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**Superconductivity—Part 7:
Electronic characteristic
measurements—Surface resistance
of superconductors at microwave
frequencies**

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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of Economy, Trade and Industry, through deliberations at the Japanese Industrial Standards Committee as the result of proposal for revision of Japanese Industrial Standard submitted by International Superconductivity Technology Center (ISTEC)/Japanese Standards Association (JSA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law applicable to the case of revision by the provision of Article 14.

Consequently **JIS H 7307:2005** is replaced with this Standard.

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Superconductivity—Part 7: Electronic characteristic measurements— Surface resistance of superconductors at microwave frequencies

Introduction

This Japanese Industrial Standard has been prepared based on the second edition of **IEC 61788-7** published in 2006 without modifying the technical contents and the structure.

The portions underlined with dots are the matters not stated in the original International Standard.

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

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 Scope

This Standard describes measurement of the surface resistance of superconductors at microwave frequencies by the standard two-resonator method. The object of measurement is the temperature dependence of R_s at the resonant frequency.

The applicable measurement range of surface resistances for this method is as follows:

- Frequency: $8\text{ GHz} < f < 30\text{ GHz}$
- Measurement resolution: $0.01\text{ m}\Omega$ at 10 GHz

The surface resistance data at the measured frequency, and that scaled to 10 GHz , assuming the f^2 rule for comparison, are reported.

NOTE : The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows:

IEC 61788-7:2006 *Superconductivity—Part 7: Electronic characteristic measurements—Surface resistance of superconductors at microwave frequencies* (IDT)

The symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21-1**.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this Standard. The most recent edition of the standard (including amendments) indicated below shall be applied.

JIS H 7005 *International Electrotechnical Vocabulary—Part 815: Superconductivity*

NOTE : Corresponding International Standard: IEC 60050-815 *International Electrotechnical Vocabulary—Part 815: Superconductivity* (MOD)

3 Terms and definitions

For the purposes of this Standard, the terms and definitions given in **JIS H 7005** and the following apply.

3.1 surface impedance

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 : the surface resistance

X_s : the surface reactance

4 Requirements

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

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

NOTE : Q -value is an amount expressing sharpness in resonance of a vibration system. See **JIS H 7002** for the details.

5 Apparatus

5.1 Measurement system

Figure 1 shows a schematic diagram of the system required for the microwave measurement. The system consists of a network analyzer system for transmission measurement, a measurement apparatus, and a thermometer for monitoring the measuring temperature.

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

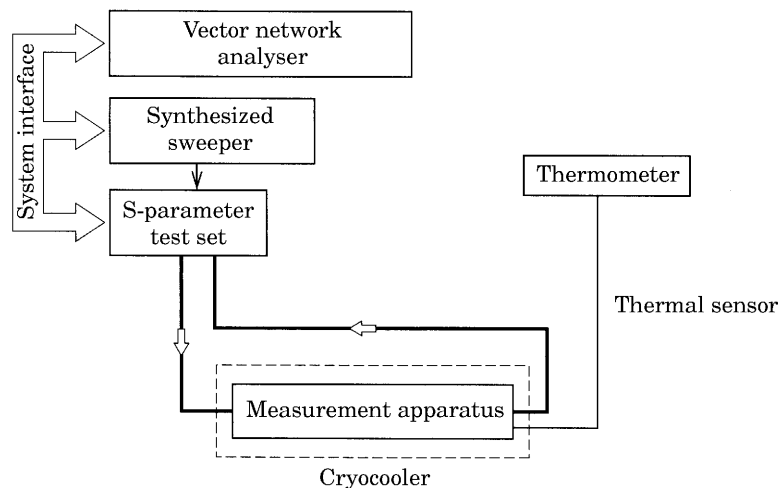


Figure 1 Schematic diagram of measurement system for temperature dependence of R_s using a cryocooler

The measurement apparatus is fixed in a temperature-controlled cryocooler.

For the measurement of R_s for superconductor films, a vector network analyzer is recommended. A vector network analyzer has better measurement accuracy than a scalar network analyzer due to its wide dynamic range.

5.2 Measurement apparatus for R_s

Figure 2 shows a schematic of a typical measurement apparatus (closed type resonator) for the R_s of superconductor films deposited on a substrate with a flat surface. The upper superconductor film is pressed down by a spring, which is made of phosphor bronze. The plate type spring is recommended to be used for the improvement of measurement accuracy. This type of spring reduces the friction between the spring and the other part of the apparatus, and allows the smooth movement of superconductor films due to the thermal expansion of the dielectric rod. In order to minimize the measurement error, the sapphire rod and the copper ring shall be set in coaxial.

Two semi-rigid cables for measuring transmission characteristics of the resonator shall be attached on both sides of the resonator in an axial symmetrical position ($\phi = 0$ and 180° , where ϕ is the rotational angle around the central axis of the sapphire rod). Each of the two semi-rigid cables shall have a small loop at the ends. The plane of the loop shall be set parallel to that of the superconductor films in order to suppress the unwanted TM_{mn0} modes. The coupling loops shall be carefully checked for cracks in the spot weld joint that may have developed upon repeated thermal cycling. These cables can move right and left to adjust the insertion attenuation (IA). In this adjustment, coupling of unwanted cavity modes to the interested dielectric resonance mode shall be suppressed. Unwanted, parasitic coupling to the other modes reduces the high Q value of the TE mode resonator. For suppressing the parasitic coupling, special attention shall be paid to designing high Q resonators. Two other types of resonators along with the closed type shown in figure 2 can be used. They are explained in clause A.4.

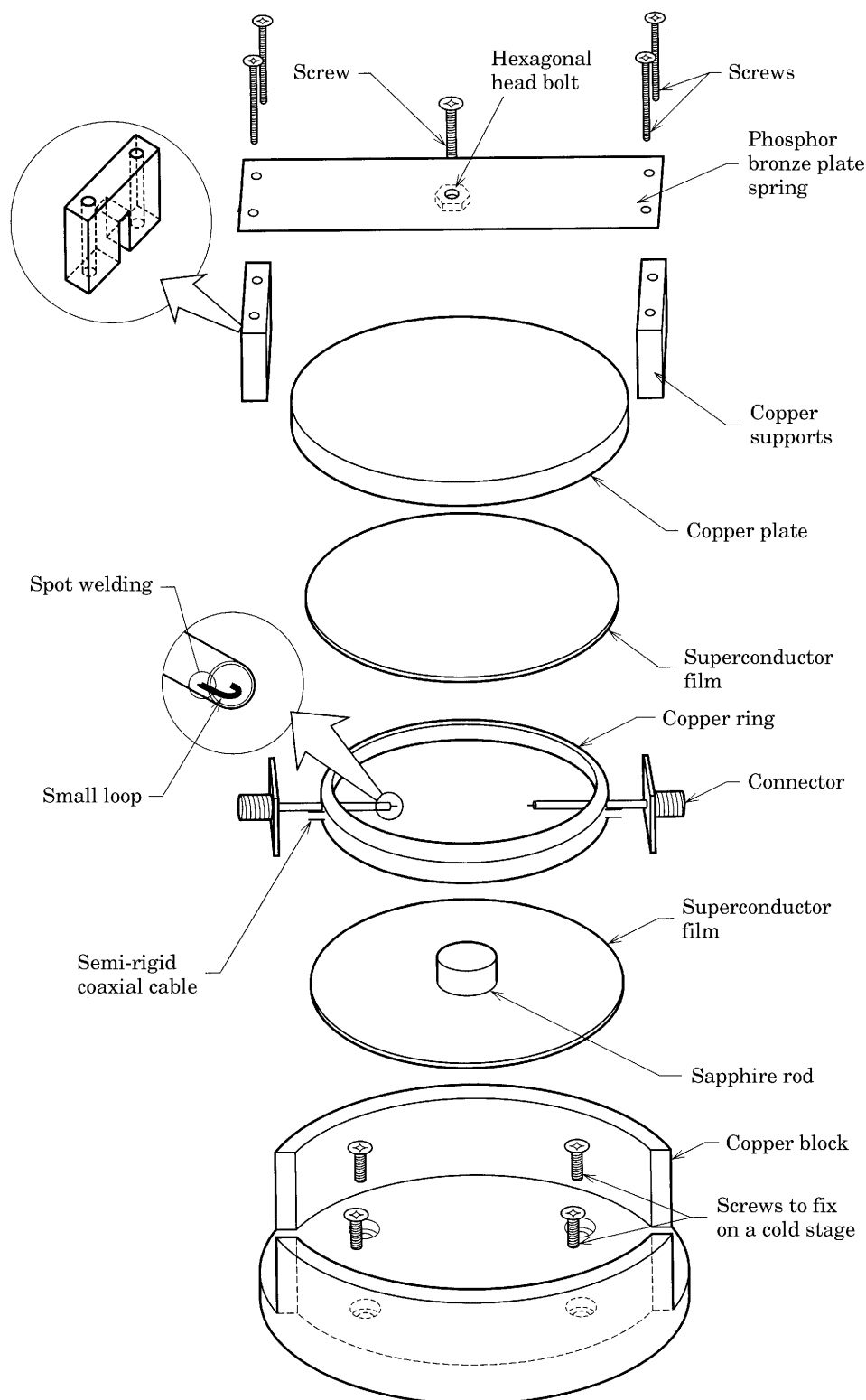


Figure 2 Typical measurement apparatus for R_s

A reference line made of a semi-rigid cable shall be used to measure the full transmission power level, i.e., the reference level. This cable has a length equal to the sum of the two cables of the measurement apparatus.

In order to minimize the measurement error, two superconductor films shall be set to be parallel to each other. To ensure that the two superconductor films remain in tight contact with the ends of the sapphire rod, without any air gap, both of the surfaces of the films and the ends of the rod shall be cleaned carefully.

5.3 Dielectric rods

Two dielectric rods with the same relative permittivity, ϵ' , and loss factor, $\tan \delta$, preferably cut from one cylindrical dielectric rod, are required. These two rods, standard dielectric rods, shall have the same diameter but different heights: one has a height three times longer than the other.

It is preferable to use standard dielectric rods with low $\tan \delta$ to achieve the requisite measurement accuracy on R_s . Recommended dielectric rods are sapphire rods with $\tan \delta$ less than 10^{-6} at 77 K. Specifications on the sapphire rods are described in 7.1. In order to minimize the measurement error in R_s of the superconductor films, both ends of the sapphire rods shall be polished parallel to each other and perpendicular to the axis. Specifications for the sapphire rods are described in clause 7.

The diameter and the heights of the standard sapphire rods shall be carefully designed so that the TE_{011} and TE_{013} modes do not couple to other TM, HE and EH modes, since the coupling between TE mode and other modes causes the degradation of unloaded Q . A design guideline for the standard sapphire rods is described in clause A.5. Table 1 shows typical examples of dimensions of the standard sapphire rods for 12 GHz, 18 GHz, and 22 GHz resonance. At higher frequencies the unloaded Q value will be lower, which makes the measurement easier, and the error will be lower.

Table 1 Typical dimensions of pairs of standard sapphire rods for 12 GHz, 18 GHz and 22 GHz

Frequency GHz	Sapphire rod	Diameter (d) mm	Height (h) mm
12	Short rod (TE_{011} resonator)	11.4	5.7
	Long rod (TE_{013} resonator)	11.4	17.1
18	Short rod (TE_{011} resonator)	7.6	3.8
	Long rod (TE_{013} resonator)	7.6	11.4
22	Short rod (TE_{011} resonator)	6.2	3.1
	Long rod (TE_{013} resonator)	6.2	9.3

6 Measurement procedure

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

Hazards exist in this type of measurement. The use of a cryogenic system is essential to cool the superconductors to 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 r.f.-generator is also essential to measure high-frequency properties of materials. If its power is too high, direct contact to human bodies can cause an immediate burn.

6.1 Specimen preparation

From error estimation, the film diameter shall be about three times larger than that of the sapphire rods. In this configuration, the reduction in precision of R_s due to the different radiation losses between TE_{011} and TE_{013} mode can be considered negligible, given the target precision of 20 %. The film thickness shall be about three times larger than the London penetration depth value at each temperature. If the film thickness is much less than three times the London penetration depth, the measured R_s should mean the effective surface resistance. Table 2 shows dimensions of the superconductor films recommended for the standard sapphire rods of 12 GHz, 18 GHz, and 22 GHz.

Table 2 Dimensions of superconductor film for 12 GHz, 18 GHz, and 22 GHz

Standard dielectric rod		Superconductor film	
Frequency GHz	Diameter (d) mm	Diameter (d') mm	Thickness μm
12	11.4	>35	≈ 0.5
18	7.6	>25	≈ 0.5
22	6.2	>20	≈ 0.5

In case of using closed type resonators, the dimensions of the superconductor films shall also be designed taking into account the dimension of the copper cylinder between the superconductor films. A design guideline for the dimension of the copper cylinder of the closed type resonator is described in clause A.6.

6.2 Set-up

Set up the measurement equipment as shown in figure 1. All of the measurement apparatus, standard sapphire rods, and superconductor films shall be kept in a clean and dry state as high humidity may degrade the unloaded Q -value. The specimen and the measurement apparatus shall be fixed in a temperature-controlled cryocooler. The specimen chamber shall be generally evacuated. The temperatures of the superconductor films and standard sapphire rods shall be measured by a diode thermometer, or a thermocouple. The temperatures of the upper and lower superconductor films, and standard sapphire rods must be kept as close as possible. This can be achieved by covering the measurement apparatus with aluminium foil, or filling the specimen chamber with helium gas.

6.3 Measurement of reference level

The level of full transmission power (reference level) shall be measured first. Fix the output power of the synthesized sweeper below 10 mW because the measurement accuracy depends on the measuring signal level. Connect the reference line of semi-rigid cable between the input and output connectors. Then, measure the transmission power level over the entire measurement frequency and temperature range. The reference level can change several decibels when temperature of the apparatus is changed from room temperature to the lowest measurement temperature. Therefore, the temperature dependence of the reference level must be taken into account.