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Standardization of Coaxial Connectors in the IEC

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Invited Paper

This paper reviews the requirements and standardization of coaxial connectors in the United States. It details the standardization of coaxial connectors within the International Electrotechnical Commission (IEC) Subcommittee SC46D "Connectors for RF Cables." A list of published IEC connector standards and a list of IEC standards under consideration are included.

I. Introduction

Coaxial connectors have been used in extremely large numbers. With the extension of solid-state devices to higher frequencies, and the development and widespread application of sophisticated microstrip circuits [1], coaxial lines are being used in much greater numbers than waveguides at RF and microwave frequencies up to 40 GHz and even for some applications in millimeter waves [2] at 75 to 110 GHz. In practice, connectors are used for interconnecting various components, subassemblies, equipments, and subsystems. Many varieties of connectors and adapters are available for the interconnections between various equipments and microwave measurement systems that employ precision coaxial connectors [3]. For accurate measurements, the limiting effects of the connectors must be known. To determine these effects, it is necessary to consider typical connector characteristics which include: characteristic impedance; reflection factor (reflection coefficient); insertion loss; screening effectiveness (RF leakage); contact resistance and their repeatabilities [4], [5]; and finally the mechanical characteristics. Therefore, it is of primary importance to obtain technical data on the performance of electrical and mechanical parameters to the extent that such data are specified in a Standards document.

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II. United States Connector Standards

A. Field Connectors

The standardization for 50-Ω field service connectors (e.g., N, BNC, SMA, etc.) in the United States (U.S.) was performed by Subcommittee C83.2 of the American National Standards Institute (ANSI) in 1964. This resulted in the development of performance specification MIL-C-39012 [6] which covers test methods for coaxial connectors. Individual specification sheets descriptive of different connector types came later. The Electronic Industries Association

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(EIA) P-5.3 Working Group on RF Connectors continues to support this effort. The physical writing of MIL-C-39012 is done at the Defense Electronic Supply Center (DESC), Dayton, OH.

B. Precision Coaxial Connectors

Precision coaxial connectors (14 and 7 mm) were standardized [7] by the IEEE Committee on Precision Coaxial Connectors resulting in IEEE Standard 287 which governs specifications on 14- and 7-mm 50-Ω precision coaxial connectors. This standard was approved by the IEEE Standards Committee and published in 1968 [8]. In 1972, the EIA P-5.3.1 Task Group A produced a connector standard [9] for 14- and 21-mm 75-Ω precision coaxial connectors.

With the trend in microwaves toward higher frequencies, the emphasis in precision coaxial connectors is toward smaller diameters. About 1970, an attempt was made to standardize a 3.5-mm sexless precision coaxial connector by the Joint Industry Research Committee for Standardization of Miniature Precision Coaxial Connectors. This effort failed when budget cuts within the sponsoring organization forced this committee to consider other standardization organizations such as the IEEE and ANSI. However, the committee chose to submit the work to the International Electrotechnical Commission (IEC) Subcommittee (SC) 46D since the IEC at that time was working on a general precision connector standard for international use. Presently, the IEC appears to be the proper vehicle to use to standardize sexed versions of the 3.5-mm precision coaxial connector.

III. IEC/SC46D "Connectors for RF Cables"

A. Background

A number of countries have national RF connector standards (e.g., British BS and German DIN), and Cenelec Electronic Components Committee (CECC) standards have been instituted in the European economic community which are applicable in several countries. However, the IEC standards have worldwide applicability. There is a concerted effort on the part of national and regional standards groups to participate in the formulation of international RF connector standards through the auspices of the IEC. The IEC subcommittee, SC46D, is the international group which has been developing RF connector standards for the past twenty years. SC46D—Connectors for RF Cables—is a subcommittee of Technical Committee 46: Cables, Wires and Waveguides for Telecommunication Equipment. Dr. Walter Druey of Switzerland is the Chairman and Dr. Bruno Weinschel of the United States is the Secretary of SC46D. The IEC activities in the United States are sponsored through ANSI.

With a variety of connector designs to choose from, the primary objective of RF connector standardization is interchangeability. Requirements for precision and low reflector factors call for fairly close tolerances, but not all designs are suitable for precision and RF usage. Requirements in practice are such that standardization must cover a wide range of different connector types without introducing new designs.

International standards for all connectors that have been standardized by SC46D are contained in IEC Publication 169. Rigid precision coaxial lines and associated hermaphroditic connectors are dealt with separately in IEC Publication 457, which covers both 50- and 75-Ω characteristic impedances. Work is also almost complete on the standardization of crimping dies for crimping connectors to cables.

It is anticipated that the IEC RF Connector Standards will either supplant national and regional standards, or more likely, the national and regional standards will be brought into conformance with the IEC standards.

B. IEC Quality Assessment System

The IEC Quality Assessment System (IECQ System) for Electronic Components is a worldwide voluntary certification system for electronic components which began in Europe in 1966. With the objective to facilitate international trade in electronic components through certification by approved manufacturers that components meet recognized and approved specifications, the IEC in recent years has started to implement a quality assessment system for electronic components (IECQ System). The objective is achieved by a national organization in each certifying country that assures operation with integrity in accordance with internationally agreed upon rules. This organization includes: a National Supervising Inspectorate (NSI) which approves electronic component manufacturers and conducts follow-on surveillance and audits; a National Standards Organization (NSO) that manages specification development in the country; and a National Calibration Service. In the United States, the NSI is the Underwriter's Laboratories, the NSO is the Electronic Industries Association, and the National Calibration Service is the National Bureau of Standards and U.S. Calibration Laboratories. An approved manufacturer's component certified to IEC specifications will be accepted in any country participating in the IECQ System without additional or conformity testing. IEC standards will form the foundation for the IECQ System and, consequently, are of major significance. Working Group 4 of SC46D is presently addressing this problem for RF connectors.

C. Basic Elements of an IEC RF Connector Standard

An IEC connector standard generally defines mating face dimensions (to ensure functional coupling), grades, climatic ratings, gauges (to ascertain that the mating characteristics are within dimensional and force specifications), standard test connector mating face dimensions (test connectors are used to facilitate the measurement of reflection factor of the connector type), a schedule for type tests (including electrical, mechanical, and environmental), a survey of patterns (a description of popular configurations), and outline dimensions of popular configurations.

The grade of a connector is a qualification of the mechanical and electrical precision with respect to a defined reflection factor. IEC document 46D (Central Office) 84 defines the various grades as follows:

General-Purpose Connector: Grade 2

A connector which makes use of the widest permitted dimensional deviations (tolerances) with the intent that minimum stated performance and intermateability is still guaranteed.

Note: A requirement for the reflection factor may or may not be specified.

High-Performance Connector: Grade 1

A connector for which limits of reflection factor are specified as a function of frequency. The same dimensional tolerances that are used for Grade 2 are normally specified. The manufacturer is responsible, however, for choosing tighter tolerances when necessary to ensure that reflection factor requirements are met.

Standard Test Connector: Grade 0

A precisely made connector of a particular type that is used to carry out reflection factor measurements on Grade 1 and Grade 2 connectors, and contributes only negligible errors to the measurement result.

Note: The standard test connector is often part of an inter-type adapter (an adapter for use between two or more connectors of a different type) which allows connection with a precision connector forming part of the measurement equipment.

Precision Connector

A connector that has coincident mechanical and electrical reference planes, air dielectric, and has the property of making connections with a high degree of repeatability without introducing significant reflections, loss, or leakage. It is intended for mounting on airlines and instruments.

Laboratory Precision Connector (LPC)

A precision connector without a dielectric support for the center conductor.

General Precision Connector (GPC)

A precision connector with a self-contained dielectric support. The GPC must be capable of supporting the unsupported center conductor of an LPC and standard airline with which it is mated.

D. *IEC Publication 169-1*

Part 1 of IEC Publication 169 addresses general requirements and measuring methods which are applicable to all RF connector standards. SC46D is nearing the completion of a very extensive revision of this basic standard which establishes uniform concepts and procedures concerning terminology; standard ratings and characteristics; classification of connectors with regard to environmental testing procedures involving temperature, humidity, and vibration; and testing and measuring procedures concerning electrical and mechanical properties. The comprehensive list of tests and measurement procedures are:

Visual examination
Dimension
Gauge retention force
Mechanical compatibility
Insulation resistance
Sealing
Engagement and separation
Voltage proof
Vibration
Bump
Shock
Damp heat, steady state
Salt mist
Climatic sequence (hot/cold)
Contact resistance
Mechanical endurance
High temperature endurance
Screening effectiveness
Effect of cable pull, torsion, rotation, and bending
Strength of coupling mechanism
Bending moment
Soldering
Contact captivation
Discharge (corona)
Resistance to solvents and fluids
Reflection factor
Rapid temperature change
Sulphur-dioxide exposure
Power rating.

1) Reflection Factor: Reflection factor is one of the most widely used parameters to characterize the RF performance of connectors. Publication 169-1 contains a full section on Reflection Factor which was recently revised by Working Group 1 of SC46D. This revision contains both frequency-domain and time-domain measurement techniques. Examples of appropriate equipment for measuring the reflection factor as a function of frequency include bridges, reflectometers, and slotted lines. Measurement setups using these equipments give test methods in the text with and without special provisions for error recognition methods.

There are some computer-controlled automated measurement systems having enhancement routines with error correction models that reduce the measurement uncertainty in reflection factor to the point where further error recognition methods are not required.

A survey of the error recognition methods along with a description of other reflection factor measurement methods is presented in an article [10] that reviews the use of the Automated Network Analyzer, the Six-Port Measurement System, and Automated Time-Domain Reflectometry.

2) Screening Effectiveness: A measure of the screening effectiveness of RF coaxial connectors is the transfer impedance Z_t, which is the ratio of the transferred voltage inside the coaxial line (into which the connectors are inserted) to the longitudinal current flowing on the outside of the coaxial line. The evaluation of Z_t and thus the screening effectiveness is a relatively complex procedure. Working Group 3 of SC46D has spent considerable time in studying measurement methods dealing with screening effectiveness of RF connectors for inclusion in IEC Publication 169-1.

A frequency-domain method for determining the screening effectiveness was developed [11] by a member of WG 3 and approved by SC46D for inclusion in Publication 169-1. The endorsed method consists of a matched triaxial arrangement with a matched T-feed. This method is usable up to frequencies where higher order modes in the outer coaxial system will appear.

A time-domain method for characterizing the screening effectiveness of RF connectors is also under consideration and is based upon work by another member of WG 3. The measurement of Z_t in the time domain is carried out using a fast-rise-time pulse generator and a sensitive detector featuring an essentially flat response amplifier. This technique has application for RF connectors that are used at frequencies below 100 MHz.

3) Upper Frequency Limit of RF Connectors: The determination of the upper frequency limit of RF coaxial connectors is new work initiated in March 1984 by SC46D. A new Working Group 5 was set up by SC46D to prepare a standard to be issued separately or incorporated in Publication 169-1 on test methods and assembled references which permit the measurement of the upper frequency limit of a mated pair of coaxial connectors, e.g., the frequency at which the first higher mode (TE_{11}) is excited. Experimental methods to determine upper frequency limits will be investigated. A standard test method and typical frequency limits for popular connectors should result from this effort.

IV. IEC Connector Standards

A. Published IEC Standards[1]

As of September 1984, the following is a list of published IEC standards which relate to RF connectors:

169—Radio-Frequency Connectors

- 169-1 (1965) Part 1: General requirements and measuring methods.
- 169-2 (1965) Part 2: Coaxial unmatched connector. Amendment No. 1 (1982).
- 169-3 (1965) Part 3: Two-pin connector for twin balanced aerial feeders.
- 169-4 (1975) Part 4: RF coaxial connectors with inner diameter of outer conductor 16 mm (0.63 in) with screw lock—Characteristic impedance 50 Ω (Type 7/16).
- 169-5 (1970) Part 5: RF coaxial connectors for cables 96 IEC 50-17 and larger.
- 169-6 (1971) Part 6: RF coaxial connectors for cables 96 IEC 75-17 and larger.
- 169-7 (1975) Part 7: RF coaxial connectors with inner diameter of outer conductor 9.5 mm (0.374 in) with bayonet lock—Characteristic impedance 50 Ω (Type C).
- 169-8 (1978) Part 8: RF coaxial connectors with inner diameter of outer conductor 6.5 mm (0.256 in) with bayonet lock—Characteristic impedance 50 Ω (Type BNC).
- 169-9 (1978) Part 9: RF coaxial connectors with inner diameter of outer conductor 3 mm (0.12 in) with screw coupling—Characteristic impedance 50 Ω (Type SMC).
- 169-10 (1983) Part 10: RF coaxial connectors with inner diameter of outer conductor 3 mm (0.12 in) with snap-on coupling—Characteristic impedance 50 Ω (Type SMB).
- 169-11 (1977) Part 11: RF coaxial connectors with inner diameter of outer conductor 9.5 mm (0.375 in) with screw coupling—Characteristic impedance 50 Ω (Type 4.1/9.5).
- 169-12 (1979) Part 12: RF coaxial connectors with screw coupling, unmatched (Type UHF).
- 169-13 (1976) Part 13: RF coaxial connectors with inner diameter of outer conductor 5.6 mm (0.22 in)—Characteristic impedance 75 Ω (Type 1.6/5.6)—Characteristic impedance 50 Ω (Type 1.8/5.6) with similar mating dimensions.
- 169-14 (1977) Part 14: RF coaxial connectors with inner diameter of outer conductor 12 mm (0.472 in) with screw coupling—Characteristic impedance 75 Ω (Type 3.5/12).
- 169-15 (1979) Part 15: RF coaxial connectors with inner diameter of outer conductor 4.13 mm (0.163 in) with screw coupling—Characteristic impedance 50 Ω (Type SMA).
- 169-16 (1982) Part 16: RF coaxial connectors with inner diameter of outer conductor 7 mm (0.276 in) with screw coupling—Characteristic impedance 50 Ω (Type N).
- 169-17 (1980) Part 17: RF coaxial connectors with inner diameter of outer conductor 6.5 mm (0.256 in) with screw coupling—Characteristic impedance 50 Ω (Type TNC).

457—Rigid Precision Coaxial Lines and their Associated Precision Connectors

- 457-1 (1974) Part 1: General requirements and measuring methods.
- 457-2 (1974) Part 2: 50-Ω 7-mm rigid precision coaxial line and associated hermaphroditic precision coaxial connector.
- 457-3 (1980) Part 3: 14-mm rigid precision coaxial line and associated hermaphroditic precision coaxial connector—Characteristic impedances 50 and 75 Ω.
- 457-4 (1978) Part 4: 21-mm rigid precision coaxial line and associated hermaphroditic precision coaxial connector—Characteristic impedance 50 Ω (Type 9/21)—Characteristic impedance 75 Ω (Type 6/21).
- 457-5 (1984) Part 5: 50-Ω 3.5-mm rigid precision coaxial line with provision for mounting connectors.

[1]IEC standards are available from the International Sales Department, American Standards Institute, Inc., 1430 Broadway, New York, NY 10018, telephone (212) 354-3379.

B. IEC Standards Under Consideration

In February 1985, the following RF connectors and ancillary items were under consideration by the IEC:

- 3.5-mm precision pin and socket coaxial connectors—characteristic impedance 50 Ω.
- RF 2-pole bayonet coupled connectors for use with shielded balanced cables having twin inner conductors.
- Two types of RF connectors with inner diameter of outer conductor 9.5 mm (0.374 in) with different versions of screw coupling—characteristic impedance 50 Ω.
- RF coaxial connectors with inner diameter of outer conductor 2.79 mm (0.110 in) with screw coupling—characteristic impedance 50 Ω (Type SSMA).
- RF coaxial connectors with inner diameter of outer conductor 2.08 mm (0.082 in) with screw coupling—characteristic impedance 50 Ω (Type SSMB).
- RF coaxial connectors with inner diameter of outer conductor 2.08 mm (0.082 in) with snap-on coupling—characteristic impedance 50 Ω (Type SSMC).
- RF coaxial connectors with screw coupling, typically used in 75-Ω cabled distribution systems (Type F).
- RF 2-pole screw (0.750-20UNEF) coupled connectors for use with shielded balanced cables having twin inner conductors, inner diameter of outer conductor 13.56 mm (0.534 in).
- Determination of upper frequency limit of RF coaxial connectors.
- Recommended dimensions for hexagonal and square crimping-die cavities, indentors, gauges, outer conduc-

tor crimp sleeves, and center contact crimp barrels for RF cables and connectors.

- Power rating of RF connectors.
- Implementation of the IEC Quality Assessment System.

V. Concluding Remarks

Standardization tends to bring about compatibility between different kinds of equipment. SC46D is concerned with the formulation and standard procedures used in the measurement of RF connectors. These are important in that they often make possible (or impossible) the compatibility or saleability of electronic equipment. With the need for foreign markets more important than ever before, the U.S. National Committee needs the support from U.S. manufacturers in order that the U.S. point of view is represented in standards that may eventually be basic to product certification on the international market.

It should be pointed out that countries participating in IEC activities do so through their National Committees. Even though the U.S. National Committee is a part of ANSI, it still works closely with the IEEE, EIA, Underwriter's Laboratories (UL), and other groups. The U.S. National Committee, for example, depends on technical advisors to select technical experts from organizations such as manufacturers, national standards laboratories, and universities for participation in the IEC technical committees. These same technical experts may serve as delegates to express the U.S. point of view at technical committee meetings.

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Commercial Calibration Services

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Invited Paper

Many commercial calibration service companies now in business operate strictly by using procedures and calibration systems supplied by the instrument manufacturers. Some service companies may lack the technical depth and financial resources to contribute much more than business management and technician labor, concentrating on efficiency in turning out repaired and calibrated instruments. The accuracy and repeatability of today's newer instruments offers a challenge to these laboratories to innovate methods of calibration which can make the most of these instruments as automated standards. A thorough understanding of Measurement Assurance [1] concepts is necessary to appreciate these methods.

The Quality and Truth in Measurement [2] ideas advanced by the ANSI Z-1 Committee's Quality Standard for Calibration systems can also serve to improve the calibration laboratory's level of service. Forward looking commercial laboratories should participate in this activity, sharing with other laboratories sound ideas in the application of metrology fundamentals to improve the quality and accuracy of their own measurement and calibration operations.

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I. Introduction

Efficient economical calibration service can be part of the competitive edge for the Nation's designers and manufacturers seeking world-wide leadership.

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