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ANAMET REPORT

Calibrating an ANA -
Techniques where calibration
kits are not available

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CALIBRATING AN ANA - TECHNIQUES WHERE CALIBRATION KITS ARE NOT AVAILABLE

Foreword

This report is an extension to the synopsis which accompanied the presentation "Techniques where calibration kits are not available", given at 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 report includes copies of the viewfoils used for the presentation, along with some explanatory text.

Nick Ridler
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February 1998

Techniques Where Calibration Kits Are Not Available

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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.

Measurement Quality ?

- What level of measurement is required ? consider uncertainty, cost measurement speed etc.
- Is there a calibration kit available which covers the required frequency range ?
- Are there some good quality adapters available to connect the DUT to the ANA after calibration ?
- What effect do the adapters have and will we need to compensate for them ?

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.

Measurement Procedure (two port measurements)

- Select adapters to suite calibration kit and item to be measured
- Perform calibration with the available calibration kit
- Connect adapters to test port leads
- Connect adapters together
- Measure adapters (all 4 S-parameters)
- Decide: Correct for adapters, or
 Ignore adapters
- Make measurements
- Apply corrections



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 the procedure shown above but note that in most cases it is possible, if 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 it from the measurement of the adapters + item (as apply corrections above).

If “good” adapters are employed for this procedure it is very often not necessary to make corrections for reflection magnitude, usually 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.

Quantifying Adapters

- Quickest: Where possible measure adapters in “insertable and matched” pairs
- Measure the reflection coefficient of the pair and assume that the VRC of each adapter is added in quadrature
- Measure the insertion loss of the pair and subtract this measurement from the total
- If insertion phase measurements are required they can be treated in the same way as insertion loss, but be careful applying corrections when the angles are close to 0° or 360°
- Where the item being measured is not insertable adapters will need to be measured and certain assumptions made

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. Corrections for the reflection coefficient measurements can only be applied if phase and magnitude measurements are used for all four S-parameters. This can be time consuming so it is often much easier to use the recorded value of reflection coefficient magnitude as a contribution in the uncertainty budget. It is often assumed that the adapters reflection coefficient magnitudes add in an RSS fashion. Adapters used to measure non-insertable devices will need to be treated differently, a method is shown on the next page.

Non-Insertable Measurements

- Adapters could be ignored !
- Measure several insertable pairs and arrive at a consensus value for insertion loss and reflection coefficient
- Phase measurements will be difficult, consider other methods if phase measurements are important

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 x-to-male adapter has the same physical loss and phase shift as the x-to-female adapter. In this way the loss of two x-to-male adapters can be reasonably approximated by measuring the insertable pair.

Measuring Adapters For Non-insertable Devices With Similar Sex Connectors

- Measure matched pair Male to Female
- Assume that Male = Female and that all adapters are equal in phase shift and loss
- Make corrections
- Consider uncertainties:-
The assumption that all adapters are equal may be incorrect so the assumed uncertainty in the measurement of the adapter should be of the same magnitude as the measured value

The process of making measurements on non-insertable devices where there is not a suitable calibration kit is shown above. 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 and produce simultaneous equations which can be solved for each adapter. This technique is used less frequently as the improved accuracy is often at the expense of increased measurement and calculation time.

Measuring Adapters For Non-insertable Devices With Dis-similar Connectors

- Need male - female insertable matched pairs of adapters for each connector on device being measured
- Measure the insertable pairs of adapters
- Assume that the male & female of each insertable pair have similar loss and phase characteristics and therefore the loss & phase shift of one adapter is half the measurement of the total
- Make measurements on the device to be measured
- Make corrections
- Consider the uncertainties



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 on the previous slide, 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 previous slide. It is often "normal" practice to ignore the effects of the adapters on the reflection measurements, instead adding 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 S11 or S22 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

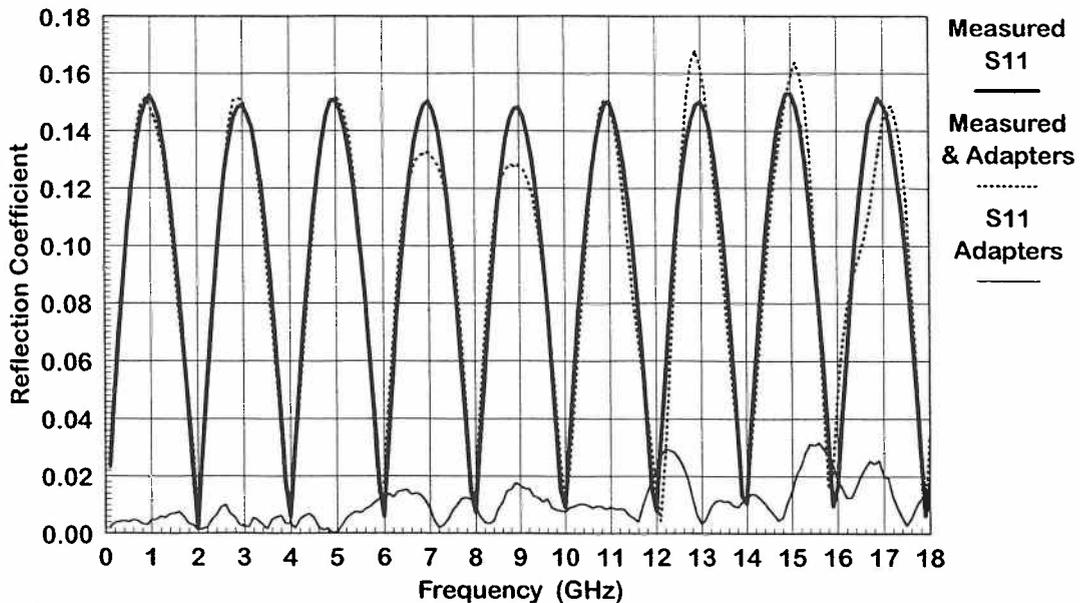
- Time domain gating is a method of mathematically locating discontinuities within a transmission line and then "removing" them from the measurements. It is often built into the firmware on modern network analysers.
- Traceability of measurement can be difficult to demonstrate
- Time domain measurements require a lot of skill
- The accuracy of time domain measurements deteriorates in the bottom 10% and top 10% of the frequency axis

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, so 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.

0.15 Γ Airline S₁₁ Reflection Magnitude Measurements



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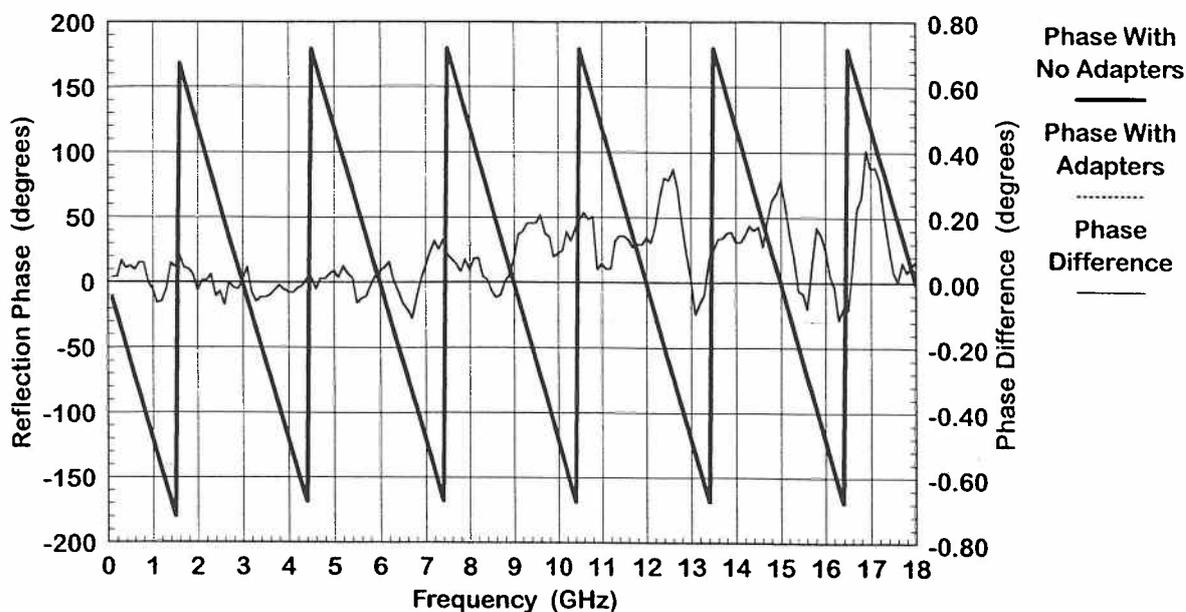
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The following measurements were performed to demonstrate the quality of measurements which are obtained when good quality adapters are connected to the DUT and simple algebraic correction employed.

This slide shows reflection magnitude measurement on a 0.15 rho APC-7 airline using an APC-7 full two port calibration and also, using the same calibration the airline has been measured through adapters. The differences are therefore only due to the effects of the adapters. The trace at the bottom is the reflection coefficient of the adapters when connected together. If we assumed that the measurement uncertainty when using the APC-7 calibration was negligible of very small, we could estimate the additional reflection magnitude uncertainty by constructing a nominally straight line along the peaks of the adapters trace.

0.15 Γ Airline S_{11} Reflection Phase Measurements



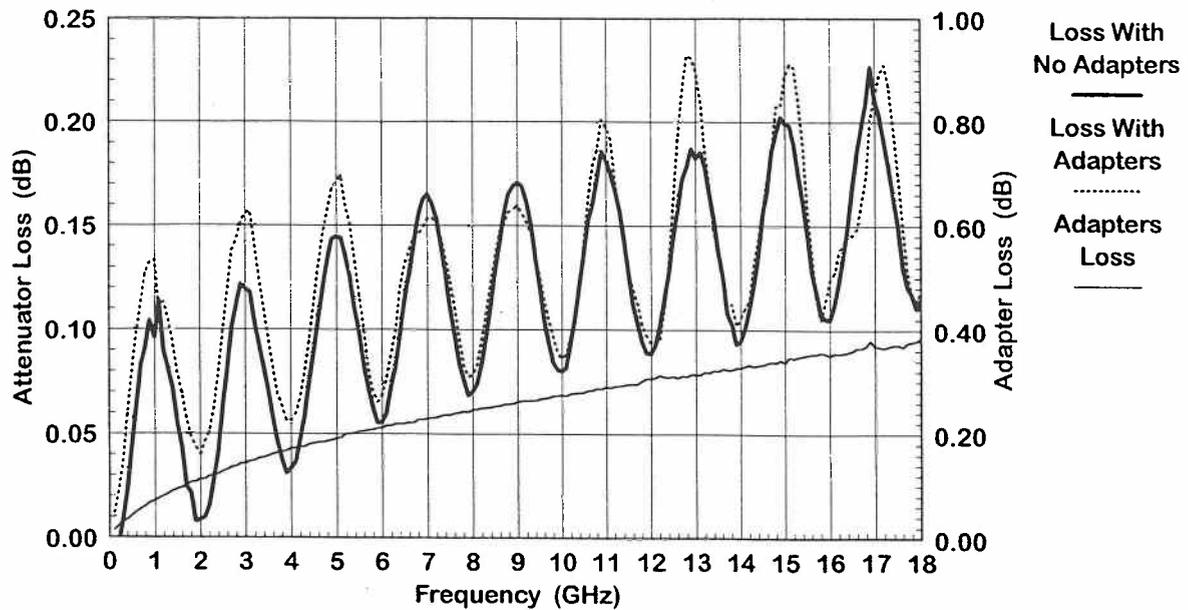
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This slide shows reflection phase measurements on the same airline. Again the reflection phase of the adapters has been subtracted from the measurements performed using the adapters. Because the two sets of measurements are so similar the thin trace was added which shows the difference between the two sets of measurements. The difference is less than 0.5° across the band, it is generally difficult to discern phase measurements to this level as the stability of the cables and repeatability of the system often exceed this value.

0.15 Γ Airline Transmission Loss Measurement Through Adapters



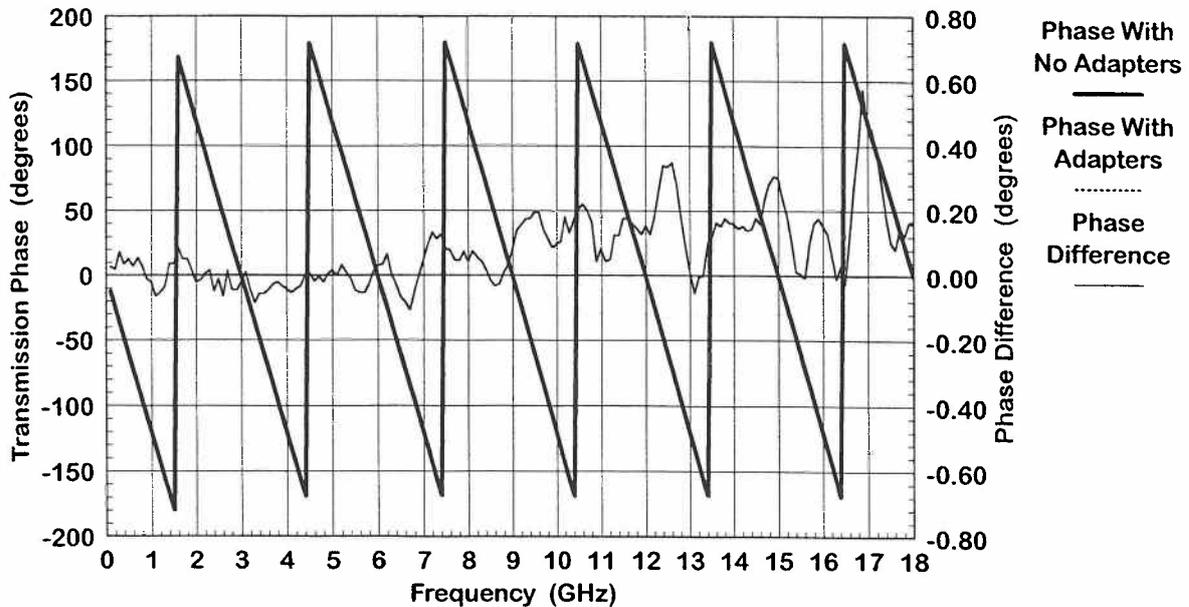
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This slide shows the transmission magnitude measurements of the same 0.15 rho airline. The effects of the adapters have been removed using simple subtraction. As shown, this technique works very well where the match of the airline approaches 50 ohms (the lower peaks) but as the match moves away from 50 ohms (towards the higher peaks) the difference between using and not using adapters becomes more obvious. Also note that the effects of mismatch loss uncertainty do not always produce higher values of loss, in some cases have combined to produce measured values lower than expected.

0.15 Γ Airline Transmission Phase Measurement Through Adapters



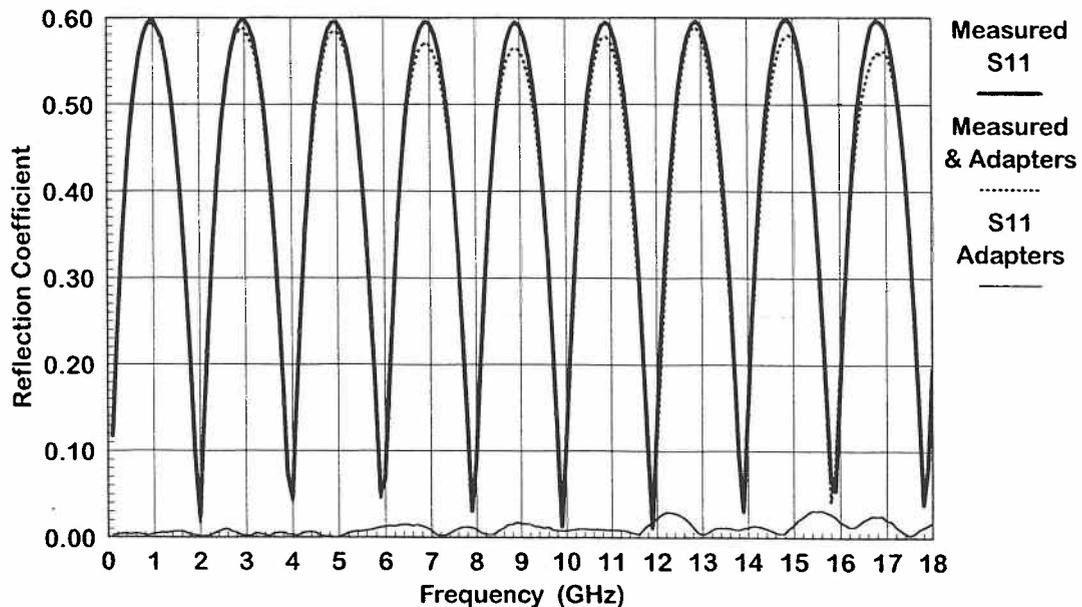
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This slide shows the transmission phase measurements performed on the same airline. Again, after the effects of the adapters have been algebraically removed from the measurements with adapters both sets of measurements look very similar. The thinner trace shows the phase difference between the two traces. As with the reflection measurements these phase differences are very small and could be accounted for with the repeatability of the analyser and its cables.

0.60 Γ Airline S_{11} Reflection Magnitude Measurements



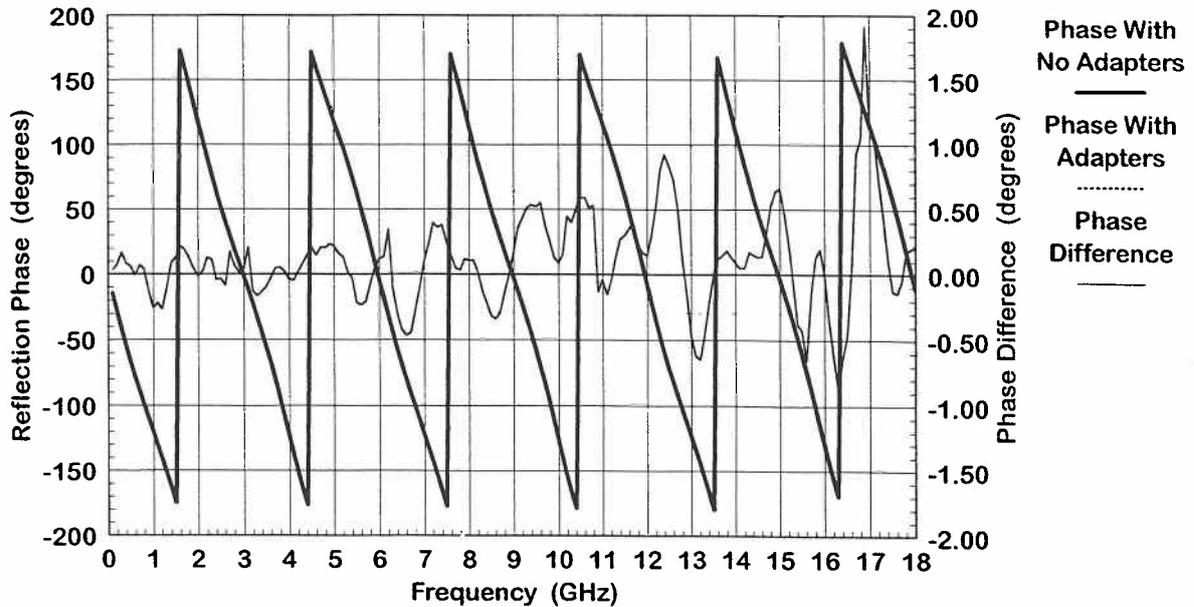
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As the mismatches become larger so the uncertainties increase. This slide shows reflection magnitude measurements performed on a 0.6 rho airline. Note that all of the measured values when using the adapters are less than those when the airline was measured directly. This is because the adapters have some loss. Reflection measurements will see twice this loss (once as the signal travels to the airline and once again as it returns) in addition to the "return loss" of the airline. Where the airline has a poor match (low return loss) the loss of the adapters will become more significant. In this case the airline has a return loss of about 6 dB and the adapters have a transmission loss of 0.2 dB in each direction.

0.60 Γ Airline S_{11} Reflection Phase Measurements



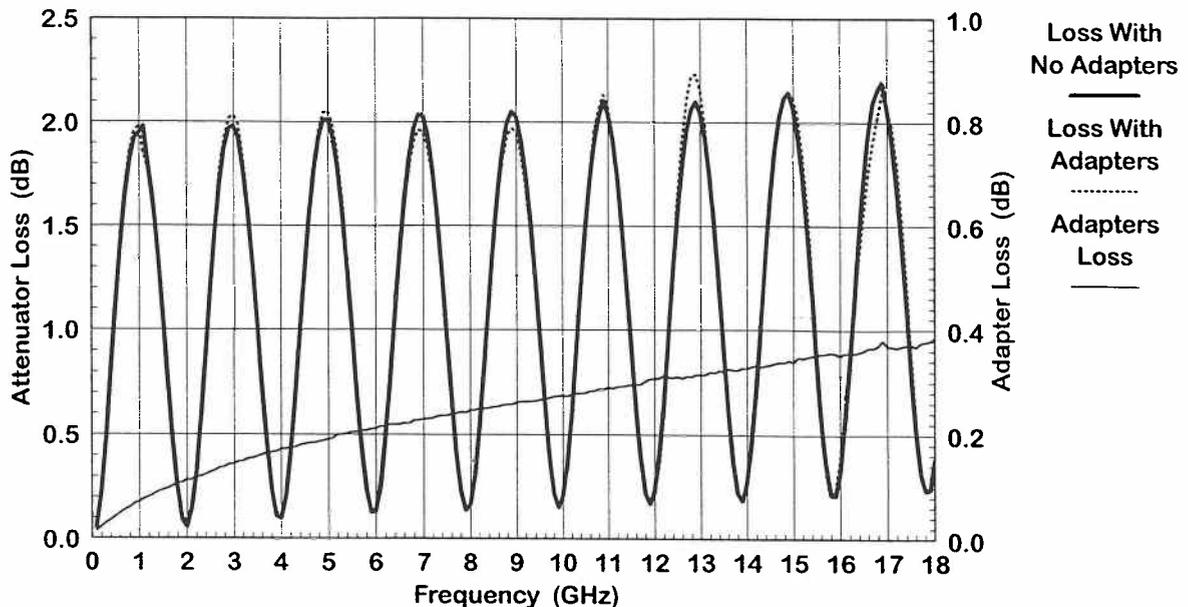
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Again, as the mismatch increases so do the uncertainties, as shown on this slide showing reflection phase measurements on a 0.6 rho airline. Although the "corrected" measurements are close to those performed without adapters, the difference between the two sets of measurements has now increased to 2° at the worst case. This deviation, however is still perfectly adequate for many measurements.

0.60 Γ Airline Transmission Loss Measurement Through Adapters



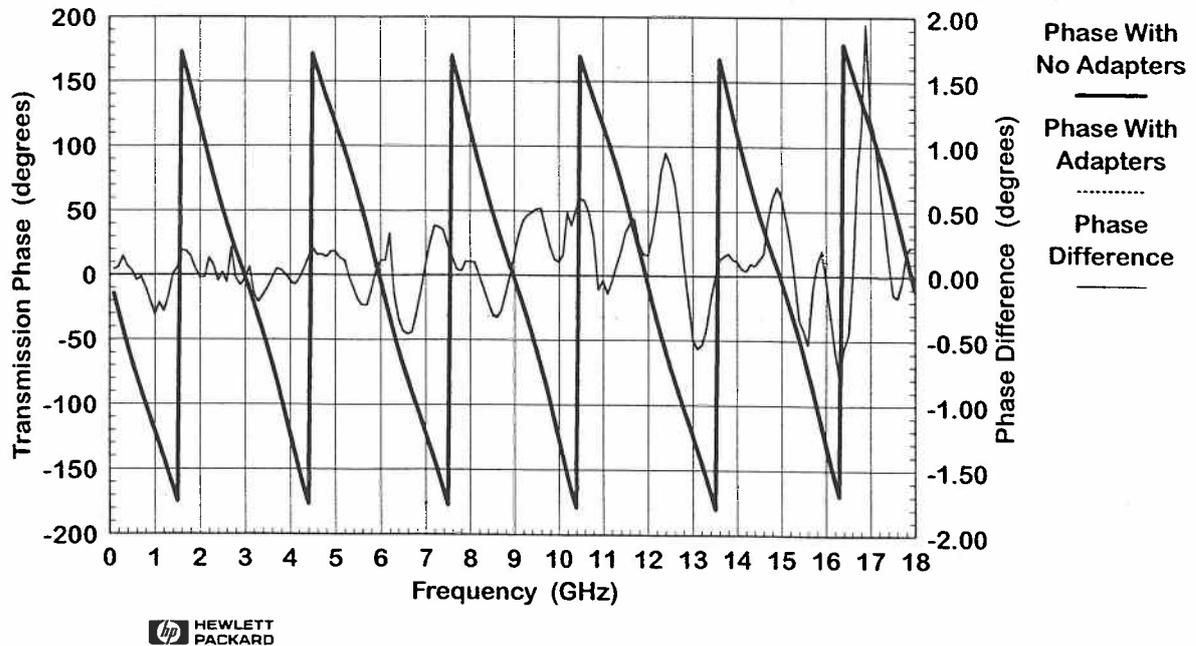
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This slide shows the transmission magnitude loss when the airline is measured directly or through adapters after a simple algebraic correction is applied. Please note the scale, the deviation between the traces is now in the order of 0.6 dB at the worst case. Also note again that the errors when measuring through adapters can either add or subtract, making them a true uncertainty. If more information is used in the "adapter removal" algorithm (all four s-parameters in terms of phase and magnitude) it is possible to fully correct these errors. The objective here, however was to demonstrate some simple and quick techniques for making measurements through adapters.

0.60 Γ Airline Transmission Phase Measurement Through Adapters



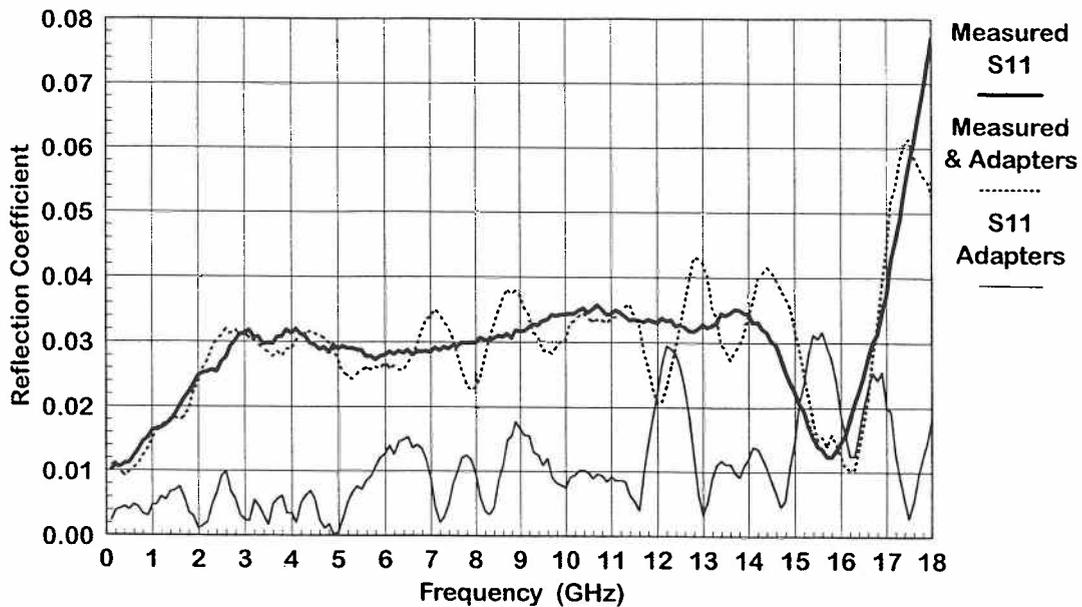
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The transmission phase measurements of the 0.6 rho airline is showing the same tendencies as previous slides, as the mismatch moves away from 50 ohm the errors become greater. Again, although the worst case difference between the two sets of measurements is now 2° they are still adequate for all but the most exacting applications.

10 dB Attenuator S_{11} Reflection Measurements



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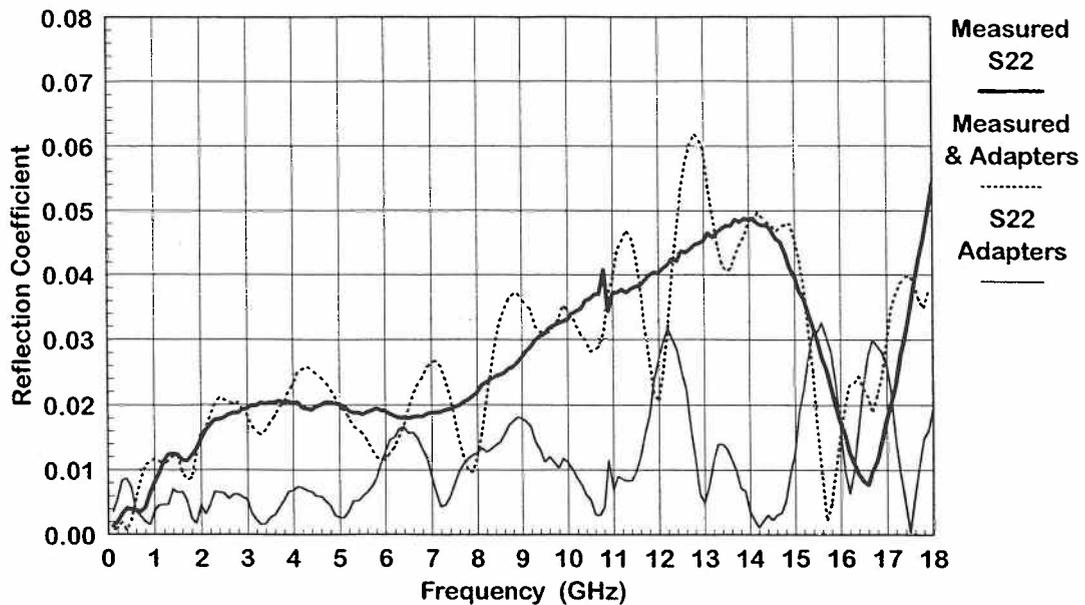
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Airlines have a predictable response but because they have very little loss between the ports any imperfections in the measurement equipment, adapters or cables can be imposed on all measurements. If an attenuator is used the effects of mismatch loss uncertainty and the uncertainties in the measurement of the mismatch tend to be isolated to the parameter being measured, for instance the mismatch measurement on port 1 will be influenced by the termination of port 2 to a much lesser extent. The isolation offered by an attenuator therefore enables us to look more easily at the individual parameters.

This slide shows the reflection magnitude measurements performed on port 1 of a 10 dB APC-7 attenuator. The effects of the adapters are clearly seen, and because the adapters mismatch is of the same order as the attenuators the additional error becomes quite significant.

10 dB Attenuator S_{22} Reflection Measurements



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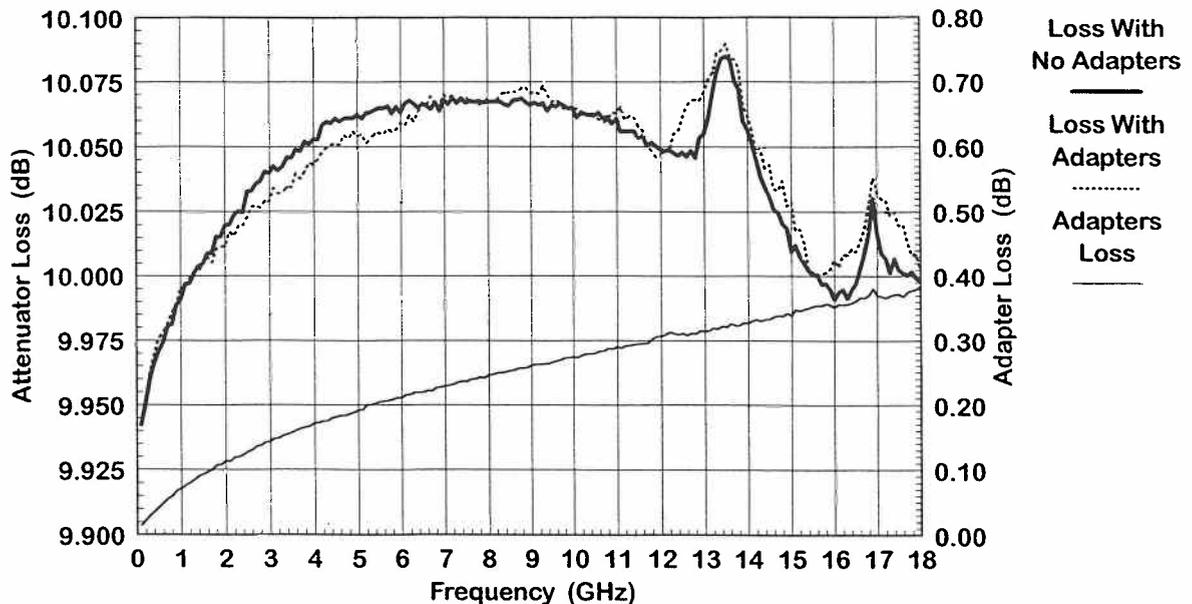
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This is the other port of the same attenuator. It is interesting to try to correlate the mismatch of the adapters and attenuator with the errors when using the adapters. Correlation is not immediately obvious as we are only looking in magnitude terms. The errors are generated as the phase vectors rotate around causing the effects of mismatch to interact with each other. The worst deviation therefore might occur away from the peaks of mismatch, but where the phase components have also combined to produce the largest combination.

A similar exercise was performed for reflection phase measurements. Unfortunately, because the adapters mismatch is in the same order as the attenuators mismatch the traces looked more like a noise plot.

10 dB Loss Measurement Through Adapters



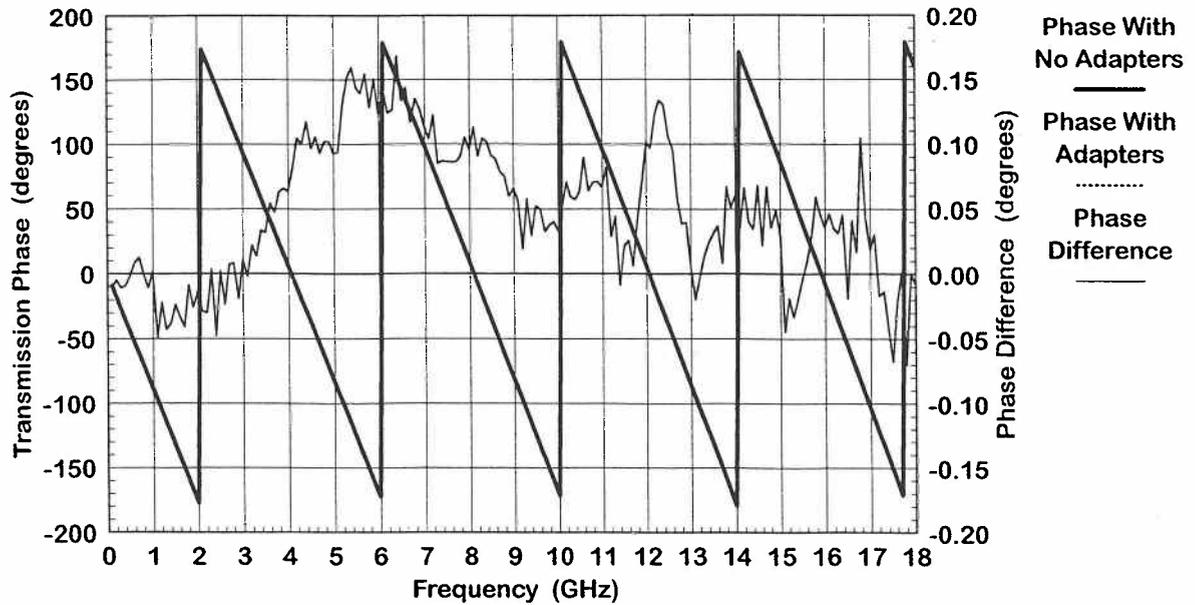
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The transmission magnitude measurement using adapters looks a lot more predictable. Notice again that although we refer to “mismatch loss uncertainty” the term can appear to have “gain” (see the 2 GHz to 6 GHz plot above). The attenuator has a reasonably good match at its ports, the adapters also have a reasonably good match so the errors observed when making measurements through adapters in this case are not too large.

10 dB Transmission Phase Measurement Through Adapters



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With some isolation between the ports and reasonably matched adapters etc. the measurement of phase can be excellent, even when using adapters. The differences shown here are well within the repeatability of the analyser and it's cables.

Conclusions

- This presentation has tried to demonstrate some “rough and ready” ways to measure the characteristics of a particular device when it may not be possible to perform a full error correction at the test port interface.
- Inevitably there are compromises to be made, with some forethought these compromises need not always have a significant effect upon the measurements.
- Measurement of very low Reflection Coefficients is always difficult, it is very likely that any adapters used would swamp the measurement.

This presentation 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 making 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 term affect the accuracy of the insertion loss and attenuation measurements.

