

Transfer impedance of a shielded cable with the shield made from Ni/Ag or Cu/Ni plated cloth tape.

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20-6-2005

The data and information contained within this report was obtained from an independent R&D project funded by EMC Consulting Inc. The contents may be used and quoted but the source must be referenced in any publication.

1) Introduction

The advantage of replacing the standard tin plated copper braid or silver plated copper over-braid shield material with a conductive cloth plated with either nickel plated over silver or nickel plated over copper are weight savings and flexibility.

2) Cable construction and test set up.

The test method used is described in reference 1. The method is also included in IEC 96-1 Amendment 2, however IEC 96-1 contains a major error in the transfer impedance equation on page 41 and does not provide the background information that reference 1 does. The test set up for the cloth braid cable is shown in figure 1. The injection circuit is designed to have a characteristic impedance of 50Ω and the Cable Under Test (CUT) is also designed to have a characteristic impedance of 50Ω .

Conductive cloth shield transfer impedance test set up 100Hz to 1GHz

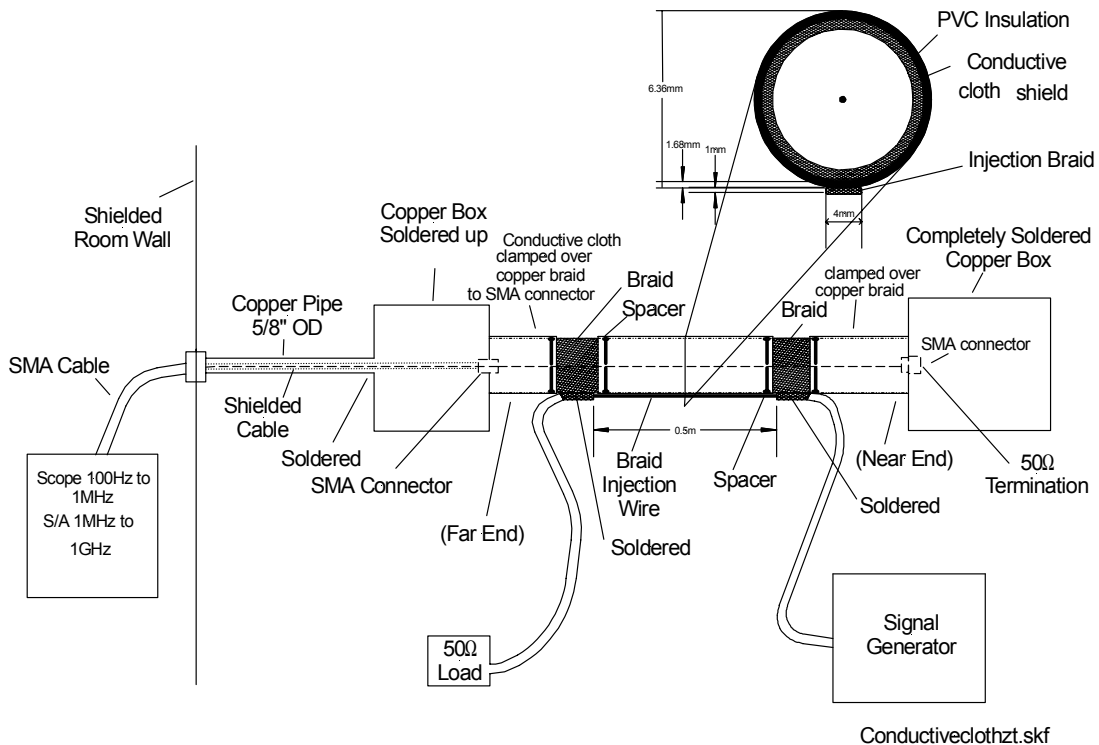


Figure 1 Cable construction and test set up

The current is injected via a 4mm wide braid located above and insulated from the cloth shield and returns to the signal generator via the shield of the CUT. This injection circuit also has a 50Ω characteristic impedance. The voltage developed across this segment of the cloth CUT shield is also measured between the center conductor of the CUT and its shield. This “transferred voltage” is used in calculating the transfer impedance of the cable when measured with a 50Ω load at the near end and open circuit at the far end of the CUT. When measured with a 50Ω load at the far end, the measured voltage is multiplied by two to obtain the transferred voltage. The major problems in the use of this conductive cloth material is the very high dc resistance and in achieving a low impedance connection of the cloth to the backshell of the connector.

Although the material was made up into a 50Ω coaxial cable it would be an impractical use due to the high dc resistance in the signal path and the high insertion loss. Instead the shield would be used over signal cables in which the signal return path is contained in the cable bundle.

Both a Ni/Ag and Ni/Cu plated cloth were tested. The results were very similar and it is the better Ni/Ag material which is reported here. In addition a second Ni/Ag cable was made up and tested. The dc resistance and transfer impedance of these two cables were very similar up to 200MHz. Above 200MHz the transfer impedance of the first cable was higher. The only difference between the two cables was the length of conductive cloth

shield over which the braid of the injection coaxial cable was bonded. In the second cable this connection was over a larger area ensuring a lower impedance at this junction. The second cable was tested more than once over a period of days to ensure reproducibility. The maximum difference in measured transfer impedance over this range of measurements was 2Ω which represents a maximum 9.3% (0.77dB) error, which is well within the measuring equipment accuracy.

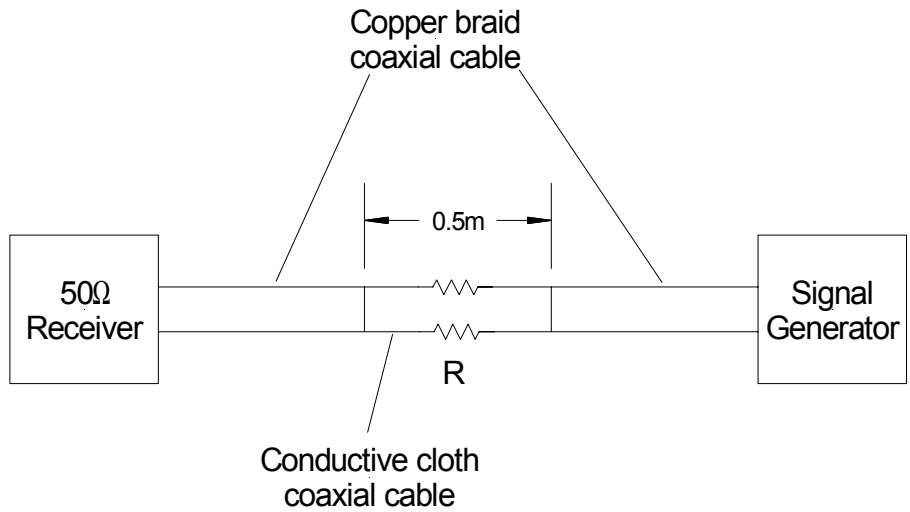
In the IEC 96-1 test set up the CUT is extended either side of the length into which the current is injected, in our case 0.5m. The problem here is the very high shield dc resistance in series with the 50Ω load and source impedances, which introduces a high CUT insertion loss. This dc resistance reduces the voltage developed across the 50Ω measuring equipment and when this voltage is multiplied by two to obtain the open circuit transferred voltage, V_t , a large error occurs.

At low frequency, up to 2MHz, this dc resistance is not important in our test set up as the 50Ω load resistance was removed and an oscilloscope was used to measure the open circuit voltage. For the higher frequency measurements into a 50Ω load, to reduce the CUT shield resistance a copper braid was threaded over the CUT either side of the injection points and this braid was soldered to the SMA connectors. The cloth shield material was then taped tightly to the outside of the copper braid.

This resulted in a lower insertion loss and error in the measurement of voltage into a 50Ω load versus open circuit. This insertion loss may account for the overlap in the two plots which can be seen at 1MHz and 2MHz in figure 3 as the measurements made from 100Hz to 2MHz were made open circuit with an oscilloscope and from 1MHz to 1GHz with a 50Ω input spectrum analyzer. However the oscilloscope measurement is inherently more accurate than the spectrum analyzer ($\pm 0.42\text{dB}$ versus $\pm 2.5\text{dB}$) and as the difference between the two plots is only 2.4Ω (which represents a difference of only 0.76dB) the difference may be due to measurement error.

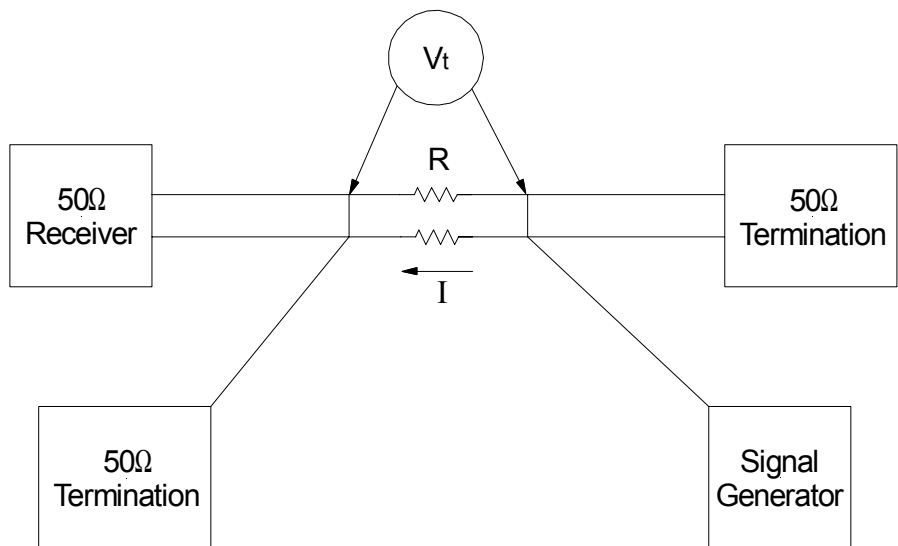
Reference 1 recommends that a measurement be made of the insertion loss of the CUT using the technique shown in figure 2a and that a correction be made in the transfer function. The high resistance of the 0.5m of cloth shield means that a high insertion loss occurs from end to end. However in the transfer impedance measurement the transferred voltage is developed across this resistance and the insertion loss is only in the much lower loss of the copper braid shielded cable attached to the CUT as shown in figure 2b.

At low frequency, leakage currents can exist between the signal generator input signal and the EMI measuring equipment and to avoid this the signal generator was supplied with ac via an isolation transformer. At higher frequencies some of the injection current can continue to flow on the outside surface of the injection shielded cable which then acts as an antenna. To minimize this current two different types of ferrite baluns one type effective at low frequency and the other at high frequency, were strung on the injection cable and these can be seen in the test set up photo 1.



Attenuation Measurement of Cable

Figure 2a



Transfer Impedance Measurement

Figure 2b

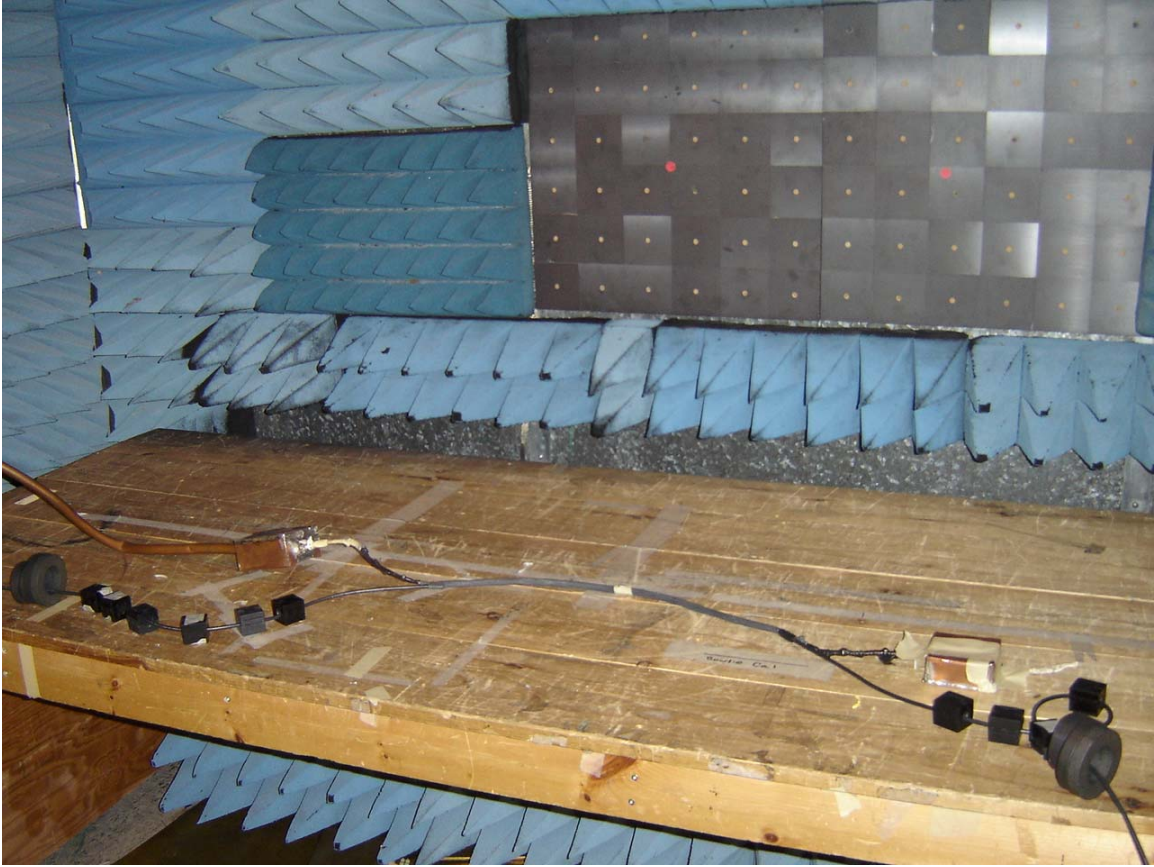


Photo 1 CUT with copper box either end and copper tube and injection cable with ferrites.

3) Test results

At low frequency the transfer impedance of a cable is equal to the dc resistance. The dc resistance of the 0.5m of CUT into which the current is injected was measured at 14.8Ω and the measured transfer impedance of the cable at 100Hz is very close at 13.9Ω . Two methods exist for the calculation of transfer impedance. One is to measure the input and output power transfer function, using the characteristic impedance of the injection circuit and the CUT circuit as described in reference 1. This method takes into account the injection cable insertion loss and the CUT loss. An alternative is to measure the voltage developed across the 50Ω termination at the end of the injection current circuit. From this voltage the injection current can be calculated. The Far End transfer impedance is then given by either the open circuit voltage developed at the Far End of the CUT or the voltage developed across 50Ω multiplied by two, assuming both CUT impedance and load and source impedances are 50Ω . (The Far End is defined as the end furthest away from the injection current point of the CUT).

Both methods were used to calculate the transfer impedance with, as expected, identical results when the injection circuit insertion loss was taken into account as required in method 1.

The measured transfer impedance from 100Hz to 1GHz is provided in figure 3, from which we see that the value is incredibly high.

The surface resistivity of the cloth is specified as $0.1\Omega/\text{sq}$ and this is exactly the value measured at EMC Consulting. Due to skin depth effect one might expect the shielding effectiveness to increase above approximately 10MHz. One reason this does not happen may be that although the material has no visible gaps it is woven and a similar effect to the porpoising coupling seen in braided shielded cables may occur.

Also in the manufacturing of the cloth it has a longitudinal seam, similar to a foil shielded cable, which is folded over and stitched. And as this is the weak link in the foil cable so it may be in the cloth cable.

In the construction of the cables great care was taken to ensure that the injection braid was not directly over the seam.

As a 50Ω cable and source and load impedances are used the shielding effectiveness is provided by:

$$20\text{Log}\left(l \times \frac{2R_0}{Z_t}\right)$$

Where l is the length of the cable

R_0 is the characteristic impedance of the CUT and load and source impedances

Thus from 10kHz to 1MHz the shielding effectiveness is no more than 10.6dB!

The hypothesis is that the increase in transfer impedance above 150MHz is almost certainly due to the increasing impedance of the shield material which is not offset by any attenuation due to skin depth effect. Thus as the increasing shield impedance reduces the injection current the voltage drop across the transfer impedance, which is the transferred voltage, does not decrease and the transfer impedance increases.

4) Conclusions

The transfer impedance of this type of cable is extremely high, but it can be reduced by increasing the diameter of the cable, which reduces the dc resistance. Also at low frequency a drain wire can be used to further reduce the dc resistance of the shield and the injected current then flows predominantly on the drain wire until its inductive reactance is higher than the dc resistance of the cable shield. The argument can be made that the conductive cloth is redundant and that a drain wire connecting the backshells of two connectors can also provide some shielding when compared to no drain wire.

A practical 1m long cable was made with a drain wire and a diameter of 28mm compared to the 3mm diameter of the CUT tested here. The overall shielding effectiveness of this cable when connected to shielded connectors with backshells was 30dB at 0.2MHz and 20dB at 10MHz. The shielding effectiveness of the CUT described here at 0.2MHz (given by $20 \log ((2xR_o/Z_t)xl) = 20 \log (2 \times 50\Omega/30\Omega/m) \times 1m = 10.46dB$). The difference in the diameters of the two cables in dB is $20 \log (28mm/3mm) = 19.4dB$ and the larger diameter cable will have a lower dc resistance. As the cable contains a drain wire the shield resistance is in parallel with the inductive reactance of the drain wire. If the drain wire reactance is ignored and the CUT measured S.E. is corrected only for the increased diameter the predicted attenuation is: $10.46dB + 19dB \approx 30dB$ which is equal to the measured attenuation of the practical 1m long cable. This shows that the S.E. at low frequency is strongly dependent on the dc resistance of the cable. As the cable would be used as an overshield and any signals on the center conductors enclosed by the shield would also contain the signal return the attenuation is of the common mode current induced into the center conductors. Although this practical cable shows an improvement over the CUT described here it is still a long way from the shielding effectiveness achieved by a Belden tin plated over-braid which was measured at 71dB at 0.25MHz, 58dB at 10MHz and 44dB at 100MHz!

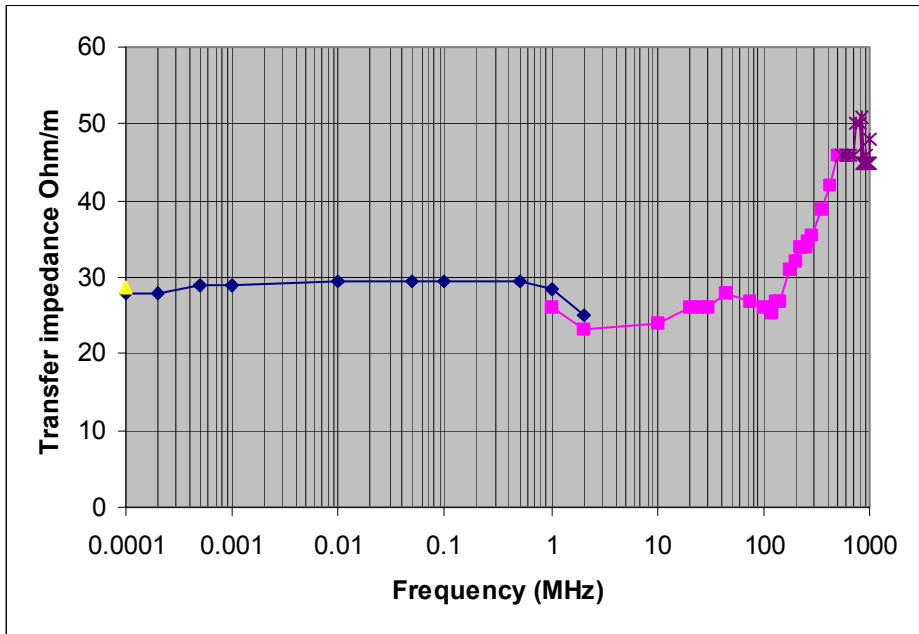


Figure 3 Measured transfer impedance of conductive cloth shielded cable. Yellow plot is dc resistance, blue is measurement into open circuit, red is the corrected measurements made into 50Ω load .

5) Discrepancy in published shielding effectiveness and measured.

The shielding effectiveness of the conductive cloth is specified at 83dB to 60dB over the 200MHz to 18GHz frequency range using the MIL-STD-285 test method. This measurement was almost certainly made using a plane wave source. Intuitively if a field with a wave impedance of 377Ω is incident on a material of infinite dimension with a surface resistivity of $0.1\Omega/\text{sq}$, approximately 71dB of shielding effectiveness can be expected, as the E field component of the plane wave is reflected. However if an H field with a wave impedance of 0.1Ω is incident the S.E. may be closer to 0dB. Using the surface resistivity of the cloth of $0.1\Omega/\text{sq}$ the predicted shielding effectiveness, from measurements described in reference 2, at 1MHz is only 1.4dB.

The surface transfer impedance cable test induces a current flow on the shield of the cable and effectively measures predominantly its magnetic field attenuation and as expected this is low.

References

- 1) Simple and accurate screening measurements on RF cables up to 3GHz. Bernhard Eicher, Christian Staeger and Balint Szentkuti, Berne, Heinz Fahrni, Solothun, Technische Mitteilungen PTT 4/1988.
- 2) Comparative magnetic field S.E. of thin conductive coatings. D. A. Weston, K. McDougall . Published on this web site.