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ANAMET-031: "LIVE" INVESTIGATION INTO THE PERFORMANCE OF ANA TEST PORT CABLES

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Abstract

This report presents results obtained from an investigation into the performance of a series of coaxial cables used as part of the configuration of an ANA's test ports. The investigation took place during the 19th ANAMET meeting, held at BAE SYSTEMS, Warton, on the 13th January 2003. The investigation focused on variations in measured S-parameters due to varying degrees of cable movement. The cables used for the investigation were supplied by some of the attendees at the meeting. This report presents a general summary of the outcome of the investigation.

1. Introduction

Nowadays, there are many different types of coaxial cable that can be used as test port cables for ANAs. These different types often exhibit varying degrees of quality and performance, particularly with regard to the generation of random errors in the measurements made by the ANA using the cables. In addition, cables are often used for long periods of time without detailed performance checks being carried out on their overall performance. This could lead to assumptions about the performance of cables that may be beyond their actual current operational status.

To address the above situation, a series of very simple 'tests' were devised that could be used to assess cable variability in a prescribed manner. The tests were used subsequently to diagnose a problem[1] encountered by one of the clients of NPL's Internet-enabled calibration and measurement service, *i*PIMMS [1]. The tests were then demonstrated at the 17th ANAMET meeting (held at NPL Teddington, in January 2002) and generated considerable interest from the delegates at that meeting. It was therefore decided to use the tests to perform a 'live' investigation of cable performance during the 19th meeting of ANAMET, held at BAE SYSTEMS, Warton, on the 13th January 2003. Meeting attendees were invited to bring cables to be used for the investigation. The investigation was assigned the identifier ANAMET-031, in line with other comparisons and investigations coordinated by ANAMET, and represented an on-going tradition within ANAMET to hold such 'live' investigations during its meetings [2-5].

The only restriction placed on the type of cable to be included in the investigation was that it had to be suitable for connection to precision 2.92 mm connectors[2] - these being the test port connectors on the ANA used for the investigation.

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[1] The reported problem was poor repeatability in a series of *S*-parameter measurements using NPL's *i*PIMMS facility [1]. Subsequent system investigations, involving both the client and NPL, diagnosed the source of the problem to be a 'faulty' cable exhibiting excessive variability during a series of disconnection and reconnection exercises at the client's ANA's test port reference planes.

[2] This meant that cables fitted with any connectors mechanically compatible with precision 2.92 mm connectors were suitable for inclusion in this investigation. This therefore included precision 2.92 mm and 3.5 mm connectors, and, SMA connectors.

This report presents the results obtained from this investigation into the performance of coaxial cables used to establish reference planes for ANA measurements. The performance of the cables was assessed in terms of variability of observed *S*-parameters (measured using an ANA) due to a series of controlled tests on the cables (during connection to the ANA). The report presents the results obtained by each participant but does not relate specific results with participants (or, indeed, cables). Therefore, the objective here is to gain an insight into the overall performance of ANA test port cables.

2. Investigation details

The investigation used a Wiltron (Anritsu) 37369A 40 GHz ANA, set up with the frequency list 0.5 GHz to 33 GHz in 0.5 GHz steps (i.e. 66 points). The ANA was operated in uncalibrated mode[3]. The averaging factor on the ANA was set to 512 and the video IF bandwidth was set to 'normal' (i.e. 1 kHz).

Since the investigation was primarily interested in measuring differences in observed *S*-parameters, the 'memory' feature on the ANA was used to store a reference trace (i.e. the trace observed before performing the test) which was then subtracted from subsequent traces (observed after performing the test) using the 'math' feature on the ANA. This technique was used for all three tests performed on the cables.

The participants in the exercise were asked to bring cables to be included in the investigation that would normally be used for measurements up to 33 GHz. These cables are described in Table 1.

Table 1: descriptions of the cables involved in the investigation

Manufacturer	Model	Connector type	Connectors' gender
Gore	FB OHA OHB 039.4	3.5 mm	Male-to-female
Gore	FB OHA OHB 039.4	3.5 mm	Male-to-female
Wiltron	3670K50-2	2.92 mm	Male-to-female
Sucoflex	104P	3.5 mm	Female-to-female
Sucoflex	104PE	3.5 mm	Male-to-male
Reynolds	-	SMA	Male-to-male
Wiltron	WL 360	2.92 mm	Male-to-female
Gore	FB OHA OHB 039.4	3.5 mm	Male-to-female

Details of the three tests performed on each cable are described in Table 2. Each test was performed having first connected the cable-under-test to the ANA (with adaptors connected to the test ports, where necessary) and leaving it to settle for a while.

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[3] This 'quick and easy' method for evaluating cables does not require the ANA to be calibrated. However, the use of a calibrated ANA would have the advantage that observations from the results of the investigation could be compared quantitatively with results from other similar investigations.

Table 2: details of the tests performed during the investigation

Test no	Cable test description	Test purpose
1	Leave cable connected without disconnecting and/or flexing	Assess system 'noise floor' (i.e. minimum level of variability) for the investigation
2	Disconnect/reconnect, at one of the cable's connectors, without flexing (i.e. minimising cable movement)	Assess combined effects of system 'noise floor' and ANA test port/cable connector repeatability
3	Disconnect at one of the cable's connectors; flex, by fully straightening then re-forming shape; reconnect cable	Assess combined effects of system 'noise floor', ANA test port/cable connector repeatability and an element of variability due to cable flexure

3. Results

The results from the above three tests showed similar trends in the observed variations in each of the four measured S-parameters (S_{11}, S_{22}, S_{21} and S_{12}). Therefore, for brevity and convenience, only the results for S_{21} are included in this report. These results, shown in Figures 1 to 3, are presented in terms of the change in the measured S-parameter, $|\Delta S_{21}|$, as a function of frequency, due to performing each of the three tests on all the cables. It should be noted that the labelling of the cables' results (as Cable 1, Cable 2, etc) has been assigned arbitrarily and does not correspond to the ordering of the cables presented in Table 1. This ensures that the anonymity of both cable type and participant is preserved in this report[4].
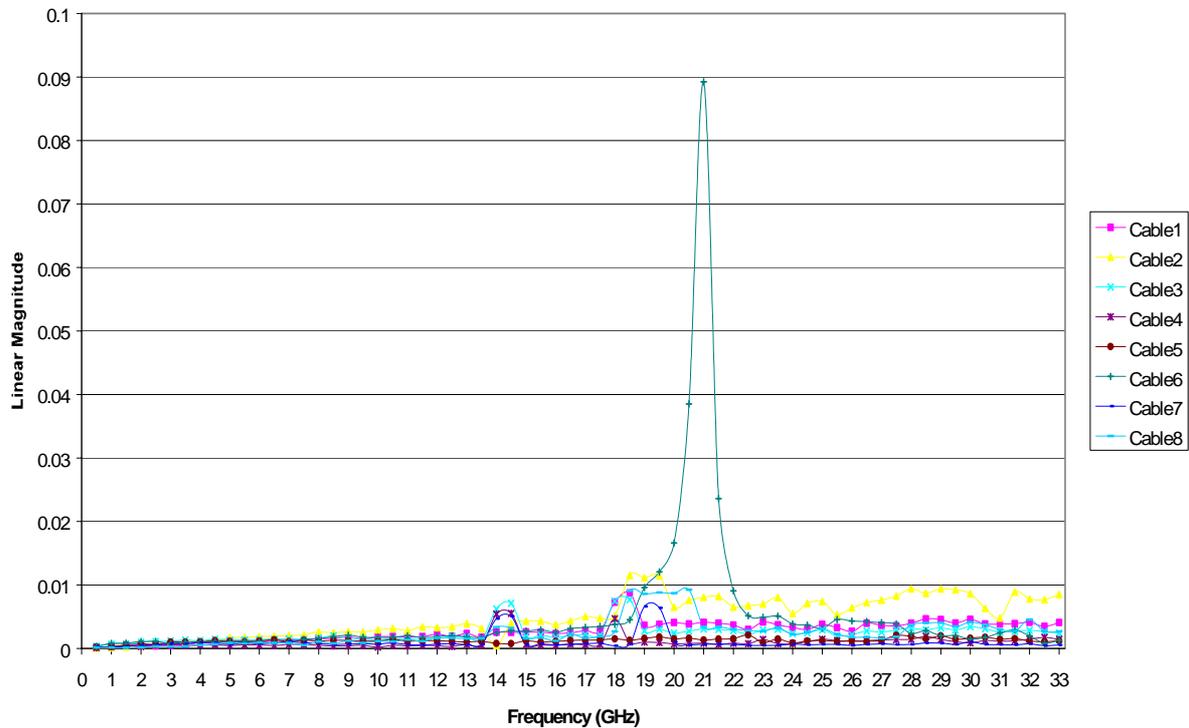

Figure 1: $|\Delta S_{21}|$ for Test 1

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[4] However, consistent with previous ANAMET comparison exercises and investigations, each participant has subsequently been made aware of the identity of their own results in the exercise.
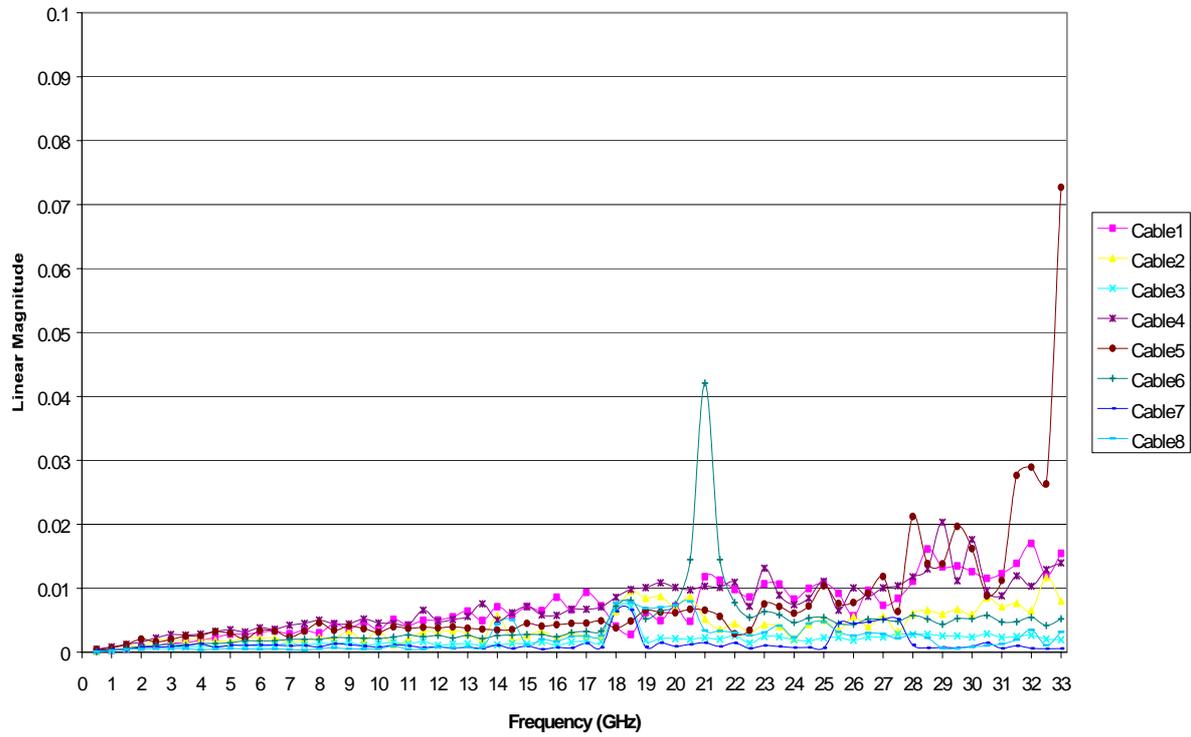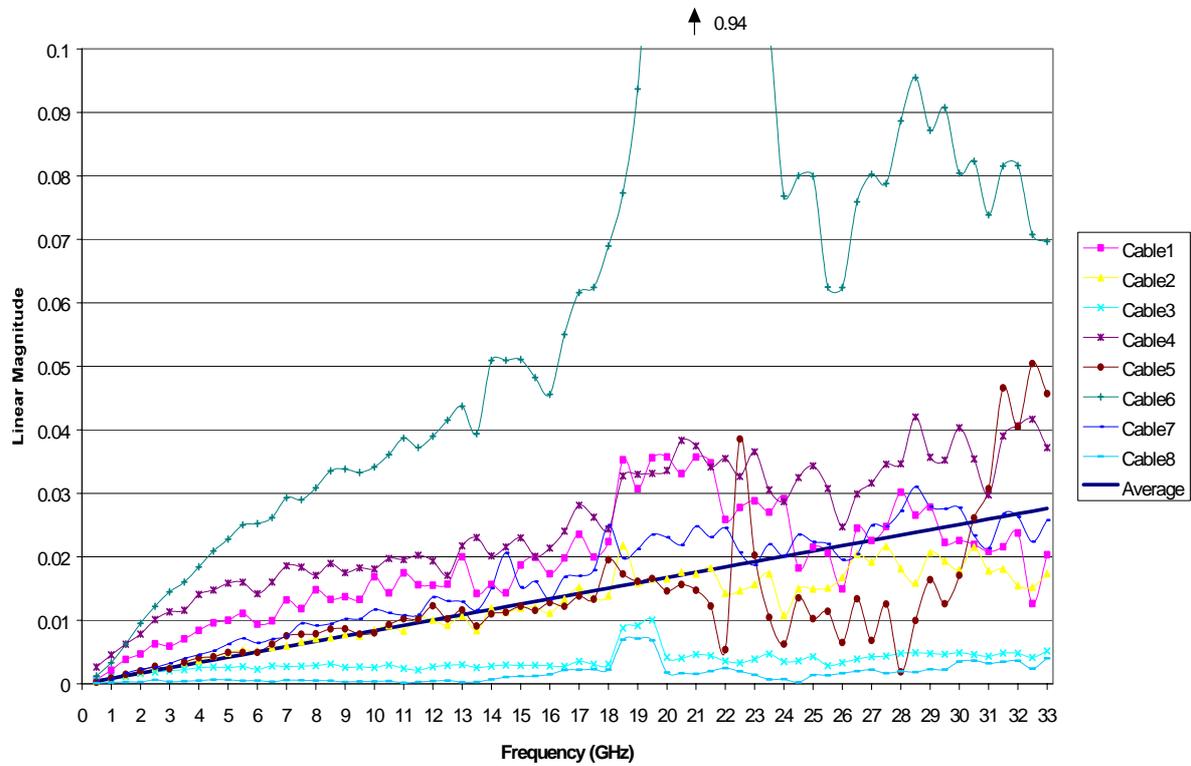
Figure2: |ΔS$_{21}$| for Test 2

Figure3: |ΔS$_{21}$| for Test 3

4. Detailed analysis of Test 3 – cable flexure

The results obtained from Test 3, shown in Figure 3, were further analysed in an attempt to:

    i)   grade the performance of the cables (in terms of a 'cable score');
    ii)   indicate an average cable performance (in terms of an 'average cable score').

4.1 <u>Obtaining cable scores</u>

An 'ideal' cable can be considered to be one that produces zero change in measured S-parameters at all frequencies due to the above tests. I.e. for S_{21}, this can be written as:

$$\sum_{i=1}^{n} \left| \Delta S_{21} \right|_i = 0$$

where n is the number of frequency values used for the tests. (For the tests performed on this occasion, $n = 66$.)[5] Therefore a simple 'scoring' mechanism for each cable's performance in Test 3 can be established using:

$$\text{Test 3 cable score} = \sum_{i=1}^{n} \left| \Delta S_{21} \right|_i \tag{1}$$

as this represents a measure of the departure from ideal in the cable's performance.

4.2 <u>Establishing average cable scores</u>

The results in Figure 3 also include a line labelled "Average". This is a straight line intersecting the origin and therefore has the form $y = mx$ (where $y \equiv |\Delta S_{21}|$, m is the line's slope and x represents the frequency). This line provides a simple summary of the behaviour of all the cables at all frequencies. The line is obtained by applying a regression estimator to the (x_i, y_i) values enabling an estimate of m, $\hat{m}$, to be obtained using:

$$\hat{y}_i = \hat{m} x_i$$

where $\hat{y}_i$ is the estimated value of y_i. During the regression process, the residuals r_i are computed as the difference between the observed value, y_i, and the estimated value, $\hat{y}_i$. I.e.

$$r_i = y_i - \hat{y}_i$$

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[5] Clearly, scores produced using this method can only be compared meaningfully with other scores if all the frequency values and the implemented method are the same.

Recognising that one or two of the cables produced very large variations in $|S_{21}|$ at certain frequencies, the following 'robust' method[6] has been used to obtain the coefficients of this 'average' line:

i)   Fit a straight line to the (x_i, y_i) data pairs such that[7]:

$$\underset{\hat{m}}{\text{minimise}} \sum_{i=1}^{n} |r_i|$$

ii)   Use equation (1) to obtain an average score based on values obtained from this straight line at the frequencies used during the investigation.

4.3 Cable score results

Table 3 shows the scores obtained for each cable using the above method[8]. (The score labelled 'Average' is the score obtained using the method described in the previous sub-section.)

Table 3: scores obtained for each cable (along with the average score)

Score	0.10	0.23	0.79	0.85	0.89	1.07	1.25	1.66	5.38
Cable No	8	3	2	5	Average	7	1	4	6

5. Observations

For each test, the following observations can be made:

Test 1:   Figure 1 shows that cable 6 exhibits very poor performance in that a very large peak is generated at 21 GHz. It is interesting to note that this cable was almost twice as long (i.e. 3 m) as the other cables and was fitted with SMA connectors. Both these features may have contributed to this poor performance.

Test 2:   Figure 2 shows that cable 6 again exhibits poor performance, with a similar peak at 21 GHz. Cable 5 also performs badly at frequencies above 31 GHz.

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[6] The method is called 'robust' since it is resilient to these excessive variations in the data during the fitting process. The justification for such an approach (i.e. using outlier resistant regression) is based on the assumption that these excessive variations are unrepresentative of cables that are in good working order. A straight line fit has been chosen (with intersect at the origin) as this represents a simple fit and is considered appropriate in the absence of any more detailed information about the frequency dependence of the observed variations.

[7] This form of data fitting is called the Least Absolute Values (LAV) method – also known as L_1 regression or, more historically, the Method of Situation. It forms an alternative to the Least Squares method, or L_2 regression, which can give unsatisfactory results when a proportion of the data are poorly behaved (as is the case on this occasion).

[8] It should be noted that a feature with this scoring mechanism is that the scores do not necessarily distinguish between a cable with moderate performance at all frequencies and a cable that is good at nearly all frequencies but poor at just one or two frequencies.

Test 3: Figure 3 shows a clear distinction in performance between the cables: cables 3 and 8 perform very well at all frequencies, with almost flat responses; cables 1, 2, 4, 5 and 7 have responses close to the 'Average' line for the data; and, cable 6 once again performs very badly[9].

The tabulated cable scores also follow these trends, with cables 3 and 8 having low scores (<0.3); cables 1, 2, 4, 5 and 7 having scores close to the average score (i.e. within a factor of two of the average value); and, cable 6 having by far the largest score (>5).

A summary of the above observations indicates that cables 3 and 8 both exhibited very good performance under all test conditions; cables 1, 2, 4 and 7 exhibited average performance; and cables 5 and 6 exhibited poor behaviour, with cable 6 being particularly poor under all test conditions. It is interesting to note that cables 3 and 8 appeared to be new cables, whereas the other cables showed varying degrees of usage. This clearly indicates that the amount of use (or, the wear and tear) of a cable is an important factor when considering the likely reliability of measurements made using such cables.

6. Conclusions

The results from a series of simple tests on ANA test port cables, made during one of the ANAMET meetings, have been presented and analysed. The tests, although simple, have been shown to be quite useful at checking the overall performance of cables used during ANA measurements. Of particular relevance is that the performance of cables has been seen to be a function of both the type of manufacturer and also age (or, condition) of the cable under test. This indicates that cables should be tested regularly to ensure that performance is likely to be as expected for a particular measurement application.

Finally, it is likely that further cable tests, similar to the ones presented in this report, will be developed in the near future to explore other issues (e.g. phase stability) relating to cable suitability for ANA measurements.

7. Acknowledgements

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[9] Note that, for cable 6, $|\Delta S_{21}| = 0.94$ at 21 GHz. This is an extremely large value and could be due to the cable becoming either open- or short-circuited at this frequency.

8. References

[1]   R A Dudley and N M Ridler, "Traceability via the Internet for microwave measurements using vector network analysers", *IEEE Trans*, **IM-52**(1), pp 130-134, February 2003.

[2]   N M Ridler and J C Medley, "ANAMET-962: dial gauge comparison exercise", *ANAMET Report 001*, July 1996.

[3]   N M Ridler and J C Medley, "Live dial gauge comparison exercise: ANAMET-963", *ANAMET Report 007*, May 1997.

[4]   N M Ridler and J C Medley, "ANAMET-971: "live" investigation into variation in ANA measurements due to different calibration loads", *ANAMET Report 008*, July 1997.

[5]   G J French, "ANAMET-982: Live torque comparison exercise", *ANAMET Report 022*, February 1999.