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Screened balanced cables – Coupling attenuation measurement, triaxial method

PUBLICLY AVAILABLE SPECIFICATION

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FOREWORD

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The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:
Draft PAS	**Report on voting**
46/107/PAS	46/110/RVD

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SCREENED BALANCED CABLES – COUPLING ATTENUATION MEASUREMENT, TRIAXIAL METHOD

1 General

This test method determines the coupling attenuation a_C of screened balanced cables. Due to the concentric outer tube, measurements are independent of irregularities on the circumference and outer electromagnetic field.

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.
For balanced cables 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 61196-1, Amendment 1.

2 Principle of the measuring method

The test set up is a triaxial system consisting of the cable under test and a solid metallic tube.

The matched cable under test which is fed by a generator forms the disturbing respectively the inner or primary circuit. The disturbed respectively the outer or the second circuit is formed by the outer conductor (or the outer most layer in the case of multiscreen cables) of the cable under test and a solid metallic tube having the cable under test in its axis.

The voltage peaks at the far end of the secondary circuit have to be measured. The near end of the secondary circuit is short-circuited. For this measurement a matched receiver is not necessary. The likely voltage peaks at the far end 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 an advantage to have a low mismatch, for example by selecting a range of tube diameters for several sizes of coaxial cables.

3 Definitions and the theoretical background

3.1 Electrical symbols

Z_1	is the characteristic impedance of the primary circuit (cable under test)
Z_2	is the characteristic impedance of the secondary circuit
Z_S	is a normalised value of the characteristic impedance of the environment of the cable under test (150 Ω secondary circuit impedance Z_2)
R	is the input impedance of the receiver
Z_T	is the transfer impedance of the cable under test in [Ω/m]
Z_F	is the capacitive coupling impedance of the cable under test in [Ω/m], $Z_F = Z_1 \cdot Z_2 \cdot j\omega \cdot C_T$ (1)
f	is the frequency, in Hz
C_T	is the through capacitance of the outer conductor per unit length [F/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
l	is the effective coupling length
λ_o	is the vacuum wavelength
c_o	is the vacuum velocity
a_s	is the screening attenuation which is comparable to the results of the absorbing clamp method
P_1	is the feeding power of the primary circuit
P_2	is the measured power received on the input impedance R of the receiver in the secondary circuit
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
P_S	is the radiated power in the normalised environment of the of the cable under test, (Z_S =150 Ω and $\lvert\Delta v/v_1\rvert$ =10 %)

$$\varphi_1 = 2\pi\left(\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right) l / \lambda_0$$
$$\varphi_2 = 2\pi\left(\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}\right) l / \lambda_0 \qquad (2,3,4)$$
$$\varphi_3 = \varphi_2 - \varphi_1 = 4\pi\sqrt{\varepsilon_{r2}}\ l / \lambda_0$$

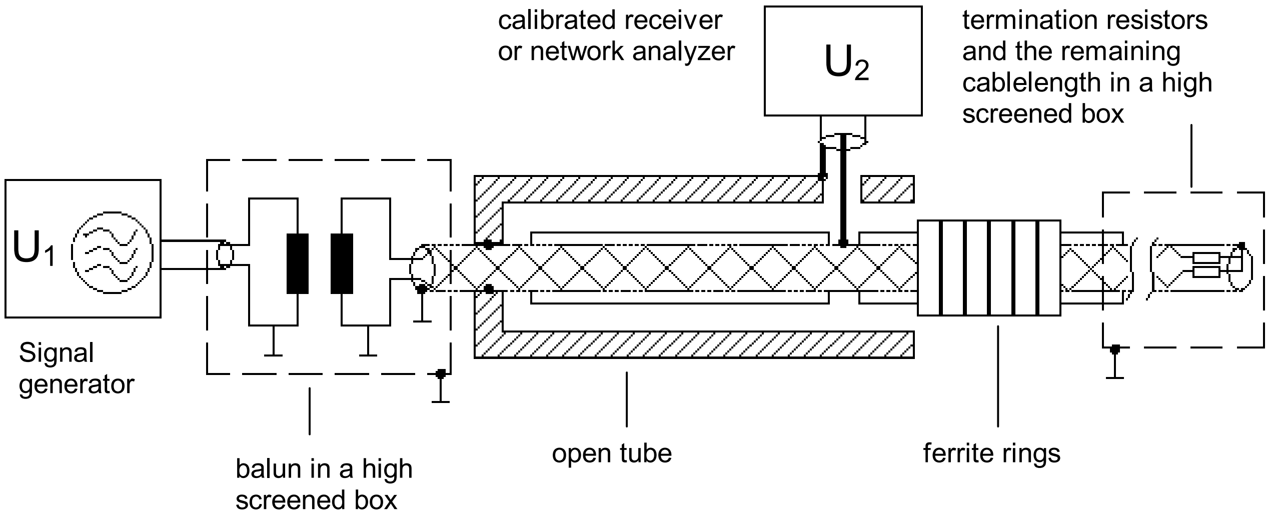

Figure 1 – Principle test set-up

3.2 Theoretical background

3.2.1 Unbalance 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, comparable to a coaxial cable.

Under ideal conditions respectively 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** (cross-unsymmetry) and the difference of the inductance and resistance between the two wires **r** (longitudinal - unsymmetry).

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

$$r = \left(R_2 + j\omega L_2\right) - \left(R_1 + j\omega L_1\right) \tag{6}$$

The coupling between the two lines is then expressed by:

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

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

Where Z_{diff} is the characteristic impedance of the differential mode (balanced) and Z_{com} of the common mode (unbalanced). These are in principle the same coupling transfer functions compared to the coupling through the screen. The integral could only be solved if the distribution of the unsymmetry along the cable length is known.

For an unsymmetry being constant along the cable length, the transfer function results in the same way as for cable screens.

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

If the cable is electrical 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 praxis we have small systematic couplings together with statistical couplings. Thus $T_{u,n}$ increase by approx. 10 dB per decade and $T_{u,f}$ by less then 20 dB per decade.

3.2.2 Screening attenuation a_s of the screen

At coaxial cables, respectively in the common mode of screened balanced cables, 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 is termed screening attenuation a_S

$$a_S = -10 \cdot \log_{10}\left(\text{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \tag{10}$$

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

$$\sqrt{\left|\frac{P_{2,max}}{P_1}\right|} \approx \frac{c_o}{\omega\sqrt{Z_1 \cdot R}} \cdot \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}\right| \tag{11}$$

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

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

i.e. formally **|** A + B **|** ·C·D, where AC is the far end crosstalk, BC is the reflected near end crosstalk and D is the mismatch factor.

Total oscillations of D are

< 2 dB, if $1 < Z_2 / R < 1{,}25$

. 3 dB, if $Z_2 / R = 1{,}4$

but 10 dB and more, if $Z_2 / R > 3$.

Maximum values of AC and BC are given, if

$\varphi_{1,2} = (2N + 1) \cdot \pi$ and N is an integer

3.2.3 Coupling attenuation a_c

Balanced cables which are driven in the differential mode will radiate a part of the input power, due to irregularities in the cable symmetry. For unscreened balanced cables, this radiation is depicted by the unbalance attenuation a_U. For screened balanced cables the disturbing power from the pair is additional attenuated by the outer screen. The unbalance causes a current in the screen which is then coupled by the transfer impedance and capacitive coupling impedance into the outer circuit.

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

$$a_c = a_u + a_s \tag{13}$$

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 is termed coupling attenuation a_C:

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

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

$$\frac{P_\mathrm{r}}{P_2} = \frac{P_\mathrm{r,max}}{P_\mathrm{2,max}} = \frac{R}{2 \cdot Z_\mathrm{S}} \tag{15}$$

There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superimposition 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.

4 Measurement

4.1 Equipment

The measuring 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 networkanalyser. (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 (applicable only for symmetrical cables), see subsection 4.2.
- Ferrite rings with an attenuation a_{Ferrit} > 10 dB in the measured frequency range.
- Metallic boxes to shield the balun and the remaining cable length including the matching resistors

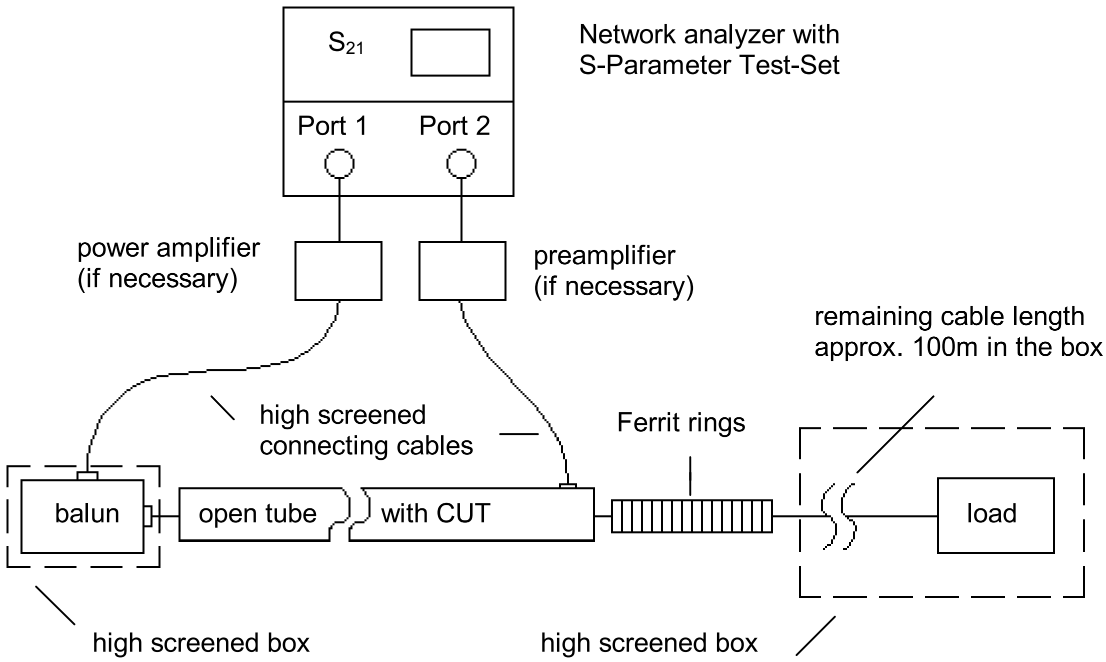

Figure 2 – Set-up to measure the coupling attenuation

4.2 Balun requirements

To match the unbalanced output from the generator to the nominal characteristic of the symmetrical cable, a balun is required. The minimum requirements to the balun 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[1)]	50 Ω (unbalanced)
Impedance, secondary[2)]	100 Ω or 150 Ω (balanced)
Insertion loss[4)] (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[3)]	≥ 50 dB from 1 MHz to 30 MHz ≥ 50 dB from 30 MHz to 100 MHz ≥ 30 dB from 100 MHz to 1 GHz

1) Primary impedance may differ if necessary to accommodate analyser outputs other than 50 Ω.

2) Balanced outputs of the test baluns shall be matched to the nominal impedance of the symmetrical cable pair. 100 Ω shall be used for termination of 120 Ω cabling

3) Measured per ITU-T Recommendations G.117 and O.9

4) Proposed measurement specified in EN 50289-9

4.3 Sample preparing

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

$$R_1 = \frac{Z_{DM}}{2} \tag{17}$$

where:

Z_{DM} nominal characteristic differential mode impedance

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

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

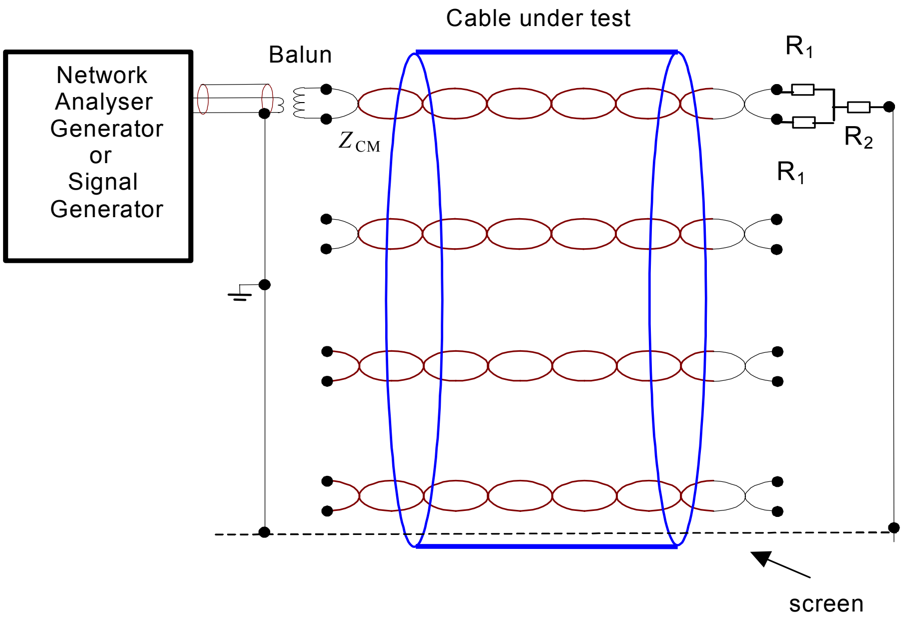

Figure 3 – Termination of the cable under test

4.4 Procedure

The the diiferential and common mode of the pair under test is terminated at the far end by ist nominal values of the characteristic impedance according to figure 2. 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.

4.6 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, each 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 set the ferrite rings as near as possible to the receiver side of the tube to absorb interfering, backward travelling waves.

5 Expression of results

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

The coupling attenuation a_C has to be calculated with the normalised value Z_S = 150 Ω:

$$a_c = 10 \cdot \log_{10} \left| \frac{P_1}{P_{r,\max}} \right| = 10 \cdot \log_{10} \left| \frac{P_1}{P_{2,\max}} \cdot \frac{2 \cdot Z_S}{R} \right| \tag{17}$$

$$= 20 \cdot \log_{10} \left| \frac{U_1}{U_{2,\max}} \right| + 10 \cdot \log_{10} \left| \frac{300\Omega}{Z_1} \right| \tag{18}$$

$$= a_{m,\min} - a_Z + 10 \cdot \log_{10} \left| \frac{300\Omega}{Z_1} \right| \tag{19}$$

where

- a_c is the coupling attenuation related to the radiating impedance of 150 Ω in dB.
- $a_{m,\min}$ 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.
- 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.
- Z_1 is the (differential mode) characteristic impedance of the cable under test in Ohms.

6 Requirement

The results of 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 operated 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.

7 Typical measuring curves of coupling attenuation

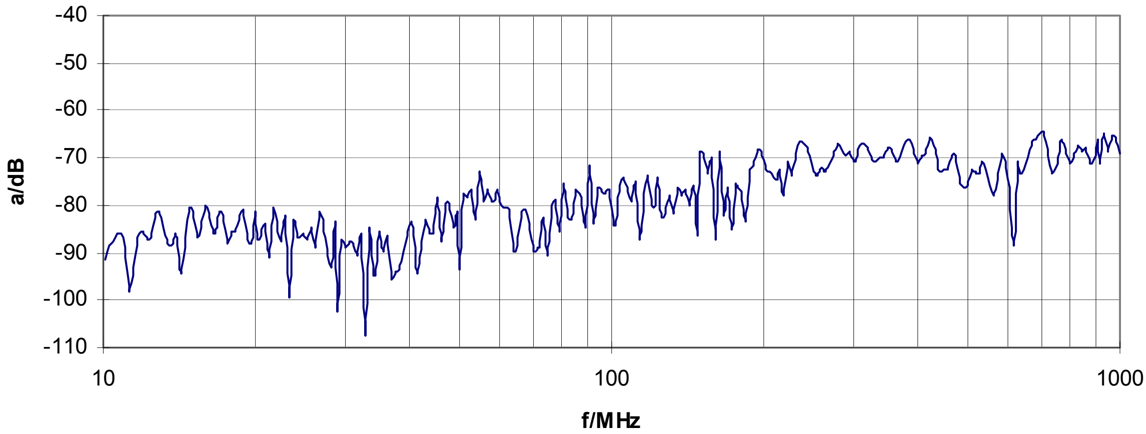

Figure 4 – Twinax 105 log

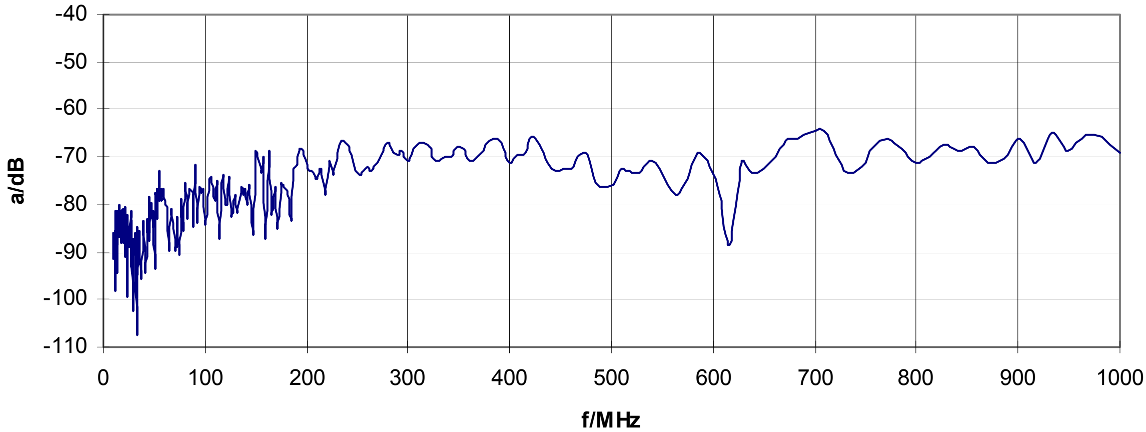

Figure 5 – Twinax 105 lin

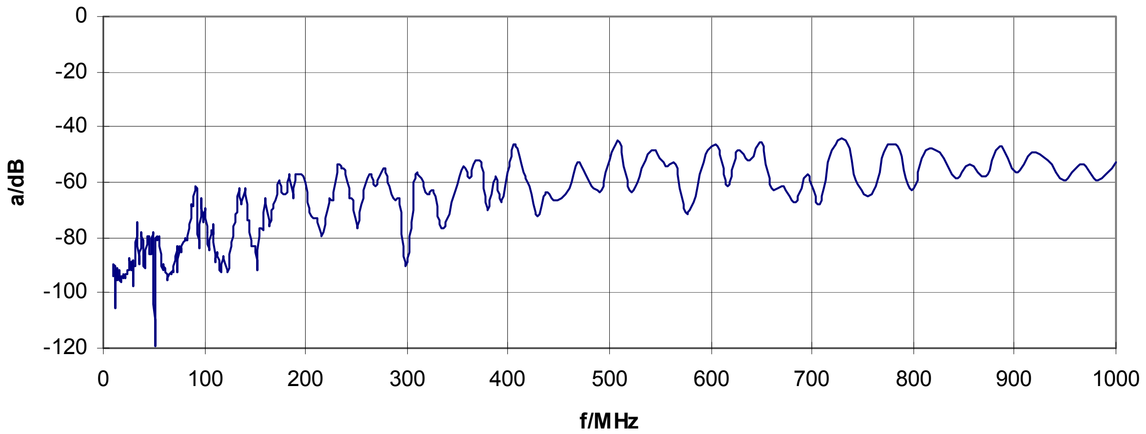

Figure 6 – FTP linear

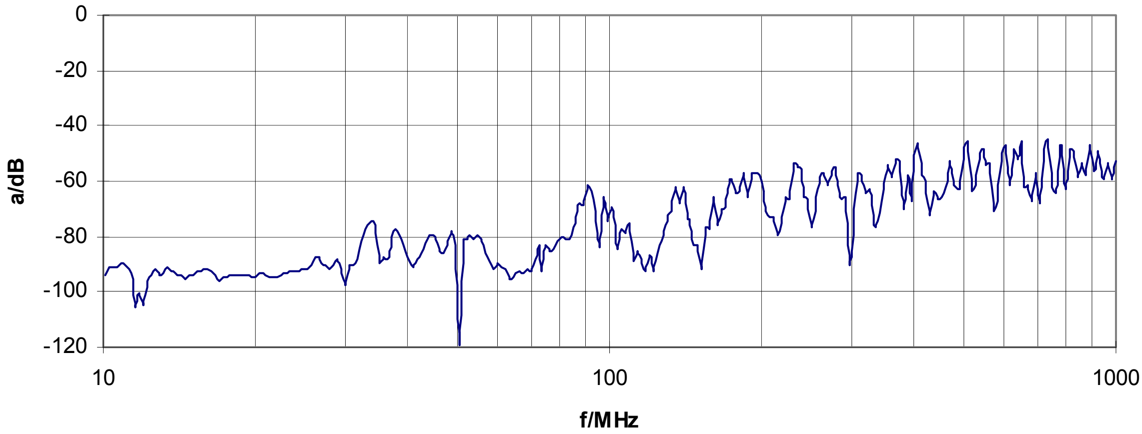

Figure 7 – FTP log

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