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The test setup and measurement procedure of the shielding effectiveness of the industrial network Y distributors

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The paper presents the test set up and the measurement procedure of the relative value of the shielding effectiveness coefficient of the Y adapters. Such elements are widely used in IT networks in industrial automation systems. They are used for transmitting analogue and digital signals between the automation devices and different kinds of sensors, and for construction of industrial networks for data transfer. The paper presents the method of measuring the shielding effectiveness of such elements by measuring the signal attenuation between the radiating element and the internal wires of the tested element. The described test set up has been constructed in such way that minimize the signal penetration by the free space, that is outside the measuring zone. The test setup can be especially useful during the control of a process production and during preparation of new solutions. The construction and exemplary results of the tests were presented.

KEYWORDS: shielding effectiveness, Y distributor, adapter, IT industrial networks

1. Introduction

The development of wire and wireless communication systems, IT systems, automation systems and electric devices forces meeting higher and higher requirements for the electronic devices in the range of electromagnetic compatibility. This is caused by the increase in the number of devices generating electromagnetic field in the range of frequencies from tens of hertz to dozen or so of gigahertz. To assure proper operation of the electronic devices exposed to the adverse electromagnetic fields protection in a form of shields is introduced, among others.

In all of the IT systems, the signal lines as well as every other element of the system, such as plugs and sockets, connectors, concentrators and adapters, have to be included into shielding from the penetration of disturbances in the range of high and very high frequencies.

Properties of the shield depend on the construction of the shield itself, in a form of metal foil or wire braid, and on the kind of the material used. Especially significant is the structure of the connection between the shields of a cable and other elements. It is difficult concerning construction, especially in the elements that are frequently connected and disconnected, and working under changing mechanical stress.

The essential measure determining the quality of the cable wires shield and shields of other elements of the system is so-called shielding effectiveness. It is defined as the ratio of the signal level induced in the cable wires, connectors and adapters to the signal level falling on these elements [1, 4]. The literature describes test set up and method of conducting measurements according to such procedure. However, their main disadvantage is using flexible cord, mounted along the elements under test as the source of radiation. Such construction of the measuring set up results in very low repeatability of the measurement conditions. Additionally, elements of the whole system interact with each other also outside the measuring zone. This occurs mainly in the cases of tests using signals of very high frequencies.

Ensuring the controlled repeatability of the measurement conditions has especially significant meaning in the case of executing the control measurements on the stage of designing and constructing the prototype of connector, adapter or concentrator. In these cases it is necessary to control only the introduced structural and material changes influence on the value of the shielding effectiveness coefficient.

2. The test set up and the measurement procedure of the shielding effectiveness

The basic indicators used to evaluate the quality of the cable shields and shields of other network systems elements are: the shielding effectiveness α_{SE}, transfer impedance Z_T, and dispersion matrix $\mathbf{S}$. These parameters and methods of their measuring set for the frequency range for which the dimensions of the elements with output cables are much lower from the wavelength of the test signal [2, 6, 7, 8].

The shielding effectiveness α_{SE} is defined as a ration of the value of the signal passing through the shield to the value of this signal falling at this shield. The signal level can be expressed as the value of the intensity of the electric and magnetic field or as the power density. In the case of the shield assessment basing on the electric field intensity, the shielding effectiveness will be described by the equation

$$\alpha_{SE} = 20\log_{10}(E_T / E_I) \text{ [dB]} \tag{2.1}$$

where E_I is the intensity of an electric field surrounding the tested element, and E_T is a value of the field in the space between the internal conductor and the shield.

Measuring the effectiveness of the cables shield and shields of other elements of the system according to the definition (2.1) is hard to execute because it requires measures of the intensity of an electric field between the shield and the internal conductor. That is why the shielding effectiveness is assessed according to this definition can be mainly used to determine the properties of the flat shields.

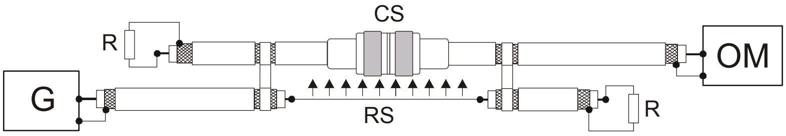

Fig. 1. Illustration of measuring the coefficient α_{SE} through measuring the power; G - testing signal generator, CS - connector set under test, R – load resistance, RS – radiation source, OM – output meter

In practice, for the assessment of effectiveness of the cable shield and shields of other elements of the system, the method being the modification of the test set up and a method presented in Fig. 1 is used. This new method relies on measuring the power P_T of the signal induced in the internal conductor of the cable or adapter and the power P_G provided by the generator G to the radiating element RS generating the electromagnetic field in direct proximity of the tested cables or other elements under test – CS, of the system. The ends of the cables are limited with resistors R ensuring wave adjustment. The shielding effectiveness α_{SE} determined with such measuring set up will be defined as

$$\alpha_{SE} = 10\log_{10}(P_T / P_G) \text{ [dB]} \qquad (2.2)$$

If we assume that the conditions of the wave adjustment between generator G and cable and between the measuring device of the output power OM and the signal – delivering cable are met, then, when using the decibel scale and expressing the power in dB in relation to mW, it can be assumed that the shielding effectiveness will be described by the equation:

$$\alpha_{SE} \approx P_{T(\mathrm{dBm})} - P_{G(\mathrm{dBm})}) \text{ [dB]} \qquad (2.3)$$

The measuring procedure according to this method is shown in Fig. 1. It has, however, a disadvantage as it is difficult to precisely determine what part of the power of the signal provided by the generator passes through the tested area and what part is being lost in the cables delivering the signal, is dispersed at the connections, waves mismatches etc. What is more, a number of measurements have shown that the reciprocal alignment of the tested cable, the adapter and the radiating element, and additionally their joint alignment against the surroundings have a significant influence on the measurement results. This indicates that the value of the shielding effectiveness coefficient determined using this set up contains information not only on the shield's properties but also on the properties of the measuring system. That is why it seems justified to introduce the term of relative shielding effectiveness coefficient and indicating it as α'_{SE}. In such case it will be possible to evaluate the differences in shielding effectiveness of the adapter with the cable between different items and types.

Lack of unambiguously specified alignment if the radiating element and conditions of performing the measurements causes that the obtained - on different measuring set up – results are incomparable between each other and thus making it impossible to assess the real properties of the shielding. While the advantage of this method is the possibility of taking measurements with an uncomplicated test set up and using relatively simple instruments. That is why it is preferred when evaluating the changes in the properties of the elements of the system and the cables alone during developing new constructions or in the process of control of the serial production quality.

The assessment of the shield properties through the measurement of the elements of the dispersion matrix **S** is being performed using the voltage wave and determined as the ratio of the wave falling V^+ on the adapters of the set up to the voltage wave flowing from V^- the adapters. The measurement is performed with a set up the same as presented in Fig. 1, but using the elements of the dispersion matrix **S** measuring device. The values of the elements of the dispersion matrix **S** are determined by the equations

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \tag{2.4}$$

In this case, the value of the effectiveness of the cable shield and other elements of the system is determined by the value of the coefficient S_{21} or S_{12}.

For the measurement of the values of the elements of the dispersion matrix, it is the best to use an instrument that automatically makes a measurement of the amplitude of the incidence and reflected wave for individual ports of the circuit, and, based on this, all coefficients of the matrix **S** are calculated.

When the test set up is properly set, the received values should fulfil the formulas: $S_{11} = S_{22} = 0$, and $S_{12} = S_{21}$. The value of the elements $S_{11} = 0$ and $S_{22} = 0$ means matching the waves on the input and output terminal, and the condition $S_{12} = S_{21}$ means that the circuit is non-directional. With the ideal shielding, the value of the coefficients S_{12} and S_{21} should tend to infinity.

The shield properties can be also evaluated by measuring the transfer impedance Z_T. It is defined as a ratio of the voltage drop U on the shield length L, to the current value I that was caused by the voltage drop and is expressed as the unit of length. The measurement of the shielding effectiveness according to this definition almost never can be used for testing the elements of the system and cables in which the shields do not have galvanic connection [3].

In the conducted test the relative value of the shielding effectiveness coefficient α'_{SE} was used to evaluate the quality of all elements. Its value was determined on the basis of the measurement of the elements of the dispersion matrix $\mathbf{S}$.

3. Construction of the test set up

During constructing the test set up we mostly followed the recommendations contained in the standard [9]. The construction scheme is shown in the Fig. 2, while the Fig. 2a shows the side view, and Fig. 2b - the top view. The test set up is intended to measure the Y adapters, in the frequency range from a few kilohertz to single gigahertz [5].

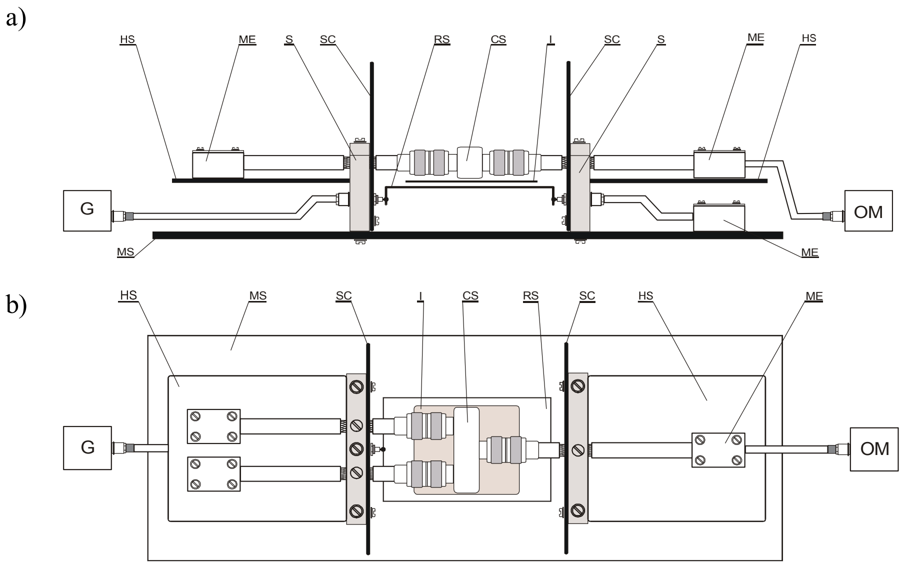

Fig. 2. The test set up scheme; a) side view, b) top view [5].
HS - horizontal screen, MS – main support, SC – screen, I – insulator, RS – radiation source, ME – matching element, OM – output meter, G - generator

The main advantage of the construction of the test set up as shown in the Fig. 2 is ensuring high stability and repeatability of the fixing of the tested adapter with the wiring, during measurement procedure. It is very important when conducting measurements of high number of adapters of the same type aiming at checking their quality during developing new constructions and in the case of performing control measurements during serial production.

The considered test set up comprises of two supports S that are fastened with screws to the main base MS. The task of the main base MS is to ensure the stiffness of the set up, ensuring fixed gaps between the elements and making the conditions of the measurement independent form the influence of the surroundings, especially the ground. To the supports S additionally two vertical screens SC, are fastened for separation of the area of the generator G side and the area of the measuring device OM side, from the area of actual measurement of the connector CS, for the signals of high frequency. Separating those areas with the screens SC, decreases the penetrating of the unwanted signals of high frequency through the free space, and, at the same time, ensures unambiguous separation of the measurement zone of the adapter CS and its wiring.

The tested adapter CS is fastened on the supports S. In upper parts of the supports recesses are made for each output cable. In the upper part of every support, crossbar is placed fastened to the supports S with screws. On the output cables on both sides of the adapter CS in a spot of their fixing in the recess of the support, the external insulation is removed until the level of the shielding wire, on the length of about 1 cm. In the crossbar, over the recess, there is a clamping screw for clamping the support S for the time of the measurement of the shielding wire of the cable. Under the recess S of every support there is a hole in which the coaxial connector is embedded. On the side of the generator G, through the coaxial cable, signal is provided to the radiating element RS, and to the coaxial connector, a short coaxial cable ending with the adjusting circuit ME is connected on the other side of the test set up. The adjusting circuits ME are constructed in a form of a metal recess closed with a cover. Resistors of the resistance value assuring wave adjustment are installed inside the recesses.

Outside the measuring zone, additional vertical separating screens HS were inserted between the cables of the examined element and the cables connecting the circuit with the generator G and the power measuring device OM. The intend of these screens is to minimise potential penetration of the signals between the generator circuit and the measuring circuit.

The tested elements CS along with the cables are placed between the supports S on the height of about 4 cm above the main base MS. Undernith, the radiating element RS is placed made of copper sheet. In a case when the tested elements are made of metal, in order to ensure galvanic separation, a thin layer of insulation I is inserted between the connector CS and the radiating element RS.

4. Results of the measurements

Based on the build test set up, measurements of the relative value of the shielding effectiveness coefficient α'_{SE} of two adapters were conducted. These elements are intended to work in the industrial networks for data transfer. Adapters of the Y type were selected, with M12 connectors, five-wire, and the connection arrangement 1:1. One adapter had the protective shield (shielded adapter), and the other one had no shield (unshielded adapter).

The measurement were performed using the test set up as presented in the Fig. 2. As the source of signal and the power meter, a vector circuit analyser was used. The test was performed in the frequency range from $50\,\text{MHz}$ to $1.3\,\text{GHz}$, with a signal of the power of $P_G = -10\,\text{dBm}$. As the result of measurement, the values of all dispersion matrix elements $\mathbf{S}$, as a function of the frequency, were recorded. The results are shown on the Fig. 3 and 4. The zero vale of the coefficient S_{11} and S_{22} indicates good adjustment of all elements of the set up. Relative value of the shielding effectiveness coefficient α'_{SE} is expressed by the value of the coefficient S_{12} and S_{21}. In the ideal case S_{12} equals S_{21}. Figure 5 presents the result of measuring the shielding effectiveness for the shielded and unshielded adapters.

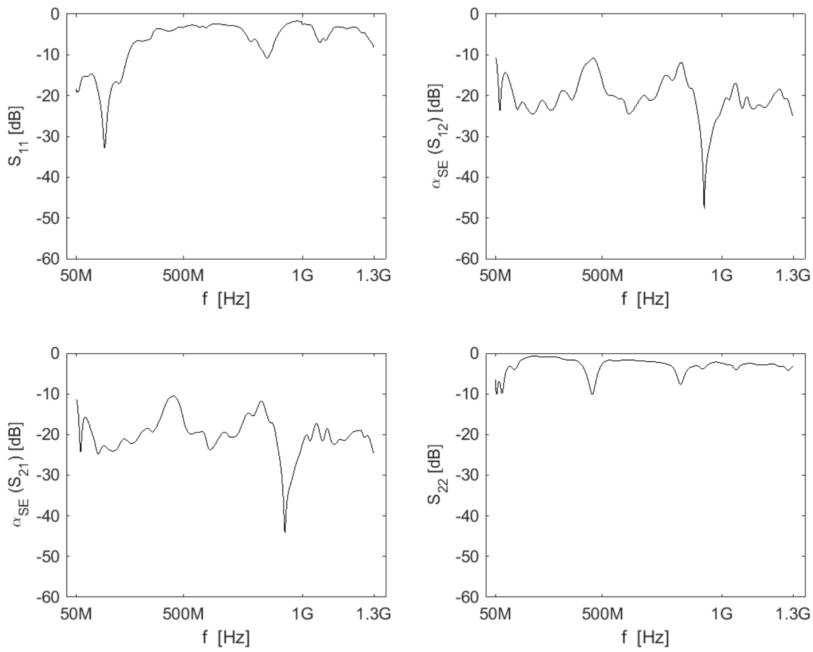

Fig. 3. Values of the elements of the matrix **S** as a function of frequency for the unshielded adapter

Figure 6 presents the relative values of the shielding effectiveness coefficient α'_{SE} for the shielded and unshielded adapter. The curves show significant differences in their values.

Measurement results confirm the possibility of using the developed test set up and proposed method for comparative measurements of the adapters of different structure, thus, for evaluation of the changes introduced to the construction and used materials during implementation procedures.

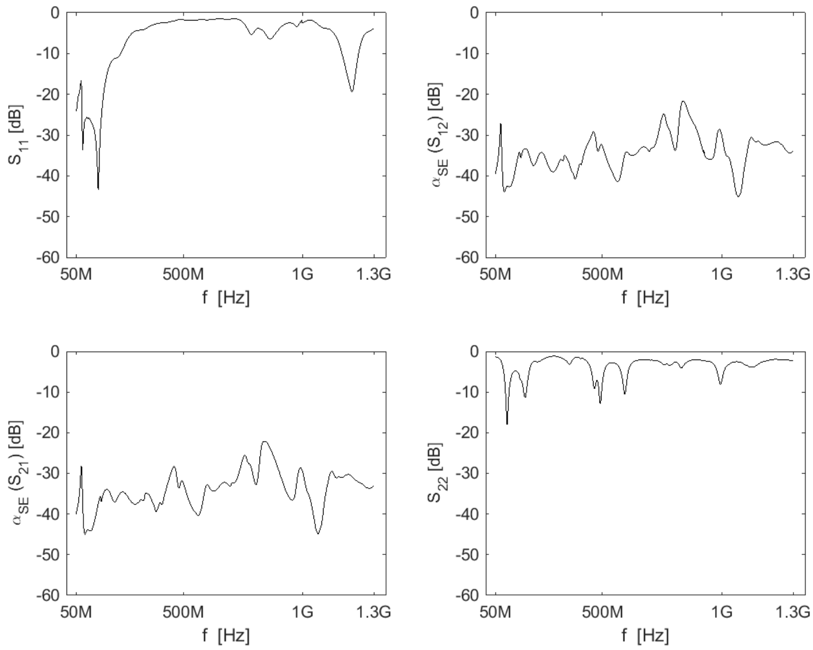

Fig. 4. Values of the elements of the matrix **S** as a function of frequency for the shielded adapter

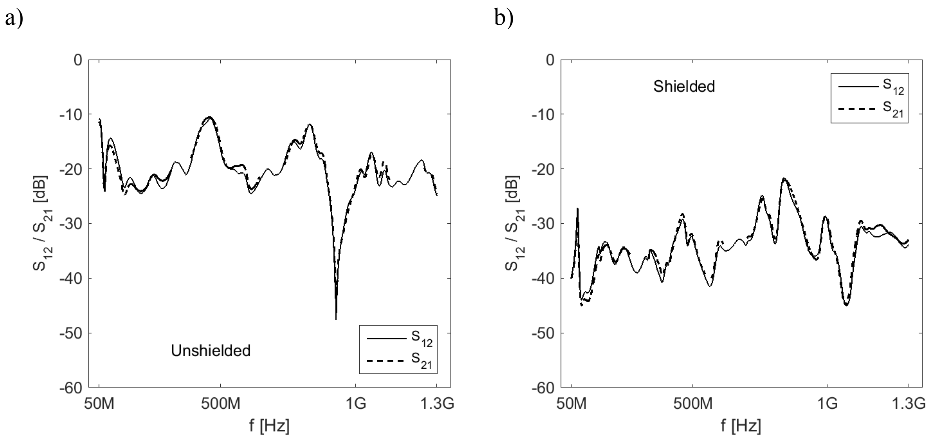

Fig. 5. Comparison of the values of the matrix elements S_{12} and S_{21} for the adapters: a) unshielded, b) shielded.

Additionally, measurements of the changes in the relative value of the shielding effectiveness coefficient α'_{SE} were taken as a function of the power of radiation source for chosen frequencies. The measurements were conducted for the generator power changing from $-40\,\mathrm{dBm}$ to $0\,\mathrm{dBm}$. Figure 7 shows the results for the frequency of $f = 50\,\mathrm{MHz}$.

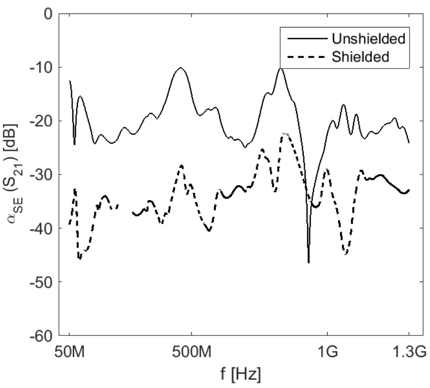

Fig. 6. Comparison of the attenuation coefficients for the tested adapters as a function of the frequency.

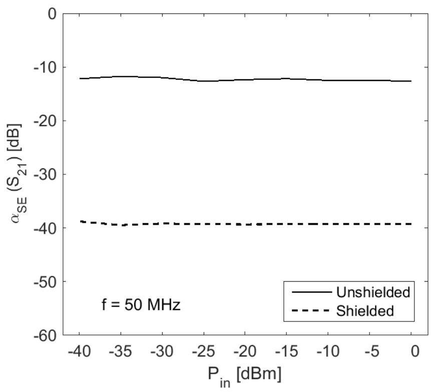

Fig. 7. Values of the attenuation coefficients for the tested adapters as a function of power of the signal source for f = 50 MHz.

The coefficient value α'_{SE} plot indicates that its value does not depend on the level of the generator G signal power.

5. Conclusions

The paper presents the structure of a test set up for determination of the relative value of the shielding effectiveness coefficient of cables and other elements intended for building industrial IT networks. The main constructional assumption was ensuring high repeatability and reproducibility of the measurement conditions. It is especially important during measurements testing the quality of the process of production or during implementation of new constructional or technological solutions. The designed solution, in comparison to the ones so far used, allows to minimise the random effects depends on multiple alignment of the tested elements and settings of the radiation source. Values of the shielding effectiveness coefficient determined using the test set up has to be treated as relative values resulting from the construction and methodology of the test performed with this particular set up. However, it enables reliable comparison of the obtained results.

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