ANAMET REPORT

"What's the best method for calibrating an ANA?"

ANAMET Colloquium Digest

ANAMET COLLOQUIUM

"WHAT'S THE BEST METHOD FOR CALIBRATING AN ANA?"

Foreword

This report contains a re-print of the synopses published in the Digest accompanying the ANAMET colloquium "What's the best method for calibrating an ANA?" The colloquium took place during the ninth meeting of ANAMET, held at Hewlett Packard Ltd, South Queensferry, on the 19th and 20th November 1997.

The colloquium was attended by 39 delegates representing 22 member organisations from eight different countries. Fundamentals of ANA calibration were addressed during the first three presentations under the headings: 'One-port calibration techniques', 'Two-port calibration techniques', and, 'Non-coaxial techniques'. This was followed by a presentation on a recently introduced ANA electronic calibrator - this was subsequently demonstrated during one of the practical sessions which also formed part of the colloquium.

Follow-up presentations addressed issues relating to techniques where calibration kits are not available, good practice tips for calibration (including coaxial connector issues), and measurement and calibration considerations when an ANA is taken into an industrial shop floor environment. The colloquium ended with a discussion session on TRM calibration techniques followed by a round table session reviewing the progress made during the colloquium.

Most presentations were accompanied by a synopsis handed out at the colloquium. These are reproduced in this report. However, the text accompanying the presentation "Calibration - some good practise tips" formed a considerable document in its own right, so this will be issued as a separate ANAMET Report in the very near future. Similarly, an extended version of the synopsis accompanying the presentation "Techniques where calibration kits are not available" will also be issued as part of the ANAMET Report series.

We hope to be able to organise further colloquia on appropriate topics at future club meetings. I will welcome any suggestions for such topics - please send them to me.

Nick Ridler
ANAMET Technical Advisor

January 1998

ANAMET Colloquium

"What's the best method for calibrating an ANA?"

Organised by the ANAMET Steering Committee

Wednesday, 19 November and Thursday, 20 November 1997

Hewlett Packard Ltd, South Queensferry

"What's the best method for calibrating an ANA?"

A colloquium organised by the ANAMET Steering Committee
to be held at Hewlett Packard Ltd, South Queensferry
Wednesday, 19 November and Thursday, 20 November 1997

PROGRAMME

Wednesday 19th November 1997

12:00 hours	**Arrive/Registration**
13:00 hours	**Lunch**
14:00 hours	"One-port calibration techniques" *Anne Knowlson, Hewlett Packard*
14:30 hours	"Two-port calibration techniques" *Steve Harter, SESC, DERA Aquila*
15:00 hours	"Non-coaxial calibrations" *Bill Oldfield, Anritsu-Wiltron*
15:30 hours	**Practical demonstration (1); Lab tour (1); Coffee**
17:00 hours	"Electronic calibrators" *Barry Smith, Anritsu-Wiltron*
17:30 hours	"Techniques where calibration kits are not available" *Ian Instone, Hewlett Packard*

Thursday 20th November 1997

08:45 hours	**Arrive/Coffee**
09:00 hours	"Calibration - some good practice tips" *Doug Skinner, Marconi Instruments*
09:30 hours	"Shop floor calibration considerations" *Dave Hepworth, EEV*
10:00 hours	**Practical demonstration (2); Lab tour (2); Coffee**
11:30 hours	Discussion session - "A look at TRM calibrations"
12:00 hours	Round table discussion - including: "What we have learnt"; and, "Where to next"
12:30 hours	**Lunch/End seminar**

One-port calibration techniques

by
Anne Knowlson, Hewlett Packard

One Port Calibration

Anne Knowlson
Hewlett-Packard Limited

Introduction

Automatic Network Analysers (ANA) are widely regarded as being versatile, time effective and accurate instruments when performing either a simple measurement such as the return loss of a termination or more complex measurements of microwave devices. The automated network analyser is calibrated and measurements performed. Unfortunately errors can effect the accuracy of calibration, the magnitude of which will affect subsequent measured results. The Standard used to perform the calibration has a direct effect on the characterisation and removal of systematic errors.
Whether measurements are to be performed in a production environment or in a standards laboratory, the users choice of calibration type and the operating frequency range of the standards need to matched to the required application

Calibration

Without correction, system errors prevent measured data from being an accurate representation of the true value of the device under test (DUT). These system errors can be removed by calibrating the ANA with known impedance standards.

A set of devices (standards) that are defined physically and electrically are used to provide a reference for the physical interface between the DUT and the ANA. After the system has been calibrated using the impedance standards and software of the ANA, measurements of the DUT can be made. Under ideal conditions, with perfectly known standards all system errors would be completely characterised and removed. The accuracy to which these standards are known over their operating frequency range establishes how well these system errors can be characterised and removed. Less than perfect modelling, will result in uncorrected systematic errors, these uncorrected systematic errors are known as residual errors. The magnitude of the residual errors after calibration will prevent measured data being a true representation of the DUT.

Reflection coefficient is measured by separating the incident signal (I), from the reflected signal (R), and then calculating the ratio of the two values. In a ideal ANA no systematic errors would remain after correction, and (R) would only consist of the signal reflected by the device under test.

Directivity

However all of the incident signal does not always reach the DUT. Some of the incident signal may appear at the interface or test port of the ANA, as leakage through the test set or other signal separation devices. Also some of the incident signal may be reflected back by imperfect ,worn or dirty connectors and adapters. Directivity (E_{DF}) is the vector sum of all the leakage signals and miscellaneous effects of test port cables and adapters. Understandably the measurement is distorted when the Directivity signal combines vectorally with the reflected signal from the DUT.

Source match

Since the measurement test port is not a perfect 50 Ω impedance, some of the reflected signal will be mismatched and will reflect back of the test port, this can also occur at any impedance transition in the line. This reflection will add or subtract to the original incident signal. The magnitude of the incident signal will vary as a function of S_{11A}. Levelling the source to produce a constant incident signal will reduce this error, but since the source cannot be exactly levelled at the test port, it will not eliminate all power variation. This re-reflection effect is known as Source Match (E_{SF}), and will cause incident signal variation.

Another form of error is Frequency response or tracking this is variations in magnitude and phase flatness versus frequency between the test and reference signal paths. These are due mainly to imperfectly matched samplers and differences in length and loss between incident and test signal paths. The vector sum of these variation is the reflection signal path tracking error.

Measurements

For the purpose of this Paper we will be looking at the reflection coefficient measurements of three DUT's
    40 dB return Loss Termination;
    0.5 Mismatch;
    Short Circuit
Each has been measured using the following calibrations:
    Short, Open, Lowband Load
    Short, Open, Sliding Load
    Short, Open, Broadband Load

The attached plots show the results of the DUT's measured on the three different calibrations

Attention should be drawn to the measurements of the 40 dB, and the Short circuit.
The the 'similarity' of the results from the Broadband termination and the Sliding load calibrations are aparent when compared with the Lowband calibration.

The 0.5 Mismatch plots indicate three measurements of the same device , the centre line being a nominal 0.5 mismatch, the measured values are expressed as the 'error' from nominal

40 dB Return Loss Comparison

Reflection Coefficient vs Frequency GHz

Legend: Sliding, Broadband, Low Band

0.5 Mismatch Comparison

Deviation vs Frequency GHz

Legend: Sliding, Lowband, Broadband

Short Circuit Comparison

Reflection Coefficient vs Frequency (GHz)

Legend: Sliding, Lowband, Broadband
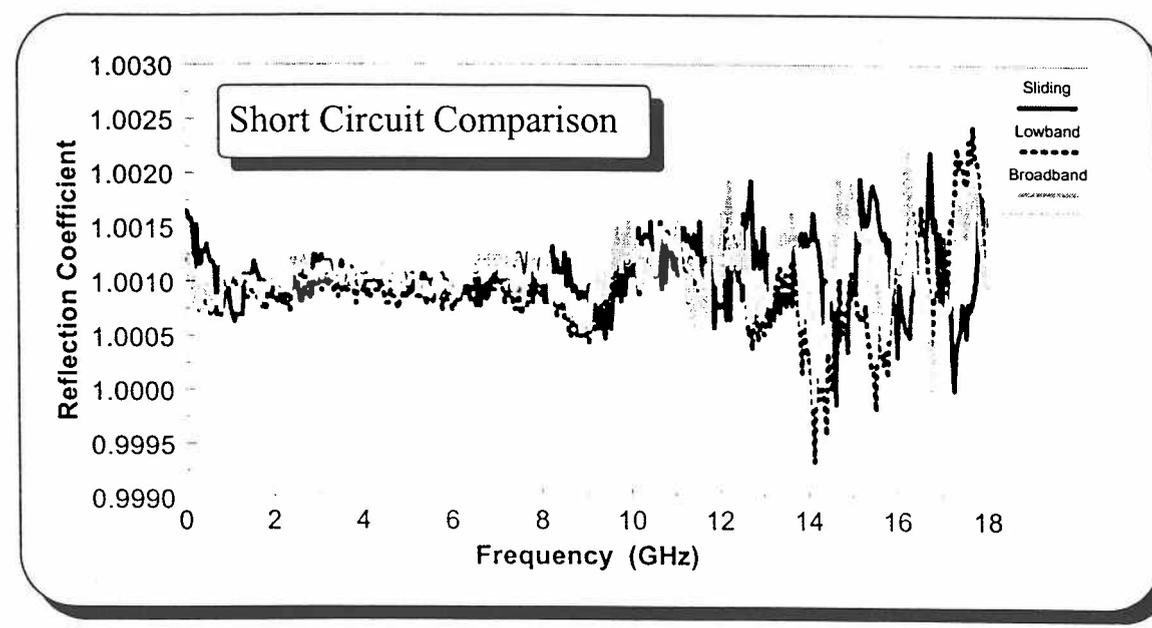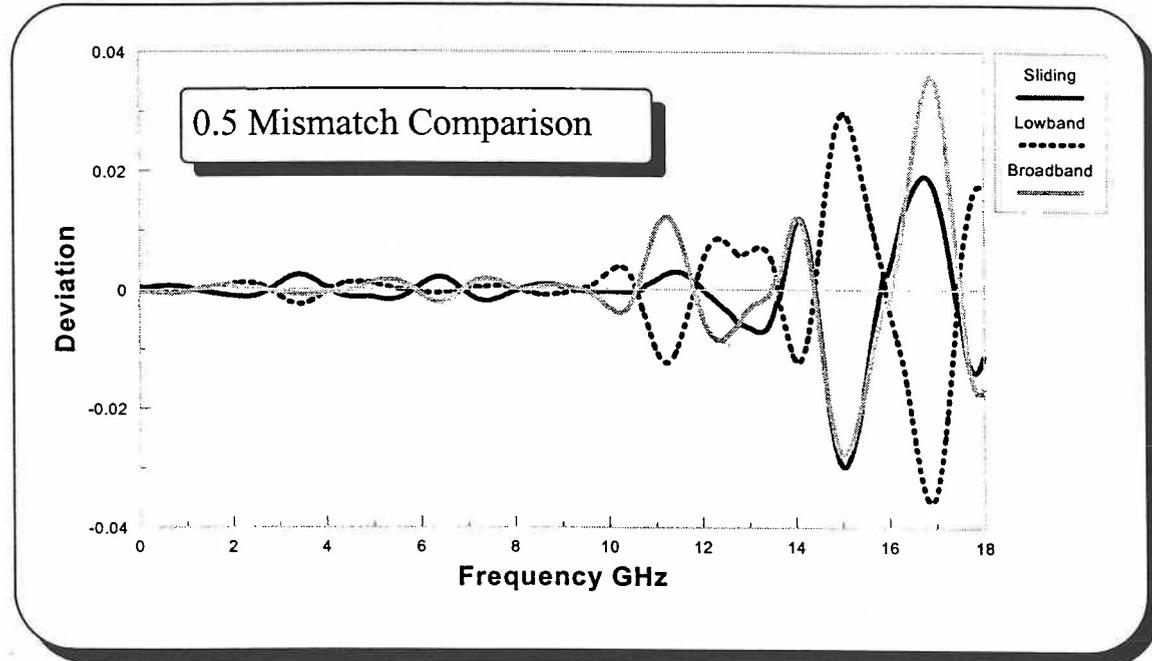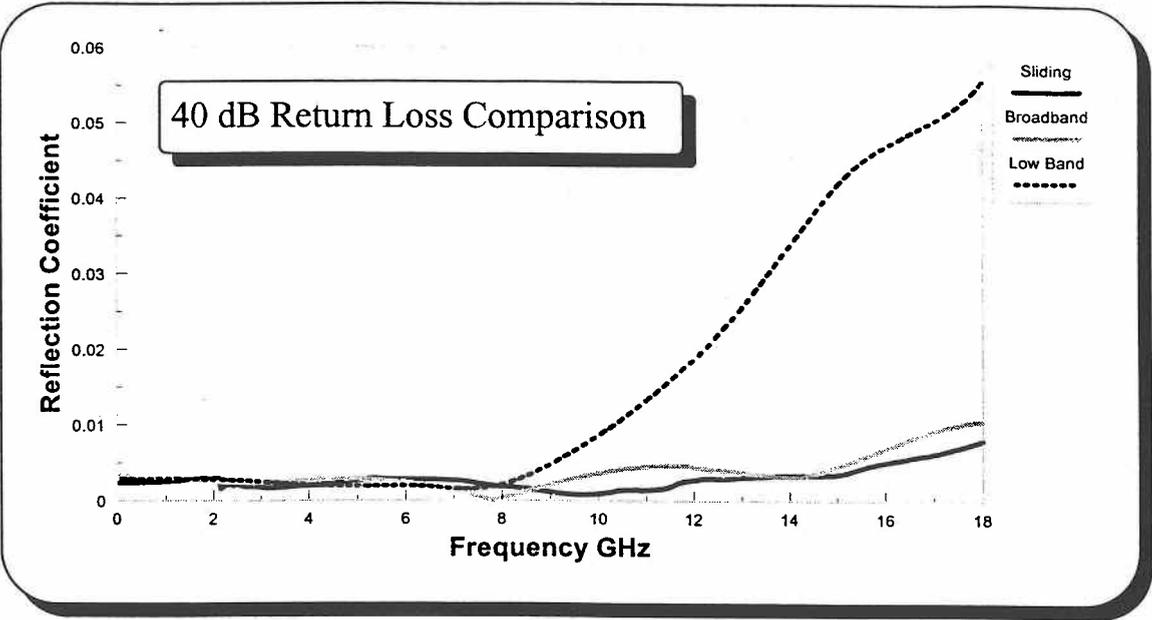
Two-port calibration techniques

by
Steve Harter, SESC, DERA Aquila

Two Port VNA Calibration Techniques

Error Correction Methods

There are two basic methods used widely in industry today. The first method uses known calibration artefacts to determine the systems error terms. There must be as many known characteristics of the calibration standards as there are error terms. The second method uses the redundancies that exist in the system equations to determine the system error terms as well as some of the characteristics of the calibration standards.

Four Known Two-Port ("SOLT") Calibration Method.

All the linear errors of the imperfect reflectometer can be combined into an error adapter yielding a system model with a perfect reflectometer combined with a fictitious error adapter. In this case, the fictitious error adapter must be a four port and has 12 error terms.

Three Two-Ports ("TRL") Calibration Method.

The 4-port system error adapter can be split into two 2-port error adapters, after removing the leakage (crosstalk) terms as a first step of calibration. It would appear there are 8 unknowns, however since all measurements made are ratios, there are actually only 7 error terms to calibrate. Measuring three 2 port standards yields a set of 12 equations and with this redundancy, the required error terms can be solved for directly plus 5 characteristics of the calibration standards.

There are a number of different two port calibration methods in common use:

Four Known Two Port Standards Methods:

OSL_f = Open, Short and Fixed Load.
OSL_s = Open, Short and Sliding Load.
SSL_o = Offset Short, Short and Offset Load
SSL_s = Offset Short, Short and Sliding Load.
SSS = Three Different Offset Shorts

Three Two-Port Standards Methods:

TRL= Thru, Reflect and Line.
LRL = Thru Line, Reflect and Line
TRM = Thru, Reflect and Matched Load.
LRM = Thru Line, Reflect and Matched Load
De-Embed = Characterize fixture, remove by math.

Two port VNA calibration method comparisons

Method	Coax	Wafer	WR-10	Ease	High G	Cost	Comments
OSLf	C	C		A	C-	A	Simple
OSLs	B			C	C	C	Traditional
SSLs	B	B	B+	C	B+	C	Traditional WG
SSS	B	C	C	B+	C+	A	One Std.
TRL/LRL	A	B	A	B	A	A/C	Accurate
TRM/LRM	B	B	B	A	B	A	Easy to use.
De-embed	B	C+	C	A/C	B-	A/C	Modelling.

Table 1.

The above table is an attempt at grading various calibration methods for different applications. The best method for low cost, easy to use coaxial calibration is the OSL$_f$ method. The most accurate calibration for coax is TRL. The best low cost and accurate method for waveguide is TRL. For fixtured or wafer probe systems the most accurate methods are either LRL or LRM. LRL is best if the desired reference impedance is the transmission line and LRM if the desired reference plane is a resistor. The easiest method to use for fixtured or wafer probe systems is LRM.

Electronic Calibration Modules

Solid state microwave two port calibration device. Unlike commonly used multiple one port or two port coaxial standards for the calibration of a VNA, the device can determine error coefficients automatically through a one time connection to a VNA. Certain designs claim that the accuracy of calibration is improved due to the reduction in connector non-repeatability and by the use of a least squared fitting algorithm to deduce one-port error model from the plurality of the reflection coefficients. Due to a one time connection, this method is physically more convenient, less prone to operator error, and less damaging to connectors. For improved accuracy transmission measurements a 'True Thru' cal connection of the test set cables can be made without the calibration module.

The new method can also perform simultaneous verification. Immediately after the calibration sequence, the module can present an additional known state, not used in the calibration.

Certainly simplifies the VNA calibration process for two port noninsertable devices.

Useful references:

1. Improved RF Hardware and Calibration Methods for Network Analysers, Roger Pollard & Douglas K. Rytting, BEMC 1991.

2. 'A Novel Procedure for Network Analyser Calibration and Verification', Vahe' Adamian, ARFTG Digest, Spring 93.

3. 'Test driving the Wiltron 36581NNF AUTOCAL ANA Calibrator', J.P.Ide, ANAMET Report 011.

Non-coaxial calibrations

by
Bill Oldfield, Anritsu-Wiltron

NON-COAX CALIBRATIONS
BILL OLDFIELD
ANTRISU

ABSTRACT

Most microwave circuits are not designed in coax. Microstrip and CPW are the most commonly used media. Coaxial connectors attached to these circuits often mask the true performance of the circuit. Calibration in the media of the circuit is the best solution, but it is not always simple. VNA calibrations are usually done in coax, and coax calibration kits are more readily available.

This paper will describe non-coax calibrations and how to accomplish them. Standards and the lack of standards will be discussed. Test equipment and its use will be described and examples given.

OUTLINE
        Few circuits are in coax
        Connectors mask circuit details
        Standards
        Calibration types LRL, SOLT, TRM
        Dot termination
        Test equipment
                Wafer probing
               Universal Test Fixtures
               Push On Fixtures POF's
        Example data

SUMMARY:

Background: Most circuits are built in microstrip or CPW topologies, while most microwave test equipment is built with coax test ports. This means that connectors must be built onto the circuits before they can be tested. Often the discontinuities of the connector-circuit interface mask the performance of the circuit itself. The main reason that microwave test equipment is built with coax is that coax connectors are easy to make and are familiar, and coax standards are also readily available to perform calibrations. Also we are accustomed to using circuits which are packaged with coax connectors so that they are easy to connect together to form systems or sub-systems.

In the distant past, single microwave circuits, such as switches, mixers, amplifiers, pads etc., were packaged as connected components. As time progressed, more and more circuits were integrated into a single connectorized package. But as more and more circuits are packaged into one housing, the problem of how to test each individual circuit becomes more critical.

Connectorless Testing: Wafer probing was one of the first chronologically and is still the first test in the process line. It was recognized that often circuits are cheap and packaging is expensive. Therefore testing circuits before packaging was a very good idea.

Historically the way to test an individual circuit was to build a special test fixture to accommodate it. Then great effort was made to "de-embed" the circuit from the connectors. This was very expensive and time consuming. The fixtures were expensive to build and the de-embed did not always fit the model.

The Universal Test Fixture (UTF) was introduced to simplify the testing of microstrip and CPW circuits. It could clamp connectors to a large variety of topologies and eliminate most test fixtures. It could also be calibrated in the microstrip or CPW transmission line of choice, eliminating the need to de-embed.

BUT! What were the standards for these measurements ? CPW and microstrip are dispersive. What does 50 ohms mean in this case? Is it possible to have standards with so many topologies having so many variables?

In the United States, NIST attempted to make a " Standard Calibration Substrate " However, this substrate topology was different from most of the topologies used by industry. It was found that a 10 mil alumina substrate was not much help as a standard for a 3 mil GaAs substrate.

Industry took their own approach. At Atritsu, time domain was used to compare the impedance of coax to the impedance of the microstrip or CPW standard lines. This did not solve the " What is 50 ohms?" problem but at least it compared the microstrip and CPW to a known standard.

CALIBRATION METHODS: OSLT is the most common coaxial VNA calibration technique. It requires a good termination for a good calibration. Good fixed terminations are very difficult to make, especially at higher frequencies. Fortunately, sliding loads are relatively easy to make and work well for calibrating. Good terminations are difficult to make in non-coax topologies, especially in microstrip. Fortunately, lines for LRL calibrations are very easy to make. LRL has the perceived limitation of an 8:1 bandwidth. I have done many tests and found that LRL calibration can go much lower in frequency that suggested by conventional wisdom. On a wide band wafer probe system, an LRL calibration covering 2 to 110 GHz gives good results. Even below 2 GHz the measurement results are generally good.

CONNECTING TO NON-COAX CIRCUITS: Wafer probes and Universal Test Fixtures have limitations. Wafer probing is best on wafers before they are diced, and does not do will on standard microstrip circuits. Universal Test Fixtures are OK but have limitations on size and number and placement of connectors. Both can work to 110 GHz, but UTFs become difficult to use at about 85 GHz because of radiation resonances between the jaw faces. A newly designed fixture called the POF (Push On Fixture) overcomes many of these difficulties and works well to 110 GHz.

Electronic calibrators

by
Barry Smith, Anritsu-Wiltron

AUTOCAL
AUTOMATIC VNA CALIBRATION

BARRY SMITH
BILL OLDFIELD
ANRITSU

ABSTRACT:

VNA calibration, especially in production environments, is a time consuming process that requires a skilled operator. Some of the latest production test requirements call for multi-connector and/or mixed connector types, which further complicates the calibration process. Automatic calibration can reduce these problems significantly. This paper will describe the Autocal system and present a simple solution to a complicated process.

OUTLINE

>   Need for Autocal
>   Place in hierarchy of cal types
>   Block diagram
>   Functional details
>   Connector types
>   CCTP
>   Multi-connections
>   Stability

SUMMARY

Automatic Calibration is substantially faster and less prone to operator error than standard calibration methods. The accuracy is slightly less than a standard sliding load calibration, but substantially better than a fixed load calibration

Automatic calibration (Autocal) of VNAs uses the concept that calibration standards do not have to be perfect, they only have to be known. The Autocal cal module consists of switches that select opens, shorts, loads and throughs at the request of the VNA being calibrated. All of the parameters of the Autocal module have been pre-measured and stored in an EEPROM located in the module. An external computer controls the VNA and the module and does the necessary calculations to provide a calibration to the VNA.

There are two types of Autocal modules. An electronic module using PIN switches covers 40 MHz to 20 GHz. An electromechanical module uses electromechanical switches and covers DC to 40 GHz. The Autocal module is available is two connector types. Type N and K Connector in the Electronic module and K connectors on the electromechanical module.

The modules with K connectors are part of the Autocal system which also provides convertible connectors for the test port cables. The CCTPs (Convertible Connector Test Port) allow the test port cables to be changed into Male or Female SMA connectors, 3.5mm Connectors or K Connectors with very little loss in accuracy. This is accomplished by making the CCTPs very simple, and different only at the connector interface. The interface is designed to cancel the capacitive interface that occurs when connectors of different types are mated.

The calibration accuracy of the Autocal modules is directly related to their stability. The modules have been exhaustively tested over the last two years and have proven exceptionally stable. The PIN switch modules are slightly more stable than the electromechanical versions. The electromechanical modules are similar in design to the "flipper" switch of high frequency step attenuators. These designs have a long history of stable performance.

Techniques where calibration kits are not available

by
Ian Instone, Hewlett Packard

Techniques Where Calibration Kits Are Not Available

Ian Instone, Hewlett-Packard Limited.

What can we do when provided with an instrument to measure and there is not a calibration kit available in that connector type ? The usual course of action is to use adapters connected to the instrument being measured and make all or some of the measurements at the adapter interface. In most cases this method is adequate, but it must be remembered that any measurements performed now include the adapters. For a reliable measurement of just the item we must remove the effects of the adapters. Many Network Analysers have an "adapter removal" routine built into the operating firmware, but for this to work effectively additional calibrations to characterise the adapters will be required. Consideration needs to be given to the trade-off in accuracy against the time required to complete the measurements.

The first thing we should consider is the acceptable quality of the measurement. In terms of measurement uncertainty we should aim for any uncertainties and errors to contribute to the overall uncertainty budget in a reasonably "insignificant" way. From Analyse Note Number 9 it is shown that "insignificant" can be defined as approximately 25% of the total uncertainty. Performing measurements using the "Adapter Removal" routines will usually produce the best results, but the measurement and set-up time will be much longer than the other methods described in this paper. The accuracy of measurements performed without using the "Adapter Removal" routine will be entirely dependant upon the quality of the adapters employed, corrections will normally be required and the accuracy of these corrections will also be dependant upon the quality of the adapters.

The adapters chosen must enable the item to be measured to be connected to the test port leads directly. Ideally, no more than one adapter should be used on each lead as the adapters will have a direct effect upon the measurement quality. Also be aware that in some cases two "good" quality adapters will produce smaller uncertainties than one "lower" quality adapter. Follow either procedure shown above but note that in most cases it is possible, if only correcting for the insertion loss (and phase) of the adapters it is usually possible to save the adapter measurements in the network analyser's memory and then subtract them from the measurement of the adapters plus the item. If "good" adapters are employed for this procedure it is very often not necessary to make corrections for reflection magnitude, usually just increasing the measurement uncertainty (due to the uncorrected adapter) is adequate. Many "good" adapters have a reflection coefficient of better than 0.02 across their operating frequency range.

Adapters are easiest to measure in insertable pairs. If possible it is best to use adapters which are of similar length so that when they are measured we can assume that each adapter contributes to the measured loss and phase shift equally. The reflection coefficient of the adapter pair should be measured but corrections for the reflection coefficient measurements can only be applied if phase and magnitude measurements are made for all four S-parameters. This can be time consuming so it is often much easier to use the recorded value of refection coefficient magnitude as a contribution in the uncertainty budget. It is often assumed that the adapters reflection coefficient magnitudes add in a quadratic fashion.

Non-insertable devices pose some of the most difficult measurement problems, even when using the adapter removal routine built into most modern network analysers. Again, it is important to have an understanding of the users requirements, it might well be acceptable to perform a calibration in a convenient connector type, then add the adapters and the device and make measurements. The measurements will include the adapters, but at low to mid microwave frequencies most "good" quality adapters will have a fairly negligible effect. In cases where better accuracy is desired the adapters will need to be measured. For non-insertable devices with similar connectors it may be possible to use adapters which are sold in "phase & loss" matched pairs.

These work on the principle that the χ-to-male adapter has the same physical loss and phase shift as the χ-to-female adapter. In this way the loss of two χ-to-male adapters can be reasonably approximated by measuring the insertable pair. Several assumptions are made which unfortunately are difficult to prove. Many manufacturers make male and female adapters which they advertise as being of similar loss and phase characteristics. For this to be true we can also assume that the reflection parameters should be similar. This measurement technique relies on these similarities to arrive at a assumed loss and phase shift value for each adapter which is to be used in the measurement process. The accuracy of this technique can be improved slightly by measuring each adapter to be measured with a similar one of the opposite sex (to form an insertable pair) and use the average values from the measurements as corrections. The most accurate methods will make at least three measurements using different adapters and produce simultaneous equations which can be solved for each adapter. This technique is used less frequently as the improved accuracy is at the expense of increased measurement and calculation time.

Non-insertable devices with dis-similar connectors are the most difficult to measure. Devices often falling into this category are couplers, splitters, combiners, and sometimes cables. Measurement techniques are similar to those shown previously, but each adapter used must be measured with a similar one of the opposite sex. Measurement uncertainties relating to each adapter used in the measurement process must be considered in the same way as the previously. It is often "normal" practice to ignore the effects of the adapters on the reflection measurements, instead putting an additional allowance in the uncertainty budget. A rough and ready estimate for this additional contribution can be obtained during the insertion loss measurement test performed to characterise the adapters. The analyser can be set to display either S_{11} or S_{22} and the reflection coefficient of the adapter pair shown. We could assume that each adapter contributes to this total in a quadratic manner, and this value should be added to any uncertainties of measurement performed with one of the adapters.

Time domain gating is a process whereby the measurements made in the Frequency Domain are mathematically converted into the Time Domain. Any discontinuities in the transmission line (such as connections) then show as a spike on the display and can be "Gated Out". The measurements can then be converted back into the Frequency Domain and the characteristics of the device being measured can be displayed. Time domain measurements are not without their problems, in order to obtain the best resolution in the Time Domain high frequencies must be used. Unfortunately, measurements in the top 10% and bottom 10% of the frequency band cannot be considered reliable. As the top frequency goes higher, so does the frequency below which measurements are considered unreliable. The use of the Time Domain function on any network analyser requires a lot of skill. It is very easy to make the same measurements several times and get very different results every time.

This paper has demonstrated some "rough and ready" methods of making microwave measurements when the appropriate calibration kit is not available. In terms of reflection coefficient the adapter used will often dominate the measurement uncertainties and this need to be borne in mind when measurements in this way. In terms of attenuation or insertion loss, the adapters loss and phase shift can be reasonably easily corrected for and will tend to have little effect upon the measurement uncertainties. However, if lower quality adapters are used their own reflection coefficient might be sufficient to degrade the equivalent load match and equivalent source match terms of the network analyser. This will in turn affect the accuracy of the insertion loss and attenuation measurements made on the instrument being calibrated.

Calibration - some good practice tips

by
Doug Skinner, Marconi Instruments

The text which accompanied this presentation will
be issued, in the near future, as an ANAMET Report.

Shop floor calibration considerations

by
Dave Hepworth, EEV

Shop Floor Calibration Considerations.

Synopsis of talk.

There are two main areas of use for V.N.A.'s in the industrial environment at EEV. These will be dealt with separately as each has it's own considerations.

As a production tool.

The use of a V.N.A. for regular testing on a production line raises several issues.

① What is the specification for the device being tested? - Accuracy vs time

② What connector type is being used?

③ How frequently are devices being tested?

④ What are the environmental conditions?

⑤ Use of Trend Analysis to check calibration validity.

As a calibration standard for measurement systems.

① What is the specification for the calibrations carried out:-

      1. Transmission media
      2. Type of calibration - What is being measured?
      3. Type of calibration - mixed connectors?
      4. Application
      5. Special measurements

② Accuracy vs time

③ Interpretation of results - Low to High power

④ Calibration kits

⑤ Verification of standards

⑥ Production vs calibration

⑦ Unusual connectors

Conclusion

Summary of the salient points with questions if requested.

Contact: David Hepworth
                          Magnetron Applications
                          EEV Ltd
                          106 Waterhouse Lane
                          Chelmsford
                          Essex
                          CM1 2QU

Discussion session

A look at TRM calibrations

TRM CALIBRATIONS
BILL OLDFIELD
ANRITSU

ABSTRACT

Accurate VNA calibration is always a laborious task, requiring a sliding load and a lot of time and expertise. If a fixed load is used instead of the sliding load, accuracy of calibration is considerably reduced due to the relative poor quality of fixed loads. Also the OSLT (Open, Short, Load, Thru) calibration is difficult if the DUT was not an insertable, (male/female connectors). Another problem with the OSTL calibration is the requirement that fringing coefficients be supplied with the Open. LRL calibrations can overcome these problems but they are difficult to use and are narrow band.

This paper will describe new cal kits using the TRM (Thru, Reflect, Match) technique. This technique uses the same mathematics as LRL, but is inherently broad band. The heart of the new cal kit is a very low reflection termination which will be described in detail.

OUTLINE

> Much simpler calibration. Fewer steps
> New terminations with very small reflection
> Calibration type comparisons
> > Accuracy comparisons
> > Speed comparisons
>
> Connectors
> > The non-insertable problem
> > Connector types
> > CCTP (Convertible Connector Test Ports)

SUMMARY

The new cal kits use the TRM (Thru, Reflect, Match) technique. This technique uses the same mathematics as LRL but is inherently broad band. The major limitation of this technique was the generally poor quality of broadband terminations, the typical Return Loss of a Precision Termination is about 27 dB at the higher frequencies.

A newly designed ultra low reflection termination eliminates this limitation. The Return Loss of these terminations is greater than 40 dB to 40 GHz. The termination uses a planar thin film substrate as both the termination element and the center conductor support. The slotted outer conductor provides a "soft" transition from coax to stripline, while also providing the proper ground shape for a reflectionless transition from 50 ohms to ground.

The specified performance of various cal kit types is shown in Table 1. The specification of the TRM cal kit is very close to the specification for a sliding load cal kit; typical performance is even closer for most operators. Ultimately a highly skilled operator can get better performance from a sliding load cal kit, but the difference is slight. Three kits are available, K Connector, 3.5mm and Type N. The Type N performance is up to 18 GHz.

CAL TYPE	DIRECTIVITY TO 20 GHz	DIRECTIVITY 20 to 40 GHz	SOURCE MATCH TO 20 GHz	SOURCE MATCH 20 TO 40 GHz
OSL FIXED LOAD	30	26	25	22
OSL SLIDING LOAD	42	38	40	33
NEW TRM	38	36	34	32

TABLE 1

The time and ease of use benefits of the TRM cal kit are shown in Table 2

CALIBRATION TYPE	NUMBER OF STANDARDS CONNECTED	NUMBER OF BUTTONS PRESSED	TYPICAL TIME TO CALIBRATE MIN
LINE-REFLECT MATCH	5	10	3
OPEN SHORT LOAD FIXED	7	14	5
OPEN SHORT LOAD SLIDING	9	38	12

TABLE 2

One of the major benefits of the TRM calibration technique is that the connectors of the DUT do not have to be of the same type. Even coax on one side and waveguide on the other can be calibrated. The only difficulty is that a through connection must be constructed. A non-perfect through will only affect the load match and to a lesser extent the source match and the frequency tracking. The directivity only depends on the quality of the terminations used.

A series of adapters is used to configure the test ports to the desired connector sex. The adapters are all phase equal and the support beads are a newly developed low reflection design; typical performance is greater than 40 dB Return Loss to 30 GHz and greater than 37 dB to 40 GHz. However, the reflections of the adapters are calibrated out during the calibration process. The through connection is made by changing one of the adapters to allow a through connection. For instance, if the desired test ports are female-female, the termination used for both test ports would be female, but the through connection would have one of the female test port adapters changed to a male adapter. If the two adapters have similar reflections, their effect will be calibrated out. Any reflection difference between the adapters will only affect the load match, not the directivity. Typically the reflection difference between adapters is greater than 40 dB. These adapters are discussed in more detail in a companion paper

The new TRL cal kits provide a faster, more accurate calibration that standard OSLT calibrations as well as providing a wide connector selection without degrading the calibration.