



# Connector Reference list

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# Abstract

## **Connector reference list**

Metas provides this reference list for metrology people working in the RF & Microwave business, who are interested in any topic linked with coaxial connectors.

The motivation for this list is based on some planned research work dealing with the characterisation and modelling of connector imperfections.

Any feedback and information about additional coaxial connector papers and documents would be appreciated very much and will be added to this list.

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# Contents

<b>1</b>	<b>Reference documents</b>	<b>1</b>
1.1	Standard documents (specifications)	1
1.2	Standardization documents	2
1.3	Guideline documents	3
1.4	Reference documents	3
1.5	Connector maintenance	3
<b>2</b>	<b>Specific connector families</b>	<b>4</b>
2.1	Overview documents	4
2.2	7 mm precision	4
2.3	Type-N (50 ohm)	5
2.4	Type-N (75 ohm)	5
2.5	7/16	5
2.6	3.5 mm	5
2.7	SMA	5
2.8	2.92 mm (K connector)	6
2.9	2.4 mm	6
2.10	1.85 mm (V connector)	6
2.11	1.1 mm	6
2.12	1.0 mm (W connector)	6
2.13	Special connectors	6
<b>3</b>	<b>Connector imperfections</b>	<b>8</b>
3.1	General papers	8
3.2	Electrical influences	9
3.3	Passive Intermodulation	9
3.4	Connector repeatability	10
<b>4</b>	<b>Test Ports and Adaptors</b>	<b>11</b>
4.1	Imperfect test ports	11
4.2	Adaptors	11
<b>5</b>	<b>TDR and connector</b>	<b>13</b>
5.1	TDR measurements and connectors	13
<b>6</b>	<b>Web site connector links</b>	<b>14</b>
<b>7</b>	<b>ANAMET Publications</b>	<b>15</b>
7.1	ANAMET Presentations	15
7.2	ANAMET Reports	15
7.3	ANALyse Notes	15



7.4	ANAMET News articles.....	15
<b>8</b>	<b>Divers papers.....</b>	<b>17</b>



# 1 Reference documents

## 1.1 Standard documents (specifications)

- [1] IEC 457-2, "Rigid precision coaxial lines and their associated precision connectors, Part 2: 50 ohm 7 mm rigid precision coaxial line and associated hermaphroditic precision coaxial connector", First edition 1974
- [2] IEC 169-15, "Radio-frequency connectors - Part 15: R.F. coaxial connectors with inner diameter of outer conductor 4.13 mm (0.163 in) with screw coupling – Characteristic impedance 50 ohms (Type SMA)", First edition 1979
- [3] IEC 169-16, "Radio-frequency connectors - Part 16: R.F. coaxial connectors with inner diameter of outer conductor 7 mm (0.276 in) with screw coupling – Characteristic impedance 50 ohms (75 ohms) (Type-N)", First edition 1982
- [4] IEC 457-5, "Rigid precision coaxial lines and their associated precision connectors, Part 5: 50 ohm 3.5 mm rigid precision coaxial line with provision for mounting connectors", First edition 1984
- [5] IEC 169-1-1, "Radio-frequency connectors", First edition 1987
- [6] IEC 169-23, "Radio-frequency connectors - Part 23: Pin and socket connector for use with 3.5 mm rigid precision coaxial lines with inner diameter of outer conductor 3.5 mm (0.1378 in)", First edition 1991-11
- [7] IEC 169-23, "Radio-frequency connectors - Part 23: Pin and socket connector for use with 3.5 mm rigid precision coaxial lines with inner diameter of outer conductor 3.5 mm (0.1378 in)", First edition 1991-11
- [8] IEC 1141, "Upper frequency limit of r.f. coaxial connectors", First edition 1992-03 (new reference number: 61141:1992)
- [9] IEC 1169-1, "Radio frequency connectors Part 1: Generic specifications", First edition 1992-08 (new reference number: 61169-1:1992)
- [10] IEC 61169-31, "Radio frequency connectors - Part 31: RF coaxial with inner diameter of outer conductor 1,0 mm (0,039 in) with screw coupling - Characteristic impedance 50 ohms (type 1,0)", Ed. 1.0 b:1999
- [11] IEC 61169-32, "Radio-frequency connectors - Part 32: RF coaxial connectors with inner diameter of outer conductor 1,85 mm (0,072 in) with screw coupling - Characteristic impedance 50 ohms (type 1,85)", Ed. 1.0 b:1999



- [12] IEC 169-xx, "Radio frequency connectors – Part xx:  
Many more standard publications for different connector families available.  
(-> new reference number IEC 61169-xx)

## 1.2 Standardization documents

- [13] Weill, V. and Camillo, C. and Gumina, L., "A new philosophy of performance specification applied to coaxial connectors", IEEE Trans. IM-13, December 1964, pp 258-264
- [14] Fossum, D., "Progress report of the IEEE instrumentation and measurement group technical subcommittee on precision coaxial connectors", IEEE Trans. IM-13, December 1964, pp 285-291
- [15] IEEE G-IM subcommittee on precision coaxial connectors, "IEEE Standard for precision coaxial connectors", IEEE Trans. IM-17, September 1968, pp 204-218
- [16] IEEE G-IM subcommittee on precision coaxial connectors, "Precision coaxial connector coupling mechanisms, contact designs, and higher mode resonances", IEEE Trans. IM-17, September 1968, pp 219-222
- [17] IEEE Std 474-1973, "Specifications and test methods for fixed and variable attenuators, DC to 40 GHz", May 24 1973
- [18] IEEE Std 287-1979, "IEEE Standard for precision coaxial connectors", (Revision of the IEEE Std 287-1968), see next 2 documents:
- [19] IEEE P287/D2, "Draft Standard for Precision Coaxial Connectors (DC to 110 GHz), August 2001, see next document:
- [20] IEEE P287/D3, "Draft Standard for Precision Coaxial Connectors (DC to 110 GHz), July 2005, this document is at present under revision.  
-> *With an interesting Bibliography list!*
- [21] Sladek, N. and Jesch, R., "Standardization of coaxial connectors in the IEC", Proc. IEEE, Vol. 74, No. 1, January 1986, pp 14-18
- [22] Botka, J., (Hewlett Packard now Agilent), "United States Patent: Adjustable length slotless female contact for connectors", Patent Number 4,797,126, Jan. 10, 1989



## 1.3 Guideline documents

- [23] Skinner, A.D., “Guidance on using coaxial connectors in measurement”, Draft for comment, 1998. (Available for download, free, from [www.npl.co.uk/anamet](http://www.npl.co.uk/anamet))
- [24] Skinner, A.D., “ANAMET connector guide”, 2nd edition, May 2004. (Available for download, free, from [www.npl.co.uk/anamet](http://www.npl.co.uk/anamet))

## 1.4 Reference documents

- [25] Beatty, R., “Effects of connectors and adapters on accurate attenuation measurements at microwave frequencies”; IEEE Trans. IM-13, No. 4, December 1964, pp 272-284
- [26] Fantom, A., “Radio frequency & microwave power measurement. Chapter 13: Connectors and adapters”, IEE electrical measurement series 7, ISBN 0-86341-120-7, 1990 Peter Peregrinus Ltd., pp 203-218
- [27] Bachmair, H. and Stumper, U., “Aktuelle Probleme bei der Weitergabe von HF-Messgrößen”, Vorträge des 139. PTB-Seminars, PTB-E-58, Juni 1998, ISBN 3-89701-173-5, pp 72-74
- [28] Ridler, N., “Connectors, air lines and RF impedance”, IEE Microwave Measurements training course notes, e-peopleserve Training Centre, Milton Keynes, 13-17 May 2002. (Copies of these notes are available from Nick Ridler, NPL.)

## 1.5 Connector maintenance

- [29] Hewlett Packard (now Agilent), “Microwave connector care”, Manual Part No. 0851-90064, April 1986
- [30] Hewlett Packard (now Agilent), “Connector care for RF & microwave coaxial connectors”, Manual Part No. 0851-90064 Edition 2, 1991
- [31] Hjiipieris, G., “RF and Microwave connector care”, Technical information, Marconi Instruments publication No. 46889-505, 1997



## 2 Specific connector families

### 2.1 Overview documents

- [32] Anderson, T., "Evolution of precision coaxial connectors", Microwave Journal, Vol. 11, No. 1, Jan. 1968, pp18-28
- [33] Oldfield, W., "Comparing miniature coaxial connectors", Microwaves & RF, September 1985, pp 171-174
- [34] Wiltron (now Anritsu), "Miniature coaxial connectors: New standard in coaxial connectors pushes frequency limit up to 46 GHz with improved impedance match and reliability", P/N: 11200-00004 Rev: B, AN K100-1, May 1986
- [35] Manz, B., "Coaxial technology vies for emerging V-band applications", Microwaves & RF, Vol. 28, No 7, July 1989, pp 35-41
- [36] Kootz, T. and Peinelt, W. and Stumper, U., "Entwicklung von Impedanznormalen und kalibrierverfahren für Streuparametermessplätze in den Koaxialsystemen 3.5 mm, 2.92 mm und 2.4 mm", PTB-E-72, April 2001, ISBN 3-89701-694-X
- [37] Marconi Instruments, "Microwave Datamate", Marconi Instruments publication No. 46889-801B, Issue 2, May 1995, pp 10-12
- [38] SUHNER, "RF Connector Guide", 2. Edition 1997
- [39] M. Maury, "Microwave coaxial connector technology: a continuing evolution", Maury AN 5A-021, 13. Dec 2005

### 2.2 7 mm precision

- [40] Ridler, N. and Medley, J., "Improving the traceability of coaxial impedance measurements at lower RF in the UK", IEE Proc.-Sci. Meas. Technol., Vol. 143, No. 4, July 1996
- [41] Ide, J., "International comparison GT-RF/83-4: measurement of scattering coefficients over the band 2 - 18 GHz", NPL Report CEM 15, July 1999





## 2.3 Type-N (50 ohm)

## 2.4 Type-N (75 ohm)

## 2.5 7/16

- [42] Szendrenyi, B., "Design of components for 7-16 precision calibration kit using the High Frequency Structure Simulator", 52nd ARFTG conference digest, December 1998, pp 101-105

## 2.6 3.5 mm

- [43] Adam, S. and Kirkpatrick, G. and Sladek, N. and Bruno, S., "A high performance 3.5 mm connector to 34 GHz", Microwave Journal, Vol. 19, No. 7, July 1976, pp 50-54
- [44] Adam, S. and Kirkpatrick, G. and Sladek, N. and Bruno, S., "A new 34-GHz 3.5-mm low-cost utility coaxial connector featuring low leakage, low standing-wave ratio, and long life", IEEE Trans., MTT-24, No. 12, December 1976, pp 995-997
- [45] Kirkpatrick, G. and Pratt, R. and Chambers, D., "Coaxial components and accessories for broadband operation to 26.5 GHz", HP Journal, 28, 10, June 1977, pp 10-16

## 2.7 SMA

- [46] Wiltron (now Anritsu), "Connector relieves nagging SMA measurement problems", Microwaves, January 1979, pp 97-99
- [47] Maury, M., "Improving SMA Tests with APC-3.5 hardware", Microwaves, Vol 20, No. 9, Sept. 1981, pp 71-76
- [48] Daw, E., "Improve accuracy of vector measurements for SMA components", Microwaves & RF, August 1988



## 2.8 2.92 mm (K connector)

- [49] Browne, J., "Precision coaxial cables and connectors reach 45 GHz", *Microwaves & RF*, Vol. 22, No. 9, Sept. 1983, pp 131-136

## 2.9 2.4 mm

- [50] Browne, J., "Team effort yields 50-GHz connectors", *Microwaves & RF*, Vol. 25, No. 4, April 1985, pp 131
- [51] Kachigan, K., "The 2.4mm Coaxial Connector - Its Design and Development Using the HP8510", 28<sup>th</sup> ARFTG conference digest, December 1986, pp 109-117
- [52] Rufenacht, J. and Zeier, M., "Comparison of scattering parameter measurements in the coaxial 2.4 mm line system", EUROMET.EM.RF-S16 Final Report, November 2004. (Available for download free, from <http://kcdb.bipm.org>)

## 2.10 1.85 mm (V connector)

## 2.11 1.1 mm

## 2.12 1.0 mm (W connector)

- [53] Howell, K. and Wong, K., "DC to 110 GHz measurements in coax using the 1 mm connector", *Microwave Journal*, Vol. 42, No. 7, July 1999, pp 22-34

## 2.13 Special connectors

- [54] Morelli, J. and Pitcher, W., "Blind-mating connectors cure modular systems woes", *Microwaves & RF*, Vol. 22, No. 4, April 1983, pp 121-128



- [55] Rohde&Schwarz, “Interchangeable Port Connector Systems, Test Port Adapter System”, Application Note, 1MA100\_1e, 04.2006



## 3 Connector imperfections

### 3.1 General papers

- [56] Soderman, R., "Application of precision connectors to high-frequency measurements", IEEE Trans. IM-16, No. 1, March 1967, pp 62-68
- [57] Neubauer, H. and Huber, F., "Higher modes in coaxial RF lines", Microwave Journal, Vol. 12, No. 6, June 1969, pp 57-66
- [58] Jurkus, A., "Computation of step discontinuities in coaxial line", IEEE Trans. Microwave Theory Tech., October 1972, pp 708-709
- [59] Estin, A., "Scattering parameters of SMA coaxial connector pairs", IEEE Trans. IM-25, No. 4, December 1976, pp 329-334
- [60] Botka, J., "A rugged slotless female contact for pin-socket type connectors, such as type N and 3.5 mm", IEEE MTT-S symposium, connector workshop, May 1984
- [61] Botka, J., "Critical considerations and recommended connection techniques of precision RF connectors", HP Palo Alto (now Agilent), Calibration laboratory and metrology seminar, July 1984
- [62] Oldfield, W., "Reflection residuals of coaxial connectors", 26<sup>th</sup> ARFTG conference digest, December 1985, pp 165-168
- [63] Simpson, G., "Mechanical characterisation of calibration standards for improved accuracy", 28<sup>th</sup> ARFTG conference digest, December 1986, pp 17-38
- [64] Botka, J., "Major improvement in measurement accuracy using precision slotless connectors", Microwave Journal, Vol. 31, No. 3, March 1988, pp 221-226
- [65] Fuks, R., "Assessing distortion at microwave interface junctions", Microwaves & RF, August 1997, pp 108-116
- [66] Szendrenyi, B., "Effects of pin depth in LCP 3.5 mm, 2.4 mm, and 1.0 mm connectors", Microwave Symposium Digest., 2000 IEEE MTT-S International ,Vol. 3 , 11-16 June 2000, pp 1859-1862
- [67] Juroshek, J., "RF connectors and transmission lines", ARFTG-NIST short course on RF measurements for a wire less world, November 2001, San Diego
- [68] Sladek, N., "Fundamental considerations in the design and application of high precision coaxial connectors" IRE International Convention Record Volume 13, Part 5, Mar 1965 Page(s):182 – 189



- [69] Kossel, M. and Leuchtmann, P. and Ruefenacht, J., "Traceable correction method for complex reflection coefficient using calculable air line impedance standards" *Instrumentation and Measurement, IEEE Transactions on* Volume 53, Issue 2, April 2004 Page(s):398 – 405
- [70] Shafii, J. and Vernon, R.J., "Mode coupling in coaxial waveguides with varying-radius center and outer conductors" *Microwave Theory and Techniques, IEEE Transactions on* Volume 43, Issue 3, March 1995 Page(s):582 – 591
- [71] Sanderson, A.E., "A New High-Precision Method for the Measurement of the VSWR of Coaxial Connectors" *Microwave Theory and Techniques, IEEE Transactions on* Volume 9, Issue 6, Nov 1961 Page(s):524 – 528

## 3.2 Electrical influences

- [72] Sorger, G., "Coaxial swept-frequency VSWR measurements using slotted lines", *IEEE Trans. IM-17*, No. 4, December 1968, pp 403-412
- [73] Engen, G., "In Search of a More Realistic Accuracy Statement for Microwave Metrology", 27<sup>th</sup> ARFTG conference digest, June 1986, pp 181-183
- [74] Daywitt, W., "A simple technique for investigating defects in coaxial connectors", *IEEE Trans., MTT-35*, No. 4, April 1987, pp 460-464
- [75] Dunsmore, J., "Modeling precision connectors with a high frequency structure simulator", 37<sup>th</sup> ARFTG conference digest, June 1991, pp 26-34
- [76] Oldfield, W., "Characterizing Blind Mate Connectors", 40<sup>th</sup> ARFTG conference digest, December 1992, pp 144-156
- [77] Watson, P., "Slotted contact study", for IEEE P287 connector committee", P 287 01-1993
- [78] Juroshek, J., "Measurements of Type-N, slotted and slotless center contacts for IEEE P287 connector committee", P 287 03-1993

## 3.3 Passive Intermodulation

- [79] Rosenberger, B., "The Measurement of Intermodulation Products on Passive Components and Transmission Lines", 50<sup>th</sup> ARFTG conference digest, December 1997, pp 13-22



## 3.4 Connector repeatability

- [80] Bergfried, D. and Fischer, H., "Insertion-loss repeatability versus life of some coaxial connectors", IEEE Trans. IM-19, November 1970, pp 349-353
- [81] Jesch, R., "Repeatability of SMA coaxial connectors", IEEE Trans. IM-25, No. 4, December 1976, pp 329-334
- [82] Warner, F., "Microwave attenuation measurement", IEE monograph series 19, ISBN 0-901223-79-4, First published 1977, Peter Peregrinus Ltd., pp 100
- [83] Juroshek, J., "A study of measurements of connector repeatability using highly reflecting loads", IEEE Trans., MTT-35, No. 4, April 1987, pp 457-460
- [84] Wong, K., "Using precision coaxial air dielectric transmission lines as calibration and verification standards", Microwave Journal, December 1988, pp 83-92
- [85] Young, P.R., "Analysing connector repeatability or microwave vector measurements", IEE Colloq. Dig., 1999, 019, 8/1-5
- [86] Furrer, J., "Die Tücke steckt im Stecker", Fachartikel Hochfrequenz-Metrologie, metINFO, Vol. 10, No. 1, 2003, pp 10-15



## 4 Test Ports and Adaptors

### 4.1 Imperfect test ports

- [87] Hodgetts, T., "The calculation of the equivalent circuits of coaxial-line step discontinuities", Royal signals & radar establishment (RSRE) memorandum No. 3422, 1981
- [88] Oldfield, W., "Improved S11 calibration for network analyzers", 28<sup>th</sup> ARFTG conference digest, December 1986, pp 1-16
- [89] Pervere, M., "Advances in vector error corrections", 29<sup>th</sup> ARFTG conference digest, June 1987, pp 113-129
- [90] Hoer, C., "Some questions and answers concerning air lines as impedance standards", 29<sup>th</sup> ARFTG conference digest, June 1987, pp 161-171
- [91] Daywitt, W., "Complex Admittance of Lossy Coaxial Open Circuit with a hollow center conductor", Metrologia 24, 1987, pp 13-22
- [92] Juroshek, J. and Hoer, C., "Calibrating network analyzers with imperfect test ports", IEEE Trans., IM-38, No. 4, Aug. 1989, pp 898-901
- [93] Oldfield, W., "The connector interface and its effect on calibration accuracy", Microwave Journal, March 1996, pp 106-114
- [94] Agilent, "Mind the Gap!", Metrology forum: technical article, (connector recession effect: on the Agilent site at <http://metrologyforum.tm.agilent.com/recess.shtml>)
- [95] Rodriguez, M., "Modelling the effect of port recessions on VNA one-port calibrations", IEE Proc.-Sci. Meas. Technol., Vol. 149, No. 6, November 2002, pp 339-344
- [96] Kwan, G., "On the modelling of test ports in microwave vector network analyzer calibrations", NCSL International 2003 Tampa, FL

### 4.2 Adaptors

- [97] Beatty, R., "Effects of connectors and adapters on accurate attenuation measurements at microwave frequencies", IEEE Trans. IM-13, December 1964, pp 272-284



- [98] “Measuring noninsertable devices”, HP product note 8510-13 (now Agilent)
- [99] Coerver, L., “Locating Reflections with the Reference Plane Extension on an Automatic Network Analyzer”, 19<sup>th</sup> ARFTG conference digest, June 1982, pp 59-76
- [100] Couper, W., “Separation of Reflections for VSWR Measurements”, 26<sup>th</sup> ARFTG conference digest, December 1985, pp 18-31
- [101] Billings, R., “An Automated Frequency Domain Scalar Network Analyzer Technique for the Separation of Small Reflections”, 28<sup>th</sup> ARFTG conference digest, December 1986, pp 118-129
- [102] Agilent, “Use of adapters in network analysis!”, Metrology forum: technical article, (on the Agilent site at <http://metrologyforum.tm.agilent.com/adapter.shtml>)
- [103] Olney, D., “The effect of adapters on vector network analyzer calibrations”, Microwave Journal, Nov. 1994, pp 60-72
- [104] Sunchana, P. and Daywitt, W., “Single-Port Technique for Adapter Efficiency Evaluation”, 45<sup>th</sup> ARFTG conference digest, May 1995, pp 113-118





## 5 TDR and connector

### 5.1 TDR measurements and connectors

- [105] Sletten, R., "Microwave Connector Analysis Using Time Domain Circuit Modeling", 27<sup>th</sup> ARFTG conference digest, June 1986, pp 100-111
- [106] Oldfield, W., "VNA S11 uncertainty measurement a comparison of three techniques", 39<sup>th</sup> ARFTG conference digest, June 1992, pp 86-105



## 6 Web site connector links

- [107] AGILENT PNA – Millimeter – Wave Connector Care :  
[http://www.home.agilent.com/cgi-bin/pub/agilent/editorial/cp\\_MiscEditorial.jsp?NAV\\_ID=-536897567.536880718.02&LANGUAGE\\_CODE=ger&CONTENT\\_KEY=751488&ID=751488&COUNTRY\\_CODE=DE](http://www.home.agilent.com/cgi-bin/pub/agilent/editorial/cp_MiscEditorial.jsp?NAV_ID=-536897567.536880718.02&LANGUAGE_CODE=ger&CONTENT_KEY=751488&ID=751488&COUNTRY_CODE=DE)
- [108] <http://ece-www.colorado.edu/~kuester/Coax/connchart.htm>
- [109] <http://www.eng.dmu.ac.uk/aeg/people.html>
- [110] [http://www.tkk.fi/Misc/Electronics/wire\\_general.html](http://www.tkk.fi/Misc/Electronics/wire_general.html)



## 7 ANAMET Publications

UNDER CONSTRUCTION !

### 7.1 ANAMET Presentations

### 7.2 ANAMET Reports

### 7.3 ANALyse Notes

### 7.4 ANAMET News articles

Instone, I., "The effects of port recession on ANA accuracy", ANAMET News, Issue 11, Autumn 1998, pp 4-6.  
(on the Agilent site at <http://metrologyforum.tm.agilent.com/recess.shtml>)

Ridler, N. and Woolliams, P. D.,  
[Tips on using coaxial connector torque spanners.](#)  
ANA Tips No 2, January 2000,

Ridler, N. and Smith, A. J.,  
[Gauge compatibility for the smaller coaxial line sizes.](#)  
ANA Tips No 1, October 1999,

Ridler, N. and Medley, J.,  
[Live dial gauge comparison exercise: ANAMET-963.](#)  
ANAMET Report 007, May 1997,

Medley, J. and Ridler, N.,  
[ANAMET 962 dial gauge comparison exercise.](#)  
ANAMET Report 001, July 1996,

Ridler, N.,  
[How much variation should we expect from coaxial connector dial gauge measurements.](#)  
ANALyse Note No 14, February 1996,



Furrer, J., “ Type-N and APC-7 connector reproducibility: experiences during power sensor calibrations”, 17<sup>th</sup> ANAMET meeting, January 2002

J Miall, K Lees, “Modelling the repeatability of type-N connectors using Microwave Studio”, 19<sup>th</sup> meeting of ANAMET, Presentation, January 2003

Ruefenacht, J., “Connector problems and their mechanical and electrical characterisation“, 24<sup>th</sup> ANAMET meeting, September 2005



## 8 Divers papers

UNDER CONSTRUCTION !

Ide, J P

[International comparison GT-RF/83-4: measurements of scattering coefficients over the band 2-18GHz.](#)

CEM 15, July 1999

Ide, J. P., "Estimating the electrical compatibility of mechanically compatible connectors",  
Microw. Eng. Eur., 1994, 43, (Aug/Sept), 39 – 40

Young, P. R., "Analysing connector repeatability on microwave vector measurements",  
IEE Colloq. Dig., 1999, 019, 8/1-5