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INTERNATIONAL STANDARD

colour inside

Coaxial communication cables –
Part 1-108: Electrical test methods – Test for characteristic impedance, phase and group delay, electrical length and propagation velocity

IEC 61196-1-108:2011(E)

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COAXIAL COMMUNICATION CABLES –

Part 1-108: Electrical test methods – Test for characteristic impedance, phase and group delay, electrical length and propagation velocity

FOREWORD

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International Standard IEC 61196-1-108 has been prepared by subcommittee 46A: Coaxial cables, of IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This second edition replaces the first edition published in 2005. The main changes to the previous edition is the enclosing of Annex A describing the measurement of phase dispersion.

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

FDIS	Report on voting
46A/1039/FDIS	46A/1057/RVD

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 standard is intended to be read in conjunction with IEC 61196-1. It is based on the second edition (2005) of that standard.

A list of all parts of IEC 61196 series, published under the general title *Coaxial communication cables,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability 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- withdrawn,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.

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

COAXIAL COMMUNICATION CABLES –

Part 1-108: Electrical test methods – Test for characteristic impedance, phase and group delay, electrical length and propagation velocity

1 Scope

This part of IEC 61196 applies to coaxial communications cables. It specifies test methods for determining the characteristic impedance, phase and group delay, electrical length and propagation velocity of coaxial cables for use in telecommunications networks.

A procedure to measure phase dispersion of coaxial cable is included as Annex A.

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 61196-1:2005, *Coaxial communication cables – Part 1: Generic specification – General, definitions and requirements*

IEC 61196-1-103, *Coaxial communication cables – Part 1-103: Electrical test methods – Test for capacitance of cable*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61196-1 apply.

4 Parameters

From the phase constant β of a cable, one can derive several parameters:

group delay

$$\tau_{\mathrm{g}} = \frac{d\beta}{d\omega} \approx \frac{\Delta\beta}{\Delta\omega} \tag{1}$$

phase delay

$$\tau_{\mathrm{p}} = \frac{\beta}{\omega} \tag{2}$$

propagation velocity

$$v = \frac{1}{\tau_{\mathrm{p}}} = \frac{\omega}{\beta} \tag{3}$$

relative propagation velocity

$$v_{\mathrm{r}} = \frac{v}{c} = \frac{1}{\tau_{\mathrm{p}} \cdot c} = \frac{l_{\mathrm{mech}}}{l_{\mathrm{e}}} \tag{4}$$

electrical length

$$l_{\mathrm{e}} = l_{\mathrm{mech}} \cdot \tau_{\mathrm{p}} \cdot c \tag{5}$$

characteristic impedance

$$Z_c = \frac{\beta}{\omega C} = \frac{\tau_p}{C} \tag{6}$$

where

β	is the phase constant in radian/m;
$\omega = 2\,\pi f$	is the angular frequency in radian/s;
τ_g	is the group delay in s/m;
τ_p	is the phase delay in s/m;
C	is the capacitance in pF/m;
c	is the propagation velocity in free space ($3 \cdot 10^8$ m/s);
l_e	is the electrical length in m;
l_{mech}	is the mechanical length in m;
v	is the propagation velocity in m/s;
v_r	is the relative propagation velocity;
Z_c	is the characteristic impedance in Ω.

Delay and velocity parameters as well as characteristic impedance are frequency-dependent and reach an asymptotic value at high frequencies. It is usual to report them at frequencies higher than 200 MHz where the frequency is sufficiently high for the theoretical approximation always to be valid. Generally, the above-given formulas are limited to low dispersive cables as coaxial communications cables typically are in their specified frequency range. Methods with a wider range of application are given in Annex A.

5 Test method

5.1 Equipment

The equipment to be used consists of:

- a capacitance metre or bridge in accordance with IEC 61196-1-103.
- a vector network analyser (VNA) capable of performing S_{21} measurements.

5.2 Test sample

Due to the cyclic behaviour of exp(-jβl), a VNA can measure the phase constant β only in the range of –180 ° to +180 ° respectively from $-\pi$ to $+\pi$ and doesn't give an information how many phase turns have already been at the lowest frequency. To avoid hidden phase turns, the maximum length of the sample should be:

$$l_{max} < \frac{500\,000}{Z_c \cdot C \cdot f} \tag{7}$$

where

C	is the capacitance of the cable in pF/m according to IEC 61196-1-103;
f	is the lowest frequency to be measured in MHz;
l_{max}	is the maximum possible sample length in m;
Z_c	is the nominal characteristic impedance of the cable.

This restriction is not applicable if solely group delay is to be measured as then only the derivative of the phase is important.

5.3 Procedure

The S_{21} or S_{12} parameter of the sample shall be measured with the VNA. The phase constant obtained from this measurement is used to calculate the above-defined parameter.

It has to be assured that the number of measurement point is high enough to detect every phase turn.

The ambient temperature shall be recorded.

6 Expression of test results

6.1 Phase constant β

For the evaluation of the phase velocity, it is necessary to have full phase shift information. Normally, a VNA measures the phase in the range of $-\pi$ and $+\pi$. In this case, the phase shift has to be transformed into a monotonic decreasing function of frequency in the range of 0 and $-\infty$ (see Figure 1). Some network analysers provide this function.

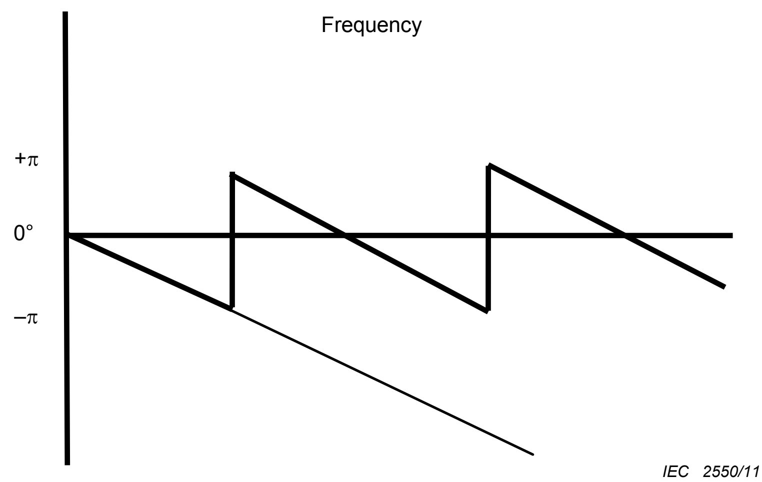

Figure 1 – Phase shift expanded

As an example for computation, the following source code may be used.

```
For I = 2 to number of frequency points
        K=0
        WHILE Phase (I) > Phase (I -1)
                K = K +1
                Phase (I) = Phase (I)- K ·2π
        END While
NEXT I
```

The phase constant β is then calculated by:

$$\beta(f) = \frac{\varphi_{\mathrm{exp}}(f)}{l_{\mathrm{sample}}} \tag{8}$$

where

$\beta(f)$ is the phase constant at frequency f in radians/m;

$\varphi_{\mathrm{exp}}(f)$	is the expanded phase shift obtained from a S_{21} or S_{12} measurement in radians at the frequency f;
l_{sample}	is the sample length in m.

6.2 Phase and group delay

The phase delay is calculated as follows.

$$\tau_{\mathrm{p}}(f) = \frac{\beta(f)}{2\pi \cdot f} \tag{9}$$

The group delay is calculated as follows.

$$\tau_{\mathrm{g}}(f) = \frac{\beta(f_2) - \beta(f_1)}{2\pi(f_2 - f_1)} \tag{10}$$

$$f_2 = f + \Delta f/2 \quad \text{if } f_2 > f_{\mathrm{max}} \quad \text{then } f_2 = f_{\mathrm{max}} \tag{11}$$

$$f_1 = f - \Delta f/2 \quad \text{if } f_1 < f_{\mathrm{min}} \quad \text{then } f_1 = f_{\mathrm{min}} \tag{12}$$

$$\Delta f \le 0{,}05 \cdot (f_{\mathrm{max}} - f_{\mathrm{min}}) \tag{13}$$

where

$\beta(f)$	is the phase constant in radian/m at frequency f;
$\tau_{\mathrm{g}}(f)$	is the group velocity in s/m at frequency f;
$\tau_{\mathrm{p}}(f)$	is the phase velocity in s/m at frequency f;
f_{min} , f_{max}	is the lowest respectively highest measured frequency.

6.3 Velocity of propagation

The velocity of propagation is calculated as follows.

$$v(f) = 2\pi \cdot \frac{f}{\beta(f)} \tag{14}$$

$$v_{\mathrm{r}}(f) = \frac{v(f)}{c} = \frac{2\pi}{c}\frac{f}{\beta(f)} \tag{15}$$

where

$\beta(f)$	is the phase constant in radian/m at frequency f;
C	is the propagation velocity in free space ($3 \cdot 10^8$m/s);
f	is the frequency in Hz;
$v(f)$	is the propagation velocity in s/m at frequency f;
$v_{\mathrm{r}}(f)$	is the relative propagation velocity at frequency f.

6.4 Electrical length

The electrical length is calculated as follows.

$$l_e(f) = l_{mech} \frac{\beta(f) \cdot c}{2\pi \cdot f} \tag{16}$$

where

$\beta(f)$	is the phase constant in radian/m at frequency f;
C	is the propagation velocity in free space ($3 \cdot 10^8$m/s);
f	is the frequency in Hz;
$l_e(f)$	is the electrical length in m at frequency f.

6.5 Characteristic impedance

The mean characteristic impedance is calculated as follows.

$$Z_c(f) = \frac{1}{C} \cdot \frac{\beta(f)}{2\pi \cdot f} \tag{17}$$

where

$\beta(f)$	is the phase constant in radian/m at frequency f;
C	is the capacitance in F/m;
f	is the frequency in Hz;
$Z_c(f)$	is the mean characteristic impedance in Ω at frequency f.

7 Test report

The test report shall give the test conditions:

- temperature,
- sample length,
- test frequency range,
- number of measurement points,

and record the values of mean characteristic impedance, phase and group delay, electrical length and propagation velocity.

8 Requirements

The values shall not exceed the requirements of the relevant detail specification.

Annex A
(normative)

Phase dispersion measurement of coaxial cables

A.1 Physical background of phase dispersion of coaxial cables

The phase constant of lossless transmission lines is in direct proportion to the frequency:

$$\beta_0 = \omega\sqrt{L'C'} = \omega Z_0 C' \tag{A.1}$$

where

β_0 is the phase constant of lossless transmission line;

ω is the angular frequency;

L' is the inductance;

C' is the capacitance;

Z_0 is the characteristic impedance.

For lossy transmission lines, the phase constant gets an additional part which is in proportion to the square root of the frequency.

$$\gamma = \alpha + j\beta = \sqrt{(R'+j\omega L')(G'+j\omega C')} \tag{A.2}$$

where

γ is the propagation constant;

α is the attenuation constant;

β is the phase constant;

R' is the resistivity;

G' is the conductance.

The phase constant can be calculated from the imaginary part of the propagation constant taking conductor and dielectric losses into account:

$$\beta = \mathrm{im}\left[\sqrt{(R'+j\omega L')(G'+j\omega C')}\right] \tag{A.3}$$

The phase dispersion of a lossy transmission line is the difference of its phase constant to the phase constant of a lossless transmission line with identical inductance and capacitance per lengths:

$$\Delta\beta = \beta_0 - \beta \tag{A.4}$$

where

$\Delta\beta$ is the phase dispersion.

Distributed parameters R', L', G' and L' of a transmission line are normally not readily available from data sheets or measurement. For a precise calculation, the parameters have to be determined individually.

For most transmission lines, the following simplifications can be made in the frequency range of a few hundred MHz:

– inductance inside the conductors can be neglected, the inductance is constant;
– dielectric losses are negligible;
– conductor losses are small.

Taking these simplifications into account, the phase delay of transmission lines can be described as follows (see Equation (A.5)) [1][1]:

$$\tau_P \approx l\sqrt{L'C'}\left[1+\frac{1}{2}d_1\right] \tag{A.5}$$

where

τ_P is the phase delay of lossy transmission line;

d_1: is the longitudinal attenuation.

With

$$Z_0 = \sqrt{\frac{L'}{C'}} \tag{A.6}$$

$$d_1 = \frac{R'}{\omega L'} \tag{A.7}$$

$$\alpha = \frac{R'}{2Z_0} + \frac{G'}{2Y_0} \tag{A.8}$$

for transmission lines with negligible dielectric losses, Equation (A.8) can be simplified:

$$\alpha \approx \frac{R'}{2Z_0} \tag{A.9}$$

Equation (A.5) becomes

$$\tau_P \approx lZ_0C'\left[1+\frac{\alpha}{\omega Z_0 C'}\right] \tag{A.10}$$

With

$$\tau = \frac{\beta}{\omega}l \tag{A.11}$$

the phase constant results

$$\beta \approx \omega_{\bar{0}}C'\left[1+\frac{\alpha}{\omega Z_0 C'}\right] \tag{A.12}$$

[1] Figures in square brackets refer to the Bibliography.

With Equation (A.12), the phase constant of lossy transmission lines can be calculated based on measured figures of characteristic impedance, capacitance and attenuation.

Investigations [2] have shown that the phase dispersion of coaxial cable with corrugated conductors is not in proportion to the square root of the frequency, rather there is an additional cubical part. The specific behaviour of corrugated cable becomes relevant only in high frequency ranges where the corrugation pitch becomes electrically longer. In lower frequency ranges where the conductor pitch is electrically short corrugated, cables behave like cables with smooth conductors.

A.2 Measurement of phase dispersion

The phase measurement must be made with a high resolution vector network analyser that is able to measure a large number of frequency points in a single sweep, 20 000 for instance. It must have the option to calculate the absolute phase. The phase measurement can either be done in transmission (S_{12}, S_{21}) or reflection mode (S_{11}, S_{22}). If the reflection mode is selected, the cable should be terminated with a short. To suppress effects of the structural return loss, the gating function should be used with the gate set at the short. In this case, the phase reading will have an offset of 180 °, respectively of π.

To show only the phase dispersion, the delay time has to be set such that the linear part is compensated. The delay time can be calculated with (10) while setting α = 0. Since the phase dispersion is typically less than 0,1 % of the total phase, impedance and capacitance have to be measured with very high accuracy. Variation of the delay time by less than 0,1 % can lead to phase dispersion change by more than 10 %. Therefore it is recommended to calculate the theoretical phase dispersion of lossy cable with Equations (1), (4) and (12) first since the dispersion mainly depends on the measured attenuation. The delay time should be tuned such that the measured curve fits best to the calculated curve up to frequencies of about 500 MHz.

A.3 Example of 1/2" cable with deeply corrugated outer conductor and smooth inner conductor wire

The following measured values are given:

C' = 82 pF/m

Z_0 = 50 Ω

l = 100 m

α @ 200 MHz = 4,7 dB/100 m

As described in Clause A.2, the following values are calculated:

$\tau_{lossless}$ = 410,0 ns

τ_{lossy} = 410,431 ns

Setting a phase delay of 410,0 ns for 100 m run of cable gives the phase dispersion curve shown in Figure A.1:

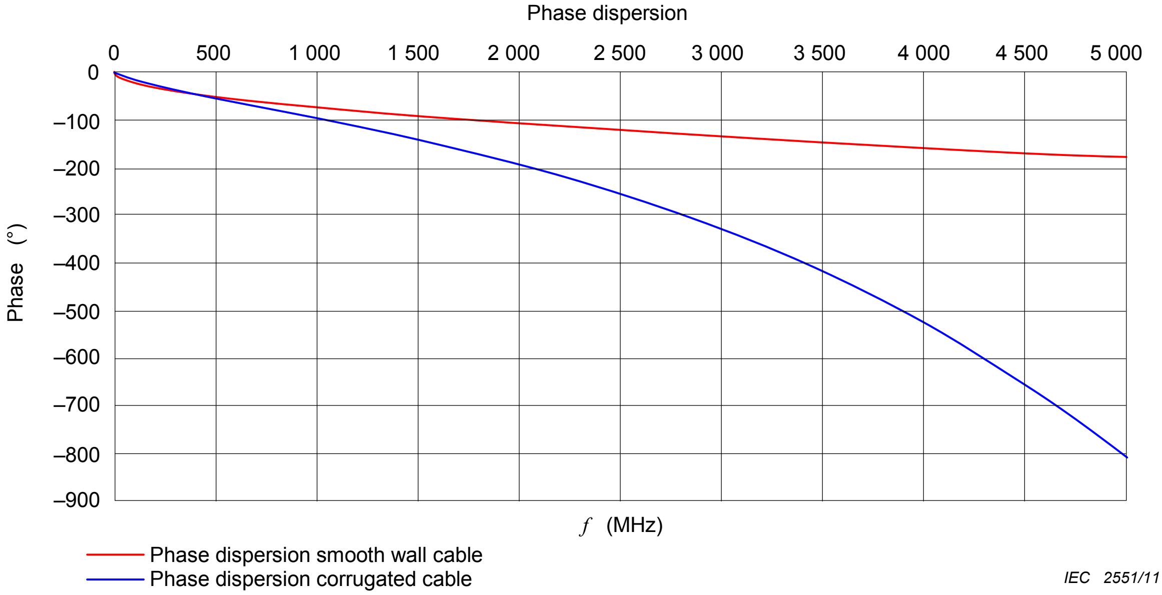

Figure A.1 – Phase dispersion of 1/2" cable with deeply corrugated outer conductor

The blue curve shows the phase dispersion measured with a delay time setting of 410,0 ns. The red curve is the theoretical phase dispersion (12) of a cable with the same attenuation but smooth conductors. The linear part has been deducted in both cases. The absolute phase at 5 GHz is 738181 °/100 m while the theoretical dispersion of a smooth wall cable with the same attenuation would be 181 °/100 m (0,03 %) and the measured phase dispersion is 810 °/100 m (0,1 %).

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[1] MEINKE H., GUNDLACH F.W., Taschenbuch der Hochfrequenztechnik, p. 244 (1962)

[2] KOTZIAN G., CASPERS F., FEDERMANN S., HÖFLE W., DE MARIA R., Ringing in the pulse response of long and wideband coaxial transmission lines due to group delay dispersion CERN-BE-2009-031. - 2009. - 3 p.

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