

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Semiconductor devices – Discrete devices –
Part 4: Microwave diodes and transistors**

**Dispositifs à semiconducteurs – Dispositifs discrets –
Partie 4: Diodes et transistors hyperfréquences**



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SEMICONDUCTOR DEVICES – DISCRETE DEVICES –

Part 4: Microwave diodes and transistors

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International Standard IEC 60747-4 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

This second edition cancels and replaces the first edition, published in 1991, its amendments 1, 2 and 3 (1993, 1999 and 2001, respectively), and constitutes a technical revision.

The major technical changes with regard to the previous edition are as follows:

- a) the clause of bipolar transistors has been added;
- b) the clause of field-effect transistors has been amended.

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

FDIS	Report on voting
47E/330/FDIS	47E/339/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The list of all parts of the IEC 60747 series, under the general title *Semiconductor devices – Discrete devices*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

SEMICONDUCTOR DEVICES – DISCRETE DEVICES –

Part 4: Microwave diodes and transistors

1 Scope

This part of IEC 60747 gives requirements for the following categories of discrete devices:

- variable capacitance diodes and snap-off diodes (for tuning, up-converter or harmonic multiplication, switching, limiting, phased shift, parametric amplification);
- mixer diodes and detector diodes;
- avalanche diodes (for direct harmonic generation, amplification);
- gunn diodes (for direct harmonic generation);
- bipolar transistors (for amplification, oscillation);
- field-effect transistors (for amplification, oscillation).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-702:1992, *International Electrotechnical Vocabulary – Chapter 702: Oscillations, signals and related devices*

IEC 60747-1:2006, *Semiconductor devices – Part 1: General*

IEC 60747-7:2000, *Semiconductor devices – Part 7: Bipolar transistors*

IEC 60747-8:2000, *Semiconductor devices – Part 8: Field-effect transistors*

IEC 60747-16-1:2001, *Semiconductor devices – Part 16-1: Microwave integrated circuits – Amplifiers*

Amendment 1(2007)

3 Variable capacitance, snap-off diodes and fast-switching schottky diodes

3.1 Variable capacitance diodes

3.1.1 General

The provisions of this part deal with diodes (excluding snap-off diodes) in which the variable capacitance effect is used; they cover four applications: tuning, harmonic multiplication, switching (including limiting), parametric amplification.

The devices for these applications are defined as follows:

Diodes for tuning

Diodes which are used to vary the frequency of a tuned circuit.

These diodes are usually characterized a frequency of resonance much higher than the frequency of use and have a known capacitance/voltage relationship.

Diodes for harmonic multiplication

These diodes must have a non-linear capacitance/voltage relationship at the frequency of operation and a high ratio of cut-off frequency to operating frequency.

Diodes for switching (including limiting)

These diodes exhibit a fast transition from a high impedance state to a low impedance state and vice versa and can be used to modulate or control the power level in microwave systems.

Diodes for parametric amplification

These diodes are intended to handle small amplitude signals and are most often used in low-noise amplifiers.

3.1.2 Terminology and letter symbols

See 3.1.3.3.

3.1.3 Essential ratings and characteristics

3.1.3.1 General

3.1.3.1.1 Rating conditions

Variable capacitance diodes may be specified either as ambient rated or case rated devices or, where appropriate, as both.

The ratings listed in 3.1.3.2 should be stated at the following temperatures:

– *ambient-rated devices:*

at an ambient temperature of 25 °C and at one higher temperature.

– *case-rated devices:*

at a reference point temperature of 25 °C and at another reference point temperature.

3.1.3.1.2 Application categories

The essential ratings and characteristics to be stated for each category of diode are marked with a + sign in the following table:

- ### 3.1.3.2 Ratings (limiting values)

3.1.3.2.1 Temperatures

3.1.3.2.2 Voltages and currents

3.1.3.2.3 Power dissipation

3.1.3.3 Electrical characteristics

3.1.3.3.1 Stray capacitance (C_p)

3.1.3.3.2 Series inductance (L_s)

3.1.3.3.3 Terminal capacitance (C_{tot})

- #### 3.1.3.3.4 Junction capacitance (C_j)

3.1.3.3.5 Effective quality factor (Q)

[illegible]

3.1.3.3.6 Cut-off frequency

Minimum value under specified conditions (notes 4 and 5)

3.1.3.3.7 Series resistance (r_s)

Maximum and/or typical values under specified conditions (note 4)

3.1.3.3.8 Reverse current

Maximum value at a specified reverse voltage

3.1.3.3.9 Thermal resistance

Maximum value between junction and ambient, or between the junction and a specified reference point

3.1.3.3.10 Switching time

Typical value under specified conditions

3.1.3.3.11 Stored charge or minority carrier life time

Typical value, for either stored charge under specified conditions including bias, or minority carrier life time under specified conditions

3.1.3.3.12 Transition time

Typical value, under specified conditions, together with a specified measurement circuit (note 1)

Categories			
1	2	3	4
	+	+	+
+	+	+	+
+	+	+	+
+	+	+	
	+	+	
+			

NOTE 1 See definition in 3.2.2.

NOTE 2 For categories 1, 2 and 3, the specified bias voltage should be –6 V and for category 4, the specified bias voltage should be 0 V.

NOTE 3 The relationship between the junction capacitance and bias voltage should be represented either by a typical curve or by a mathematical form. The mathematical form should be as follows:

$$C_j = K (V + \phi)^\gamma$$

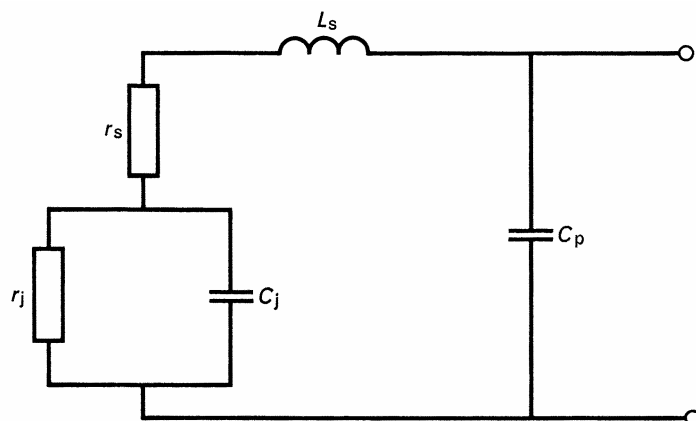
where V is the magnitude of the applied reverse voltage and K , ϕ and γ are three constants. The manufacturer should specify the typical values for K , ϕ and γ .

NOTE 4 If the Q value and the series resistance are not specified for category 1, then the cut-off frequency must be specified.

NOTE 5 The cut-off frequency f_c is defined as:

$$f_c = \frac{1}{2\pi r_s C_j}$$

where r_s is the series resistance and C_j is the capacitance of the junction measured at a specified bias point r_s is determined by the equivalent circuit shown in Figure 1 below; its value depends on the measuring method used and on the bias voltage.



IEC 1108/01

Key

C_j junction capacitance

C_p stray capacitance

r_s series resistance

L_s series inductance

r_j low frequency resistance of the junction

In general, r_j is sufficiently high to be neglected.

Figure 1 – Equivalent circuit

3.1.3.4 Application data

For harmonic multiplication applications, the *efficiency* should be stated.

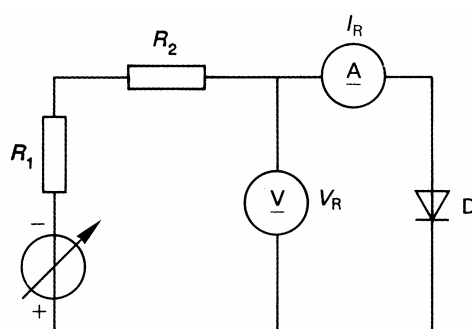
3.1.4 Measuring methods

3.1.4.1 Reverse current I_R

a) Purpose

To measure the reverse current of a diode under specified reverse voltage.

b) Circuit diagram



IEC 1109/01

Key

D diode being measured

Figure 2 – Circuit for the measurement of reverse current I_R

c) *Circuit description and requirements*

R_1 is a calibrated resistor (pulse measurement only).

R_2 is a protective resistor.

If a pulse measurement is required, the variable voltage generator is replaced by a voltage pulse generator, the voltmeter is replaced by a peak-reading instrument and the ammeter is replaced by a peak-reading voltmeter across the calibrated resistor R_1 .

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of reverse voltage V_R across the diode.

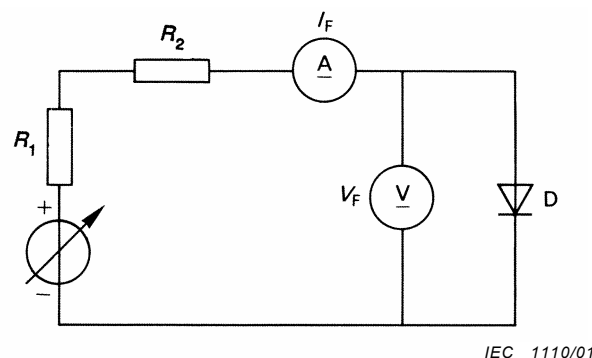
The reverse current I_R is read from the ammeter A.

e) *Specified conditions*

- Ambient, case or reference-point temperature (t_{amb} , t_{case} , t_{ref}).
- Reverse voltage (V_R).
- Pulse width and duty cycle, where applicable.

3.1.4.2 **Forward voltage V_F** a) *Purpose*

To measure the forward voltage across a signal or switching diode under specified conditions.

b) *Circuit diagram***Key**

D diode being measured

Figure 3 – Circuit for the measurement of forward voltage V_F

c) *Circuit description and requirements*

R_1 is a calibrated resistor (pulse measurement only).

R_2 is a high value resistor.

If a pulse measurement is required, the variable voltage generator is replaced by a voltage pulse generator, the voltmeter is replaced by a peak-reading instrument and the ammeter is replaced by a peak-reading voltmeter across the calibrated resistor R_1 .

d) *Measurement procedure*

The temperature is set to the specified value.

The variable voltage generator is adjusted to obtain the specified value of forward current I_F .

The forward voltage V_F is read from the voltmeter V .

e) *Specified conditions*

- Ambient or case temperature (t_{amb} , t_{case}).
- Forward current (I_F).
- Pulse width and duty cycle, where applicable.

3.1.4.3 Capacitance C_{tot}

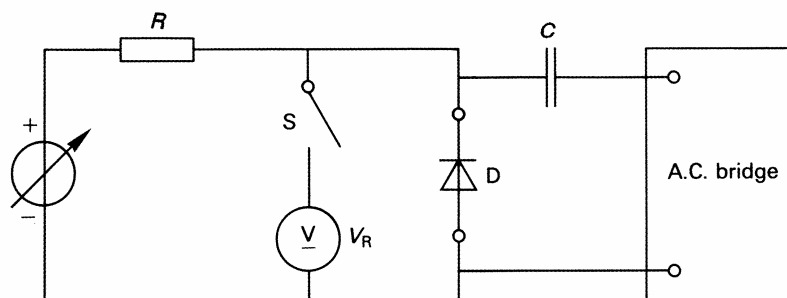
The measurement of total capacitance ($C_{tot} = C_j + C_p$) should be made at a sufficiently low frequency (below microwave frequencies) so that the effects of the lead inductance may be neglected. Under these conditions, the measured value of terminal capacitance is independent of frequency.

The total capacitance at a given bias condition is obtained by the method stated hereafter.

a) *Purpose*

To measure the total capacitance of a diode under specified conditions.

b) *Circuit diagram*



IEC 1111/01

Key

D diode being measured

Figure 4 – Circuit for the measurement of capacitance C_{tot}

c) *Circuit description and requirements*

The conductance of resistor R should be low compared with the admittance of the diode being measured.

The capacitor C must be able to withstand the reverse bias voltage of the diode and should present a short circuit at the frequency of measurement.

d) *Precautions to be observed*

The bridge shall be able to withstand the reverse bias voltage of the diode without affecting the accuracy of the measurement. If the measured capacitance is very small, the mounting conditions will affect the accuracy of the results and they should be specified.

e) *Measurement procedure*

The temperature is set to the specified value.

The voltage across the diode is adjusted to the specified value V_R . Then the voltmeter V is taken out of the circuit and the capacitance of the diode being measured is determined using the a.c. bridge by subtracting the value without the diode in its mounting from the value with the diode in its mounting.

f) *Specified conditions*

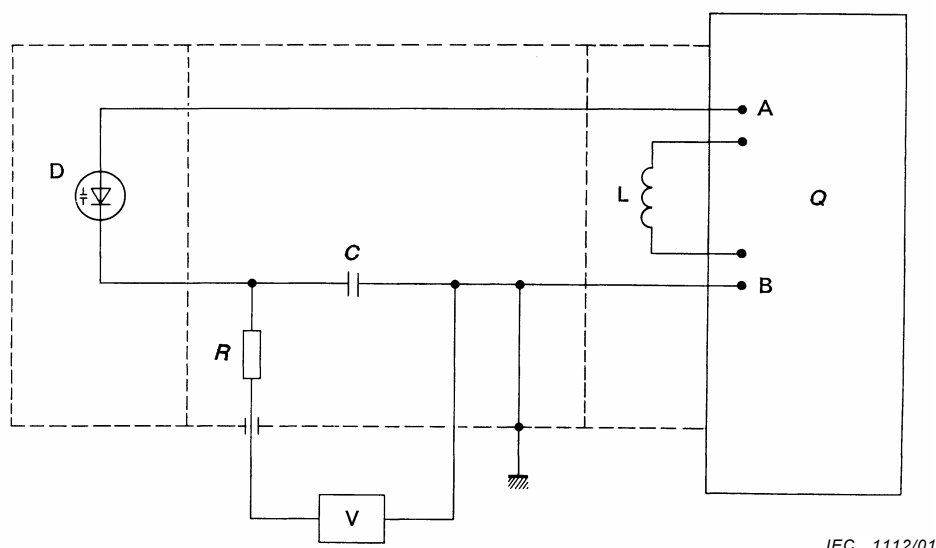
Ambient or case temperature (t_{amb} , t_{case}).

- Reverse voltage (V_R).
- Measurement frequency, if different from 1 MHz.
- Mounting conditions of the diode, if necessary.

NOTE The variation of total capacitance with bias voltage may be found by measurements as described above, made at a number of bias points.

3.1.4.4 **Effective quality factor Q**

The effective quality factor Q of a variable capacitance diode can be measured using a "Q-meter" or an impedance bridge (see Figure 5).

**Key**

- D diode being measured
 V voltage source
 Q Q-meter

Figure 5 – Circuit for the measurement of effective quality factor

Description

- a) The voltage source should present a high impedance at the frequency of measurement compared to that of the capacitor C ; this is obtained by means of series resistor R .
- b) C is a decoupling capacitor having a low impedance at the frequency of measurement.
- c) L is an inductor chosen to resonate with the parallel circuit capacitor at the frequency of measurement.
- d) It is assumed that there is a low resistance path through the Q-meter between points A and B.

The basic circuit of such a meter consists of a signal generator of negligible output impedance driving a high Q inductance in series with a high-quality variable capacitance. The factor Q of this circuit can be measured at a given frequency by tuning the variable capacitance for resonance.

Q is given by the ratio of the voltage across the capacitance to the voltage supplied by the generator. In order to measure the factor Q of a variable capacitance diode, it shall be connected in parallel with the variable capacitance in the Q -meter. DC isolating components shall be used so that the desired bias voltage may be applied to the diode being measured, but the biasing circuit must remain connected to the Q -meter throughout the measurement.

Four measurements are made: Q and C_1 , the factor Q of the circuit and the magnitude of the variable capacitance with the diode not in circuit; and Q_2 and C_2 , the factor Q of the circuit and the value of the variable capacitance for resonance at the same frequency with the diode connected to the circuit.

The factor Q of the diode is then calculated using the expression:

$$Q = \left(\frac{Q_1 Q_2}{Q_1 - Q_2} \right) \left(\frac{C_1 - C_2}{C_1} \right)$$

Two precautions are necessary:

- 1) The measurement shall be made at a frequency at which the reactance of the self-inductance of the diode is negligible compared with the reactance of the capacitor.
- 2) The magnitude of the signal applied to the variable capacitance diode shall be kept relatively small so that only a small excursion is made over the non-linear capacitance characteristic. The result must be independent of the signal level.

NOTE

$$Q = \frac{1}{2\pi f \times C_j \times r_s} = \frac{f_c}{f}$$

Since $C_p \leq C_j$ for these diodes, C_1 and C_j can be used interchangeably in this section.

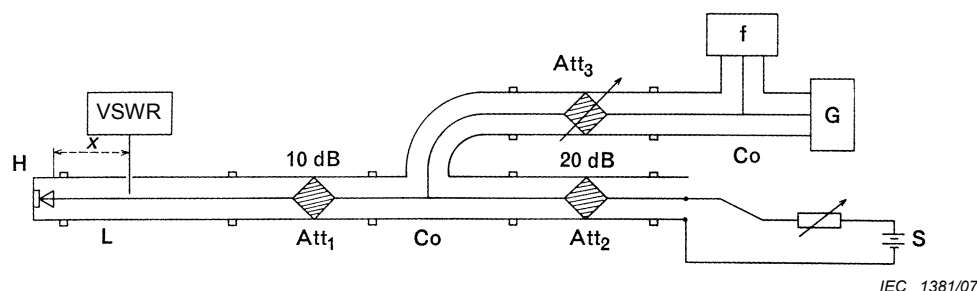
3.1.4.5 Series resistance r_s

The effective value of series resistance r_s can be deduced from the values of C_j and f using the formula given in 3.1.4.4.

3.1.4.6 Series inductance L_s

Measurements should be conducted in the frequency region where the effect of stray capacitance C_p relative to the terminal impedance of the diode can be neglected.

The diode is inserted in the measuring head as shown in Figure 6 which is set on the tip of the inner conductor of the coaxial slotted line.

**Key**

VSWR	voltage standing wave ratio meter
x	distance
H	diode head
L	slotted line
Att	attenuator
Co	coupler
G	microwave generator
S	bias supply
f	frequency meter

Figure 6 – Circuit for the measurement of series inductance

Measurements are as follows:

First, determine position x_m where the standing wave voltage is minimum as measured at a bias voltage in the forward region where the terminal capacitance becomes independent of the change of bias voltage. This bias voltage should be sufficiently high so that an increase of this voltage would not affect the result of the measurement. (This condition may be satisfied when about 5 mA forward current flows.)

Next, without any break in the impedance of the line, a metal block is inserted in the measuring head in place of the diode. This is done in order to provide a short-circuit at the reference plane position which is defined and should be specified by the manufacturer of the diode. In this condition, position x_s nearest to x_m and larger than x_m is found where the standing wave voltage is minimum.

The reactance of the diode is obtained by the following equation:

$$X = Z_0 \tan \frac{2\pi(x_s - x_m)}{\lambda}$$

where

Z_0 is the characteristic impedance of the coaxial line;

λ is the wavelength of the measuring frequency.

The series inductance L_s can be obtained by use of the following equation:

$$L_s = \frac{X}{2\pi f}$$

NOTE The structure of some devices may prevent this method of measurement from giving correct results. In this case, a value for the inductance will have to be given by the manufacturer.

3.1.4.7 Thermal resistance R_{th}

3.1.4.7.1 Purpose

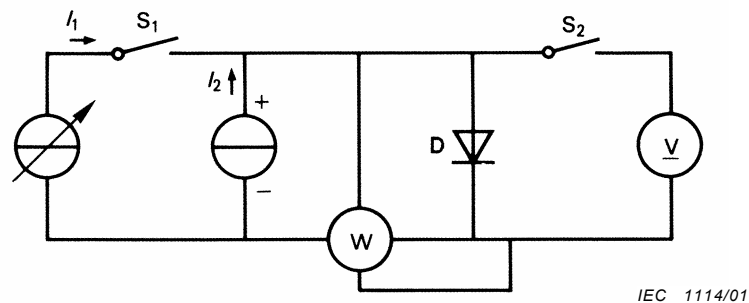
To measure the thermal resistance between the junction and a reference point (preferably at the case) of the device being measured.

3.1.4.7.2 Principle of the method

The temperatures T_1 and T_2 of the reference point of the device are measured for two different power dissipations P_1 and P_2 and cooling conditions causing the same junction temperature. The forward voltage at a reference current is used to verify that the same junction temperature has been reached.

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

3.1.4.7.3 Basic circuit diagram



Key

D device being measured

Figure 7 – Circuit for the measurement of thermal resistance R_{th}

3.1.4.7.4 Circuit description and requirements

- I_1 = load current generating the power loss P in the junction, either a d.c. current or an a.c. current
- I_2 = reference d.c. current monitored when the load current I_1 , is interrupted periodically for short time gaps
- W = wattmeter to indicate the power loss P in the junction caused by the load current I_1 ; for the a.c. method, W measures the average power dissipated in the device being measured
- S_1 = electronic switch to interrupt periodically the load current I_1 ; for the d.c. method, switch S_1 is not mandatory
- S_2 = electronic switch, which is closed when the load current I_1 , is interrupted
- V = null-method voltmeter

3.1.4.7.5 Precautions to be observed

Voltage transients occur due to excess charge carriers when switching from the load current I_1 , to the reference current I_2 . Additional voltage transients occur if the case of the device under test contains ferromagnetic material. The switch S_2 should not be closed before these transients have disappeared.

NOTE The load current I_1 defined in 3.1.4.7.4 may be zero, in which case the power loss P_1 is also zero and the virtual junction temperature is the same as the reference-point temperature T_1 .

3.1.4.7.6 Measurement procedure

The device being measured is clamped onto a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the temperature of the device being measured. The measurement is carried out in two steps:

- a) The heat sink is maintained at an elevated temperature. A low load current I_1 is applied causing the power loss P_1 in the junction. After reaching thermal equilibrium, the null-method voltmeter V is adjusted for zero balance.

The reference-point temperature T_1 is recorded.

- b) The heat sink is maintained at a lower temperature. The load current I_1 is raised until the power loss P_2 warms up the junction to the same temperature as in the preceding step. This is indicated by zero balance of the null-method voltmeter V .

The reference-point temperature T_2 of the case is recorded.

The thermal resistance R_{th} is calculated using the expression:

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

3.1.4.8 Transient thermal impedance Z_{th}

3.1.4.8.1 Purpose

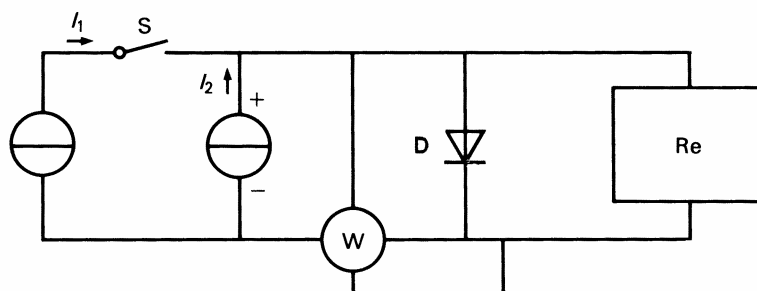
To measure the transient thermal impedance between the junction and a reference point (preferably at the case) of the device being measured.

3.1.4.8.2 Principle of the method

After applying the heating current and waiting until thermal equilibrium is reached, the power dissipated in the device is recorded. The heating current is then interrupted and the forward voltage at the reference current together with the reference-point temperature are recorded as a function of time.

The virtual junction temperature as a function of time is then calculated by means of the calibration curve obtained for the same reference current.

3.1.4.8.3 Basic circuit diagram



IEC 1115/01

Key

D device being measured

Figure 8 – Circuit for the measurement of transient thermal impedance Z_{th}

3.1.4.8.4 Circuit description and requirements

I_1 = load current generating the power loss P in the junction

I_2 = reference d.c. current

S = switch to interrupt the load current I_1

W = wattmeter to indicate the power loss P in the junction caused by the load current I_1

Re = recording equipment, e.g. an oscillograph, to record the time variation of the forward voltage caused by I_2

3.1.4.8.5 Measurement procedure

- 1) A calibration curve is prepared by measuring the on-state or forward voltage generated by the reference current I_2 as a function of the virtual junction temperature by varying the device temperature externally e.g. by means of an oil bath.
- 2) The device being measured is clamped onto a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the reference point temperature T_c of the device being measured. The heating current I_1 is applied generating the power loss P in the device being measured until thermal equilibrium is reached.
- 3) The heating current I_1 , is interrupted by opening the switch S. The forward voltage generated by the reference current I_2 is recorded as a function of the cooling time by the recording equipment Re. The reference point temperature is recorded during this time.
- 4) The curve of the recorded forward voltage is converted to the virtual junction temperature T_{vj} by means of the calibration curve. The transient thermal impedance $Z_{(th)t}$ is calculated using the expression:

$$Z_{(th)t} = \frac{[T_{vj}(0) - T_c(0)] - [T_{vj}(t) - T_c(t)]}{P}$$

where

$T_{vj}(0)$ and $T_c(0)$ are the temperatures at the time $t = 0$ when opening switch S;

$T_{vj}(t)$ and $T_c(t)$ are the temperatures at the time t .

3.1.4.9 Case of varactor diodes

The following methods of measurement are recommended for use as appropriate to the intended conditions of operation and structure of the type of diode to be measured.

In the case of the measurement of the effective factor Q of the diode, it is recommended that, when a value of Q is quoted, the particular method of measurement used to obtain that value should be stated. This is necessary because it is possible to obtain different values of Q for a given diode when using the two given methods.

3.1.4.9.1 Transmission line measurements

These measurements are suitable for evaluating the main properties of microwave diodes which may be used in a wide range of applications, particularly those diodes which are unencapsulated, or those diodes whose package shunt capacitance has a reactance value larger than the value of diode series resistance at the series resonant frequency.

3.1.4.9.1.1 Theory

Observation is made of the effect on the transmission characteristics of any non-radiating transmission system by the introduction of a shunt impedance, in this case a diode.

The diode is mounted in shunt with the transmission line so that the mounting arrangement provides a minimum of excess reactance; for example, when using a waveguide transmission system, the diode is fitted as given in Figure 9.

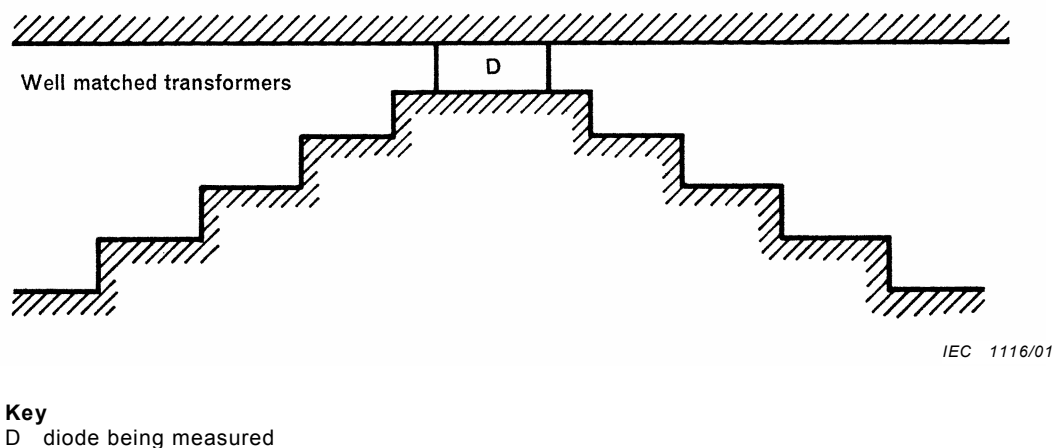


Figure 9 – Waveguide mounting

Measurements of transmission loss introduced by the diode in the region of the series resonant frequency enable the elements of the diode equivalent circuit to be evaluated and also permit the capacitance law as a function of bias to be determined.

The equivalent circuit of the mounted diode is shown in Figure 10.

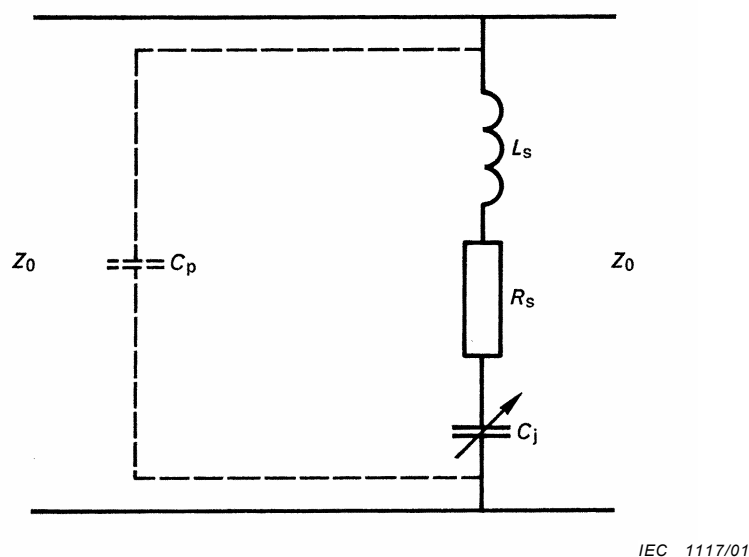


Figure 10 – Equivalent circuit of mounted diode

where

Z_0 is the characteristic impedance of the transmission line;

C_p is the package capacitance;
 L_s is the series inductance;
 R_s is the series resistance;
 C_j is the junction capacitance.

Near series resonance, the effect of the package capacitance (C_p) is negligible and may be ignored.

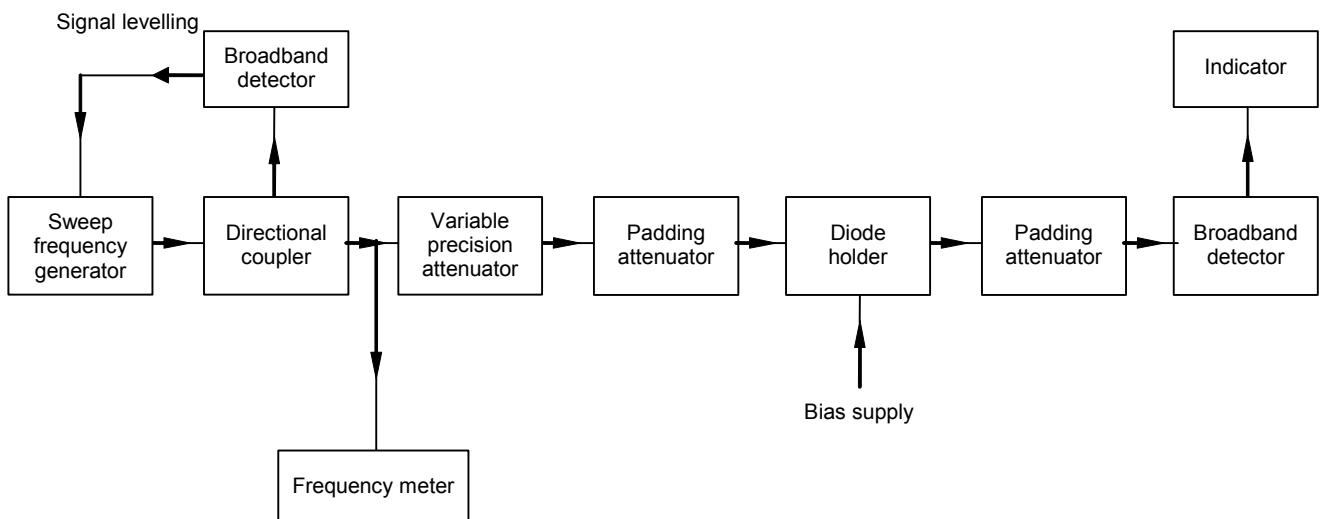
Four measurements, namely:

- transmission loss at the series resonant frequency at zero bias;
- the bandwidth of the transmission characteristic;
- the value of the series resonant frequency;
- the variation of the series resonant frequency with bias;

enable the four unknown quantities:

- series resistance (R_s);
- junction capacitance (C_j);
- series inductance (L_s);
- variation of junction capacitance with bias to be determined.

3.1.4.9.1.2 Circuit diagram



IEC 1118/01

Figure 11 – Block diagram of transmission loss measurement circuit

3.1.4.9.1.3 Circuit description and requirements

The test equipment should be assembled using good microwave transmission line engineering techniques. All components, such as directional couplers, frequency measuring apparatus, attenuators and detectors, should be checked to ensure proper matching and operation over the required frequency and power test conditions.

The components of the system should be sufficiently broadband to ensure that only negligible variations or errors over the band of frequencies used for the measurement are introduced.

The RF signal generator should be capable of stable operation at a signal level equivalent to the normal small-signal conditions of the diode.

The diode holder should conform with the specified mount details.

A typical arrangement comprises a tapered mount with a choke on one face to enable bias to be applied. The tapered mount usually is a requisite feature to ensure that only the diode characteristics are being measured. In this way, the complication of using inductive posts for mounting the diode is avoided (see Figure 9).

3.1.4.9.1.4 Measurement procedure

The diode is inserted into the specified holder which is connected in a transmission system equivalent to that shown in Figure 11.

3.1.4.9.1.4.1 Series resonant frequency

The series resonant frequency may easily be obtained by operating the diode at the required bias voltage and observing the indicated transmitted power, in front of and behind the diode, as the frequency is swept over a suitable frequency range. The series resonant frequency is indicated by the point of minimum transmitted RF power. The incident RF power level on the diode shall be kept constant during the sweep.

3.1.4.9.1.4.2 Transmission loss (T)

The transmitted signal level at resonance with zero bias (or any other required value) applied to the diode is recorded. The diode is then removed from the holder and the precision attenuator adjusted to give the same indicated transmitted signal level as the one recorded initially. The change in the attenuator setting then gives the transmission loss (T) at resonance. It is essential that the incident RF power level on the diode shall be kept constant during this measurement.

Alternatively, the transmission loss introduced by the diode at the series resonant frequency may be obtained by firstly observing the power level incident on the matched detector at a frequency remote from the resonant frequency. The frequency is then changed to the resonant value and the precision attenuator adjusted to return the indicated power level to the same value as that obtained when the frequency was remote from resonant value. The change in attenuator reading will provide the transmission factor (T) (see Figure 12).

3.1.4.9.1.4.3 Series resistance

If the frequency of measurement chosen is equal to the series resonant frequency (f_s) given by:

$$f_s = \frac{1}{2\pi\sqrt{L_s C_j}} \quad (1)$$

where

L_s is the series inductance;

C_j is the effective capacitance of the PN junction having a required applied bias voltage.

The loss in a transmission may be measured as in 3.1.4.9.1.4.2 and the effective shunt resistance derived from:

$$R_s = \frac{Z_0}{2\sqrt{T} - 1} \quad (2)$$

where

Z_0 is the characteristic impedance of the transmission line in the vicinity of the loss element.
In the case of a waveguide mount, the power/voltage definition should be used;

T is the ratio of available power incident on the diode being measured to that transmitted past the diode.

The variation of R_s with bias may be obtained by the adjustment of the measuring frequency to the corresponding series resonant value obtained for each bias value used and measuring the transmission factor (T) in each case.

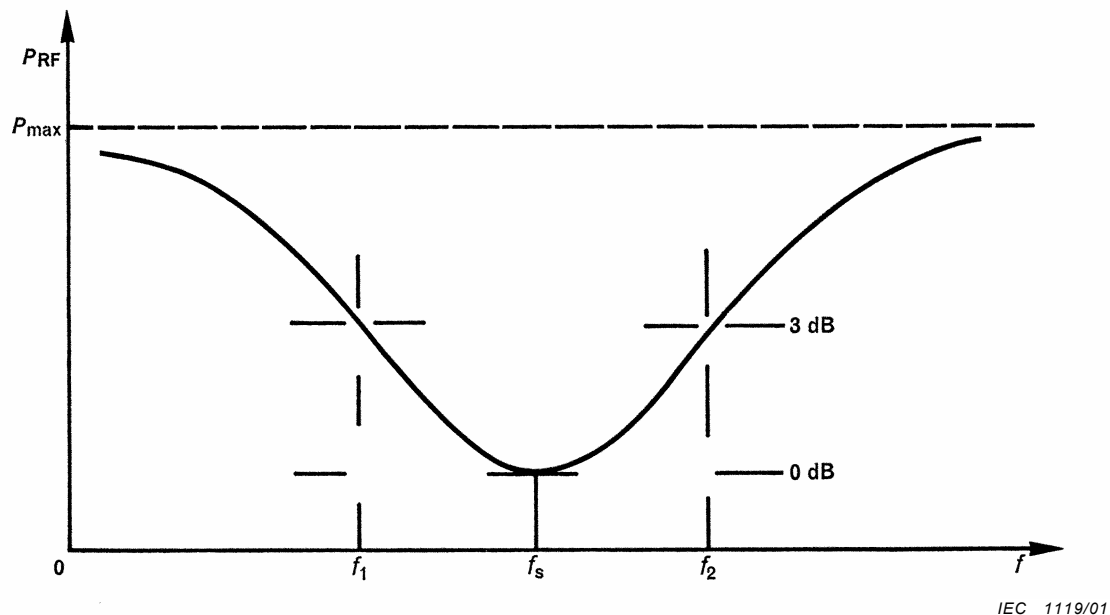
A measure of the change in the effective Q value with bias may also be obtained.

3.1.4.9.1.4.4 Effective Q value

a) First method

The effective Q value at a given bias voltage may be obtained by varying the measuring frequency to values on either side of the series resonant frequency and observing the value of those frequencies which cause the power transmitted to be twice the one obtained at the resonant frequency (see Figure 12). If the frequencies at which this is achieved are f_1 and f_2 , then:

$$Q = \frac{f_s}{|f_1 - f_2|}$$



Key

f_s series resonant frequency

Figure 12 – Curve indicating transmitted power versus frequency

Alternatively, since

$$C_j \sim \frac{1}{f_s^2}$$

from equation (1), a plot of $\frac{1}{f_s^2}$ against bias will provide a plot of KC versus bias, where K is a constant.

If the frequency is adjusted to the series resonant frequency at zero bias, the forward bias voltage (V_1) and the reverse bias voltage (V_2) required to double the transmitted power are obtained.

Using the plot of KC_j versus bias, corresponding values of KC_{j1} and KC_{j2} may be found. The value of Q may then be derived from:

$$Q = \frac{KC_{j1} + KC_{j2}}{KC_{j1} - KC_{j2}}, \text{ i.e. : } \frac{f_{s2}^2 + f_{s1}^2}{f_{s2}^2 - f_{s1}^2}$$

If $f_{s2} - f_{s1}$, is small, this can be reduced to:

$$\frac{f_s}{f_{s2} - f_{s1}}$$

without serious error.

b) *Alternative method*

The effective Q value may also be obtained by the transformed impedance measurement as given in 3.1.4.10.

3.1.4.9.1.4.5 Cut-off frequency

The cut-off frequency (f_c) at zero bias may then be obtained from:

$$f_{c(0V)} = Qf_{s(0V)} \quad (3)$$

3.1.4.9.1.4.6 Junction capacitance at zero bias

This may be obtained using the value of the cut-off frequency (f_c) from equation (3) and R_s from equation (2):

$$C_{j(0V)} = \frac{1}{2\pi R_s f_{c(0V)}}$$

The value of junction capacitance at zero bias may then be used to calibrate the plot of $\frac{1}{f_s^2}$ versus bias in terms of C_j (see 3.1.4.9.1.4.4).

3.1.4.9.1.4.7 Series inductance

If the series inductance value is required, this may be obtained from:

$$f_{s(0V)} = \frac{1}{2\pi\sqrt{L_s C_{j(0V)}}}$$

3.1.4.9.1.4.8 Capacitance variation coefficient (γ)

The capacitance variation coefficient is defined as the normalized capacitance change over a defined range of operating conditions of forward current and reverse voltage.

The bias voltage which is required to provide the defined value of forward current is determined. Then using this forward voltage (V_F) and the defined reverse voltage (V_{-x}), corresponding values of C_j may be obtained from the $\frac{1}{f_s^2}$ or KC_j plot against the bias voltage (see 3.1.4.9.1.4.4).

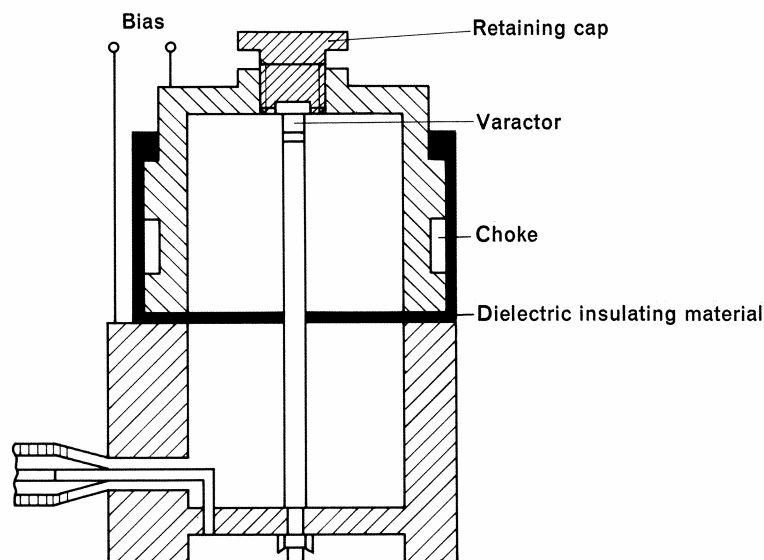
If $C_{j(V_F)}$ and $C_{j(V_{-x})}$ are the capacitance values respectively, then:

$$\gamma = \frac{C_{j(V_F)} - C_{j(V_{-x})}}{2[C_{j(V_F)} + C_{j(V_{-x})}]}$$

3.1.4.9.2 Cavity method

This method is satisfactory for measuring varactors having an effective quality factor which exceeds 15 at the measuring frequency; the results are not affected by changes in the series resistance with bias.

NOTE It is considered that this method is usable up to a measurement frequency of 15 GHz (whereas method 1, described in 3.1.4.9.1, is more practical for measurement above 6 GHz).



IEC 1120/01

Figure 13 – Example of cavity

3.1.4.9.2.1 Theory

In this method, the effect is evaluated of a varactor diode on the resonant frequency and Q-factor of a coaxial cavity resonator about half-wavelength at the operating frequency. The diode is mounted between the centre conductor and the plane wall of the cavity resonator as shown in Figure 13.

In order to limit the range of variation of the cavity resonant frequency when the junction capacitance or the diode is changed, it is essential to use a resonator having a large ratio of external to internal conductor diameter (high-characteristic impedance of the coaxial cavity).

This method will determine the junction capacitance C_{j0} and the cut-off frequency f_{c0} at bias voltage V_0 .

These quantities enable the determination of the series resistance r_s and the effective Q-factor Q_{eff} of the varactor.

The following characteristics must be determined for the cavity:

- f_{r0} is the resonant frequency of the cavity with the varactor at the bias voltage V_0 ;
- Q_{r0} is the loaded Q-factor of the cavity with the varactor at the bias voltage V_0 ;
- C_p is the stray capacitance of the varactor case;
- $C_T(V)$ is the variation of the total low-frequency capacitance of the varactor (junction capacitance) versus the bias voltage around V_0 ;
- $f_r(V)$ is the variation of the resonant frequency of the cavity with the varactor versus bias voltage around V_0 ;
- f' is the resonant frequency of the cavity when the varactor is replaced by a metallic dummy diode with the same dimensions as the diode being measured;
- Q' is the unloaded-Q of the cavity when the varactor is replaced by the dummy diode.

From the knowledge of $C_T(V)$ and $f_r(V)$, a curve can be derived which represents f_r versus C_T . This curve enables a quantity "a" to be evaluated, "a" being the slope of the curve at $C_T = C_T(V_0)$.

This junction capacitance, deduced at the bias voltage V_0 is given by:

$$C_{j0} = C_T(V_0) - C_p$$

and the cut-off frequency:

$$f_{c0} = 2 a k Q_{r0} C_{j0}$$

where k is a correction factor introduced to take into account losses in the cavity walls; for the second TEM resonance frequency, it is given by:

$$k = \frac{1}{1 - \frac{Q_{r0}}{Q'} \sqrt{\frac{f'}{f_{r0}}}}$$

Series resistance, at the bias voltage V_o , is given by:

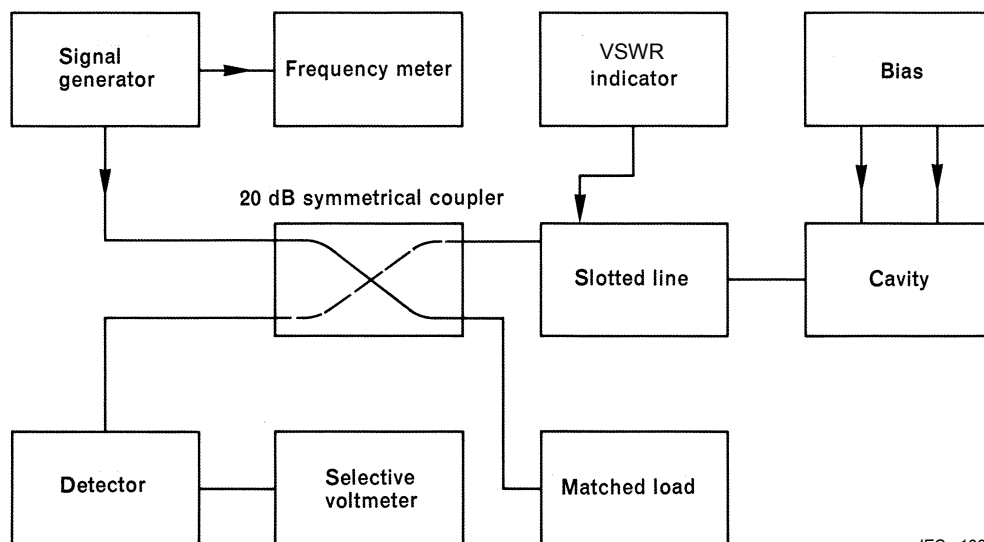
$$r_{so} = \frac{1}{2\pi f_{co} C_{jo}}$$

and the effective Q_{eff} at bias voltage V_o is given by:

$$Q_{eff} = \frac{f_{co}}{f_{ro}}$$

3.1.4.9.2.2 Measurements

3.1.4.9.2.2.1 Circuit diagram



IEC 1382/07

Figure 14 – Block diagram for the measurement of effective Q in cavity method

3.1.4.9.2.2.2 Circuit description and requirements

The RF signal shall be of high-frequency stability and modulated at a low frequency appropriate to the selective voltmeter and VSWR indicator and is applied to the cavity through a 20 dB directional coupler.

The amplitude of the peak RF signal V_p must be low enough to ensure that non-linearity does not occur at the operating point of the characteristic.

The incident power at the cavity input shall not exceed the value given by the expression:

$$P = \frac{\pi (r+1)^2}{4r} \frac{f_{ro}^2}{f_{co}} C_{jo} V_p^2$$

where r indicates the VSWR in the slotted line at the input of the cavity. Since the limitation on the incident power is not critical, an estimated value can be used for f_{co} .

3.1.4.9.2.3 Measurement procedure

a) *Measurement of $f_r(V)$ and f_{r0}*

The measurement of the resonant frequency $f_r(V)$ is performed at a number of bias points around V_0 (e.g. if $V_0 = -6$ V, f_r can be measured at the following voltages: -4 V; $-4,5$ V; -5 V; $-5,5$ V; -6 V; $-6,5$ V; -7 V; $-7,5$ V).

The measurement is performed by varying the signal frequency and observing the value for minimum reflected power. To ensure a high accuracy, it is better to determine f_r as the average between two frequencies adjacent to f_r which have the same power from the cavity.

b) *Measurement of Q_{r0}*

Set the bias voltage to V_0 and determine the value of the loaded Q_{r0} by means of VSWR measurement.

c) *Measurement of f' and Q'*

These values are obtained in the same way as f_r and Q_{r0} after the varactor has been replaced by a dummy diode.

These are fundamental characteristics of the cavity.

3.1.4.9.2.3 Measurement of $C_T(V)$ and C_p

The total capacitance of the varactor diode:

$$C_T(V) = C_j(V) + C_p$$

is obtained by a conventional low-frequency bridge measurement.

The value of C_p can be deduced using the expression:

$$C_p = \frac{(\varphi - V_2)^n C_T(V_2) - (\varphi - V_1)^n C_T(V_1)}{(\varphi - V_2)^n - (\varphi - V_1)^n}$$

where

V_1 and V_2 are the two values of bias voltage; for reverse bias, V_1 and V_2 will be negative terms;

φ is the contact potential difference (e.g. 0,7 V for silicon diodes);

n is the factor of non-linear dependence of C_j on V .

3.1.4.9.2.4 Direct measurement of C_p

C_p can be measured directly when the ohmic contact between the internal metallic lead and the semiconductor chip has been interrupted in a varactor.

3.1.4.10 Transformed impedance method

This method is satisfactory for the measurement of diodes which are only to operate within that part of the diode characteristic in which the value of series resistance is sensibly independent of the value of the bias voltage.

3.1.4.10.1 Theory

The normalized impedance (Z) at any place in a lossless transmission line is related to the reflection coefficient (ρ) at that place by the expression:

$$Z = \frac{1 + \rho}{1 - \rho}$$

The form of this relation indicates that the normalized impedance and the reflection coefficient at any plane are bilinearly related; hence it may be shown that, for a lossless transformation between two impedance planes Z_1 and Z_2 , one can write:

$$Z_2 = \alpha Z_1 + j\beta \quad (4)$$

where α and β are real numbers.

If two values of impedance (Z^a and Z^b) at one place which only differ in the value of their reactive components are then considered, corresponding impedance at a second plane may be written as:

$$Z_2^a = \alpha (R_1 + jX_1) + j\beta = \alpha R_1 + j(\alpha X_1 + \beta) \quad (5)$$

and
$$Z_2^b = \alpha (R_1 + jX_1 + \Delta X) + j\beta = \alpha R_1 + j(\alpha X_1 + \alpha \Delta X + \beta) \quad (6)$$

From equation (4), it will be seen that circles of constant resistance on a Smith chart at one plane transform into the same family of circles at another, but that the resistance value is changed in the ratio α .

This transformation is pertinent to the reactance values, so that the ratio $\frac{\Delta X}{R}$ as obtained from equations (5) and (6), is seen to be independent of the transformation constants α and β .

Thus, for a transmission line which is terminated in an impedance whose reactive component is varied, the impedance locus at a plane in the measuring line which corresponds to the terminal plane also lies on a circle of constant resistance.

If the impedance plane of Z_1 is taken as being that of the diode element itself, then $\frac{\Delta X}{R}$ in any corresponding plane is the same as the value ΔQ of the diode.

Hence if:

$$\Delta X_{12} = |X_1 - X_2|, \text{ then } \frac{\Delta X_{12}}{R} = \Delta Q_{12} \text{ i.e. } |Q_1 - Q_2|$$

where the subscripts 1 and 2 correspond to the value of the parameter which is obtained at the bias voltages V_1 and V_2 respectively.

Now the effective quality factor Q at any required point may be given by:

$$Q = \Delta Q \times \sigma \quad (7)$$

where σ is a constant factor relating two bias points, for a given type of diode.

One of the two bias points (V_1 or V_2) can be the required value.

Derivation of σ

The value of σ_{12} may be obtained from the expression:

$$\sigma_{12} = \frac{C_1}{\Delta C_{12}} = \frac{1}{1 - \left(\frac{\phi - V_1}{\phi - V_2} \right)^\eta} \quad (8)$$

where

ϕ is the quasi-contact potential difference;

η is the factor of non-linear dependence of C on V .

EXAMPLE: For silicon varactors made by a diffusion process, η is usually given as $\frac{1}{3}$ and ϕ is of the order of 0,5 V.

If $V_1 = -4,5$ V and $V_2 = -6$ V, then $\sigma = 10$, i.e. $Q = 10 \Delta Q$.

The value of σ may be obtained experimentally by the measurement of the capacitance variation between three closely grouped bias points, say 1, 2 and 3, to give ΔC_{12} and ΔC_{23} .

The value of σ may then be obtained from:

$$\sigma = \frac{1 + \frac{\Delta C_{23}}{\Delta C_{12}}}{1 - \frac{\Delta C_{23}}{\Delta C_{12}} \frac{\Delta Q_{12}}{\Delta Q_{23}}} \quad (9)$$

The corresponding values of ΔQ_{12} and ΔQ_{23} may be obtained using equations such as (10), (11), (12) or (13) as convenient.

Derivation of ΔQ

The value of ΔQ may be obtained from using either of the two equations (10) or (12) as shown below:

$$\Delta Q_{12} = \sqrt{\frac{(\eta_1 - \eta_2)^2 + (\eta_1^2 - 1)(\eta_2^2 - 1)\sin^2 \Delta\Psi}{\eta_1 \eta_2}} \quad (10)$$

where

$10 \log (\eta_1^2)$ is the power standing wave ratio (dB) at bias value 1;

$10 \log (\eta_2^2)$ is the power standing wave ratio (dB) at bias value 2:

$$\Delta\Psi = \frac{M_1 - M_2}{\lambda_g} \times 360^\circ$$

where M_1 and M_2 are positions of minimum at bias values 1 and 2 respectively.

For very large values of η_1 and η_2 (viz. values usually obtained in the case of high-quality diodes), equation (10) may be simplified to:

$$\Delta Q_{12} = \sqrt{\eta_1 \eta_2} \sin \Delta \Psi \quad (11)$$

$$\Delta Q_{12} = \sqrt{A_1 A_2 - B_1 B_2 \cos \theta - 2} \quad (12)$$

where $A_1 A_2$ and $B_1 B_2$ are of the general form:

$$A_x = \frac{r_x^2 + 1}{r_x \sqrt{2}} \quad \text{and} \quad B_x = \frac{r_x^2 - 1}{r_x \sqrt{2}}$$

where

r_x is the VSWR at bias value x ;

θ is the phase change of reflection coefficient between bias values 1 and 2.

This formula in practice may, for an accuracy better than 1 %, be reduced to:

$$\Delta Q_{12} = \sin \frac{\theta}{2} \sqrt{r_1 r_2} \quad (13)$$

Considering equation (12) for the particular case when adjusting for $r_1 = 1$ (i.e. matched condition at required bias voltage), the formula reduces to:

$$\Delta Q_{12} = \frac{r_2 - 1}{\sqrt{r_2}} \quad (14)$$

If adjustments are made to provide matched conditions at the required bias voltage, the impedance in the measuring plane will be coincidental with the unit resistance circle on the Smith chart. It follows that this defines the plane in which the impedance Z_{in} is given by:

$$Z_{in} = Z_0 \left(1 + j \frac{\Delta X}{R} \right) = Z_0 (1 + j \Delta Q) \quad (15)$$

where

Z_0 is the characteristic impedance of the transmission line.

The change in reactance ΔX is then measured "relative to R " as ΔQ , to give:

$$\Delta Q = \frac{X_{(v)} - X_0}{R} = Q - Q_0 \quad (16)$$

Q_0 may be found by replacing the non-linear element with a short-circuit at the plane of the diode; whence:

$$\frac{|Z_{in}|}{R_0} = \frac{|X_0|}{R} = Q_0. \quad (17)$$

The value of Q at any other bias may then be found using equation (16).

3.1.4.10.2 Measurement procedure

The diode is inserted into a specified holder and connected to a circuit equivalent to the one shown in Figure 15.

The transformation between the diode and slotted line is obtained using a variable short-circuit behind the diode and tuning stubs in front of the diode (e.g. an E-H tuner).

The bias voltage is then adjusted to the required value and transformation adjustment made so that the measured normalized impedance point is in the central region of a Smith Chart where the scale is the most open, for example to provide a match in the measuring line at the required bias value. The effect on accuracy, for non-matched conditions over a substantial impedance range about the centre of the Smith chart, is small.

The bias voltage is then adjusted to other bias voltage points as required and, maintaining a fixed tuner adjustment, the resultant normalized impedance values are plotted on the Smith chart.

The value of Q may then be obtained using the measured VSWR values; change in reflection phase and Equations (7) to (14) as appropriate.

It is possible to obtain the effective quality factor without the derivation of σ as given in equations (8) and (9).

The transformation is made to match the diode impedance into the transmission line at the required bias, and so as to obtain an impedance point at the centre of the Smith chart. The diode bias is then changed to other values, and corresponding impedance points on the Smith chart obtained. This means that any reactance change in the impedance of the diode will, in the measuring plane, be coincidental with the unit resistance circle on the Smith chart.

The diode is then replaced by an effective short circuit and the normalized impedance is measured using the same reference plane as for the diode. An example of a diode plot is given in Figure 16. The value of Q may then be derived using equations (16) and (17).

An effective short circuit may be approximated by the use of a diode encapsulation in which the semiconductor material has been replaced by a highly conductive material having identical geometry. In some cases, the impedance of the non-linear element (diode) can approach zero with a high forward current and, as a consequence, be acceptable as an effective short -circuit.

The plotted points obtained at the various bias values are rotated round the centre of the Smith chart so that they coincide with the unit resistance circle. The short-circuit point is similarly treated. (Note that the normalized impedance points for high forward current fall on a constant reactance line in the plot.)

As this variation in the method depends on

- a) the effectiveness of the short circuit,
 - b) the ability to obtain a match condition in the measuring plane at the standard bias voltage, and
 - c) the effect of the tuning element losses,
- it becomes difficult to accurately determine the real part of the Q value of the diode. It is therefore recommended that this form of measurement be restricted to diodes having a low Q factor and those diodes which operate in the lower microwave frequencies.

3.1.4.10.3 Precautions to be observed

- a) The variable transformer and the mount losses shall be minimized. As the losses depend on the field pattern in the vicinity of the transforming elements, which in turn depend on the diode being measured, satisfactory correction is not readily achieved.
- b) If accurate values are to be obtained, the line losses, etc. which can cause serious decrease in the measured values of standing wave ratios used in Equations (10) and (11), shall be determined. The transmission line length is the length between the standing wave probe position at the nearest voltage minimum and the plane of the active region of the varactor diode seated in its mount. In addition, the mount and connector loss shall be taken into account.
- c) It should be verified that the series resistance is independent of varactor bias over an adequate range of the characteristic by checking that the impedance plot lies on the $\frac{R}{R_0} =$

1 circle. However, deviation from a circle may be caused by losses. An estimate of the significance of the combined losses can be made by comparing measurements using different settings of the transforming elements and different match bias values.

It is possible to transform points in one experimental plot to points close to the centre of the chart. If losses are negligible, the results will agree. For example, in Figure 16, the losses are negligible and the results for $-9,0$ V and $-4,0$ V, when matched at $-6,0$ V, should be shown by points marked by crosses.

An alternative method to verify the dependence of the series resistance (R_s) on bias is to calculate the values of ΔQ_{12} , ΔQ_{23} and ΔQ_{13} for the three bias values as given for equation (9) and then examine whether the values satisfy the following relation:

$$\Delta Q_{13} = \Delta Q_{12} + \Delta Q_{23} \quad (18)$$

If this relation is satisfied within acceptable limits, then it can be assumed that the series resistance value is sensibly independent of the bias voltage. Equations (7) and (9) may then be used to evaluate Q .

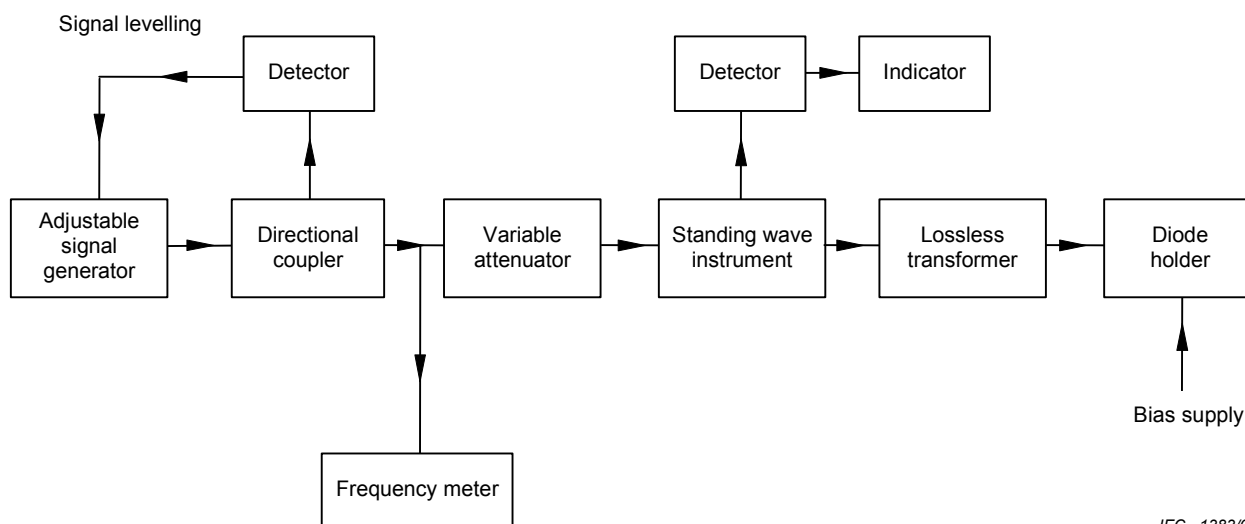
Capacitance measurement

This measurement is made usually at non-microwave frequencies. To obtain the capacitance of the non-linear element, the cartridge capacitance shall be subtracted from the total varactor capacitance.

The simplest and most direct method of obtaining the package capacitance is to substitute a unit in which there is no contact to the semiconductor. Another method can be used, if the form of the relation between capacitance and voltage is known (see, for example, equation (19)). The cartridge capacitance may be deduced by measuring the total capacitance at an appropriate number of bias points, which yields $C_c + C(V)$ and, since the form of $C(V)$ is known, both C_c and $C(V)$ can be obtained.

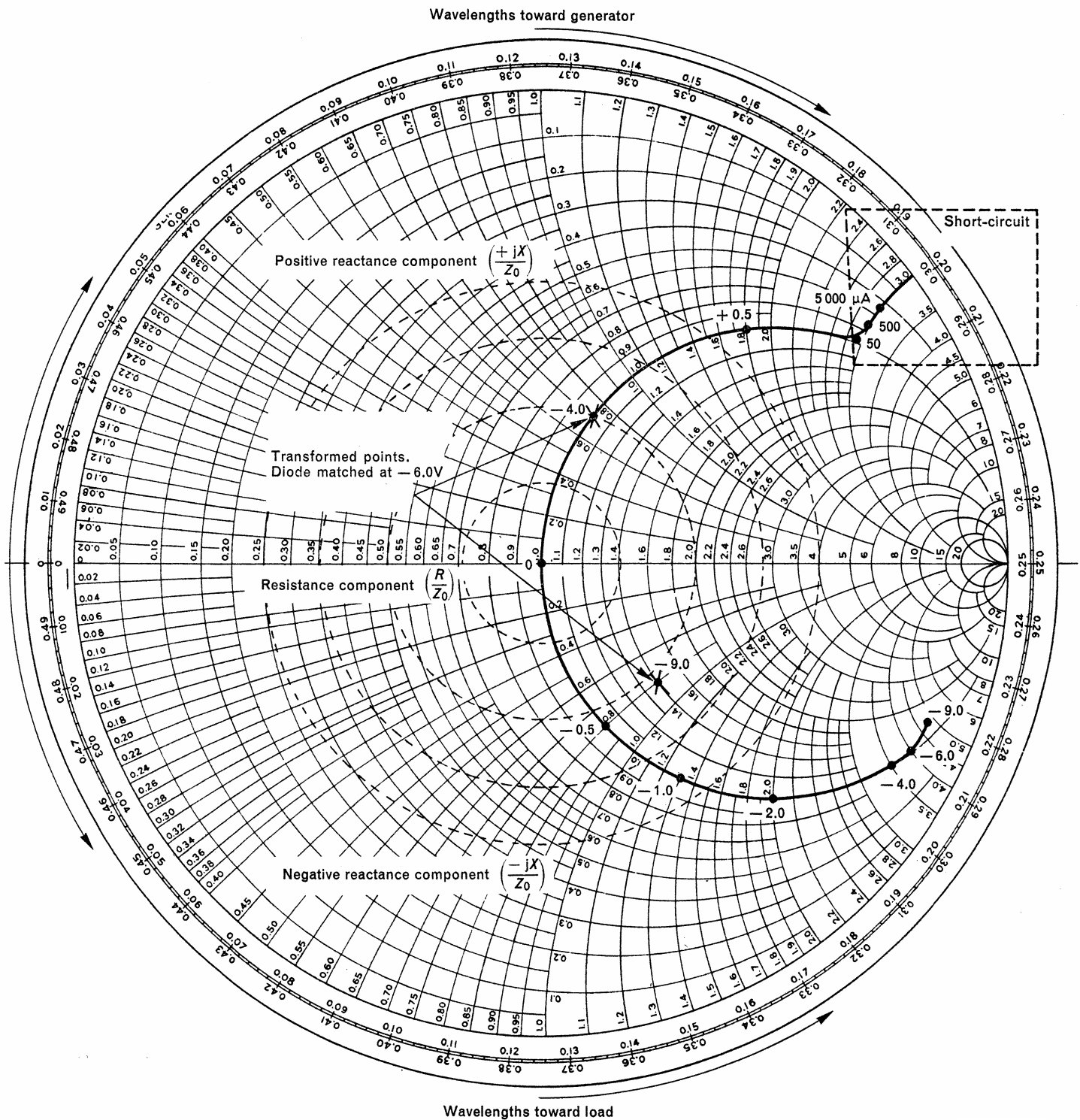
$$C(V) = C(V) \left(\frac{\phi - V'}{\phi - V} \right)^{1/n} \quad \text{with } n > 0 \quad (19)$$

NOTE Although the measurements in this subclause may be made using a standing wave detector, they may also be made by the use of an automatic impedance plotting instrument, an example of which is the automatic Smith Chart display unit. Because the value of Q is given by the normalized reactance change in a plane corresponding to the diode element for any lossless transformation, the Smith Chart may be adapted to give direct readings of Q as given in 3.1.4.11.



IEC 1383/07

Figure 15 – Block diagram of transformed impedance measurement circuit



IEC 1123/01

Key
 Frequency 10 GHz
 Diameter $\varnothing$ 0,5 V

Figure 16 – Example of plot of diode impedance as a function of bias

3.1.4.11 Method of constant quality factor circles

As it has been shown in 3.1.4.10.1 (Theory), ΔQ is given by the normalized reactance change in a plane corresponding to the diode element for any lossless transformation; it follows that the Smith Chart may therefore be adapted to give direct readings of ΔQ from two impedance measurements for any arbitrary transformation. This may be done by introducing a grid of lines to represent fixed values of $\frac{X}{R}$ (i.e. Q).

The normalized impedance (Z) for any measuring plane is given in terms of the complex reflection coefficient (ρ) by:

$$Z = R + jX = \frac{1 + \rho}{1 - \rho}$$

thus:

$$R = \frac{1 - \rho\rho^*}{1 + \rho\rho^* - \rho - \rho^*}$$

and:

$$jX = \frac{\rho - \rho^*}{1 + \rho\rho^* - \rho - \rho^*}$$

hence:

$$\frac{jX}{R} = \frac{\rho - \rho^*}{1 - \rho\rho^*} = jQ$$

from which:

$$\rho\rho^* + \frac{j}{Q}\rho^* - \frac{j}{Q}\rho - 1 = 0 \quad (20)$$

Equation (20) represents the equation of a circle and, when comparing it with the general equation for a circle, viz.:

$$(\rho - a)(\rho^* - a^*) = K^2$$

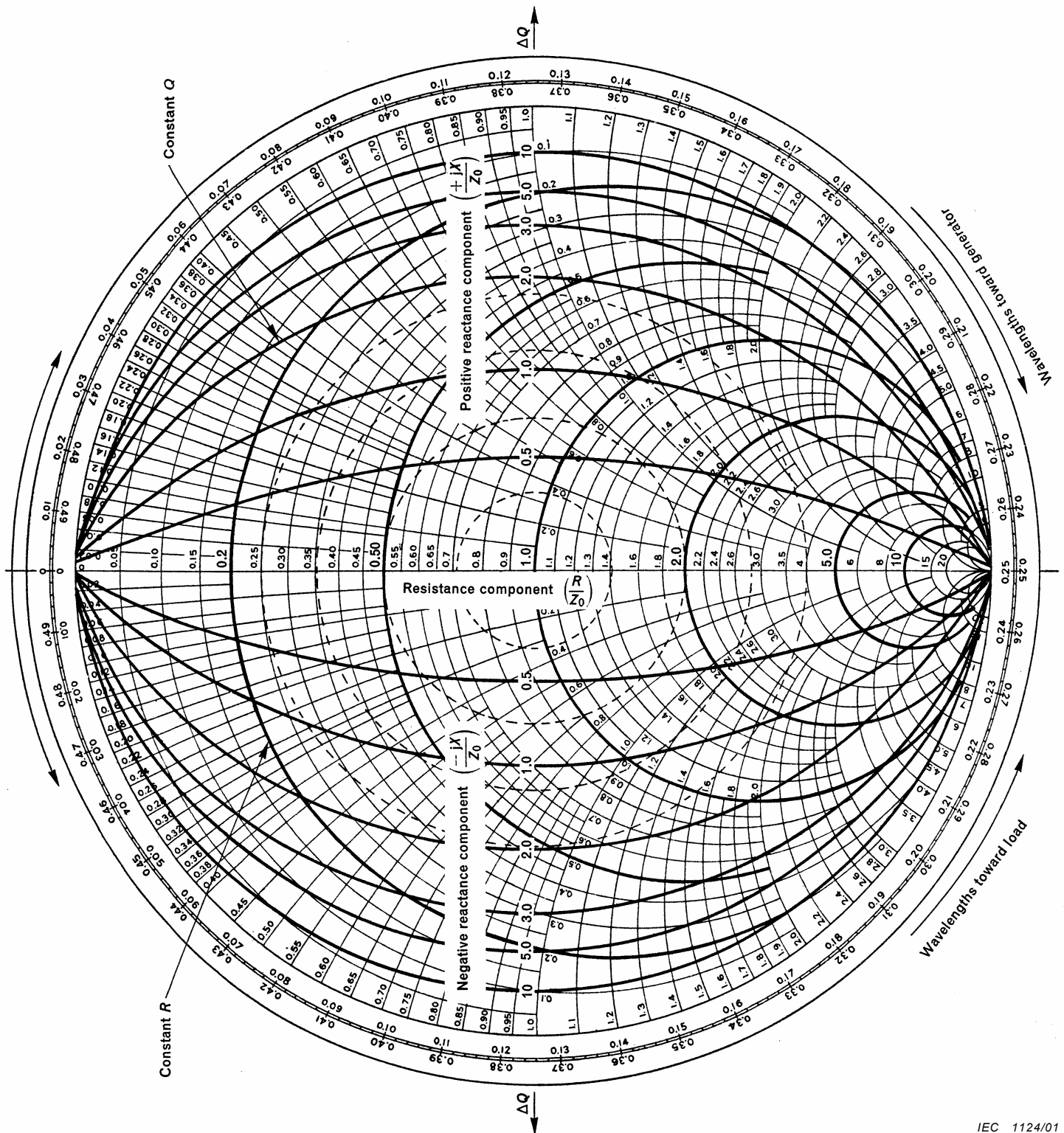
it can be deduced that the radius K is given from equation (20) by:

$$K = \sqrt{1 + \frac{1}{Q^2}}$$

and having a centre displaced from the origin of coordinates by a vector value of $\frac{j}{Q}$.

A family of circles representing constant Q may thus be constructed on a Smith chart and these, together with the family of constant resistance circles, are sufficient to determine ΔQ . An example of the resulting chart is shown in Figure 17.

When applying the chart for the diode measurement, the diagram is orientated so that the measured normalized impedance points, corresponding to the two bias conditions, appear on a constant resistance circle. The corresponding Q values are then obtained.



IEC 1124/01

Figure 17 – Modified Smith chart indicating constant Q and constant R circles

3.2 Snap-off diodes, Schottky diodes

3.2.1 General

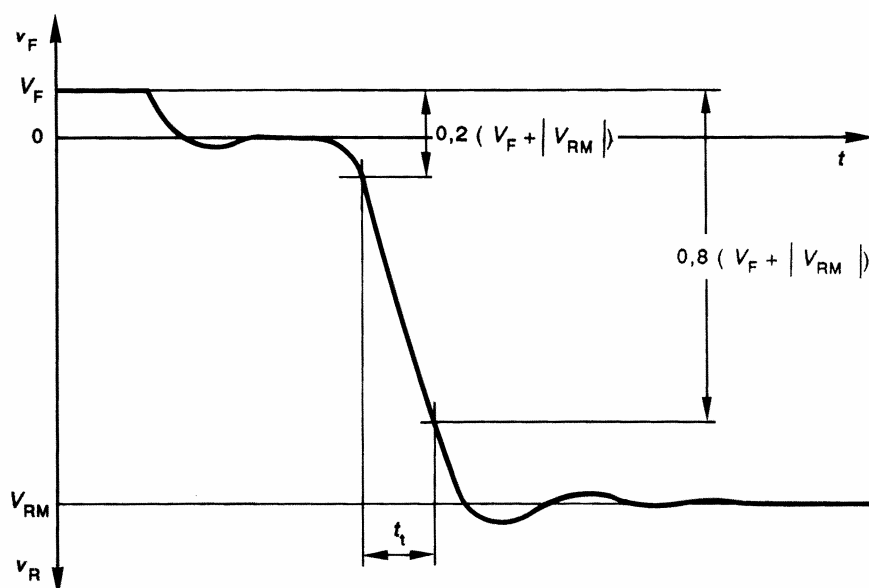
Snap-off (step recovery) diodes may be specified either as ambient rated or case rated or, where appropriate, as both.

3.2.2 Terminology and letter symbols

Transition time (of a snap-off diode) t_t

The time taken for the voltage across a snap-off diode to change from a specified low fraction of the total voltage step ($V_F + |V_{RM}|$) to a specified high fraction of the voltage step, when the diode is switched from forward current to reverse voltage (see Figure 18).

NOTE Values of 20 % and 80 % are preferred.



IEC 1125/01

Figure 18 – Transition time t_t

For other parameters: see 3.2.3.

3.2.3 Essential ratings and characteristics

3.2.3.1 General

See 3.1.3.1.

3.2.3.2 Ratings (limiting values)

The following ratings should be stated:

3.2.3.2.1 Temperatures**3.2.3.2.1.1 Range of operating temperatures****3.2.3.2.1.2 Range of storage temperatures****3.2.3.2.2 Voltage and currents**

The following ratings must be valid for the whole range of operating conditions as stated for the particular device.

3.2.3.2.2.1 Maximum peak reverse voltage.**3.2.3.2.2.2 Maximum mean forward current, where appropriate****3.2.3.2.2.3 Maximum peak forward current, where appropriate****3.2.3.2.3 Power dissipation**

Maximum dissipation, under stated conditions, over the operating temperature range.

3.2.3.3 Electrical characteristics

Unless otherwise specified, the following characteristics should be stated at 25 °C:

3.2.3.3.1 Series inductance (L_s)

Typical value under specified conditions.

3.2.3.3.2 Terminal capacitance ($C_{tot} = C_j + C_p$)

Minimum and maximum values at specified bias voltage and specified frequency.

3.2.3.3.3 Junction capacitance (C_j)

Minimum and maximum values at a specified bias voltage and specified frequency. If the order of magnitude of C_p is the same as that of the terminal capacitance C_{tot} , a typical value for C_j should be given instead.

3.2.3.3.4 Series resistance

Typical or maximum value, as appropriate, under specified conditions.

3.2.3.3.5 Reverse current

Maximum value at a specified reverse voltage.

3.2.3.3.6 Stored charge or minority carrier storage time

Maximum value, under specified conditions, which may be stated either as a stored charge per unit of current (e.g. in $\frac{\text{picocoulombs}}{\text{milliamperes}}$), or as minority carrier storage time (e.g. in nanoseconds), the test circuit being also specified.

3.2.3.3.7 Transition time

Maximum value under specified conditions, the test circuit also being specified.

3.2.3.3.8 Forward voltage (where appropriate)

Maximum value for specified forward current.

3.2.3.3.9 Efficiency (where appropriate)

Minimum value, under specified conditions, of input power, input frequency, output frequency and test circuit.

3.2.3.4 Application data

- Relationship between junction capacitance and bias voltage. Typical value, in either a graphical or mathematical form.
- Cut-off frequency.

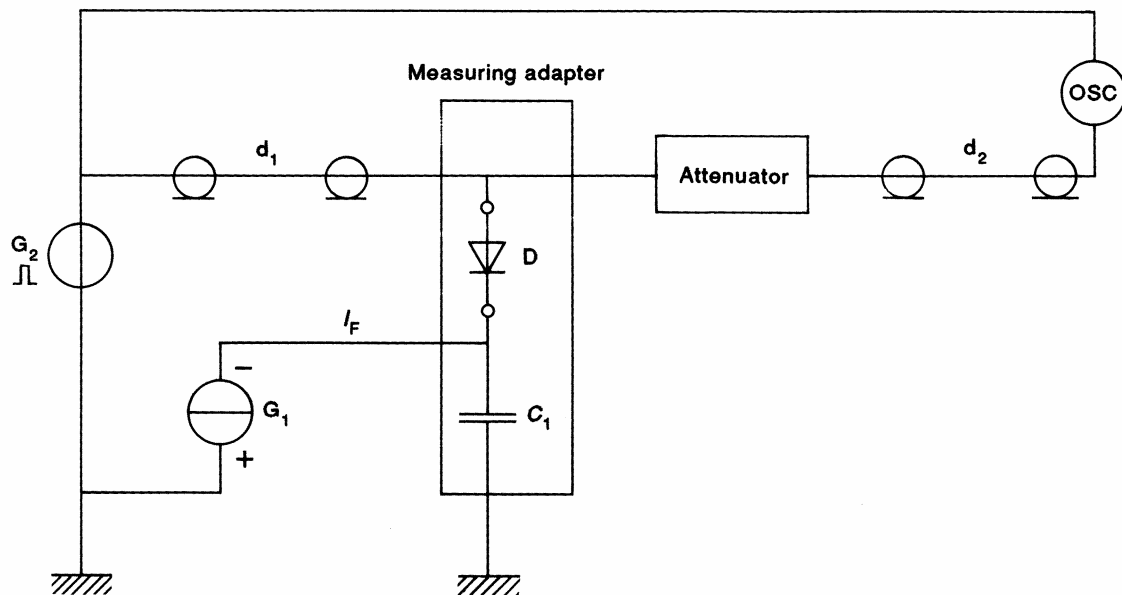
3.2.4 Measuring methods

3.2.4.1 Transition time (t_t)

a) Purpose

To measure the transition time t_t , for snap-off diodes.

b) Circuit diagram



IEC 1126/01

Key

- G_1 is the forward current generator (I_F)
 G_2 is the pulse generator
 d_1 and d_2 are the matched transmission lines
 OSC is the sampling oscilloscope

Figure 19 – Circuit for the measurement of transition time (t_t)

c) *Circuit description and requirements*

The rise time of the pulse from the generator G_2 should be equal or lower than:

$$0,5 \frac{Q_s Z_0}{V_{RM}}$$

where

Q_s is the stored charge;

Z_0 is the characteristic impedance of the line (50 Ω) at which the measurement is carried out.

The pulse duration of the reverse voltage should meet the following requirement:

$$t_{VRM} \geq 1,5 \frac{Q_s Z_0}{V_{RM}}$$

The measuring adapter should be in the form of a line with the characteristic impedance, Z_0 equal to 50 Ω ; and should have a good matching at the input and the output in the frequency range from zero to $f > 0,5/t_t$.

Inductance of the measuring adapter L_s which includes inductances of the elements connecting of the diode D and the capacitor C_1 should meet the following requirement:

$$L_s \leq \frac{t_t Z_0}{5,6} - L_{sc}$$

where

L_{sc} is the case inductance of the diode being measured.

The capacitance of the capacitor C_1 should meet the following requirement:

$$C_1 \geq \frac{75 Q_s}{V_{RM}}$$

A segment length of line d_1 should meet the requirement:

$$d_1 > c \frac{Q_s Z_0}{\sqrt{\epsilon_r} V_{RM}}$$

where

c is the rate of propagation of electromagnetic oscillations in the vacuum;

ϵ_r is the relative dielectric permeability of the line segment.

The transition time of the diode being measured is calculated using the expression:

$$t_t = \sqrt{(t_{t1})^2 - (0,64 t_r)^2} \quad (21)$$

where

t_{t1} is the transient rise time measured on the oscilloscope between levels 0,2 and 0,8 of the voltage step;

t_r is the rise time of the oscilloscope between 10 % and 90 %.

d) *Measurement procedure*

The forward d.c. current I_F is applied to the diode being measured from the forward current source (G_1) and a voltage pulse with the amplitude $V_{RM} + V_F$ is set in the reverse direction.

The time interval (t_{t1}) between levels 0,2 and 0,8 of the total voltage step ($V_F + |V_{RM}|$) is read on the screen of the oscilloscope (see Figure 20).

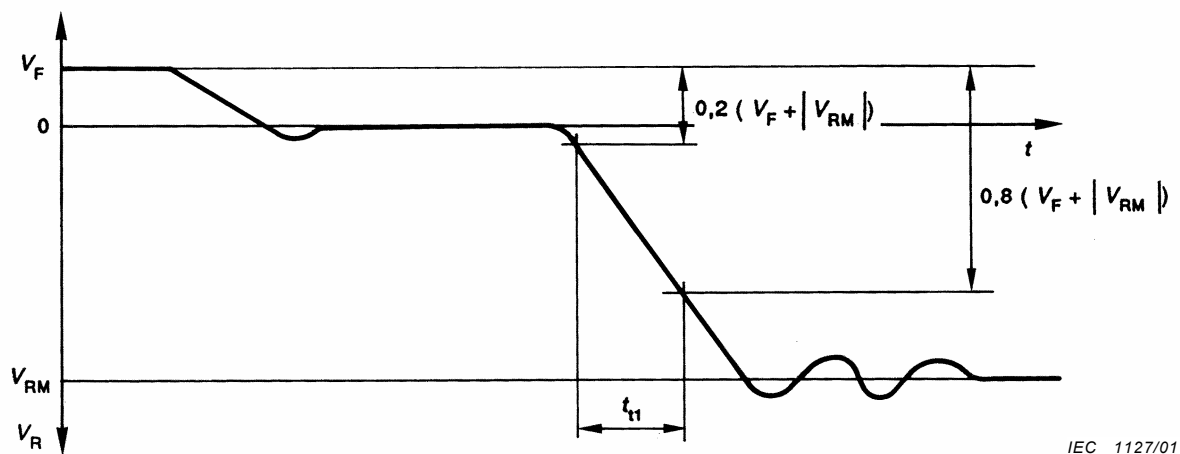


Figure 20 – Time interval (t_{t1})

Using the measured time interval, the transition time is calculated from equation (21).

If $0,64 t_r \leq 0,3 t_{t1}$, to, the time interval read on the oscilloscope is sufficiently close to the transition time of the diode.

e) *Specified conditions*

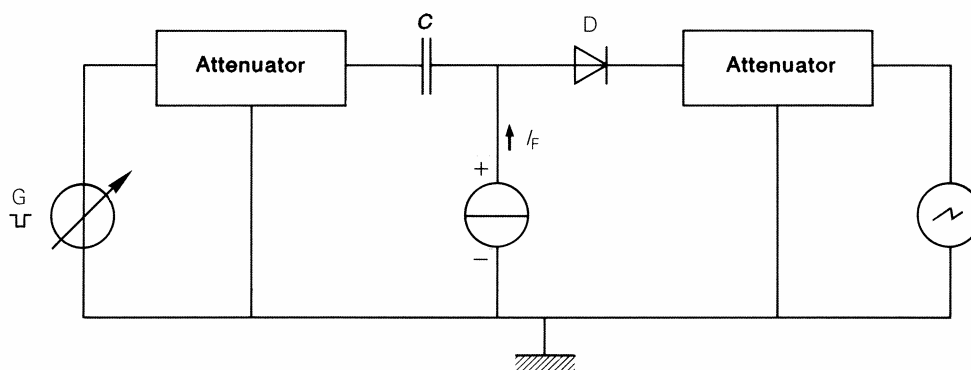
- Forward current (I_F)
- Reverse voltage (V_{RM})
- Characteristic impedance of the line (Z_0), if different from 50 Ω .
- Case inductance of the diode (L_{sc}).
- Stored charge (Q_s).

3.2.4.2 Reverse recovery time (with I_{RM} specified)

a) *Purpose*

To measure the reverse recovery time of a fast diode, e.g. with reverse recovery time less than 100 ns.

b) *Circuit diagram*



Key

D diode being measured

Figure 21 – Circuit for the measurement of reverse recovery time

c) *Circuit description and requirements*

The output impedance of the generator G and the input impedance of the oscilloscope are equal to $50\ \Omega$ unless otherwise specified. The rise times of the generator and of the oscilloscope should be small compared with t_{rr} .

The pulse width should be larger than $3\ t_{rr\ max}$.

Attenuators should have a characteristic impedance of $50\ \Omega$ unless otherwise specified, and an attenuation higher than or equal to 6 dB and should be able to carry d.c. current.

The time constant $R_L\ C_L$ should be lower than $1/10\ t_{rr\ max.}$, unless otherwise specified, with:

R_L = real part of the total impedance, as seen by the diode;

C_L = total capacitance of the circuit including the diode.

C should be high compared with $t_{rr\ max.}/R_L$.

The impedance Z_i of the current generator should be greater than R_L .

d) *Precautions to be observed*

No special precaution.

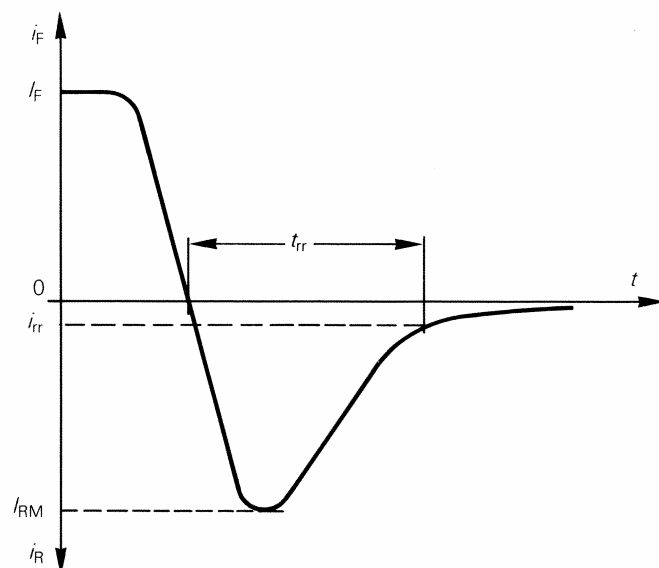
e) *Measurement procedure*

The temperature is set to the specified value.

The current generator delivers the specified forward current I_F to the diode.

Pulses, delivered by generator G, are applied to the diode; the magnitude of the pulses is increased until the specified peak reverse current I_{RM} is reached.

The reverse recovery time t_{rr} is the time interval between the instant at which the current passes through zero and the instant when the current is reduced from I_{RM} to the specified recovery current i_{rr} (see Figure 22).



IEC 1129/01

Figure 22 – Reverse recovery time t_{rr}

f) *Specified conditions*

- Ambient or reference-point temperature (t_{amb} , t_{ref})
- Forward current (I_F)
- Peak reverse current (I_{RM})
- Reverse recovery current (i_{rr})
 - Example of specified conditions: $I_F = 10 \text{ mA}$
 $I_{RM} = 10 \text{ mA}$
 $i_{rr} = 1 \text{ mA}$

3.2.4.3 Measuring method of the excess carrier effective lifetime of diodes for fast-switching applications (snap-off diodes and Schottky diodes)

3.2.4.3.1 Purpose

To measure the excess carrier lifetime of diodes (following the Krakauer method, for example).

NOTE The conventional method has been modified so as to separate clearly the carrier lifetime owing to the carriers in excess, from the charges and discharges of the capacitance of the diode under test and of the parasitic elements (diode, case, mounting).

The carrier lifetime of a fast diode (Schottky, for example) has a very low value (theoretically zero for a Schottky diode). In practice, this measurement is generally made to determine the value of the forward current for which the parasitic elements of the diode under test contribute markedly to the carrier lifetime (guard-ring injection, etc.).

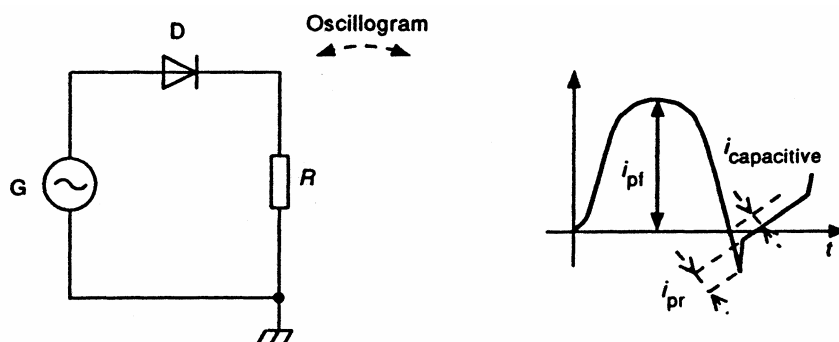
3.2.4.3.2 Principle of measurement

The diode to be measured is connected in series with a resistor, the set "diode + resistor" is supplied by a sinusoidal waveform generator (frequency ω).

The peak value of the forward current is compared with the reverse current, taking into account:

- a) the charge and discharge current of the parasitic capacitance in parallel with the diode under test;
- b) the electrostatic junction voltage ψ of the diode.

The values of the forward and reverse currents are calculated from the voltage measured across the resistor.



IEC 1140/01

Figure 23 – Principle of the measurement of the excess carrier effective lifetime

It can be shown that:

$$\omega\tau = \frac{i_{pr}}{i_{pf}} \left(1 - \frac{\Psi}{E_p}\right) \quad \text{and so:} \quad \tau = \frac{1}{2\pi f} \frac{i_{pr}}{i_{pf}} \left(1 - \frac{\Psi}{E_p}\right)$$

under the condition that both: $\omega\tau < 0,3$ and $i_{pr} > i_{capacitive}$

where

τ is the carrier lifetime of the diode under test;

f is the frequency of the sinusoidal waveform generator, G;

i_{pr} is the peak value of the reverse current without capacitive effects;

i_{pf} is the peak value of the forward current;

Ψ is the forward voltage;

E_p is the peak value of open-circuit voltage of the sinusoidal waveform generator.

3.2.4.3.3 Circuit diagram

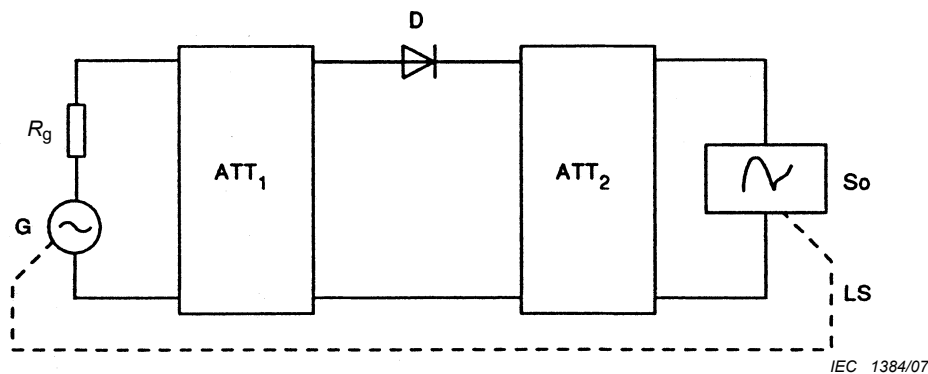


Figure 24 – Circuit for the measurement of the excess carrier effective lifetime

where

G is the sinusoidal waveform voltage generator with frequency, f ;

R_g is the internal resistance of the sinusoidal wave generator;

ATT₁ is the attenuator, $Z_0 = R_g$;

D is the diode under test;

ATT₂ is the attenuator, $Z_0 = R_g$;

So is the oscilloscope, $Z_{input} = R_g$;

LS is the synchronization for the oscilloscope.

3.2.4.3.4 Measurement procedure

The diode to be measured is put in the test fixture similar to that shown in Figure 24 (circuit diagram).

The frequency of the sinusoidal waveform generator is set and the output level adjusted to the specified value of i_{pf} .

NOTE 1 When the oscilloscope is calibrated in voltage, the value of i_{pr} can be calculated from the voltage at the input of the oscilloscope and the input impedance of the oscilloscope ($R_e = R_g$), taking into account the attenuation of ATT₂.

The value of i_{pr} corresponds to the difference between the peak value of the reverse current and the extrapolated value of the capacitive current. The value of τ is calculated with the formula in 3.2.4.3.2, after having determined the value of E_p and the value of ψ (for example, with a curve tracer).

NOTE 2 For the circuit diagram of Figure 24, the value of e_{rms} can be measured directly on the calibrated oscilloscope when the attenuators ATT_1 and ATT_2 are directly connected (for example, a short circuit across the diode).

$$E_p = 2\sqrt{2} \times e_{rms} \left(e_{rms} = \frac{V_{rms}}{10^{(ATT_1/20)}} \right)$$

Caution: It should be ascertained that:

$$\omega\tau < 0,3$$

$$i_{pr} > i_{capacitive}$$

Example: Given

$$R_g = 50 \, \Omega$$

$$V_{rms} = 10 \, V$$

$$f = 54 \, MHz$$

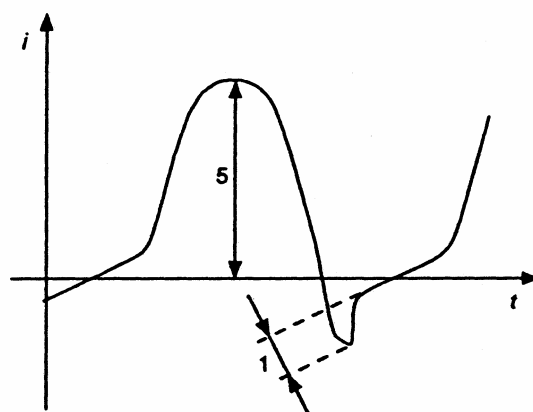
$ATT_1 = 10 \, dB$, $ATT_2 = 20 \, dB$ (these values are generally sufficient to reduce the effect of the mismatch appearing during the cycle after the carrier lifetime measurement).

The value of i_{pf} is read directly from the oscilloscope, and taking into account the attenuation of ATT_2 , the following values are obtained:

$$i_{pf} = 75 \, mA, \, \psi = 1,35 \, V \text{ and } E_p = 8,9 \, V.$$

From the oscilloscope the ratio of i_{pr} to i_{pf} is derived:

$$\frac{i_{pr}}{i_{pf}} = \frac{1}{5}$$



IEC 1142/01

Figure 25 – Ratio of i_{pr} to i_{pf}

From the formula in 3.2.4.3.2, it follows: $\tau = 500 \, ps$.

3.2.4.3.5 Requirements

The value of τ shall be within the limits specified in the relevant specification.

3.2.4.3.6 Specified conditions

- Ambient or case temperature.
- Frequency of sine wave generator, f .
- Peak value of forward current, i_{pf} .
- Values of the elements of the circuit, and the circuit diagram with values of the elements, if different from Figure 24.

4 Mixer diodes and detector diodes

4.1 Mixer diodes used in radar applications

4.1.1 General

Although a number of measurements may be carried out on a diode by itself, it is necessary for an assessment of diode performance to provide a standard mounting arrangement to enable satisfactory measurements to be made. Usually, the mounting takes the form of a standard holder designed for the purpose. If the holder is adjustable, all adjustments are made to conform with given measurement requirements.

In the case of reversible diodes, it may be necessary for measurements to be made with the diode connected to provide an assessment of performance in each polarity.

All microwave components used in the measuring equipment shall be checked to ensure satisfactory operation over the required frequency band. It is recommended that this be performed using swept frequency techniques.

The time constants, or pulse response characteristics of any indicating instrument, shall not affect the measurement results when modulation is used.

It is essential to ensure that stray electromagnetic fields do not significantly affect the accuracy of measurement.

In addition, any signal source used as part of the measuring circuitry shall be capable of stable operation at a signal level equivalent to the small-signal conditions of the diode being measured.

Unless otherwise stated, it is recommended that the maximum tolerances permitted for microwave signal levels should be:

- a) $\pm 0,1$ % for low-power measurements required under small-signal conditions, and
- b) ± 1 % for high-power measurements.

Where a specified temperature is required, the temperature of the body of the measuring mount shall be measured when equilibrium conditions have been reached.

4.1.2 Terminology and letter symbols

See 4.1.3.3.

4.1.3 Essential ratings and characteristics

4.1.3.1 General

The essential ratings and characteristics for each category of diode are marked with a + sign in the following table: