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## Characteristics of metal oxide varistors for the protection of telecommunication installations

Recommendation ITU-T K.77



## **Recommendation ITU-T K.77**

### **Characteristics of metal oxide varistors for the protection of telecommunication installations**

#### **Summary**

Recommendation ITU-T K.77 gives the basic requirements to be met by metal oxide varistors (MOVs) for the protection of power circuits and signal circuits of telecommunication installations from surges.

The purpose of this Recommendation is to provide technical guidelines for purchasers and manufacturers of MOVs to ensure their satisfactory operation in the applications for which they are intended.

This Recommendation is intended to be used for the harmonization of existing or future specifications issued by MOV manufactures, telecommunication equipment manufactures, administrations or network operators.

#### **Source**

Recommendation ITU-T K.77 was approved on 13 January 2009 by ITU-T Study Group 5 (2009-2012) under Recommendation ITU-T A.8 procedures. This version includes the corrections agreed upon by ITU-T Study Group 5 (2009-2012) on 29 May 2009.

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## Introduction

Two types of metal oxide varistor (MOV) may be differentiated by their constructions: leadless surface mounting device (SMD)-type MOVs and leaded disc-type MOVs (including wire-terminations and strap terminations), while by their application fields the MOV may be divided into MOVs for power circuit use and MOVs for signal circuit use. Table 1 gives the applicable test items for various type MOVs.

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# Recommendation ITU-T K.77

## Characteristics of metal oxide varistors for the protection of telecommunication installations

### 1 Scope

This Recommendation:

- gives the characteristics of metal oxide varistors (MOVs) used in accordance with [b-ITU-T K.11] for the protection of power supply circuits and signal circuits of telecommunication installations against overvoltages;
- does not deal with combinations of several MOVs connected in series and/or in parallel, nor combinations of MOV with other components;
- does not deal with mountings and their effect on MOV characteristics, the characteristics apply to MOV as a component, mounted only in the ways described for the tests;
- does not deal with mechanical dimensions;
- does not deal with quality assurance requirements.

### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- |                  |                                                                                                                                             |
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### 3 Definitions

This Recommendation defines the following terms:

**3.1 applied voltage ratio ( $R_{ap}$ ):** Ratio of d.c. voltage or peak of a.c. voltage applied on the MOV to the varistor voltage  $U_N$ .

**3.2 clamping voltage ( $U_{cla}$ ):** Maximum peak voltage across the MOV measured under conditions of a specified waveform impulse with current peak  $I_P$ . If there is both a front peak and rear peak on the voltage waveform, the rear peak voltage is defined as the clamping voltage.

NOTE – For an individual MOV, peak voltages shall be measured in two directions, and the larger value of the two is referred to as the clamping voltage of this MOV.

**3.3 clamping voltage ratio ( $R_{cla}$ ):** Ratio of the clamping voltage  $U_{cla}$  to the varistor voltage  $U_N$  ( $R_{cla} = U_{cla}/U_N$ ).

**3.4 combination impulse (1.2/50-8/20):** Impulse with open-circuit voltage of 1.2/50  $\mu$ s ( $T_1/T_2$ ) and short-circuit current of 8/20  $\mu$ s ( $T_1/T_2$ ), which is expressed by "voltage peak/current peak".

NOTE – Unless otherwise specified, the effective impedance shall be 2  $\Omega$ , which is the quotient of the open-circuit voltage peak  $U_P$  and the short-circuit current peak  $I_P$ .

**3.5 current peak de-rating curve:** Curves expressing the relationship of the three variables of  $I_P$ ,  $n$ ,  $\tau$ , where  $I_P$  is impulse current peak,  $\tau$  is the impulse width, and  $n$  is average application numbers of the impulse that the MOV can withstand in terms of specified pass criterion. The current  $I_P$  shall be de-rated with the increasing of  $\tau$  and/or  $n$ , that may be represented by equations 3-1 and 3-2.

$$\lg I_g = A - a \lg n \quad (\tau = \text{constant}) \quad (3-1)$$

$$\lg I_g = B - b \lg \tau \quad (n = \text{constant}) \quad (3-2)$$

Where  $A$ ,  $a$ ,  $B$  and  $b$  are four constants which depend on the type and manufacturing of the MOV, also  $A$  and  $a$  depend on  $\tau$  values,  $B$  and  $b$  depend on  $n$  values.

NOTE – Equations 3-1 and 3-2 agree well with the actual characteristics of MOV when  $n \geq 10$ , while for  $n$  less than 10,  $I_P$  deviated from these equations.

**3.6 current de-rating fraction ( $F_I$ ):** Ratio of impulse current peak  $I_P$  ( $n$ ,  $\tau$ ) to the maximum discharge current  $I_{\max}$ .

$$F_I = I_P(n, \tau) / I_{\max}$$

**3.7 effective resistance:** Ratio of the rear peak voltage to the applied impulse current peak of the specified waveform, unless otherwise specified, 8/20 impulse current shall be used.

**3.8 effective linear resistance ( $R_V$ ):** Linear component of the effective resistance determined by the high-impulse-current method.

NOTE – The linear resistance of the MOV may be determined by the high-frequency-signal method, infrared method and high-impulse-current method, but they may give different results.

**3.9 effective non-linear resistance ( $R_Z$ ):** Non-linear component of the effective resistance which can be expressed by equation 3-3

$$R_Z = A_1 \cdot I_P^{(\beta-1)} \quad (3-3)$$

Where:  $A_1$  is the virtual clamping voltage at 1 A of specified impulse;  
 $\beta$  is the non-linearity current index.

**3.10 endurance at maximum operating temperature:** Property to operate at maximum operating temperature and maximum continuous operating voltage (MCOV) for 1000 h.

NOTE – Unless otherwise specified, the maximum operating temperature shall be 85°C.

**3.11 front peak voltage ( $U_F$ ):** Maximum voltage across the MOV occurring at the initial time of an applied impulse current of specified waveform and peak value. The front peak voltage represents a time-dependent modification of the highly non-linear conduction process responsible for varistor action.

**3.12 high (low) voltage varistors:** The varistors of varistor voltage  $U_N \geq 82$  V are called high voltage varistors, and those of varistor voltage smaller than 82 V are named low voltage varistors.

**3.13 impulse:** Unidirectional wave of voltage or current without appreciable oscillation.

Six impulses are used in this Recommendation: current impulse 8/20, 10/350, 10/1000, 2-ms rectangular wave, electrostatic discharge, and 1.2/50-8/20 combination impulse.

**3.14 impulse current peak ( $I_P(n, \tau)$ ):** Repetitive impulse current peak which can be applied for application numbers ( $n$ ) with impulse width  $\tau$ .

**3.15 impulse width ( $\tau$ ):** Normalized impulse duration which is the ratio of the waveform area to the impulse peak, by means of  $\tau$  any waveform of impulse can be converted into an equivalent rectangular wave.

**3.16 informative characteristics:** Characteristics of a metal oxide varistor (MOV) which are of significance for applications and should be provided by manufactures, but they are not covered by an acceptance inspection programme, for example: V-I characteristics, V-I characteristics of low field region, current peak de-rating curve, temperature de-rating curve.

**3.17 leakage current a.c. ( $I_{La}$ ):** Current passing through the metal oxide varistor (MOV) with the maximum a.c. voltage  $U_C$  applied on it, and at a specified temperature, it may be r.m.s value or peak value.

**3.18 leakage current d.c. ( $I_{Ld}$ ):** Current passing through the metal oxide varistor (MOV) with the maximum d.c. voltage  $U_{DC}$  applied on it, and at a specified temperature.

**3.19 long (short) duration impulse:** An impulse with an impulse width  $\tau \geq 100 \mu s$  is called a long duration impulse, in contrast, an impulse of  $\tau < 100 \mu s$  is called a short duration impulse.

NOTE – In this Recommendation, a long (short) duration impulse is denoted by the letter "L" ("S")

**3.20 maximum continuous operating voltage (MCOV) ( $U_C$  ( $U_{DC}$ )):** Maximum a.c. r.m.s. voltage  $U_C$  or maximum d.c. voltage  $U_{DC}$  which can be applied continuously at a temperature of 25°C.  $U_C$  shall be a substantially sinusoidal voltage (less than 5% total harmonic distortion).

**3.21 maximum discharge current ( $I_{max}$ ):** The maximum allowable crest value of impulse current with 8/20 waveform for two applications.

**3.22 metal oxide varistor (MOV):** Component made of ZnO and a few additives whose conductance, at a given temperature, increases rapidly with the voltage increasing over a certain voltage range. It is also known as a voltage-dependent resistor (VDR).

**3.23 nominal discharge current ( $I_n$ ):** The crest value of impulse current with 8/20 waveform that is intended for clamping voltage measurement of the metal oxide varistors (MOVs) for power circuit use.

**3.24 non-linearity current index ( $\beta$ ):** Slope of the volt-ampere characteristic when the effective linear resistance is much smaller than the effective non-linear resistance. It is always less than 1. For the convenience of calculation, equation 3-4 may be used.

$$\beta = \frac{\lg(U_{cla1}/U_{cla2})}{\lg(I_{P1}/I_{P2})} \quad (3-4)$$

NOTE – For most commercially available metal oxide varistors (MOVs), it is considered that the effective linear resistance is much smaller than the effective non-linear resistance when the 8/20 current density  $J_P$  is less than 320 A/cm<sup>2</sup>.

**3.25 rated dissipation power ( $P_m$ ):** Maximum allowable average power dissipation when subjected to the stress of successive impulses and at the temperature of 25°C.

**3.26 rated impulse energy ( $W_m$ ):** Maximum single impulse energy which can be absorbed by the metal oxide varistor (MOV) for a specified waveform. Unless otherwise specified, a 2 ms rectangular current impulse or 10/1000 current impulse shall be used.

**3.27 rear peak voltage ( $U_R$ ):** Maximum voltage across the metal oxide varistor (MOV) occurring at the time behind the front peak with an application of impulse current of specified waveform and sufficient peak values.

**3.28 temperature de-rating curve:** Graphical representation of parameters de-rating against temperature.

NOTE – Typical parameters are maximum continuous operating voltage  $U_C$  ( $U_{DC}$ ), maximum discharge current  $I_{max}$ , nominal discharge current  $I_n$ , impulse current peak  $I_P(n, \tau)$ , rated dissipation  $P_m$ , and rated impulse energy  $W_{tm}$ .

**3.29 temporary overvoltage (TOV) ( $U_T$ ):** a.c. voltage (r.m.s) or d.c. voltage that the metal oxide varistor (MOV) can withstand;  $U_T$  exceeds the maximum continuous operating voltage  $U_C$  or  $U_{DC}$ .

**3.30 temporary overvoltage (TOV) withstanding capability:** The specified TOV stress that a metal oxide varistor (MOV) should be capable of withstanding, and evaluated by the energy absorbed by the MOV and element temperature of the MOV under this stress.

NOTE – This property of the MOV is intended to match the operation of thermal disconnectors of the surge protective devices (SPDs) that use the MOV.

**3.31 unit thickness voltage:** Ratio of varistor voltage  $U_N$  to the thickness of the metal oxide varistor MOV element, expressed in "V/mm".

NOTE – The peak values of long duration impulse and impulse energy that the MOV is able to withstand depend strongly on the unit thickness voltage of the MOV.

**3.32 varistor voltage ( $U_N$ ):** Voltage, at specified d.c. current, used as a reference point in the component characteristic, unless otherwise specified, 1 mA d.c. current shall be used.

**3.33 virtual clamping voltage at 1 A ( $A_1$ ):** A constant in the V-I characteristic equation which is a deduced clamping voltage at current peak of 1 A.

**3.34 volt-ampere characteristic (V-I characteristic):** A description of the voltage limiting property of the metal oxide varistor (MOV) which is described by the relationship between clamping voltage  $U_{cla}$  and 8/20 current peak  $I_P$  over a specified range of  $I_P$ . Unless otherwise specified, the 8/20 current peak  $I_P$  shall cover the range from the current peak density  $J_P$  of about 32 A/cm<sup>2</sup> to the maximum discharge current. For this range of the 8/20 current, the V-I characteristic is expressed by equations 3-5 or 3-6.

$$U_{cla} = A_1 \cdot I_P^\beta + R_V \cdot I_P = I_P(R_Z + R_V) \quad (3-5)$$

Where:  $A_1$  is the virtual clamping voltage at 1 A,  $\beta$  is the non-linearity current index,  $R_Z$  is the effective non-linear resistance, and  $R_V$  is the effective linear resistance.

$$U_{cla} = a_1 \cdot U_N \cdot I_P^\beta + R_V \cdot I_P \quad (3-6)$$

Where:  $U_N$  is the varistor voltage,  $a_1 = A_1 / U_N$ .

NOTE – For a production lot of the MOV, the varistor voltage of the individual product may vary within an allowable tolerance, but the  $a_1$  and the  $R_V$  do not depend on the varistor voltage.

**3.35 volt-ampere characteristic of low field region:** Relationship between d.c. currents through the metal oxide varistor (MOV) and the voltages across the MOV over a specified operating temperature range, usually the test current is below 1 mA/cm<sup>2</sup> d.c.

NOTE – The volt-ampere characteristic of the low field region is expressed as equation 3-7, by means of which the leakage current is easily obtained at a given applied voltage and temperature.

$$I = I_0 \exp\left(-\frac{E_g - \beta\sqrt{U}}{kT}\right) \quad (3-7)$$

Where:

$I$  ( $\mu\text{A}$ ) is the d.c. current through the MOV with the d.c. voltage  $U$  (V) applied on it, and at the temperature  $T$  (K).

$k = 1.38 \times 10^{-23} \text{ J/K}$ , Boltzmann constant.

$I_0$ ,  $E_g$  and  $\beta$  are three constants that depend on the part number of the MOV, and being determined by laboratory test.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

|      |                                      |
|------|--------------------------------------|
| ESD  | Electrostatic Discharge              |
| LPF  | Low Pass Filter                      |
| MCOV | Maximum Continuous Operating Voltage |
| MOV  | Metal Oxide Varistor                 |
| PS   | Power Source                         |
| SMD  | Surface Mounting Device              |
| SPD  | Surge Protective Device              |
| TOV  | Temporary Overvoltage                |
| VDR  | Voltage-Dependent Resistor           |

## 5 Storage conditions

MOVs of encapsulated types shall be capable of withstanding the following storage conditions without damage:

- Temperature:  $-40^\circ\text{C}$  to  $+115^\circ\text{C}$
- Relative humidity: up to 95%

MOVs which are to be soldered after shipment from the manufacturer should be left in the original packing and kept in the following conditions during the storage period:

- Temperature:  $-25^\circ\text{C}$  to  $+45^\circ\text{C}$
- Relative humidity (without condensation): less than 70% annual average, and less than 90% on a maximum of 30 days per annum.

## 6 Electrical requirements

MOVs of various types should have the characteristics listed in Table 1 when tested in accordance with clause 7.

### 6.1 Varistor voltage

When tested according to clause 7.1, varistor voltage should be within the specified limits. Tables 2a and 2b show the nominal varistor voltages of high voltage and low voltage disc types that are commonly used; their allowable tolerances are  $\pm 10\%$ .

The nominal varistor voltages and tolerances listed in Table 2c are typical for SMD types.

## 6.2 Maximum a.c. (d.c.) continuous operating voltage

Unless otherwise specified, MOVs shall have a maximum a.c. (d.c.) continuous operating voltage  $U_C$  ( $U_{DC}$ ) as given in Tables 2a, 2b and 2c, the conformity shall be evaluated according to clause 7.2.

## 6.3 Leakage current d.c.

When tested according to clause 7.3, the leakage current, d.c., under maximum continuous d.c. voltage  $U_{DC}$ , shall be less than the maximum value specified by the manufacturer and there shall be no upward drifting during the application of the test voltage  $U_{DC}$ .

## 6.4 Leakage current a.c.

When tested according to clause 7.4, the leakage current, a.c., under maximum continuous a.c. voltage  $U_C$ , shall be less than the maximum value specified by the manufacturer.

## 6.5 Capacitance

When tested according to clause 7.5, the measured value of capacitance shall not exceed the value specified by the manufacturer.

## 6.6 Clamping voltage

When tested according to clause 7.6, the measured clamping voltage at a specified impulse current shall be no more than the specified values or the values indicated in Tables 2a, 2b and 2c. Unless otherwise specified, 8/20 impulse current having the peak as specified in Tables 2a.1, 2b.1 and 2c shall be used.

Table 1 – MOV characteristics summary

| Test item                                  | Clause number |             | MOV types          |      |                     |
|--------------------------------------------|---------------|-------------|--------------------|------|---------------------|
|                                            | Requirement   | Test method | For power circuits |      | For signal circuits |
|                                            |               |             | a.c.               | d.c. |                     |
| Electrical characteristics                 |               |             |                    |      |                     |
| Varistor voltage                           | 6.1           | 7.1         | ○                  | ○    | ○                   |
| Max. continuous voltage                    | 6.2           | 7.2         | ○                  | ○    | ○                   |
| Leakage current, d.c.                      | 6.3           | 7.3         |                    | ○    | ○                   |
| Leakage current, a.c.                      | 6.4           | 7.4         | ○                  |      |                     |
| Capacitance                                | 6.5           | 7.5         | ○                  | ○    | ○                   |
| Clamping voltage                           | 6.6           | 7.6         | ○                  | ○    | ○                   |
| Max. discharge current                     | 6.7           | 7.7         | ○                  | ○    | ○                   |
| ESD impulse test                           | 6.8           | 7.8         |                    |      |                     |
| Rated dissipation                          | 6.9           | 7.9         | ○                  | ○    | ○                   |
| Rated impulse energy                       | 6.10          | 7.10        | ○                  | ○    | ○                   |
| Impulse durability                         | 6.11          | 7.11        | ○                  | ○    | ○                   |
| Endurance at maximum operation temperature | 6.12          | 7.12        | ○                  | ○    |                     |
| TOV withstanding capability                | 6.13          | 7.13        | ○                  |      |                     |

**Table 1 – MOV characteristics summary**

| Test item                                      | Clause number |             | MOV types          |      |                     |
|------------------------------------------------|---------------|-------------|--------------------|------|---------------------|
|                                                | Requirement   | Test method | For power circuits |      | For signal circuits |
|                                                |               |             | a.c.               | d.c. |                     |
| Insulation resistance (Note)                   | 6.14          | 7.14        | ○                  | ○    | ○                   |
| Voltage proof (Note)                           | 6.15          | 7.15        | ○                  | ○    | ○                   |
| <b>Environmental tests</b>                     |               |             |                    |      |                     |
| Robustness of terminations                     | 8.1           |             | ○                  | ○    | ○                   |
| Solderability                                  | 8.2           |             | ○                  | ○    | ○                   |
| Resistance to soldering heat                   | 8.3           |             | ○                  | ○    | ○                   |
| Vibration                                      | 8.4           |             | ○                  | ○    | ○                   |
| Bump                                           | 8.5           |             | ○                  | ○    | ○                   |
| Rapid changes of temperature                   | 8.6           |             | ○                  | ○    | ○                   |
| Climatic sequence                              | 8.7           |             | ○                  | ○    | ○                   |
| Damp heat, steady state                        | 8.8           |             | ○                  | ○    | ○                   |
| Fire hazard                                    | 8.9           |             | ○                  | ○    | ○                   |
| Solvent resistance of marking                  | 8.10          |             | ○                  | ○    | ○                   |
| Component solvent resistance                   | 8.11          |             | ○                  | ○    | ○                   |
| <b>Informative characteristics</b>             |               |             |                    |      |                     |
| Voltage vs. current peak curve                 | 9.1           |             | ○                  | ○    | ○                   |
| Peak current de-rating curve                   | 9.2           |             | ○                  | ○    | ○                   |
| Volt-ampere characteristic of low field region | 9.3           |             | ○                  | ○    | ○                   |
| NOTE – For insulated MOV only.                 |               |             |                    |      |                     |

**Table 2a – Voltage ratings of high voltage disc types**

| Nominal varistor voltage $U_N$ (V) | Max. continuous voltage (V) |               | Clamping voltage (Note), $U_{cla}$ (V) |             |
|------------------------------------|-----------------------------|---------------|----------------------------------------|-------------|
|                                    | a.c. (r.m.s) $U_C$          | d.c. $U_{DC}$ | 8/20, $I_{P1}$                         | 8/20, $I_n$ |
| 82                                 | 50                          | 65            | 135                                    |             |
| 100                                | 60                          | 85            | 165                                    |             |
| 120                                | 75                          | 100           | 200                                    |             |
| 150                                | 95                          | 125           | 250                                    |             |
| 180                                | 115                         | 150           | 300                                    |             |
| 200                                | 130                         | 170           | 340                                    | 520         |
| 220                                | 140                         | 180           | 360                                    | 550         |
| 240                                | 150                         | 200           | 395                                    | 605         |
| 275                                | 175                         | 225           | 455                                    | 695         |

**Table 2a – Voltage ratings of high voltage disc types**

| Nominal varistor voltage $U_N$ (V) | Max. continuous voltage (V) |               | Clamping voltage (Note), $U_{cla}$ (V) |             |
|------------------------------------|-----------------------------|---------------|----------------------------------------|-------------|
|                                    | a.c. (r.m.s) $U_C$          | d.c. $U_{DC}$ | 8/20, $I_{P1}$                         | 8/20, $I_n$ |
| 300                                | 195                         | 250           | 505                                    | 770         |
| 330                                | 210                         | 270           | 545                                    | 835         |
| 360                                | 230                         | 300           | 595                                    | 910         |
| 390                                | 250                         | 320           | 650                                    | 985         |
| 430                                | 275                         | 350           | 710                                    | 1090        |
| 470                                | 300                         | 385           | 775                                    | 1190        |
| 510                                | 320                         | 410           | 845                                    | 1290        |
| 560                                | 350                         | 450           | 930                                    | 1420        |
| 620                                | 385                         | 505           | 1025                                   | 1570        |
| 680                                | 420                         | 560           | 1120                                   | 1720        |
| 750                                | 460                         | 615           | 1240                                   | 1900        |
| 820                                | 510                         | 670           | 1355                                   | 2070        |
| 910                                | 550                         | 745           | 1500                                   | 2300        |
| 1000                               | 625                         | 825           | 1650                                   | 2530        |
| 1100                               | 680                         | 895           | 1815                                   | 2780        |
| 1200                               | 750                         | 1060          | 2000                                   | 3040        |

NOTE – The clamping voltages listed represent the clamping voltages of the MOVs having varistor voltages of 10% higher than the nominal values. The test currents shall be 8/20 impulse with the peaks listed in Table 2a.1. The  $I_n$  is used for MOVs for power distribution system applications, while the  $I_{P1}$  is used for MOVs for other applications.

**Table 2a.1 – Test current peaks for clamping voltages of high voltage disc types**

| MOV diameter (mm)         | 5 | 7  | 10 | 14 | 20  | 25  | 32     | 40   | 53   |
|---------------------------|---|----|----|----|-----|-----|--------|------|------|
| Current peak $I_{P1}$ , A | 5 | 10 | 25 | 50 | 100 | 150 | 200    | 300  | 450  |
| Current peak $I_n$ , A    |   |    |    |    |     | 8 k | 12.5 k | 20 k | 30 k |

**Table 2b – Voltage ratings of low voltage disc types**

| Nominal varistor voltage $U_N$ (V) | Maximum continuous voltage (V) |               | Clamping voltage (Note) $U_{cla}$ (V) |
|------------------------------------|--------------------------------|---------------|---------------------------------------|
|                                    | a.c. (r.m.s) $U_C$             | d.c. $U_{DC}$ |                                       |
| 18                                 | 11                             | 14            | 36                                    |
| 22                                 | 14                             | 18            | 43                                    |
| 27                                 | 17                             | 22            | 53                                    |
| 33                                 | 20                             | 26            | 65                                    |
| 39                                 | 25                             | 31            | 77                                    |