

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Superconductivity –
Part 22-2: Normal state resistance and critical current measurement –
High- T_C Josephson junction:**

**Supraconductivité –
Partie 22-2: Mesurage de la résistance à l'état normal et du courant critique –
Jonction Josephson à T_C élevée**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2021 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, ...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC online collection - oc.iec.ch

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études, ...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

IEC online collection - oc.iec.ch

Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Superconductivity –
Part 22-2: Normal state resistance and critical current measurement –
High- T_C Josephson junction:**

**Supraconductivité –
Partie 22-2: Mesurage de la résistance à l'état normal et du courant critique –
Jonction Josephson à T_C élevée**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 29.050

ISBN 978-2-8322-1039-7

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Terms and definitions	7
4 Symbols	8
5 Principle of measurement method.....	9
6 Apparatus.....	9
6.1 General.....	9
6.2 Cryogenic system	9
6.3 Electrical measurement system.....	10
6.4 Circuitry	10
7 Estimation of normal state resistance (R_n) and intrinsic critical current (I_{ci}).....	11
7.1 Calculation method	11
7.2 Geometric mean criterion for hyperbolic function fitting	12
8 Standard uncertainty	12
8.1 General.....	12
8.2 Type A uncertainty	12
8.3 Type B uncertainty	14
8.3.1 General	14
8.3.2 Temperature	14
8.3.3 Voltage measurement.....	16
8.3.4 Current measurement	16
8.4 Budget table	17
8.5 Uncertainty requirement.....	18
9 Test report.....	18
9.1 Identification of test device	18
9.2 R_n value.....	18
9.3 I_{ci} value	18
9.4 Standard uncertainty.....	18
9.5 Atmospheric pressure	18
9.6 Miscellaneous optional report	18
Annex A (informative) Calculation technique and practical application to high- T_c Josephson junctions	20
A.1 General.....	20
A.2 Hyperbolic function fitting method	20
A.3 Geometric mean method	21
A.4 Combined method.....	22
A.5 Estimation of R_n , I_{ci} , $u_{A,R}$ and $u_{A,I}$	23
A.5.1 General	23
A.5.2 High- T_c Josephson junction (JL350)	23
A.5.3 High- T_c Josephson junction (JL351)	25
A.5.4 High- T_c Josephson junction (TUT).....	27
Annex B (informative) Practical application to low- T_c Josephson junctions.....	30

B.1	General.....	30
B.2	Estimation of R_n , I_{cj} , $u_{A,R}$ and $u_{A,I}$	30
B.2.1	General	30
B.2.2	Low- T_C Josephson junction (IU1)	30
B.2.3	Low- T_C Josephson junction (IU2)	31
B.2.4	Low- T_C Josephson junction (IU3)	32
B.2.5	Low- T_C Josephson junction (IU4)	34
	Bibliography.....	35
	Figure 1 – Typical circuitry for voltage-current ($U-I$) characteristic curve measurement	10
	Figure 2 – Ideal $U-I$ characteristic curve (red line) and hyperbolic function (RSJ) model curve (dotted line).....	11
	Figure 3 – Geometric mean criterion and RSJ model fitting for TUT-JJ05 at 75,8 K.....	15
	Figure 4 – Geometric mean criterion and RSJ model fitting for TUT-JJ05 at 76,3 K.....	16
	Figure A.1 – $U-I$ curve based on resistively shunted junction (RSJ) model	21
	Figure A.2 – $U-I$ curve affected by noise-rounding and self-heating.....	21
	Figure A.3 – Application of geometric mean method to ideal $U-I$ in Figure A.1.....	22
	Figure A.4 – Application of geometric mean method to $U-I$ with noise-rounding and self-heating effects in Figure A.2.....	23
	Figure A.5 – $U-I$ curve of JL350	24
	Figure A.6 – Application of geometric mean method to Figure A.5	24
	Figure A.7 – Result of RSJ model fitting for JL350	25
	Figure A.8 – $U-I$ curve of JL351	26
	Figure A.9 – Application of geometric mean method to Figure A.8	26
	Figure A.10 – Result of RSJ model fitting for JL351	27
	Figure A.11 – $U-I$ curve of TUT with a small I_m	28
	Figure A.12 – Application of geometric mean method to TUT	28
	Figure A.13 – Application of adjusted geometrical mean method to TUT	29
	Figure A.14 – Result of RSJ model fitting for TUT	29
	Figure B.1 – Application of geometric mean method to IU1	31
	Figure B.2 – Result of RSJ model fitting for IU1	31
	Figure B.3 – Application of geometric mean method to IU2	32
	Figure B.4 – Result of RSJ model fitting for IU2	32
	Figure B.5 – Application of geometric mean method to IU3	33
	Figure B.6 – Result of RSJ model fitting for IU3	33
	Figure B.7 – Application of geometric mean method to IU4	34
	Figure B.8 – Result of RSJ model fitting for IU4	34
	Table 1 – Typical relative standard Type A uncertainty for high- T_C Josephson junctions	14
	Table 2 – Budget table for R_n	17
	Table 3 – Budget table for I_{cj}	17
	Table A.1 – R_n , I_{cj} , $u_{A,R}$ and $u_{A,I}$ values of high- T_C Josephson junctions	23
	Table B.1 – R_n , I_{cj} , $u_{A,R}$ and $u_{A,I}$ values of low- T_C Josephson junctions.....	30

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SUPERCONDUCTIVITY –

Part 22-2: Normal state resistance and critical current measurement – High- T_c Josephson junction

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 61788-22-2 has been prepared by IEC technical committee 90: Superconductivity. It is an International Standard.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
90/484/FDIS	90/486/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

IEC 61788-22 (all parts) is a series of International Standards on superconductor electronic devices. Superconductivity offers various possibilities of realizing sensors and detectors for a variety of measurands. Several types of superconductor sensors and detectors have been developed, using such features as superconducting energy gaps, sharp normal-superconducting transition, nonlinear current-voltage characteristics, superconducting coherent states and quantization of magnetic flux. Superconductors are influenced by interaction with electromagnetic fields, photons, ions, etc. The superconductor sensors and detectors have extremely high performance in resolution, time response and sensitivity, which cannot be realized by any other sensors and detectors.

IEC 61788-22-1 lists various types of superconductor sensors and detectors. A key element of some sensors and detectors is Josephson junction. The superconductor material types used for Josephson junctions are divided into two categories: low- T_c superconductor (LTS) and high- T_c superconductor (HTS). This document (IEC 61788-22-2) defines a measurement method of normal state resistance (R_n) and intrinsic critical current (I_{ci}) of HTS Josephson junctions, which are used for magnetic measurement with superconductor quantum interference device (SQUID), detection of millimetre to terahertz band radiation and other applications.

The measurement method covered in this document is intended to give an appropriate and agreeable technical base for those engineers working in the field of superconductor technology. Although the mechanism of high- T_c superconductivity is under investigation, the occurrence of the Josephson effect in such weak link structures as bicrystal, step-edge and ramp edge is reliable, and characteristic parameters for conventional LTS Josephson junctions are valid also for HTS Josephson junctions. The important parameters of HTS Josephson junctions for designing superconductor devices are normal state resistance (R_n) and critical current (I_c), which are combined as $I_c R_n$ product that is obtained experimentally. At this moment, most HTS Josephson junctions exhibit a non-hysteretic characteristic voltage-current ($U-I$) curve, which is typical for superconductor/normal-conductor/superconductor (SNS) junctions. On $U-I$ curves, two types of distortions are often observed: noise-rounding and self-heating effects. Especially, maximum current values without voltage drop on the $U-I$ curves are often considerably reduced because of the noise-rounding effect, and therefore it is difficult to estimate an intrinsic critical current value. This document provides a method to obtain intrinsic values by selecting a data set range to eliminate the distortions and by fitting a model function even when two effects are present.

The critical current obtained by this standard method is therefore called intrinsic critical current with the variable symbol of I_{ci} , eliminating the noise-rounding effect on $U-I$ curves. On the other hand, the normal state resistance is insensitive to the noise rounding and it is possible to avoid the self-heating effect, so that the variable symbol R_n is used. The $I_{ci} R_n$ product is more essential for designing superconductor devices than the $I_c R_n$ product. I_{ci} values estimated by this document are usually higher than experimental I_c values.

Practical application of this document to HTS Josephson junctions is shown in Annex A. The estimation method in this document is applied to SNS-type LTS Josephson junctions to check universality in Annex B.

SUPERCONDUCTIVITY –

Part 22-2: Normal state resistance and critical current measurement – High- T_c Josephson junction

1 Scope

This part of IEC 61788 is applicable to high- T_c Josephson junctions. It specifies terms, definitions, symbols and the measurement and estimation method for normal state resistance (R_n) and intrinsic critical current (I_{ci}), based on a combination of selecting a data set from measured U - I curves with a geometric mean criterion and fitting a hyperbolic function to that data set.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 61788-22-1, *Superconductivity – Part 22-1: Superconducting electronic devices – Generic specification for sensors and detectors*

IEC 60617, *Graphical symbols for diagrams*: available at <http://std.iec.ch/iec60617>

IEC 60050-815:2015, *International Electrotechnical Vocabulary – Part 815: Superconductivity*: (available at <http://www.electropedia.org/>)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

U - I characteristic curve

V - I characteristic curve

I - V characteristic curve

data set of voltage drop between two superconductors of a Josephson junction and current applied to the junction