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SERIES K: PROTECTION AGAINST INTERFERENCE

Surge parameters of isolating transformers used in telecommunication devices and equipment

Recommendation ITU-T K.95

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Summary

Telecommunication devices and equipment can use non-linear limiting, linear attenuating, or both types of functions to mitigate surges occurring on services. Isolating transformers attenuate common-mode voltage surges on a service. Recommendation ITU-T K.95 gives test methods and preferred values for the isolating transformer surge parameters that are harmonized with established international standards on insulation coordination levels and test techniques.

History

Edition	Recommendation	Approval	Study Group	Unique ID[*]
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Keywords

Insulation, insulation resistance, isolation transformer, rated impulse voltage, surge, withstand voltage.

FOREWORD

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Surge parameters of isolating transformers used in telecommunication devices and equipment

1   Scope

This Recommendation sets terms, test methods, test circuits, measurement procedures and preferred result values for the surge parameters of isolating transformers used in telecommunication devices and equipment. Three types of isolating transformer are covered: mains, switched mode power supply and signal. The surge parameters of the isolating transformer insulation barrier covered by this Recommendation are:

• rated impulse voltage;

• input winding to output winding capacitance;

• insulation resistance.

Additional parameters for signal isolating transformers are:

• core saturation voltage-time product;

• rated input winding root mean square (rms) current for a given temperature rise.

This Recommendation does not cover the transformer parameters required to help ensure appropriate operation on the service, e.g., signal transformer return loss.

2   References

None.

3   Definitions

3.1   Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1   breakdown [b-IEC 61340-1]: Failure, at least temporarily, of the insulating properties of an insulating medium under electric stress.

3.1.2   clearance [b-IEC/TR 60664-2-1]: Shortest distance in air between two conductive parts.

3.1.3   creepage distance [b-IEC/TR 60664-2-1]: Shortest distance along the surface of a solid insulating material between two conductive parts.

3.1.4   electric screen [b-IEC 60050-151]: Screen of conductive material intended to reduce the penetration of an electric field into a given region.

3.1.5   hazard [b-IEC GUIDE 116]: Potential source of harm.

NOTE – The term hazard can be qualified in order to define its origin (e.g., electrical hazard, mechanical hazard) or the nature of the potential harm (e.g., electric shock hazard, cutting hazard, toxic hazard, fire hazard).

3.1.6   impulse withstand voltage [b-IEC/TR 60664-2-1]: Highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation under specified conditions.

3.1.7   insulation (electrical) [b-IEC 62477-1]: Electrical separation between circuits or conductive parts provided by clearance or creepage distance or solid insulation or combinations of them.

3.1.8 insulation coordination [b-IEC/TR 60664-2-1]: Mutual correlation of insulation characteristics of electrical equipment taking into account the expected microclimate and other influencing stresses.

3.1.9 insulation resistance [b-IEC 62631-1]: Resistance under specified conditions between two conductive bodies separated by the insulating material.

3.1.10 isolating transformer [b-IEC 60065]: Transformer with protective separation between the input and output windings.

3.1.11 pollution [b-IEC 60664-1]: Any addition of foreign matter, solid, liquid, or gaseous that can result in a reduction of electric strength or surface resistivity of the insulation.

3.1.12 pollution degree [b-IEC 60664-1]: Numeral characterizing the expected pollution of the micro-environment

3.1.13 pollution degree 1 [b-IEC 61131-2]: No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.

3.1.14 pollution degree 2 [b-IEC 61131-2]: Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected.

3.1.15 pollution degree 3 [b-IEC 61131-2]: Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation, which is expected.

3.1.16 overvoltage [b-IEC/TR 60664-2-1]: Any voltage having a peak value exceeding the corresponding peak value of maximum steady-state voltage at normal operating conditions.

3.1.17 rated impulse voltage [b-IEC/TR 60664-2-1]: Impulse withstand voltage value assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against transient overvoltages.

3.1.18 thermal equilibrium [b-IEC 61810-1]: Variation of less than 1 K between any two out of three consecutive measurements made at an interval of 5 min.

3.1.19 thermal resistance [b-IEC 62590]: Quotient of the temperature difference between two specified points or regions and the heat flow between these two points or regions under conditions of thermal equilibrium.

NOTE – For most cases, the heat flow can be assumed to be equal to the power dissipation.

3.1.20 withstand voltage [b-IEC/TR 60664-2-1]: Voltage to be applied to a specimen under prescribed test conditions which does not cause breakdown and/or flashover of a satisfactory specimen.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 common-mode surge: Surge appearing equally on all conductors of a group at a given location.

NOTE 1 – The reference point for common-mode surge voltage measurement can be a chassis terminal, or a local earth/ground point.

NOTE 2 – Also known as longitudinal surge or asymmetrical surge.

3.2.2 component type: Identification number assigned to a component, based on an identification system used by a particular organization.

NOTE – Model number, product ID, product name, product number; product type, part number; part ID are used as synonyms to component type.

3.2.3 differential-mode surge: Surge occurring between any two conductors or two groups of conductors at a given location.

NOTE 1 – The surge source maybe be floating, without a reference point or connected to reference point, such as a chassis terminal, or a local earth/ground point.

NOTE 2 – Also known as metallic surge or transverse surge or symmetrical surge or normal surge.

3.2.4   guarded measurement (three terminal network): Measurement technique that allows the direct impedance between two terminals to be measured correctly by applying a compensating voltage to the third terminal that removes the shunting effects of any impedances to the third terminal.

3.2.5   microclimate: Climatic condition at the place where a component is installed in the product.

NOTE – Only the in product maximum air temperature (classes X1 to X7) and, optionally, the maximum air humidity class (classes Y1 to Y4) are taken into account.

3.2.6   rated winding d.c.: Maximum winding current that will not cause the winding conductor temperature to exceed a specified increase above the ambient temperature.

3.2.7   surge: Temporary disturbance on the conductors of an electrical service caused by an electrical event not related to the service.

4   Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

IR   Insulation Resistance

RMS   Root-Mean-Square

5   Conventions

This Recommendation uses the following symbols to represent the different transformer configurations.
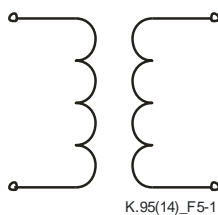
Figure 5-1 shows the symbol for a two-winding transformer.

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Figure 5-1 – Symbol for a two-winding transformer

Figure 5-2 shows the symbol for a two-winding transformer with instantaneous voltage polarity indicators.
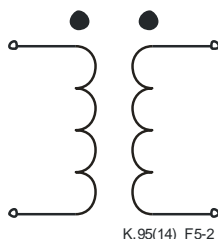

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Figure 5-2 – Symbol for a two-winding transformer with polarity indication

Figure 5-3 shows the symbol for a two-winding transformer with an electric screen between the windings.
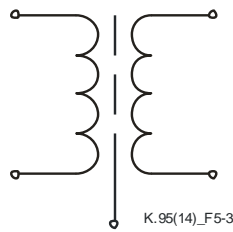
Figure 5-3 – Symbol for a two-winding transformer with electric screen

Figure 5-4 shows the symbol for a transformer centre-tapped windings. When testing is done with shorted windings the centre tap is also connected to the short, other testing is done without any connection to the centre tap terminal.
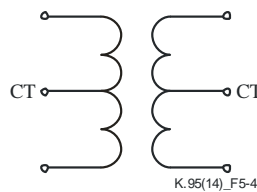

Figure 5-4 – Transformer with centre-tapped windings

When a single twisted pair signal service also carries a d.c. powering voltage a series capacitor is needed to block the d.c. voltage and couple the signal to the transformer. To maintain circuit symmetry (i.e., balance) either each conductor has a series capacitor inserted or the transformer winding is made in two halves and a single capacitor connects the two halves together. For test purposes a transformer having the winding in two halves should have a shorting link made between the halves, so that a continuous winding is formed. The link effectively forms the CT connection shown in Figure 5-4.

6 Surge parameters

6.1 Transformer surge mitigation

An isolating transformer couples a service across the transformer insulation by magnetic induction. When common-mode surges occur on the incoming service the insulation is voltage stressed. The insulation has three physical paths:

• transformer winding insulation: insulating material interposed between the two windings;

• creepage distance;

• clearance.

Clearance distances should be set so that the maximum expected voltage difference does not break down the clearance. Creepage distances should be set so that the maximum expected voltage difference and pollution degree do not cause surface flashover or breakdown (tracking). Solid insulation thickness should be set so that the maximum expected voltage difference does not cause breakdown.

The higher frequency components of a surge impulse will be a.c. coupled by the transformer inter-winding capacitance (shown as $C_{P-SA} + C_{P-SB}$) from one winding to the other (see Figure 6-1). In Figure 6-1, the inter-winding capacitance is shown as two lumped capacitive elements: one connecting the upper winding terminals, path and suffix A; and one connecting the lower winding terminals, path and suffix B.
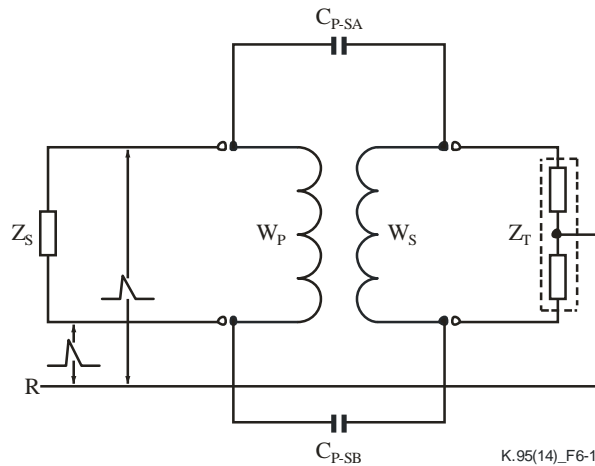
W_P	Primary winding	C_{P-SA}, C_{P-SB}	Primary to Secondary inter-winding capacitance, paths A and B
W_S	Secondary winding	Z_S	Service source impedance
R	Reference plane or point	Z_T	Terminating or load impedance

Figure 6-1 – Common-mode surge conditions for the transformer

To reduce inter-winding capacitance a conducting electric screen can be used between the windings (see Figure 6-2). In Figure 6-2 the parasitic capacitances are shown as two lumped delta configured networks: one connecting to the upper winding terminals and electric screen, path and suffix A; and one connecting to the lower winding terminals and electric screen, path and suffix B. The electric screen decouples most of the winding capacitance, shown as $C_{P-ScreenA}$, $C_{P-ScreenB}$, $C_{S-ScreenA}$ and $C_{S-ScreenB}$, leaving a much smaller value of inter-winding capacitance, shown as C_{P-SA} and C_{P-SB}.
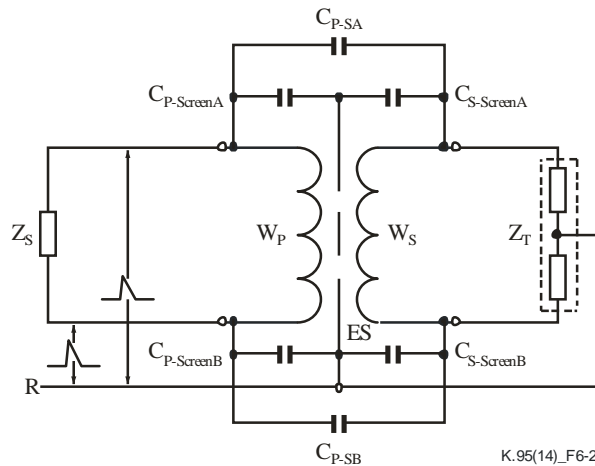
W_P	Primary winding	$C_{P-ScreenA}$, $C_{P-ScreenB}$	Primary to Screen parasitic capacitance, paths A and B
W_S	Secondary winding	$C_{S-ScreenA}$, $C_{P-ScreenB}$	Secondary to Screen parasitic capacitance, paths A and B
ES	Electric screen	C_{P-SA}, C_{P-SB}	Primary to Secondary unscreened parasitic capacitance, paths A and B
Z_S	Service source impedance	Z_T	Terminating or load impedance
R	Reference plane or point		

Figure 6-2 – Common-mode surge conditions for a transformer with an electric screen

6.2 Common-mode surges

Figure 6-2 shows the isolating transformer under common-mode surge conditions. The insulation rated impulse voltage must be equal to or greater than the peak common-mode surge voltage for

insulation coordination (see clause 8.2). Any primary to secondary capacitance (shown as $C_{P-SA} + C_{P-SB}$) that is not decoupled by the electric screen, provides a capacitive current flow path from the primary to secondary circuit (see clause 7.2).

The major surge parameters for common-mode surges are the rated impulse voltage and the inter-winding capacitance, plus a post-test insulation resistance (IR) check on the insulation integrity.

6.3 Differential-mode surges

Differential-mode surges are typically caused by system asymmetry, such as asynchronous surge protective device or component operation, converting what should be common mode surges to differential surges. Transformer action occurs on differential-mode surges and the isolation transformer does little to mitigate them. In some cases, the transformer bandwidth will result in filtering of the output surge frequency spectrum. Signal transformers may suffer core saturation, which truncates the secondary voltage (see clause 7.4), although, until the core saturation occurs, normal transformer action takes place.

When a differential travelling wave of surge voltage propagates down a cable, it meets a termination impedance mismatch, such as a mains power transformer, and this mismatch reflects the voltage wave and can double its amplitude. This situation is a system interaction, not strongly dependent on the transformer surge parameters, and is not covered in this Recommendation. Signal transformers are typically matched to the cable impedance and substantial surge level changes do not occur due to the transformer. The incorporation of series or shunt non-linear surge limiters can result in an impedance mismatch when they operate.

Signal transformers may suffer core saturation, which truncates the secondary voltage (see clause 7.4). Some standards specify testing for differential power faults, requiring the signal transformer to have a primary winding current rating (see clause 8.3).

7 Characteristics

7.1 Characteristic measurement

Characteristics are measureable component parameters at the time of test and the values obtained are for the component tested. Characteristics may be specified by the manufacturer as: typical, maximum, minimum or combinations of these quantities.

7.1.1 Test environment

The temperature and humidity environment recommended for the characteristic measurements are class 3K1 from [b-IEC 60721-3-3]:

a)   low air temperature: 20°C ±2°C

b)   high air temperature: 25°C ±2°C

c)   low relative humidity: 20%

d)   high relative humidity: 75%

7.1.2 Microclimates

When a component is installed in the product its local climatic condition (microclimate) can be different than the product climate; usually the microclimate air temperature will be higher. Where a component parameter is temperature dependent, testing can also be done at the extremes of the component rated temperature range. Table 7-1 lists the maximum high air temperature microclimate classifications according to [b-IEC 721-3-9] and commonly used component temperature ranges.

Table 7-1 – Classification of microclimate conditions

| High air temperature severity (°C)	Class	Typical component temperature ranges (°C)	Product application
55	X1		
70	X2	0 to 70	Commercial
85	X3	–40 to 85	Industrial
100	X4		
125	X5	–55 to 125	Military
155	X6	–65 to 150	Storage (See Note)
200	X7		
NOTE – Storage temperature rating verification is outside the scope of this Recommendation. See [b-IEC 60068-2-1] and [b-IEC 60068-2-2] for low and high temperature endurance testing.			

7.2 Inter-winding capacitance

7.2.1 Purpose

This test measures the effective inter-winding capacitance of the transformer.

7.2.2 Test method

Figure 7-1 shows a test circuit to measure the transformer inter-winding capacitance. In Figure 7-1, only the transformer capacitive component is shown. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited. The inter-winding capacitance is measured between the two shorts.
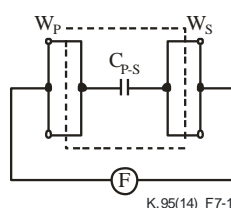
|			
W_P	Primary winding	C_{P-S}	Primary to Secondary capacitance
W_S	Secondary winding	F	Capacitance meter

Figure 7-1 – Test circuit to measure the transformer inter-winding capacitance

Figure 7-2 shows a test circuit to measure the inter-winding capacitance of a transformer with an electric screen. In Figure 7-2, only the transformer capacitive components are shown. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited. The inter-winding capacitance is measured between the two shorts. A guarded measurement of the inter-winding capacitance shall be made to remove the winding to electric screen capacitances.

In Figure 7-2, the capacitive current caused by the C_H voltage applied to $C_{P-Screen}$ and the C_H coaxial cable capacitance is removed from the measurement as this current flows to G connection and not into C_L. At balance, the voltage on the C_L connection is zero, meaning there is zero capacitive current taken by $C_{S-Screen}$ and the C_L coaxial cable. As a result, the only current flowing into C_L is from C_{P-S}, As the C_H voltage applied to C_{P-S} is known and the current from C_{P-S} into C_L can be measured, the instrument can determine the value of C_{P-S}.

Guarded measurements are done using either a 3-wire (Hi, Lo, Guard) or 6-wire (Hi, Lo, Guard feed and Hi, Lo, Guard sense) techniques. Figure 7-2 shows the use of a 3-wire transformer ratio arm

bridge [b-Blumlein]. The use of coaxial cables removes the connecting cable shunting capacitance from the measurement.
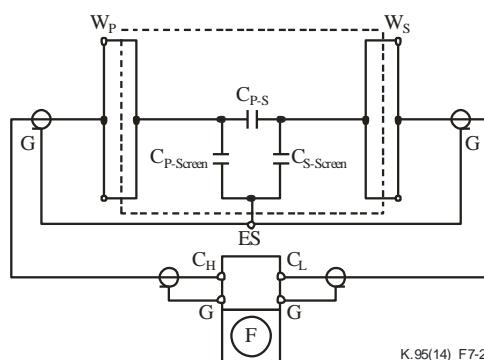
W_P	Primary winding	$C_{P\text{-}Screen}$	Primary to Screen capacitance
W_S	Secondary winding	$C_{S\text{-}Screen}$	Secondary to Screen capacitance
ES	Electric screen	$C_{P\text{-}S}$	Primary to Secondary residual capacitance
C_H	Capacitance measurement connection Hi	G	Guard connection (coaxial cables screen)
C_L	Capacitance measurement connection Lo	F	Guarded measurement capacitance bridge

**Figure 7-2 – Test circuit to measure the inter-winding capacitance
of a transformer with an electric screen**

By connecting the guard, G, to the primary, and the measurement leads to the two remaining connections, the secondary to electric screen capacitance, $C_{S\text{-}Screen}$, may be measured. Similarly, connecting the guard, G, to the secondary, and the measurement leads to the two remaining connections, the primary to electric screen capacitance, $C_{P\text{-}Screen}$, may be measured.

7.2.3   Values

This Recommendation covers mains power, switched mode and signal transformers of any size and construction. With this degree of variation, it is impractical to create a list of preferred values. The inter-winding capacitance value can be used to predict the level of capacitive surge current passed on to the following circuitry. In the case of two or more transformers connected in series, their insulation capacitance values can be used to predict the instantaneous voltage distribution across the insulations. Where one or more of the transformers have an electric screen, the values of the winding to screen capacitance are also needed.

7.2.4   Criteria

The measured value of the inter-winding capacitance shall be within the manufacturers' specified limits. When the manufacturer only gives a typical value, if the measured value is outside ±30% of the typical value, the manufacturer should be contacted to verify the measurement technique and product parameter distribution.

7.3   Insulation resistance

IR meters can produce voltages of up to 1 kV d.c. or more. To avoid possible electric shock or personal injury, the safety guidelines issued by the IR meter manufacturer should be followed.

7.3.1   Purpose

This test measures the resistance of the insulation at a defined d.c. voltage.

7.3.2 Test method

The insulation resistance meter shall be set for the specified value of d.c. test voltage (see clause 7.3.3). The test voltage shall be applied for at least 60 s before the insulation resistance value is taken.

Figure 7-3 shows the test circuit to measure the insulation resistance of a transformer. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited. The insulation resistance is measured between the two shorts.

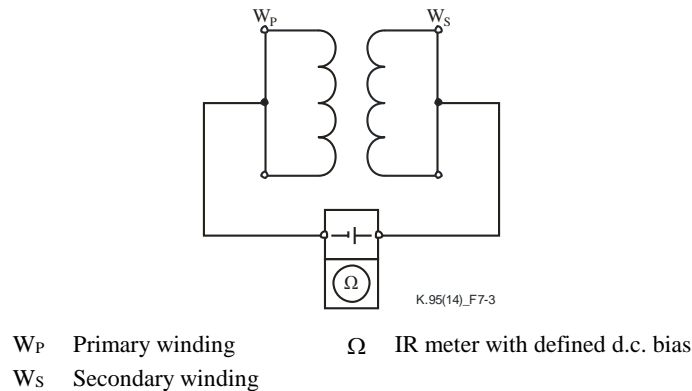|	
W_P Primary winding	Ω IR meter with defined d.c. bias
W_S Secondary winding	

Figure 7-3 – Test circuit to measure the insulation resistance of a transformer

Figure 7-4 shows the test circuit to measure the insulation resistance of a transformer with an electric screen. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited. The insulation resistance is measured between the two shorts. Unless otherwise specified, two measurements are taken: one with the selector switch, SW, connecting the electric screen, ES, to the primary winding, W_P, and one with the selector switch, SW, connecting the electric screen, ES, to the secondary winding, W_S.
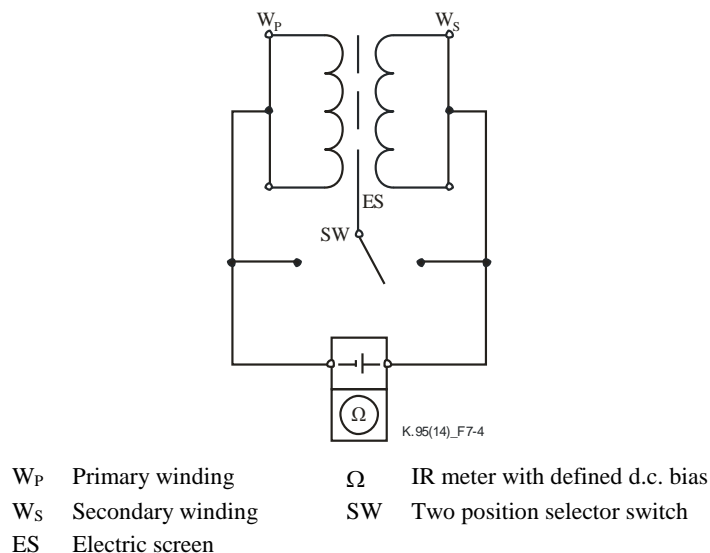

W_P Primary winding	Ω IR meter with defined d.c. bias
W_S Secondary winding	SW Two position selector switch
ES Electric screen	

**Figure 7-4 – Test circuit to measure the insulation resistance
of a transformer with an electric screen**

7.3.3 Values

The preferred test value of d.c. voltage is 500 V and the resistance reading is made after the d.c. voltage has been applied for 60 s minimum. On an international basis, a 500 V d.c. test would

test the insulation for mains voltages up to 230 V/240 V nominal. Other common values are shown in Table 7-2.

Table 7-2 – Typical test voltages

D.C. test voltage (V)	Related nominal single phase a.c. supply voltage (V rms)
250	120
500	230/240
1000	–

7.3.4 Criteria

The measured insulation resistance values should be 2 MΩ or more, measured at 500 V d.c.
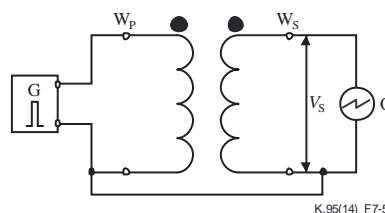
7.4 Signal transformer voltage-time product

7.4.1 Purpose

This test measures the transformer voltage-time product, a measure of the secondary winding differential-mode surge let-through.

7.4.2 Test method

Figure 7-5 shows the test circuit for voltage-time measurement. The pulse generator, G, has adjustable voltage amplitude and pulse duration.

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W_P Primary winding   G   Pulse generator, 50 Ω source impedance
W_S Secondary winding   O   Oscilloscope monitoring v_S
V_S peak secondary winding voltage

Figure 7-5 – Test circuit to measure the transformer voltage-time product

Figure 7-6 shows the generator open-circuit output voltage and the resultant secondary winding voltage. The generator pulse voltage amplitude, V_G, and duration are adjusted to cause transformer core saturation. Core saturation is shown by the secondary winding voltage pulse being truncated, having a shorter duration, t_S, than the generator pulse. To allow accurate measurement, the generator voltage amplitude shall be adjusted such that the core saturation time, t_S, is not less than 10 µs.

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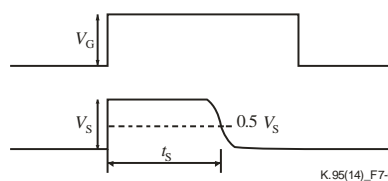
V_G Open-circuit pulse generator peak voltage t_S Secondary winding voltage time above 50% V_S
V_S Secondary winding peak voltage

Figure 7-6 – Generator and transformer secondary voltage waveforms

On the secondary winding voltage, v_S, measure the peak amplitude V_S and the 50% V_S duration time, t_S. The transformer voltage-time product is given by $V_S t_S$, expressed in µVs.

7.4.3 Values

The transformer voltage-time product depends on the transformer size, construction and the parameters required to operate satisfactorily in the intended telecommunication system. With this degree of variation, it is impractical to create a list of preferred values. The voltage-time product value can be used to predict the peak secondary voltage level before truncation resulting from a defined surge waveform when there are no secondary voltage limiting components.

7.4.4 Criteria

The measured value of voltage-time product shall be within the manufacturer's specified limits. When the manufacturer only gives a typical value, if the measured value is outside ±30% the typical value, the manufacturer should be contacted to verify the measurement technique and product parameter distribution.

8 Ratings

8.1 Rating verification

A rated value defines either a limiting capability or a limiting condition for a component type. Ratings apply to the component type and, for the ratings in this Recommendation, are maximum values. Ratings are checked by stressing the component at a maximum condition, then measuring specific component characteristics afterwards to verify that the product has not been degraded. Degradation limits may be that the component characteristic values shall not exceed the component type characteristic limits after the stress test or by defining a maximum permitted change of the component characteristic values measured before and after the stress test. Often the component will be monitored during the test to check for any abnormal operation.

8.1.1 Test environment
See clause 7.1.1.

8.1.2 Microclimates
See clause 7.1.2.

8.2 Rated impulse voltage

8.2.1 Purpose

This test verifies the insulation rated impulse voltage specified by the transformer manufacturer for the component type.

8.2.2 Test method

The insulation rated impulse voltage is traditionally tested using a 1.2/50 voltage impulse (see Appendix I). Transformer insulation can also be tested with high voltage a.c. or d.c. However, high voltage a.c. and d.c. test voltages are unsuitable for testing assemblies, devices or equipment ports for the following reasons: such tests do not truly represent the electrical environment and fail to correctly test the resistibility of other circuit components. This Recommendation only specifies insulation impulse testing as it is a universal approach that can be used for component, assembly, device and equipment port testing.

Figure 8-1 shows the test circuit used for insulation voltage withstand testing of a transformer. A 1.2/50 impulse generator, whose voltage waveform is monitored by oscilloscope, O, has its impulse

voltage applied to the insulation separating windings, W_P and W_S. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited.
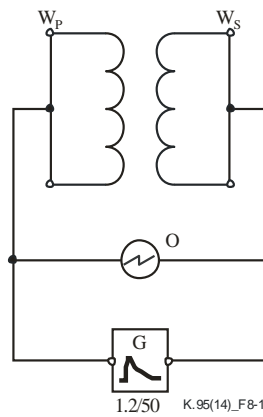
W_P	Primary winding	G	1.2/50 surge generator
W_S	Secondary winding	O	Oscilloscope or equivalent monitoring impulse voltage

**Figure 8-1 – Transformer rated impulse voltage test circuit**

Figure 8-2 shows the test circuit used for insulation voltage withstand testing of a transformer with an electric screen. A 1.2/50 impulse generator, whose voltage waveform is monitored by oscilloscope O, has its impulse voltage applied to the insulation separating windings W_P and W_S. Both the primary winding, W_P, and secondary winding, W_S, are short-circuited. Unless otherwise specified, two tests are made; one with the selector switch, SW, connecting the electric screen, ES, to the primary winding, W_P, and one with the selector switch, SW, connecting the electric screen, ES, to the secondary winding, W_S.
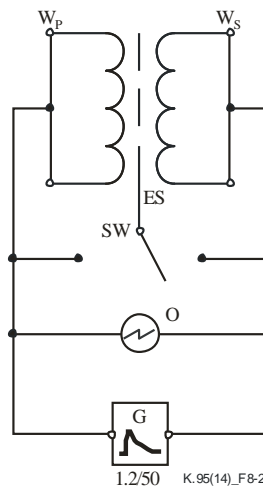
W_P	Primary winding	G	1.2/50 surge generator
W_S	Secondary winding	O	Oscilloscope or equivalent monitoring impulse voltage
ES	Electric screen	SW	Two position selector switch

Figure 8-2 – Rated impulse voltage test circuit for a transformer with an electric screen

Before testing the insulation the test pass/fail template shall be determined. Set the generator, G, voltage to the impulse withstand voltage listed in Table 8-1 that corresponds to the transformer rated impulse voltage. Record the generator, G, voltage waveform. Construct a template from the generator, G, open-circuit 1.2/50 waveform consisting of an upper limit, created by moving the waveform up by 10% of the peak amplitude, and a lower limit, created by moving the waveform down by 10% of the peak amplitude (see Figure 8-3).
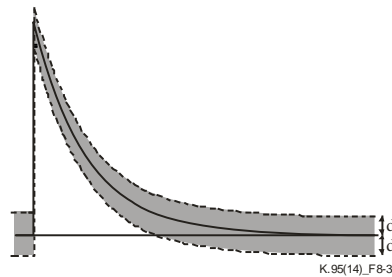
d   Positive and negative vertical waveform displacement distance
of the 1.2/50 open-circuit voltage waveform. Distance d is equal
to 10% of the peak open-circuit voltage

Figure 8-3 – Construction of pass/fail template from the 1.2/50 open-circuit waveform

An example use of the template is shown in Figure 8-4, in which the template is shown as a shaded area. To pass the insulation test, any waveform aberrations during the insulation test shall not be outside the template area (Figure 8-4a). Any insulation breakdown causing aberrations such as waveform serration (Figure 8-4b) and truncation (Figure 8-4c) are outside the template area and are test failures.
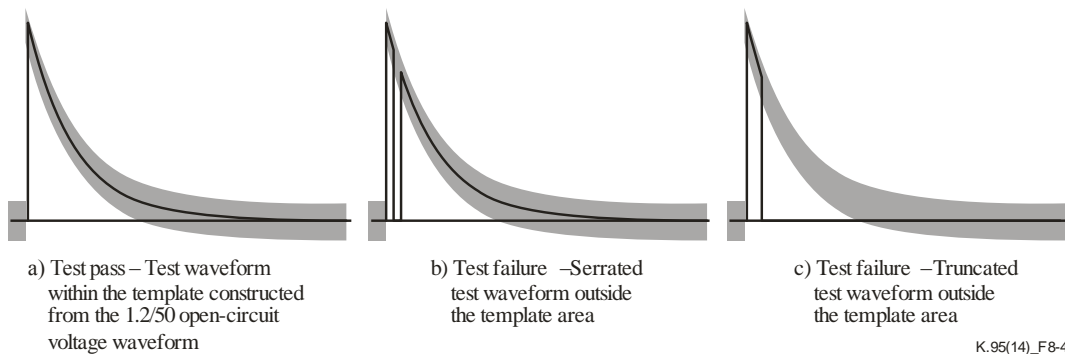

a) Test pass – Test waveform
within the template constructed
from the 1.2/50 open-circuit
voltage waveform

b) Test failure – Serrated
test waveform outside
the template area

c) Test failure – Truncated
test waveform outside
the template area

Figure 8-4 – Pass/fail template and test waveforms

Using test circuits of Figure 8-1 or Figure 8-2, as appropriate, apply the impulse withstand test voltage corresponding to the transformer insulation rated impulse voltage to the insulation from the impulse generator, G, while recording the impulse waveform on oscilloscope, O. Check if the recorded voltage complies with Figure 8-4a. For a transformer with an electric screen (see Figure 8-2), two tests are made: one with the selector switch, SW, connecting the electric screen, ES, to the primary winding, W_P, and one with the selector switch, SW, connecting the electric screen, ES, to the secondary winding, W_S. In both tests the recorded voltage shall comply with Figure 8-4a.

After the impulse withstand test, measure the insulation resistance as described in clause 7.3.

8.2.3   Values

Table 8-1 lists the preferred values for the transformer insulation rated impulse voltage together with the corresponding impulse withstand test voltage. To verify the insulation rated impulse voltage is at least its specified value, the applied impulse withstand test voltage must be higher in voltage. The ratio of impulse withstand to rated impulse voltage used in Table 8-1 is 1.17 for voltages less than 4 kV and 1.23 for voltages of 4 kV and above in accordance with [b-IEC 60664-1] and [b-IEC/TR 60664-2-1].

Table 8-1 – Impulse withstand test voltage for rated impulse voltage

Rated impulse voltage (kV)	Impulse withstand voltage[a] (kV)
1.5	1.75
2.5	2.92
4	4.92
6	7.39
8	9.85
12	14.8
15	18.5
25	30.8
40	49.2
60	73.9
80	98.5
120	148

[a] The 1.2/50 peak voltage amplitude tolerance shall be ±5% in accordance with [b-IEC/TR 60664-2-1].

8.2.4 Criteria

The waveform during testing shall comply with the requirements of Figure 8-4a, and the after test insulation resistance shall comply with clause 7.3.4.

8.3 Signal transformer rated winding d.c.

8.3.1 Purpose

This test verifies that the specified winding conductor temperature rise, for the component type, is not exceeded at the rated transformer winding d.c. This rating is only required when the transformer is to be used in devices and equipment ports that are required to be tested under differential-mode a.c. power fault conditions.

8.3.2 Test method

This test is applicable to copper conductor transformer windings and assumes the transformer thermal resistance is constant. Figure 8-5 shows the two measuring circuits used. Circuit a) is to measure the pre-test values of winding resistance and ambient temperature. Circuit b) is to measure the winding voltage at the rated d.c. and the local ambient temperature of the transformer after thermal equilibrium is reached.

As the winding temperature is not measured directly, thermal equilibrium is taken as when the measured winding voltage has a variation of less than 0.4% between any two out of three consecutive measurements made at an interval of 5 min. Generally, most signal transformers will reach thermal equilibrium within 30 min. For these tests, the transformer shall be placed in a draught-free environment.

The pre-test values of winding resistance, R_1, and ambient temperature, T_{A1}, obtained from test circuit of Figure 8-5a, shall be recorded. The rated d.c., I_{DC}, shall then be applied to the transformer winding and the winding voltage measured at intervals of 5 min. When it has been determined that thermal equilibrium has been reached the winding voltage, V_W, and local ambient, T_{A2}, at that time shall be recorded.

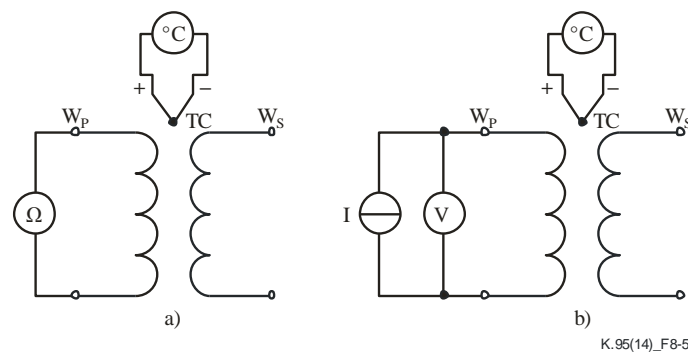The following calculations shall be done:

Increase in resistance value, ΔR:

$$\Delta R = \frac{V_w}{I_{DC}} - R_1 \tag{1}$$

Increase in winding temperature, ΔT, using a 0.00393 temperature coefficient for copper conductors:

$$\Delta T = \frac{\Delta R}{0.00393 R_1} \tag{2}$$

To compensate for any increase in local ambient temperature ($T_{A2} - T_{A1}$), the effective temperature increase, ΔT_{DC}, caused by I_{DC} is calculated from:

$$\Delta T_{DC} = \Delta T - \left(T_{A2} - T_{A1}\right) \tag{3}$$

W_P	Primary winding	Ω	Ohm meter to measure winding resistance
W_S	Secondary winding	I	Current source set to the winding rated d.c., IDC
TC	Thermocouple, placed 10 mm ±2 mm from the transformer for sensing the local ambient temperature	V	Voltmeter to measure winding voltage, VW
°C	Meter measuring the local ambient temperature		

Figure 8-5 – Winding conductor temperature rise test circuit

The insulation resistance (see clause 7.3) shall be measured after the test.

8.3.3 Values

The transformer primary rated winding d.c. depends on the transformer size, construction and the parameters required to operate satisfactory in the intended telecommunication system. With this degree of variation, it is impractical to create a list of preferred values. The transformer rated winding d.c. can be used to predict the maximum continuous a.c. root-mean square (RMS) power fault winding current that can be sustained before overcurrent protection is needed.

8.3.4 Criteria

At the rated d.c., I_{DC}, the calculated winding temperature rise, ΔT_{DC}, shall not exceed its specified value. The testing shall not cause a hazard nor result in an insulation resistance lower than specified in clause 7.3.

Annex A

Additional Transformer parameters to model Ethernet transformer differential surge let-through

(This annex forms an integral part of this Recommendation.)

A.1 Purpose

This annex is intended to help the designer to model the circuit operation during a differential surge condition from a few simple measurements on the Ethernet magnetics. It is assumed that whoever takes these measurements is competent in basic measurement techniques.

Under differential surge conditions the Ethernet transformer secondary winding triangular surge current let-though consists of three phases:

1   Transformer linear current transfer from primary, which determines the secondary current

2   Transformer core saturation event setting the peak secondary current

3   Saturated core secondary winding energy dump set by the transformer saturated core winding inductance, the peak secondary current and the secondary load impedance.
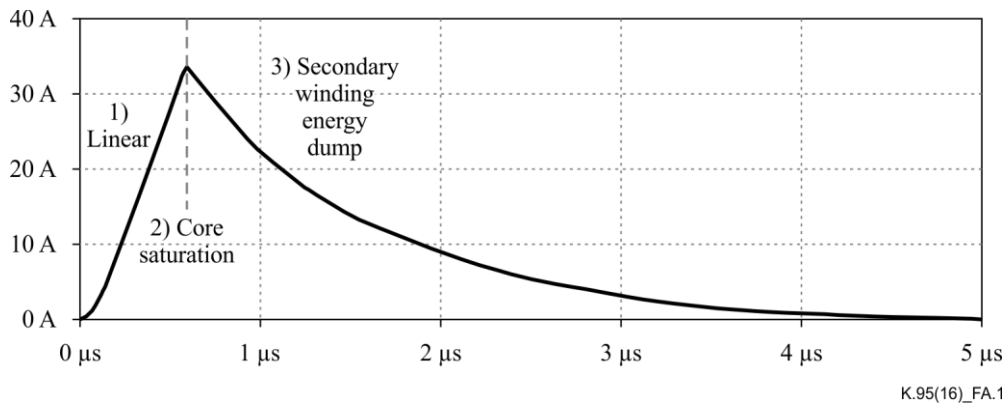

Figure A.1 – Three phases of secondary winding current

The two circuit conditions for parameter measurement are for phase 1 and phase 3, see Figure A.2.
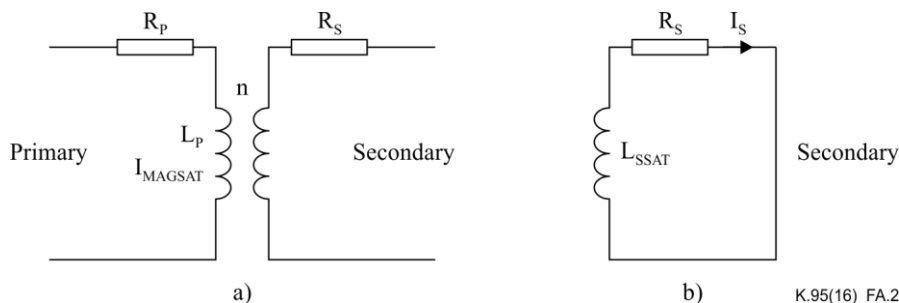

Figure A.2 –a) equivalent circuit for R_P, R_S, and L_P measurement b) equivalent circuit for secondary surge current measurement and determination of L_{SSAT}, I_{SM} and I_{MAGSAT}

The parameters derived or used are:

R_P = Primary resistance measurement

R_S = Secondary resistance measurement

L_P = Primary inductance measurement

$L_{SSAT} =$ Saturated core secondary inductance from surge waveforms and R_S

$n =$ Data sheet value of transformer turns ratio

$I_{SM} =$ Peak secondary current measurement

$I_{MAGSAT} =$ Core saturation value of the primary magnetising current from surge waveforms, n and R_S

These measurements are not recommendations for production testing.

A.2 Parameter measurements for phase 1

A.2.1 Series resistance, R_P and R_S

The magnetics assembly input, R_P, and output, R_S, resistance can be simply measured with a digital multi-meter having a resolution of 0.1 Ω or better as illustrated in Figure A.3.
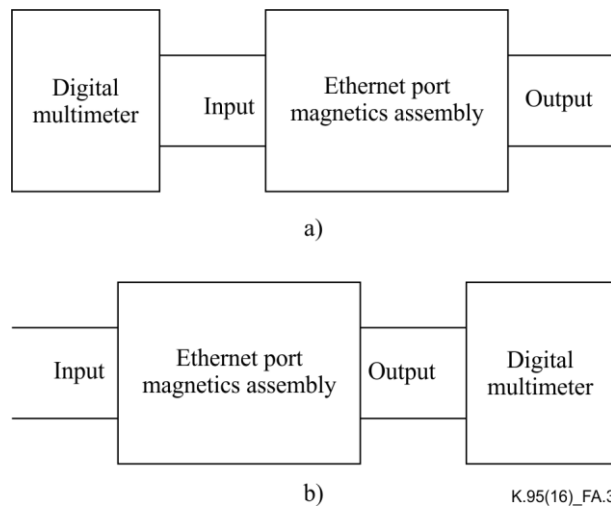

Figure A.3 – Digital multi-meter used to measure a) input resistance, R_P, and b) output resistance, R_S

A.2.2 Primary inductance, L_P

The magnetics assembly input, L_P, inductance can be simply measured with an LCR meter as illustrated in Figure A.4.
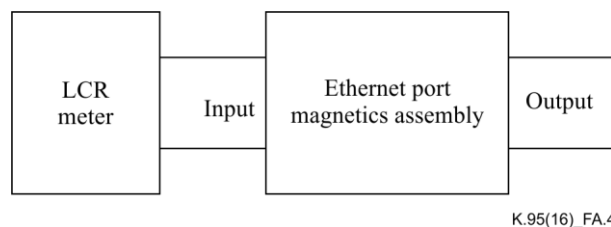

Figure A.4 – LCR meter used to measure input inductance L_P

A.3 Parameter derivations for phase 3

The quickest way to determine the working values of L_{SSAT} and I_{MAGSAT} is to apply a surge to the magnetics assembly input and measure the shorted output current.

A.3.1 Test circuit

The surge test circuit uses a 1.2/50-8/20 generator with a series resistor of 12 Ω and the transformer secondary short circuited, see Figure A.5.
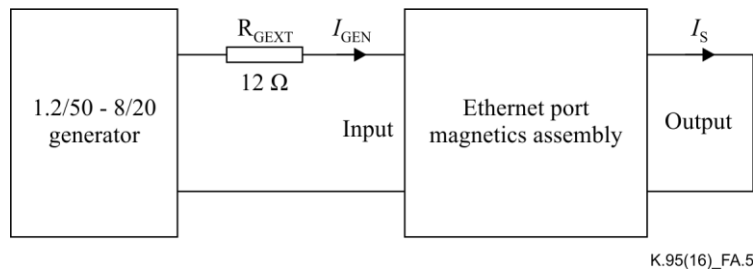
Figure A.5 – Output parameter test circuit

A.3.2 Measurements

With the generator set to 2.5 kV, the resulting output short circuit surge current, I_S, waveform is recorded for analysis.

A.3.3 Derived parameter values, L$_{SSAT}$, I_{SM} and I_{MAGSAT}

The peak secondary current, I_{SM}, is the peak value of the triangular current waveform recorded, see Figure A.6, which has an I_{SM} value of 42.2 A.
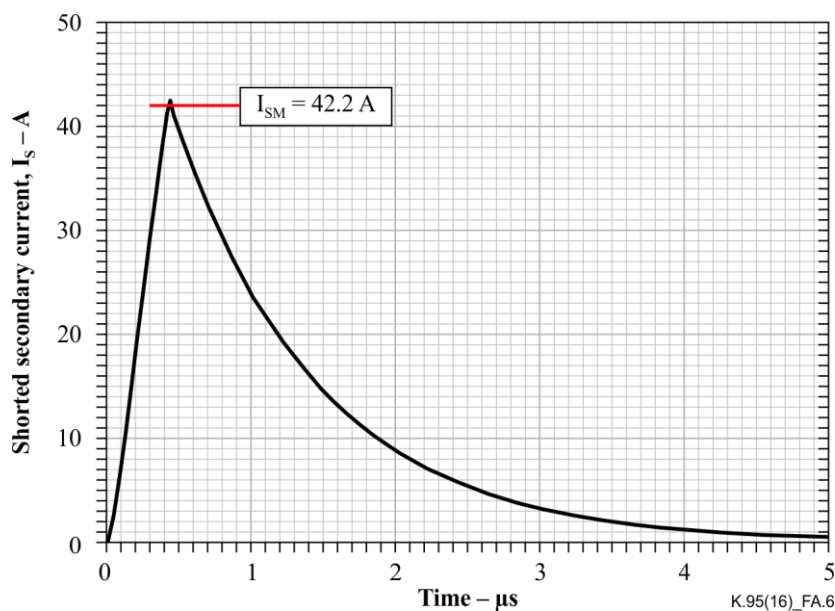

Figure A.6 – Short-circuit secondary current, I$_S$, versus time

The saturated secondary inductance value, L$_{SSAT}$, can be estimated from the slope of the current decay curve and the measured output resistance, R$_S$. The time constant of L$_{SSAT}$/R$_S$ determines the rate of current decay. In one L$_{SSAT}$/R$_S$ period the current decays to 1/e or 0.368 of the starting value. This applies to any part of the exponential decay. For example, if the reference starting level was set to 80% of I$_{SM}$ to be away from any aberrations that might occur at the peak, then the time to reach 80*0.368 = 29.4% of I$_{SM}$ is one L$_{SSAT}$/R$_S$ period, see Figure A.7. Multiplying this time by R$_S$ gives the value of L$_{SSAT}$.
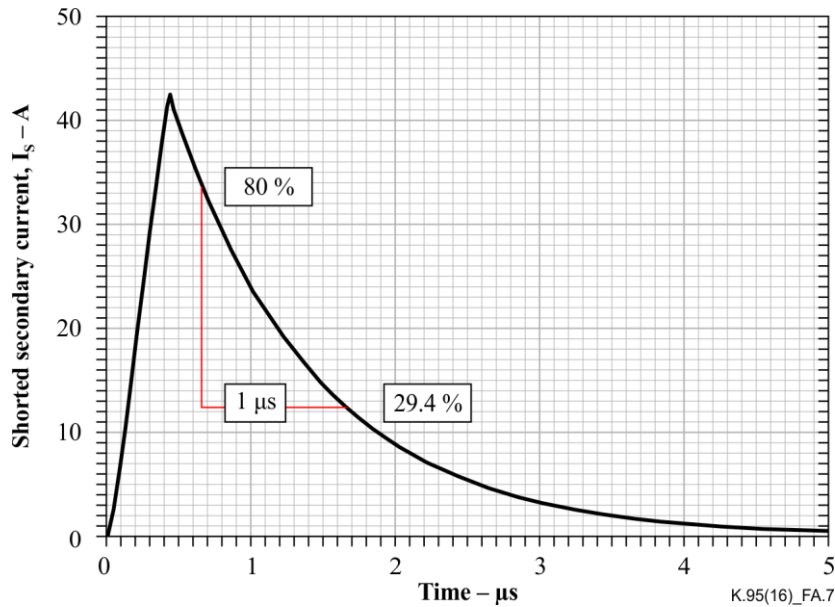
**Figure A.7 – 80% to 29.4% amplitude time measurement to determine
the L/r time constant**

Figure A.7 shows an example where I_{SM} is 42.2 A, R_S is 2 Ω and the 80% (33.7 A) to 29.4% (12.4 A) L_{SSAT}/R_S decay time is 1 µs. Thus $L_{SSAT} = 1*R_S = 1*2 = 2$ µH.

The peak secondary winding voltage will be $I_{SM}*R_S = 42.2*2 = 84.4$ V. The secondary voltage waveshape will be the same as the secondary current waveshape. The time to the peak current, I_{SM}, is 0.44 µs (Figure A.6) making a secondary Vs product to core saturation of 0.5*0.44*84.4 = 18.6 µVs. For a turns ratio of n = 1 and a primary winding inductance, L_P, of 350 µH, the working value of primary saturation current, I_{MAGSAT}, is $V_S/L_P = 18.6/350 = 0.05$ A.

Appendix I

1.2/50 impulse

(This appendix does not form an integral part of this Recommendation.)

I.1   Introduction

Generators delivering 1.2/50 open-circuit voltage impulses at the levels given in Table I.1 are commercially available. Some generators, called combination wave generators, also deliver a defined 8/20 short-circuit current. Generally 1.2/50-8/20 combination wave generators have a maximum open-circuit voltage of 6 kV peak.

I.2   Term definitions

This clause lists the definitions of the terms used in this appendix. Figure I.1 shows the time periods and amplitudes referenced in these definitions.

virtual front time [b-IEC 60060-1]: The front time T_1 of a voltage impulse is 1/0.6 times the interval T between the instants when the impulse is 30% and 90% of the peak value.

virtual origin; O_1 [b-IEC 60060-1]: For the impulse voltage waveform, it is the instant at which a straight line drawn through the 30% and 90% amplitude values crosses the time axis.

virtual time to half-value; T_2 [b-IEC 60060-1]: Interval of time between the instant of virtual origin O_1 and the instant when the voltage or current has decreased to half the peak value.

designation of an impulse shape [b-IEC 60099-4]: Combination of two numbers, the first representing the virtual front time (T_1) and the second the virtual time to half-value on the tail (T_2).

It is written as T_1/T_2, both in microseconds, the sign "/" having no mathematical meaning.
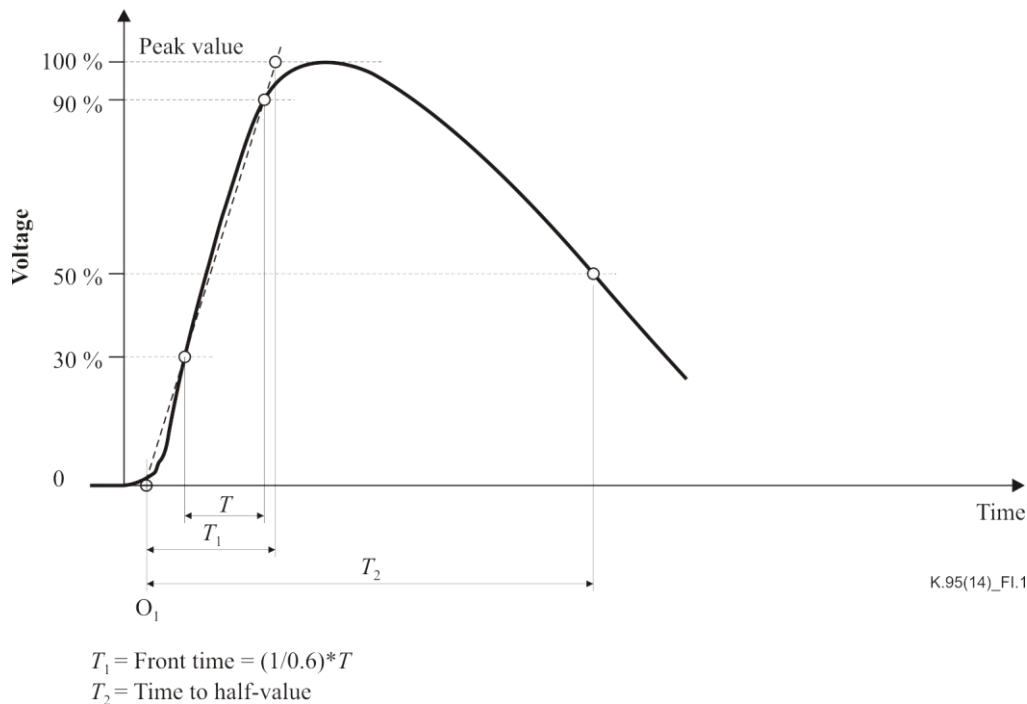

T_1 = Front time = (1/0.6)*T
T_2 = Time to half-value

Figure I.1 – 1.2/50 time periods and voltage amplitudes

I.3　1.2/50 waveform parameters

Table I.1 shows the 1.2/50 waveform details.

Table I.1 – 1.2/50 voltage impulse generator parameters

Designation	Condition	Period	Time and tolerance	Peak amplitude
1.2/50 [b-IEC 60060-1]	Open-circuit voltage	T_1	1.2 µs ±30%	±3% [a]
		T_2	50 µs ±20%	
	Short-circuit current	Current waveform not defined.		
[a]　The 1.2/50 peak voltage amplitude tolerance for insulation testing can be increased to ±5% in accordance with [b-IEC/TR 60664-2-1].				

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[b-IEC GUIDE 116]	IEC GUIDE 116, Ed. 1.0, *Guidelines for safety related risk assessment and risk reduction for low voltage equipment.*
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