IEC 61196-1-108

Edition 3.0 2025-01

INTERNATIONAL STANDARD

colour inside

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

IEC 61196-1-108:2025-01(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 33.120.10

ISBN 978-2-8327-0135-5

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FOREWORD

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

This third edition cancels and replaces the second edition published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Change of title, "phase and phase constant" was added.
b) Clause 6, "Preparation of test sample (TS)" was added.

c) Clause 7, "Test procedure" was added.

d) Clause 8, "Failure criterion" was added.

e) Clause 9, "Information to be given in the relevant specification" was added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
46A/1705/FDIS	46A/1717/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

This document is to be read in conjunction with IEC 61196-1:2005.

A list of all the parts in the 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 document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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COAXIAL COMMUNICATION CABLES –

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

1 Scope

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

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

4 Parameters

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

phase constant

$$\beta = \frac{\pi}{180^\circ} \times \frac{\Phi}{l} \qquad (1)$$

group delay

$$\tau_{\mathrm{g}} = \frac{d\beta}{d\omega} \approx \frac{\Delta\beta}{\Delta\omega} \tag{2}$$

phase delay

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

propagation velocity

$$v = \frac{1}{\tau_{\mathrm{p}}} = \frac{\omega}{\beta} \tag{4}$$

relative propagation velocity

$$v_{\mathrm{r}} = \frac{v}{c} = \frac{1}{\tau_{\mathrm{p}} \times c} = \frac{\omega}{\beta \times c} \tag{5}$$

electrical length

$$l_{\mathrm{e}} = \frac{l}{v_{\mathrm{r}}} = l \times \tau_{\mathrm{p}} \times c = l \times \frac{\beta \times c}{\omega} \tag{6}$$

mean characteristic impedance

$$Z_{\mathrm{c}} = \frac{\beta}{\omega \times C} = \frac{\tau_{\mathrm{p}}}{C} \tag{7}$$

where

β is the phase constant in radian/m;

Φ is the expanded phase in °;

l is the length of a cable in 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;

v is the propagation velocity in m/s;

v_r is the relative propagation velocity;

c is the propagation velocity in free space (3×10^8 m/s);

l_e is the electrical length in m;

Z_c is the characteristic impedance in Ω;

C is the capacitance in F/m.

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, Formula (1) to Formula (7) 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 equipment

The equipment to be used consists of

– a capacitance meter or bridge in accordance with IEC 61196-1-103, and

– a vector network analyser (VNA) capable of performing S21 measurements.

6 Preparation of test sample (TS)

6.1 General

There are two test methods. No matter method 1 or method 2, first, measure the capacitance of the cable sample according to IEC 61196-1-103; ensure that the sample length shall meet Formula (8).

$$l_{max} < \frac{500000}{Z_c \times C \times f} \tag{8}$$

where

l_{max} is the maximum possible sample length in m;

Z_c is the nominal characteristic impedance of the cable in Ω;

C is the measured capacitance of the cable in pF/m according to IEC 61196-1-103;

f is the lowest frequency to be measured in MHz.

6.2 Method 1 – Long cables

A cable with sufficient length l is connected to a pair of connectors to form a cable assembly as a test sample (TS) as shown in Figure 1. The phase of the pair of connectors is negligible compared with the cable under test.

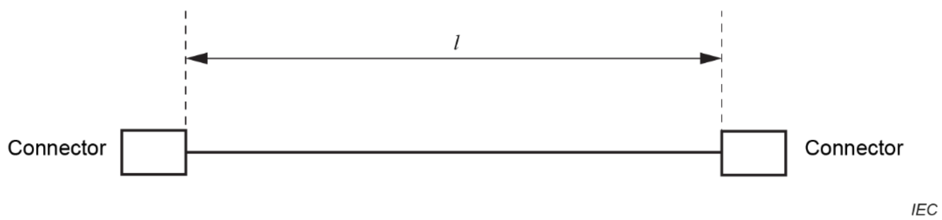
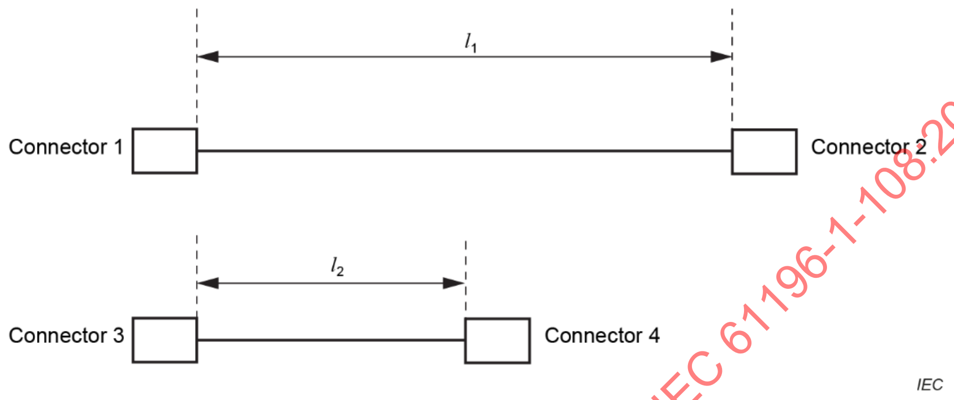


Figure 1 – Preparation of long cable

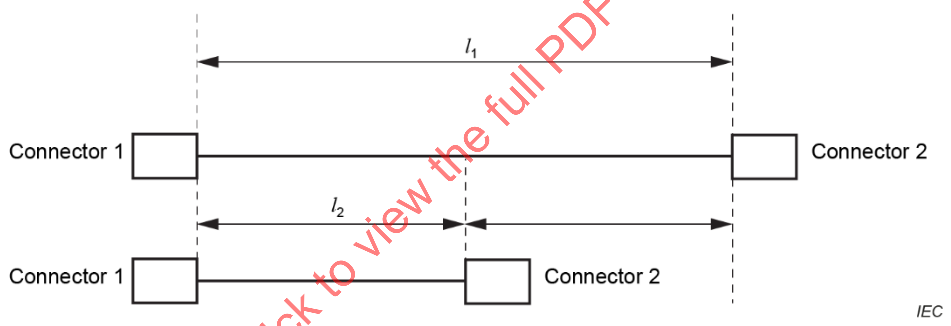
6.3 Method 2 – Short cables

Two cables with different length shall be cut from the same cable product and make two cable assemblies as two test samples (TS_1 and TS_2), terminated with two same kind and quality of connector pairs. As shown in Figure 2 a), normally, $l_1 = 2l_2$.

To improve the test precision, the shorter test sample (TS_2) can also be made by using the longer test sample (TS_1) after it has completed all the tests, as shown in Figure 2 b).



a) Two separate short test samples



b) One short test sample made by the longer sample

Figure 2 – Preparation of short cables

7 Test procedure

7.1 Phase

7.1.1 Method 1 – Long cables

Test procedure is as follows:

a) after the VNA is fully preheated, set the measurement frequency and other related parameters, and then set its test mode to measure the expand phase;

b) calibrate the test system;

c) connect the TS to the VNA, and measure and record the phase $\Phi_l(f)$ which is the phase of the length l of the cable.

7.1.2 Method 2 – Short cables

Test procedure is as follows:

a) after the VNA is fully preheated, set the measurement frequency and other related parameters, and then set its test mode to measure the expand phase;

b) calibrate the test system;

c) connect the longer cable assembly TS_1 to the VNA, measure and record its phase $\Phi_{l_1}(f)$;

d) connect the shorter cable assembly TS_2 to the VNA, measure and record the phase $\Phi_{l_2}(f)$;

e) calculate the phase $\Phi_l(f)$ of the length l cable by Formula (9):

$$\Phi_l(f) = \Phi_{l_1}(f) - \Phi_{l_2}(f) \tag{9}$$

where

$l = l_1 - l_2$ is the length difference in m between TS_1 and TS_2;

$\Phi_l(f)$ is the calculated expanded phase of length l cable in ° at the frequency f;

$\Phi_{l_1}(f)$ is the measured expanded phase of the TS_1 in ° at the frequency f;

$\Phi_{l_2}(f)$ is the measured expanded phase of the TS_2 in ° at the frequency f.

7.2 Phase constant

Test procedure is as follows:

a) measure the expanded phase $\Phi_l(f)$ according to 7.1.1 or 7.1.2.

b) the phase constant $\beta(f)$ is then calculated by Formula (10) or Formula (11):

1) when using method 1 in 7.1.1:

$$\beta(f) = \frac{\pi}{180°} \times \frac{\Phi_l(f)}{l} \tag{10}$$

where

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

$\Phi_l(f)$ is the measured expanded phase in ° at frequency f;

l is the length of the sample in m.

2) when using method 2 in 7.1.2:

$$\beta(f) = \frac{\pi}{180°} \times \frac{\Phi_l(f)}{l} = \frac{\pi}{180°} \times \frac{\Phi_{l_1}(f) - \Phi_{l_2}(f)}{l_1 - l_2} \tag{11}$$

where

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

$l = l_1 - l_2$ is the length difference in m between TS_1 and TS_2;

$\Phi_l(f)$ is the calculated expanded phase in ° at the frequency f;

$\Phi_{l_1}(f)$ is the measured expanded phase of TS_1 in ° at the frequency f;

$\Phi_{l_2}(f)$ is the measured expanded phase of TS_2 in ° at the frequency f;

l_1 is the length of TS_1 in m;

l_2 is the length of TS_2 in m.

7.3 Phase delay

Test procedure is as follows:

a) measure the phase constant $\beta(f)$ according to 7.2.

b) the phase delay $\tau_p(f)$ is then calculated by Formula (12):

$$\tau_p(f) = \frac{\beta(f)}{2\pi f} \quad (12)$$

where

$\tau_p(f)$ is the phase delay in s/m at the frequency f;

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

f is the test frequency in Hz.

7.4 Propagation velocity

Test procedure is as follows:

a) measure the phase constant $\beta(f)$ according to 7.2.

b) calculate the propagation velocity $v(f)$ by Formula (13):

$$v(f) = \frac{2\pi f}{\beta(f)} \quad (13)$$

where

$v(f)$ is the propagation velocity in m/s at the frequency f;

f is the test frequency in Hz;

$\beta(f)$ is the phase constant in radian/m at frequency f.

c) calculate the relative propagation velocity $v_r(f)$ by Formula (14):

$$v_r(f) = \frac{v(f)}{c} = \frac{2\pi}{c} \times \frac{f}{\beta(f)} \quad (14)$$

where

$v_r(f)$ is the relative propagation velocity;

$v(f)$ is propagation velocity in m/s at the frequency f;

c is the propagation velocity in free space (3×10^8 m/s);

f is the test frequency in Hz;

$\beta(f)$ is the phase constant in radian/m at frequency f.

7.5 Electrical length

The test procedure is as follows:

a) measure the phase constant $\beta(f)$ according to 7.2.

b) calculate the electrical length $l_e(f)$ by Formula (15):

$$l_e(f) = \frac{l}{v_r(f)} = l \times \frac{c}{2\pi} \times \frac{\beta(f)}{f} \tag{15}$$

where

$l_e(f)$	is the electrical length in m at the frequency f;
l	is the cable length in m (for method 2, $l = l_1 - l_2$);
$v_r(f)$	is the relative propagation velocity;
c	is the propagation velocity in free space (3×10^8 m/s);
f	is the test frequency in Hz;
$\beta(f)$	is the phase constant in radian/m at frequency f.

7.6 Group delay

7.6.1 Method 1 – long cables

The test procedure is as follows:

a) after the VNA is fully preheated, set the measurement frequency range and other related parameters, and then set its test mode to measure the expand phase;

b) calibrate the test system;

c) select two frequencies f_1 and f_2. f_1 and f_2 shall meet the requirements of Formula (16), Formula (17) and Formula (18):

$$\Delta f \le 0{,}05 \times (f_{max} - f_{min}) \tag{16}$$

$$f_1 = f - \frac{\Delta f}{2} \tag{17}$$

$$f_2 = f + \frac{\Delta f}{2} \tag{18}$$

where

Δf	is frequency spacing between f_1 and f_2;
f_{max}	is the highest measured frequency;
f_{min}	is the lowest measured frequency;
f	is the specified frequency.

d) measure the expanded phase $\Phi_l(f_1)$ and $\Phi_l(f_2)$ according to 7.1.1.

e) calculate the group delay $\tau_g(f)$ by Formula (19):

$$\tau_g(f)=\frac{\beta(f_2)-\beta(f_1)}{2\pi\times(f_2-f_1)}=\frac{\Phi_l(f_2)-\Phi_l(f_1)}{360°\times l\times(f_2-f_1)} \tag{19}$$

where

$\tau_g(f)$ is the group delay in s/m at frequency f;

$\beta(f_1)$, $\beta(f_2)$ is the phase constant in radian/m at frequency f_1, f_2;

f_1, f_2 is the test frequency in Hz;

$\Phi_l(f_1)$, $\Phi_l(f_2)$ is the expanded phase in ° at frequency f_1, f_2.

7.6.2 Method 2 – Short cables

Test procedure is as follows:

a) after the VNA is fully preheated, set the measurement frequency range and other related parameters, and then set its test mode to measure the expand phase;
b) calibrate the test system;
c) select two frequency f_1 and f_2. f_1 and f_2 shall meet the requirements of Formula (16), (17) and (18);
d) measure the expanded phase $\Phi_{l_1}(f_1)$, $\Phi_{l_1}(f_2)$ according to 7.1.2;
e) measure the expanded phase $\Phi_{l_2}(f_1)$, $\Phi_{l_2}(f_2)$ according to 7.1.2;
f) calculate the group delay $\tau_g(f)$ by Formula (20):

$$\tau_g(f)=\frac{\beta(f_2)-\beta(f_1)}{2\pi\times(f_2-f_1)}=\frac{\Phi_{l_1}(f_2)-\Phi_{l_2}(f_2)-\Phi_{l_1}(f_1)+\Phi_{l_2}(f_1)}{360°\times(f_2-f_1)\times(l_1-l_2)} \tag{20}$$

where

$\tau_g(f)$ is the group delay in s/m at frequency f;

$\beta(f_1)$, $\beta(f_2)$ the phase constant in radian/m at frequency f_1, f_2;

f_1, f_2 is the test frequency in Hz;

l_1, l_2 is the length in m of two short TS;

$\Phi_{l_1}(f_1)$, $\Phi_{l_1}(f_2)$ is the expanded phase in ° of the short TS at frequency f_1, f_2;

$\Phi_{l_2}(f_1)$, $\Phi_{l_2}(f_2)$ is the expanded phase in ° of the shorter TS at frequency f_1, f_2.

7.7 Mean characteristic impedance

The test procedure is as follows:

a) measure the capacitance of the cable according to IEC 61196-1-103 before preparing the test samples according to Clause 6;
b) measure the phase constant $\beta(f)$ according to 7.2;

c) the mean characteristic impedance is calculated as follows:

$$Z_c(f) = \frac{1}{C} \times \frac{\beta(f)}{2\pi \times f} \tag{21}$$

where

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

8 Failure criterion

The phase, phase constant, phase and group delay, propagation velocity, electrical length or mean characteristic impedance shall be in accordance with the relevant standards.

9 Information to be given in the relevant specification

The following information shall be given in the relevant standards:

a) frequency or frequency range to be measured;
b) method to be used;
c) length of the cable to be measured;
d) test results;
e) difference from this test method.

10 Test report

Test report shall include information as the following:

a) test name;
b) environmental conditions;
c) name of the test equipment used; number and validity of the measurement;
d) test sample and test frequency
e) test results;
f) name of the operator and test date.

Annex A
(informative)

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:

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

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:

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

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 C' of a transmission line are normally not readily available from data sheets or measurement. For a precise calculation, the parameters shall 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 Formula (A.5):

$$\tau_\mathrm{p} \approx l\sqrt{L'C'}\left[1+\frac{1}{2}d_1\right] \quad \text{(A.5)}$$

where

τ_p is the phase delay of lossy transmission line;

l is the length of lossy transmission line;

d_1 is the longitudinal attenuation.

With

$$Z_0 = \sqrt{\frac{L'}{C'}} \quad \text{(A.6)}$$

$$d_1 = \frac{R'}{\omega L'} \quad \text{(A.7)}$$

$$\alpha = \frac{R'}{2Z_0} + \frac{G'}{2Y_0} \quad \text{(A.8)}$$

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

$$\alpha \approx \frac{R'}{2Z_0} \quad \text{(A.9)}$$