Power splitters – measuring up to specification?

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Coaxial power splitters are used extensively throughout the RF and microwave industry in applications ranging from communications base stations right through to the very highest levels of accuracy found on precision test benches and in calibration laboratories. The performance of these power splitters is usually specified in terms of the input and output matches (i.e. VSWRs) and the tracking between the two output ports.

A challenge for measurement laboratories is to be able to determine these specification parameters with a high level of confidence. Of particular interest is the equivalent output match of the splitter, which is the match seen looking into the outputs of the splitter when it is used in a levelling loop or as a reference to a ratio system. There are several established methods for doing this, but little evidence as to the reliability of the results obtained.

This situation was acknowledged recently by the ANAMET measurements group and led to the group running a comparison exercise of power splitter measurements made by various members of this group. In all, 17 leading measurement laboratories from around the world took part in the exercise – the details of these labs are listed in Appendix A. The exercise was coordinated by NPL (the UK’s national measurement lab) and began back in August 2002. It took nearly two years for all the labs to complete their measurements, during which time, the power splitter travelled more than 60,000 km in order to get to all of these labs!

This article presents a brief summary of the exercise. A full report has been published by ANAMET [1] and can be obtained from electromagnetic@npl.co.uk.

Comparison details

The device chosen for the exercise was a Weinschel model 1870A two-resistor power splitter, as shown in Figure 1. This device comes with three female Type-N connectors and contains two 50 ohm matching resistors in series with the two output ports [2]. A schematic diagram of the splitter is shown in Figure 2.

The exercise looked at comparing measurements of the following specification quantities at frequencies from 1 GHz to 18 GHz, in 1 GHz steps:

1) Input VSWR at port 1;
2) Equivalent output VSWR at port 2;
3) Equivalent output VSWR at port 3;
4) Output tracking between ports 2 and 3.

Definitions of these quantities are given in Appendix B.

Measurement details

Measuring instruments: 15 of the 17 participants chose to use Vector Network Analysers (VNAs) to do the measurements. The other two participants used scalar systems based on combinations of VSWR Bridges and receiver-based attenuation systems. 14 of the VNAs were Agilent (formerly HP) 8510 series instruments with the remaining system being a Rohde & Schwarz ZVK.

Measurement methods: the participants chose several different methods to do the measurements. The most popular method was to directly measure the S-parameters of the splitter and derive the measured results from these S-parameters (using the equations in Appendix B). During these measurements, any unused ports on the splitter were terminated with well-matched loads.

Two alternative methods were also used to obtain the equivalent output VSWRs at ports 2 and 3. These were the Direct Calibration Method of Juroshek [3] and methods derived from a technique proposed originally by Engen [4] and later re-evaluated by Moyer [5] where it was called the Passive Open-Circuit method. This method utilises variable high reflectors (e.g. using a sliding short-circuit or a range of different offset short- and open-circuits) attached to port 1 of the splitter to establish a null condition in the transmission between, or the reflection coefficients at, ports 2 and 3.

Results

A detailed analysis of all the results obtained during the exercise is given in the full report on this exercise [1]. The full report includes a detailed statistical analysis of all the results obtained during the exercise. Only a summary of these results is given here in terms of a few selected graphs. On all graphs, the results for the participants have been labelled arbitrarily as Lab A, Lab B, and so on, to preserve the anonymity of each participant’s results.

Input VSWR at port 1: Figure 3 shows a plot of the results obtained by the participants for the splitter's input.
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Figure 3: Measurements of input VSWR at port 1.

VSWR at port 1. This plot shows relatively good agreement between the participants although it could be argued that the results labelled Lab C and Lab O do depart noticeably from the majority of values at some of the frequencies. It turns out these participants used the scalar measurement systems.

Output VSWRs at ports 2 and 3: Figure 4 shows a plot of the results for the equivalent output VSWR at port 2. The results for the equivalent output VSWR at port 3 showed similar trends. Most participants show good agreement, however the notable exception is Lab O who has produced much higher values at all frequencies. It turns out that Lab O actually measured different quantities – namely, the VSWRs at ports 2 and 3 derived only from the measurements of S22 and S33 of the splitter. These VSWRs are expected to be of the order of 1.7 instead of less than 1.15 for the equivalent output VSWR values (as discussed in [3]). This explains why this participant measured VSWRs close to 1.7 instead of the smaller values measured by the other participants. Under these circumstances, we can exclude this participant’s results for this quantity.

Figure 4: Measurements of equivalent output VSWR at port 2.

Figure 5 shows the same data as figure 4, except omitting the results for Lab O. This means that a much finer scale can be used to plot the results and so it is possible to examine the results in more detail. The first thing that becomes clear is that a second grouping of values begins to emerge from the main grouping of values at frequencies above approximately 11 GHz. This grouping consists of Lab B, Lab H and Lab Q. It turns out that these participants used measurement methods derived from the high reflect ‘nulling’ technique (described in [4, 5]) to make this measurement.

Figure 5: Measurements of equivalent output VSWR at port 2, with a black line included to show the specification limit.

To examine the possible significance of the difference between these two groupings of results, Figure 5 also shows a line that represents the specification limit for equivalent output VSWR for this type of power splitter (see www.weinschel.com). It is clear that two of the participants in this secondary grouping (i.e. Lab B and Lab H) have measured the splitter as being out of specification at 17 GHz. This could mean that, if testing this device to its specification, these laboratories would reject the device as noncompliant. This is interesting when considering that the majority of participants (i.e. those using other measurement methods) would accept the device as compliant with the specification. In other words, the device can either meet or fail the specification depending on which measurement method is used! This is obviously an unsatisfactory situation and clearly indicates that more work needs to be done to understand these methods in more detail.

Output tracking between ports 2 and 3: Figure 6 shows a plot of the results for the output tracking between ports 2 and 3. Again, these results generally show good agreement between all the participants.

However, the results for Lab C, Lab I, Lab N and Lab O do, at some frequencies, show significant departures from the majority of values. It is interesting to note that this grouping includes the participants that used the scalar measurement systems.

Conclusions

An exercise to compare measurements of the specification parameters of microwave coaxial power splitters has been recently undertaken. 17 leading measurement laboratories from around the world were involved and the results obtained generally showed good agreement. However, several interesting features in the results have been identified that relate the results supplied by the participants to either the choice of instrument or technique used for the measurements. For example, for measurements of the input VSWR at port 1 and output tracking between ports 2 and 3, the scalar measuring instruments produced greater variability in the values obtained. This could be due to different sources of error in these systems compared with the VNAs.

Similarly, for the output VSWRs at ports 2 and 3, participants using the high reflect ‘nulling’ measurement technique [4, 5] obtained values that were similar with each other, but different from the other participants’ values at the higher frequencies. It was further shown that this difference could cause a dispute over whether a particular power splitter was inside or outside its specification. This has significant commercial implications for manufacturers and users of splitters, as well as for the laboratories involved in calibrating or testing these devices. This
indicates that more work needs to be done to understand these measurement techniques, including performing a detailed analysis of the errors in the measurement processes. This should resolve any future doubts about whether or not a microwave power splitter measures up to its specification.

Acknowledgements

The authors would like to thank the participants (listed in Appendix A) for their involvement with this comparison exercise. The ANAMET measurement group is funded by membership subscriptions and the National Measurement System Directorate of the Department of Trade and Industry, UK.

References


Appendix A - the participants

The 17 organisations that took part in the exercise are listed alphabetically below (along with the main contact persons for the measurements). Eight of these organisations are national measurement labs and seven are accredited labs (to ISO 17025).

Ian Instone and Mike Little, Agilent Technologies, South Queensferry, UK; Anne Knowson, Agilent Technologies, Wimshurst, UK; Luis Cirista and Rui José de Castro Varcla Pais, ANACOM, Barcarena, Portugal; Steve Harter and Peter Constable, ASAP Calibration Services, Bromley, UK; Erik Dressler

and MJ Prinsloo, CSIR-NML, South Africa, Pretoria, South Africa; Karel Drazil, Czech Metrology Institute, Prague, Czech Republic; Alan Coster, Dowding & Mills, Camberley, UK; Pertti Saarinen and Tuomas Hauto, Finnish Defence Forces, Riihimaki, Finland; Michael Chow, Hong Kong Standards and Calibration Laboratory, Wanchai, Hong Kong; Patrick Haggarty, IFR Ltd, Dunfermline, UK; Manuel Rodriguez, INTA, Madrid, Spain; Juerg Ruefenacht, METAS, Bern-Walnern, Switzerland; Jan de Vreede, NMI-VSL, Delft, Netherlands; Martin Salter, National Physical Laboratory, Teddington, UK; Joachim Schubert and Harald Jaeger, Rohde & Schwarz GmbH, Munich, Germany; Patrik Persson, Saab Metsch AB, Arboga, Sweden; Senel Yaran, UME, Kocaeli, Turkey.

where the effective output reflection coefficients, \( \Gamma_2 \) and \( \Gamma_3 \), are given by:

\[
\Gamma_2 = \frac{S_{22} - S_{12}S_{23}/S_{13}}{S_{22} + S_{12}S_{23}/S_{13}}
\]

and

\[
\Gamma_3 = \frac{S_{33} - S_{13}S_{32}/S_{12}}{S_{33} + S_{13}S_{32}/S_{12}}
\]

Finally, the output tracking, \( T \), expressed in dB, is given by:

\[
T = 20 \log_{10} |S_{21}/S_{31}|
\]

Notes

1 ANAMET is an interest group of organisations and people involved in RF, microwave and millimetre-wave measurements. More information on ANAMET can be found at: www.npl.co.uk/ananet.

2 The match of these loads was either assumed to be perfect or a correction applied to take account of the reflection.

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Microwave Engineering Europe ● June 2005 ● www.mwee.com

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