

Errata

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HP References in this Application Note

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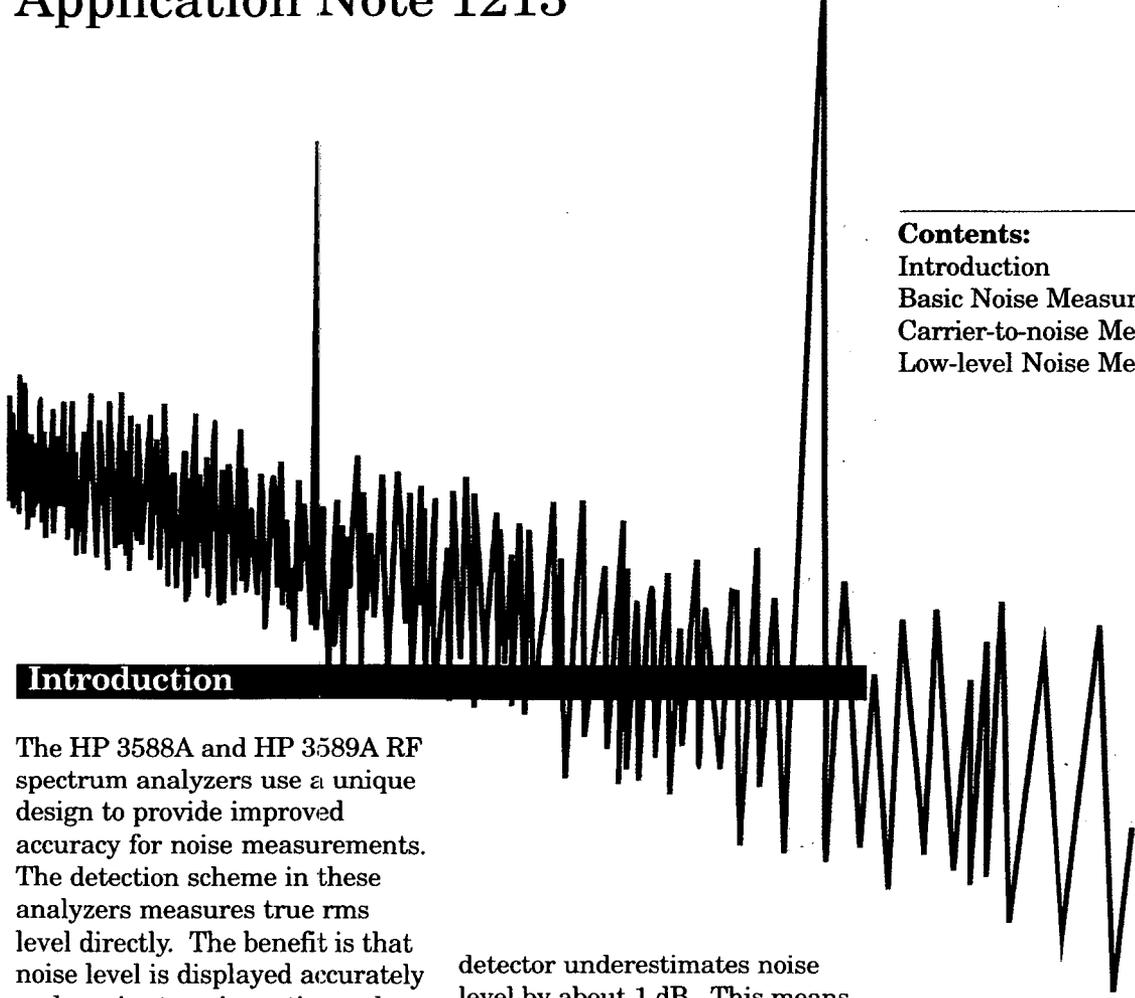
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Better Noise Measurements with the HP 3588A & HP 3589A

Application Note 1213

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Introduction

The HP 3588A and HP 3589A RF spectrum analyzers use a unique design to provide improved accuracy for noise measurements. The detection scheme in these analyzers measures true rms level directly. The benefit is that noise level is displayed accurately and carrier-to-noise ratio can be determined directly from a single measurement. This is different from most RF spectrum analyzers which typically underestimate noise level and therefore require correction factors for noise measurements.

Traditional analyzers use log amplifiers and envelope detection schemes that introduce errors into noise measurements. (See figure 1). The log amp will tend to compress noise level by about 1.45 dB. The standard diode

detector underestimates noise level by about 1 dB. This means that displayed noise level will be 2.5 dB too low, giving you the impression there is only about half as much noise power as there really is. This can be misleading in carrier-to-noise measurements, because the carrier level is displayed accurately but the noise level is displayed too low. Therefore, it is a common practice to apply a 2.5 dB correction factor to a noise measurement made with a traditional analyzer.

Even with the use of correction factors, you may not get an accurate noise measurement with a traditional analyzer. The correction factors are based on the assumption that the measured noise has a gaussian distribution. Often, the distribution of the noise being measured is unknown. In contrast, the HP 3588A & HP 3589A spectrum analyzers correctly detect and display the level of all types of noise, as well as CW signals.

Benefits of Digital Technology

Figure 1 shows the main differences between the HP 3588A & HP 3589A and traditional analyzers. The key to making more accurate noise measurements is the digital technology. In the last IF stage of the analyzer, the analog signal is converted to a digital information stream. As a result, the resolution bandwidth filter (RBW filter) becomes a programmable digital filter and the detector becomes a mathematical algorithm. Both provide benefits.

The digital filters have accurate bandwidths, which reduces uncertainty in noise measurements. Since noise level is always referenced to an equivalent noise bandwidth, or ENBW, it is important to know the precise bandwidth of the filters. Traditional analyzers can have a 20% uncertainty in bandwidth, which translates into noise level uncertainty of up to 1.5 dB. In contrast, the bandwidths of the digital filters are known within 1%, which translates to a noise level uncertainty of less than .1 dB.

Bandwidth uncertainty directly affects the accuracy of the noise marker, which normalizes the noise level at one point to a 1 Hz bandwidth. Since it divides the measured noise level by the ENBW, any uncertainty in the filter bandwidth translates into an uncertainty in the computed result. Since the digital filters are so precise, the accuracy of the noise marker is improved over traditional designs.

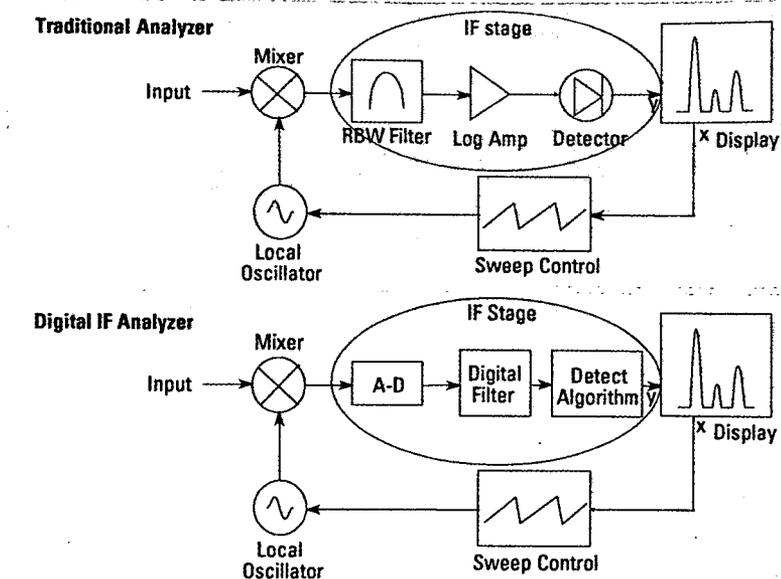


Figure 1: The digital IF analyzer replaces the analog RBW filter with a digital filter that offers more predictable noise bandwidth. The log amplifier and envelope detector are replaced by a digital algorithm that computes average power that provides accurate detection for both CW signals and noise.

In addition to precise bandwidths, the digital filters have an excellent shape factor. Figure 2 compares the shape of the digital filters (shape factor of 5:1) to the analog ones used in traditional analyzers (typically 11:1 shape factor). The excellent shape results in an ENBW that is nearly the same as the resolution bandwidth of the filter, which simplifies some noise measurements. The ENBW is only 1.06 times greater than the resolution bandwidth, as compared to 1.11 or 1.2 in other analyzers.

After the data passes through the digital filter, it goes to the detector stage. With digital processing, it is easy to implement an algorithm that computes true average power, and from that true rms level. As discussed earlier, true rms level detection provides more accurate noise measurements.

This application note describes in detail how to use the HP 3588A and HP 3589A RF spectrum analyzers to make accurate noise measurements. This note also

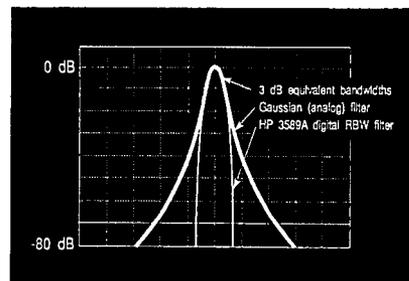


Figure 2: Shape of the digital filters in the HP 3588A is shown by the thin line. The heavy line estimates the shape of analog filters in traditional analyzers.

explains how to compare these measurements to those made on other spectrum analyzers which do not have the same filter bandwidths or detection scheme.

Since the HP 3588A and HP 3589A have identical digital filters and detectors, they will be referred to as the HP 3588/9A in the remainder of this note.

Basic Noise Measurements

Overview

- Analyzer must be in peak (off) display mode.
- Analyzer must have oversweep turned off.
- Correction factors for the detector are not required.
- The noise bandwidth is about 1.06 times the resolution bandwidth.
- The noise marker automatically normalizes results to 1 Hz noise bandwidth.
- The 17 kHz RBW filter produces results that match un-corrected measurements made with the 30 kHz filter in most other analyzers.

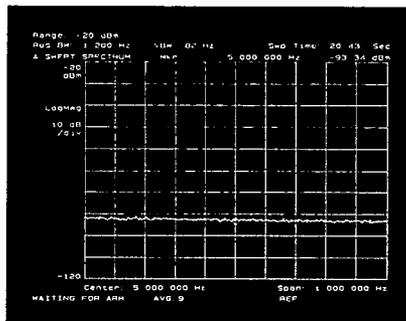
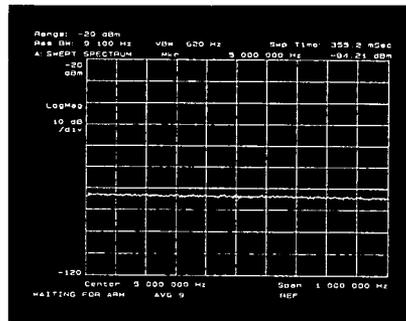
Noise Power and Analyzer Bandwidth

When you use a spectrum analyzer to measure noise, the noise level changes when you change the resolution bandwidth. This is different from measurements of CW signals, whose level stays the same when the resolution bandwidth is changed.

Noise measurements are dependent on bandwidth because noise, by definition, consists of spectral energy distributed continuously over frequency. (Unwanted energy that is isolated to a few discrete frequencies is referred to as distortion). When the resolution bandwidth is increased, the detector in the analyzer is exposed to noise over a wider bandwidth, and measures more total noise. Figures 3A and 3B show how displayed noise level changes when the resolution bandwidth is changed. To allow comparison between different analyzers, noise measurements are often normalized to a 1 Hz bandwidth. Noise power in a 1

Hz bandwidth is called power spectral density

As you can see, noise measurements made in different bandwidths cannot be compared directly. For this reason, noise measurements are often normalized to unity bandwidth (1 Hz). The normalized results, called power spectral density, can be compared directly.



Figures 3A and 3B: Noise power changes proportionally with bandwidth. In 3A, the marker indicates a level of -84 dBm in a 9100 Hz bandwidth. In 3B the bandwidth is 7.6 times less which translates to about 9 dB. As expected, the marker in 3B indicates -93 dBm.

Equivalent Noise Bandwidth (ENBW)

The noise bandwidth is not the same as the resolution bandwidth because the final IF filter in the analyzer does not have a perfect rectangular shape. Figure 4

illustrates how equivalent noise bandwidth (ENBW) is defined. It is the width of a rectangular filter that passes the same noise power as the IF filter in question. Since ENBW is usually not specified, it is computed by multiplying the RBW (resolution bandwidth) by a scale factor that is determined by the filter design:

$$\text{ENBW} = k \cdot \text{RBW}$$

In the case of the HP 3588/9A the "k" factor is about 1.06. Since the digital filters are absolutely predictable, the precise noise bandwidth at each resolution bandwidth setting is known exactly and is displayed in the state table of the analyzer. In addition, the noise bandwidth is available as an operator for math operations so an entire noise trace can be normalized to a 1 Hz bandwidth.

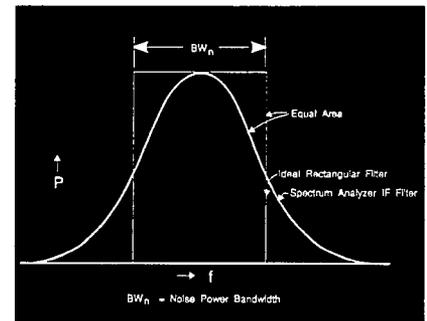


Figure 4: Noise power bandwidth is defined by an ideal filter that has the same area as the actual filter in the analyzer.

Normalizing to 1 Hz Bandwidth (Power Spectral Density)

To compare two different noise measurements, the noise bandwidths should be the same. If they are not, they should be normalized to unity bandwidth. For random noise, power doubles when bandwidth is doubled. (This is different from impulsive noise, which doubles in voltage when bandwidth is doubled). The bandwidth correction for random noise is computed this way:

$$\text{correction factor} = 10 \log (\text{new NBW} / \text{measured NBW})$$

Example: Normalize a 290 Hz RBW measurement to 1 Hz Noise Bandwidth

$$\text{correction factor} = 10 \log (1 \text{ Hz} / 306 \text{ Hz}) = -24.9 \text{ dB}$$

Note:
306 Hz is the noise bandwidth shown in the HP 3588/9A state table.

This means a noise measurement made in the 290 Hz resolution bandwidth can be normalized to a 1 Hz bandwidth by subtracting

24.9 dB. Normalization to 1 Hz of an entire noise trace can be done with a math operation. (See appendix about the math operation). The noise marker automatically normalizes to a 1 Hz bandwidth.

The Noise Marker

The noise level marker is designed to make a precise noise measurement at the frequency selected by the marker. With the noise level marker turned on, the analyzer sweeps until it reaches the frequency of the marker. Then the analyzer stops sweeping to make several noise measurements at that frequency. These measurements are averaged together to reduce variance. After the averaging is complete,

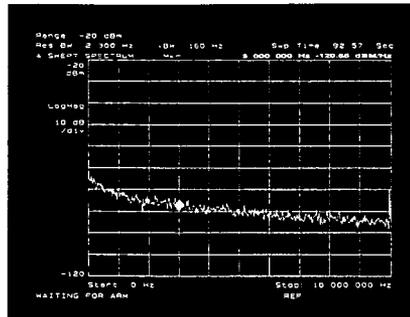


Figure 5: With the noise marker on, the analyzer pauses at the marker frequency to make several noise measurements. These are averaged together and the result is normalized to 1 Hz. The normalized result is expressed in power spectral density which has units of power per unit bandwidth: dBm/Hz.

the result is normalized to a 1 Hz bandwidth and the analyzer continues on its sweep. Figure 5 shows the result of the noise marker.

Normalizing to Measurements Made on Other Analyzers

There are times when you do not want to normalize noise data to a 1 Hz bandwidth. To compare noise measurements from the HP 3588/9A to those made on other analyzers, you must consider two things: the difference in bandwidth and the difference in detectors.

Example:

Normalize 17 kHz on the HP 3588/9A to 30 kHz on the HP 3585A.

Noise Power

$$\text{Bandwidth Correction} = 10 \log (30 \text{ kHz} * 1.11 / 18.1 \text{ kHz}) = +2.65 \text{ dB}$$

Notes:

The noise bandwidth of the HP 3585A is 1.11 times greater than the 30 kHz resolution bandwidth.

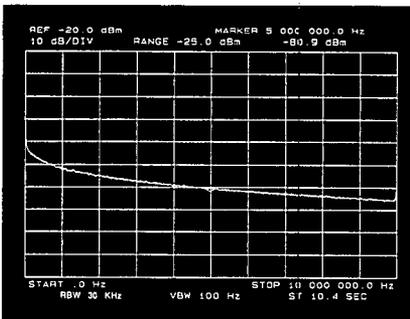
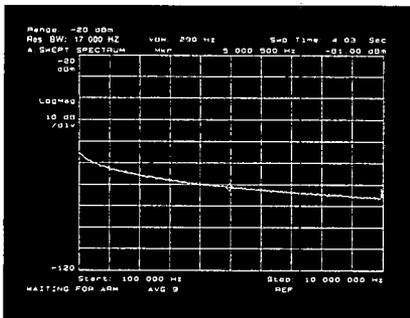
The 17 kHz resolution bandwidth filter in the HP 3588/9A has a 18.1 kHz noise bandwidth.

The 17 kHz resolution bandwidth filter in the HP 3588/9A sees 2.65 dB less noise power than the 30 kHz filter in the HP 3585A.

To compare the measurements of random noise on two different analyzers, we must also consider the difference between the detector schemes. The HP 3588/9A measures 2.5 dB higher than most other analyzers because it has a true rms detector as opposed to other analyzers which use a scheme that under estimates noise level. (In a traditional analyzer, the envelope detector under estimates noise by 1.05 dB. The log amplifier effectively compresses a noise signal so that the average level is 1.45 dB low. The total is 2.5 dB.) The correction between the two different displays is best expressed this way:

$$\begin{aligned}
 \text{Total Correction} &= \frac{\text{Traditional analyzer}}{\text{HP 3588/9A}} = \text{Bandwidth factor} + \text{detector factor} \\
 &= +2.65 \text{ dB} + (-2.5 \text{ dB}) \\
 &= +.15 \text{ dB}
 \end{aligned}$$

In this case, the bandwidth factor is positive because the 30 kHz bandwidth used on the traditional analyzer sees greater noise power than the 17 kHz bandwidth used in the HP 3588/9A. The detector factor is negative because a traditional analyzer under estimates noise while the HP 3588/9A measures it correctly. This analysis shows the 17 kHz bandwidth of the HP 3588/9A displays almost the same noise level as the 30 kHz bandwidth of a traditional analyzer. The



Figures 6A and 6B: The 17 kHz filter in the HP 3588A (6A) produces the same result as the 30 kHz filter in traditional analyzers like the HP 3585A (6B).

measurements in figures 6A and 6B illustrate this.

The 30 kHz bandwidth in traditional analyzers is commonly used for noise measurements, but if the HP 3588/9A had a 30 kHz resolution bandwidth, the displayed noise level would be 2.5 dB higher than with a traditional analyzer. Fortunately, the 17 kHz bandwidth in the HP 3588/9A can be used to produce a measurement that looks about the same as an uncorrected noise measurement made with a traditional analyzer in a 30 kHz bandwidth.

In summary, you must consider 4 things when comparing noise measurements from the HP 3588/9A to other analyzers:

1: Noise measurements made on most other analyzers underestimate noise level by 2.5 dB. The HP 3588/9A has a true rms detector and measures noise level correctly.

2: The HP 3588/9A has unusual resolution bandwidths. It is best to normalize noise measurements to a 1 Hz bandwidth so they can be compared to any other power spectral density display. Remember that the noise marker does the normalization automatically.

3: Many analyzers have a special noise marker to provide accurate and consistent noise measurements normalized to 1 Hz. In the case of the HP 3588/9A, the noise marker only needs to correct for bandwidth. In traditional analyzers, the noise marker corrects for the detector and log amplifier (2.5 dB for gaussian random noise) in addition to the bandwidth.

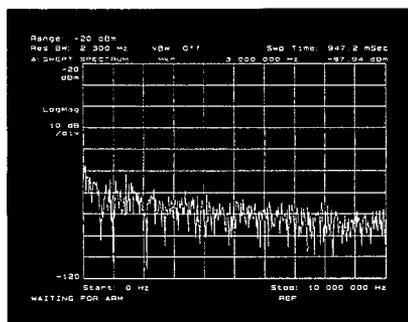
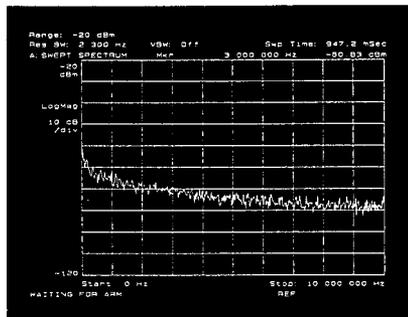
4: Since most noise measurements made in a 30 kHz resolution bandwidth are not corrected for the detector, the 17 kHz resolution bandwidth on the HP 3588/9A can be used to produce a comparable display (within .15 dB, which is better than the accuracy of most noise measurements). Specifically, the narrower bandwidth reduces the noise level by about the same amount that a traditional analyzer underestimates noise level.

Display Modes for Noise Measurements

Like most modern spectrum analyzers, the HP 3588/9A has a digital display that provides two different display modes: one for CW signals and one for noise. A digital display has the benefit of not flickering like an analog one. Unfortunately, a digital display provides a fixed number of display points. During a slow sweep, the spectrum analyzer can measure at many more frequency points than can be displayed. The display mode determines which of the measured points actually gets displayed.

The peak (on) mode is needed for measuring the amplitudes of CW signals when the resolution bandwidth is very narrow compared with the measurement span. (See figures 9A and 9B). The peak (on) mode is not useful for noise measurements because it will display only peak noise level. This is a problem if you want to use averaging to determine the average noise level.

Therefore, noise measurements require a different display mode that simply samples the detected level at regular frequency intervals. This display mode is called the sample or peak (off) mode. Figure 7A shows a noise measurement with the display mode set to peak (on), which is the default for the analyzer. Notice the variance in the noise seems very low. Figure 7B shows the same measurement with display mode set to peak (off). In this mode, you see true variance of the noise measurement and this allows you to estimate the true average noise level. Video averaging or filtering is then used to reduce the variance and display the true noise level.



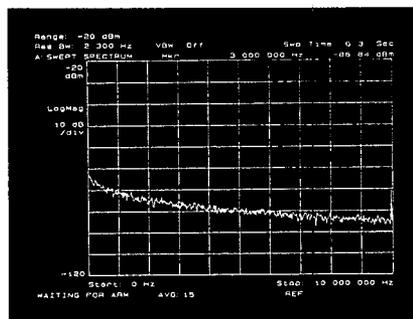
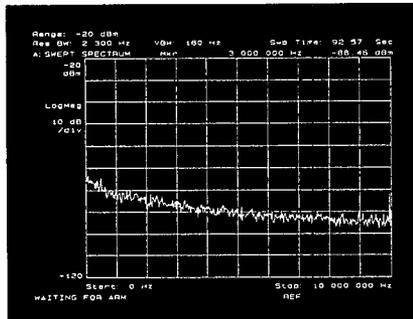
Figures 7A and 7B: The peak display mode shows only the peak noise level (7A). This is much higher than the average noise level which is seen in the peak (off) display mode (7B).

Video Filtering and Averaging

Noise is generally random in nature and that is why a single noise measurement has a lot of variance. There are two ways to reduce variance and determine the average noise level: video filtering and video averaging.

The video filtering is a method that effectively integrates the noise level over some period of time. The video filter is a low pass filter that is placed after the detector. As the bandwidth of this filter is reduced, the effective integration time is increased. The analyzer automatically slows down the sweep speed to account for the time constant of the video filter. The slower sweep speed allows the noise at each frequency to be integrated over the time constant of the filter and therefore the noise variance is reduced.

Video averaging is similar in concept. It works by making many sweeps, each at the fastest sweep rate allowed by the resolution bandwidth filter, and then averaging each new measurement with previous ones in an exponential average. Even though each new sweep produces a measurement with a high level of variance, the average converges on the average noise level. The number of measurements in the exponential average can be changed to provide the desired amount of variance reduction.



Figures 8A and 8B: Video filtering (8A) and video averaging (8B) are effective ways to reduce the variance of the noise measurement shown in figure 7B.

Video filtering and video averaging work for the same basic reason: total measurement time is increased so that the noise at each frequency is observed for a long time. Extending the observation time (by decreasing the video filter bandwidth or increasing the number of averages) reduces the variance and produces a better estimate of the average noise level. Figures 8A and 8B show the results of video filtering and video averaging.

The HP 3588/9A provides both video filters and video averaging, but video averaging is usually preferred because it permits the fastest sweep speed during averaging, instead of the single slow sweep you get with a video filter. This allows you to see signals that drift during the averaging process.

Remember, the analyzer must be in the peak (off) display mode. Since the HP 3588/9A defaults to the peak (on) display mode, you must switch it manually. (See appendix for key press information).

Oversweep

The HP 3588/9A defaults to a corrected oversweep mode at turn on time. In this mode, the analyzer sweeps four times faster than a traditional analyzer would permit. The measured data is then corrected, but the correction assumes cw signals have been measured. As a result, corrected oversweep introduces error into noise measurements. Therefore, oversweep must be turned off for noise measurements. With oversweep off, the analyzer sweeps slow enough to let the RBW filter respond fully to random noise and permits an accurate noise measurement.

Carrier-To-Noise Measurements

Overview

- The offset marker is used for carrier-to-noise measurements.
- The carrier should be measured with peak (on) display mode.
- The noise level must be measured with the peak (off) display mode.
- The noise marker can be used with the offset marker to get a carrier-to-noise measurement normalized to 1 Hz.

The offset marker

Carrier-to-noise measurements are a simple extension of basic noise measurements. There is one new issue: the level of the carrier must be detected correctly. This usually is not a problem. Figures 10A and B show typical measurements. Notice that the width of the RBW filter is visible. This means that the peak (off) display mode can be used to measure both the carrier level and noise level in the same measurement. To make the carrier-to-noise measurement, move the marker to the carrier peak, reference the offset marker to that level, and then move the marker into the noise. The offset marker will display the difference between the carrier level and the noise level.

If the width of the RBW filter is very narrow compared to the span, then display modes become

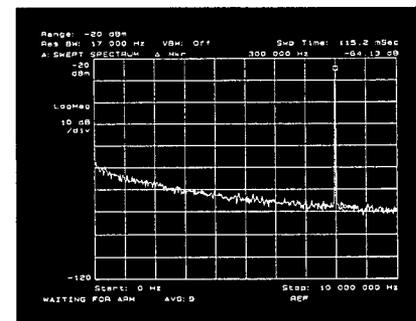
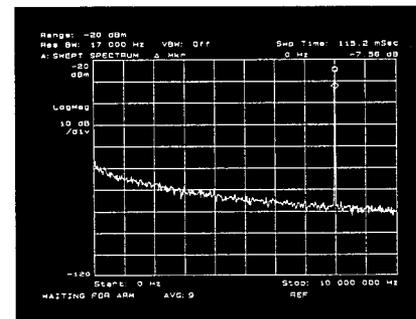
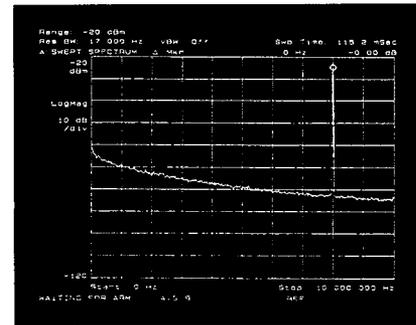
an issue in making good measurements. Look at figures 9A,B and C. In this case, the RBW filter is narrower than the spacing of points on the display and therefore the carrier appears as a spike on the display. In this case, peak(on) display mode must be used to measure the carrier level and then the peak(off) display mode must be used to measure the noise level.

Figure 9A shows a measurement of a carrier and noise. Remember the analyzer defaults to the peak (on) display mode. In this figure, the marker was moved to the carrier peak and then the offset marker was switched on. Since the marker is at the reference point for the offset marker, the offset frequency and amplitude are both zero.

After the offset reference has been set at the carrier peak, the display mode is changed so that the noise level can be measured. Figure 9B shows what can happen to the measured carrier level when the display mode is changed. In this case, the resolution bandwidth is narrower than the spacing of the display points on the analyzer and the peak frequency of the carrier falls at a frequency that is between two display points. Even though the displayed level of the carrier is not correct, the square symbol for the marker reference stays at the correct level.

Figure 9C shows the marker moved 300 kHz away from the carrier and the marker readout shows the carrier to noise ratio.

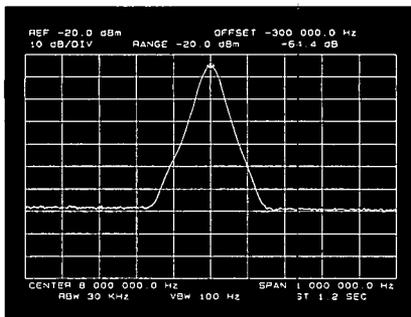
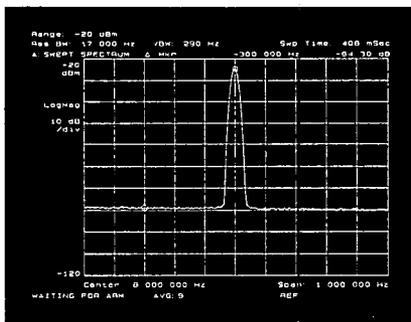
Remember that the measured carrier-to-noise ratio will change if the resolution bandwidth is changed.



Figures 9A, 9B and 9C
The offset marker is used to make carrier-to-noise measurements. 9A shows the marker at the carrier peak and the offset marker referenced to that level. Notice the marker readout shows zero. In 9B the display mode was changed to peak (off) to prepare for measuring the noise level. Notice the displayed carrier level dropped because the resolution bandwidth is narrower than frequency spacing of the points on the display. This is okay since the offset marker reference was set to the true peak. In 9C the marker is moved 300 kHz away from the carrier and the marker readout indicates the carrier-to-noise ratio.

Normalizing to Another Bandwidth

To compare different carrier-to-noise measurements, they must be normalized to the same noise bandwidth. As described earlier, correction factors can be computed to normalize a noise measurement to another bandwidth.



Figures 10A and 10B:The 17 kHz bandwidth on the HP 3588A (10A) produces the same result as an uncorrected measurement made in a 30 kHz bandwidth on a traditional analyzer like the HP 3585A (10B).

Typically, measurements on magnetic storage media are referenced to a 30 kHz resolution bandwidth, and phase noise measurements are normalized to a 1 Hz noise bandwidth. While the HP 3588/9A does not measure

directly at these bandwidths, it is designed to make these bandwidth normalizations easy.

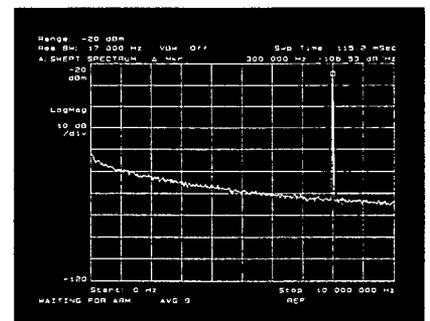
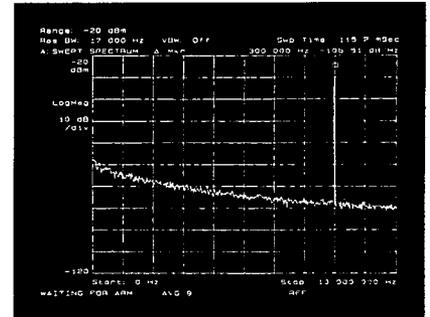
As described earlier, a measurement made with the HP 3588/9A in the 17 kHz bandwidth will provide about the same result as an un-corrected noise measurement made with a traditional analyzer in its 30 kHz bandwidth. See figures 10A and 10B.

To normalize to a 1 Hz bandwidth, use the noise marker or trace math. (The procedure is described in the appendix).

Using the Noise Marker

Since noise measurements are often normalized to a 1 Hz bandwidth, the noise marker was designed to simplify the carrier to noise measurement. The noise marker works correctly even if the display mode is set to peak (on). This means the noise marker uses the measurement data directly and provides the same result in either display mode. See figures 11A and 11B.

To make a carrier-to-noise measurement, use the analyzer in its default display mode which is peak (on). Reference the offset marker to the carrier peak and then move the offset marker into the noise. Turn on the noise marker. (The procedure is described in the appendix).



Figures 11A and 11B:The noise marker is the most accurate and reliable way to make a noise measurement because it does not use displayed data. Instead the analyzer pauses at the marker frequency and measures noise directly.

In 11A and 11B, the reference for the offset marker was set with the peak (on) display mode. In 11A, the display mode is changed to peak (off) for the noise measurement. In 11B, the display mode is left at peak (on), but the noise marker still shows the correct result because it does not use the displayed data.

Low-Level Noise Measurements

To make an accurate noise measurement, the measured noise level should be at least 10 dB above the noise floor of the analyzer. If the noise is close to, or below, the sensitivity of the analyzer, a pre-amplifier is needed. The sensitivity of the HP 3588/9A and is specified at -132 dBm in a 1 Hz bandwidth and is typically -140 dBm/Hz.

To determine if you need a pre-amplifier, check the difference between the noise floor of the analyzer and the measured noise. First disconnect any cables from the input and measure the noise floor. Then, measure the noise signal; if it is not 10 dB above the noise floor, a pre-amplifier should be used.

A pre-amplifier must do two things: boost the level of the noise signal and do so without adding too much extra noise. The HP 8447D pre-amplifier fits this requirement and is recommended for use with the HP 3588/9A. It has 25 dB of gain and an 8 dB noise figure.

The sensitivity of a system composed of a pre-amplifier and analyzer is determined by comparing the noise output of the pre-amplifier to the noise floor of the analyzer. Since the noise output of the HP 8447D is less than the noise floor of the analyzer, the system sensitivity is roughly determined by subtracting the gain of the pre-amplifier from the noise floor of the analyzer.

$$\begin{aligned} \text{system sensitivity} &= \text{analyzer noise floor} - \text{pre-amp gain} \\ &= -134 \text{ dBm} - 25 \text{ dBm} \\ &= -159 \text{ dBm} \end{aligned}$$

Note: If you use a different pre-amp with greater noise output (gain * noise figure) the system sensitivity will start to be limited by the noise figure of the pre-amp.

Remember that the analyzer does not automatically account for the gain of the pre-amplifier. You must account for it manually, or by using math to change the display scale. With the math feature in the analyzer, you can input the 25 dB scale factor into the analyzer so that the displayed data reads out correctly.

It is important to note that a pre-amplifier does not increase dynamic range. While the sensitivity is increased, the maximum input power is reduced by at least the gain of the pre-amplifier. When measuring high level noise or signals, the pre-amplifier should not be used because it may produce distortion.

For more details on pre-amplifiers and noise figure, refer to Hewlett-Packard Application Note 150.

Appendix: Keystrokes to Make Noise Measurements

The noise marker makes an accurate noise measurement at the marker frequency.

MARKER FCTN
Noise Lvl (on)

To make a noise measurement the display mode must be set to peak (off).

MEAS TYPE
Peak Det (off)

To reduce variance in the measurement, use video averaging or a video filter.

Averaging
AVG/PK HLD
Video Average
Number Averages XX Enter
Video Filter
RES BW
Vid Fltr (on)
Video BW press up or down
arrow keys

To make a carrier-to-noise measurement, set the reference of the offset marker at the carrier peak, and then move the marker into the noise. If the resolution bandwidth is less than .5% of the span, the carrier peak must be measured with the display mode in peak (on). If the noise level is measured with the noise marker, then the display mode can be left in peak (on). If the noise level is measured with the standard marker, the display mode must be set to peak (off).

Move marker to peak.

MARKER
Mkr → Peak

Set the reference of the offset marker.

MARKER
Zero Offset

If you are going to use the standard marker, change the display mode. If you are going to use the noise marker, skip this.

MEAS TYPE
Peak Det (off)

Move the marker into the noise. The offset marker now displays the frequency offset and amplitude difference, which is the carrier-to-noise ratio. If the noise marker is turned on, the carrier-to-noise ratio is normalized to a 1 Hz bandwidth.

An entire noise trace can be normalized to a 1 Hz bandwidth by using the math capabilities in the analyzer.

The math function is defined to be the ratio of the spectrum to the noise bandwidth. The math operators assume all data has units of volts, therefore the bandwidth normalization factor is expressed as the square root of the noise bandwidth.

MATH
Define F1
Spectrum
/
Sqrt(NBW)
Enter

After the math function is defined, it is not displayed until selected.

TRACE DATA
Function(F1-F5)
F1

The reference level may need to be changed. This is done with the softkeys under the SCALE hardkey.

To turn oversweep off.
SWEEP
Oversweep (off)

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(301) 670 4300

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(404) 955 1500

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6877 Goreway Drive
Mississauga Ontario L4V 1M8
(416) 678 9430

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Yokogawa-Hewlett-Packard Ltd.
15-7 Nishi Shinjuku 4 Chome
Shinjuku-ku
Tokyo 160, Japan
(03) 5371 1315

Latin America:

Hewlett-Packard
Latin American Region Headquarters
Monte Pelvoux No. 111
Lomas de Chapultepec
11000 Mexico, D.F.
(525) 202 0155

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31-41 Joseph Street
Blackburn, Victoria 3130
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Italy:

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Switzerland:

(057) 31 21 11 (Headoffice)
(022) 780 41 11 (Suisse Romande)
(046) 05 15 05 (Customer Information
Center)

Turkey:

(1) 175 29 70

U.K.:

(0344) 369 369

Europe/Africa/Middle East:

Hewlett-Packard
European Marketing Centre
P.O. Box 999
1180 A7 Amstelveen
The Netherlands