NEW MEASUREMENT TECHNIQUES FOR TESTING BOTH LINEAR AND NONLINEAR DEVICES WITH THE HP 8753B RF NETWORK ANALYZER

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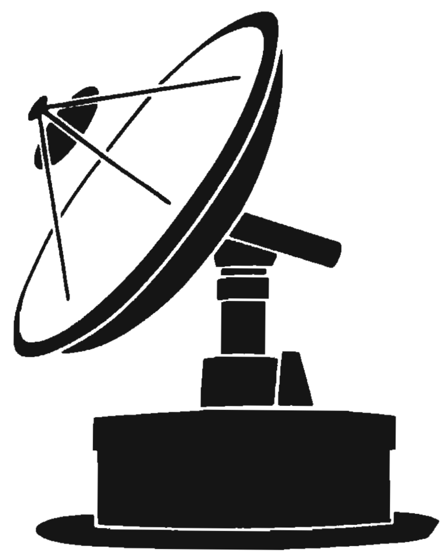
RF & Microwave Measurement Symposium and Exhibition



HEWLETT PACKARD

ABSTRACT

NEW MEASUREMENT TECHNIQUES FOR TESTING BOTH LINEAR AND NONLINEAR DEVICES WITH THE HP8753B RF NETWORK ANALYZER

Nonlinear devices, like amplifiers and mixers, require more complicated test procedures than linear devices. Thorough testing of these devices includes the measurement of harmonic distortion, gain compression, conversion loss, and two-tone intermodulation distortion, in addition to linear parameters like gain or insertion loss, bandwidth, group delay, reflection coefficient, reverse isolation, and so forth. This paper describes how to make these measurements, utilizing the powerful new capabilities of the HP8753B Vector Network Analyzer. Detailed measurement setups and the proper techniques for best accuracy are discussed, along with many practical examples.

AUTHOR

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PAT7421A

OBJECTIVES

- Define the nonlinear properties of amplifiers, and show how they are measured.
- Do the same for mixers.
- For each of these measurements, emphasize the recommended "BEST PRACTICES" to use for good results.
- Understand the block diagram of the HP 8753B and how it makes these measurements.

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This paper examines the measurement of some nonlinear parameters of amplifiers and mixers with the HP8753B Network Analyzer. Because these are more complex than linear measurements, there are some details that affect the accuracy of the result. The main objective of this paper is to demonstrate the proper techniques that will give the most accurate data. It is also helpful to study the analyzer's block diagram so as to better understand why some of these details are necessary.

OUTLINE

→ 1. Introduction
2. Amplifier Measurements
3. Mixer Measurements
4. Conclusion

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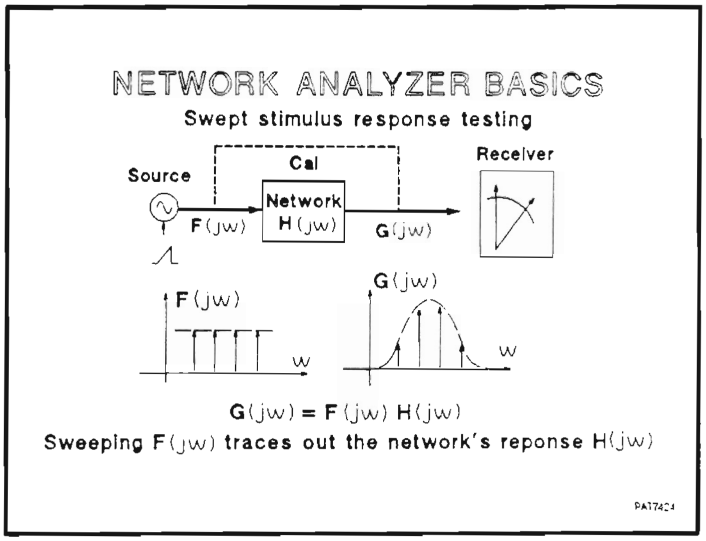
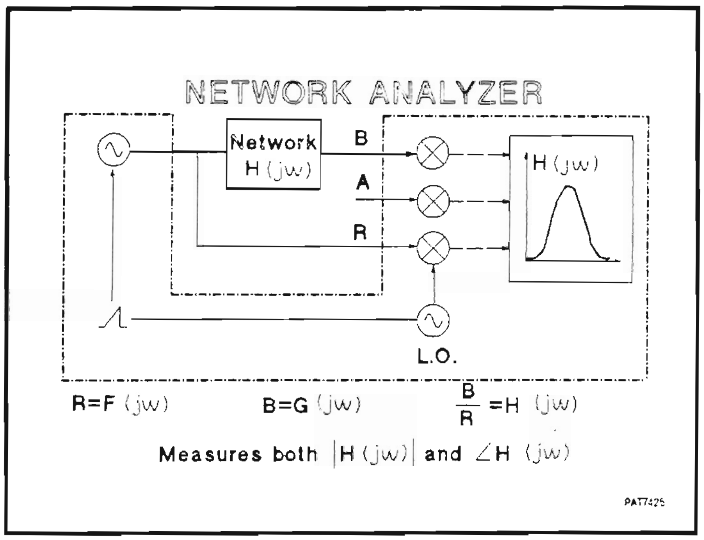
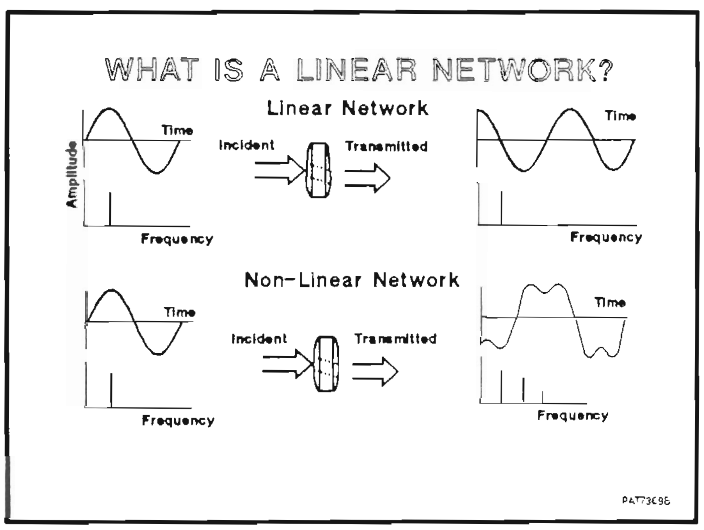
The first section reviews the basics of how a network analyzer works, and considers the difference between linear and nonlinear networks. The next section will deal with nonlinear amplifier measurements, and will explain the swept harmonic measurement capability of the HP8753B. Then we will look at some mixer measurements and the network analyzer's frequency offset capability. Many example measurements are shown, along with the resulting data.



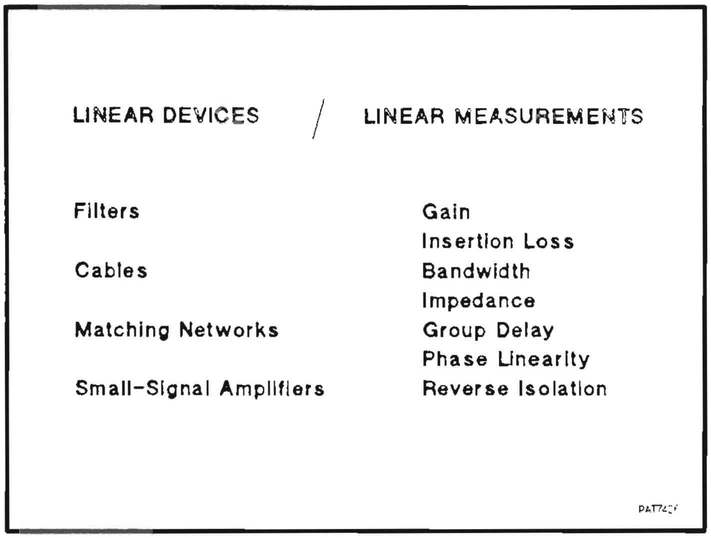
Here is a simple picture of how a network analyzer works. A sinewave generator applies a signal to the network and a receiver measures the network's response to this stimulus. If the frequency of the sinewave generator is swept, then the receiver's output will be the transfer function of the network; e.g., gain versus frequency. If the source and receiver are not perfect, then their frequency response can be corrected by making a calibration measurement.



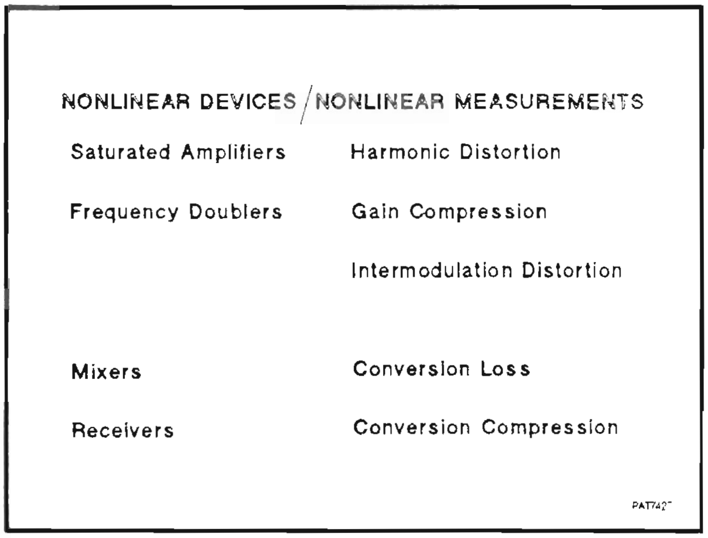
A vector network analyzer measures both the magnitude and the phase of the transfer function. It has two or more matched channels in the receiver so it can measure the input and output signals simultaneously and take their ratio. The receiver usually mixes the signals down to some lower IF frequency where they are actually measured and displayed.



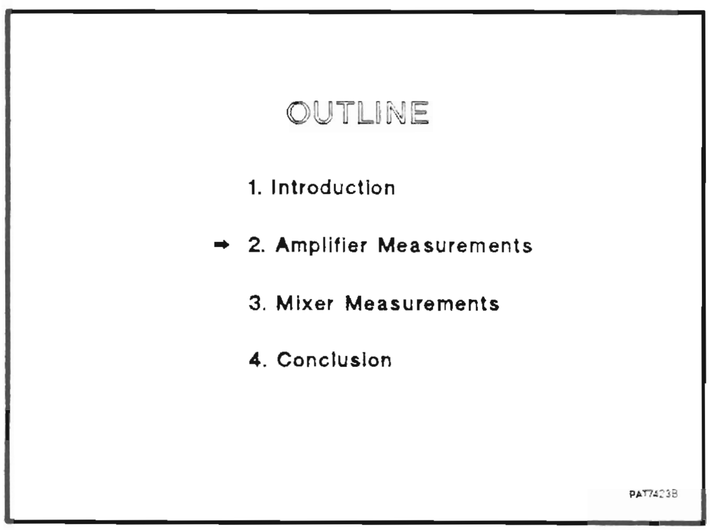
This type of instrument works very well when measuring linear networks, where a sinewave input produces a sinewave output at the same frequency with only an amplitude and phase change. A nonlinear network, however, produces an output composed of many frequencies which is dependent on the power level of the input. Most network analyzers cannot measure an output signal at a different frequency than the input signal, so they can only make limited measurements of nonlinear devices.



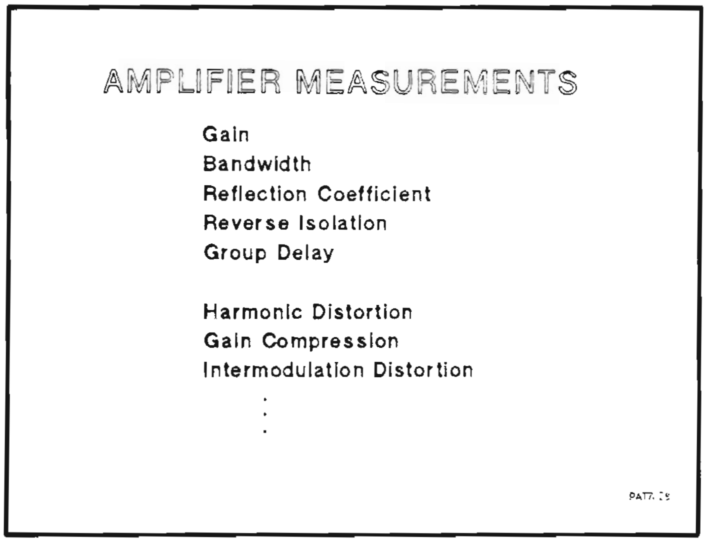
Some examples of linear networks are filters, cables, and small-signal amplifiers. Parameters of interest include gain, bandwidth, impedance, group delay, and reverse isolation, all of which can be measured with a vector network analyzer.



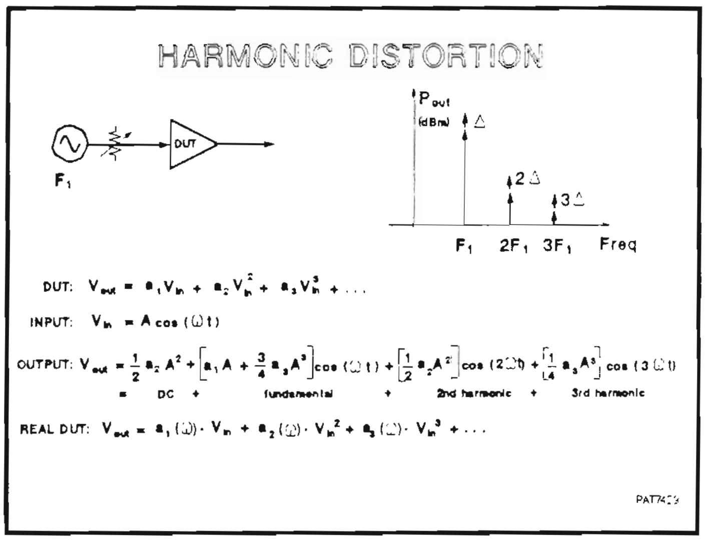
Nonlinear networks such as amplifiers near saturation and mixers have parameters which are more difficult to measure. Usually, things like harmonic distortion and mixer conversion loss are measured with a signal generator and spectrum analyzer, one frequency at a time. If the device under test is a broadband amplifier, for example, it may require many measurements at different frequencies to adequately characterize the harmonic distortion. We will see how to make swept measurements of these nonlinear parameters with the HP8753B, which greatly speeds up the process.



Now that we have an understanding of the basics of network analysis, let's consider measuring an amplifier, and look at some specific examples of how to set up these measurements.

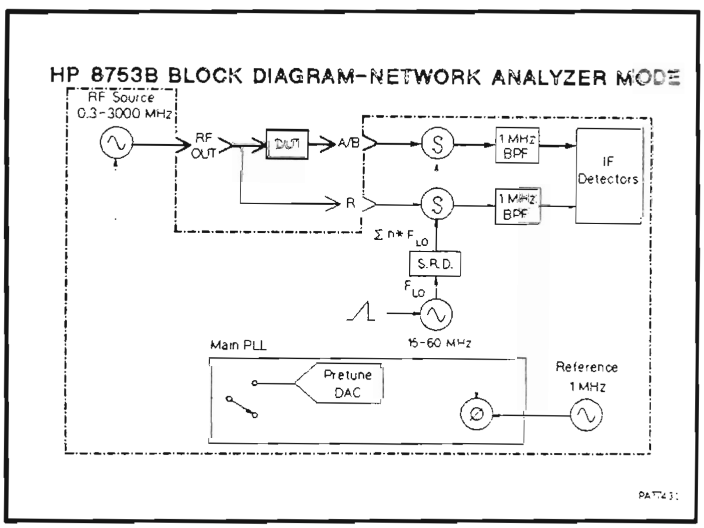


Here is a partial list of the measurements that might need to be made on an amplifier. Of course, many of these are linear measurements and can be made with a network analyzer in a straightforward manner. Others, such as harmonic distortion or intermod distortion, have traditionally been beyond the capabilities of a network analyzer. This section will show how to make these more sophisticated measurements with the HP8753B.

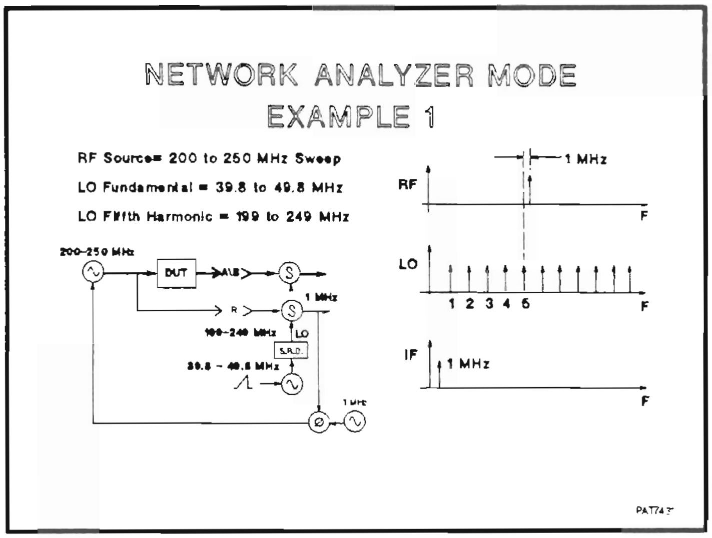


At small signal levels, an amplifier provides linear gain, but as the level increases the nonlinearity of its transfer function becomes significant. If the input is a sinewave, then the output is a sinewave plus harmonics, generated by the amplifier's nonlinearity. In most amplifiers, this nonlinearity is a function of frequency, and so the level of the harmonics may change quite a bit as the input frequency changes. In this case, many measurements at different frequencies have to be made for a thorough test.

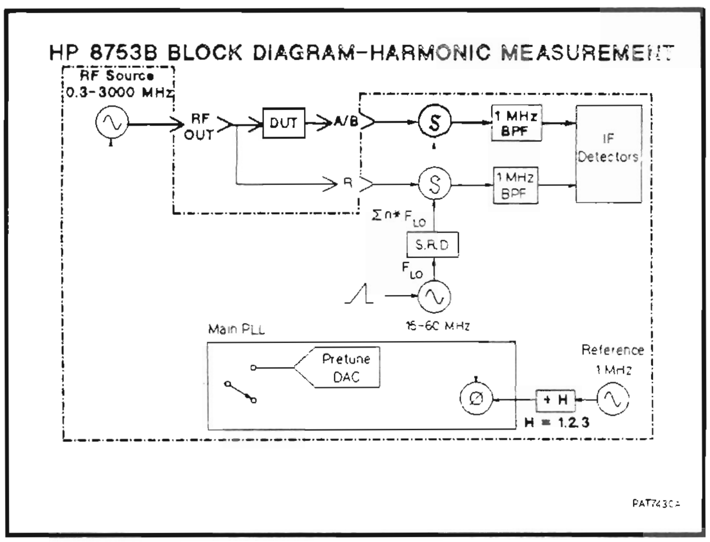
The HP8753B can measure harmonic distortion as the frequency is swept. We will examine its block diagram to see how this works.



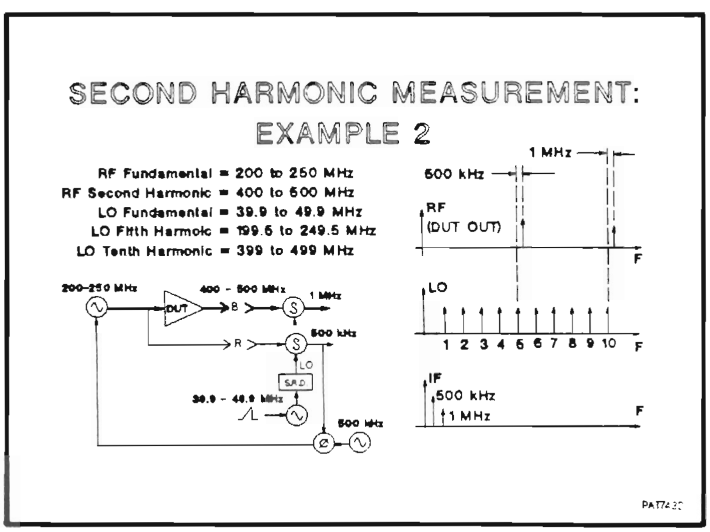
Network analyzer mode is the normal operating mode for linear, two-port measurements. The receiver uses sampling converters to down-convert the RF input signals to 1 MHz IF signals. The LO is generated by a 15 to 60 MHz synthesizer and step recovery diode. The S.R.D. output is a very narrow pulse with harmonics that extend to 6 GHz. The main phase locked loop controls the RF source frequency and forces it to be 1 MHz above one of the LO harmonics. There must be an external path from RF OUT to R in order to complete this loop. At the beginning of each sweep, the pretune DAC tunes the RF source to approximately the correct frequency, so that it will phase lock to the desired LO harmonic.



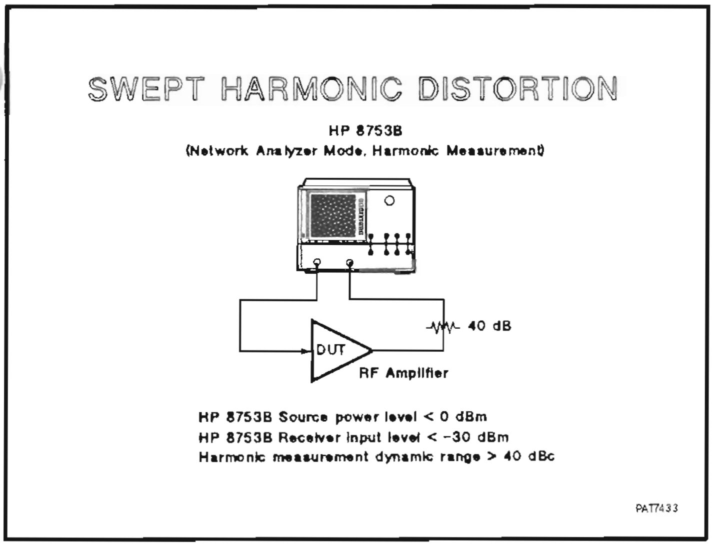
As an example, suppose the instrument's start and stop frequencies are 200 and 250 MHz. At the beginning of the sweep, the synthesized LO frequency is set to 39.8 MHz, so the fifth harmonic of the S.R.D. pulse is at 199 MHz. The RF source is pretuned to approximately 200 MHz and the phase locked loop is closed. Then the LO sweeps from 39.8 to 49.8 MHz, its fifth harmonic sweeps from 199 to 249 MHz, and the RF source sweeps from 200 to 250 MHz, tracking the LO's fifth harmonic.



The HP8753B can also make swept harmonic measurements, where the level of the second or third harmonic produced by the DUT is displayed versus frequency. For this measurements, the main PLL reference frequency is divided by the harmonic number and becomes 500 KHz for second harmonic or 333 KHz for third. The RF source fundamental frequency is down converted in the samplers to this reference frequency and is rejected by the 1 MHz bandpass filters. The second or third harmonic is down converted to 1 MHz and is measured by the IF circuitry.

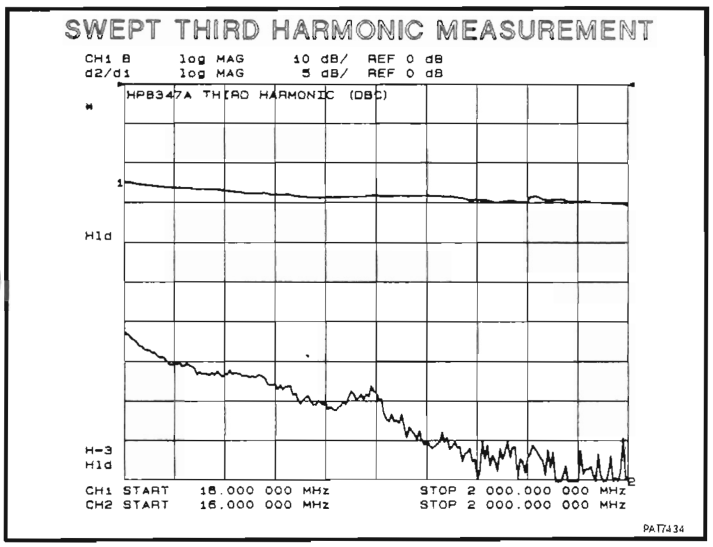


For example, suppose you are making a second harmonic measurement with start and stop frequencies of 200 and 250 MHz (these are the fundamental frequencies). The synthesized LO sweeps from 39.9 to 49.9 MHz, and its fifth harmonic sweeps from 199.5 to 249.5 MHz, so the fundamental of the RF source is down-converted to 500 KHz. The tenth harmonic of the LO sweeps from 299 to 499 MHz and the second harmonic of the RF source sweeps from 400 to 500 MHz, so it is down-converted to 1 MHz. Hence, the second harmonic signal is measured and not the fundamental.

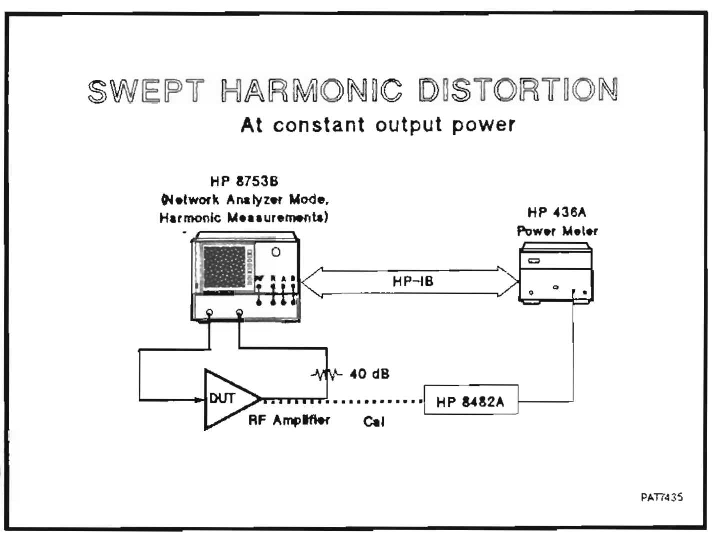


Here is a setup showing the swept harmonic measurement. The HP8753B displays the level of the second or third harmonic of the fundamental frequency, so the harmonic level can be measured over a broad frequency range in a single sweep. This is much faster than taking the data one frequency at a time with a signal generator and spectrum analyzer.

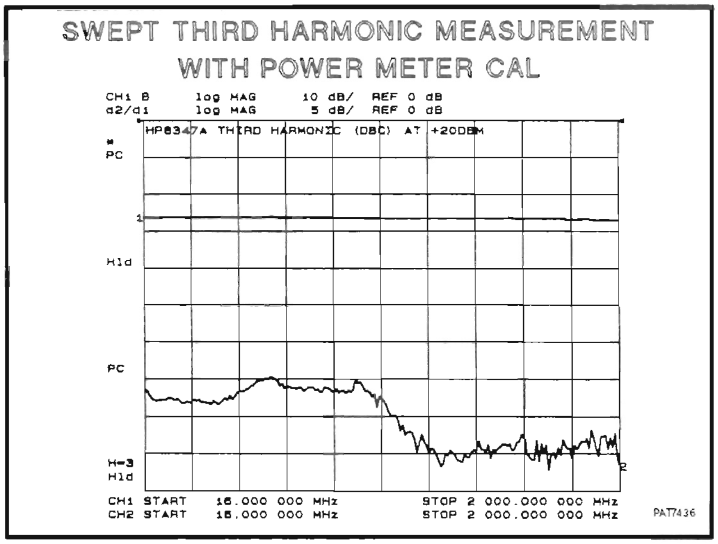
A pad may be needed on the output of the amplifier to reduce the signal levels at the receiver inputs. If the receiver levels are <-30 dBm and the HP8753B source power is <0 dB, the harmonic measurement has 40 dB dynamic range.



This data shows the level of the third harmonic signal relative to the fundamental signal at the output of the amplifier. The next question is - what is the output power level that produces these harmonics? Because of the amplifier's frequency response. its output level is not constant in this data. Generally, the harmonics need to be measured at some specified output power which should be constant versus frequency.

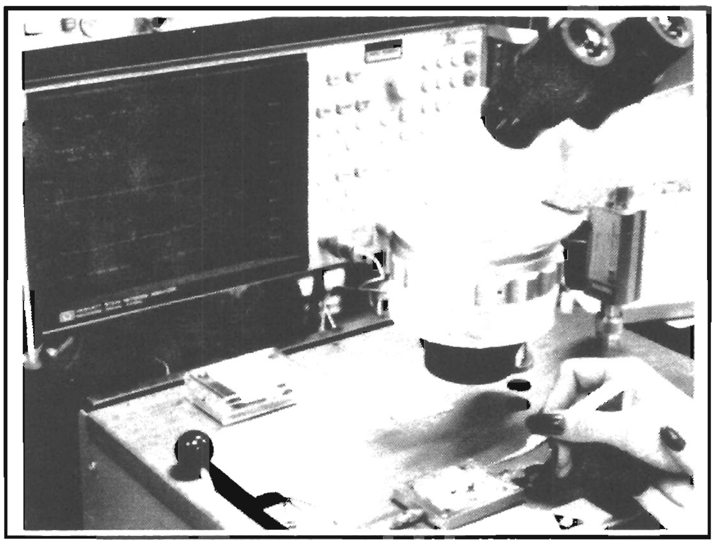


We can use the new power meter calibration feature of the HP8753B to maintain a constant output power from the amplifier. The power sensor is connected to the amplifier output and the HP8753B reads the power meter over HPIB, then corrects its source power to maintain a constant amplifier output power versus frequency. Then the amplifier output is reconnected to the test set and the source power remains corrected while the measurement is made.

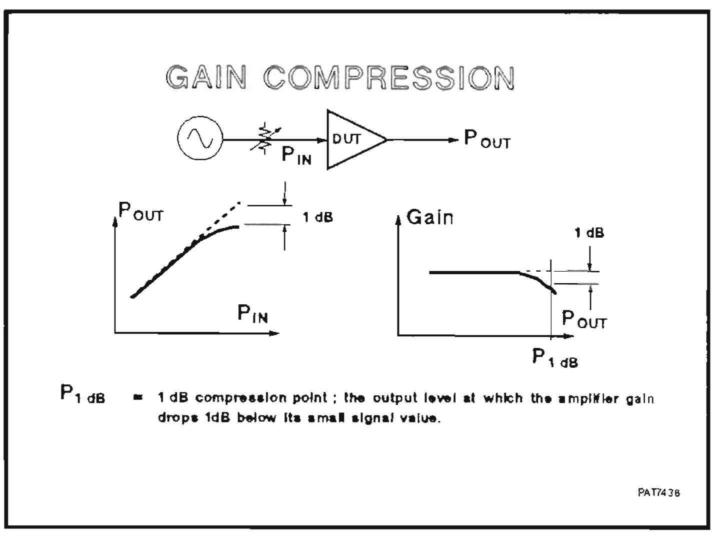


Here is the third harmonic data again, but this time a power meter cal was used to hold the output level at a constant +20 dBm.

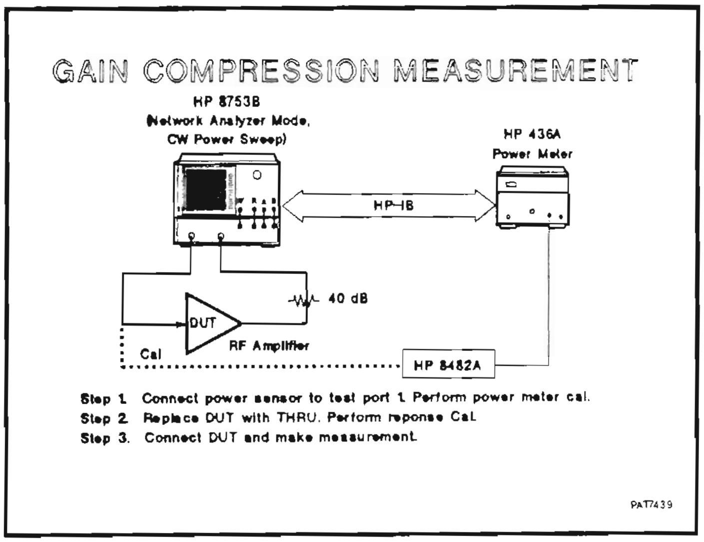
If the amplifier needs to be tuned during the measurement, it is best to have the power meter correction running continuously. In this case, a power splitter can be used on the amplifier output with the power sensor connected to one arm and the test set connected to the other. The HP8753B continually corrects its source power to maintain constant amplifier output power, even though the amplifier's gain may be changing.



This swept harmonic measurement is used on our production lines at Hewlett-Packard to measure the performance of amplifier microcircuits.

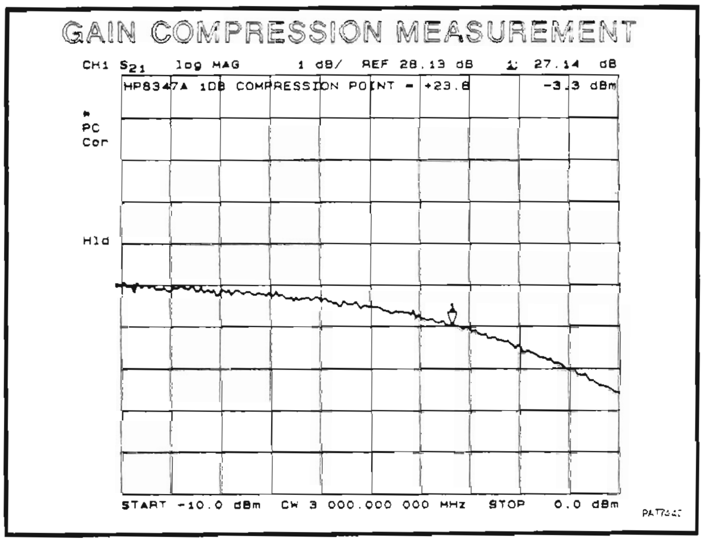


Gain compression is another measure of an amplifier's nonlinearity. It can be represented as output power versus input power, or gain versus output power. For small signals, the output power is proportional to the input power. But as the level increases and the amplifier approaches saturation, the output power reaches a limit and the gain drops. The 1 dB compression point is often specified; it is the output power level at which the gain is 1 dB less than its small signal value.



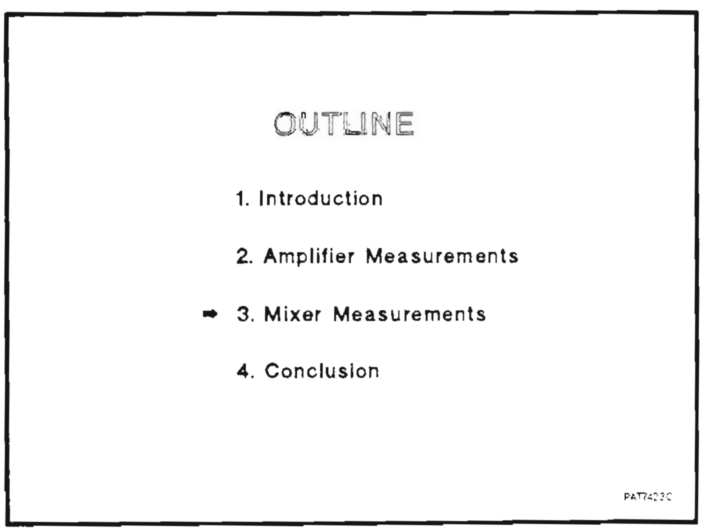
To make this gain compression measurement, the HP8753B sweeps its source power at a fixed frequency, and displays the gain of the amplifier versus power level. But the power levels on the display apply to the signal at the network analyzer's "RF OUT" connector, not the signal at the test port. This setup uses the power meter cal to improve the accuracy of the power level at the input of the amplifier.

A pad may be necessary on the amplifier's output to prevent overdriving the instrument. The receiver channels' signal levels should be kept in their most linear region (-10 to -60 dBm.) The response of the pad and test set can be removed with a response cal.

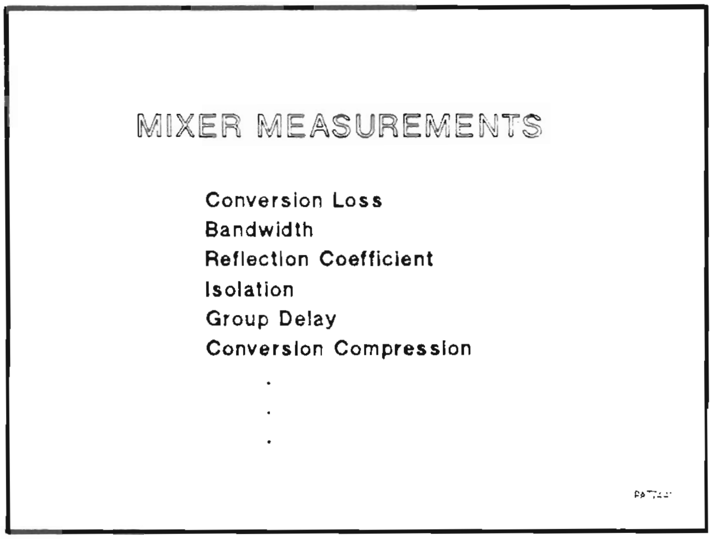


This is the compression data for the amplifier; it shows gain versus input power, and the 1 dB compression point is shown at the marker. To get the output power at this point, just add the gain to the input power.

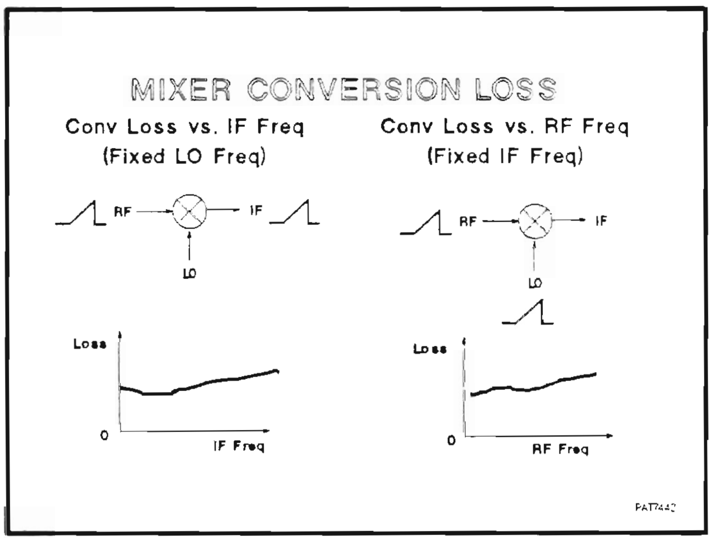
A third measure of an amplifier's nonlinearity is the two-tone intermodulation distortion. A spectrum analyzer is the most convenient instrument for this measurement, but the HP8753B can also be used. Details of this are given in Appendix A. for the interested reader.



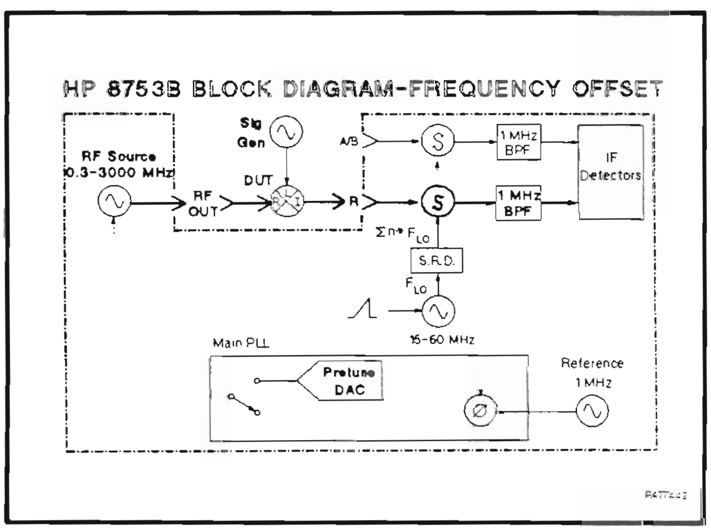
In the next section, we will look at how to make mixer measurements using the new capabilities of the HP8753B.



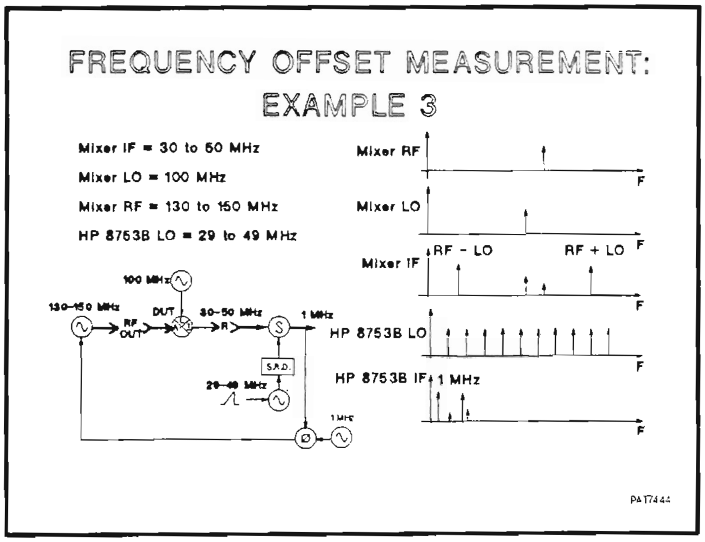
Here are some of the measurements that are made on mixers, tuners, receivers, and frequency translation devices, in general. Most of these are very difficult for vector network analyzers, because the input and output signals of the DUT are at different frequencies. One problem is that there is no simple calibration process to remove the errors of the measurement system, as there is for linear two-port measurements.



Conversion loss is a parameter commonly specified for a mixer. It is the IF power over the RF power as a function of either the IF frequency (with a fixed LO) or the RF frequency (with a fixed IF.) We will see how to make both of these measurements with the HP8753B; first we will consider the fixed LO measurement, which uses the HP8753B's frequency offset mode.

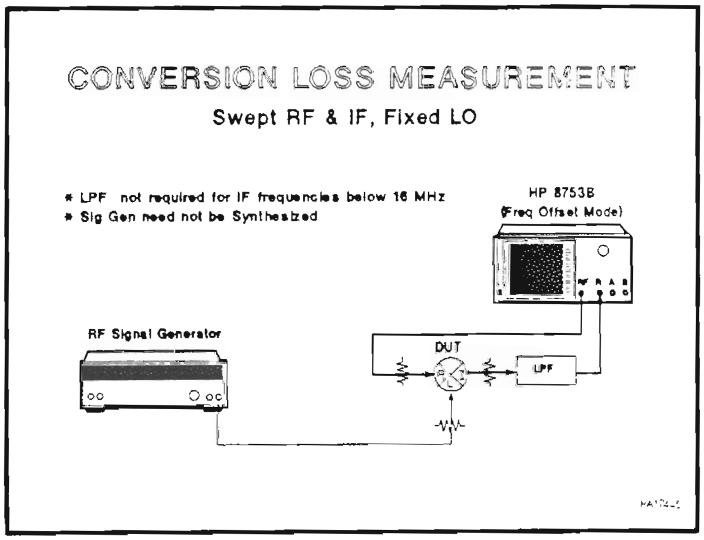


Frequency offset mode is the major contribution of the HP8753B to mixer testing. It allows the RF source to be offset from the receiver by a fixed frequency, as they sweep. The operator enters the IF start and stop frequencies and the offset value from the HP8753B front panel. At the start of the sweep, the RF source is pretuned to the IF frequency plus the offset, and the main PLL is locked up. Then the receiver sweeps over the IF range, and the source tracks it with the fixed offset.

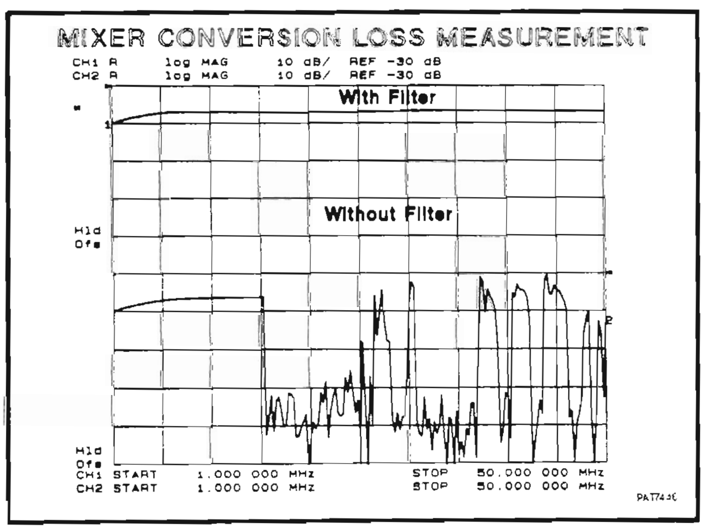


Suppose, for instance, that the signal generator is set to 100 MHz and the HP8753B start and stop frequencies are 30 and 50 MHz. Then the receiver will sweep from 30 to 50 MHz while the RF source sweeps from 130 to 150 MHz. The HP8753B will display conversion loss as a function of IF frequency.

Note that other signals will come out of the mixer besides the desired IF. These unwanted signals can mix with the harmonics of the network analyzer LO and produce signals that interfere with the 1 MHz IF. This can cause measurement errors, or even a loss of phase lock.

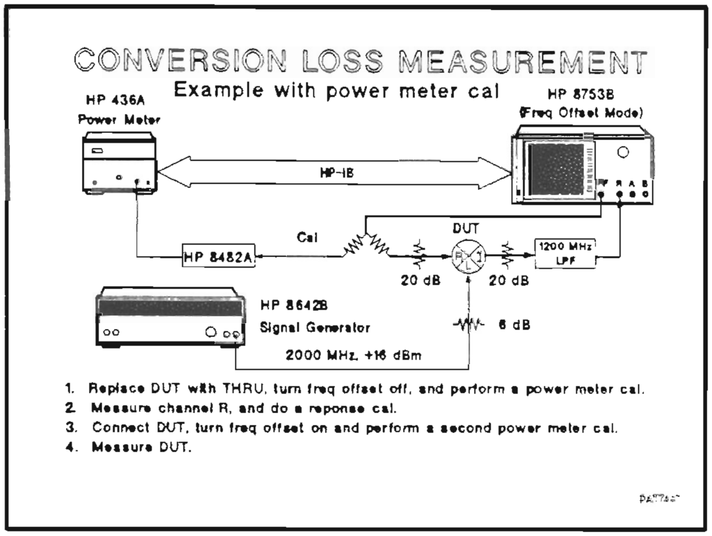


To make a conversion loss measurement with fixed LO frequency, the HP8753B is used in frequency offset mode and an external CW signal source supplies the LO. The RF frequency is always greater than the LO frequency, because of internal constraints on the HP8753B's main phase locked loop. Pads should be used to improve the match on all three ports of the mixer, as this affects the conversion loss.

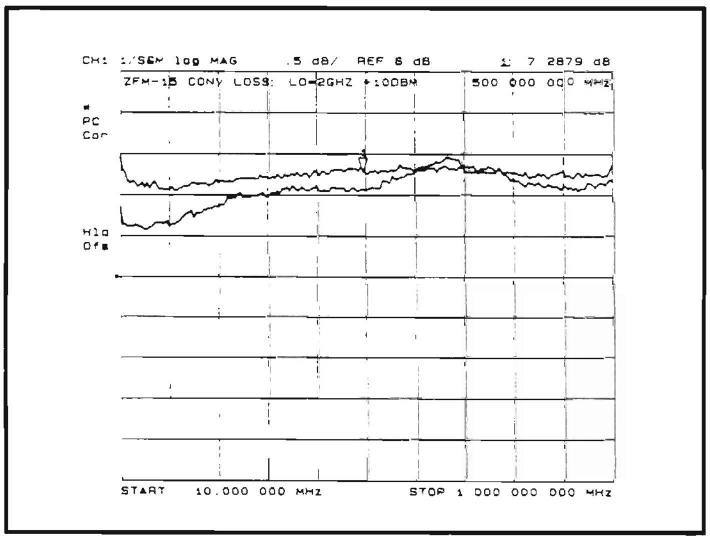


It is usually necessary to place a filter on the receiver's input to remove the unwanted mixer products which may interfere with the desired IF, as discussed earlier.

The top trace in this data is a conversion loss measurement with a proper filter. The bottom trace is with no filter. For receiver frequencies less than 16 MHz, the HP8753B uses fundamental mixing rather than sampling, so the filter is not needed.

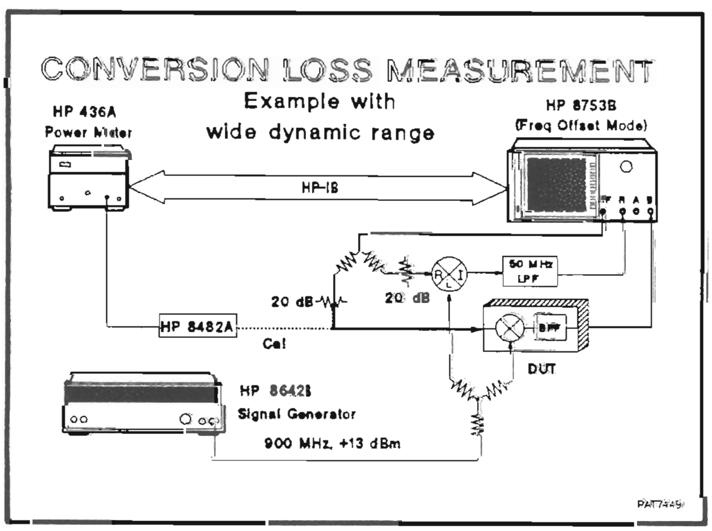


Here is an example of a mixer conversion loss measurement. The IF range is 10 to 1000 MHz, the fixed LO is 2000 MHz, and the RF range is 2010 to 3000 MHz. Power meter cal can be used, as shown here, to improve the power accuracy of the HP8753B source. To remove the response of the pads, lowpass filter, and receiver channel, a thru cal was performed as outlined. These steps considerably improve the accuracy of the measurement, as detailed in Appendix B.

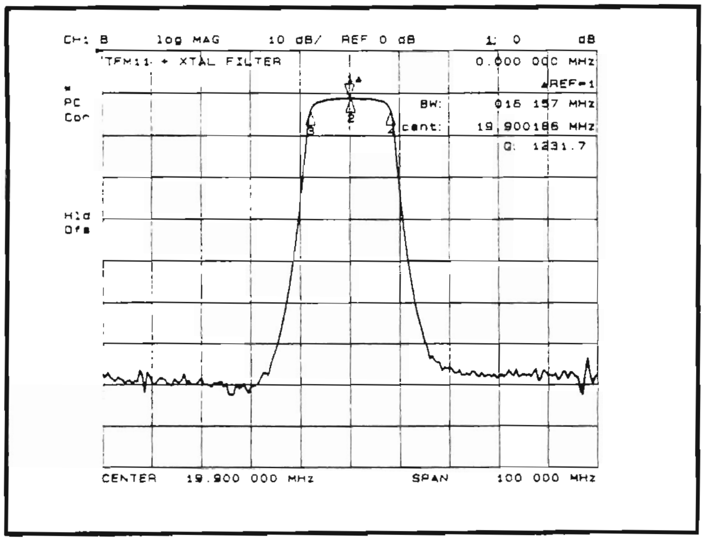


This is the conversion loss data from the example. The 1/S conversion was used to invert the data, so the vertical axis is loss. The top trace used power meter cal and a thru calibration, and the bottom trace did not.

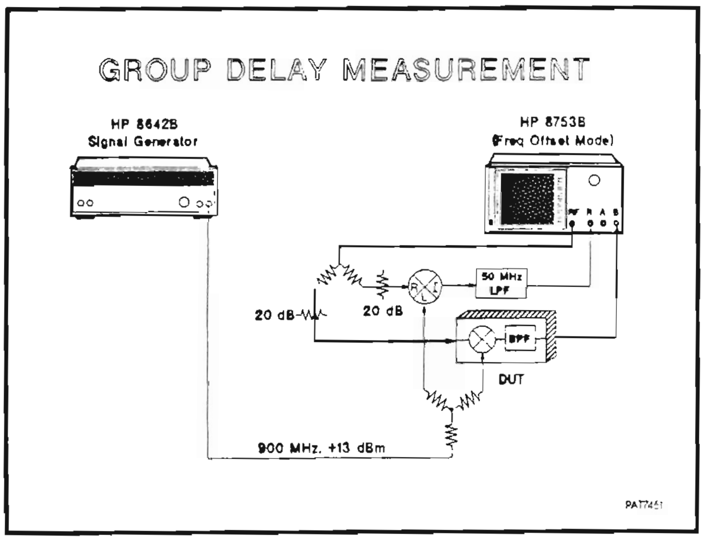
One limitation on this measurement is that the R-channel input level must be at least -35 dBm for the main PLL to operate correctly. If the DUT is a tuner or receiver that includes some built-in filtering, the R-channel may not have enough dynamic range to look at the stopbands of the DUT.



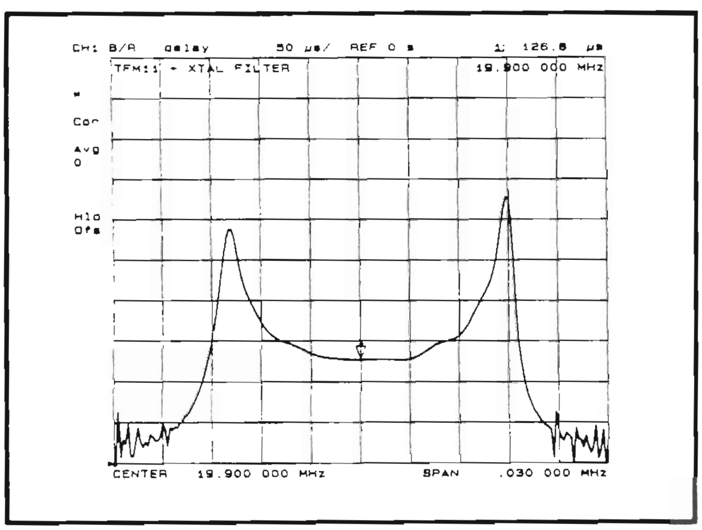
To make a wider dynamic range measurement, the DUT is placed in A or B channel and a broadband mixer and appropriate filter are placed in R-channel. The R-channel components are used only to complete the phase locked loop and do not affect the data. Power meter cal and a thru calibration can be used to improve accuracy, as before.



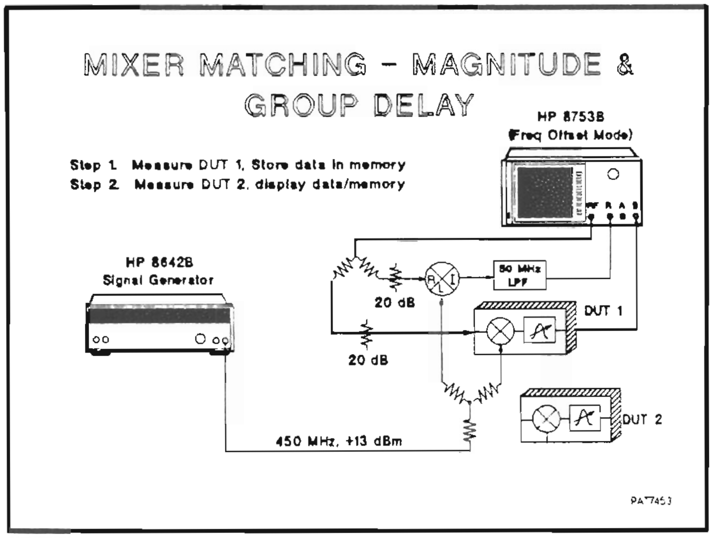
The data for this example shows the wide dynamic range achieved with this technique.



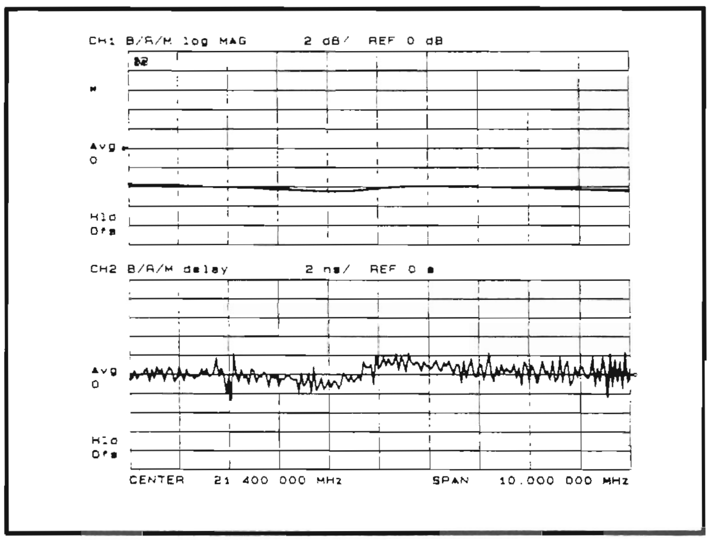
A group delay measurement is also possible with this same configuration. In this case, B/R is measured and so the R-channel components do affect the data. A thru calibration will remove the affects of the cable lengths, the R-channel filter, and the receiver channels, but not the R-channel mixer.



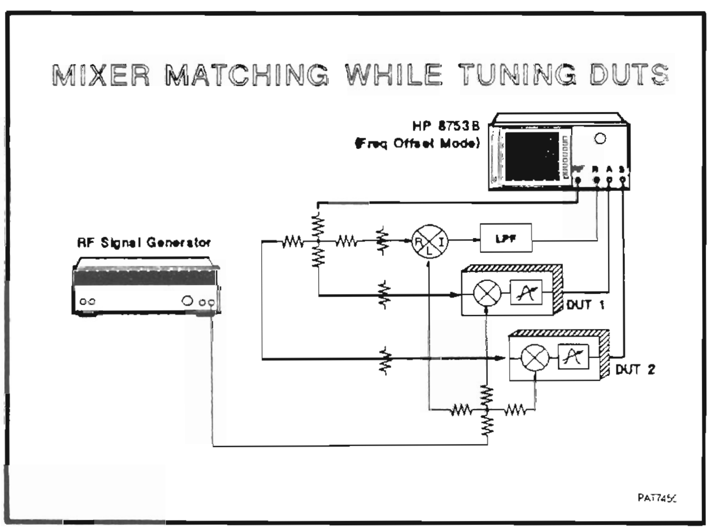
For this example, the group delay of the R-channel mixer is very small compared to the DUT, so it contributes little error.



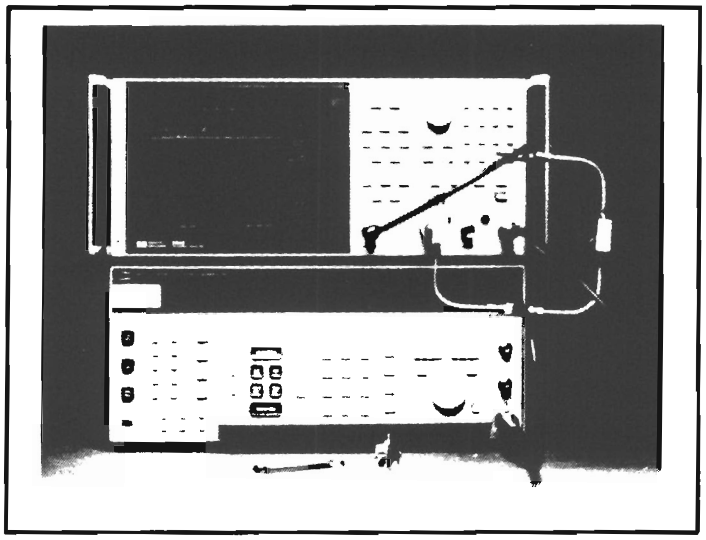
Sometimes two mixers or two receivers need to be matched in magnitude or group delay. The set up shown here can be used to make this matching measurement. First one DUT is measured and its response is stored in memory. Then the second DUT is measured and DATA/MEMORY is used to compare them. The response of the test system drops out because the two DUTs are measured with exactly the same conditions.



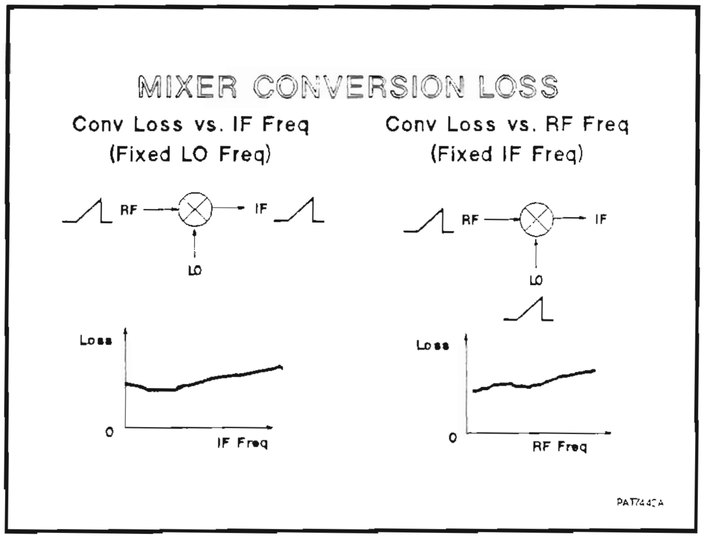
This data shows the magnitude and delay match between the two DUTs.



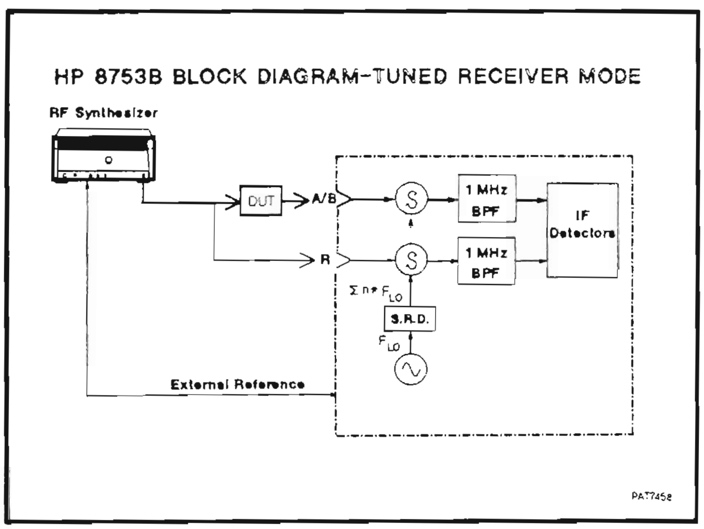
If both DUTs must be measured simultaneously (for tuning), one can be placed in B-channel and one in R-channel, or else use three-way splitters and place the DUTs in A and B-channels (for wide dynamic range). In either case, a thru calibration with frequency offset turned off, should be performed for better accuracy.



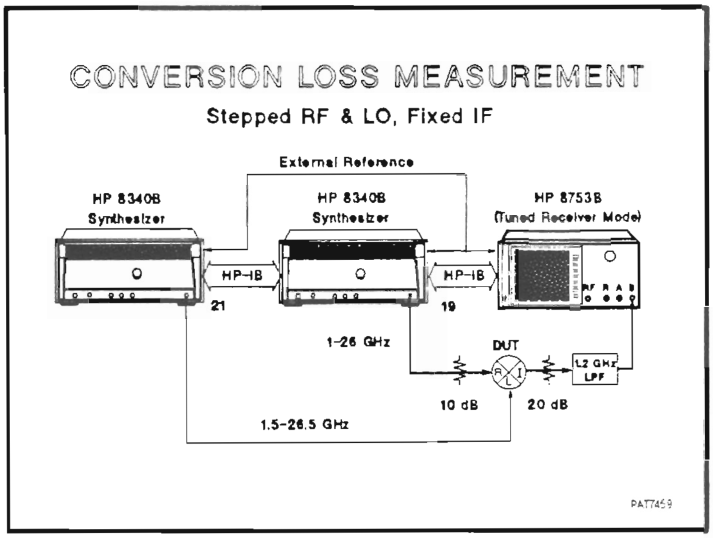
In this photograph is shown a typical configuration for matching mixers.



Now let's consider the second way that conversion loss is specified, i.e., with a fixed IF frequency while the RF and LO frequencies are varied. The HP8753B is used in its tuned receiver mode to make this measurements.



This is the analyzer's simplest mode of operation: it functions as a "tuned receiver" with a synthesized LO, and the RF source and main PLL are not used at all. An external synthesizer can be used as the source if the instruments' timebases are locked together through their reference input/output connectors. This mode is only useful for CW measurements.

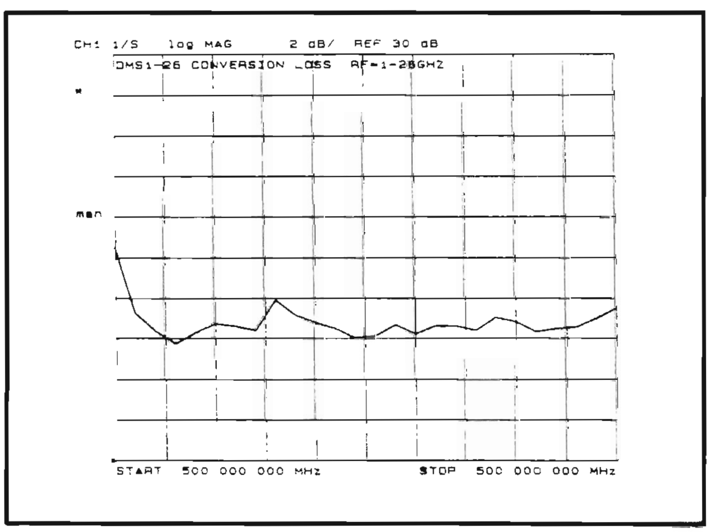


To make this conversion loss measurement requires two synthesizers to provide the RF and LO signals. The HP8753B is in tuned receiver mode and it measures the IF signal. As the RF and LO frequencies are stepped along in unison, the HP8753B takes data and displays the conversion loss at the fixed IF frequency. The timebases of all the instruments must be tied together.

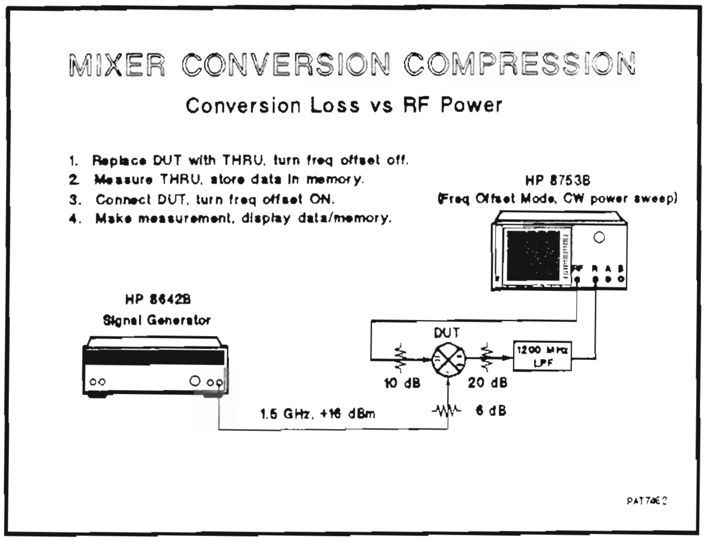
```
SEQUENCE CONLOSS1
Start of Sequence
RECALL PRST STATE
SYSTEM CONTROLLER
ADDRESS: PRINTER
 19x1
ADDRESS: P MTR/HPIB
 21x1
TUNED RECEIVER
EDIT LIST
ADD
CENTER
 500 M/u
SPAN
 0 x1
NUMBER of POINTS
 26x1
DONE
DONE
LIST FREQ
 8

SCALE/DIV
 2 x1
REFERENCE POSITION
 0 x1
REFERENCE VALUE
 30 x1
CONVERSION
1/S
MANUAL TRG ON POINT
TITLE
 PL0.2DB;SF1GZ;CW1GZ
TITLE TO PRINTER
TITLE
 PL8DB;SF1GZ;CW1.5GZ
TITLE TO P MTR/HPIB
LOOP COUNTER
 26x1
DO SEQUENCE
SEQUENCE 2

SEQUENCE CONLOSS2
Start of Sequence
TITLE
 UP
MANUAL TRG ON POINT
TITLE TO PRINTER
TITLE TO P MTR/HPIB
DECR LOOP COUNTER
IF LOOP COUNTER <> 0 THEN DO
 SEQUENCE 2
TITLE
DMS1-26 CONVERSION LOSS RF=1-26GHZ
ADDRESS: PRINTER
 1 x1
ADDRESS: P MTR/HPIB
 13 x1
```

PAT74..

The HP8753B's test sequence function can be used to write a simple sequence that controls the frequencies of the synthesizers and takes the data point by point. These sequences can easily be entered from the front panel, and then stored on disc, if desired. With the test sequence function, many simple tasks like this one can be automated without the need for an external computer.



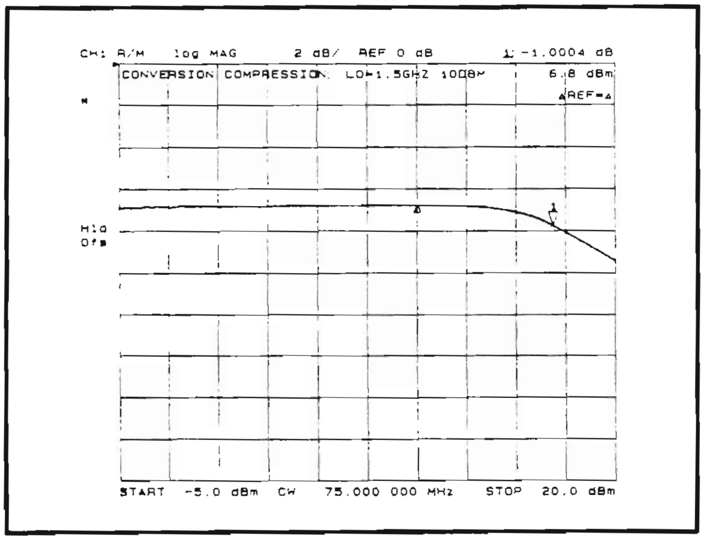
This is the data generated by the test sequence, showing conversion loss versus RF frequency, at a fixed IF frequency. It took four seconds to measure 26 data points. The RF and LO signals in this test setup can extend to mm-waves, so long as the IF frequency is below 6 GHz.



Mixers also exhibit conversion compression, which is analogous to gain compression in an amplifier. At higher RF port power, the conversion loss increases. A 1 dB compression point is often specified for mixers.

The RF power to the mixer is swept at a single frequency, and the IF power is measured. This measurement can be normalized by measuring a thru with FREQ OFFSET off and storing it in memory. Then turn FREQ OFFSET on, measure the mixer, and display data/memory. The conversion loss of the mixer will then be displayed versus power level.

Power meter calibration can also be used in this measurement to improve the power accuracy, just as in the amplifier compression measurement.



Here is the conversion compression data: the 1 dB compression point is +6.8 dBm input power. Note that the numbers on the horizontal axis are offset by 10 dB, due to the pad.

You can also measure conversion loss as a function of LO power with fixed RF power. This measurement procedure is very similar to that used for conversion compression.

OUTLINE

1. Introduction
2. Amplifier Measurements
3. Mixer Measurements
→ 4. Conclusion

OBJECTIVES

√ Define the nonlinear properties of amplifiers, and show how they are measured.

√ Do the same for mixers.

√ For each of these measurements, emphasize the recommended "best practices" to use for good results.

√ Understand the block diagram of the HP 8753B and how it makes these measurements.

PAT7464

This completes the objectives of this paper. We have explained the new capabilities of the HP8753B Vector Network Analyzer for measuring nonlinear devices, and examined its block diagram in order to understand how it makes these measurements. We have also seen many example measurements of amplifiers and mixers and the details which must be considered for best accuracy.

SUMMARY

NEW INSTRUMENT CAPABILITIES	=	NEW MEASUREMENT CAPABILITIES
SWEPT HARMONIC MEASUREMENT		AMPLIFIERS: SECOND & THIRD HARMONIC
FREQUENCY OFFSET		GAIN COMPRESSION
		TWO-TONE IMD
TUNED RECEIVER MODE		
		MIXERS:
POWER METER CAL		CONVERSION LOSS
		MATCHING
TEST SEQUENCE FUNCTION		CONVERSION COMPRESSION

In summary, the HP8753B Vector Network Analyzer offers exciting new capabilities to increase the speed and accuracy of measurements of nonlinear devices like amplifiers and mixers. These include swept harmonic measurement, frequency offset mode, tuned receiver mode, power meter calibration, and the test sequence function. But measuring nonlinear devices is still not simple: it often requires careful techniques to avoid pitfalls. Using the best practices described in this paper will help you achieve success.

Bibliography:

"Amplifier Measurements using the HP8753 Network Analyzer." Product Note 8753-1.

"Amplifier Measurements using the Scalar Network Analyzer." Application Note 345-1.

"Amplitude and Phase Measurements of Frequency Translation Devices using the HP8510B Network Analyzer." Product Note 8510-7.

"Fundamentals of RF and Microwave Power Measurements." Application Note 64-1.

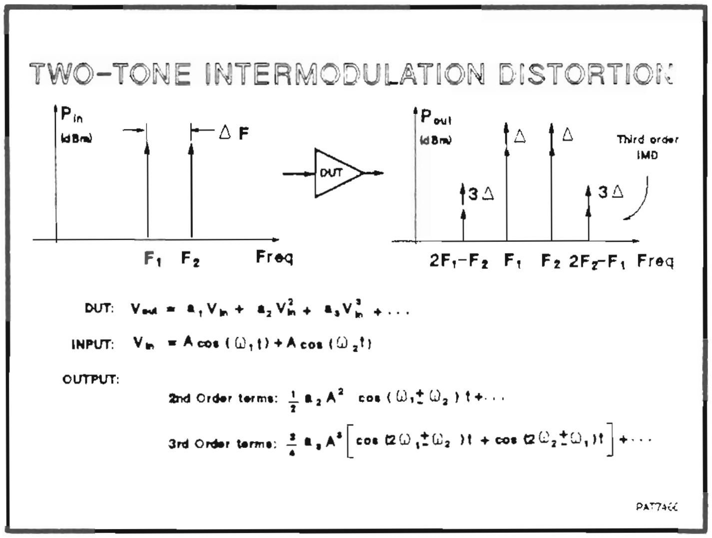
"Mixer Measurements using the HP8753B Network Analyzer." Product Note 8753-2.

"Mixer Measurements using the Scalar Network Analyzer." Application Note 345-2.

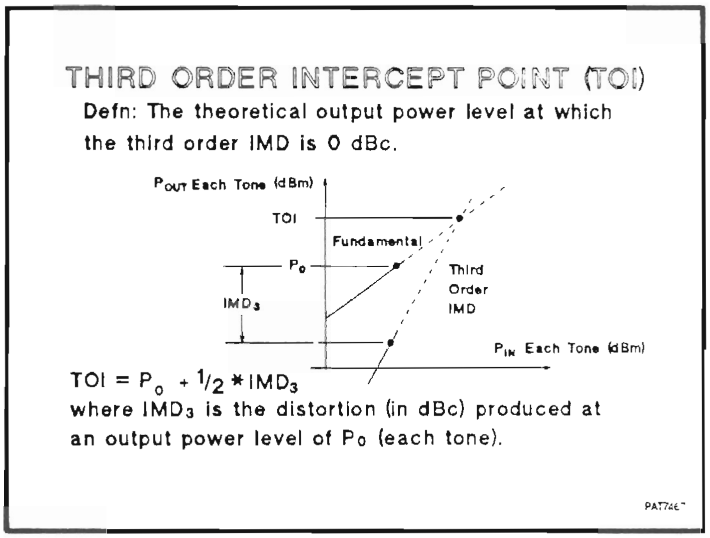
Bartz, Manfred. "Designing Effective Two-Tone Intermodulation Distortion Test Systems." RF Design. Nov., 1987.

Curran, Jim. "Simplify your Amplifier and Mixer Testing." RF Design, April, 1988.

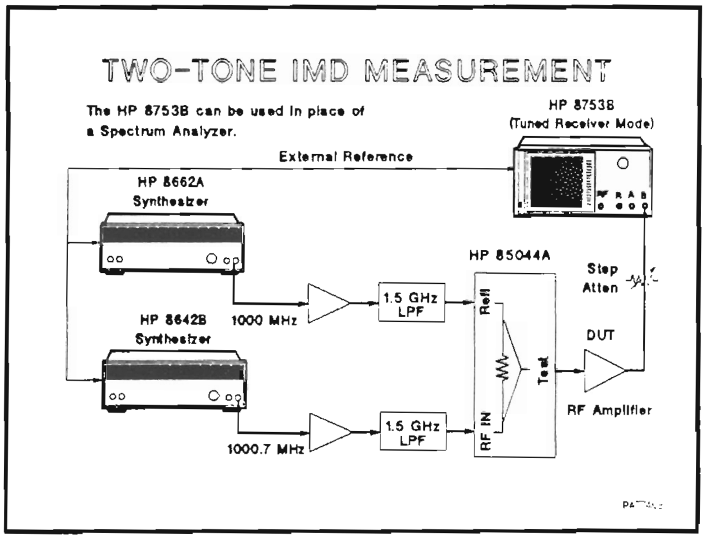
Two-Tone Intermodulation Distortion



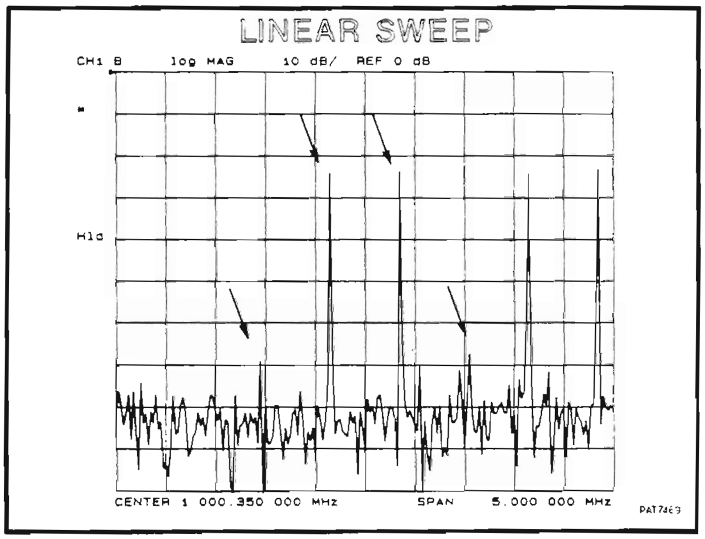
In addition to harmonic distortion and gain compression, a third common measure of an amplifier's nonlinearity is the two-tone intermodulation distortion (IMD). In this test, two closely spaced signals of equal amplitude are applied to the DUT, and its nonlinearity generates third order distortion signals at frequencies 2F1-F2 and 2F2-F1. Second order terms and higher order terms are also generated, but the third order products are particularly troublesome in many applications because they are close to the two fundamental tones, which makes them hard to filter out.



A common parameter used to compare amplifiers is the third order intercept point (TOI). It is defined as the theoretical output power level at which the third order IMD products are equal to the fundamentals. In practice, the amplifier will saturate before it reaches this level, so the distortion is measured at some smaller level and extrapolated to find the TOI.



To make this measurement requires two synthesizers to generate the two tones, and some kind of power combiner to combine them. A resistive combiner may be adequate, but usually some sort of hybrid combiner is needed to provide more isolation between the synthesizers. Inadequate isolation can allow one synthesizer to modulate the other and produce sidebands at the same frequencies as the IMD. In this example, a HP85044A test set was used as the combiner. The amplifiers and filters on the outputs of the synthesizers may be needed for testing some DUTs. The amplifiers provide additional isolation and the filters attenuate the second harmonics on the two signals. The HP8753B, in tuned receiver mode, measures and displays the output signal from the DUT. A step attenuator is usually needed to reduce the signal level so that the analyzer's input circuits do not generate excessive IMD.



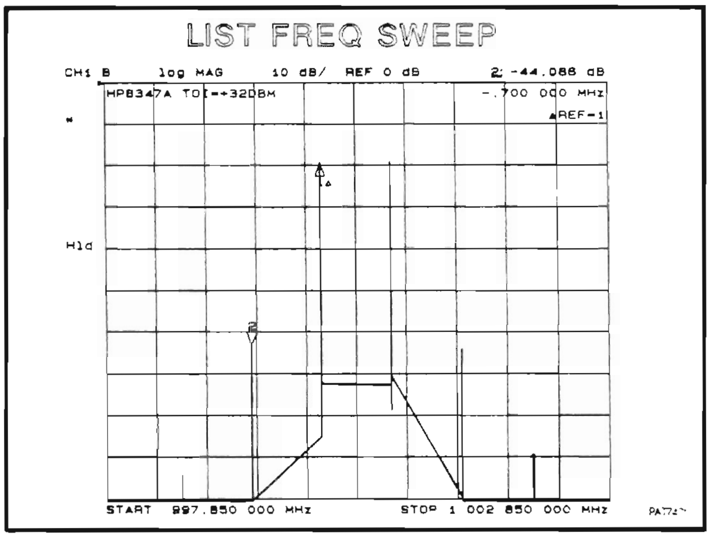
The HP8753B is used in place of a spectrum analyzer for this measurement, but it actually does not behave quite like one. Since it uses sampling converters without an input preselector, it is subject to spurious responses at the image frequencies. If a linear sweep is used to display the data, the spurious signals may appear on the screen, as shown here. The real signals are marked with arrows, and the others are spurious.

FREQ LIST FOR IMD MEASUREMENT

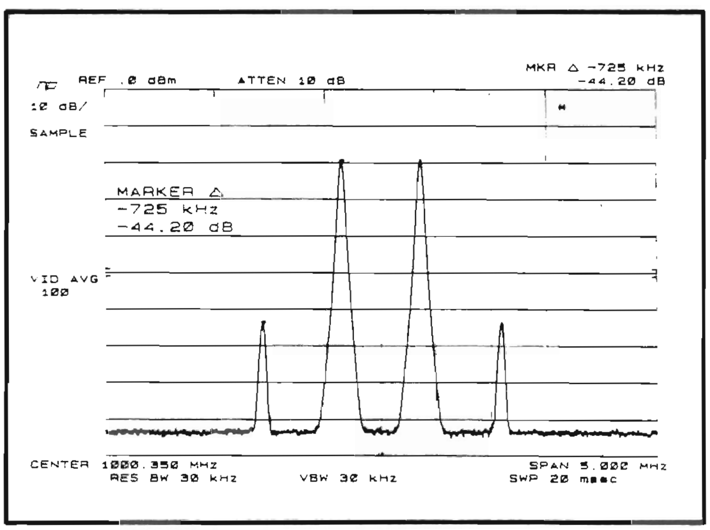
SEG	CENTER (MHz)	SPAN (MHz)	POINTS
1	1 000.350 000	5.000 000	2
2	998.600 000	0.200 000	5
3	999.300 000	0.200 000	5
4	1 000.000 000	0.200 000	5
5	1 000.700 000	0.200 000	5
6	1 001.400 000	0.200 000	5
7	1 002.100 000	0.200 000	5

IF BW = 30 Hz

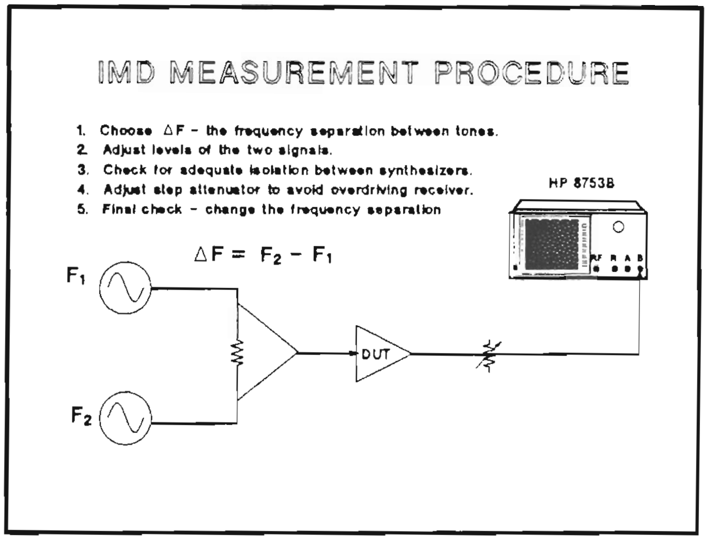
A better technique is to use a list frequency sweep and set up a list of several small segments centered on the true signals. In this manner, the confusing spurious responses are not displayed and the true signals are measured correctly.



This is the measured data for the amplifier under test. The step attenuator was set to 30 dB. The IMD level is -44 dBc at an output power level of +10 dBm (each tone). The computed third order intercept point (TOI) is +32 dBm.



For comparison, here is the same measurement made with a spectrum analyzer in place of the HP8753B. The result is practically identical.



The following procedure will yield an accurate measurement of IMD:

Step 1: Avoid "bad" two-tone separation frequencies: use 10 KHz < Δ F <1.8 MHz, excluding 15.4 KHz, 500 KHz, 992 KHz, and 1 MHz. Measure the level of the lower IMD sideband. If it seems noisy, change the separation frequency by 5 or 10 KHz. These "bad" frequencies are the values where a spurious response of the HP8753B lands on top of one of the IMD sidebands.

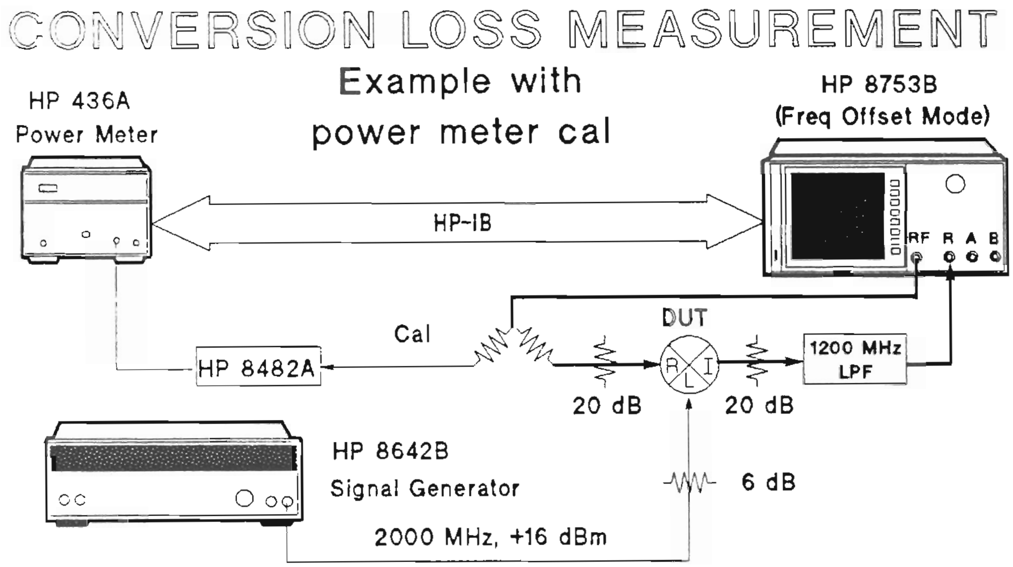
Step 2: Set up the measurement with the DUT in place and set the levels of the two tones. If you want to compute TOI, the IMD sidebands should be -40 to -50 dBc.

Step 3: Replace the DUT with a thru and adjust the step attenuator for -20 dBm signals on the HP8753B. The sidebands should be small compared to the level of the IMD you intend to measure. If not, more isolation is needed between the synthesizers.

Step 4: Re-connect the DUT, adjust the attenuator for -20 dBm signals at the HP8753B, and measure the IMD.

Step 5: Try a couple more separation frequencies to verify the validity of the measurement. As long as Δ F is much less than the DUT's bandwidth, the level of the two IMD sidebands should be equal and constant as Δ F is changed. If not, this invariably indicates a measurement problem.

Appendix B
Conversion Loss Measurement Accuracy Analysis



1. Replace DUT with THRU, turn freq offset off, and perform a power meter cal.
2. Measure channel R, and do a reponse cal.
3. Connect DUT, turn freq offset on and perform a second power meter cal.
4. Measure DUT.

PAT7447

The idea behind this procedure is to establish a certain available source power, Pavs, using a power meter cal at the IF frequencies. This will make the power splitter output look like a "perfect" source. Then, with a single channel response calibration, remove the frequency response errors of the pads, cables, filter, and R-channel. Next, establish the same Pavs at the RF frequencies with a second power meter cal and measure the DUT.

Each of these steps can have an error associated with it, as shown in the following equation:

Total Error	=	Error in setting Pavs at IF frequency	+
		Mismatch errors in response CAL	+
		Error in setting Pavs at RF frequency	+
		Mismatch errors when measuring DUT	

$$E_{TOT} = E_1 + E_2 + E_3 + E_4$$

Actually, we will use the root-sum-of-squares (RSS) method in this analysis, so that:

$$E_{TOT} = (E_1^2 + E_2^2 + E_3^2 + E_4^2)^{1/2}$$

Each of these four terms can be further broken down and calculated from data sheet specs.

E_1 = Error in setting Pavs at IF frequency.
E_1 = Power sensor mismatch error + cal factor uncertainty + power splitter tracking error.

HP8482A, 1 MHz - 2 GHz : SWR <1.1, ρ <0.05
HP11667A, DC - 4 GHz : SWR <1.1, ρ <0.05
Power sensor mismatch error = .05 x .05 = .0025

HP8482A, 10 - 1000 MHz : Cal factor error <1.6% RSS

HP11667A, DC - 4 GHz : Output tracking error <3.5% (.15 dB)

$E_1 = [(.0025)^2 + (.016)^2 + (.035)^2]^{1/2} = .0386$

E_2 = Mismatch error between pads during response cal

HP8493A, DC - 8 GHz : SWR <1.2, ρ <0.09

$E_2 = .09 \times .09 = .0081$

E_3 = Error in setting Pavs at RF frequency.
E_3 = Power sensor mismatch error + cal factor uncertainty + power splitter tracking error

HP8482A, 2 - 4.2 GHz : SWR <1.3, ρ <0.13
HP11667A, DC - 4 GHz : SWR <1.1, ρ <0.05
Power sensor mismatch error = .13 x .05 = .0065

HP8482A, 2 - 4 GHz : Cal factor error <1.5% RSS

HP11667A, DC - 4 GHz : Output tracking error <3.5%

$E_3 = [(.0065)^2 + (.015)^2 + (.035)^2]^{1/2} = .0386$

E_4 = Mismatch errors when measuring DUT.
E_4 = Mismatch error at RF port of DUT + mismatch error at IF port of DUT

HP8493A, DC - 8 GHz : SWR <1.2, ρ <0.09
ZFM - 15 Mixer, 2 - 3 GHz : RF SWR <2.5, ρ <0.43
RF port mismatch error = .09 x .43 = .0387

ZFM - 15 Mixer, 10 MHz - 1 GHz : IF SWR <1.5, ρ <0.2
IF port mismatch error = .09 x .20 = .018

$E_4 = [(.0387)^2 + (.018)^2]^{1/2} = .0427$

Note that E_4 depends on the SWRs of the DUT you are measuring.

$E_{TOT} = [(.0386)^2 + (.0081)^2 + (.0386)^2 + (.0427)^2]^{1/2}$

$E_{TOT} = +/-0.07$ or **TOTAL ERROR = +/-0.3 dB**

The largest contributor of error in this example is E_4. the mismatch errors when measuring the DUT. This could be reduced by measuring and selecting 20 dB pads which have better SWRs than the spec. Another large contributor is the tracking error between the two arms of the power splitter. This can be eliminated by measuring the tracking error and loading this data into the 8753B's "POWER LOSS" list.

One potential error that was not accounted for in this analysis is the frequency response of the RF port pad and cable. These were measured at the IF frequencies during the response cal, but they are used at the RF frequencies when the DUT is measured. Since these are 18 GHz components, this example assumes that they are perfectly flat from DC to 3 GHz - usually a fair assumption. Of course, the pad and cable can be measured and their frequency response can be removed from the DUT's data in an external computer program.

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