How to use a CCC01 to measure cable shielding effectiveness through transfer impedance

The CCC01 is based on the design described in IEC 96-1 Amendment 2:1993, also used in IEC 62153-4-6:2006 and mandated for the line injection method in EN 50289-1-6.

EN 50289-1-6:2002 states "The transfer impedance Z_T of an electrically short uniform cable is defined as the quotient of longitudinal voltage induced in the outer circuit due to the current in the inner circuit or vice versa, related to unit length". York EMC Services has historically measured Z_T "vice versa", and this method will be described here.

The transfer impedance definition can be summarised as:

$$Z_T = \frac{V_L}{I_{SH} L}$$

V_L (longitudinal voltage) is the voltage between points 1 and 2 on the inner conductor (Figure 1). I_{SH} is the shield current and L is the coupled length. As it is impractical to measure V_L directly the voltage measurement is made across the load impedance as indicated. Normally values of Z_T are given in W/m.
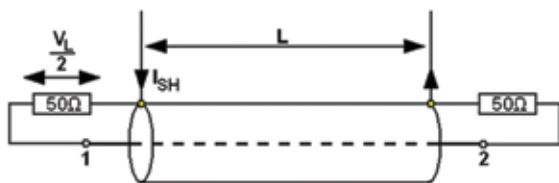

Figure 1. Theoretical arrangement for measuring Z_T

Description of the line injection method

A schematic diagram of the line injection method is shown in Figure 2. This is the simplest method of achieving the theoretical arrangement described above.
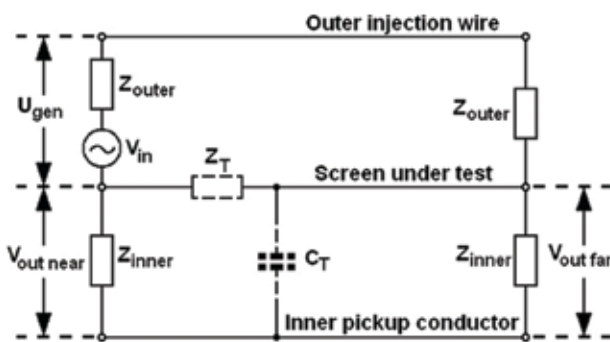

Figure 2. Schematic diagram of line injection method

To ensure both inner and outer circuits of the line injection arrangement are matched, the transmission line comprising the outer injection wire and the screen under test must have a characteristic impedance (Z_0) of Z_{OUTER}. Similarly, Z_0 for the transmission line of the screen under test and the inner pick up conductor should equal Z_{INNER}.

Required test instrumentation

The measurement of Z_T is most easily achieved by using a Network Analyser. For example an Agilent 8753ES 30 kHz to 6 GHz model gives a dynamic range ~100 dB (allowing ~ 100 dB of shielding to be measured without using additional amplifiers) and high immunity to external noise sources. The optional time domain upgrade also allows the reflection factor of the CCC01 "launchers" to be measured easily.

High quality microwave cables with N-type connectors are needed to connect the network analyser to the CCC01. Unwanted coupling through the screens of low quality coaxial cables may affect the measurement. Similarly, good quality 50 Ω loads are needed.

The measurement of a 50 Ω coaxial cable is described here. Cables with different characteristic impedances can be measured, but require special consideration.

The CCC01 can be configured to provide a coupling length of either 0.5 m or 0.3 m. The standards provide a formula for calculating the maximum cable length for a given frequency, based on the assumption that the sample must be electrically short at the frequency of interest. For IEC 62153-4-6:2006 the formula is:

$$f_{max} \leq \frac{c}{\pi \times L_{max} \left| \sqrt{\varepsilon_{r2}} \pm \sqrt{\varepsilon_{r1}} \right|}$$

where;

- ε_{r1} is the relative permittivity of the dielectric of the injection circuit;
- ε_{r2} is the relative permittivity of the cable dielectric;
- ± refers to near/far end measurement (+near, -far);
- c is the velocity of light, 3×10^8 m/s;
- f_{max} is the highest frequency to be measured in Hz;
- L_{max} is the maximum coupled length in m.

For example assuming a relative permittivity of the cable jacket (ε_{r1}) of 2.7 (pure PVC) and a relative permittivity of the cable inner dielectric (ε_{r1}) of 3.8 (pure Nylon), the results of the calculation are summarised in Table 1.

Theoretical f_{max}	L_{max} = 0.3 m	L_{max} = 0.5 m
Near end measurements	88.6 MHz	53.2 MHz
Far end measurements	1.04 GHz	623.7 MHz

Table 1. f_{max} vs L_{max}, from IEC 62153-4-6:2006

In practice one of the features of the jig is that samples can be electrically long, with little standing wave disturbance for far end measurements, so calculated values of electrical length are not as important as suggested by the standards. Slightly improved return loss on the injection circuit might be obtained for a 0.3 m sample, whereas a 0.5 m sample gives increased coupling. For well screened cables the latter makes the measurement dynamic range requirements slightly less onerous. In this example a coupled length of 0.5 m is used, requiring a 1 m test cable terminated with N-type connectors.

The preparation of the test cable is covered in detail in the CCC01 Operation Manual. Once the test cable is fitted into the CCC01, the injection circuit must be added and this is most easily implemented by attaching adhesive copper foil to the test cable jacket.
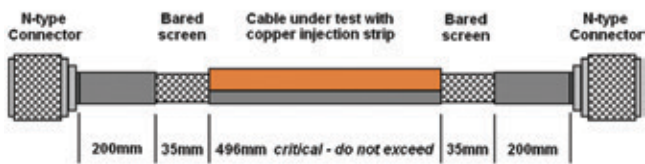

Figure 3. Prepared test sample with injection strip

The characteristic impedance of the injection circuit is adjusted by altering the foil strip width. For guidance, the following formula derived from Kraus[1] is useful, where W = width of strip and H = height above shield, normally ~ 1 mm for a typical cable jacket):

$$\frac{W}{H} = \frac{377}{\sqrt{\varepsilon_r}\, Z_0} - 2$$

This gives a strip width of 2.5 mm for $\varepsilon_r = 2.7$ (PVC) and $Z_0 = 50\ \Omega$. It should be noted that the text book value of ε_r given for PVC is unlikely to be correct due to variations in manufacturing processes and polymer "recipes".

Once the width of the injection strip is decided it should be fitted and soldered to the wires protruding from the launchers as shown in Figure 4.

Figure 4. Injection strip fitted to Cable Under Test (CUT)

Example measurements

According to IEC 62153-4-6:2006 the injection circuit should be matched to give a return loss of better than 20 dB (i.e. a reflection factor at each launcher <0.1). This is achievable for frequencies up to a few hundred MHz, but by 1 GHz this is not possible. Figure 5 shows typical return loss measurements on the outer injection and the inner circuits. If available on the network analyser, the time transform option can be used to locate the regions where mismatch is the greatest and if appropriate, improvements can made by altering the copper tape width or height.
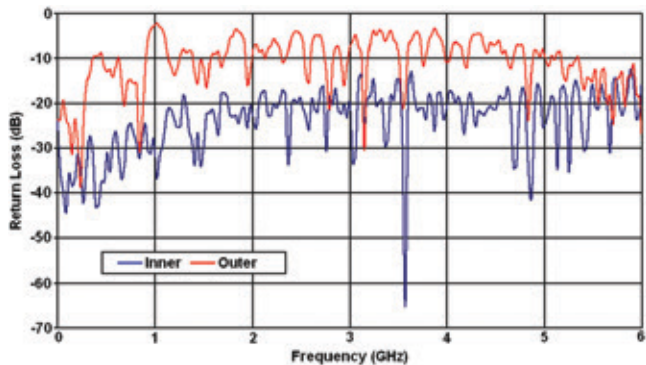

Figure 5. Injection (outer) and inner circuit return loss

Measurements of coupling

Measurements of coupling can be made at the "near" end or far "end". Figure 6 shows the CCC01 configured for a near end measurement. Figure 7 shows the raw results for near and far end coupling measurements. As can be seen, the far end measurements are generally greater than those at the near end, and furthermore are generally free from major disturbance from standing wave effects.
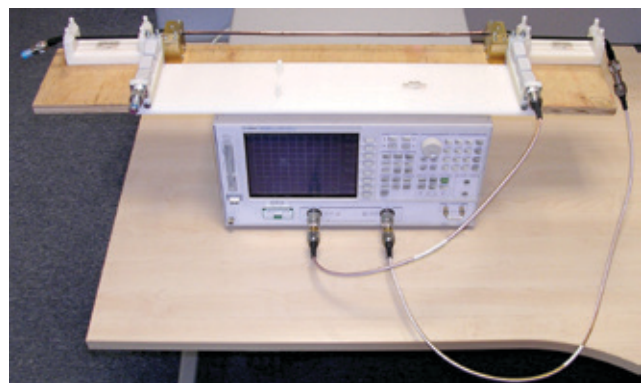

Figure 6. CCC01 configured for a "near" end coupling measurement

IEC 62153-4-6:2006 requires that both near and far end measurements are made. However, as shown in Figure 7 and discussed later, for high frequency measurements (above 50 MHz) it is likely that near end measurements will have too much resonant structure to be valid. In such cases it is reasonable to measure Z_T above 50 MHz using far end measurements only.
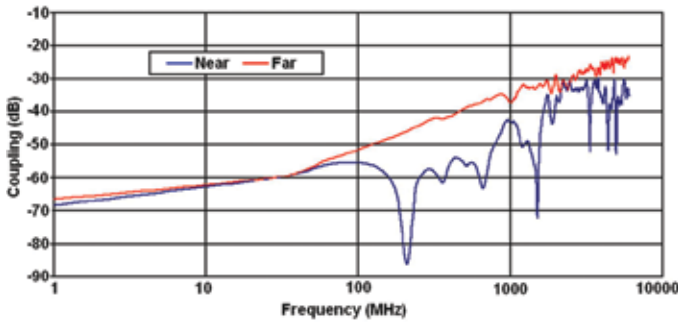
Figure 7. Typical coupling measurement results using log frequency scale as per IEC 62153-4-6:2006

For IEC 62153-4-6:2006 at least four measurements should be made, with the test cable rotated in the clamp each time (i.e. 0°, 90°, 180°, 270°). This is to identify any seams in the shield, as would occur with a foil shield.

Treatment of Results

The network analyser measurements of S_{21} can be used to derive Z_{TE} (Equivalent Transfer Impedance).

Z_T is a measurement of inductive coupling. If the shield is loosely braided then some capacitive coupling will also be measured. The inductive and capacitive parts of the coupling cannot be separated so the standards define the parameter Z_{TE} that comprises both inductive and capacitive coupling (should it be present). IEC 62153-4-6:2006 requires that results give Z_{TE} in units of ohms per unit length.

Z_{TE} from S_{21} in accordance with IEC 62153-4-6:2006

Equation (17) of IEC 62153-4-6:2006 states:

$$Z_{TE} = \frac{2R_2}{L_c \times k_m} 10^{\left(\frac{-A_T}{20}\right)}$$

where for our example 50 Ω coaxial cable

$$A_T = 20 \log_{10} \left(\frac{U_{gen}}{U_{rec}} \right)$$

$R_2 = 50\ \Omega$ (load resistance)
$L_C = 0.5$ m (the coupled length)
$k_m = 1$ (matching network voltage gain – nonexistent in our example so $k_m = 1$)

U_{gen} is shown on Figure 2 and U_{rec} corresponds to V_{OUTFAR} or $V_{OUTNEAR}$ on that diagram.

Expressing Equation (17) in dB for our example:

$$Z_{TE}\,(dB\Omega/m) = 46\,dB + U_{rec}\,(dB\mu V) - U_{gen}\,(dB\mu V)$$

Due to the definition of S_{21}:

$$S_{21}\,(dB) = U_{rec}\,(dB\mu V) - U_{gen}\,(dB\mu V)$$

Thus: $\quad Z_{TE}\,(dB\Omega/m) = S_{21}\,(dB) + 46$

So to express Z_{TE} in line with IEC 62153-4-6:2006 for the example 0.5 m long 50 Ω coaxial cable, add 46 dB to the S_{21} measurement.

References

[1] Kraus/Fleisch, *Electromagnetics with Applications*, fifth edition, 1999, ISBN 0-07-116429-4, McGraw-Hill International Editions