

ANAMET Report 046

August 2004

**28, 75 and 100 Ohm Impedance Air
Line Standards**

B Williams and S Harter

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NMS Contract GBBK/C/2/31

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30 January 2004

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Abstract / Executive Summary

This report describes the activities associated with NMS contract GBBK/2/40C ~ 75 Standards (Maintenance). The ITT called for “28, 75 and 100 ohm coaxial line sizes, reference impedance’s for each of these are required in 7mm line size”. In response, QinetiQ Metrology (later to become ASAP Calibration Services Ltd) put in the successful bid that pointed out that its facility at SESC Aquila had already produced a National Standard Measurement system, which included 75Ω reference air lines in 7mm N. The proposal was to extend this approach to include 28Ω and 100Ω, in 7mm N configuration, together with appropriate adapters.

These designs were completed and negotiations initiated with the preferred manufacturer regarding price and delivery.

However, some additional background research, into ‘chip to chip interconnects’, suggested that the above design was not quite in line with the original industry input to the programme formulation.

The difference, in requirement, hinged on the ‘end’ connector of these reference air lines. In the original proposal these would be 7mm N (with characteristic impedance of 28, 75 and 100Ω), whereas literature searches suggested that the ‘Interconnect’ industry would prefer 7mm APC7 (50Ω) connectors but with a defined section of line in-between these connectors of characteristic impedance 28, 50, 75 or 100Ω. This allows the air lines to be conveniently connected to the popular TDR systems used in PCB testing. These systems are specified in recent USA Industry Standards, including IPC-TM-650 [2]. The equivalent European Document, IEC-61189-3.[3] 1999, has the method “Under consideration”.

In view of the above information a report was produced [5] that recommended use of a **suitable** standard in order for it to be of practical use for Industry. The Maury Microwave set of six high precision special impedance Air Lines, model 2603Q, were selected for this task.

Measurement of the impedance section of each of the air lines traceable to national standards has been achieved through mechanical measurements. Measurements were provided by ASAP Calibration Services on UKAS certificates. The reported measurement uncertainty of all measurements was $\pm 0.001\text{mm}$, a two-fold improvement on the contract requirement.

Measurements confirmed that the new set of air lines supplied by Maury Microwave meet the manufacturers specification of ± 0.1 ohm. A calibration service has been established to provide measurement of the air line impedance traceable to national standards.

When using air lines to verify the accuracy of time domain measurement techniques consideration should be given to the cut-off frequency of the air line. The estimated cut-off frequency of each air line has been calculated and presented.

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1 Introduction

1.1 Original 'bid' and air line design

This report describes the activities associated with NMS contract GBBK/2/40C ~ 75 Standards (Maintenance). The ITT called for "28, 75 and 100 ohm coaxial line sizes, reference impedance's for each of these are required in 7mm line size". In response, QinetiQ Metrology (later to become ASAP Calibration Services Ltd) put in the successful bid that pointed out that SESC had already produced a National Standard Measurement system, which included 75Ω reference air lines in 7mm N. The proposal was to extend this approach to include 28Ω and 100Ω, in 7mm N configuration, together with appropriate adapters.

These designs were completed and negotiations in progress with the preferred manufacturer regarding price and delivery.

The difference, in requirement, hinges on the 'end' connector of these reference air lines. In the original proposal these would be 7mm N (with characteristic impedance of 28, 75 and 100Ω), whereas literature searches now suggest that the 'Interconnect' industry would prefer 7mm APC7 (50Ω) connectors but with a defined section of line in-between these connectors of characteristic impedance 28, 50, 75 or 100Ω. This allows the air lines to be conveniently connected to the popular TDR systems used in PCB testing.

In view of the above information a report was produced [5] that recommended use of a **suitable** standard in order for it to be of practical use for Industry. The Maury Microwave set of six high precision special impedance Air Lines, model 2603Q, were selected for this task.

1.2 Interpretation of '7mm' with respect to connectors

The ITT quoted above does not refer to any particular connector system, it merely states 7mm line size. It is a trivial point but, to many microwave engineers this would imply a whole range of possible connectors such as APC7, N. BNC, TNC or even precifix! To others, particularly in the United States of America, the bald statement, 7mm, means APC7 exclusively. Any other connector would have to be mentioned specifically by name. This has lead to misunderstandings in the past when ordering from US companies.

2 The demands of Industry

2.1 Background

The high demands from the Internet and high-performance computer products have been driving the need for more bandwidth. As chip technology has crossed the 1GHz boundary, the bottleneck in system design has become the rate at which data can be transferred between chips. This also applies to a whole range of digital consumer products including televisions, camcorders, DVD's, games etc. In support of these products enormous measurement effort is expended on testing PCBs for a wide range of parameters both for product engineering and manufacturing control.

In order to meet these needs for rapid signal transfer the tracks on the PCB have to be treated as transmission lines and the characteristic impedance optimised to match the load impedance presented by the various components/chips. These impedance's vary according to application but 28Ω and $40 - 56\Omega$ are widely used and originated from Rambus Inc. The $85 - 100\Omega$ is another popular range. All these values in combination can and do appear on any one PCB!

The preferred method for the measurement of the characteristic impedance of the 'strip lines' formed on PCB's is with a 'Controlled Impedance Test System' or CITS, which is in fact a Time Domain Reflectometer, TDR. At one end of the scale this may be a relatively simple pulse driven TDR instrument and at the other end a sophisticated gated ANA. However, the one thing they have in common is that they operate in 7mm, APC7, 50Ω line sizes!

It follows therefore that impedance standards in the range 28Ω to 100Ω , with 7mm APC7 (50Ω) connectors, would be necessary to calibrate these measurement systems.

Intel and Rambus Inc. have both published Test Methods for checking these TDR systems with 28Ω and 50Ω air line standards. The Institute for Interconnecting and Packaging Electronic Circuits has published a standard test method IPC-TM-650, [2], which recommends the use of the Maury 2603D (10cm 7mm APC7) air line as a standard and suggests that similar artefacts at $<30\Omega$ and $>85\Omega$ would improve accuracy. These can be used to check the impedance linearity of the system or used, at the time of the PCB measurement for direct comparison. Some of the manufacturer's method sheets suggest that minimum air line length should be from 15cm to 30cm.

Polar Instruments (USA) manufacture an automated test system, RITS 520A, that can perform rapid printed circuit board impedance measurements. The system is calibrated in terms of 7mm APC7, 30cm lines, with internal characteristic impedance's of 28, 50, 75 and 100Ω . Here, the coaxial connectors at either end of the air line are standard 50Ω 7mm APC7 types. However, in between these connectors there is a defined length that has characteristic impedance of 28, 50, 75, or 100Ω . It is stated the lines are traceable to NIST. These standards appear to be identical to the Maury Microwave 2603Q series featured in this report.

In Europe the equivalent standard document concerning PCB testing is IEC61189-3 [3]. However, although published in 1999 the document states that impedance test methods are "under consideration" and refers to IEC326-2/ BS 6221 part 2 [4], circa 1990 which has essentially the same message.

3 Maury Microwave High Precision Special Impedance Air Lines

As a solution to the NMSPU project specification a set of the Maury Microwave 2603Q series of reference air lines with APC7 7mm connectors were purchased. A manufacturers data sheet is provided in Appendix B. On receipt of these standards dimensional measurements were performed to determine the impedance characteristics traceable to UK national standards. No adapter characterisations are required to establish air line traceability.



Figure 1 Dismantled 100Ω 20cm Air Line shown with an assembled line.

3.1 Air Line disassembly in preparation for dimensional measurements

On receipt of the air lines the first task was to dismantle each air line in preparation for mechanical measurements. A dismantled 100Ω 20 cm line is shown in Figure 1, note the fragile centre conductor in the centre of the picture. The dismantling procedure should be conducted using standard GPC7 connector tools. The 30cm 75Ω and 100Ω air lines both have a dielectric support at the centre position of the line, as shown in the foreground of Figure 2. Removal of these centres is the most challenging operation of the dismantling procedure. A complete 30cm section is shown in the foreground of Figure 3.

In Figure 3 the 50Ω GPC7 connector centre section of each of the centre conductors can clearly be seen.

28, 75 and 100 ohm Impedance Air Line Standards

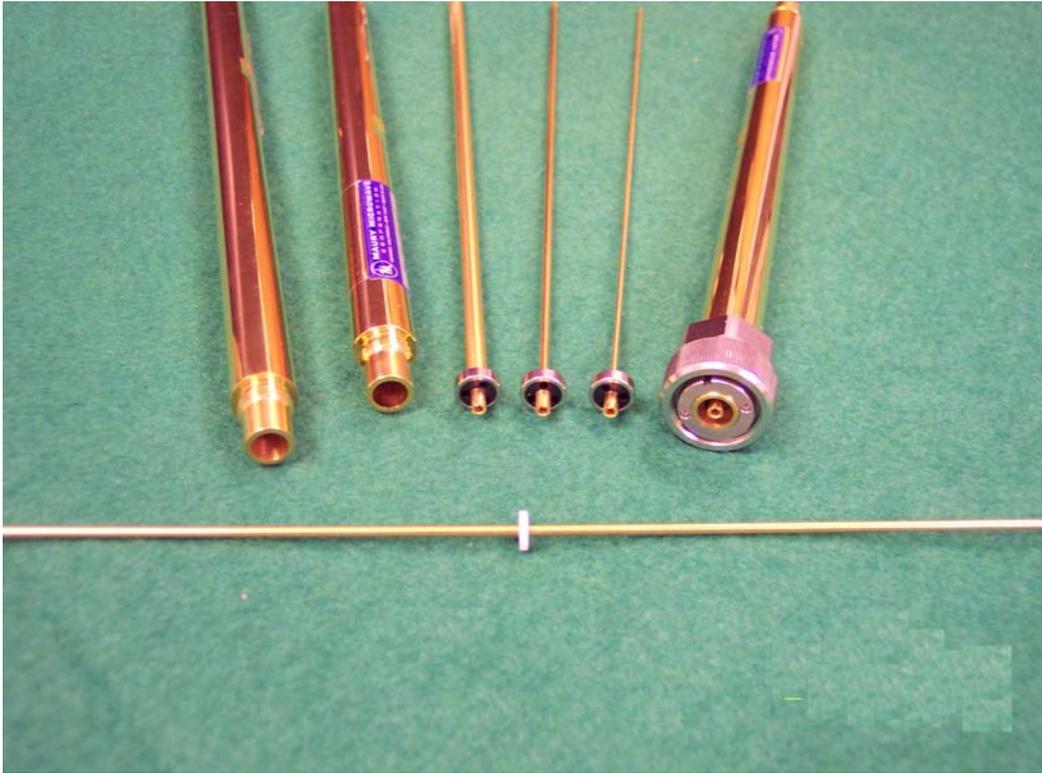


Figure 2 Dismantled 20cm Air Lines



Figure 3 Dismantled Air Lines including the 30cm 100Ω model in the foreground

3.2 Dimensional Measurements performed on each air line

3.2.1 Measurement of the bore diameter (A) of the outer conductor.

Two measurements (M) taken, single measurements at a nominal distance of 10mm from each end as shown in Figure 4. Each measurement is derived from a minimum sample of five with the bore rotated between each sample.

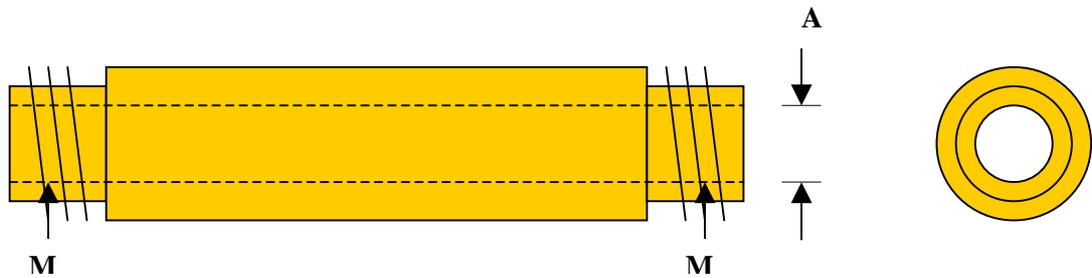


Figure 4 Diagram of Air Line Outer Conductor measurement points (not to scale)

3.2.2 Measurement of the shaft diameter (B) of the inner conductor.

Three measurements taken, one measurement at the centre of the shaft and the remainder measurements at a nominal distance of 10mm from each end, as shown in Figure 5. Each measurement is derived from a minimum sample of five with the centre rotated between each sample.

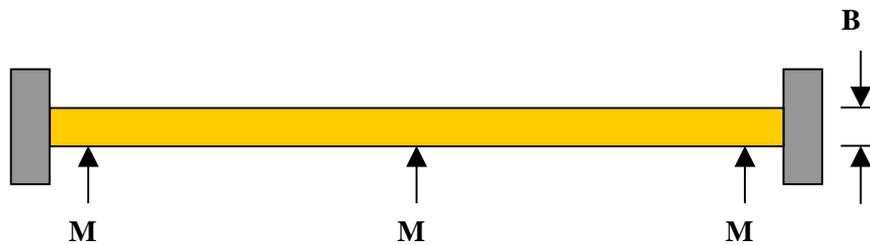


Figure 5 Diagram of Air Line Inner Conductor measurement points (not to scale)

3.3 Dimensional Traceability

Copies of calibration certificates for the following Maury Microwave 2603Q items are provided in Appendix A :

Type Number	Description	Serial No
2603Q28	20cm (7.884 inch) Airline	A268
2603Q28A	30cm (11.799 inch) Airline	A189
2603Q75	20cm (7.884 inch) Airline	A079
2603Q75A	30cm (11.799 inch) Airline	A269
2603Q100	20cm (7.884 inch) Airline	A270
2603Q100A	30cm (11.799 inch) Airline	A267

4 Results

4.1 Air Line Measurement Results

The following tables display the measurement results for the air lines obtained from the calibration certificates provided in Appendix A. Calculated values of air line impedance use the manufacturers relationship Equation 1 obtained from the data sheet provided in Appendix B:

$$Z = 59.939 \ln\left(\frac{D}{d}\right)$$

Equation 1

where:

D is the Outer Conductor Diameter (mm)

d is the Centre Conductor Diameter (mm)

The Outer conductor ‘measurement 2’ is an average of measurement 1 and 3 and are presented in *italics*.

	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	7.0040	<i>7.0046</i>	7.0053
Inner Conductor	mm	4.3877	4.3876	4.3878
Impedance Z	Ω	28.032	28.039	28.041
Impedance Error	Ω	+0.032	+0.039	+0.041

Table 1 28 Ohm air line 20cm

	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	6.9996	<i>7.0001</i>	7.0007
Inner Conductor	mm	4.3884	4.3884	4.3884
Impedance Z	Ω	27.984	27.989	27.994
Impedance Error	Ω	-0.016	-0.011	-0.006

Table 2 28 Ohm air line 30cm

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	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	7.0007	7.0007	7.0007
Inner Conductor	mm	2.0060	2.0078	2.0078
Impedance Z	Ω	74.915	74.862	74.862
Impedance Error	Ω	-0.085	-0.138	-0.138

Table 3 75 Ohm air line 20cm

	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	6.9990	6.9990	6.9990
Inner Conductor	mm	2.0077	2.0077	2.0081
Impedance Z	Ω	74.850	74.850	74.838
Impedance Error	Ω	-0.150	-0.150	-0.162

Table 4 75 Ohm air line 30cm

	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	6.9993	7.0000	7.0003
Inner Conductor	mm	1.3220	1.3219	1.3221
Impedance Z	Ω	99.898	99.909	99.902
Impedance Error	Ω	-0.102	-0.091	-0.098

Table 5 100 Ohm air line 20cm

	Units.	Measurement 1	Measurement 2	Measurement 3
Outer Conductor	mm	6.9991	7.0005	7.0020
Inner Conductor	mm	1.3205	1.3204	1.3195
Impedance Z	Ω	99.964	99.981	100.034
Impedance Error	Ω	-0.036	-0.019	+0.034

Table 6 100 Ohm air line 30cm

4.2 Measurement Uncertainty

The Measurement uncertainty of air line impedance is a direct conversion from the stated uncertainty on the mechanical measurement calibration certificates. Each impedance measurement is comprised of two mechanical measurements of $\pm 0.001\text{mm}$. The spread of the total contribution is applied to the measured mechanical values to obtain the total impedance measurement uncertainty contribution using Equation 1. Values are tabulated below in Table 7:

Description	Impedance Uncertainty
	$\pm \Omega$
28 Ω Airlines	0.022
75 Ω Airlines	0.038
100 Ω Airlines	0.054

Table 7 Measurement uncertainty of Air Line Impedance measurements to 95% confidence.

4.3 Results analysis

It would appear from Table 4 that the 75 Ohm 30cm airline is out of specification, taking into account the combined manufacturers specification of $\pm 0.1\Omega$ and the estimated measurement uncertainty. However, using an alternative air line impedance calculation [1], the air line is clearly within specification as shown in Chart 4. These calculations against frequency are described in the following section.

5 Air-Line Characteristic Impedance against frequency Calculations

This section describes the calculations for the variation in air line characteristic impedance with frequency. Calculations assume that the air lines are made of copper and gold plated.

As an example, Table 8 shows the characteristic impedance spreadsheet of a 100 Ohm Air Line utilising Daywitt [1].

The charts 1 to 6 show the characteristic impedance variation with frequency, calculated using the spreadsheet. Individual plots show:

- Calculated characteristic impedance from the measured values. Error bars are supplied on one of the characteristics to represent the estimated measurement uncertainty.
- A theoretical / ideal plot of the air line characteristic impedance. (Blue line)
- The spread of values that would be experienced through perturbations of the air line dimensions with a tolerance of $\pm 0.002\text{mm}$. These values are calculated using the spreadsheet of Table 8 incorporating the dimensional changes.

5.1 The Theory

The four line elements R , L , C and G have been derived by Daywitt [1] and expressed as follows:

$$R = 2\omega L_o d_o \left(1 - \frac{k^2 a^2 F_o}{2} \right)$$

Equation 2

$$G = \omega C_o d_o k^2 a^2 F_o$$

Equation 3

$$C = C_o (1 + d_o k^2 a^2 F_o)$$

Equation 4

where:

$$L_o = \frac{\mu \ln(b/a)}{2\pi}$$

Equation 5

$$C_o = \frac{2\pi\epsilon}{\ln(b/a)}$$

Equation 6

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$a = 0.002194 \times 10^{-3} \text{ m}$	28 Ohm Inner conductor outer radius
$a = 0.00066 \times 10^{-3} \text{ m}$	100 Ohm Inner conductor outer radius
$a = 0.0035 \times 10^{-3} \text{ m}$	28 Ohm Outer conductor inner radius
$a = 0.0035 \times 10^{-3} \text{ m}$	100 Ohm Outer conductor inner radius
$\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$	for pure copper at 296.2K

From general theory the four coaxial line elements R , L , G and C can be used to obtain the line propagation constant γ and the characteristic impedance Z as follows:

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

Equation 14

$$Z = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$$

Equation 15

28, 75 and 100 ohm Impedance Air Line Standards

Freq. (GHz)	0.1	0.5	1	4	10	18	23	26
<i>a</i>	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066
<i>b</i>	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
<i>F_o</i>	3.573663							
<i>k</i>	2.096525	10.48263	20.96525	83.861	209.6525	377.3745	482.2008	545.0965
<i>d_o</i>	0.001718	0.000768	0.000543	0.000272	0.000172	0.000128	0.000113	0.000107
<i>L_o</i>	3.34E-07							
<i>C_o</i>	3.34E-11							
R	0.720344	1.610606	2.277156	4.530932	6.957022	8.593202	8.947475	8.928986
L	3.35E-07	3.34E-07						
G	2.46E-10	1.38E-08	7.79E-08	2.49E-06	2.46E-05	0.000107	0.000198	0.000269
C	3.34E-11							
<i>α</i>	0.003596	0.008048	0.011384	0.022774	0.036014	0.048321	0.054623	0.058077
<i>β</i>	2.100127	10.49068	20.97664	83.88378	209.6885	377.4228	482.2554	545.1546
<i>ω</i>	6.28E+08	3.14E+09	6.28E+09	2.51E+10	6.28E+10	1.13E+11	1.45E+11	1.63E+11
Z Re	100.1668	100.0718	100.0493	100.0219	100.011	100.005	100.0022	100.0007
Z Im	-0.1715	-0.07676	-0.05426	-0.02686	-0.016	-0.00996	-0.00723	-0.00573
Z mag	100.167	100.0719	100.0493	100.0219	100.011	100.005	100.0022	100.0007

Table 8 Spreadsheet derivation of Z for 100 Ohm Air Line using Daywitt [1]

28, 75 and 100 ohm Impedance Air Line Standards

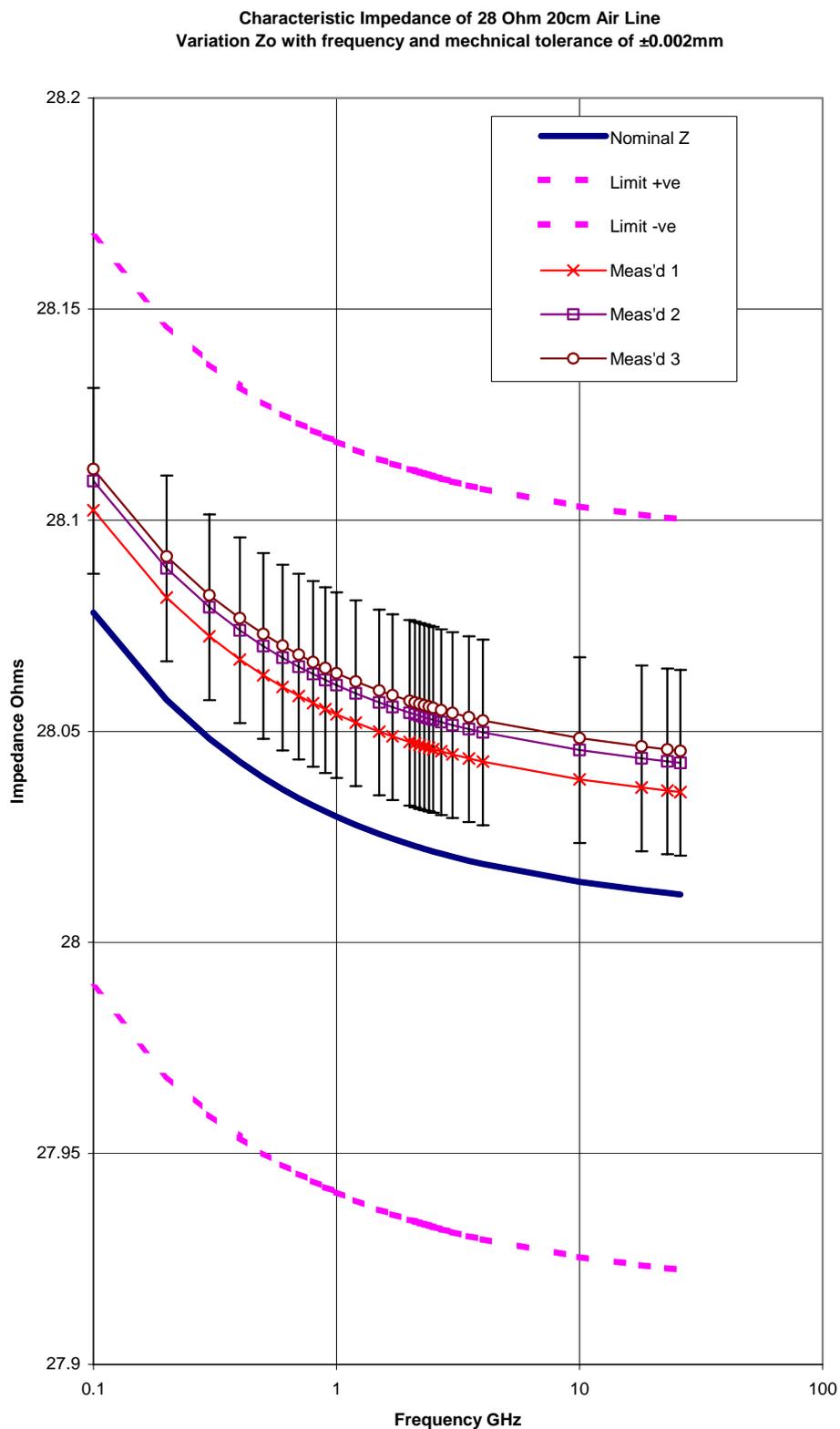


Chart 1 Characteristic Impedance of 28 Ohm 20cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

28, 75 and 100 ohm Impedance Air Line Standards

Characteristic Impedance of 28 Ohm 30cm Air Line
Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

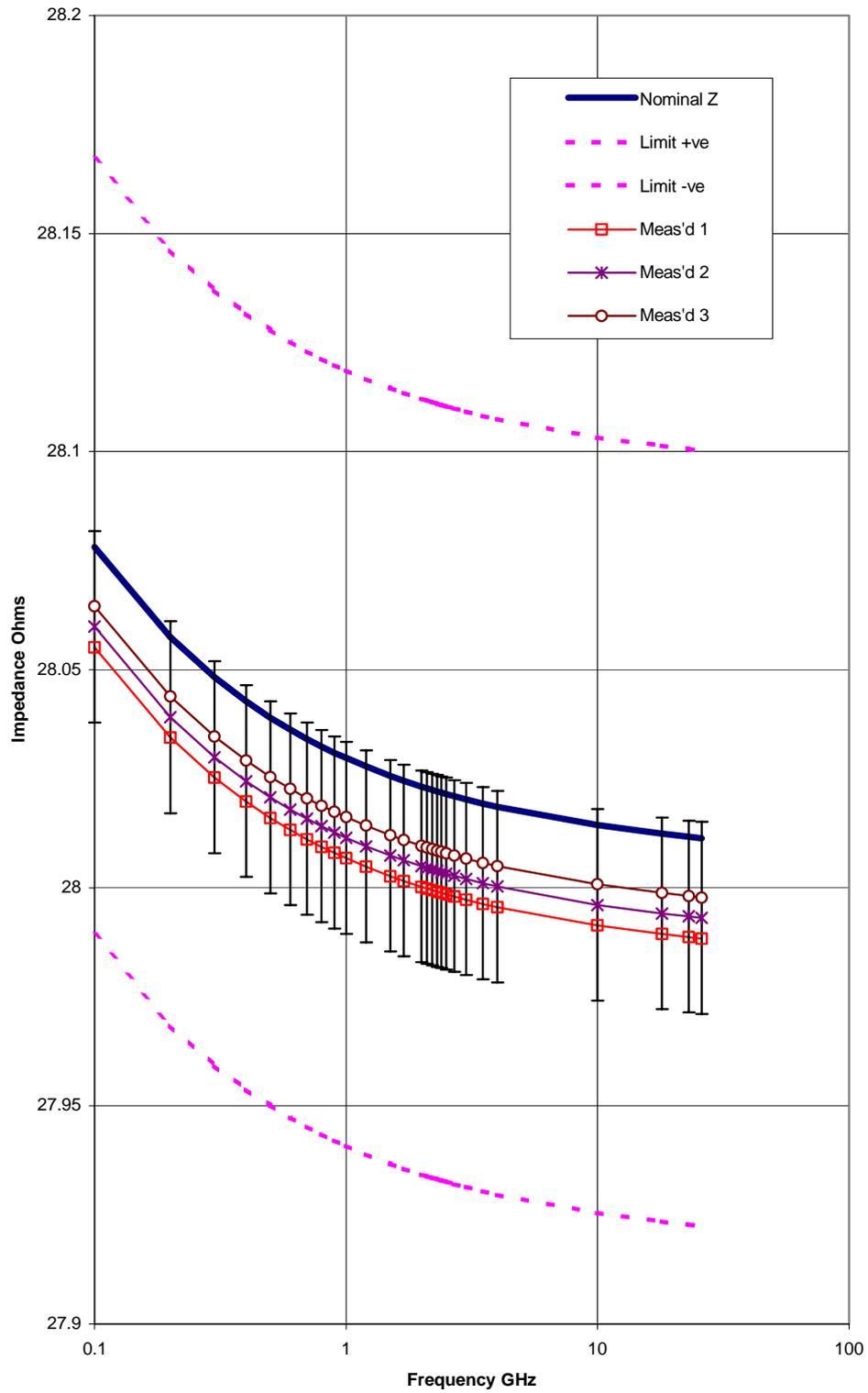


Chart 2 Characteristic Impedance of 28 Ohm 30cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

28, 75 and 100 ohm Impedance Air Line Standards

**Characteristic Impedance of 75 Ohm 20cm Air Line
Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$**

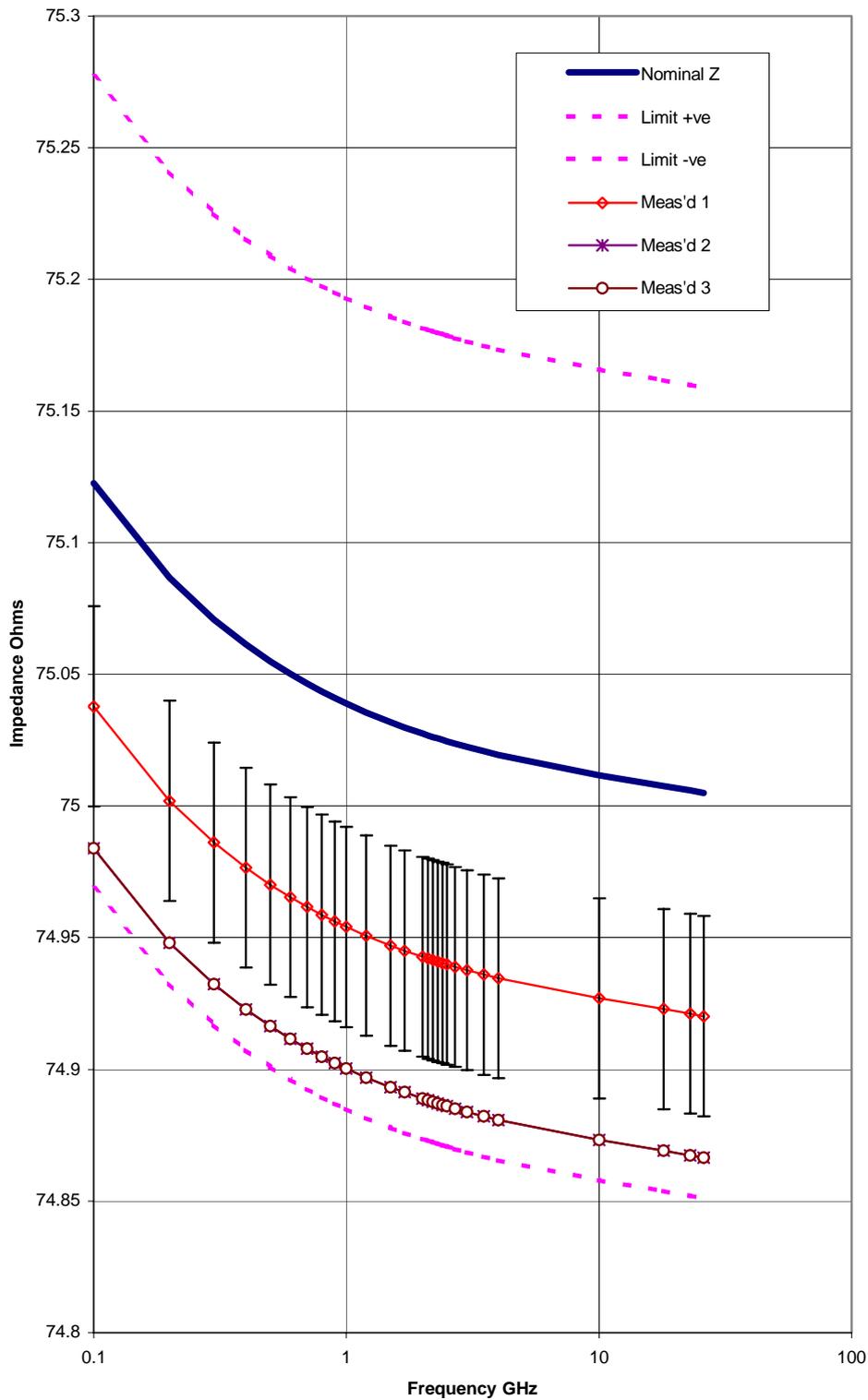


Chart 3 Characteristic Impedance of 75 Ohm 20cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

28, 75 and 100 ohm Impedance Air Line Standards

Characteristic Impedance of 75 Ohm 30cm Air Line
Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

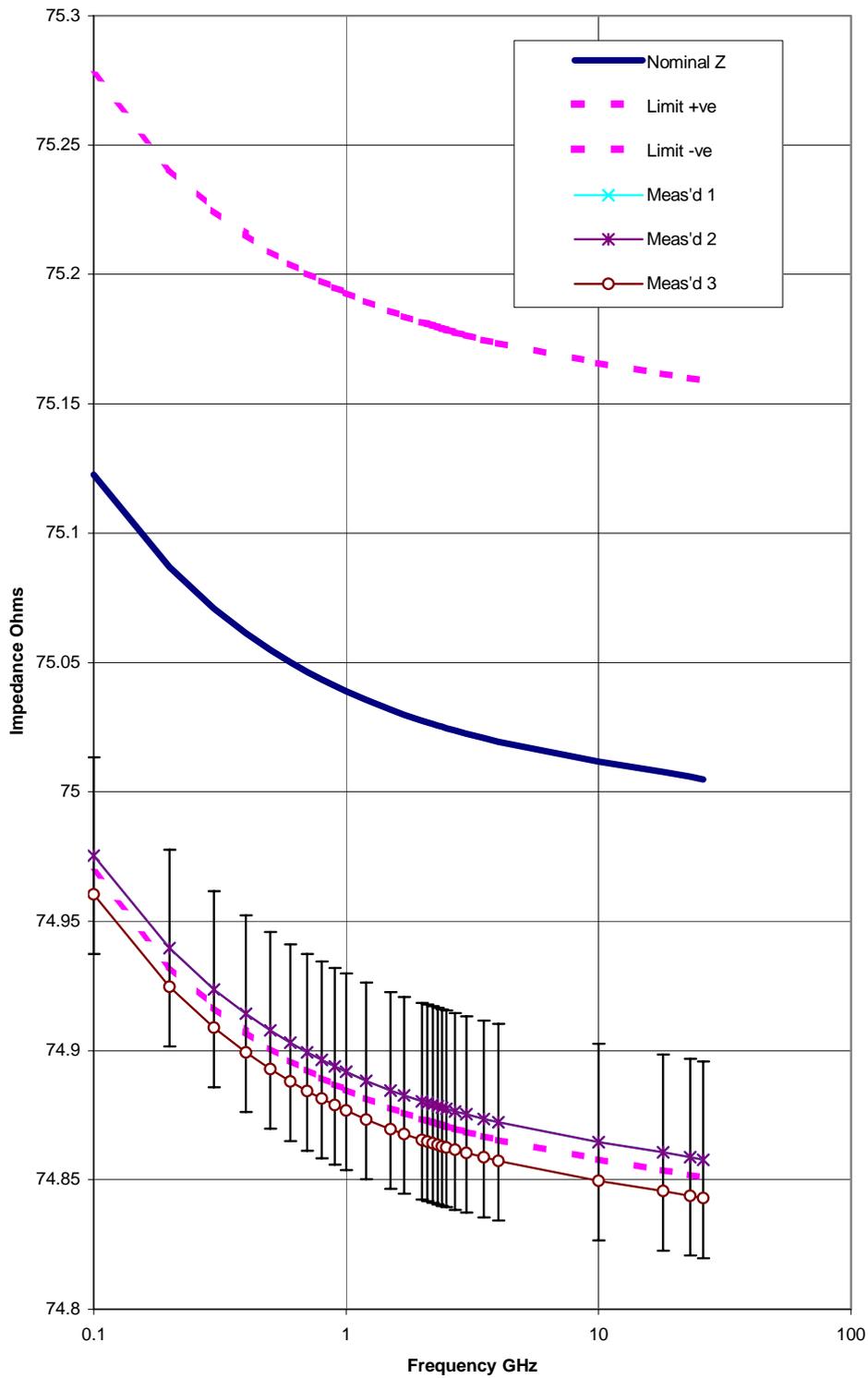


Chart 4 Characteristic Impedance of 75 Ohm 30cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

28, 75 and 100 ohm Impedance Air Line Standards

Characteristic Impedance of 100 Ohm 20cm Air Line
Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

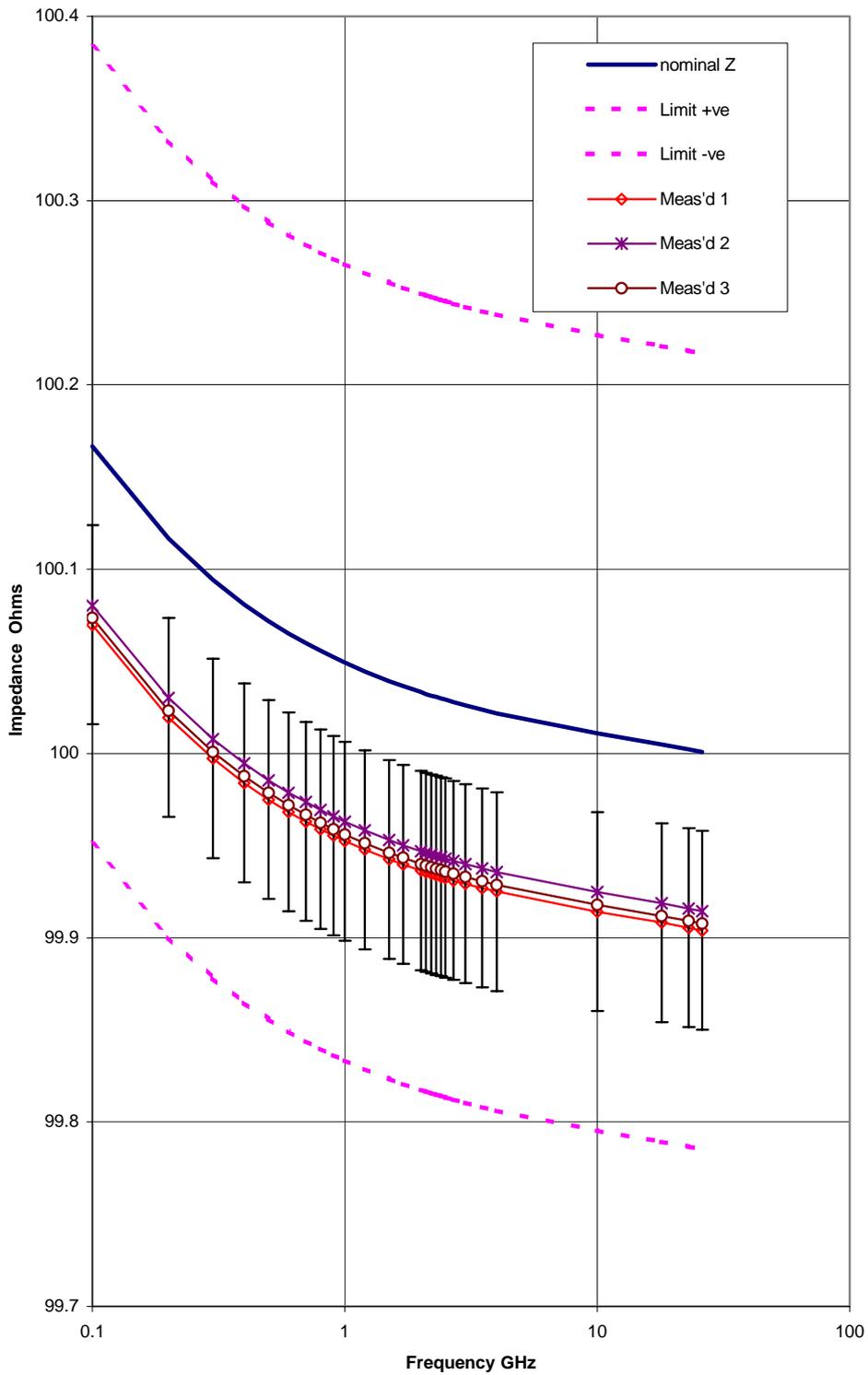


Chart 5 Characteristic Impedance of 100 Ohm 20cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

28, 75 and 100 ohm Impedance Air Line Standards

Characteristic Impedance of 100 Ohm 30cm Air Line
Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

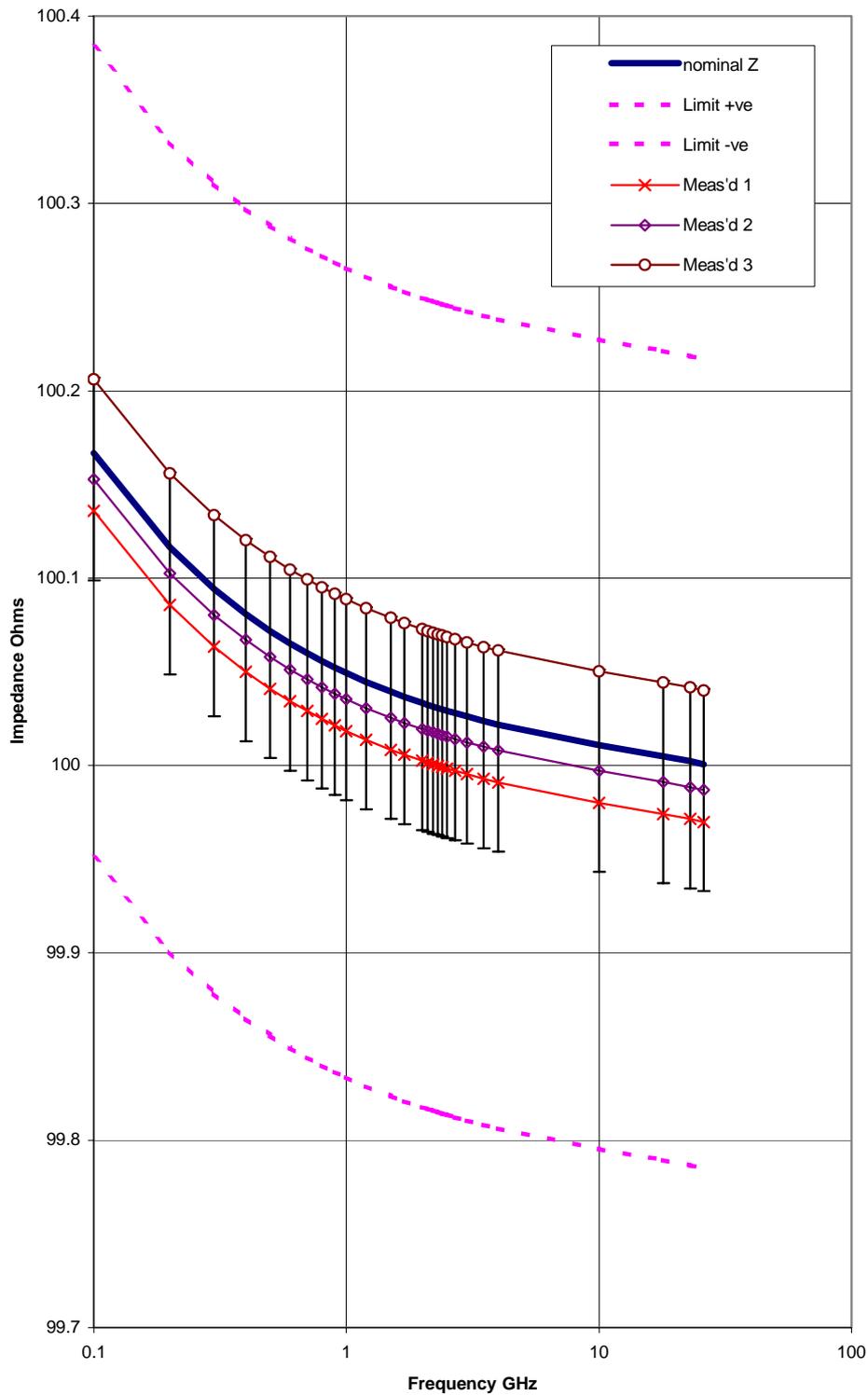


Chart 6 Characteristic Impedance of 100 Ohm 30cm Air Line. Variation Z_0 with frequency and mechanical tolerance of $\pm 0.002\text{mm}$

6 Cut-off Frequency of 7mm Air Lines

6.1 Estimated cut-off frequency of 7mm co-axial line

When using air lines to verify the accuracy of time domain measurement techniques consideration should be given to the cut-off frequency of the air line. Above the cut-off frequency additional modes to the main TEM transmission mode can generate line characteristics that are not a function of the TDR measurement system being evaluated.

The cut-off frequency of each air line is presented in the table below. These are based on the minimum frequency at which the first 'waveguide' mode, TE_{11} , is estimated to occur [6].

Air Line	Cut-off Frequency (GHz)
28 Ohm	16.89
75 Ohm	21.78
100 Ohm	23.40

Table 9 Cut-off frequency of 7mm air lines

The dielectric support bead in the 75 and 100 Ohm 30cm air lines will have a significantly lower cut-off frequency than indicated above. However, the support bead width is small compared to the cut-off wavelength thus any effect should be confined within the bead.

7 Conclusions

The Maury Microwave model 2603Q high precision special impedance Air Lines were identified as suitable impedance standards for 28, 75 and 100 ohm in 7mm coaxial line. A set of the air lines were purchased for evaluation. On receipt the relevant dimensions were measured by a UKAS accredited laboratory, measurement results were used to derive the characteristic impedance of each line. The reported measurement uncertainty of all measurements was $\pm 0.001\text{mm}$, a two-fold improvement on the contract requirement.

Two approaches were used to derive the characteristic impedance of the air lines, namely the manufacturers and a frequency dependent derived from theory [1]. Results of both techniques are presented and confirm that the delivered items meet the manufacturers specification of ± 0.1 ohm. A calibration service has been established to provide measurement of the air line impedance traceable to national standards.

Extreme care needs to be taken during both the dismantling and dimensional measurement procedures as many air line components are fragile. Some aspects of the dismantling procedure are described. Disassembly probably renders the supplier warranty void.

When using air lines to verify the accuracy of time domain measurement techniques consideration should be given to the cut-off frequency of the air line. The estimated cut-off frequency of each air line has been calculated and presented. Above the cut-off frequency additional modes to the main TEM transmission mode can generate line characteristics that are not a function of the TDR measurement system under evaluation.

8 References / Bibliography

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- [5] B.Williams 'Design and status of the 28, 75 and 100 ohm air line standards' QINETIQ/TLS/WLSD/CR020044, July 2002
- [6] B.Williams 'Over moding transmission characteristics of Type-N connector 7mm line between 18 and 26 GHz' NMS Contract GBBK/C/2/31, January 2004

9 Acknowledgements

Thanks go to Geoff Coombs for numerous Time Domain measurements performed on the air lines, using in-house Vector Network Analyser systems.

A System Traceability Certificates

Copies of calibration certificates are presented:

Type Number	Description	Serial No
2603Q28	20cm (7.884 inch) Airline	A268
2603Q28A	30cm (11.799 inch) Airline	A189
2603Q75	20cm (7.884 inch) Airline	A079
2603Q75A	30cm (11.799 inch) Airline	A269
2603Q100	20cm (7.884 inch) Airline	A270
2603Q100A	30cm (11.799 inch) Airline	A267

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CERTIFICATE OF CALIBRATION



0013

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006920D

ASAP Calibration Services Ltd

Leigh Laboratory
GREENFOLD WAY
LEIGH COMMERCE PARK
LEIGH
GREATER MANCHESTER
WN7 3XJ

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Facsimile 01942 261198

Email info@asap-cal.co.uk

Website www.asap-cal.co.uk



PAGE 1 OF 3 PAGES

APPROVED SIGNATORY

[] B.Bowden

[] T.Simms

[]

[]

Customer : ASAP SESC AQUILA
Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q28

Serial No : A268

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006920

Certified by

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22-005-079/008/JUN2003

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UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006920D

PAGE 2 OF 3 PAGES

SERIAL NUMBER:A268

INVENTORY NUMBER:2603Q28

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor.Two measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor.Three measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006920D

PAGE 3 OF 3 PAGES

SERIAL NUMBER:A268

INVENTORY NUMBER:2603Q28

RESULTS at 20°C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 7.00395 mm

RIGHT H/SIDE 7.00525 mm

INNER CONDUCTOR

LEFT H/SIDE 4.3877 mm

CENTRE 4.3876 mm

RIGHT H/ SIDE 4.3878

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006919D



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PAGE 1 OF 3 PAGES

APPROVED SIGNATORY

[] B.Bowden
[✓] T.Simms
[]
[]

Customer : ASAP SESC AQUILA
Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q28A

Serial No : A189

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006919

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CERTIFICATE NUMBER

N3006919D

PAGE 2 OF 3 PAGES

SERIAL NUMBER:A189

INVENTORY NUMBER:2603Q28A

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor.Two measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor.Three measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

CERTIFICATE NUMBER

N3006919D

UKAS Accredited Calibration Laboratory No. 0013

PAGE 3 OF 3 PAGES

SERIAL NUMBER:A189

INVENTORY NUMBER:2603Q28A

RESULTS at 20° C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 6.9995 mm

RIGHT H/SIDE 7.00065 mm

INNER CONDUCTOR

LEFT H/SIDE 4.3884 mm

CENTRE 4.3884 mm

RIGHT H/ SIDE 4.3884

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006921D



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APPROVED SIGNATORY

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[]

Customer : ASAP SESC AQUILA
Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q75

Serial No : A079

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006921

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CERTIFICATE NUMBER

N3006921D

PAGE 2 OF 3 PAGES

SERIAL NUMBER:A079

INVENTORY NUMBER:2603Q75

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor.Two measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor.Three measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

CERTIFICATE NUMBER

N3006921D

UKAS Accredited Calibration Laboratory No. 0013

PAGE 3 OF 3 PAGES

SERIAL NUMBER:A079

INVENTORY NUMBER:2603Q75

RESULTS at 20°C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 7.00065 mm

RIGHT H/SIDE 7.00065 mm

INNER CONDUCTOR

LEFT H/SIDE 2.00600 mm

CENTRE 2.0078 mm

RIGHT H/ SIDE 2.0078

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006923D



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[]

Customer : ASAP SESC AQUILA

Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q75A

Serial No : A269

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006923

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CERTIFICATE NUMBER

N3006923D

PAGE 2 OF 3 PAGES

SERIAL NUMBER:A269

INVENTORY NUMBER:2603Q75A

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor.Two measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor.Three measurements at the positions indicated (M) on the supplied Drawing,the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006923D

PAGE 3 OF 3 PAGES

SERIAL NUMBER: A269

INVENTORY NUMBER: 2603Q75A

RESULTS at 20° C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 6.99895 mm

RIGHT H/SIDE 6.99895 mm

INNER CONDUCTOR

LEFT H/SIDE 2.0077 mm

CENTRE 2.0077 mm

RIGHT H/ SIDE 2.0081

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer _____

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006922D



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APPROVED SIGNATORY

B. Bowden

T. Simms

Customer : ASAP SESC AQUILA
Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q100

Serial No : A270

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006922

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CERTIFICATE NUMBER

N3006922D

PAGE 2 OF 3 PAGES

SERIAL NUMBER: A270

INVENTORY NUMBER: 2603Q100

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor. Two measurements at the positions indicated (M) on the supplied Drawing, the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor. Three measurements at the positions indicated (M) on the supplied Drawing, the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006922D

PAGE 3 OF 3 PAGES

SERIAL NUMBER:A270

INVENTORY NUMBER:2603Q100

RESULTS at 20° C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 6.9993 mm

RIGHT H/SIDE 7.00025 mm

INNER CONDUCTOR

LEFT H/SIDE 1.3220 mm

CENTRE 1.3219 mm

RIGHT H/ SIDE 1.3221

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

DATE OF ISSUE 14 January 2004

CERTIFICATE NUMBER N3006924D



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[] B.Bowden

[/] T.Simms

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[]

Customer : ASAP SESC AQUILA
Address :

Order No :

Apparatus Tested - 7MM20CM BEADED AIRLINE

Type No : 2603Q100A

Serial No : A267

Inventory No : -

Manufacturer : MAURY MICROWAVE CO

Range/Scale :

Test Conditions -

Date Instrument Received : 09 January 2004

Date Calibration Completed : 14 January 2004

Ambient Temperature : 20 ± 1 °C

Reference No : 3006924

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UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006924D

PAGE 2 OF 3 PAGES

SERIAL NUMBER:A267

INVENTORY NUMBER:2603Q100A

REPORT

- 1 Measurement of the bore Diameter (A) of the outer conductor. Two measurements at the positions indicated (M) on the supplied Drawing, the measurement were taken at 10mm from each end, And the results recorded are from left to right
- 2 Measurement of the Shaft Diameter (A) of the inner conductor. Three measurements at the positions indicated (M) on the supplied Drawing, the measurement were taken at the centre and 10mm from each end, And the results recorded are from left to right.
- 3 The Outer and Inner conductor units were re-assembled as the received condition (As per customers special instruction)
- 4 The measured results are recorded on Page 3 of 3

Test Engineer _____



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS Accredited Calibration Laboratory No. 0013

CERTIFICATE NUMBER

N3006924D

PAGE 3 OF 3 PAGES

SERIAL NUMBER:A267

INVENTORY NUMBER:2603Q100A

RESULTS at 20°C (units MM)

OUTER CONDUCTOR

LEFT H/SIDE 6.99905 mm

RIGHT H/SIDE 7.00195 mm

INNER CONDUCTOR

LEFT H/SIDE 1.3205 mm

CENTRE 1.3204 mm

RIGHT H/ SIDE 1.3195

UNCERTAINTY OF MEASUREMENT: ± 0.001 mm

End of Certificate

Test Engineer



The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2.00$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

B **Manufacturers Data Sheet**

Data sheet for the Maury Microwave 2603Q series of reference air lines

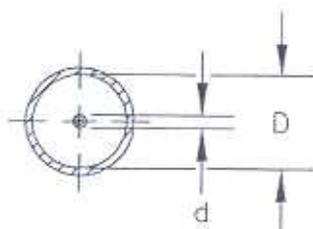
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HIGH PRECISION SPECIAL IMPEDANCE AIR LINES

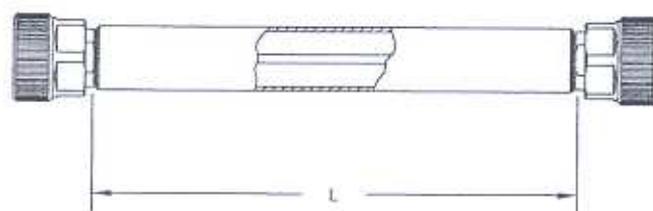
REFERENCE AIR LINES FOR TDR CALIBRATIONS

Description

The Maury 2603Q series of reference air lines are precision coaxial air lines sections with 7mm connectors. They are designed specifically for applications requiring the calibration or verification of TDR's (Time Domain Reflectometers) and Controlled Impedance Test Systems (CITS). The impedance of the air line is established by the ratio of the outer conductor to the inner conductor along the length (L) of the air line. The 28 ohm air line was designed specifically for calibrating systems used for measurements of the RAMBUS® pcb standard. Exact reference impedance for verifying the accuracy of the test equipment can be established using the specific air line. In addition, the linearity of the equipment can be determined by using a combination of different impedance air lines. The air lines can also be used as an impedance standard for gated measurements on vector network analyzers.



$$Z=59.939\ln(D/d)$$



Specifications

Frequency Range	DC to 18 GHz
VSWR	<1.004 + .003f (GHz)
Impedance	see chart
Impedance Accuracy	±.1 ohm*
Accuracy of Length (L)	±.001 inch
Connectors	7mm (APC7)

*Based on mechanical dimensions.

Model	Impedance ohms	Length (L)	
		inches	(cm)
2603Q28	28	7.884	(20)
2603Q28A	28	11.799	(30)
2603Q75	75	7.884	(20)
2603Q100	100	5.905	(15)
2603Q75A	75	11.799	(30)
2603Q100A	100	11.799	(30)

Recommended Accessories

Adapters: 7mm to 3.5mm (f) model 8022A1
7mm to 3.5mm (m) model 8022B1