ANAMET comparison of reflection coefficient measurements at RF

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ABSTRACT

This paper reports on an exercise to compare measurements of the complex reflection coefficient of coaxial terminations at RF (100 kHz to 1 GHz). The results obtained by the eleven laboratories participating in the exercise are summarised in terms of the between-laboratory reproducibility. These values are compared with a within-laboratory repeatability assessment made by the pilot laboratory for the exercise. The exercise was coordinated by ANAMET - the Automatic Network Analyser METrology club operated by NPL.

1 INTRODUCTION

This paper reports on a recent comparison exercise of complex voltage reflection coefficient (VRC) measurements made in 7 mm 50 ohm coaxial line. Six terminations fitted with type N connectors (three male and three female) were used as the test artefacts for the exercise (see Figure 1) which consisted of measurements at 16 frequencies from 100 kHz to 1 GHz. (The microwave properties of these terminations have been investigated in an earlier ANAMET comparison exercise [1,2] over the frequency range 1 GHz to 18 GHz.)

The exercise was coordinated by ANAMET – the Automatic Network Analyser METrology club operated by NPL. Eleven member organisations of ANAMET chose to participate in the exercise, including six national metrology institutes from around the world. The pilot laboratory was NPL Malvern.

This paper presents general observations about the exercise consistent with earlier reports on ANAMET comparison exercises [1-5]. These include: comparing the between-laboratory variation (*i.e.*, reproducibility) with a within-laboratory variation (*i.e.*, repeatability); predicting the likely significant sources of error in the VRC measurements; assessing any variability trends (*e.g.*, due to frequency, VRC value, etc); and, estimating the number of measurements far-removed from the majority of values (*i.e.*, statistical outliers). Finally, the variability of the data in this exercise is compared with that obtained in the earlier ANAMET comparison exercise from 1 GHz to 18 GHz.

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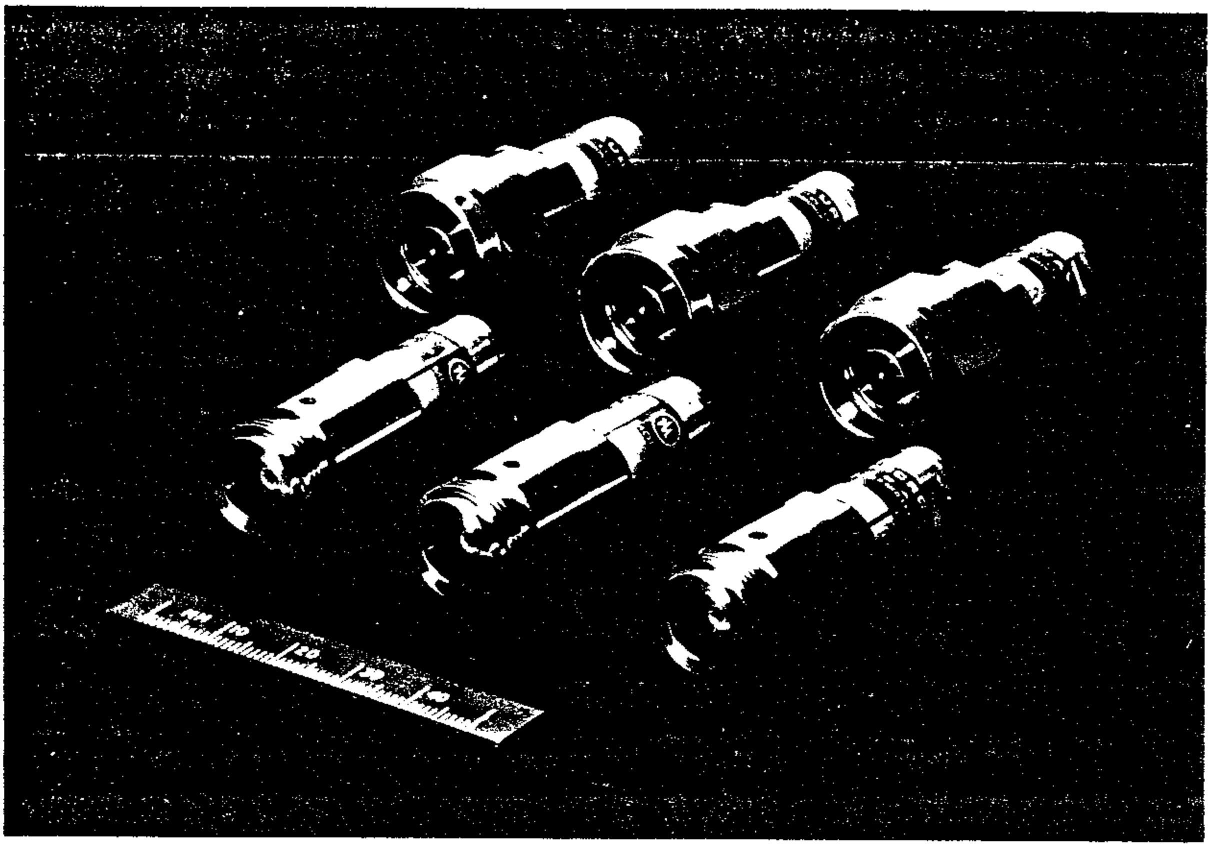

Figure 1: photograph showing the terminations used for the exercise

2 COMPARISON DETAILS

The terminations provided nominal values of VSWR of 1.05, 1.2 and 1.5 for both the male and female connectors. (*I.e.*, VRC magnitudes of nominally 0.024, 0.091 and 0.200.) The participants were invited to submit measurements of complex VRC, magnitude and phase, at the following frequencies; 100 kHz, 300 kHz, 1 MHz, 3 MHz, 10 MHz, 30 MHz, 100 MHz and in steps of 100 MHz to 1 GHz, making a total of 16 frequencies.

Eight of the participants supplied results at all the frequencies. Two participants supplied results at all frequencies except 100 kHz and one participant at all frequencies from 100 MHz to 1 GHz.

3 MEASUREMENT SYSTEM DETAILS

For the purposes of this paper, the participants supplied details of the systems they used for the measurements.

- The Hong Kong Government Standards and Calibration Laboratory, Hong Kong, used a HP 8752A ANA calibrated using a HP 85032B kit.

- The National Metrology Laboratory, CSIR, South Africa, used a HP 8510C ANA with a HP 8515A Test Set calibrated using a HP 85054A kit.

- Assessment Services, Titchfield, used a HP 4192A LF Impedance Analyser, for the measurements at 100 kHz, and a HP 8753A ANA with a HP 85046A Test Set for all other frequencies. Both instruments were calibrated using a HP 85032B kit.

- SESC, DRA Aquila, Bromley, used a HP 8751A ANA with a HP 87511A Test Set for the measurements up to 100 MHz and a HP 8753B ANA with a 85047A Test Set above 100 MHz. Both systems were calibrated using a HP 85032B kit.

- Hewlett Packard, Winnersh, used a HP 8753B ANA with a HP 85047A Test Set calibrated using a HP 85054B kit.

- Hewlett Packard, Queensferry, used a HP 3577A ANA with a HP 35677A Test Set for the measurements to 200 MHz and a HP 8510B ANA with a HP 8515A Test Set above 200 MHz. The 8510B was calibrated using a HP 85054B kit.

- INTA, Spain, used a HP 8751A ANA with a HP 87511A Test Set and a HP 8510C ANA with a HP 8517A Test Set.

- Swiss Telecom PTT, Switzerland, used a HP 8753D ANA calibrated using a HP 85032B kit.

- Marconi Instruments, Stevenage, used a HP 3577A ANA with a HP 35677A Test Set up to 200 MHz and the MI 6210 reflection analyzer from 250 MHz. Both systems were calibrated using a Wiltron kit and Marconi Instrument's own standards.

- NMi, The Netherlands, used a Quadtech 7600 Precision RLC Meter at 100 kHz and a HP 8753B ANA with a HP 85046A Test Set for all other frequencies. The calibration kit was a HP 85032B.

- NPL, Malvern, used a HP 8751A ANA with a HP 87511A Test Set for the measurements up to 500 MHz and a HP 8753B ANA with a 85046A Test Set above 500 MHz. Both systems were calibrated using a HP 85054B kit.

All participants who supplied details concerning the method used to calibrate the ANAs used the short-open-load technique, where the load was a fixed near-matched termination. Assessment Services used a S/C and O/C to calibrate their LF Impedance Analyser.

4 STATISTICAL ANALYSIS

4.1 Variability assessment

As with previous ANAMET comparison exercises, the variation in the results was assessed using the concepts given in [6] – specifically, in terms of the between-laboratory reproducibility of values and compared with a within-laboratory repeatability assessment made by the pilot laboratory.

The reproducibility values indicate the level of variation found in the results supplied by the participants whereas the repeatability values indicate a typical variation experienced by one participant performing repeat measurements under essentially the same measurement conditions. Therefore, the repeatability values provide a useful base-line to assess the variability in the participants' measurements.

Frequency	VRC MAD Repro	
	Linear magnitude (mU)	Phase (°)
100 kHz	0.6	0.002
1 MHz	0.4	0.019
10 MHz	0.3	0.035
100 MHz	0.3	0.04
1 GHz	0.7	0.21

Table 2: A selection of VRC MAD values, at different frequencies, produced by the 1.5 VSWR female termination.

Both of the effects observed in the MAD phase values are to be expected. Firstly, phase becomes generally more difficult to measure at higher frequencies as it relates directly to the ability to discriminate length, or distance. For example, a 1° phase change at 100 kHz equates to a distance of 8 m whereas the same phase change at 1 GHz is equivalent to a distance of 0.8 mm. Secondly, for a given (fixed) scatter in a set of VRC values, the subsequent scatter in the phase parameter increases as the set of values move towards the origin (*i.e.*, zero VRC) of the complex plane describing the VRC. (This effect is described in more detail in [8].)

(ii) Previous comparison exercises [1-5] have produced a significant number of unusual values (statistical outliers). This led to the introduction of the robust statistical techniques which have been used here to summarise the data. The robust techniques are relatively unaffected by outlying values making them a very useful mechanism for dealing with outliers when summarising the data sets. However, as an objective assessment of the overall calibre of the exercise, the identification of outlying data is a valuable part of the data analysis.

A visual inspection of all the |VRC| results in the exercise showed that none were obvious candidates to be classified as outlying. Similarly, the VRC phase values did not suffer from the extreme 180° problems encountered in the previous two ANAMET exercises [3-5]. However, some phase values were clearly well-removed from the main cluster of values suggesting potential measurement problems.

6.3 Comparison with microwave measurement comparison

The microwave properties of the items in this exercise have been compared in an earlier ANAMET exercise [1,2]. The VSWRs of the items were compared from 1 GHz to 18 GHz and the variability (between-laboratory reproducibility) reported using the standard deviation of each data set.

In order to compare meaningfully the variations found in both exercises it is necessary to convert the values in the earlier exercise from VSWR standard deviations to |VRC| MADs. In [2] it was shown that, for small |VRC|s, the standard uncertainty (or standard deviation) in |VRC|, $s(|VRC|)$, is approximately equal to half the standard uncertainty in VSWR, $s(VSWR)$. *I.e.*;

$$s(|VRC|) \approx s(VSWR)/2$$

Another useful relationship relates the standard deviation, $s(x)$, to the MAD;

$$\text{MAD} \approx 0.674 \times s(x)$$

(Strictly speaking, this is only true for large sample sizes drawn from a normal distribution.)

These two expressions have been used to convert the repeatability and reproducibility VSWR standard deviations from the earlier exercise (Tables 5 and 6 in [1]) into equivalent |VRC| MAD values. These values are presented in Table 3.

Comparing MAD values in Tables 1 and 3 shows that, in general, the variability is consistently larger with the measurements made at microwave frequencies in the earlier comparison exercise. This observation is consistent with engineering folk-lore which says that "microwave measurements are more difficult to make than low frequency ones".

Test item	VRC linear magnitude (mU)	
	MAD Repeat	MAD Repro
1.05 (male)	0.24	3.0
1.05 (female)	0.34	4.7
1.2 (male)	0.34	4.4
1.2 (female)	0.61	5.4
1.5 (male)	0.57	7.1
1.5 (female)	0.81	8.1

Table 3: Equivalent MAD values for the repeatability and reproducibility for |VRC| measurements obtained in the earlier ANAMET comparison.

7 CONCLUSIONS

This comparison, the fourth in ANAMET's on-going series of exercises, has further contributed to the catalogue of information which is emerging on network measurements and the performance of network measuring instruments in the 1990s. This body of data is providing vital information on actual performance figures for these systems over a wide range of applications.

The comparison focused on the lower RF region of the electromagnetic spectrum including frequencies where traceability is currently not available in the UK for this type of measurement (*i.e.*, below 50 MHz). The agreement between the participating laboratories was encouragingly good with none of the measurement anomalies (180° phase errors) which contaminated the data sets in the two previous comparison exercises [3-5]. Systematic errors appear to be dominating these measurements. This indicates potential avenues of research for the further improvement of the quality of these measurements.

ANAMET will continue to conduct measurement comparison exercises on behalf of its membership, with the focus likely to move towards some of the less well understood areas of RF, microwave and millimetre-wave metrology.

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