



BSI Standards Publication

Superconductivity

Part 16: Electric characteristic measurements
— Power-dependent surface resistance of
superconductors at microwave frequencies

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The UK participation in its preparation was entrusted to Technical Committee L/-/90, Super Conductivity.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Superconductivity -
Part 16: Electronic characteristic measurements -
Power-dependent surface resistance of superconductors at microwave
frequencies
(IEC 61788-16:2013)**

Supraconductivité -
Partie 16: Mesures de caractéristiques
électroniques -
Résistance de surface des
supraconducteurs aux hyperfréquences
en fonction de la puissance
(CEI 61788-16:2013)

Supraleitfähigkeit -
Teil 16: Messung der elektronischen
Eigenschaften -
Leistungsabhängiger
Oberflächenwiderstand bei
Mikrowellenfrequenzen
(IEC 61788-16:2013)

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Foreword

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The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated

Superconductivity - Part 15: Electronic characteristic measurements - Intrinsic surface impedance of superconductor films at microwave frequencies	EN 61788-15	-
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INTRODUCTION

Since the discovery of high- T_c superconductors (HTS), extensive researches have been performed worldwide for electronic applications and large-scale applications.

In the fields of electronics, especially in telecommunications, microwave passive devices such as filters using HTS are being developed and testing is underway on sites [1,2,3,4]¹.

Superconductor materials for microwave resonators, filters, antennas and delay lines have the advantage of ultra-low loss characteristics. Knowledge of this parameter is vital for the development of new materials on the supplier side and the design of superconductor microwave components on the customer side. The parameters of superconductor materials needed to design microwave components are the surface resistance R_s and the temperature dependence of the R_s . Recent advances in HTS thin films with R_s , several orders of magnitude lower than normal metals has increased the need for a reliable characterization technique to measure this property [5,6]. Among several methods to measure the R_s of superconductor materials at microwave frequencies, the dielectric resonator method [7,8,9] has been useful due to that the method enables to measure the R_s nondestructively and accurately. In particular, the sapphire resonator is an excellent tool for measuring the R_s of HTS materials [10]. In 2002, the International Electrotechnical Commission (IEC) published the dielectric resonator method as a measurement standard [11].

The test method given in this standard enables measurement of the power-dependent surface resistance of superconductors at microwave frequencies. For high power microwave device applications such as those of transmitting devices, not only the temperature dependence of R_s but also the power dependence of R_s is needed to design the microwave components. Based on the measured power dependence, the RF current density dependence of the surface resistance can be evaluated. The simulation software to design the device gives the RF current distribution in the device. The results of the power dependence measurement can be directly compared with the simulation and allow the power handling capability of the device to be evaluated.

The test method given in this standard can be also applied to other superconductor bulk plates including low- T_c material.

This standard is intended to give an appropriate and agreeable technical base for the time being to those engineers working in the fields of electronics and superconductivity technology.

The test method covered in this standard is based on the VAMAS (Versailles Project on Advanced Materials and Standards) pre-standardization work on the thin film properties of superconductors.

¹ Numbers in square brackets refer to the Bibliography.

SUPERCONDUCTIVITY –

Part 16: Electronic characteristic measurements – Power-dependent surface resistance of superconductors at microwave frequencies

1 Scope

This part of IEC 61788 involves describing the standard measurement method of power-dependent surface resistance of superconductors at microwave frequencies by the sapphire resonator method. The measuring item is the power dependence of R_s at the resonant frequency.

The following is the applicable measuring range of surface resistances for this method:

Frequency: $f \sim 10$ GHz

Input microwave power: $P_{in} < 37$ dBm (5 W)

The aim is to report the surface resistance data at the measured frequency and that scaled to 10 GHz using the $R_s \propto f^2$ relation for comparison.

2 Normative references

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

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at: <http://www.electropedia.com>)

IEC 61788-15, *Superconductivity – Part 15: Electronic characteristic measurements – Intrinsic surface impedance of superconductor films at microwave frequencies*

3 Terms and definitions

For the purposes of this document, the definitions given in IEC 60050-815, one of which is repeated here for convenience, apply.

3.1 surface impedance

impedance of a material for a high frequency electromagnetic wave which is constrained to the surface of the material in the case of metals and superconductors

Note 1 to entry: The surface impedance governs the thermal losses of superconducting RF cavities.

Note 2 to entry: In general, surface impedance Z_s for conductors including superconductors is defined as the ratio of the electric field E_t to the magnetic field H_t , tangential to a conductor surface:

$$Z_s = E_t / H_t = R_s + jX_s,$$

where R_s is the surface resistance and X_s is the surface reactance.

4 Requirements

The surface resistance R_s of a superconductor film shall be measured by applying a microwave signal to a sapphire resonator with the superconductor film specimen and then measuring the insertion attenuation of the resonator at each frequency. The frequency shall be swept around the resonant frequency as the center and the insertion attenuation - frequency characteristics shall be recorded to obtain the Q-value, which corresponds to the loss.

The target relative combined standard uncertainty of this method is the coefficient of variation (standard deviation divided by the average of the surface resistance determinations), which is less than 20 % for a measurement temperature range from 30 K to 80 K.

It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Hazards exist in such measurement. The use of a cryogenic system is essential to cool the superconductors and allow transition into the superconducting state. Direct contact of skin with cold apparatus components can cause immediate freezing, as can direct contact with a spilled cryogen. The use of an RF-generator is also essential to measure the high-frequency properties of materials. If its power is excessive, direct contact to human bodies could cause immediate burns.

5 Apparatus

5.1 Measurement system

5.1.1 Measurement system for the $\tan \delta$ of the sapphire rod

Figure 1 shows a schematic diagram of the system required for the $\tan \delta$ measurement. The system consists of a network analyzer system for transmission measurements, a measurement apparatus in which a sapphire resonator with superconductor films is fixed, and a thermometer for monitoring the measuring temperature.

The incident power generated from a suitable microwave source such as a synthesized sweeper is applied to the sapphire resonator fixed in the measurement apparatus. The transmission characteristics are shown on the display of the network analyzer. The measurement apparatus is fixed in a temperature-controlled cryocooler.

To measure the $\tan \delta$ of the sapphire rod, a vector network analyzer is recommended, since its measurement accuracy is superior to a scalar network analyzer due to its wide dynamic range.

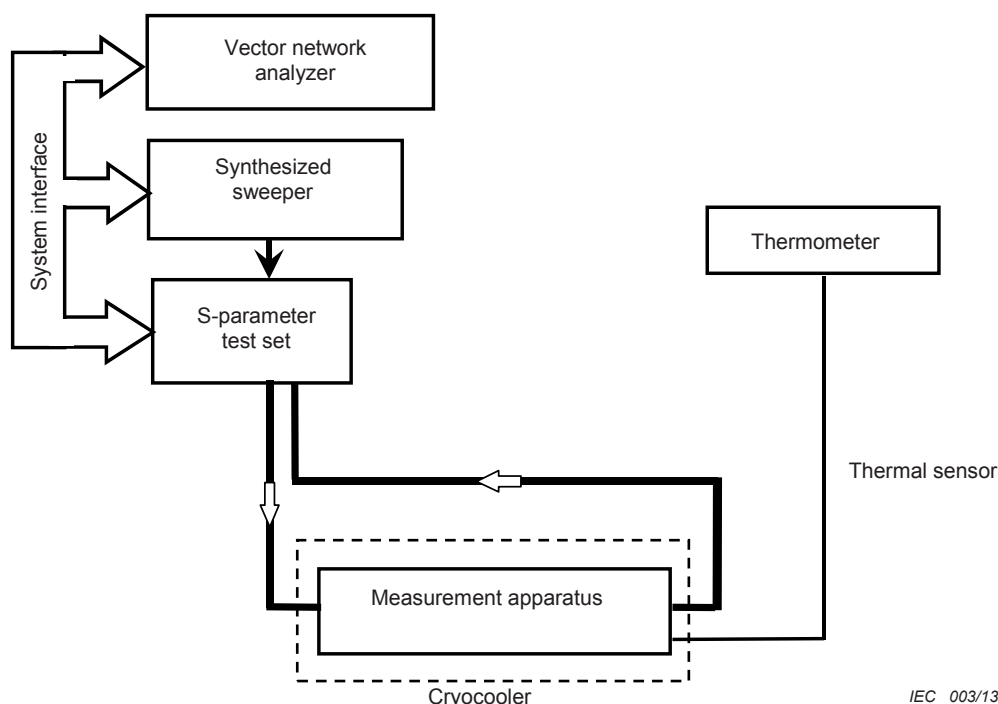


Figure 1 – Measurement system for $\tan \delta$ of the sapphire rod

5.1.2 Measurement system for the power dependence of the surface resistance of superconductors at microwave frequencies

Figure 2 shows the measurement system for the power dependence of the surface resistance of superconductors using a sapphire resonator. A travelling wave tube (TWT) power amplifier with a maximum output power of around 40 dBm is inserted at the input into the resonator. The maximum input power into the resonator is around 37 dBm in this measurement system shown in Figure 2. The typical maximum input power of a network analyzer is in the order of 0 dBm, so a measurement circuit shall be designed to avoid direct exposure of high powered microwaves to the network analyzer, and also by using a circulator and an attenuator, significant reflection from the sapphire resonator should not affect the TWT amplifier.

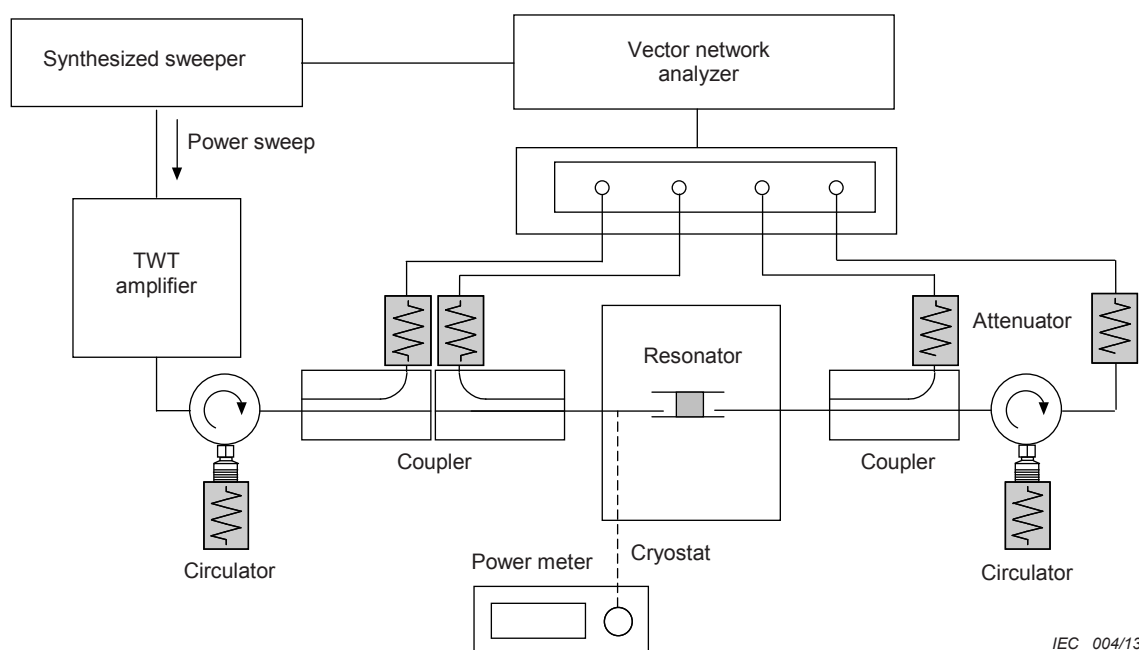


Figure 2 – Measurement system for the microwave power dependence of the surface resistance