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MEMO - Grounding of the straw detector - theory and design

1. Methods of the electronic circuits analysis.

If the linear dimensions of the analysed circuit satisfy the constraint:

$$\left.\begin{matrix} x \\ y \\ z \end{matrix}\right\} << \lambda \qquad (1)$$

where λ - the wavelength of the electromagnetic wave, corresponding to the upper boundary of the analysed frequency range,

then the ***Circuit Theory*** (currents, voltages, resistances, capacitances, Kirchoff's law, Ohm law, etc.) may be used. If the constraint is not satisfied, the Circuit Theory is not adequate and the ***Field Theory*** (Maxwell equations) must be used for the analysis.

In fact, the Field Theory allows analysis of only these circuits, which have simple, well defined structure (waveguides, antennas, microwave ovens etc.).

Very important case, from the practical point of view, is that when only one linear dimension of the circuit does not satisfy the constraint (1). In such case the circuit may be considered as so-called distributed - constants circuit (characterised by the resistance, inductance, capacitance etc. per the unit length) and analysed using Circuit Theory methods (transmission lines, for example: coaxial cables, twisted pair cables etc.).

It is very difficult to give an explicit definition of the range of the circuit dimensions to the wavelength ratio, for which the Circuit Theory is adequate. However, some recommendations, based on the literature, may be formulated:

- if the circuit dimensions are smaller than $\frac{1}{100}\lambda$, then the Circuit Theory may be safely applied;
- if the dimensions are grater than $\frac{1}{4}\lambda$, then the application of the Circuit Theory methods is a serious error.
- in the electronic engineering practice, the assumed limits of the circuit dimensions, allowing application of the Circuit Theory, vary between $\frac{1}{20}\lambda$ and $\frac{1}{8}\lambda$.

2. **Main goals of the grounding systems.**

First, obvious goal of the grounding system is to provide security of the user and the entire system (protection against shock and lightening hazards). Excluding that, the goals of grounding system may be defined as follows:

a) reduction of the level of the noise pick-up from the electrical component of the electromagnetic waves (grounding of the shielding);
b) protection of the circuits against undesirable couplings on the impedances, common for different circuits. This type of coupling may lead, in some extreme conditions, to the generation (oscillation) of the circuit.

Fulfilment of the goal a) is not technically difficult. For the achievement of the aim b) one has to ensure that the impedance of the connections between the circuit and the ground are as close to zero as possible.

3. **Designing of the grounding systems.**

Structure of the grounding system depends on the upper limit of the frequency range of the most sensitive component of the circuit [1].

In the case of the straw chamber, the input of the ASD8B amplifier is the most sensitive circuit. The frequency range of the ASD8B is approximately 1 ÷ 100 MHz (Fig.2c). It corresponds to the wavelength of 3 ÷ 300m. For the most critical region of high frequencies (100 MHz) we get: $\frac{1}{8}\lambda \approx 0.4m$.

There are two main variants of the ground system structure (plus various different hybrid structures) [1]:

1. singe point grounding (Fig.1 - 8.5). All ground lines are connected to the one, main point („star configuration”). Individual connections of all circuit components to the ground help to avoid common impedance coupling problems, making fulfilment of the goal b) easier. This configuration is often and willingly applied in the circuits working in the low-frequency range.
2. multi-point grounding (Fig.1 - 8.7). In this configuration the conductive plane is used and the grounds of the particular parts of the circuit are connected to this plane in many points. This solution does not provide as good separation of the circuits as the single-point method, however, the common impedance is small (thanks to the big surface of the conductive plane). This type of grounding is frequently used in the high frequency range. If, additionally, all cables are placed on the surface of the plane, this method may be used beyond the limit of $\frac{1}{8}\lambda$ [1].

The conclusion is that „the single-point grounding operates better at low frequencies and a multi-point ground behaves best at high frequencies” [1]. The choice of the grounding system type depends on both: highest significant operating frequency of the circuit and distance between the furthest located equipments. The cross-over regions of single-point vs multi-point grounding is shown in Fig.1 - 8.8.

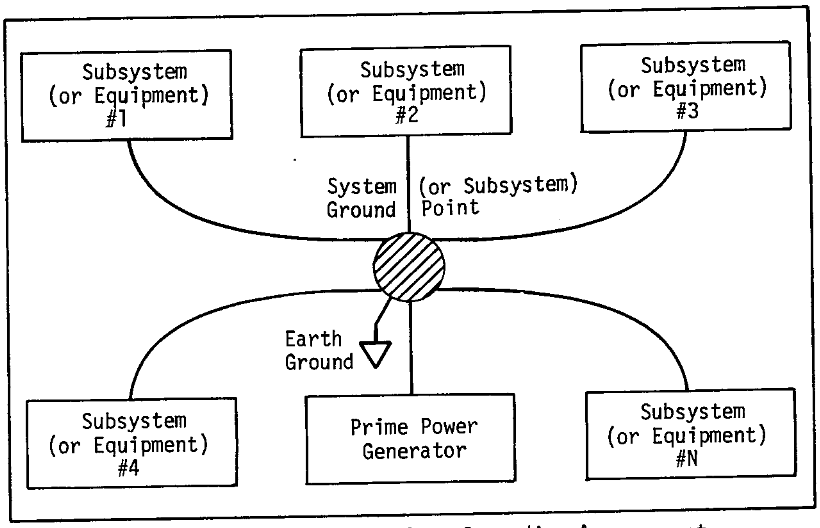

Figure 8.5 - Single-Point or Star Grounding Arrangement

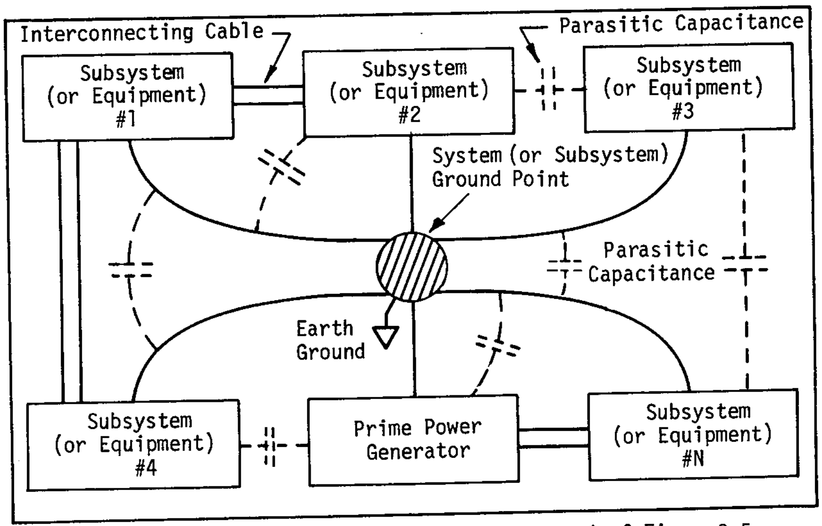

Figure 8.6 - Degeneration of Single-Point Ground of Fig. 8.5 by Interconnecting Cables and Parasitic Capacitance.

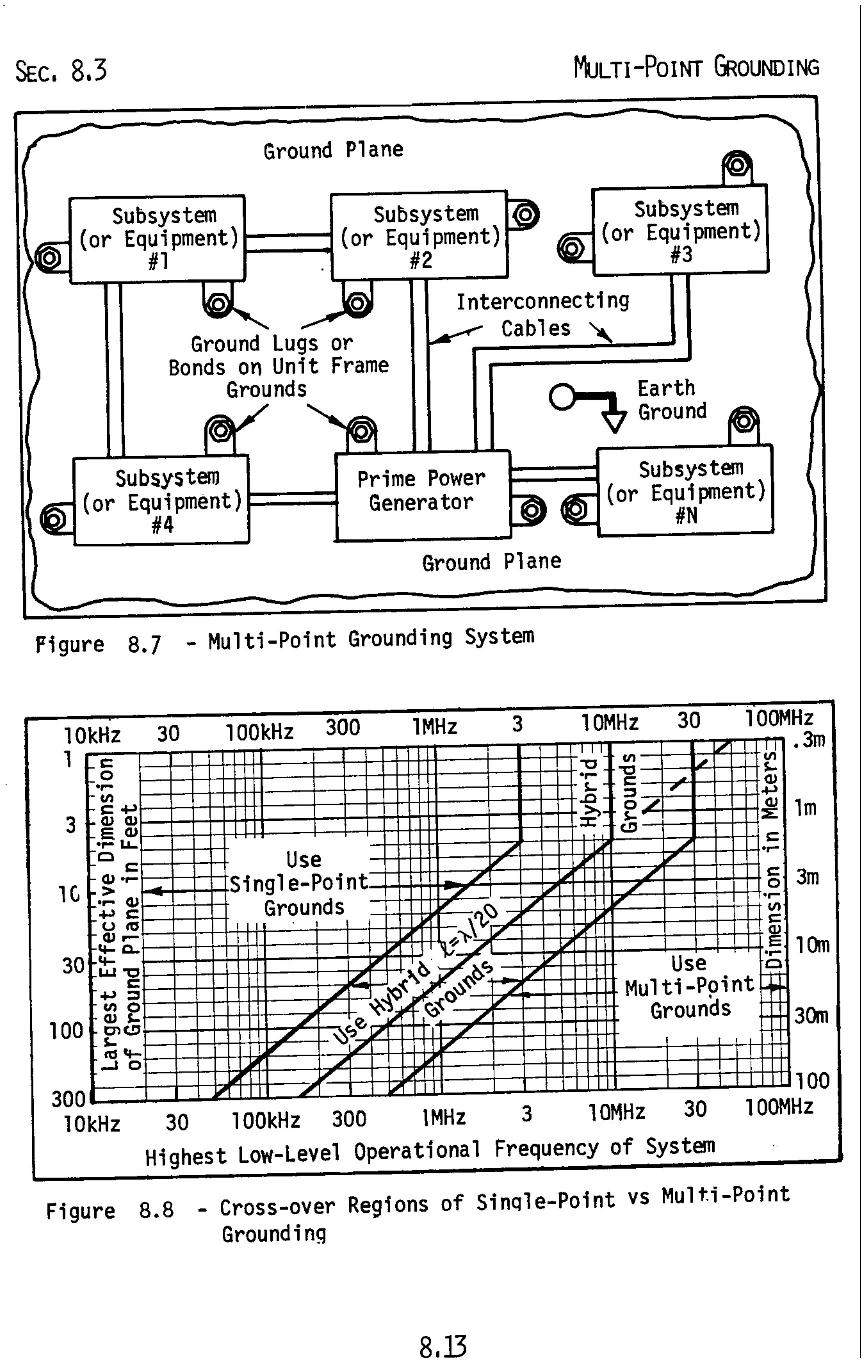

Fig.1. Copy of the Figures from the book [1]

Impedance of the grounding.

Impedance between two points of the grounding system may be expressed as [1] :

$$|Z| = R_{RF} \cdot \left(1 + \left|\tan\left(\frac{2\pi l}{\lambda}\right)\right|\right),$$ where: l is a distance between points;

for the copper plane:

$R_{RF} = 0.26 \cdot 10^{-6} \cdot \sqrt{f}\ [\Omega / square]$, where: f - frequency;

for the copper bar:

$R_{RF} = 0.26 \cdot 10^{-6} \cdot \sqrt{f} \cdot \frac{l}{p}$, where: p - circumference of the bar cross-section;

Values calculated for the copper strip of the width of 5cm and length of 1.5 m is shown in Fig.2. The quarter-wave resonator effect is clearly seen - for the connection length equal to $\frac{1}{4}\lambda, \frac{3}{4}\lambda$ etc., the impedance goes to infinity, independently of the thickness and resistivity of the connection.

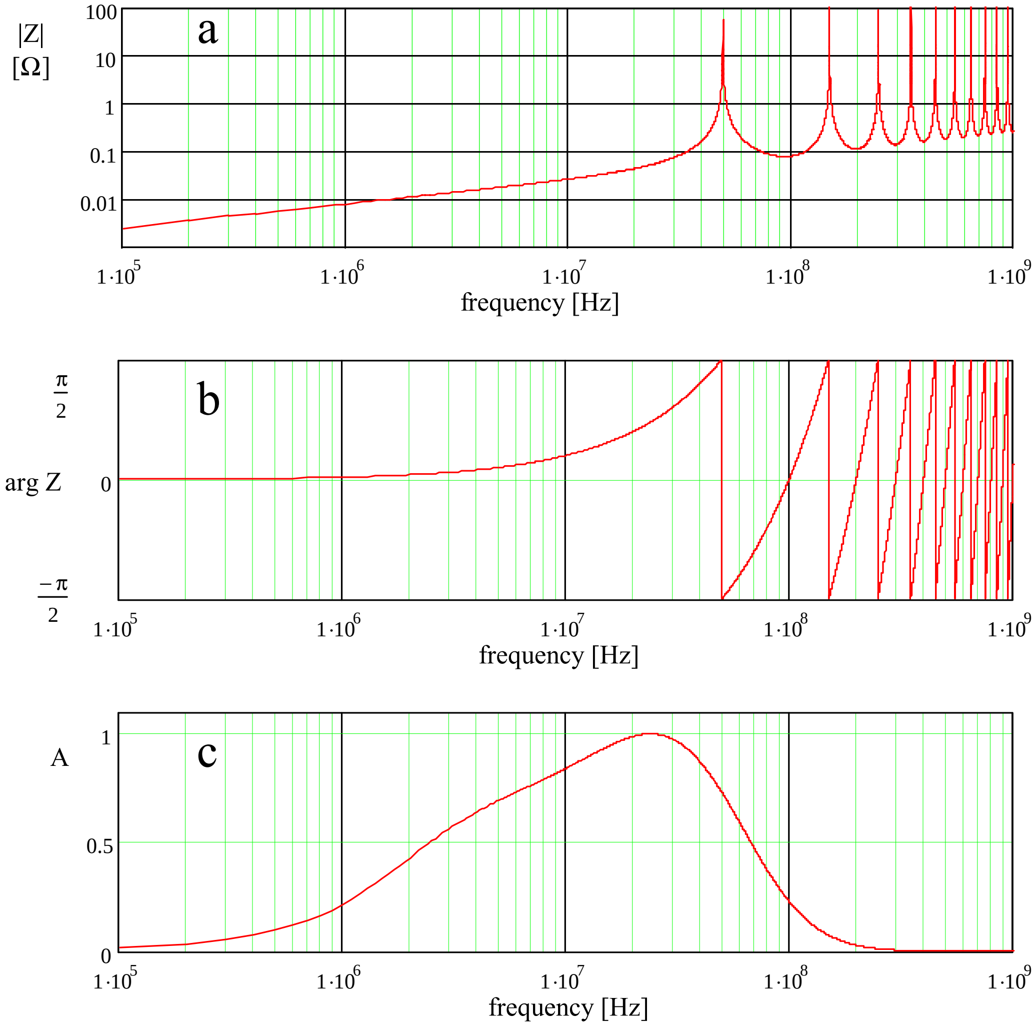

Fig.2. *Impedance of the copper strip of the width of 5 cm and length of 1.5 m (a - module, b - phase) and c - amplification of the ASD8B chip (maximum value normalised to unity).*

Conclusions:

1. The proposed grounding system (*electronic ground*) has a single-point structure of dimensions of tens of meters. Therefore, it is efficient for the frequencies lower than few MHz. Because the straw chamber system works in the frequency range of 1 ÷ 100 MHz, the „electronic ground" may be used only as a safety ground.
2. Since the dimensions of the „electronics" of the straw chamber exceed the limit of $\frac{1}{8}\lambda \approx 0.4m$, the single-point grounding is not applicable. Organisation of the multi-point grounding is impossible for technical and economical reasons. Therefore, we propose the grounding system without the common ground, consisting of „local grounds" connected via transmission lines (Fig.3).
3. The remaining ground connections can be „cut-off" in the frequency range of 1 ÷ 100 MHz, using Common Mode Chokes (CMC).

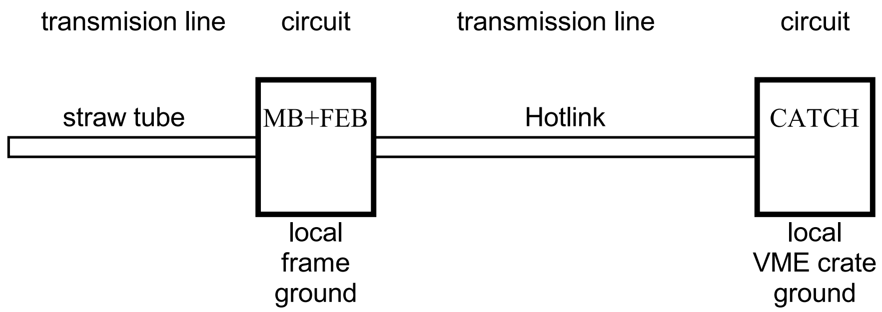

Fig.3. *Illustration of the idea of the straw detector grounding.*

The proposed grounding system of the straw chamber system.

The suggested grounding system of a straw detectors is shown in Fig.4.

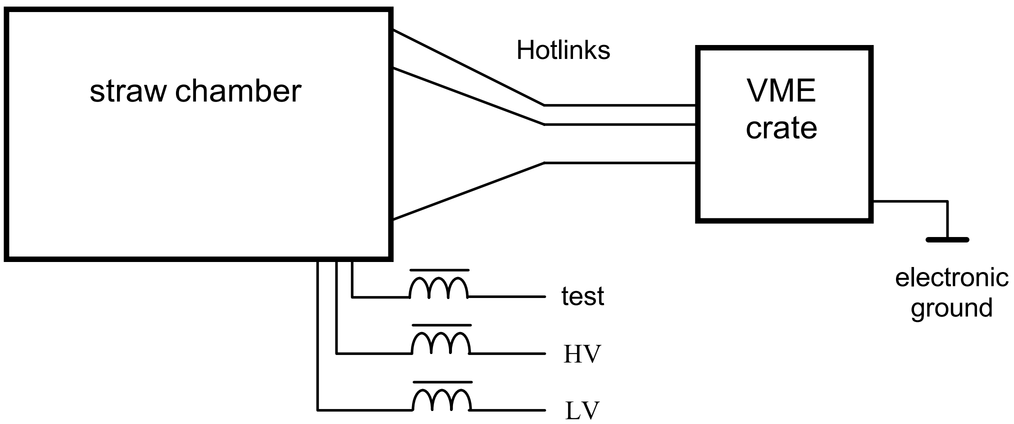

Fig.4. *Suggested grounding system of the straw chamber.*

If the level of the noise pick-up turns out to be too high, we would foresee the following modifications:

1. Since the lengths of the chamber frame bars exceed limiting value of $\frac{1}{8}\lambda \approx 0.4m$, one may expect substantial interferences from the currents induced in the frame by the magnetic component of the electromagnetic field. In this case we would suggest to use CMCs for each Hotlink cable (Fig.5).

2. The straw chambers are not effectively shielded (requirement of the low mass in the chamber window does not allow effective shielding). Therefore, one may expect significant noise pick-up from the electric component of the disturbing electromagnetic field. The straw chamber is surrounded by big objects, connected to the „structure ground". One may expect that the connection of the straw chamber to the magnet <u>for high frequencies</u> should decrease this kind of interference significantly. This solution does not agree with the assumed grounding rules. Therefore, it may be used only with the approval of the Technical Co-ordinator and the entire group.

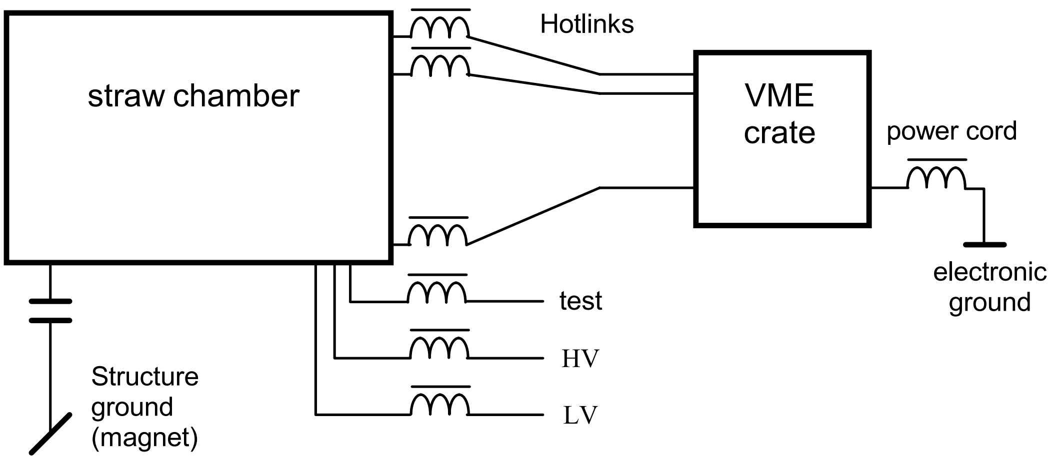

Fig.5. *Modifications of the grounding system suggested in the case of high noise pick-up from the electrical component of the electromagnetic field.*

Appendix: Ground separation with CMCs (Common Mode Chokes)

The ferrite cores used for the EMI (Electromagnetic Interference) suppression are made of the special kind of ferrite materials, showing high energy loses in the high frequency region (Fig.6). Thanks to that, the resistive component of the impedance of such chokes dominates over the inductive component. The cores usually have a shape of rings, tubes or sets of two half-tubes (this kind of shape allows easy applying of the core for the cable without disassembling of the plug) (Fig.7).

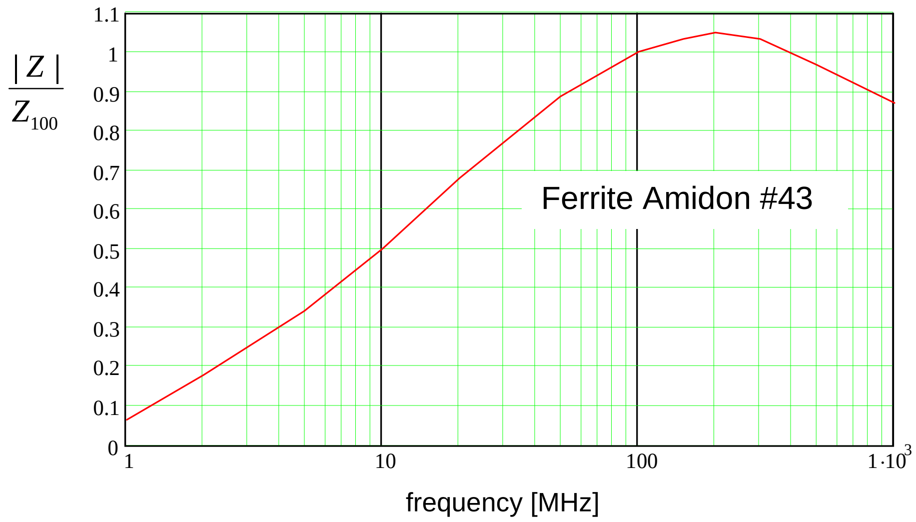

Fig.6. *Frequency characteristics of the impedance of coils with the core made of the AMIDON #43 ferrite.*

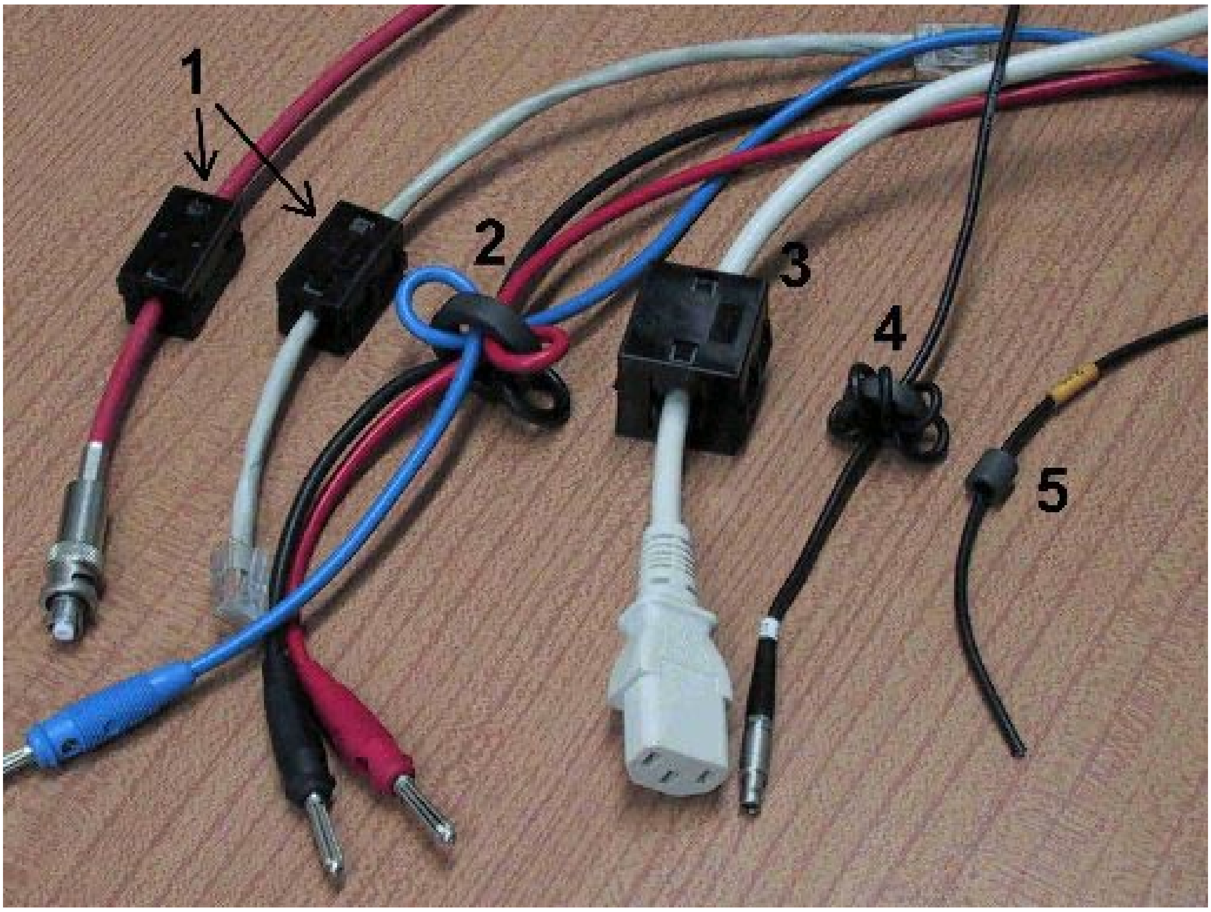

Fig.7. *Examples of the Common Mode Chokes - their properties are described in the Tab. 1.*

Tab.1. Impedance of different types of Common Mode Chokes, shown in Fig.7

Number (Fig.7)	Application	AMIDON type	$|Z_{100MHz}|$
1	HV cable, TP cable	2x-43-251	275 Ω
2	Power cord	2x-43-151	245 Ω
3	Low Voltage cables	FT-240-43	108 Ω
4	Scope cable	FT-82-43	750 Ω
5	Test Pulse cable	FB-43-6301	55 Ω

CMC - chokes with few parallel turns or the ferrite core placed around the multi-wire (or coaxial) cable, have two, very valuable features:

1. in the case of the supply cables (Fig.7 - 2) - the sum of the currents flowing through all wires is equal to zero. Thanks to that there is no magnetizing current and even small core can work without the saturation in the high power circuit.
2. in the case of the signal cables (Fig7- 4,5) - the sum of the signal currents is equal to zero - the core on the cable doesn't distort the signal shape.

As it was shown in [2], the CMCs may be used even in relatively strong magnetic fields.

Literature:

[1] D.R.J.White - „Electromagnetic Interference and Compability (EMI Control Methods and Techniques), Vol.3", Don White Consultants, Inc., Gainesville, 1981

[2] J.Marzec, K.Zaremba, Z.Pawlowski, B.Konarzewski, EMI suppression properties of the chokes in the external magnetic fields", COMPASS Note 2000-9