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Metallic communication cable test methods –
Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method

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International Standard IEC 62153-4-9 has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This standard cancels and replaces IEC/PAS 62338 published in 2002.

The text of this standard is based on the following documents:

CDV	Report on voting
46/190/CDV	46/222/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62153 series can be found, under the general title *Metallic communication cable test methods*, on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition; or
- amended.

A bilingual version of this publication may be issued at a later date.

METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method

1 Scope

This part of IEC 62153 applies to metallic communication cables. It specifies a test method for determining the coupling attenuation a_C of screened balanced cables. Due to the concentric outer tube, measurements are independent of irregularities on the circumference and external electromagnetic fields.

A wide dynamic and frequency range can be applied to test even super screened cables with normal instrumentation from low frequencies up to the limit of defined transversal waves in the outer circuit at approximately 4 GHz. However, the upper frequency is limited by the properties of the baluns.

The procedure to measure the coupling attenuation a_C is based on the procedure to measure the screening attenuation a_S according to IEC 62153-4-5.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-726, *International Electrotechnical Vocabulary (IEV) – Chapter 726: Transmission lines and wave guides*

IEC/TR 62153-4-1, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements*

IEC 62153-4-5, *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

3 Terms, definitions and symbols

For the purposes of this document the terms and definitions given in IEC 60050-726, IEC 62153-4-1 and IEC 62153-4-5, as well as the following symbols apply.

a_s is the screening attenuation which is comparable to the results of the absorbing clamp method in dB;

a_c is the coupling attenuation related to the radiating impedance of 150 Ω in dB;

a_u is the unbalanced attenuation;

$a_{m,min}$ is the attenuation recorded as minimum envelope curve of the measured values in dB;

a_z is the additional attenuation of an eventually inserted adapter, if not otherwise eliminated e.g. by the calibration, in dB;

C_T is the through capacitance of the outer conductor in F/m;

c_0 is the vacuum velocity in m/s;

dx is the differential length operator of integraton;

λ_0 is the vacuum wavelength in m;

ε_{r1} is the relative dielectric permittivity of the cable under test;

ε_{r2} is the relative dielectric permittivity of the secondary circuit;

$\varepsilon_{r2,n}$ is a normalised value of the relative dielectric permittivity of the environment of the cable;

f is the frequency in Hz;

j is the imaginary operator (square root of minus one);

L is the transmission line parameter-inductance;

l is the effective coupling length in m;

φ is a phase factor in the ratio of the secondary to primary circuit end voltages (U_1/U_2);

P_1 is the feeding power of the primary circuit in W;

P_2 is the measured power received on the input impedance;
R of the receiver in the secondary circuit in W;

P_r is the radiated power in the environment of the cable, which is comparable to $P_{2,n}$ + $P_{2,f}$ of the absorbing clamp method in W;

$P_{r,max}$ is the periodic maximum values of the common mode radiated power in W;

P_s is the radiated power in the normalised environment of the cable under test,
(Z_s = 150 Ω and $|\Delta v / v_1|$ = 10 %) in W,

$$\varphi_1 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \qquad (1)$$

$$\varphi_2 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \qquad (2)$$

$$\varphi_3 = \varphi_2 - \varphi_1 = 4\pi \times \sqrt{\varepsilon_{r2}} \times l / \lambda_0 \qquad (3)$$

R is the input impedance of the receiver in Ω;

R_1 is the differential mode termination, Ω;

S is the summing function;

T is the coupling transfer function;

U_1 is the input voltage of the primary circuit formed by the cable in V;

U_2 is the output voltage of the secondary circuit in V;

Ω is the radian frequency;

Z_1 is the (differential mode) characteristic impedance of the cable under test (primary circuit) in Ω;

Z_2 is the characteristic impedance of the secondary circuit in Ω;

under test (150 Ω secondary circuit impedance Z_2) in Ω;

Z_{com} is the common mode (unbalanced);

Z_{diff} is the nominal characteristic differential mode impedance of the differential mode (balanced);

Z_F is the capacitive coupling impedance of the cable under test in Ω/m,

Z_s is the normalised value of the characteristic impedance of the environment of the cable

Z_T is the transfer impedance of the cable under test in Ω/m;

$$Z_F = Z_1 \times Z_2 \times j \times 2 \times \pi \times f \times C_T \qquad (4)$$

4 Principle of the measuring method

The test set up (see Figure 1) is a triaxial system consisting of an outer solid metallic tube in which are concentrically positioned the first several meters of a longer length of the cable to be tested. The length of the cable under test that extends past the tube is placed in a highly shielded box and terminated with common mode and differential mode terminations.

The disturbing circuit (the inner or primary circuit) consists of the test cable which is fed by a generator and is impedance-matched at the near and far ends. The disturbed circuit (the outer or secondary circuit) is formed by the solid metallic tube and the short section of the cable under test covered by the tube. The disturbed circuit is terminated at the near end in a short circuit and is terminated at the far end with a calibrated receiver or network analyzer.

The voltage peaks at the far end of the secondary circuit are measured with a calibrated receiver or network analyzer. For this measurement a matched receiver is not necessary. These voltage peaks are not dependant on the input impedance of the receiver, provided that it is lower than the characteristic impedance of the secondary circuit. However, it is advantageous to have a low mismatch, for example by selecting a range of tube diameters for several cable sizes.

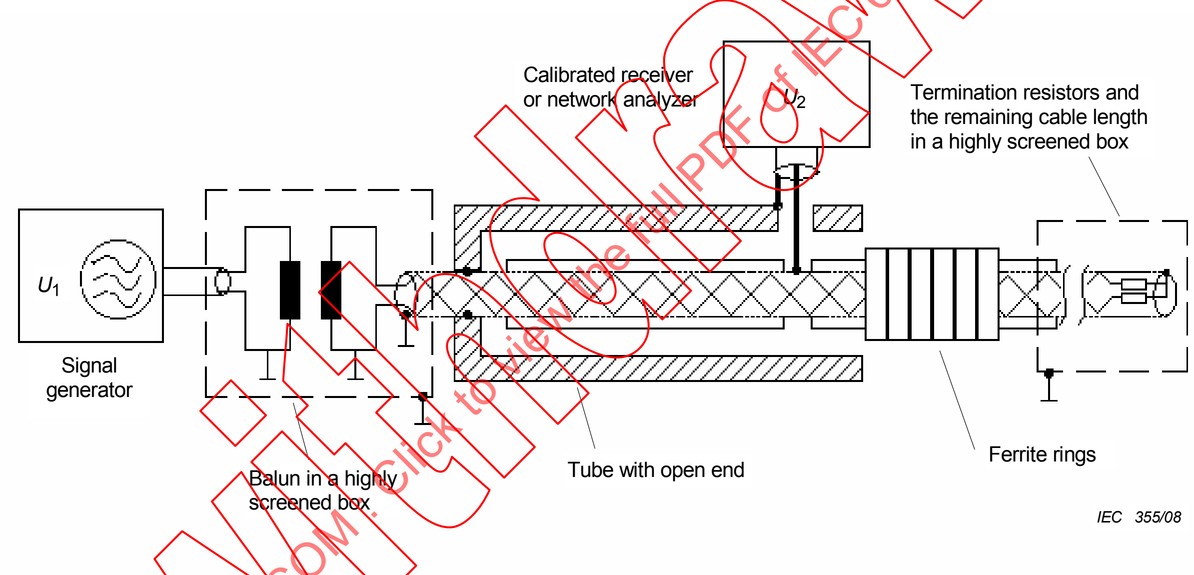

Figure 1 – Principle test set-up

5 Theoretical background

5.1 Unbalanced attenuation a_u

Screened balanced pairs may be operated in the differential mode (balanced) or the common mode (unbalanced). In the differential mode, one conductor carries the current +*I* and the other conductor carries the current -*I*; the screen is without current. In the common mode, both conductors of the pair carry half of the current +*I*/2; and the screen is the return path with the current -*I*.

Under ideal conditions with ideal cables, both modes are independent of one another. Actually both modes influence each other. Differences in the diameter of the core insulation, unequal twisting and different distances of the pair. The unsymmetry is caused by the capacitive unbalance to earth *e* (transverse - unsymmetry) and the difference of the inductance and resistance between the two wires *r* (longitudinal - unsymmetry).

$$e = C_{10} - C_{20} \tag{5}$$

$$r = (R_2 + j\omega \times L_2) - (R_1 + j\omega \times L_1) \quad (6)$$

The coupling transfer functions between the two modes at the near and far ends is then expressed by:

$$T_{u,n} = \frac{1}{4} \times \frac{1}{\sqrt{Z_{diff} \times Z_{com}}} \times \int_0^l (j\omega \times e(x) \times Z_{diff} \times Z_{com} + r(x)) \times e^{-(\gamma_{diff} + \gamma_{com}) \times x} dx \quad (7)$$

$$T_{u,f} = \frac{1}{4} \times \frac{1}{\sqrt{Z_{diff} \times Z_{com}}} \times \int_0^l (j\omega \times e(x) \times Z_{diff} \times Z_{com} - r(x)) \times e^{(\gamma_{diff} - \gamma_{com}) \times (l-x)} dx \quad (8)$$

Z_{diff} and Z_{com} are in principle the same coupling transfer functions compared to the coupling through the screen. The integral may be solved if the distribution of the unsymmetry functions along the cable length is known.

For a constant unsymmetry along the cable length, the coupling function is expressed by (similar to the form of the coupling function for cable screens):

$$T_{uf}^{n} = (j\omega \times e \times Z_{diff} \times Z_{com} \pm r) \times \frac{1}{\sqrt{Z_{diff} \times Z_{com}}} \times \frac{l}{4} \times S_f^n \quad (9)$$

If the cable is electrically long, there is the same phenomenon as for the coupling through the screen. Depending on the velocity difference between the differential and the common mode circuit, the envelope of the transfer function approaches a constant value which is frequency and length independent. However, if the velocity difference is zero, then the transfer function at the far end increases by 20 dB per decade over the whole frequency range ($S_f = 1$). In practice, there are small systematic couplings as well as statistical couplings. Thus $T_{u,n}$ increases by approximately 10 dB per decade and $T_{u,f}$ by less then 20 dB per decade.

5.2 Screening attenuation a_s

The screening attenuation a_s is given by

$$a_s = -10 \times \log_{10}\left(\text{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \quad (10)$$

At high frequencies and when the cable under test is electrically long:

$$\sqrt{\left|\frac{P_{2max}}{P_1}\right|} \approx \frac{c_0}{\omega\sqrt{Z_1 \times Z_2}} \times \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}\right| \quad (11)$$

For exact calculation, if feedback from the secondary to the primary circuit is negligible, the ratio of the far end voltages U_1 and U_2 are given by:

$$\left|\frac{U_2}{U_1}\right| \approx \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_1}\right] + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_2}\right]\right| \times \left|\frac{1}{\omega \times Z_1}\right| \times \left|\frac{c_0}{2 + (Z_2 / R - 1) \times \left(1 - e^{-j\varphi_3}\right)}\right| \quad (12)$$

5.3 Coupling attenuation a_c

Balanced cables which are driven in the differential mode may radiate a small part of the input power, due to irregularities in the cable symmetry. For unscreened balanced cables, this radiation is related to the unbalanced attenuation a_u. For screened balanced cables, the unbalance causes a current in the screen which is then coupled by the transfer impedance and capacitive coupling impedance into the outer circuit. The radiation is attenuated by the cable screen and is related to the screening attenuation a_s.

Consequently, the effectiveness against electromagnetic disturbances of shielded balanced cables is the sum of the unbalanced attenuation a_u of the pair and the screening attenuation a_s of the screen. Since both quantities are usually given in a logarithmic ratio, they may simply be added to form the coupling attenuation a_c:

$$a_c = a_u + a_s \quad (13)$$

Coupling attenuation a_c is determined from the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the power $P_{r,max}$ (which may be radiated due to the peaks of voltage U_2 in the outer circuit):

$$a_c = -10 \times \log_{10}\left(\mathrm{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \quad (14)$$

The relationship of the radiated power P_r to the measured power P_2 received on the input impedance R is:

$$\frac{P_S}{P_2} = \frac{P_{Smax}}{P_{2max}} = \frac{R}{2 \times Z_S} \quad (15)$$

There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superposition of the partial waves caused by the surface transfer impedance Z_T ,the capacitive coupling impedance Z_F (travelling to the far and near end) and the totally reflected waves from the near end.

6 Measurement

6.1 Equipment

The measurement set-up is shown in Figure 2 and consists of:

- a metallic non ferromagnetic tube with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn;
- a network analyser (a separate generator and receiver may also be used);

- a balun for impedance matching of unbalanced generator output signal to the characteristic impedance of balanced cables , see 6.2;
- ferrite rings with an attenuation $a_{Ferrite}$ > 10 dB in the measured frequency range;
- metallic boxes to shield the balun and the remaining cable length including the matching resistors.

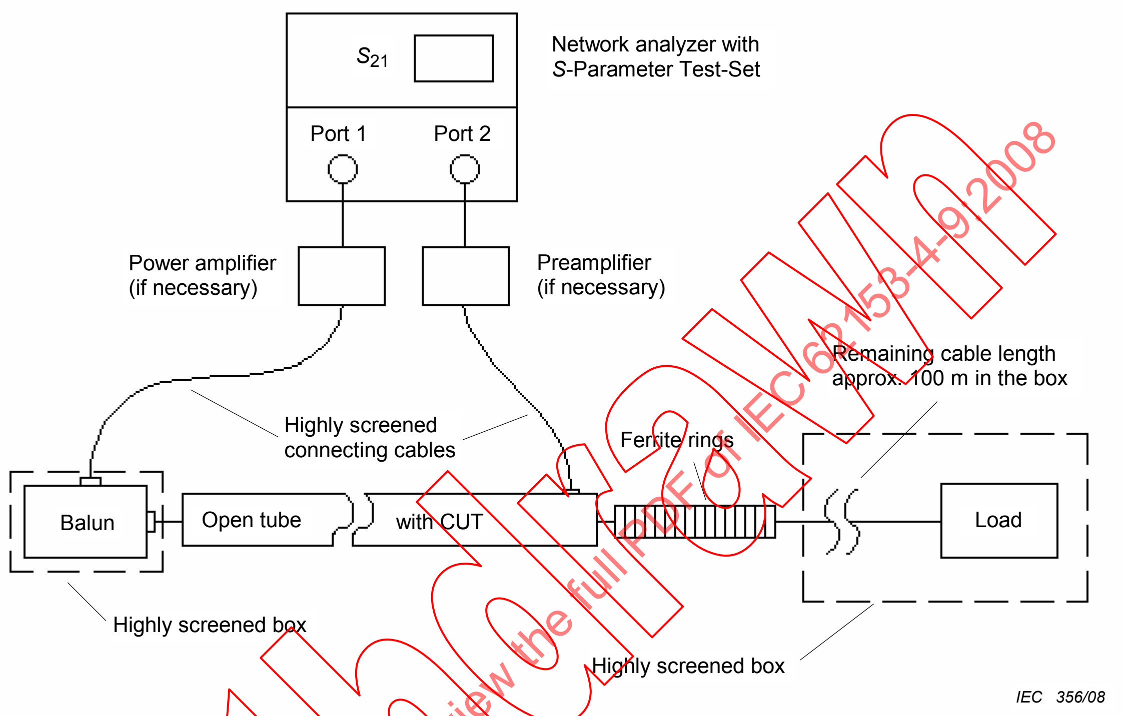

Figure 2 – Set-up to measure the coupling attenuation

6.2 Balun requirements

A balun may be required to match the output impedance of the generator (a balun is not required when a balanced output generator is used) to the nominal characteristic impedance of the cable under test. The balun performance requirements are specified in Table 1.

The attenuation of the balun shall be kept as low as possible because it will limit the dynamic range of the coupling attenuation measurements.

Table 1 – Balun performance characteristics (1 MHz to 1 GHz)

Parameter	Value
Impedance, primary[a]	50 Ω (unbalanced)
Impedance, secondary[b]	100 Ω or 150 Ω (balanced)
Insertion loss[d] (including matching pads if used)	≤ 10 dB
Return loss, bi-directional	≥ 6 dB
Power rating	To accommodate the power of the generator and amplifier (if applicable)
Output signal balance[c]	≥ 50 dB from 1 MHz to 30 MHz ≥ 50 dB from 30 MHz to 100 MHz ≥ 30 dB from 100 MHz to 1 GHz

[a] Primary impedance may differ if necessary to accommodate analyser outputs other than 50 Ω.

[b] Balanced outputs of the test baluns should be matched to the nominal impedance of the symmetrical cable pair. 100 Ω should be used for termination of 120 Ω cabling.

[c] Measured per ITU-T Recommendations G.117 [1][1] and O.9 [2].

[d] The insertion loss of a balun shall be mathematically deduced from 3 insertion loss measurements with 3 baluns back-to-back (see also 62153-4-5).

6.3 Sample preparation

A differential mode termination is required for each pair at the near and far end of the cable.

$$R_1 = \frac{Z_{\text{diff}}}{2} \quad (17)$$

The center taps of the terminations shall be connected together; and shall be connected to the screens.

The entire length of the cable shall be at least 100 m.

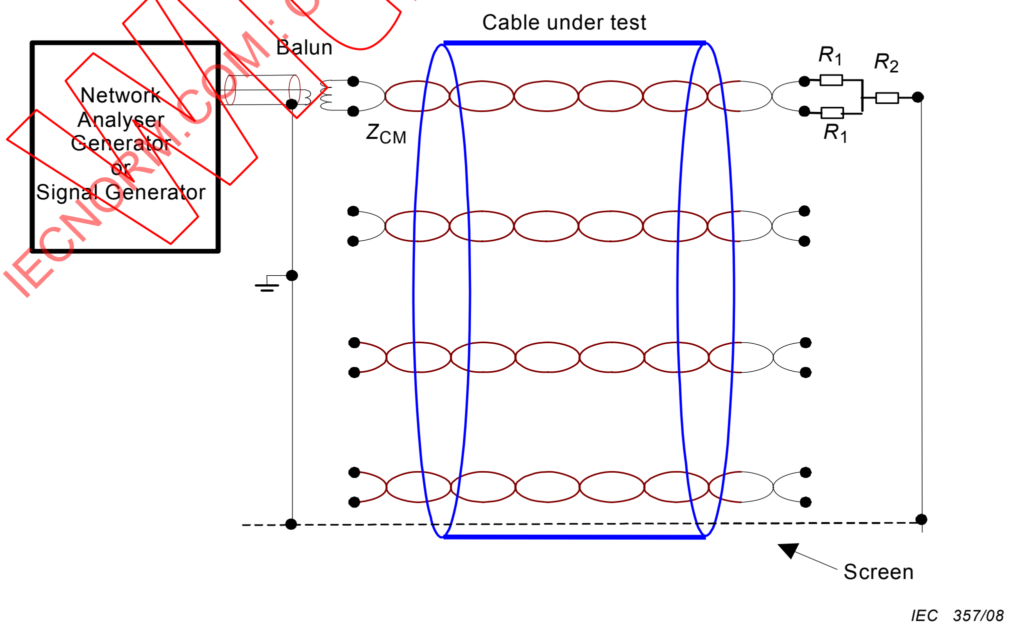

Figure 3 – Termination of the cable under test

1 Figures in square brackets refer to the bibliography.

6.4 Procedure

The pair under test is terminated at the far end by differential and common mode terminations according to Figure 3. The sample is then centered in the tube and fed by a generator in the differential mode via a balun.

The quotient of the voltages at the output of the outer circuit and the input of the cable is measured, either directly by a network analyser or with a calibrated step attenuator [assuming that the receiver has the same input impedance as the output impedance of the signal generator ($R = Z_1$)] which is inserted as an alternative to the triaxial apparatus.

Only the peak values of the maximum of the voltage ratio or the minimum of the attenuation must be measured and recorded as a function of the frequency in order to determine the envelope curve.

Attenuation introduced by the inclusion of adapters, instead of direct connection, must be taken into account when calibrating the triaxial apparatus.

The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

6.5 Measurement Precautions

The cable under test shall be positioned as concentric as possible in the outer tube to obtain homogeneous wave propagation.

The balun and the remaining cable length, including the matching resistors, shall be positioned in a well screened box to avoid disturbances from outside into the test set-up as well as to avoid radiation from the test set-up.

It is important to place the ferrite rings as near as possible to the receiver side of the tube to absorb interfering, backward travelling waves.

7 Expression of results

The attenuation of the balun shall be subtracted from the measuring results.

The coupling attenuation a_c shall be calculated with the normalised value Z_S = 150 Ω:

$$a_c = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R} \right| \qquad (18)$$

$$= 20 \times \log_{10} \left| \frac{U_1}{U_{2max}} \right| + 10 \times \log_{10} \left| \frac{300\ \Omega}{Z_1} \right| \qquad (19)$$

$$= a_{m,min} - a_z + 10 \times \log_{10} \left| \frac{300\ \Omega}{Z_1} \right| \qquad (20)$$

8 Requirements

The results of the minimum coupling attenuation shall comply with the value indicated in the relevant cable specification.

If a limiting value of the radiating power is specified for a cable system operating with a defined power level, the difference between the power level and the limit of radiating power shall not be greater than the coupling attenuation of the cable provided for the system.

9 Plots of coupling attenuation versus frequency-typical results

Coupling attenuation for 105 Ω twinax cable is shown plotted versus frequency on logarithmic and linear scales respectively in Figures 4 and 5. The same parameter is plotted for FTP cable in Figures 6 and 7.

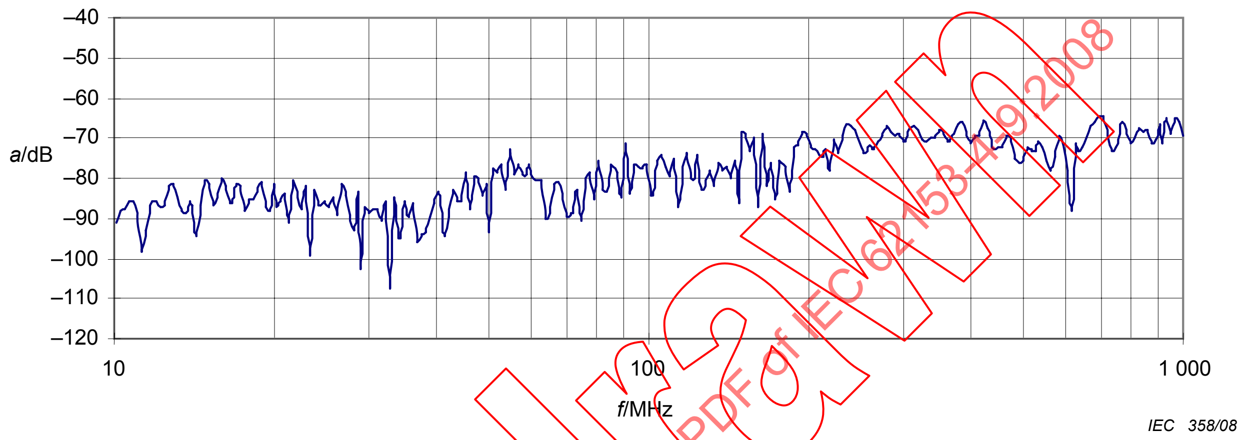

Figure 4 – Twinax 105 log

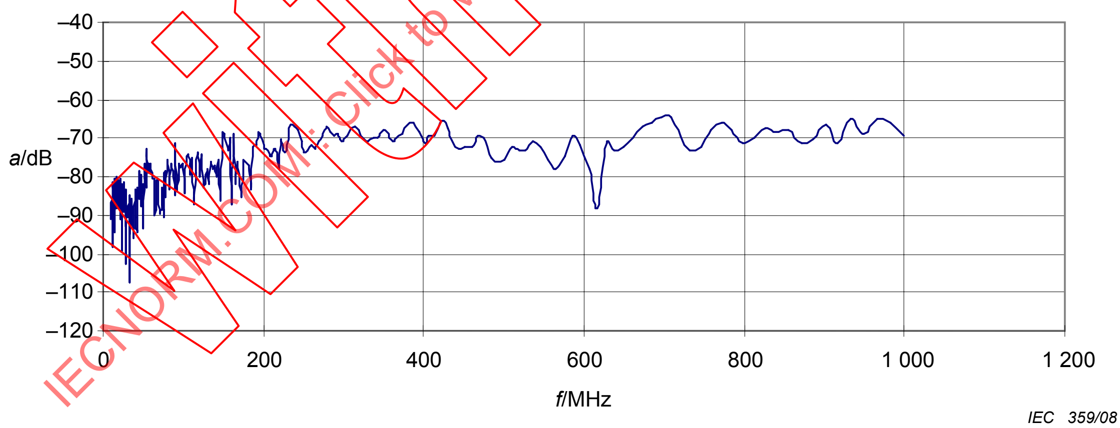

Figure 5 – Twinax 105 linear

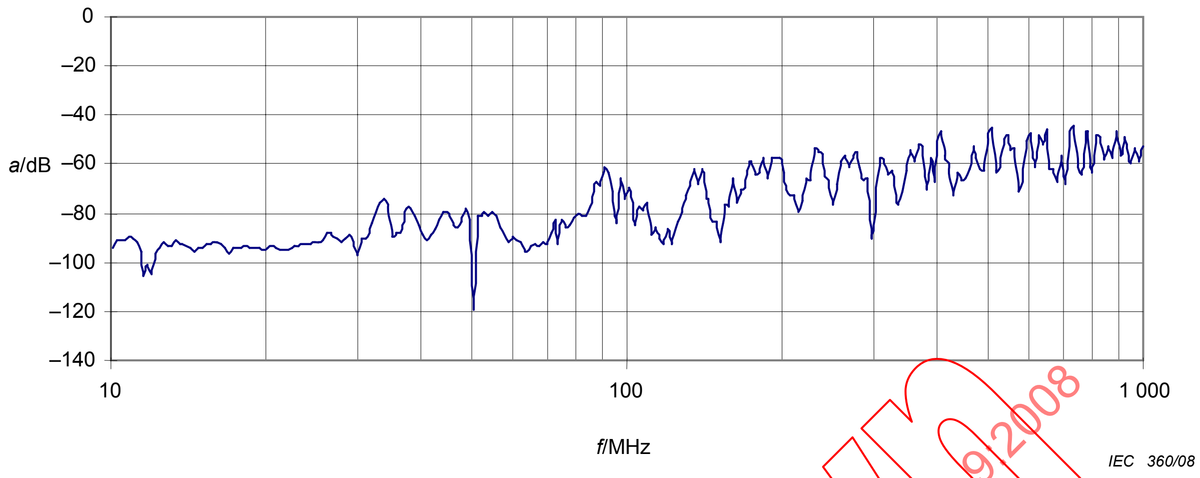

Figure 6 – FTP log

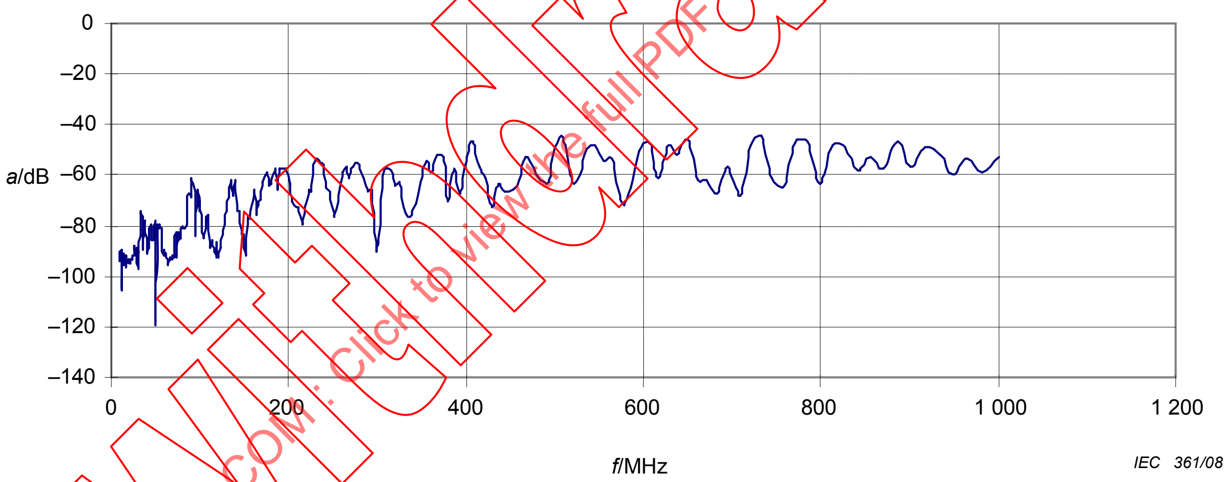

Figure 7 – FTP linear