Minimizing the Interference Coupling into Standard Coaxial Cables with Braided Shield

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Abstract: In this contribution the investigations to minimize the interference coupling into standard coaxial cables with braided shield are described. Considering the transfer impedance as the coupling describing quantity, it is shown that reducing the coverage of the cable RG213/U by 25% results in lower values of the transfer impedance of appr. 20 dB within the important frequency range between 1 and 100 MHz.

1. INTRODUCTION

The cable transfer impedance is a purely cable specific quantity which describes the connection between the current on the cable screen and the induced voltage between the inner conductor and the screen. To analyze the behaviour of the transfer impedance, it is necessary to understand the coupling mechanism. In Fig. 1 the principle of the coupling process is shown. A generator with the voltage $U_0$ drives a current $I_0(x)$ on the screen of an arbitrarily arranged cable. The current distribution $I_0(x)$ depends on the geometry, the electrical quantities of the cable screen, and the environment of the cable. This current $I_0(x)$ induces a voltage $dU_T = Z_T I_0(x)dx$ inside the cable between the core and the screen. The induced interference signal produces voltages across the load impedances $Z_1$ and $Z_2$. The transmission line theory which considers the interference signal within the cable. To use this theory, the propagation constant $\gamma$, the characteristic impedance $Z_0$ and the load impedances $Z_1$ and $Z_2$ must be known. Equation (1) [3] shows the relation between the voltages $U_2$ and $U_0$.

$$U_2 = -Z_2 \int_0^l I(x, U_0) Z_T [Z_1 \sinh(\gamma x) + Z_0 \cosh(\gamma x)] dx$$

(1)

where

$$n = \frac{1}{(Z_1 Z_2 + Z_0^2) \sinh(\gamma l) + Z_0 (Z_1 + Z_2) \cosh(\gamma l)}$$

(2)

Equation (1) can be written in a more easy way as

$$U_2 = Z_T FU_0.$$  

(3)

From equation (3) it can be seen that the transfer impedance is a simple but a complex constant. The coupling factor $F$ includes the current distribution on the cable screen and the propagation inside the cable. To determine the coupling factor $F$, the current on the cable screen must be computed and the cable parameters must be known. With the factor $F$ and the ratio $U_2/U_0$ the transfer impedance can be obtained by a simple division.

2. MEASURING WITH THE CCM

For determining the transfer impedance the Computed Current Method (CCM) can be used [1]. The CCM is based on a combination of numerical computing and measurement. Fig. 2 shows a possible test setup. A cable under test formed in a semicircle ($R=25$ cm) is arranged above a copper plain (2 m x 2 m). A generator between the cable screen and the copper plain at the left-hand side excites the system. At each cable end the inner conductor is terminated to the shield by an impedance. The right-hand end of the cable screen is connected to the copper plain. Across the impedance $Z_3$ inside the cable the voltage $U_2$ has to be picked up. A network analyzer measures the ratio $U_2/U_0$. The current on the cable screen can be determined...
by an algorithm based on the Methods of Moments. Using the current on the screen and the cable parameters yields the coupling factor $F$. Knowing the ratio $L_{rz}/V_0$ and the coupling factor $F$, we can compute the transfer impedance by a simple division. This method is a comfortable way to reach very accurate measuring results up to 500 MHz and higher.

3. THE SINGLE BRAID CABLE SCREEN

Fig. 3 shows a section of a cable shield. The braid consists of $N$ wire groups, each of $n$ wires (diameter $d$). The angle between the cable direction and the wires is called $\Theta$. It is useful to know a little bit more about the coupling mechanism to be able to minimize the interference coupling respectively the transfer impedance. Three coupling mechanisms are known. In the low frequency range the braided shield can be described as a homogeneous tube. Using the parameters of the cable braid the homogeneous tube can be described as [5]

$$Z_d' = \frac{4}{\pi d^2 n N \kappa \cos \Theta} \cdot \frac{kd}{\sinh kd'}$$

$$k = (1 + j) \sqrt{\frac{\mu \kappa}{\mu_0 \kappa}}$$

(4)

$k$ is the conductivity. In the higher frequency range the hole coupling and porpoising becomes apparent. The hole coupling considers the magnetic coupling through the holes in the braided screen. A derivation for lossless hole coupling was shown by Tyni [4].

$$M_h' = \frac{\mu_0 2N}{\pi \cos \Theta} \cdot \frac{b^2}{(\pi D_m)^2} e^{-\frac{\pi d}{2}}$$

(5)

Another interesting derivation to describe the hole coupling, using elliptical integrals is proposed by Vance [5]. The hole coupling causes a transfer impedance with a phase of $+90^\circ$ like a mutual inductance. The wire groups of the braided shield alternate between inside and outside of the screen and so does the screen current. Due to the alternation of the current in conjunction with the wire direction $\Theta$ there is a coupling effect which is called porpoising [4].

$$M_h' = -\frac{\mu_0 2d}{4\pi D_m} (1 - \tan^2 \Theta)$$

(6)

In opposition to the hole coupling, porpoising causes a transfer impedance with a phase of $-90^\circ$. This is valid for wave angles with $\Theta < 45^\circ$. Now the transfer impedance can be written as

$$Z_T' = Z_d' + j\omega M_h' + j\omega M_h'$$

(7)

On the EMC-chair of the Dresden University of Technology many standard coaxial cables with braided shields have been measured. Most of these cables have a transfer impedance with a phase of approx. $-110^\circ$ in the higher frequency range ($> 10$ MHz). It seems that porpoising is dominating.

4. OPTIMIZING THE BRAID OF CABLE SHIELDS

In an experiment the screen of a RG 213/U cable has been degenerated step by step. The undegenerated braid of a RG 213/U cable consists of 24 wire groups each of 8 wires. At the first test, from each wire group one wire was pulled out (RG 213-1). At the second test, two wires were removed (RG 213-2) and so on. Fig. 4 shows the results. The curve RG 213/U indicates the typical behaviour of a coaxial cable with a braided shield. In the low frequency range the transfer impedance is equal to the DC resistance of the screen. In the higher range the magnitude increases. The phase decreases and stabilizes at appr.$-110^\circ$. The magnitude of the RG213-1 cable is a little bit lower than the magnitude of the RG213/U, and
the phase comes up to -105°. A very different behaviour can be seen at the RG213-2 cable. Above 1 MHz the magnitude decreases and the phase remains stable at appr.-45°. It seems that hole coupling and porpoising compensate each other so that from 1 MHz to 500 MHz the screen behaviour is improved up to a factor of appr. 10 (20 dB). A reduction of the screen coverage of 25% of the RG213/U yields the lower transfer impedance, which means an optimized cable screen. The magnitudes of the curves RG213-3 and RG213-4 increase faster than that of the RG213/U. The phase reaches values appr. +90°. Hole coupling dominates. Hole coupling and porpoising and their compensation are also proven by measurements in [2].

To verify the measuring results it has been tried to simulate a braided shield. A feasible simulation and a model which has the same electromagnetic behaviour like a cable braid have to be developed. To get a closer insight the cable screen is modeled by wire grids. A program, based on the Methods of Moments, is used to compute currents on the wire grids. The model is shown in Fig. 5. A piece of a cable with a braided shield is used. Both ends of the braid are short circuited to the inner conductor. Two wires connect the braid with the plain. A generator $U_0$ on the left-hand side drives the system. The braid is builded up by two layers. The inner layer consists of a group of wires which are left-hand oriented, wound like a helix. The wires of the upper layer are right-hand oriented. The two helixes are wound in a wave angle of $\Theta = 28°$ and have a length of $l = 1.57$ cm. Up to appr. 100 MHz the current $I_n$ can be assumed to be constant. In the middle of the braid a wire represents the inner conductor. To determine the coupling voltage $U_2$ a resistance with $R = 100 \Omega$ is positioned at the right-hand side of the inner conductor. The transfer impedance for this modeled braid can easily be predicted by

$$Z_T = \frac{U_2}{I_n}.$$  \hspace{3cm} (8)

In the calculation the braid is modeled by ten, twenty, thirty, and forty wires in each layer. For these models the transfer impedance has been simulated. The results are given in Fig. 6. The curve with forty wires in each layer is similar to the typical behaviour of the transfer impedance of a single braided shield. In the low frequency range the
transfer impedance is equal to the DC resistance of the screen. In the higher range the magnitude increases. The phase reaches appr. -90°. The magnitude of the cable with thirty wires in each layer is a little bit lower in the higher frequency range than the magnitude of the cable with the forty wires layer. The phase also reaches -90° at higher frequency. A very different behaviour can be seen at the simulation with twenty wires. The magnitude increases but more slowly. The phase reaches +45°. It seems that hole coupling and a coupling mechanism similar to porpoising compensate each other. The magnitude for the simulation with ten wires increases faster and the phase reaches +90°. Hole coupling dominates. Simulation and measurement show in principle the same behaviour. If the optical coverage is choosen in a right way, hole coupling and 'porpoising' compensate each other. This gives a opportunity to improve cable screens.

CONCLUSION
There are three known mechanisms which describe the coupling into single braided cable shields. In the low frequency range the cable screen can be described as a homogeneous tube. In higher range porpoising and hole coupling become apparent, but hole coupling and porpoising are counteracting. If optimal cable parameters are chosen hole coupling and porpoising compensate each other. For a RG 213 cable the shield is improved up to 20 dB by reducing the coverage. A simulation model which seems to have the same behaviour as a cable screen is shown. The simulation confirms that 'porpoising' and hole coupling can compensate. It is planned to improve this model in future to get a deeper understanding about cable coupling.

REFERENCES


