Measuring of cable microphony attenuation

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Coaxial cables, which are subjected to mechanical stresses such as shock, pulling force, physical pressure and torsion, generate electrical charges which are noticeable as disturbing currents or disturbing voltages on the cable. These disturbances, called 'mechanically induced noises' or 'cable microphony', are superimposed on the signals which the cable is carrying. They become significant in the case of low level-signals.

In this article, the basics of cable microphony are briefly described, including piezoelectricity and triboelectricity, as are their effects on coaxial cables. A new measuring procedure, which has been developed by the Institute of Technology TH-Darmstadt, Germany, in cooperation with Bedea, is introduced. Using this procedure, cable microphony is measured with exactly defined mechanical stress and good reproducibility by measuring the electrical charge generated by the cable.

For simple classification of cables with different noise behaviour the cable microphony attenuation in dB nano-Coulomb/micrometer dB (nC/µm) is introduced as a unit of measurement where zero dB is 1 nano-Coulomb.

Introduction

When a coaxial cable is subjected to mechanical stress, such as shock, pulling force, physical pressure or torsion, the cable generates electrical charges.

This effect is often observed with microphone connector cables and is noticeable as rumbling and crackling noises in the loudspeaker which are produced when the microphone cable is in motion or subjected to mechanical stress.

These disturbances, called 'mechanically induced noises' or 'cable microphony', are superimposed on the signals which the cable is carrying. They become significant in the case of low-level signals.

The frequency range of this mechanical-electrical transformation reaches up to about 20 kHz. In the literature listed at the end of the article, fast pulses up to the GHz range are described which are not discussed here.

To prevent cable microphony, cables are designed with special features, such as lubricants on the central conductor, conducting plastics or tapes between dielectric and outer conductor and with special dielectrical materials.

To compare noise performance of different types of cables and of cables from different manufacturers, knowledge is required concerning the magnitude of cable microphony. However, cable manufacturers' data concerning the noise performance of cables differ considerably because they use different measuring procedures and different measuring equipment.

Internationally standardised measuring procedures – American military standard Mil-C-17-G or the procedure according to the IEC 96-4 – provide little reproducibility and are designed for superscreened cables with low flexibility, as well as for special applications.

Below is given a brief introduction to the basics of cable microphony, followed by a description of a new measuring procedure with exactly defined mechanical stress and with good reproducibility which has been developed by the Institute of Technology TH-Darmstadt in cooperation with Bedea's factory laboratories.

For simple classification of cables with different noise behaviour, the cable microphony attenuation in dB nano-Coulomb/micrometer dB (nC/µm) is introduced as a unit of measurement, where zero dB is 1 nano-Coulomb.

Equivalent circuit of coaxial cables

Coaxial cables, Figure 1, normally consist of two concentric conducting cylinders, the inner and outer conductors which are separated by an insulating layer of plastic, the dielectric.

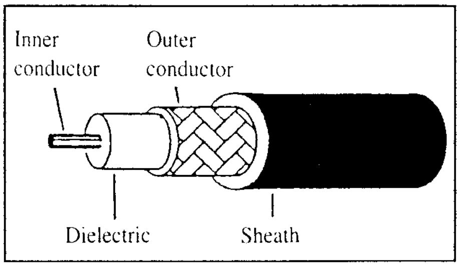

Figure 1. Typical coaxial cable

An additional plastic cylinder, the cable jacket, protects the coaxial cable from environmental influences.

In the equivalent circuit, Figure 2, the coaxial cable is depicted as a two port device. The cable microphony is represented by the current source I_m. The current of this source is determined by the *Leitwert* G_k and the Capacitance C_k of the cable, ie C_k and G_k are considered as the inner resistance of the source in the mechanically stressed part of the cable.

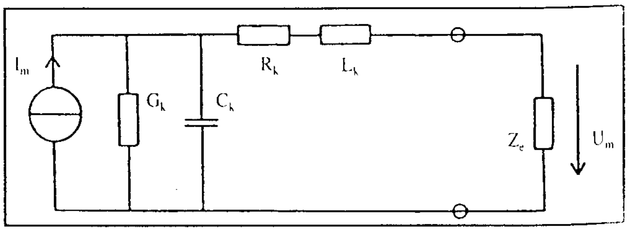

Figure 2. Equivalent circuit

Physical basics of cable microphony

As the origin of cable microphony, both piezoelectric and triboelectric effects have to be considered. Further effects are believed to exist but they have not yet been proved.

Piezoelectric effects cause a movement of charge between the inner side and the outer side of the dielectric which is in contact with the inner and outer conductors, Figure 3.

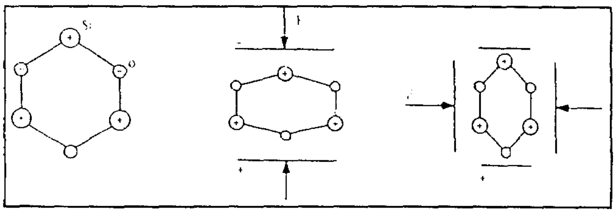

Figure 3. Piezoelectric effect

Triboelectric effects cause the separation of charge when conductors and the dielectric or outer conductor and sheath are quickly separated.

It is not yet possible to separate piezoelectric and triboelectric effects through measurement of the finished cable.

Piezoelectric effect

Piezoelectricity is described as the characteristic of some materials to generate an electric field under the influence of mechanical power, such as physical pressure, pulling or tension, or the characteristic to deform itself under the influence of an electrical field.

Under the influence of mechanical stress, the molecular structure is deformed in such a way that it is no longer electrically neutral, but shows dipolar behaviour. Electrical charges with opposite electrical signs are originated on the boundary surfaces.

Generally, piezoelectric behaviour occurs in materials with at least one or more polar axes. Members of this group of materials are polymeric plastics with a defined arrangement of molecules.

Triboelectricity

Triboelectricity, which is also known as contact electrification, originates from static contact between different materials. If two different materials are in contact with each other, electrons penetrate from one material into the other until there is no difference in the polarity of their surfaces.

If these two materials are then quickly separated and if there is no way for the electrons to compensate, a positive charge remains on the material from which the electrons are emitted, and a negative charge remains on the material where electrons were admitted.

On coaxial cables this event happens both between the inner conductor and the dielectric and between the outer conductor and the dielectric, as well as between the outer conductor and the sheath when a coaxial cable is in motion or when it is physically stressed and conductors are separated from the dielectric.

The magnitude of the triboelectric voltage generated in a cable depends on the distance of the conductor and the dielectric.

For polymer plastics, a triboelectric sequence is given which describes the triboelectric behaviour of these plastics and makes it possible to choose suitable materials for low noise cables. Plastics from the middle of this triboelectric sequence show lower triboelectricity than those from either end.

Known measuring procedures

The internationally standardised procedures to measure cable microphony are:

- The procedure according to the American military standard Mil-C-17-G, 4.8.14, mechanically induced noise, Figure 4.
- The procedure according to the International standard IEC 96-4-1, Appendix B, Test method for cable microphony, Figure 5.

With the procedure according to Mil-C-17-G, the cable under test is fixed between two clamps hanging slack with a weight in the middle of the cable. The cable with the weight is then pulled into a 90° arc and released. The generated charge is measured as voltage with an oscilloscope that has an input resistance of $10 \bullet 10^6\,\Omega$.

The insulation resistance of a PE-insulated cable is more than $10 \bullet 10^{12}\,\Omega \bullet \mathrm{m}$, so that the input resistance of the oscilloscope can be viewed as a shortcircuit to the cable under test. With this undefined excitation of the cable under test and an input resistance lower than the insulation resistance of the test sample a reproducible measurement of low charges is not possible.

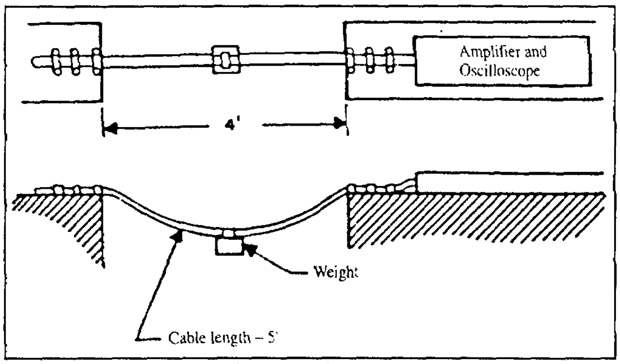

Figure 4. Measuring procedure according to Mil-C-17-G

The procedure according to IEC 96-4-1 is designed for superscreened cables with low flexibility and/or for cables for special applications. The long cable length under test and the input impedance of the amplifier affects the measured results because a part of the generated charge is compensated for by the cable capacitance and the cable resistance.

Besides these two standardised measuring methods, a number of procedures to measure cable microphony using different methods of excitation of the cable sample and with different types of measuring equipment were investigated.

The drawback of all the procedures investigated is the bad reproducibility of the measured results because of the undefined or irregular excitation.

New measuring procedure

Design of test equipment

The purpose of the new procedure is to produce results more easily and with better reproducibility than the procedures discussed above by exactly defined and controlled excitation of the cable sample.

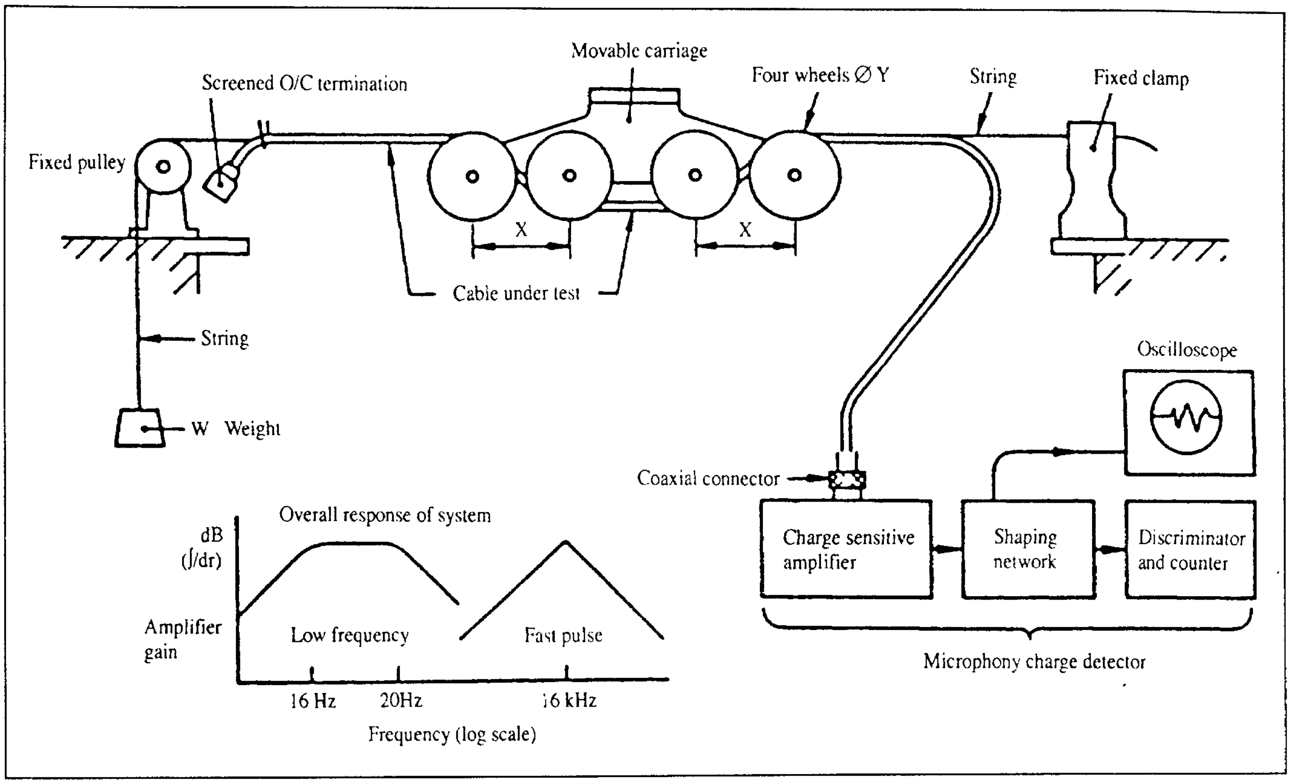

Figure 5. Measuring procedure according to IEC 96-4-1

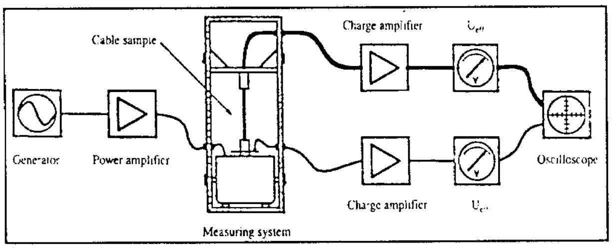

Figure 6. Schematic of new measuring setup

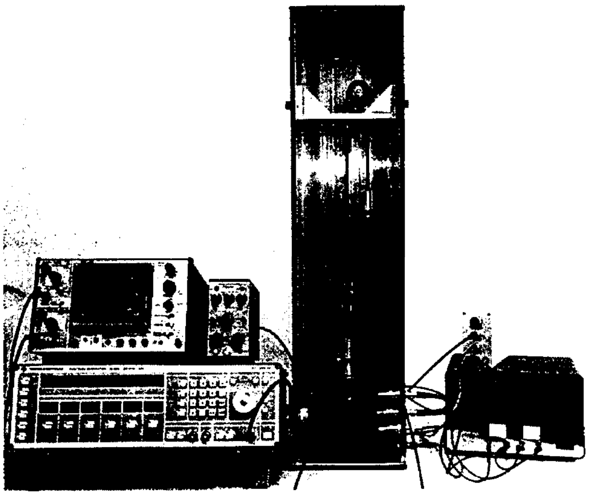

Figure 7. Test equipment used for the measuring of cable microphony attenuation

The cable under test is fixed with one end at the membrane of a vibrator and stretched with a defined weight. The other end of the cable is connected to a charge amplifier. The clamping jaws used to fix the cable under test in the test rig have been specially designed and are similar to a drill chuck.

The vibrator (in principle, the same as a loudspeaker), which is fed by an amplified sinusoidal signal, stretches and compresses the cable under test periodically on its longitudinal axis.

In this way both effects, the piezoelectric by stretching and the triboelectric by compressing the cable, are achieved by only one measuring procedure

The extension of the cable is measured and controlled by measuring the acceleration of the vibrator with accelerometer. The accelerometer is connected to one of the charge amplifiers which gives a voltage proportional to the elongation of the cable by double integrating the accelerometer signal.

The correlation between acceleration a and distance s of the cable elongation $\Delta l/l$ is given by:

$$s = s_0 \cdot \sin(\omega \cdot t + \theta)$$

$$a = \frac{d^2 s}{dt^2} = -s_0 \cdot \omega^2 \cdot \sin(\omega \cdot t + \theta)$$

$$a_0 = (2 \cdot \pi \cdot f)^2 \cdot s_0$$

The elongation of the cable under test should be within a dynamic range of the cable to imitate its practical application so that the cable is not destroyed during the test procedure.

The cable under test is connected to an additional charge amplifier which has an input resistance of about zero. With this input resistance the cable under test is short circuited; thus the ►

whole generated charge can be measured, independent of the length of the connecting cable. The charge amplifier gives a voltage, which is proportional to the charge, to a connected oscilloscope or to a personal computer.

Investigations

During a number of tests with the new setup, Figures 6 and 7, the dependence of the measured cable generated charge from different parameters such as excitation frequency, sample length, elongation, torsion and defined preloading were investigated.

During the second round of tests by TH-Darmstadt, measuring setups used by Kabelmetal Electro of Nürnberg, Bedea of Aßlar and the setup from TH-Darmstadt itself were available. In this way a comparison of different measuring devices was achieved.

Frequency of excitation

During the investigation of suitable frequencies, mechanical resonances from the measuring setup emerged and superimposed the measured cable microphony. After eliminating these mechanical resonances in several steps, a straight trace in measured charge was visible using all of the measuring setups in the range from 50-200 Hz where the elongation $\Delta l/l$ of the sample was in the range of $\leq 0.40‰$.

To avoid mechanical resonances, attention should be paid to fast mounting of the vibrator and the fixing points of the cable sample using only a few components with short lever arms. A ground plate of solid steel mounted on a solid socket is advantageous.

Sample length and elongation

In the range of elongation $\Delta l/l$ of the sample from 0.1‰ up to 0.6‰ a linear increase of the measured charge was visible. At elongation's $\Delta l/l > 0.6‰$ irregularities emerged and finally the boundary line of generated charge was found at values of elongation $\Delta l/l > 1‰$.

The relationship between sample length and measured charge was also linear under the above-mentioned conditions. The maximum permissible sample length depends on the power of the vibrator.

Maximum lengths are 0.3 m with the measuring setups from TH-Darmstadt and Bedea, and 0.5 m with the setup from Kabelmetal Electro. Attention should be paid to resonances from the cable sample when longer samples are under test, especially in the case of smooth samples.

Fixing and mechanical preloading

To fix the cable sample special clamping jaws were designed. Care should be taken not to fix the sample with torsion or mechanical preloading, because depending on the torsion and preloading different results for cable microphony were obtained. If the sample is compressed the results are incorrect. Therefore, a defined mechanical preloading is required for reproducible results.

This defined mechanical preloading is obtained using a guide pulley and a weight in combination with the clamping jaw, Figure 8. For cables with outer diameters up to 5 mm a weight of 500 g is useful. During the investigation of mechanical preloading it was found that a vertical mounting of the cable sample in the test rig is preferable.

The clamping jaw at the vibrator end also acts as a static screen and prevents the cable from disturbing LF-noises from the environment.

Temperature performance

For the investigation of the temperature performance of cables the measuring fixture was modified with an air channel leading preheated air to the cable sample; thus the cable sample was enclosed with preheated air, which was measured and controlled.

The sample under test was conditioned for a sufficient period of time at every temperature step. The cable under test in Figure 9 was designated 0.5/2.95z-TPK, which is specially designed for a temperature range up to 135 °C, with thermoplastic elastomer materials for the dielectric and sheath.

In the range of 50-150 Hz a nearly linear increase of charge versus temperature is visible.

In the upper frequency range resonances occur which are attributable to an increasing softening of the cable; the same effect as if the excited length is too long.

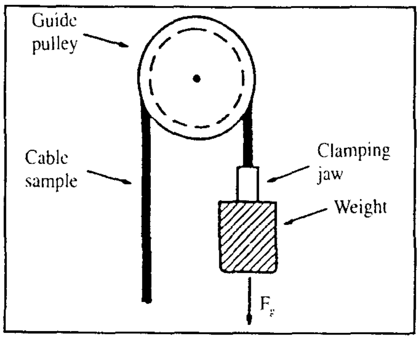

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Figure 8. Defined mechanical preloading

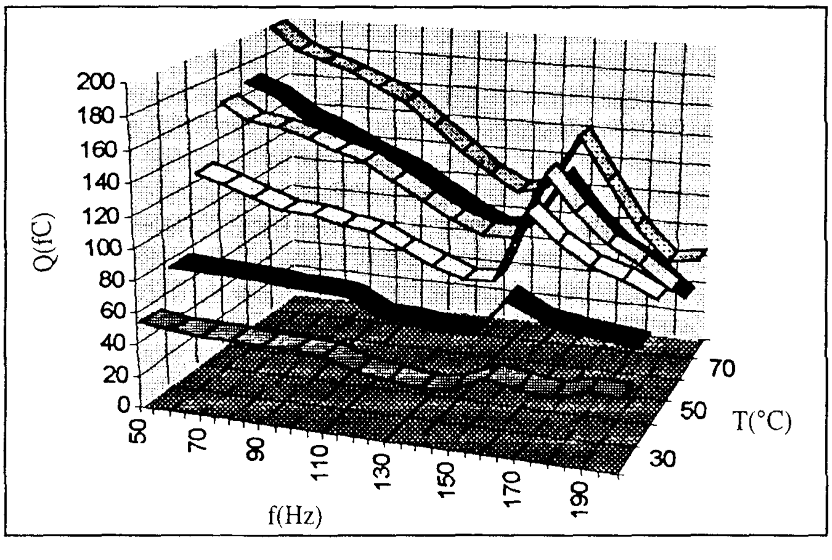

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Figure 9. Temperature performance

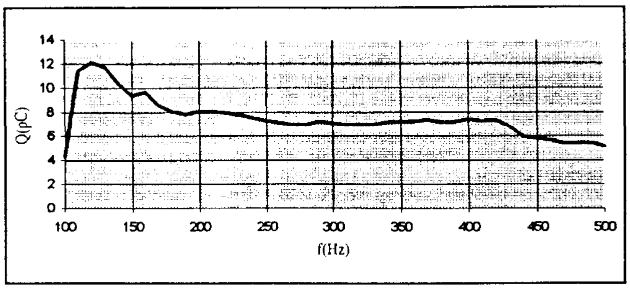

Figure 10. Measured charge Q versus frequency with resonance at 125 Hz

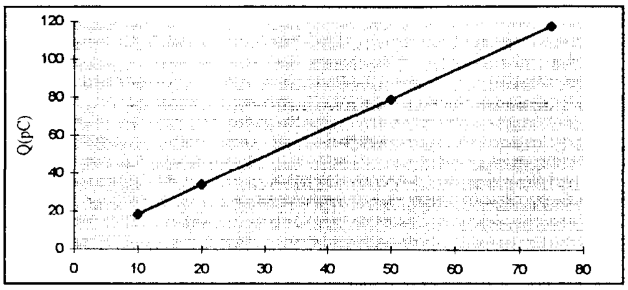

Figure 11. Charge Q versus elongation Δl/l

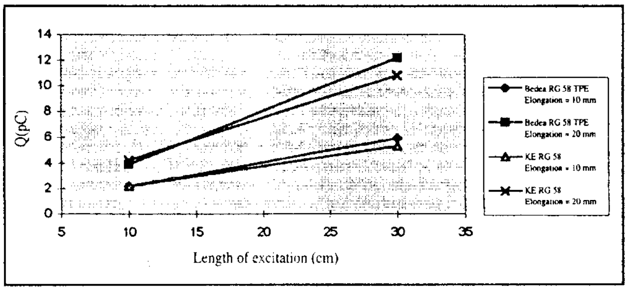

Figure 12. Charge Q versus sample length

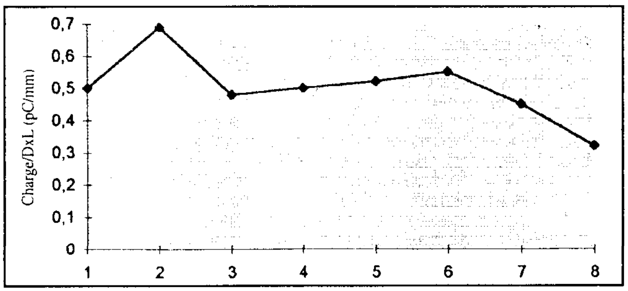

Figure 13. Homogeneity of charge versus cable length

Expression of results

The measured charge depends on the magnitude of excitation as well as on the excited length. This relationship is accepted as a linear behaviour up to a maximum of the magnitude of excitation as well as up to a maximum of the excited length, depending on the size of the measuring setup.

Measuring results can therefore be easily related to the elongation $\Delta l/l$ and the excited length l. Thus the quotient of charge Q_R c an be obtained by:

$$Q_R = Q_{mess} / (\Delta l/l \bullet l) = Q_{mess}/\Delta l$$

where

Q_{mess} = the measured charge in nano Coulomb

Δl = the elongation of the cable sample in µm

l = the length of excitation in m.

For simple classification of low noise cables this quotient of charge Q_R is turned to a logarithmic value defined as 'cable microphony attenuation', where zero dB is 1 nano Coulomb with:

$$Q_{log} = 20\log(Q_R \bullet 1\,\mu m / 1\,nC)\,dB\,(1\,nC/\mu m).$$

Reproducibility of results

On all other investigated measuring procedures the results obtained varied by slightly more than a factor of 10. This was caused by undefined excitation magnitude and procedure, undefined excitation length and other problems. Thus, reproducibility was of great importance during development of the new measuring procedure. Particular attention was paid to:

- Fixing the sample without torsion and with defined preloading.
- Horizontal setup.
- Length and magnitude of excitation in the linear range.
- Setup without resonance.

In this way, a maximum deviation of factor 2 was obtained with the new measuring setup. To obtain better results, statistical methods can be used.

Measurements of the homogeneity of the cable microphony over the cable length came to a distribution of about factor 2, where length of excitation was 50 mm with ten samples from a 15 m length.

Homogeneity of the noise behaviour of a cable depends on the type of cable, the magnitude of generated charge and the quality of the cable, and all should be investigated further. However, such investigations are only useful in the case of reproducible measuring device.

Literature

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