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Improve Test Throughput for Duplexers and Other Multiport Devices

David Ballo

Hewlett-Packard Company
Microwave Instruments Division
1400 Fountaingrove Parkway
Santa Rosa, California 95403
U.S.A.

1996 Device Test Seminar

Effective Test Methods for Today's RF Devices

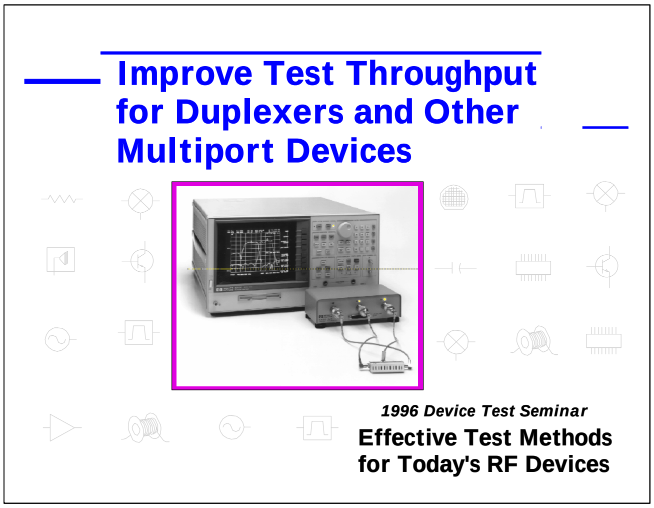
Abstract

Many of the components necessary for today's wireless communications systems have three or more ports, requiring multiple connections for complete characterization with a two-port network analyzer. You can simplify high-volume tuning and testing of these devices by using a multiport test set between your device under test (DUT) and a network analyzer. This paper discusses several applications where multiport test sets are useful, for example, tuning and testing duplexers. The impact of these test sets on the raw performance of a test system is covered, along with calibration issues and strategies and the associated measurement uncertainty.

David Ballo is currently a Market Development Engineer for Hewlett-Packard's Microwave Instruments Division in Santa Rosa, California. David has worked for HP for over 15 years, where he has acquired extensive RF and microwave measurement experience. After getting a BSEE from the University of Washington in Seattle in 1980, he spent the first ten years in R&D doing analog and RF circuit design on a variety of Modular Measurement System (MMS) instruments. He followed that with a year in manufacturing. For the past four years, he has worked in the marketing department developing application notes, magazine articles, and seminar papers on topics including TWT amplifier test, group delay and AM to PM conversion of frequency- translating devices, adjacent-channel power measurements, and designing and calibrating RF fixtures for surface-mount devices.

Improve Test Throughput for Duplexers and Other Multiport Devices

Slide #1



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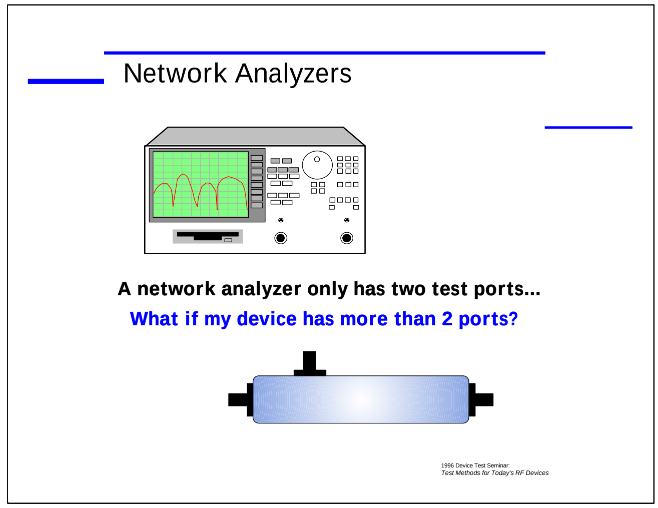

Traditional two-port network analyzers are the principle instruments used for RF component test. They provide frequency and power sweeps with displays of magnitude and phase data, allowing you to perform a variety of parametric tests to completely and accurately characterize your RF devices. However, many of the devices necessary for today's communications systems have more than two ports (we will refer to components falling into this class as multiport devices). Complete characterization of multiport devices with a two-port network analyzer requires multiple connections to test all of the signal paths and ports.

You can simplify high-volume tuning and testing of multiport devices by using a multiport test set between your device under test (DUT) and a network analyzer. A multiport test set lets you test all desired signal paths and ports while connecting to the DUT only once.

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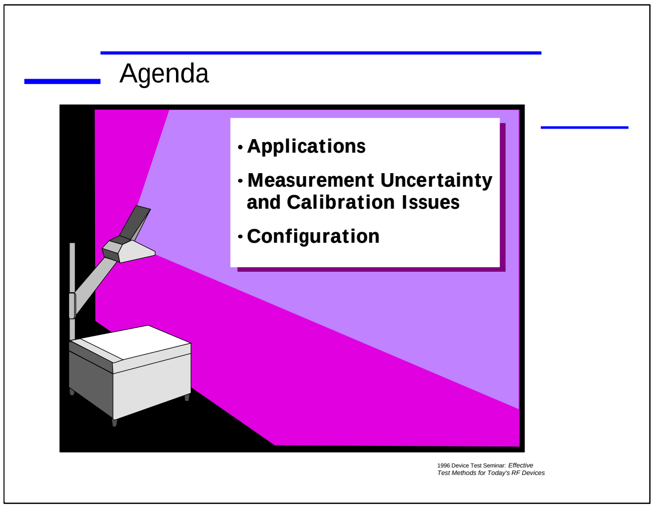

This paper will explore the use of multiport test sets with network analyzers. The term "multiport test set" is meant to include anything between the network analyzer and a multiport DUT. We will start out by discussing several applications where multiport test sets can be extremely helpful, such as for duplexer tuning and testing. We will look at how various applications might affect the design of the multiport test set. The next section will provide an in-depth look at performance and calibration issues. We will see that multiport test sets can significantly degrade the raw (uncorrected) performance of the test system, making calibration very important. Finally, we will briefly cover how multiport test sets are configured to work with Hewlett-Packard's family of RF network analyzers.

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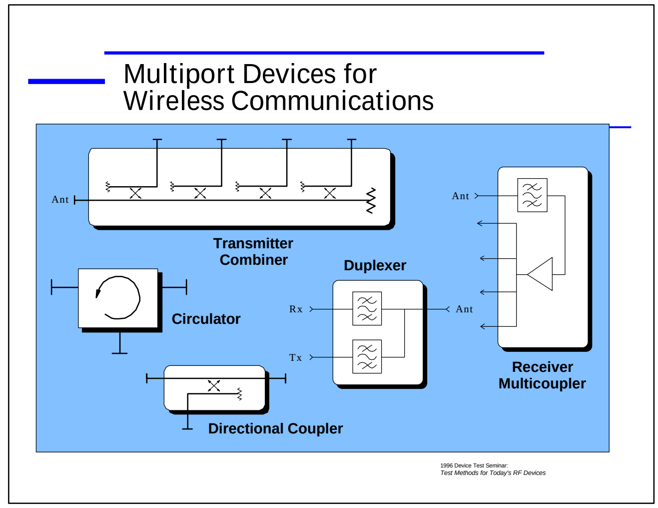

Multiport devices used for wireless communications vary from three to many ports. Duplexers are manufactured in very large volumes since they are needed in every cellular, cordless or personal-communications telephone hand-set, and in the corresponding base stations. Other base-station components include directional couplers, circulators, transmitter combiners and receiver multicouplers. These latter devices are used to amplify RF signals coming from an antenna and to divide them into multiple outputs for different receivers.

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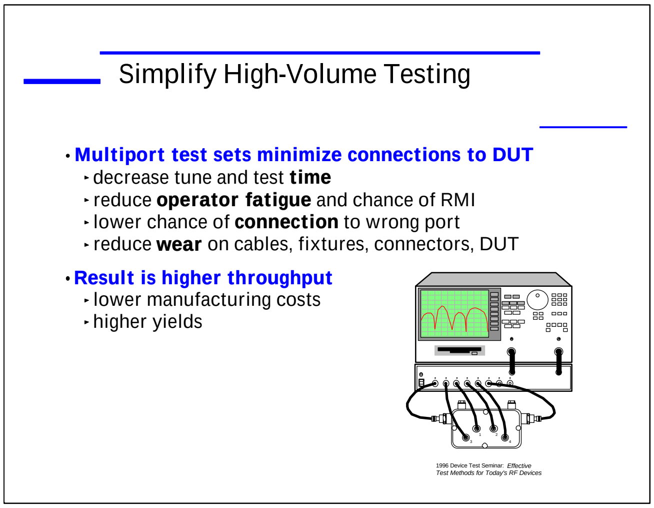

Multiport test sets dramatically reduce overall tune and test times because the DUT only needs to be connected once to test multiple signal paths. Minimizing the number of connections also reduces operator fatigue and lowers the chance of connection to the wrong port. In addition, fewer connections means less wear on cables, connectors, fixtures and DUTs.

The use of multiport test sets can result in higher test-throughput and higher yields, both of which serve to lower manufacturing costs. reduce

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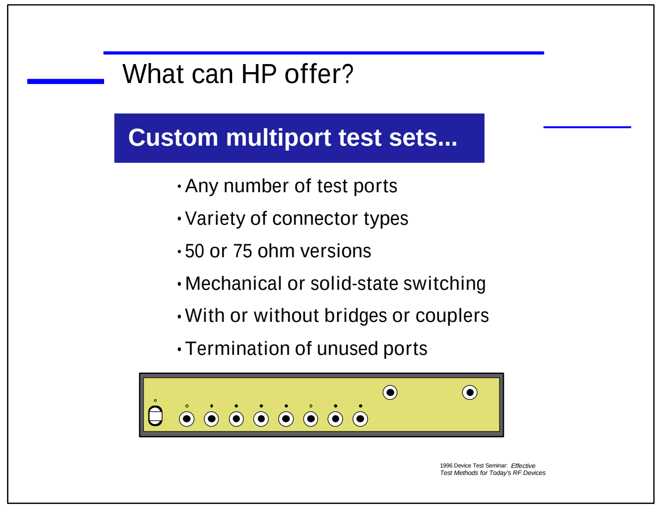

Hewlett-Packard multiport test sets can be customized to your measurement application with any number of ports, and a variety of connector types and switching arrangements. In their simplest configuration, they serve as switch matrices between your multiport device and any two-port network analyzer with an internal or external test set. Alternatively, they can be configured with internal couplers or bridges as well as switches. This allows consolidation of both the signal-splitting and switching functions into one test set for optimal performance.

These test sets are available in both 50 ohm and 75 ohm versions, with electromechanical or solid-state switching. Mechanical switches offer the lowest loss and best isolation, while solid-state switching provides fast and highly repeatable measurements. All unused test ports are terminated internally to reduce unwanted reflections.

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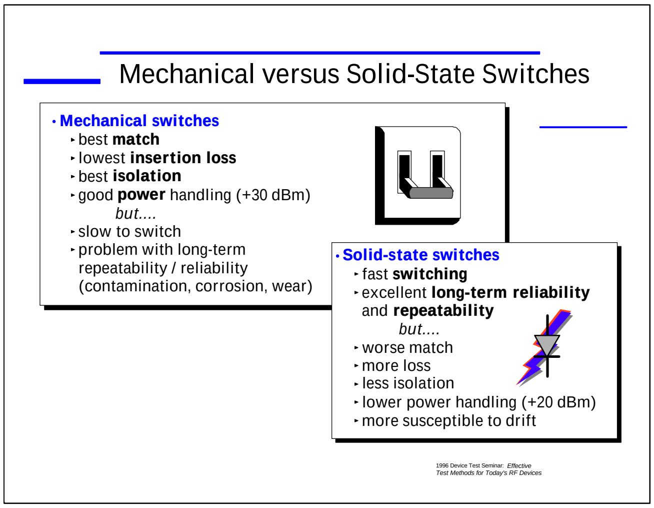

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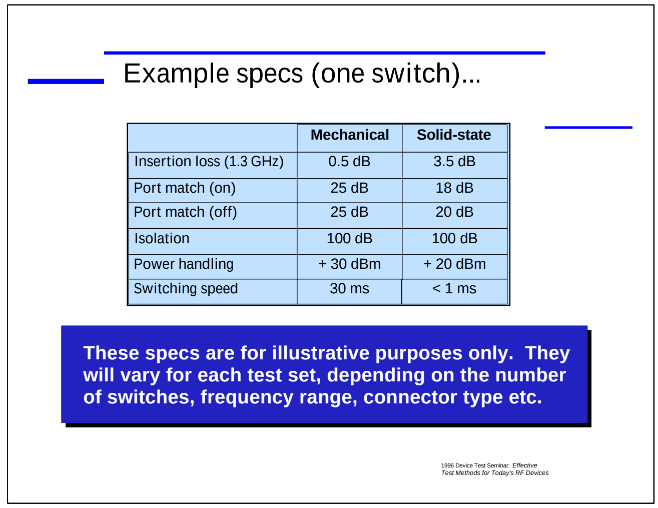

The choice between using electromechanical or solid-state switches should be based on the intended application. Each switch type has advantages and disadvantages, which must be weighed against the desired test goals. Mechanical switches have the best RF performance. They provide a good match, low insertion loss, high isolation and good power handling capability (+30 dBm typically). However, they can be slow to switch and, more importantly, their overall lifetime is much lower than that of solid-state switches. As the mechanical contacts wear out, corrode, or are otherwise contaminated, the repeatability of the switch starts to diminish. Eventually mechanical switches fail altogether, usually after several million cycles. This is a severe limitation for high-volume manufacturing lines or when the test set switches continuously as is the case for duplexer tuning. For these applications, it is not uncommon to reach several million switch cycles in just a few months.

Solid-state switches offer fast switching and excellent long-term reliability and repeatability, as long as they are not electrically abused (with too much voltage or power for example). The RF performance of solid-state switches, however, is usually worse than for mechanical switches. Solid-state switches have poorer match, more loss, and lower power handling capability (+20 dBm typically). They are also more susceptible to drift as they warm up after turn-on, or if environmental conditions change significantly.

The above table shows typical specifications for a single solid-state and mechanical switch. For everything except isolation, the mechanical switch offers superior RF performance. The solid-state switch, however, takes considerably less time to switch.

These specifications are for illustrative purposes only. They will vary for each test set, depending on the number of switches, the frequency range, and the type of connector used. Multiple solid-state switches in series can result in fairly large insertion loss, which, as we will see later on, significantly degrades the raw directivity of our test system.

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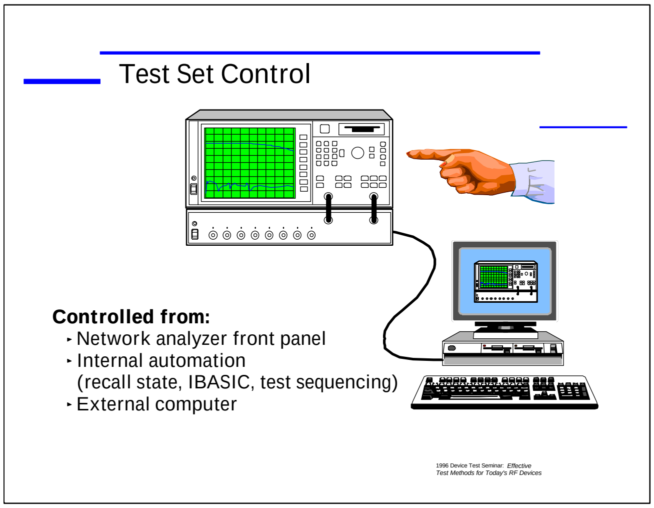

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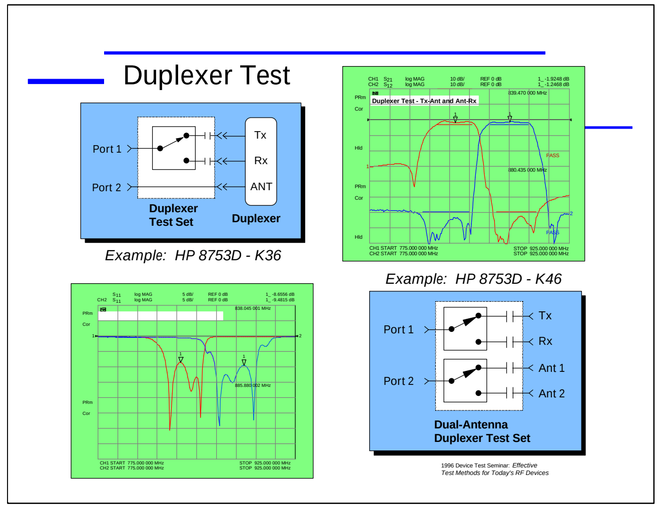

Multiport test sets can be controlled manually from the front panel of the network analyzer, with internal automation tools such as recall states, Instrument BASIC (IBASIC) or test sequencing, or by an external computer. We will explore each of these options in more detail in the last section.

Duplexers are three-port filters used to separate transmitted and received signals that share a common antenna. When using a duplexer test set with only one internal solid-state switch as shown above (upper left), you can simultaneously measure the insertion loss from transmitter to antenna ports and antenna to receiver ports. This allows both sides of the duplexer to be tuned and tested at the same time. Path interactions can also easily be observed on the instrument display, eliminating the retest and rework that occurs when only one path at a time is measured. A duplexer test set also allows you to measure return loss of all three ports of the DUT. When limit-line displays are used with multiport test sets, pass-fail testing of return loss, insertion loss, bandwidth, and stopband rejection is fast and repeatable.

Testing duplexers requires a solid-state switch because the test set is continuously switching between the transmit and receive ports. A mechanical switch would quickly wear out in this application. By adding one more switch to the test set, dual-antenna duplexers can also be tested (above, lower right). While not explicitly shown, both of these test sets use switches that are terminated in the open position.

If you need to test the isolation between the transmit and receive ports of the duplexer, a full three-port test set is required for single-connection measurements.

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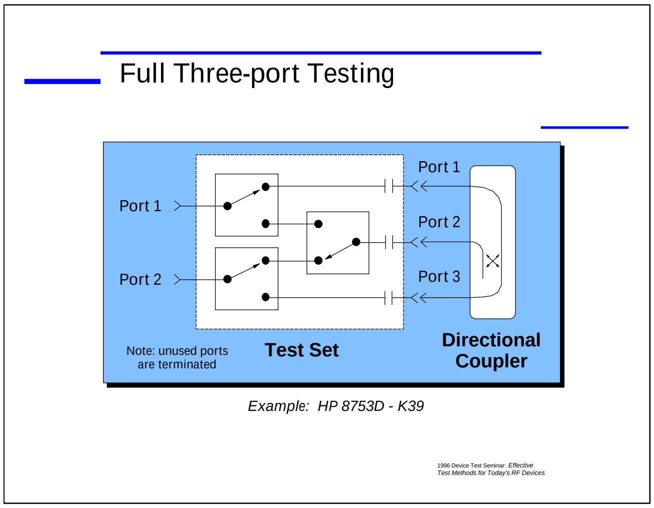

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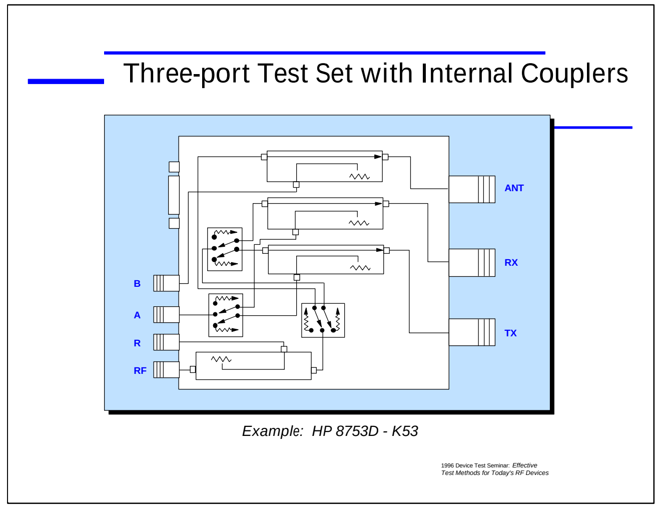

Transmission measurements between all three ports of a device can be accomplished by adding two more switches to a duplexer test set, as shown above. These measurements are often required for three-port components such as directional couplers and circulators. A full three-port test set also allows you to measure isolation between the transmitter and receiver ports of a duplexer.

As was mentioned earlier, signal-splitting devices such as couplers can be included in the multiport test set, between the switches and the DUT. This configuration offers significant improvement in the overall raw performance of the test system. Test sets such as these are meant to work with network analyzers that have direct access to the receiver ports, such as the HP 8753D option 011 (where the internal test set is deleted).

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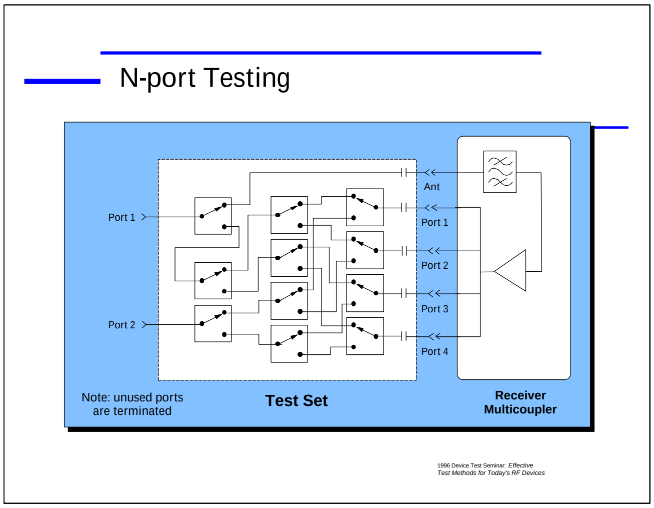

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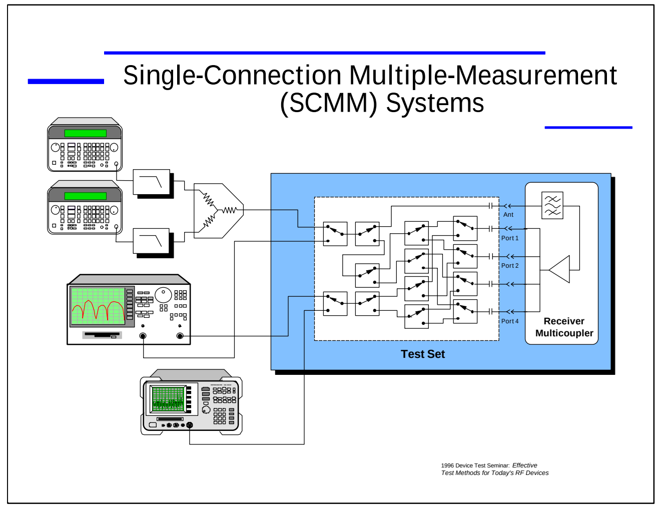

As the number of ports on the DUT increases, so does the complexity of the test set. Shown above is one implementation of a test set intended for testing receiver multicouplers, using SPDT switches. Switches with multiple poles could also be used, which would simplify the test set but still provide the same functionality.

A multiport test set like the one shown above combined with a network analyzer allows a single connection for swept-frequency linear transmission and reflection measurements, and for nonlinear measurements such as 1 dB gain compression (using power sweeps).

If other nonlinear measurements are needed, the test set can incorporate additional switches and ports to allow connection of other instruments to the DUT. For example, additional sources and a spectrum analyzer could be switched in place of the network analyzer to perform third-order intermodulation measurements. Another example would be the inclusion of a broadband noise source for measuring noise figure. In this manner, a multiport test set can greatly improve measurement throughput by providing a true single-connection, multiple-measurement test system.

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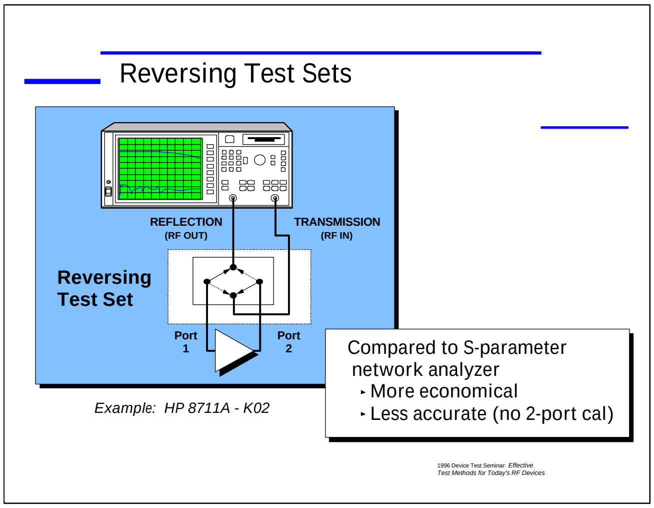

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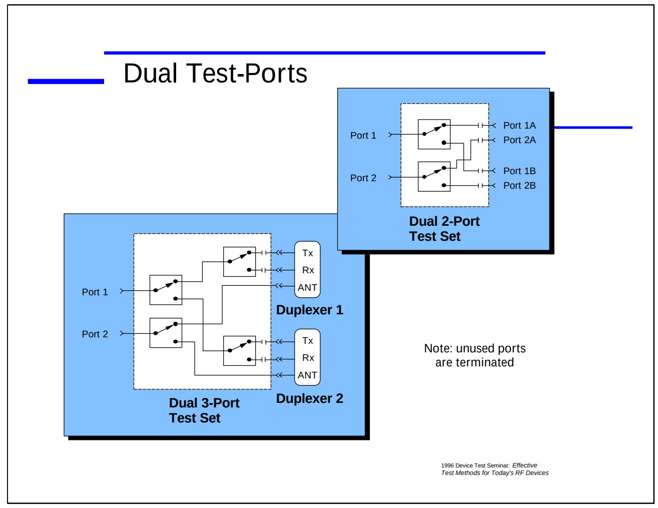

Network analyzers such as the HP 8752C or the HP 8711B family that are based on an internal transmission/reflection (T/R) test set are cost-effective instruments that provide the right level of accuracy for many applications. However, T/R test sets are limited to forward measurements only. By adding an external reversing test set as shown above, you get both forward and reverse transmission and reflection measurements with a single connection. This eliminates the need to disconnect the DUT, turn it around, and reconnect it to the network analyzer. This approach is less accurate since two-port calibration is unavailable, but more economical than using an S-parameter network analyzer. Transfer switches can be incorporated into multiport test sets as well, allowing T/R-based network analyzers to make forward and reverse measurements on multiport devices with a single connection.

A multiport test set is valuable in manufacturing applications where the time required for device connection, handling, and/or configuration is significantly greater than the test time. In these situations, a dual-port test set allows two operators or two part-handlers to share a single network analyzer, which increases the throughput per network analyzer. For example, two duplexers can be connected to the same test set as shown above (lower left), allowing testing on one device while an operator connects or disconnects cables on the other device.

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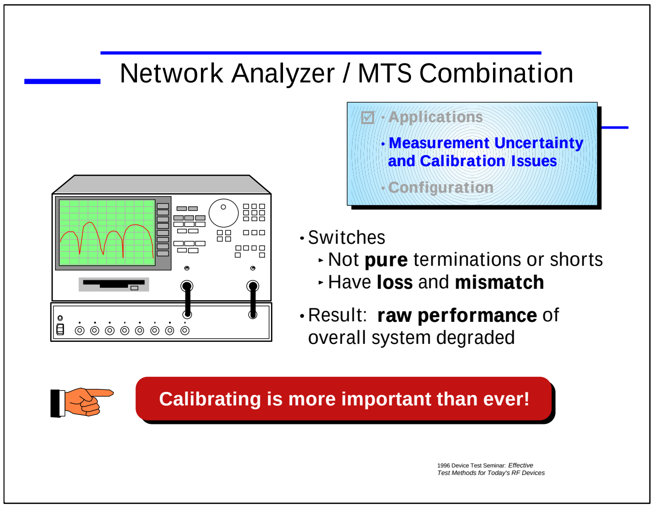

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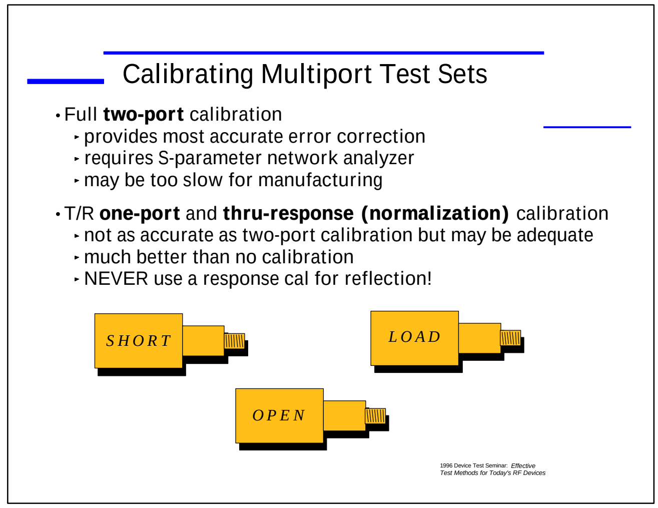

We are now starting the section on measurement uncertainty and calibration. Ideally, our test system should behave exactly the same whether we are using a network analyzer by itself or we have added a multiport test set between the DUT and the network analyzer. However, RF switches used in external test sets are not pure terminations or shorts. Instead, they have loss and mismatch. We will discover shortly than even moderate amounts of loss and mismatch can have a severe effect on the raw performance of our test system. This means that in order to get accurate measurements, calibration will be more important than ever, especially when measuring bi-directional low-loss devices. A typical example of this is measuring duplexer passbands.

The most accurate measurements are achieved using two-port calibration with an S-parameter network analyzer such as the HP 8753D. Two-port calibration corrects for all of the major sources of measurement error. Its only drawback is that it can result in measurements that are too slow for high-volume manufacturing applications. This problem can be avoided if external software is used for error-correction.

More economical T/R-based network analyzers such as the HP 8711B family offer one-port calibration for reflection measurements and a response (normalization) calibration for transmission measurements. This level of error-correction, while not as good as that achieved with full two-port calibration, certainly provides a large improvement in measurement accuracy compared to not calibrating at all. For many devices, T/R-based network analyzers provide sufficient measurement accuracy. When using this type of analyzer, it is not wise to use a response calibration for reflection measurements. Measurement accuracy is poor with this technique, especially when using multiport test sets.

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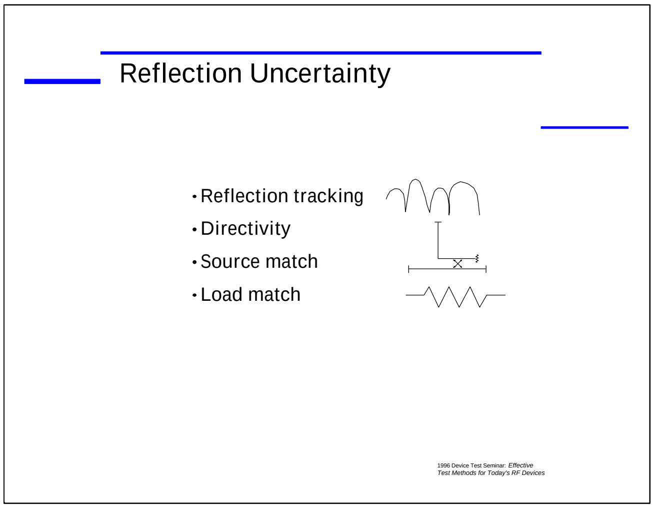

We will now examine the main sources of error for both reflection and transmission measurements. These raw error terms are always present when using a network analyzer and they can be seriously degraded by the addition of a multiport test set. As we examine these sources of error, it is important to remember that we can remove the effects of some or all of them by calibrating the overall test system. We will see examples of how to calculate the raw performance of a test set/network analyzer combination, and some examples of calculating measurement uncertainty when using the error correction available with T/R-based network analyzers.

For reflection measurements, the main sources of measurement error are reflection tracking, directivity, source match, and load match.

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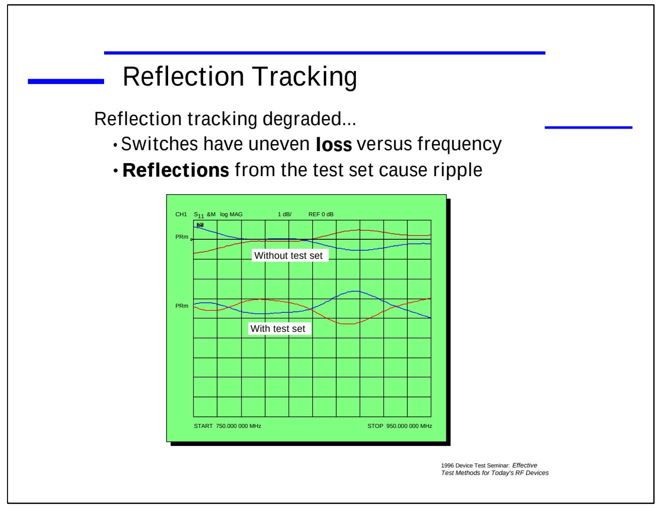

Reflection tracking indicates how well two receiver channels in the network analyzer track over frequency during ratioed measurements. This is important for measurements such as return loss, VSWR, and impedance. Multiport test sets affect the raw frequency response by adding uneven loss versus frequency, and by introducing ripple due to the reflections from the imperfect switches. This source of error is removed with one- or two-port calibration.

Improve Test Throughput for Duplexers and Other Multiport Devices

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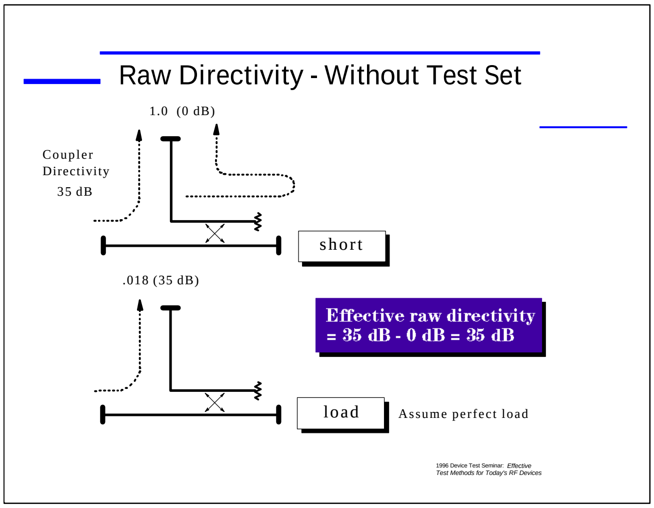

Raw directivity is the measure of how well our signal-separation devices perform. These devices, usually couplers or bridges, are typically integrated within the network analyzer, or they can be part of the multiport test set itself. Raw directivity is simply the amount of signal that leaks from the input port to the reflection port of the signal-separation device. Ideally, there should be infinite isolation between these two ports. The effect of raw directivity is greatly reduced with one- or two-port calibration.

In the above example, our directional coupler has 35 dB of directivity. This can be verified by first measuring a short standard as a reference, and then measuring a load standard. Since the load should have zero reflection, the signal measured at the reflection port is what leaks through as shown. The raw directivity is the difference (in dB) between these two measurements. While we will assume a perfect load to illustrate our point, in reality, the reflection from the load is often what sets the boundary for measuring raw directivity. In other words, it is very difficult to measure better directivity than the return loss of our load standard.

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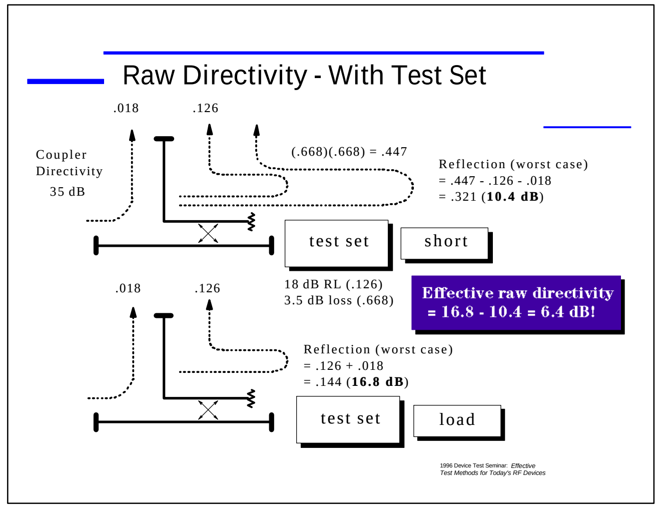

Now let's see what happens when we add a multiport test set that has 3.5 dB of insertion loss and test ports with 18 dB return loss. These specifications were taken from the technical data sheet of the HP 8753D-K36 duplexer test set.

First we connect the short standard and measure the worst case combination of signals. Instead of getting all of our signal reflected back as we would expect, the loss of the test set is encountered twice, which severely lowers the amplitude of the main reflected signal (.447). We also see a signal due to the mismatch of the test set (.126) and the signal due to the coupler directivity (.018). Since we want 100 percent reflection when measuring a short, the worst case condition is minimum reflection. This means we will subtract the signals.

Now let's connect the load standard. Now we see only two main terms: the coupler directivity and the reflection from the test set port. For a worst-case calculation, we will add the two signals (more signal is bad for this measurement since we are expecting no reflection from the load). If we take the difference of the return loss of these two measurements, we see that our worst case raw directivity in only 6.4 dB. If we were to try to make reflection measurements without calibration, we could never measure anything better than a 6.4 dB return loss! Clearly, this would be unacceptable for the vast majority of today's RF devices.

Improve Test Throughput for Duplexers and Other Multiport Devices

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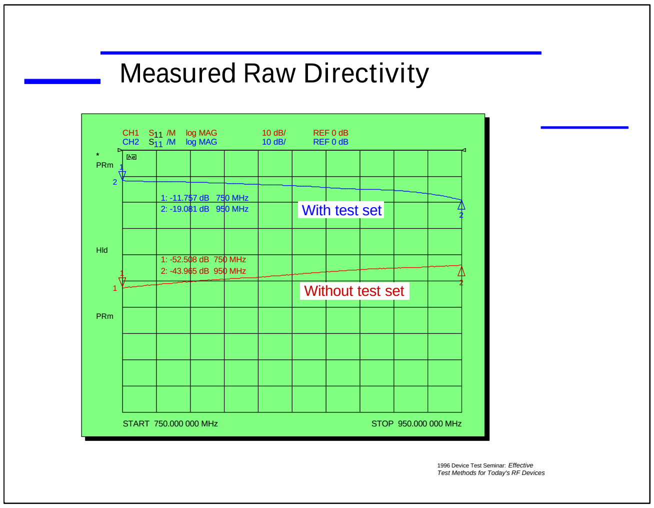
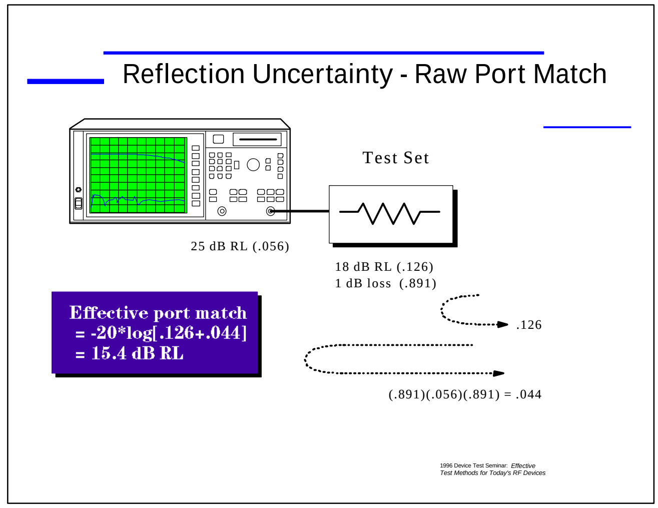


The above plot shows an actual measurement of raw directivity, with and without an HP 8753D-K36 duplexer test set. In both cases, a short was used for the reference. We can see that the network analyzer by itself has between 44 and 53 dB of raw directivity over the frequency range needed to measure our duplexer (750 MHz - 950 MHz). When the test set is added to the measurement set-up, the raw directivity degrades to between 12 and 19 dB, which is not as bad as our worst case analysis predicted. This is likely due to the test set having less loss and mismatch at these frequencies than what was used in our example.

Slide #24



The raw port match of the test system is determined by the reflection from the test set and the network analyzer's test ports. In our example, the test set match is 7 dB worse than that of the network analyzer, which is a fairly typical occurrence. The insertion loss of the test set is 1 dB in this example, which gives a worse raw port match than that resulting from the 3.5 dB insertion loss used in the directivity example. The worst case is when both reflections add, giving an effective port match of only 15.4 dB. Note that as the loss in the test set increases, the effective port match rapidly approaches the match of the test set by itself, since the reflection from the network analyzer gets attenuated by twice the value of the insertion loss of the test set.

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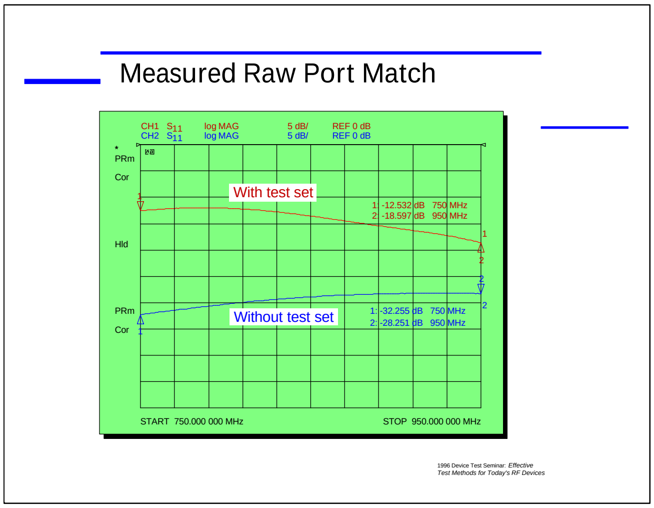

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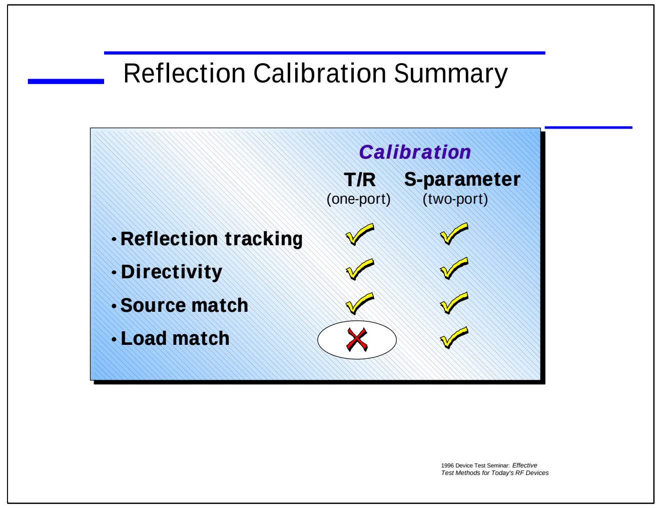

The above plot shows an actual measurement of raw port match, with and without an HP 8753D-K36 duplexer test set. In both cases, a one-port calibration was done at the end of a test cable, and then this cable was used to measure the match of the test port directly. We can see that the network analyzer by itself has a port match between 28 and 35 dB over the frequency range needed to measure our duplexer (750 MHz - 950 MHz). When the test set is added to the measurement set-up, the overall port match degrades to between 12 and 19 dB (our example predicted an effective port match of 15.4 dB).

We have just shown how the four main sources of error for reflection measurements are degraded when a test set is added that has loss and mismatch. The directivity term was the most severely degraded. If we perform a two-port calibration, we will correct for all four error terms. If we only do a one-port calibration (all that can be done with a T/R-based network analyzer), we will not correct for the effect of load match.

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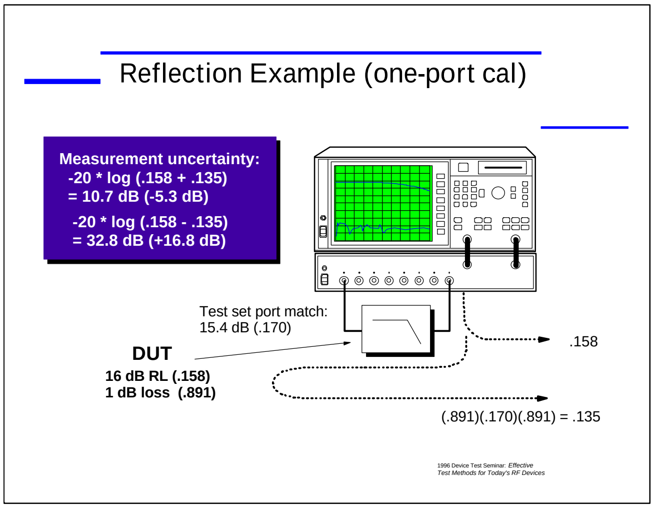
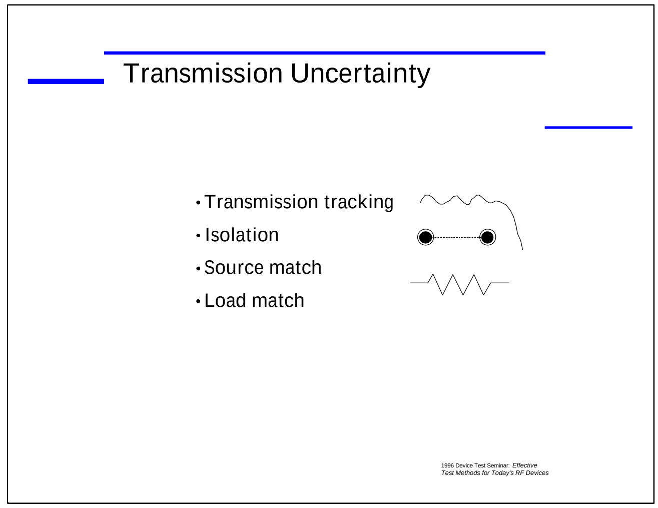
Slide #27



Here is an example of how much measurement uncertainty we might encounter when measuring the output match of a filter after a one-port calibration. In this example, our filter has a return loss of 16 dB, and 1 dB of insertion loss. Our effective (raw) port match is the 15.4 dB that we previously calculated. The reflec- tion from the test port connected to the filter's input is attenuated by twice the filter loss, which is only 2 dB total in this case. This illustrates why low-loss devices are more difficult to measure accurately. For measure- ment uncertainty, we add and subtract the undesired reflection signal (.135) from the signal reflecting from the DUT (.158). The measured return loss of our 16 dB filter will be anywhere between 10.7 dB and 32.8 dB, which is a rather large variation (-5.3 dB, +16.8 dB). We might pass a filter that doesn't meet its specifications, or we might reject a filter that did.

What if we were testing an amplifier with good isolation from output to input (good in this case means isolation >> gain)? We would have much less measurement uncertainty because the reflection due to load match would be severely attenuated by the product of the amplifier's isolation and gain.

If we wanted to improve our raw port match to reduce measurement uncertainty, we could disconnect the input of the filter and terminate it with a high-quality load, but this would defeat the purpose of using a multiport test set in the first place. Alternatively, we could add a moderate-value series attenuator (say 3 dB) which would improve our raw port match by 6 dB, but at the expense of raw directivity. If the stability of our raw directivity was good, this would be a good trade-off. For multiport devices, the load match of unused test ports can be very important, depending on how much isolation the DUT has between ports.



Slide #28

Let's look at raw transmission error terms now and see how they will affect our measurements. We have three of the same errors (tracking, source and load match), with isolation replacing directivity for the fourth term.

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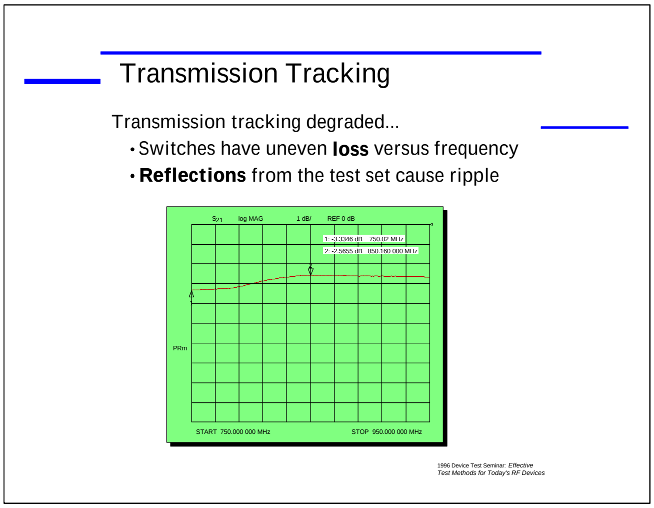
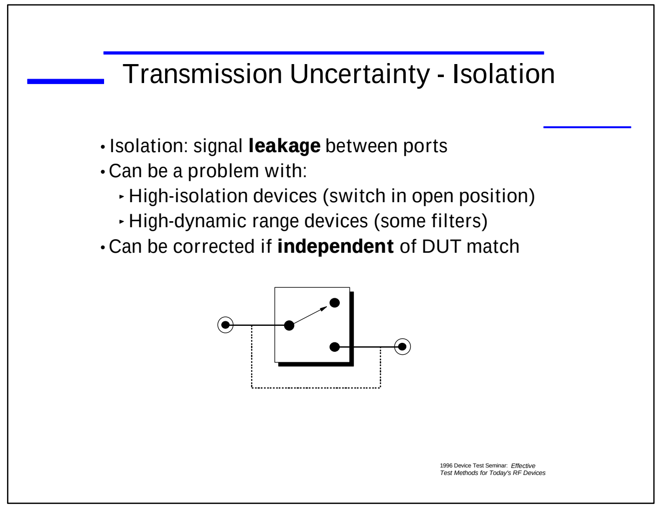


Just like reflection tracking, transmission tracking is a measure of how well two receiver channels in the network analyzer track over frequency during ratioed measurements. We use a different combination of receiver channels for measuring transmission than for reflection. Transmission tracking is important for measurements such as gain, insertion loss and isolation. Multiport test sets affect the raw frequency response by adding uneven loss versus frequency, and by introducing ripple due to the reflections from the imperfect switches. This term is removed with response or two-port calibration

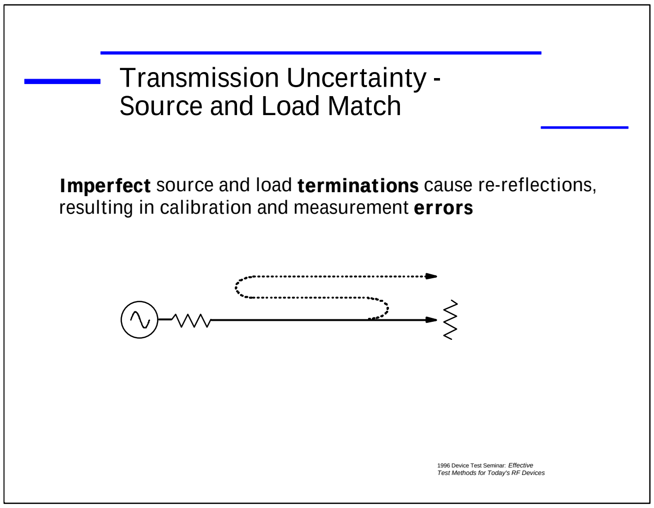
Slide #30



Isolation is a measure of how much signal leaks between ports, bypassing the DUT. We can ignore the effect of isolation for most measurements, as it is very small. It can be a problem if we try to measure a DUT whose isolation is very large (an open switch for example), or if we try to make very high dynamic-range measurements (on some filter stopbands for example). As long as the isolation term is constant and independent of the match of the DUT, then it can be easily corrected as part of the calibration routine, if desired (it is much more difficult to correct for match-dependent isolation).

Multiport test sets generally have excellent isolation between ports so this term does not degrade significantly with the addition of a test set.

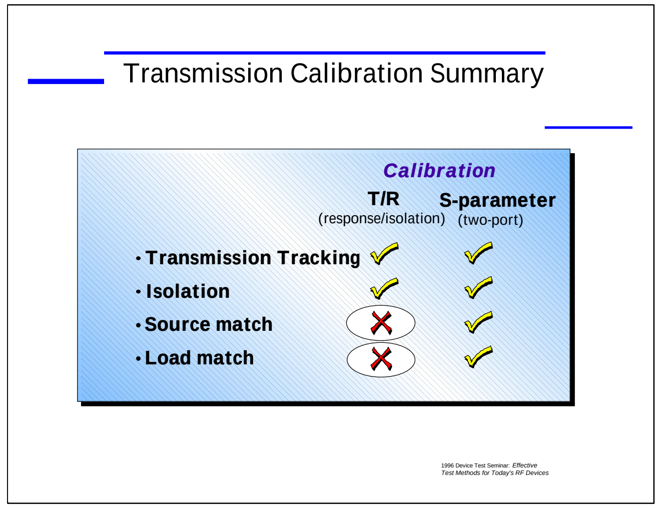
Slide #31



The biggest source of measurement uncertainty in transmission measurements is due to non-ideal source and load match. Imperfect source and load terminations cause multiple reflections, resulting in both calibration and measurement errors when making measurements using thru-response calibration. Even when using two-port calibration with an S-parameter network analyzer, the load match of unused ports can affect measurements of transmission and reflection, as we shall see later.

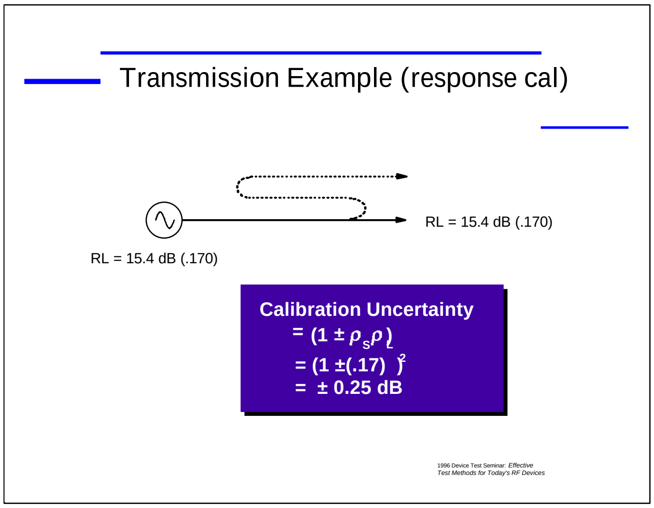
The addition of a multiport test set degrades raw source and load match in the same way as we have already discussed for reflection measurements.

Slide #32



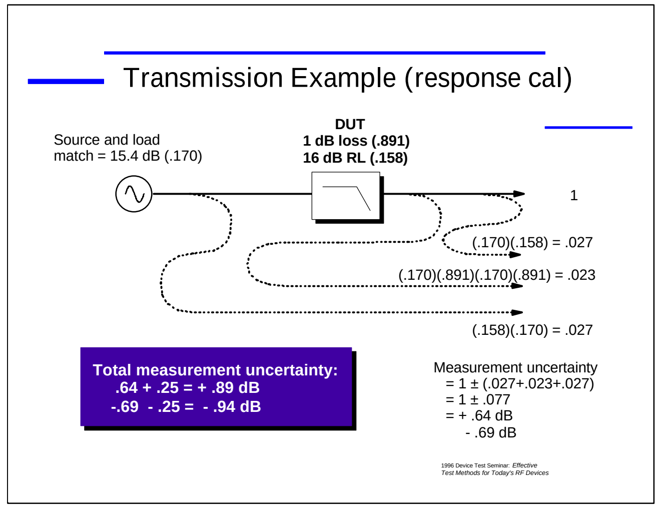
We have just shown how three of the four main sources of error for transmission measurements are degraded when a test set is added that has loss and mismatch. If we perform a two-port calibration, we can correct for all four error terms. If we only do a response calibration (all that can be done with a T/R-based network analyzer), we will not correct for the effects of imperfect source and load match.

Slide #33



Let's do an example transmission measurement using only response calibration. The first step is to make a thru connection between the two ports that form our measurement path. We will use the same 15.4 dB port match that we have used for previous examples. The ripple caused by this amount of mismatch is easily calculated as shown above (+/- 0.25 dB). This amount of error is now present in our reference data, and it has to be added to the uncertainty when the DUT is measured to compute the worst-case overall measurement uncertainty.

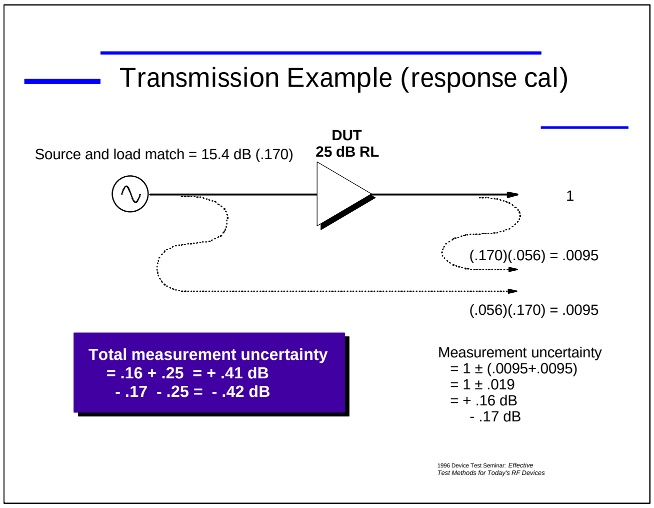
Slide #34



Now lets look at the measurement uncertainty when the DUT is inserted. We will use the same loss and mismatch specifications for the DUT and test set as before. We have three main error signals due to reflections between the ports of the test set and the DUT. There are higher-order reflections present as well, but they don't add any significant error since they are small compared to the three main terms. One of the signals passes through the DUT twice, so is attenuated by twice the loss of the DUT. The worst case is when all of the reflected error signals add together in-phase (.027 + .023 + .027 = .077). In that case, we get a measurement uncertainty of +0.64 dB, -0.69 dB. The total measurement uncertainty, which must include the 0.25 dB of error incorporated into our calibration measurement, is about +/- 0.9 dB.

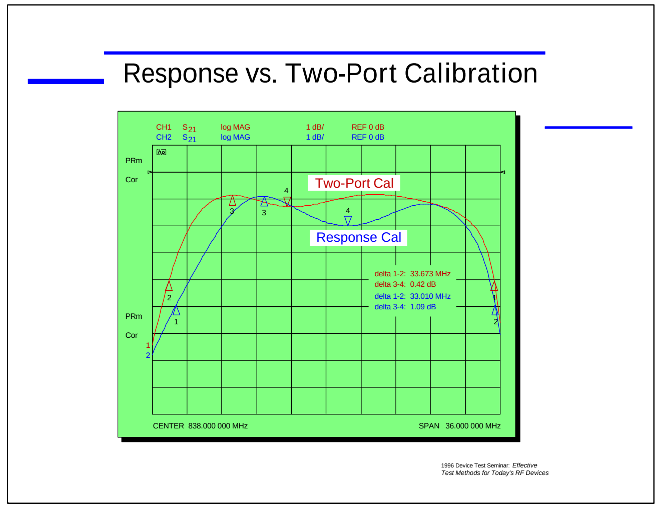
Improve Test Throughput for Duplexers and Other Multiport Devices

Slide #35



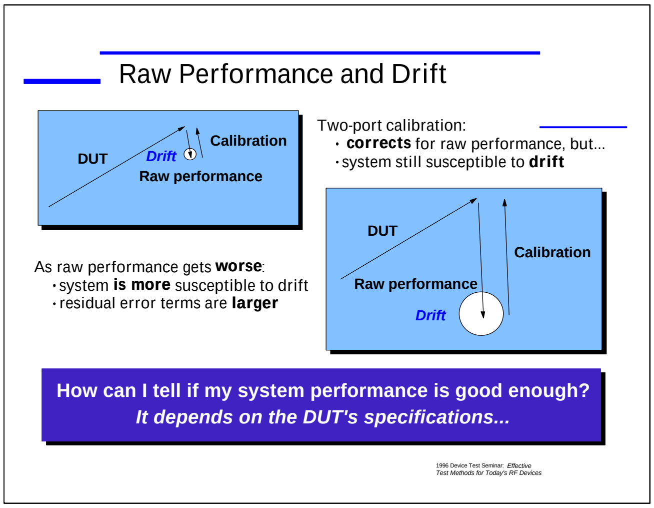
Now let's look at an example of measuring an amplifier that has port matches of 25 dB. The match of our test ports remains the same as previous examples. We see that the middle error term in no longer present, due to the reverse isolation of the amplifier. This fact, coupled with the better amplifier port match, has reduced our measurement uncertainty to about +/- .16 dB. Our total measurement error now has been reduced to about +/- 0.4 dB, versus the +/- 0.9 dB we had when measuring the filter. Again, when using response calibration, measurement uncertainty is worse for low-loss bi-directional devices than for devices with good isolation in one direction.

Slide #36

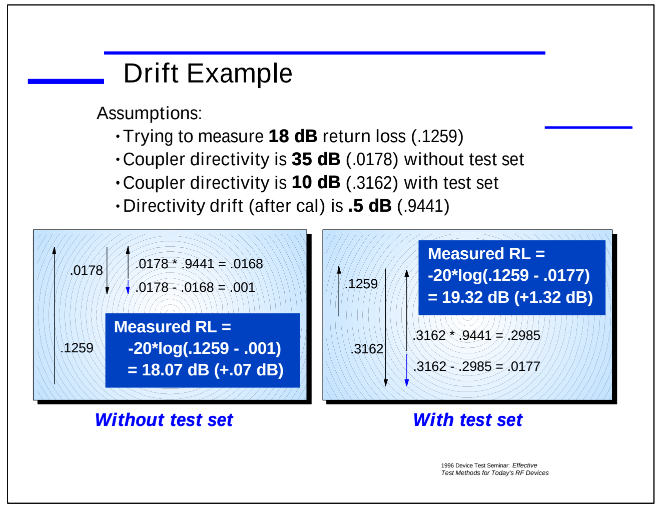


The above plot shows a detailed view of the passband of the transmit-antenna path of our duplexer, with two different types of calibration. The upper trace shows the results after a two-port calibration, while the lower trace shows the results with a thru-response calibration. Notice that compared to the data using two-port corrections, the data taken with a response calibration shows much more ripple (1.09 dB versus 0.42 dB), an inaccurate 3 dB bandwidth (33.010 MHz versus 33.673 MHz), and a skewed center frequency (about 2 MHz too high).

Slide #37



Slide #38



We have just finished showing how using one-port and response calibrations can result in some large measurement uncertainties. But even if we use two-port calibration to cancel out all of the major error terms, we are still susceptible to drift in the test system that occurs after a calibration has been performed. As raw performance gets worse, the more impact drift will have on our measurement accuracy. We can conceptually see this by considering our raw performance to be an error vector added to the actual performance of the DUT. Two-port calibration cancels out the error vector as long as it does not drift. If the raw performance of the test system changes, our calibration no longer exactly cancels the error vector. A fixed amount of drift in dB actually represents a percentage in linear terms, so the larger the error vector, the larger the amount of change. Therefore, as raw performance gets worse, drift is more likely to introduce large measurement uncertainties.

An additional reason why raw performance is important is that the residual error terms that remain after calibration (the result of slight imperfections in the calibration standards) depend somewhat on raw performance. As raw performance gets worse, the residual error terms get larger. So degraded raw performance negatively affects our measurement uncertainty in two ways: greater susceptibility to drift, and larger residual error terms.

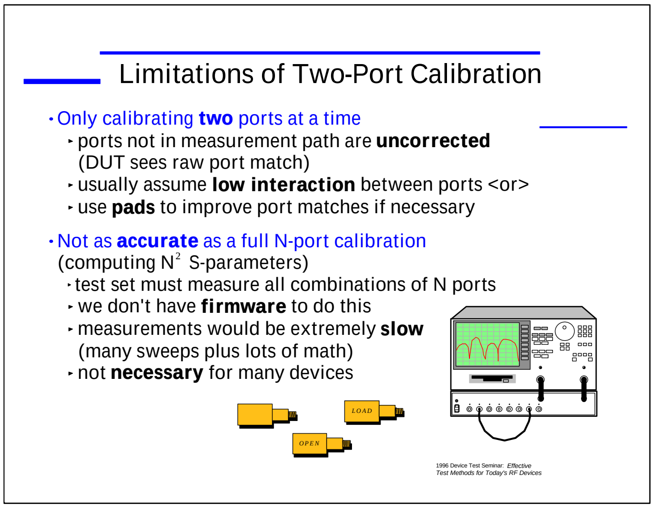
How do you know if your overall system performance is good enough? It depends on the specifications of the DUT. It might be acceptable to test a part with loose specifications with a T/R -based analyzer, or we may need an S-parameter analyzer with tight environmental control to achieve the desired measurement accuracy.

Let's look at an example of measurement uncertainty where our directivity drifts by 0.5 dB *after* calibration has been done. In the first case, we will assume that we are measuring the return loss of a DUT using only a network analyzer, with a raw directivity of 35 dB. In the second case, we will add the effect of the test set, which causes the raw directivity to degrade to 10 dB (which is not hard to do as we have already seen). We will assume that the calibration has exactly cancelled out the directivity error before the drift occurs. In both cases we are measuring a DUT with a return loss of 18 dB. We will calculate the measurement error on the 18 dB that is a result of the 0.5 dB drift. In this example, the 0.5 dB of drift will decrease the leakage signal (making directivity 0.5 dB better), meaning we will multiply the linear directivity term by 0.9441.

Without the test set, our 35 dB raw directivity (.0178) is reduced to .0168, which means we are over-correcting for directivity by .001 (.0178 - .0168). This amount of error is very small compared to the reflection from the DUT (.1259), and results in a measurement change of only .07 dB.

With the addition of the test set, the 0.5 dB drift in directivity causes the 10 dB raw directivity to change from .3162 to .2985, resulting in over-correction by .0177 (.3162-.2985). This amount of error is almost twenty times larger than the previous calculation, and results in a change in return loss of +1.32 dB (instead of only .07 dB as before). It is clear from this example that degraded raw performance due to drift caused a substantial increase in measurement error. Even though the raw directivity actually improved, the drift occurred after a calibration was done. This then resulted in measurement error since the network analyzer used inaccurate error-correction data.

Slide #39

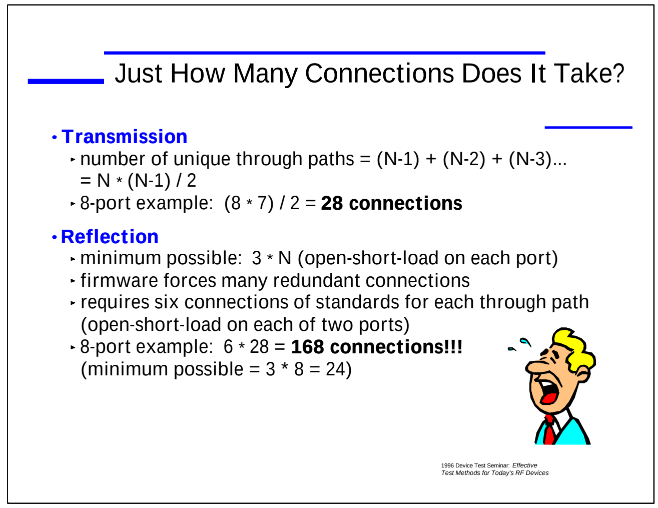


Even without considering drift, two-port calibration has its limitations in multiport applications. This is because we can only calibrate two test ports at a time. Test ports that are not in the measurement path are uncorrected. Another way of saying this is that ports of the DUT that are not being measured see the raw port match of the test set. This is not a problem if there is low interaction between ports of the DUT (good isolation). However, for some DUTs (particularly passive devices), this assumption may not be valid. If raw port match needs to be improved to meet the desired level of measurement accuracy, then the only option is to add pads on the ports where improvement is needed (port match will improve by twice the value of the pad in dB). Again, this will degrade raw directivity and therefore make reflection measurements more susceptible to drift, but this may be an acceptable trade-off for stable test systems.

The rigorous alternative to using two-port calibration is to use N-port calibration. This requires a test set that can fully measure all combinations of the N ports, resulting in the calculation of N^2 S-parameters. While calculating N^2 S-parameters could be accomplished using external software (this task is beyond the capability of today's network analyzers), the impact to measurement speed could be significant, especially as the number of ports needing test increases. Measurements could be extremely slow as N^2 sweeps would have to be taken to calculate any one S-parameter, and the amount of time it would take for math computations would be much longer than needed for two-port calibration.

While full N-port correction achieves the highest possible level of measurement accuracy, it is simply not necessary for many devices.

Slide #40



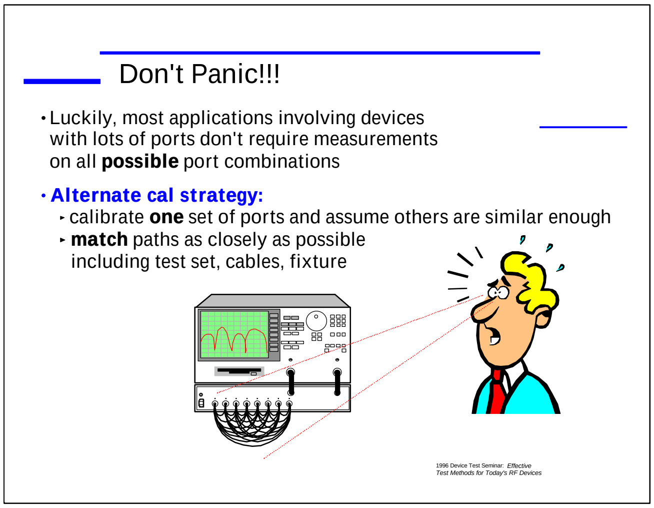
We now know that two-port calibration is the best practical alternative we have for reducing measurement uncertainty. Let's see just how many connections it takes to achieve this using the built-in calibration routine of the network analyzer.

For transmission, we must make a through connection for all possible measurement paths. The number of unique transmission paths is (N-1) + (N-2) + (N-3) ... This equation can be simplified to [N * (N-1) / 2]. If we need to measure all combinations of an eight-port device, there would be 28 different paths.

Unfortunately, it is much worse for reflection measurements. The firmware of the network analyzer treats every set of two-port calibration data as totally unique. It cannot share data between pairs of ports. In other words, doing a two-port calibration on ports 1 and 2, and then on ports 3 and 4, does not yield correction data for ports 1 and 3, 1 and 4, 2 and 3, or 2 and 4. We end up having to make many redundant connections. For our eight-port example, we would have to make six connections of standards for each two-port calibration of a measurement path (an open, short, and a load on each port), for a total of 168 connections! Each port of the test set would see the equivalent of seven one-port calibrations. Ideally, we should only have to make the equivalent of a single one-port calibration at each port. This would mean a total number of connections equal to three times the number of ports, or 24 in this case.

Improve Test Throughput for Duplexers and Other Multiport Devices

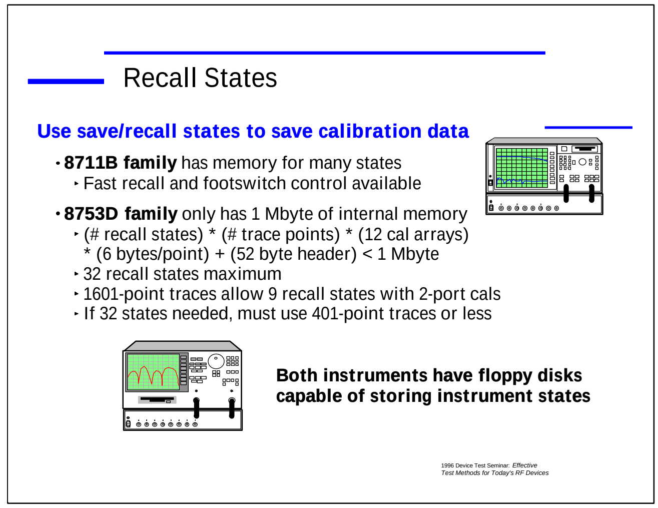
Slide #41



It's not quite time to panic yet. For many devices with a large number of ports, it is not necessary to measure (and therefore calibrate) all possible signal paths. Often, one signal path in the DUT is representative of several other paths. We can then measure this one path (using calibration) and assume that the other paths will behave similarly.

An alternate calibration strategy is to assume that the test set has the same raw performance at each of its test ports. We now can measure one set of ports accurately and apply the correction data to the other ports. For this strategy to work well, the measurement paths must be matched fairly closely, including the test set, test cables, and any text fixture that is used.

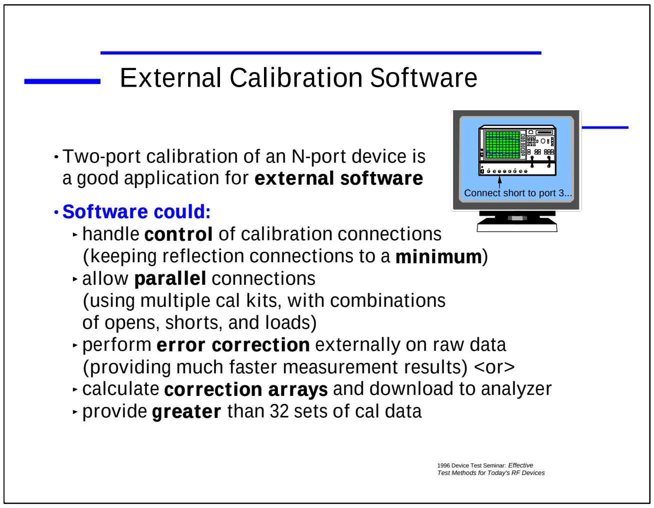
Slide #42



The best way to deal with multiple sets of calibration data (without using external software) is to save the instrument state and calibration data for each measurement path in the internal memory of the network analyzer. The HP 8711B family has room for lots of states, but the HP 8753D has some memory limitations. When storing 1601-point traces with full two-port error correction, only nine states can be saved. To store the maximum number of 32 states with two-port corrections, you are limited to traces with 401 points or less.

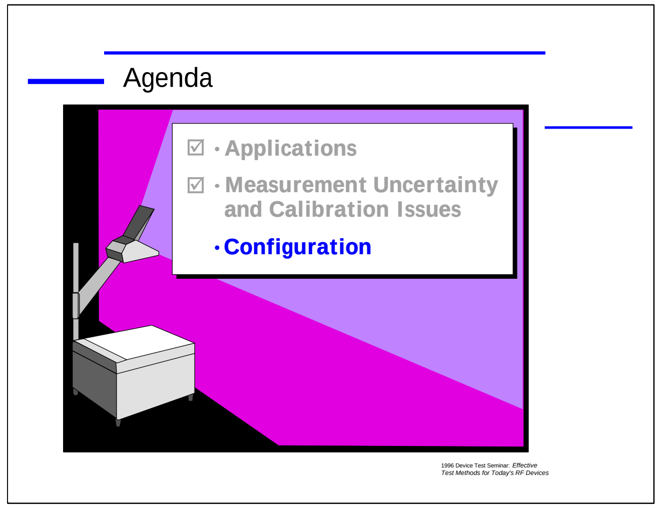
Instrument states and calibration data can also be stored to either instrument's internal floppy disk drive, but recall from this medium is fairly slow.

Slide #43



Performing two-port calibration and error correction for N-port devices is an ideal task for external software. The biggest advantage would be in the handling of the calibration arrays, which could keep the number of reflection connections to the minimum amount possible. The software could provide useful prompts to help the user keep track of which ports were calibrated, and could allow the practice of parallel connections (for example, using three calibration kits for an eight-port test set so that all eight ports could be calibrated at once using a combinations of shorts, opens, and loads). Overall measurement speed could be improved considerably with external software since error correction could be done using faster and more advanced processors than those currently used in network analyzers. If doing error correction in the network analyzer is desired, the software could calculate the correction arrays based on which set of ports were being used, and download these arrays into the network analyzer. And finally, there would be no limitation of 32 instrument states, which is necessary for full characterization of devices with more than eight ports.

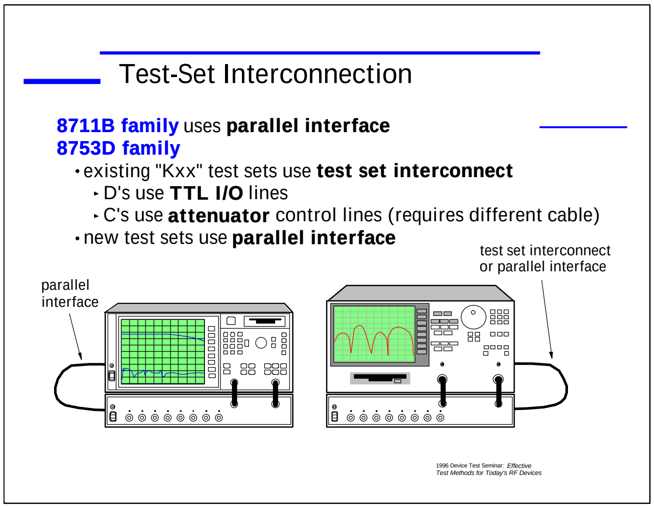
Slide #44



This final section gives information about how Hewlett-Packards's custom multiport test sets are interfaced to the HP 8711B and 8753D family of RF network analyzers.

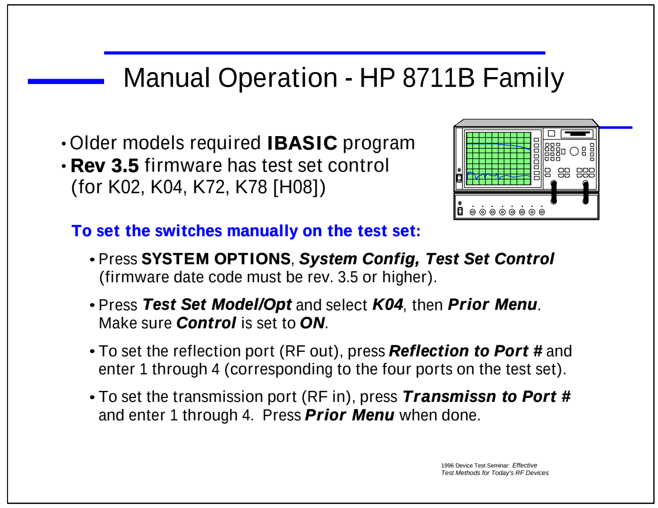
Improve Test Throughput for Duplexers and Other Multiport Devices

Slide #45



When using test sets with the HP 8711B family of economy RF network analyzers, instrument control is established via the parallel interface. For the HP 8753D family of high-performance analyzers, existing "K" model test sets are controlled via the test-set interconnect interface. HP 8753C models control the test-set switches via attenuator control lines, while the newer D models use dedicated TTL I/O lines. There is a different interconnect cable used for C and D models. Newly designed test sets for the HP 8753D are controlled with the parallel bus.

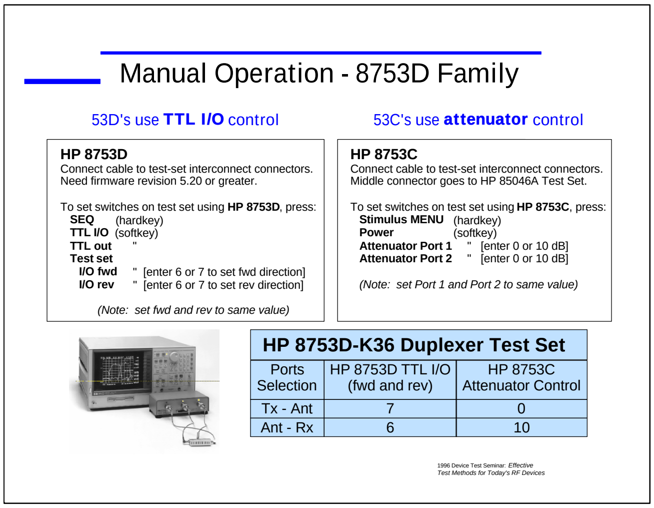
Slide #46



Manual operation with the HP 8711B family is achieved in older models using IBASIC to write commands to the parallel-interface port (IBASIC is available as option 1C2). Models with firmware revision 3.5 and above have direct control of the most commonly used test sets. Other test sets can be also be controlled using IBASIC.

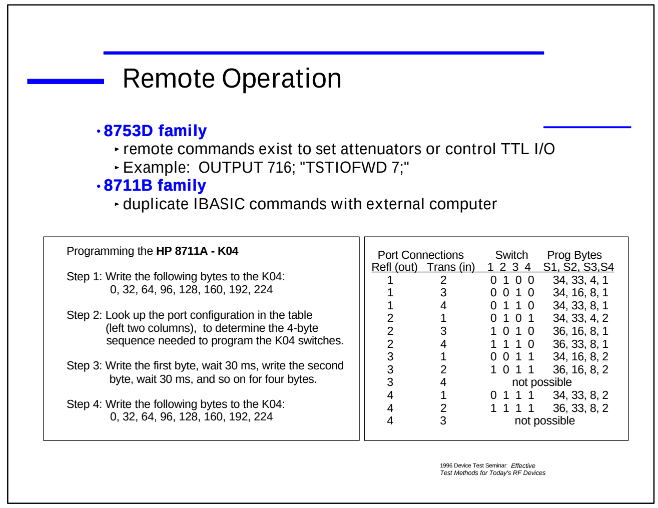
Improve Test Throughput for Duplexers and Other Multiport Devices

Slide #47



Manual operation with the HP 8753C or D is accomplished from the front panel as shown above.

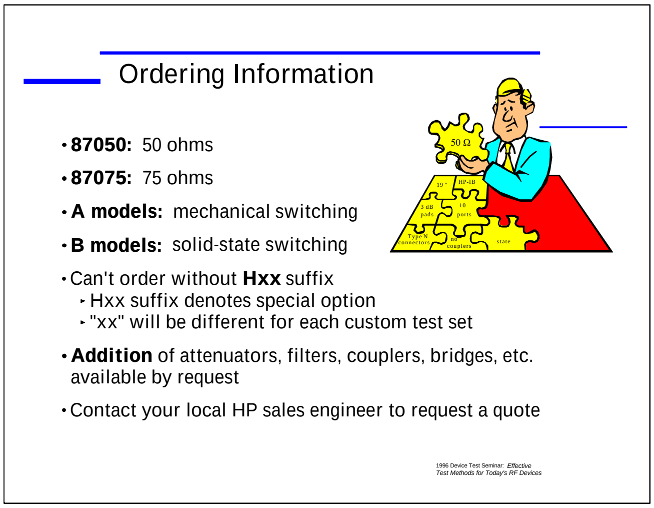
Slide #48



Remote operation of existing test sets is accomplished by sending commands to the network analyzer as shown above. Some test sets also have an HP-IB interface, which allows an external computer to talk to the test set directly if desired.

Improve Test Throughput for Duplexers and Other Multiport Devices

Slide #49

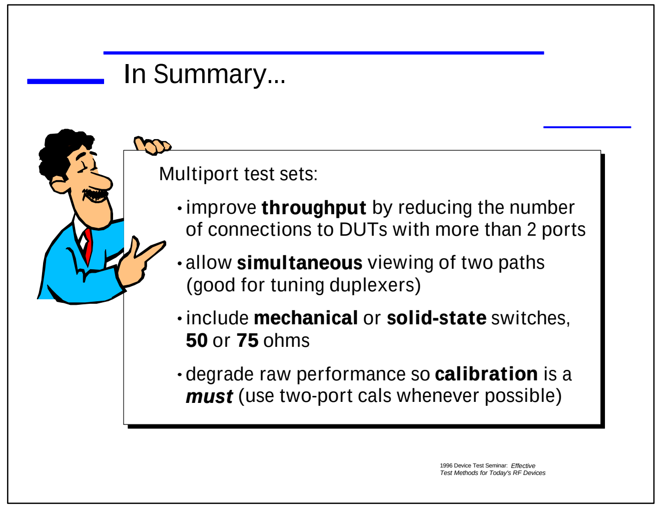


Price, delivery and relevant specifications for multiport test sets are quoted on a custom-basis by HP's special handling department. The HP 87050 series of model numbers cover all 50 ohm test sets, while 75 ohm test sets are covered under the HP 87075 series. "A" models use electromechanical switches and "B" models provide solid-state switching (more information about custom test sets can obtained by ordering HP literature number **5964-3830E)**.

Hewlett-Packard also has several existing test-set specials with product numbers that are tied to specific network analyzer or test-set model numbers. An example is the HP 8753D option K36 duplexer test adapter, which you have seen during today's demo (more information on this product can be obtained by ordering HP literature number **5963-3941E**).

Please consult your local HP sales engineer for help in determining the best solution for your multiport test application.

Slide #50



We have seen how multiport test sets can improve measurement throughput of multiport devices by allowing you to test multiple signal paths with a single connection to your DUT. This is especially useful when two paths need to be viewed simultaneously, such as when tuning and testing duplexers. Minimizing the number of connections also reduces operator fatigue and lowers the chance of connection to the wrong port. Fewer connections also means less wear on cables, connectors, fixtures and DUTs.

We have also seen that adding a test set, even one with moderate loss and mismatch, can cause serious degradation to the raw performance of a network analyzer, making calibration extremely important. Two-port calibration should be used whenever possible to provide the most measurement accuracy. Response calibrations for transmission measurements can have significant error due to source and load match errors. Degraded raw performance also means our test system is more susceptible to measurement errors caused by drift.

With a good understanding of these issues, the appropriate trade-offs in test-set performance can be made to optimize test of your particular DUT. Hewlett-Packard can provide the hardware and measurement expertise to help you obtain the right solution for your multiport device-testing needs.

Improve Test Throughput for Duplexers and Other Multiport Devices

References

Improved RF Hardware and Calibration Methods for Network Analyzers, Douglas K. Rytting, Hewlett-Packard RF and Microwave Symposium paper, 1991.