt and resistance values for signal and control cables.

Frequency	Signal and control cables WR group Max. Zt (dBmΩ/m)	Signal and control cables WR group Max. resistance (mΩ/m)	Signal cables group WT Max. Zt (dBmΩ/m)	Signal cables group WT Max. resistance (mΩ/m)
100 Hz	20	10	12	4
1 kHz	20	10	12	4
5 kHz	20	10	12	4
10 kHz	23	14	14	5
100 kHz	32	40	24	16
500 kHz	38	79	30	32
1 MHz	44	158	36	63
10 MHz	64	1 585	55	562
100 MHz	84	15 849	77	7 079

EMC safety requirements are usually ensured by shielding, the effectiveness of which must meet the following parameters (Table 2).

Table 2

Shielding efficiency for cables.

Frequency range	Long distance cables	Cables for buildings installation	Distribution cables
0.15–1 000 MHz	> 85 dB	> 75 dB	> 65 dB
1 000–2 500 MHz	> 75 dB	> 65 dB	> 55 dB

5. TEST RESULTS

Several signal cables were chosen for transfer impedance testing. The first cable was of JXFOE-R 2×2×0.8 type. Its construction is shown in Fig.3.

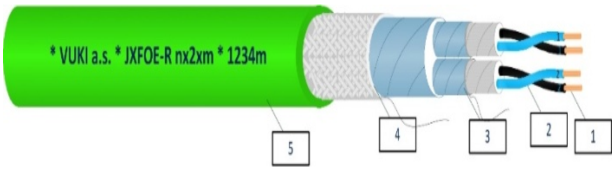

Fig. 3. – JXFOE R 2×2×0,8 cable construction.

Marked numbers on the cable construction stand for the following:

1. Core solid Cu;
2. Insulation crosslinked polyethylene;
3. Individually shielded pairs PET+AL PET tape with CuSn wire 0.8 mm + PET;
4. Collective screen Al PET tape rotated with a conductive part to the braiding + CuSn braid with a density of 80% with CuSn wire 0.8 mm;
5. Outer sheath HFFR green.

Figure 4 shows the frequency dependence of transfer impedance. The blue curve displays measured data, the red one shows the requirements given in EMC concept for WK cable.

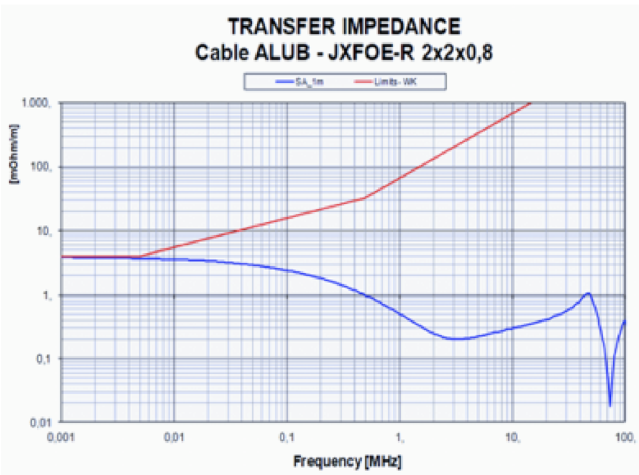

Fig. 4 – Frequency dependence of the cable transfer impedance JXFOE-R 2×2×0.8.

As seen in Fig. 4, the blue curve is below the red one, so the cable meets the requirements of the EMC concept within the entire frequency range from 1 kHz to 100 MHz.

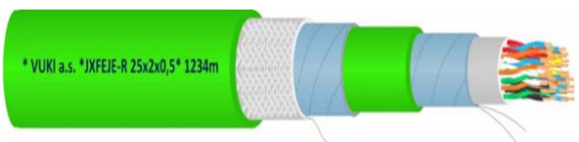

Fig. 5 – XFEJE-R 25×2×0.5 cable construction.

Next the results of type JXFEJE-R 25×2×0.5 follow. As seen from the marking, this cable contains 25 twisted pair conductors. Its construction is depicted in Fig. 5.

During the measurement all cores were connected together and terminated in compliance with the requirements of the coupling information measurement standard. Result is shown in Fig. 6. Similar to Fig. 4, the measured transfer impedance curve is shown in blue, and requirements (EMC concept) are shown in red. This type of JXFEJE-R 25×2×0.5 cable does not meet the requirements of the EMC concept in the range from 1 kHz to 10 kHz.

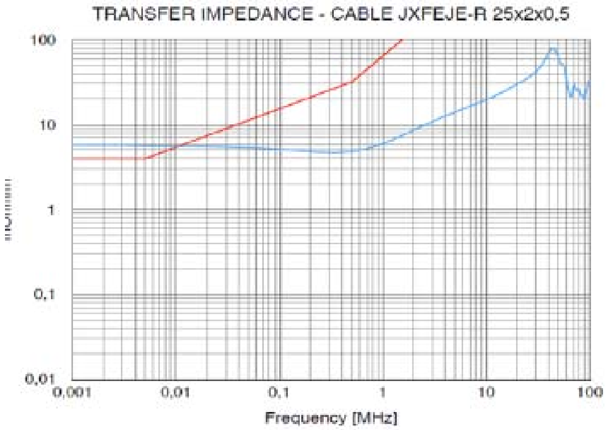

Fig. 6 – Transfer impedance's frequency dependence for JXFEJE-R 25×2×0.5 cable.

The range of these "low" frequencies (1kHz – 10 kHz) is closely connected with the cross-section and the electrical resistance of the shield. It means that the unsatisfactory result of the transfer impedance measurement is caused by an insufficient cross-section of the shield. It was necessary to make additional adjustments in the cable construction and increase the cross section of the CuSn braid.

6. UNCONVENTIONAL SHIELDING MATERIALS

As mentioned above, the JXFEJE-R 25×2×0.5 cable did not fulfill the requirements for lowest measured frequencies due to the cross-section its shielding. However, the originally designed JXFE-R 25×2×0.5 cable construction has not complied with EMC requirement at any required frequency at all. Applying an additional shielding (Al PET tape rotated with a conductive part for braiding + CuSn braid with a density of 80 % CuSn wire 0.5 mm) is achieved result shown in Fig. 6.

The problem is related to the depth of penetration of electromagnetic radiation. In addition, the frequency of electromagnetic radiation is closely related to the properties of the material as the electrical conductivity and relative permeability of the shielding. In case of electrotechnical copper application, the only possibility is to increase the cross-section of the shielding system. Because of the price of copper, the costs of entire cable increase as well.

As a solution application of platinum-plated copper on steel strip (or wire) can be used. Copper clad steel (CCS), known under the trade name Copperweld, is a bimetallic product used mainly in the conductor industry, combining the high mechanical resistance of steel with corrosion resistance and conductivity of copper [4].

Copper coated steel (FeCu) is mainly used for the production of durable radio antennas, where its conductivity in the high frequency range is almost identical to that of a Cu conductor with the same diameter.

The application of FeCu conductors has been found mainly in earthing systems, in telephone cables, or as an internal conductor of coaxial cables – both for thin cables of the RG-174 and CATV type. It is also used in some antennas for high frequency conductors.

FeCu conductors in earthing systems are used for connection of earthing rods to metal structures, earthing grid networks, switchboards, power equipment and lightning arresters. Low impedance copper is the outer conductive Cu layer of these conductors, where only the center is steel with a higher impedance, thus the surface effect provides high-frequency transmission lines with low impedance, even at high frequencies (*e.g.*, atmospheric discharge).

Described material has been verified on coaxial cable samples by measuring the transfer impedance in a fire-retardant version design RG 6 type VCsCJE-R 75-4.8 with FeCu core Fig. 7 and RG 6 type VCCJE-R 75-4.8 with Cu core Fig. 8.

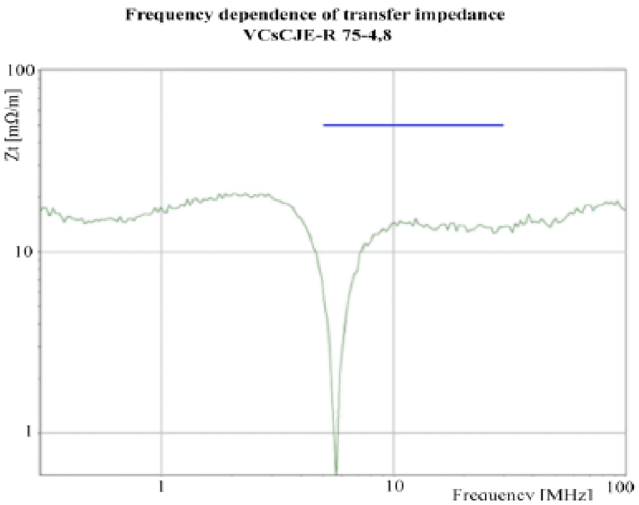

Fig. 7 – Frequency dependence of transfer impedance, cable with core FeCu.

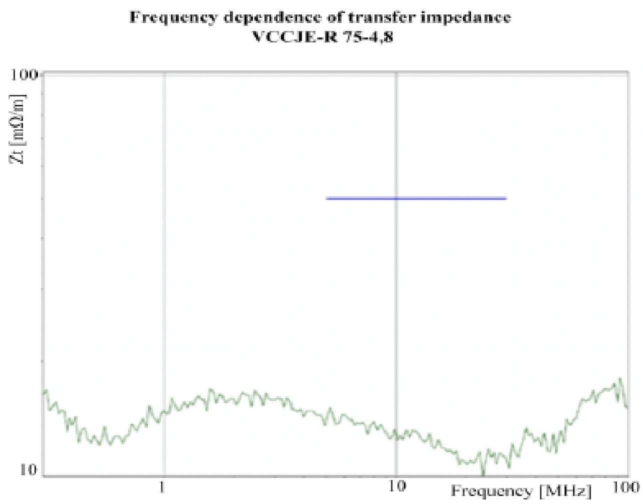

Fig. 8 – Frequency dependence of transfer impedance, cable with core Cu

Both Cu core and FeCu core cables had similar course of frequency dependence of measured attenuation, whereas FeCu design had about 1 to 2 dB lower attenuation at 100 m throughout whole 100 MHz to 3 GHz measurement range.

Marginally, we remark the fact that there have been appearing cables with FeCu cores for energy transmission on the market recently, bringing considerable risks from the electrical safety point of view of such lines, as electrical conductivity of these conductors is about 5 times lower than that of Cu conductors.

7. **CONCLUSIONS**

The mutual interaction of different types of cables laid in cable trays and channels might cause significant problems in both digital and analog control systems of large industrial complexes. Therefore, attention is constantly paid to cables and conductors, which are objectively responsible for a relatively large proportion of failures in large technological units. The issue of EMC cable and conductor systems is therefore highly actual, and attention needs to be paid to both shielding and routing alongside with laying.

Research and optimization of the design as well as unconventional materials used for cable shielding are highly important in order to reduce the interaction of radiated and input signals. Signal transmission, especially via optical routes, hits its limits within the field of complexity, reliability and the price of systems.

Although the importance of EMI in the area of technical technology is growing, the importance of its impact on the human health has declined slightly, despite being repeatedly emphasized. The negative impact of electromagnetic radiation on human health in the field of digital signal transmissions has not been convincingly demonstrated yet. The proof is, that one of research project of the German-Japanese team of electrical engineers and doctors has been recently finished after 5 years, because have concluded that it did not make sense to continue in the research and the negative effect of EMC on living organisms has not been demonstrated. Anyway, this fact does not diminish the importance of EMC within pplication in electrotechnical equipment and thus, of course, in the field of cables and wires. The effects on no-failure operation and reliability can be significantly affected by the interactions between individual cables and cable lines, henceforward great attention in this area needs to be paid [5].

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