Residual Phase Noise and AM Noise Measurements and Techniques

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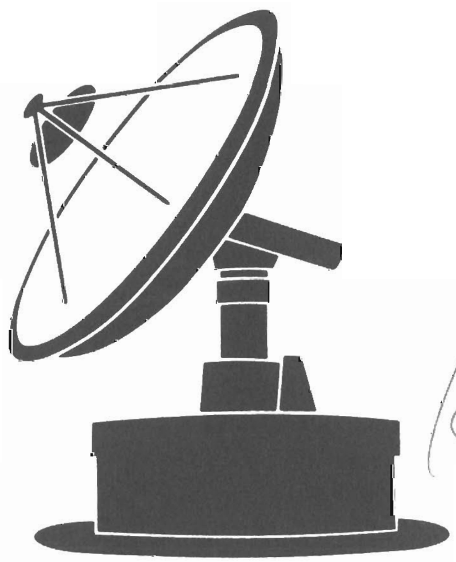
RF & Microwave Measurement Symposium and Exhibition



HEWLETT PACKARD

Agenda

- What is Residual Noise?
- Why are residual and AM noise measurements important?
- Measurement systems
- Residual phase noise measurements
  - Calibration and measurement guidelines
  - Calibration methods
  - Examples of residual phase noise measurement
- AM source noise measurements
  - Calibration and measurement guidelines
  - Calibration methods
  - Example of AM source measurement

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Slide 2

This presentation is an abbreviated version of our paper "Residual Phase Noise and AM Noise Measurements and Techniques" by Thomas R. Faulkner and Robert E. Temple, Part No. 03048-90011. It is a collection of test procedures and considerations which are the product of our experience in this fast-growing field.

For purposes of this presentation, we shall be using the HP 3048A as our basic measurement system. Our methods, however, are applicable to other measurements systems.

AMSO

What is residual noise?

- The noise added to a signal by any two-port network contains both AM and PM components.
- The sum of additive and multiplicative noise

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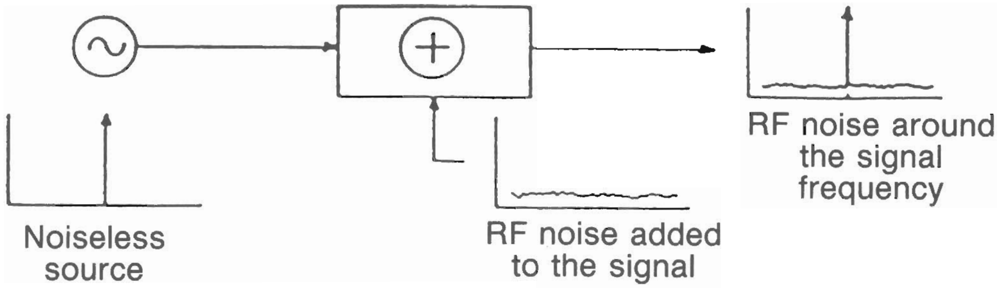
Slide 3

RESIDUAL NOISE is the noise added to a signal when processed by a two-port device (amplifiers, dividers, filters, mixers, multipliers, and any two-port network). Residual noise contains both AM and PM components and is the sum of ADDITIVE and MULTIPLICATIVE noise.

Additive Noise

- adds in a linear fashion to the signal



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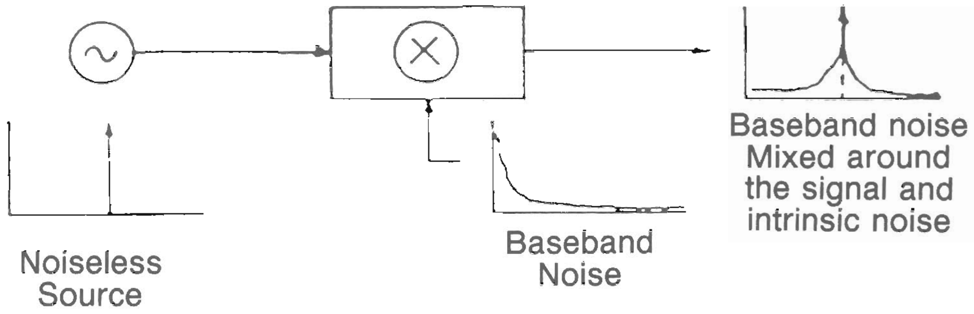
ADDITIVE NOISE is generated by the two-port device at or near the signal frequency and adds in a linear fashion to the signal.

Multiplicative Noise

- Intrinsic, direct phase modulation
- Baseband noise modulation



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Slide 5

MULTIPLICATIVE NOISE is an intrinsic, direct phase modulation with a 1/f spectral density (origin unknown). It may also be noise modulating an RF signal by multiplying baseband noise with the signal (origin: nonlinearities in the two-port network).

Why are residual and AM noise measurements important?

- Ensure overall system noise performance
- Troubleshooting unsatisfactory noise performance
- Optimizing oscillator design
- Two-port network design
- Low-noise AM sources:
  - Reduce effects of AM to PM conversion
  - Measurement of adjacent channel noise

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Slide 6

In recent years it has become apparent to primary contractors that to ensure overall system noise performance residual noise must be specified for all subsystems.

When troubleshooting unsatisfactory phase noise performance it may be necessary to measure both the AM noise and residual PM noise of the system components to locate the problem.

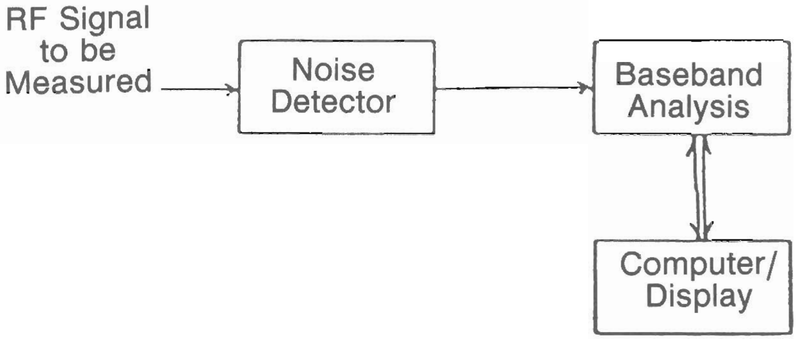
The absolute noise of an oscillator is set by the residual noise of the active device, the residual noise of the resonator, and the bandwidth of the resonator.

Noise is degraded by the residual noise of all subsequent devices: amplifiers, dividers, filters, mixers, multipliers, phase-locked loops, synthesizers, etc.

Any active or nonlinear device produces some level of AM-to-PM noise conversion. This AM noise can contribute to the residual phase noise. This includes AM noise in phase detectors.

AM noise is important in its own right in some applications such as in generators for residual phase noise testing or adjacent channel receiver testing.

Basic noise measurement procedure



The HP 3048A measures noise by:

1. Calibrating the noise detector sensitivity.
2. Measuring the detected baseband noise.
3. Multiplying the detected noise by the detector sensitivity.
4. Displaying measured data in the required format.

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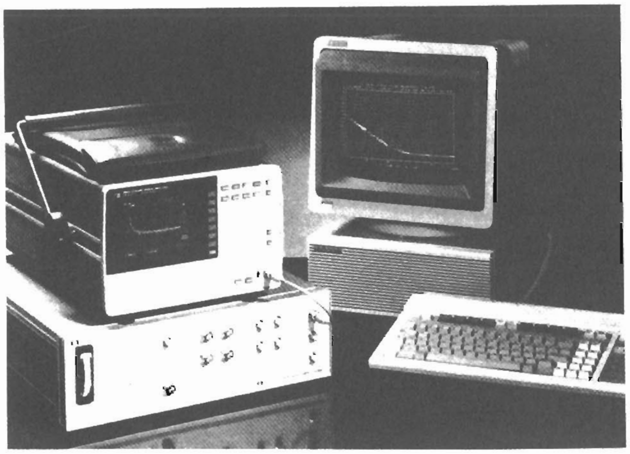
Slide 7

Noise may be measured by demodulation of the RF signal and its analysis at baseband. Once the detector is calibrated, the system analyzes the baseband noise (signal which must be measured) over a range of frequencies regardless of the signal's origin.

The detector calibration is accomplished by applying a known signal to the detector. The known signal is then measured at baseband. The transfer function between the known signal and the measurement baseband signal is then calculated.

Basic measurement system



HP 3048A carrier frequencies: 5 MHz to 1.6 GHz
to 18 GHz (with Opt. 201).

Offset frequencies: .01 Hz to 100 kHz
to 40 MHz with optional analyzer.

Accuracy: ±2 dB to 1 MHz offset
±4 dB to 40 MHz offset

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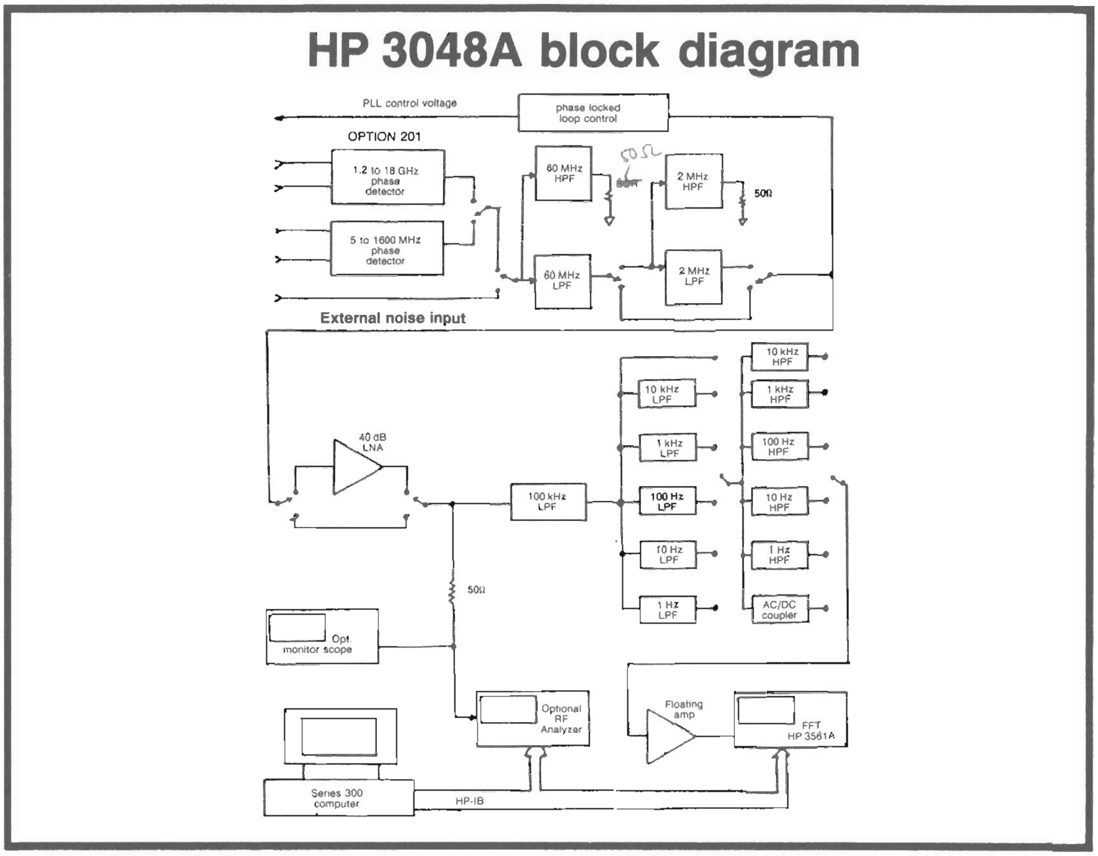
Slide 8

The basic HP 3048A Phase Noise Measurement System consists of the HP 11848A Phase Noise Interface which provides signal demodulation and conditioning, an HP 3561A Dynamic Signal Analyzer, and a system controller with measurement software. An optional RF spectrum analyzer will increase the maximum noise analysis frequency from 100 kHz to 40 MHz. The optional microwave phase detector will increase the maximum phase detector input frequency from 1.6 GHz to 18 GHz.



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Slide 9

The noise around the input signal is first detected and converted to a noise voltage at baseband. The system inputs include: an internal phase detector(s) and an external noise voltage input, where external noise detectors may be connected. The noise voltage input may also be used for direct baseband noise voltage analysis.

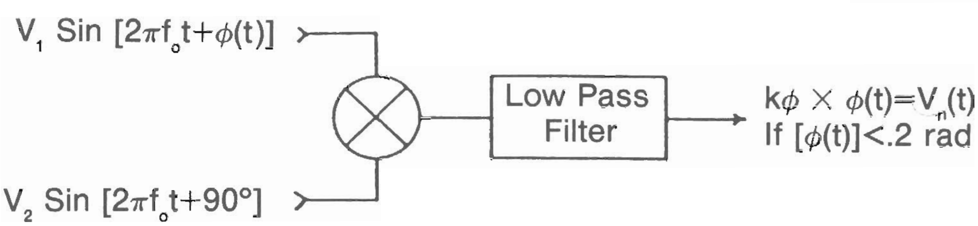
After the input signal is converted to baseband, it is filtered to prevent detector feedthrough and undesired detector products from saturating the low-noise amplifier (LNA). Below 95 MHz, the maximum carrier offset measured is 2 MHz; above 95 MHz, the offset may be increased to 40 MHz.

The filtered signal is then split. A sample is sent to the phase-locked loop control circuitry, which phase-locks the phase reference to the device under test (DUT) during a source-type phase noise measurement.

The main signal is sent to the input LNA. When engaged, it provides 34 dB of gain to the optional RF spectrum analyzer, and 40 dB of gain to the FFT spectrum analyzer. The FFT analyzer input is further filtered to prevent out-of-band noise and spurs from saturating the FFT. A series of switchable high- and low-pass filters limit the input bandwidth to the decade of frequencies being measured.

Doubly balanced mixer used as phase detector

Noise voltage



$$S_\phi = \frac{S_n(f)}{K^2\phi}$$

$$\mathcal{L}(f) = \frac{S_\phi(f)}{2} = \frac{S_n(f)}{2K^2\phi} \quad \text{because} \quad |\phi(t)| < .2\text{rad}$$

1. Demodulate RF signal and analyze at baseband
2. Measure spectral density of noise fluctuation
3. Calculate phase noise

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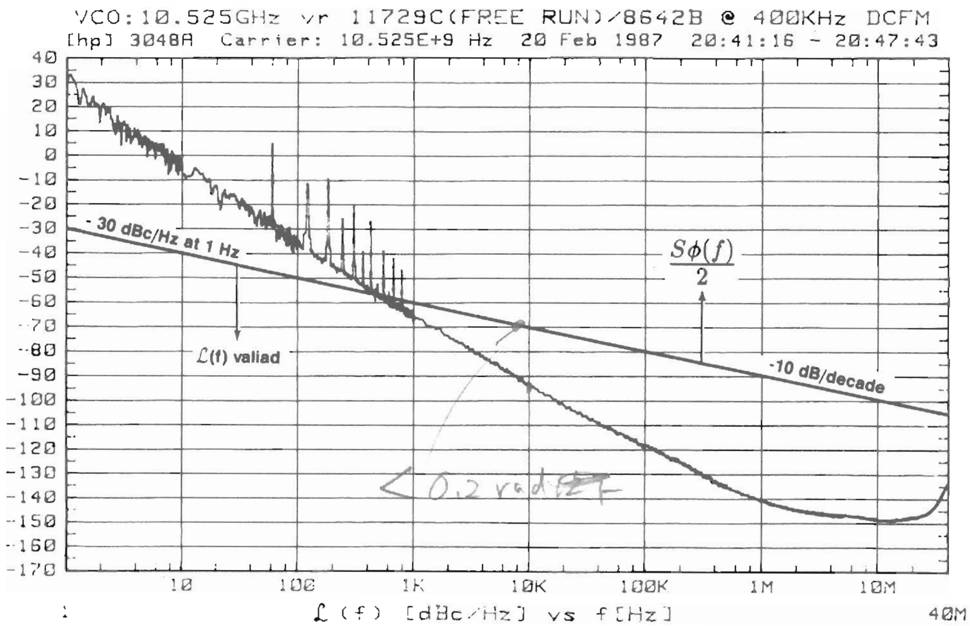
Slide 10

When operated as a phase detector, the two signals are input to the double-balanced mixer at the same frequency. The phase difference between the signals is adjusted to 90° (quadrature) to minimize the detector's sensitivity to AM fluctuations, and to maximize its sensitivity to phase fluctuations. Any phase fluctuations not common to both signals (ie, $\phi(t)$) result in a voltage fluctuation proportional to the phase difference, provided the phase fluctuations are less than approximately 0.2 radians. This voltage output $v_n(t)$ is equal to the difference in phase fluctuations multiplied by the phase detector gain of the mixer, K_ϕ, in volts per radian. The spectral density of the phase fluctuations, $S_\phi(f)$, is calculated by measuring the spectral density of voltage fluctuations, $S_n(f)$, and dividing it it by the square of the phase detector constant (squared because of the power relationship of spectral density). The single sideband phase noise power, $\mathcal{L}(f)$, and the spectral density of frequency fluctuations, $S_v(f)$, can then be calculated from $S_\phi(f)$.

Region of validity of $\mathcal{L}(f) = S_\phi(f)/2$



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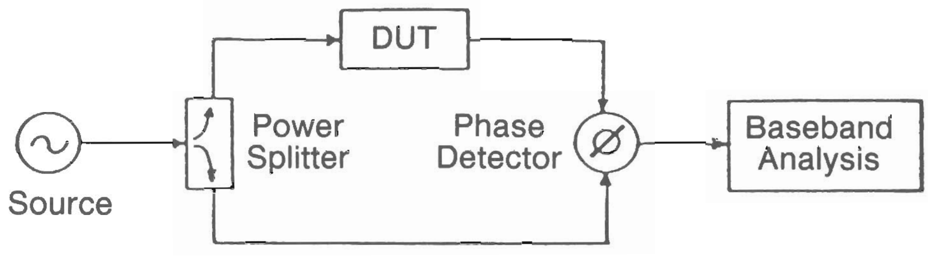
Slide 11

Because of the small-angle criterion, caution must be exercised when $\mathcal{L}(f)$ is calculated from the spectral density of phase fluctuations, $S_\phi(f)$. This plot of $\mathcal{L}(f)$ results from the phase noise of a free-running VCO and illustrates the erroneous results that can occur if the instantaneous phase modulation exceeds 0.2 radians. Approaching the carrier, $\mathcal{L}(f)$ is obviously increasingly in error as it reaches a relative level of +35 dBc/Hz at a 1 Hz offset (35 dB more power at 1 Hz offset in a 1 Hz bandwidth than the total power in the signal).

The −10 dB/decade line is drawn on the plot for an instantaneous phase deviation of 0.2 radians integrated over one decade of offset frequency. At approximately 0.2 radians the power in the higher-order sidebands of the phase modulation is still insignificant compared to the power in the first-order sideband, therefore ensuring the validity of $\mathcal{L}(f)$. Below the line the plot of $\mathcal{L}(f)$ is correct; above the line $\mathcal{L}(f)$ becomes increasingly invalid and $S_\phi(f)$ must be used to represent the phase noise of the signal.

Basic assumptions of residual phase noise measurement



- Source noise is correlated at the phase detector
- Correlated phase noise cancels
- Typical AM noise rejection 20 to 30 dB

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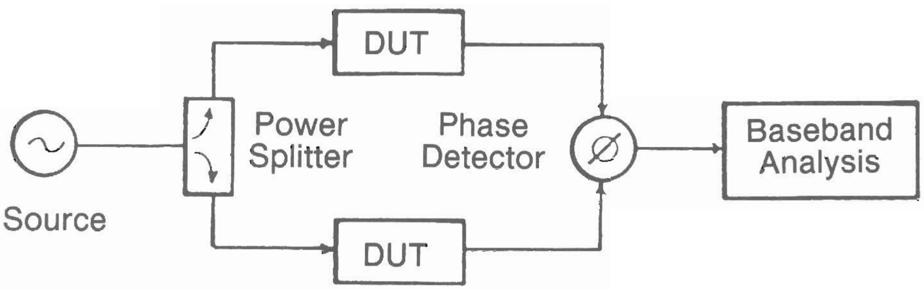
Slide 12

The source noise in each of the two phase detector paths is correlated at the phase detector for the frequency offset range of interest (later this restriction will be examined more closely). Correlated phase noise at the phase detector will cancel.

Source AM noise is small. A typical mixer-type phase detector only has about 20 to 30 dB of AM noise rejection.

Given these restrictions, if a device under test (DUT) is placed ahead of either of the two phase detector inputs, then all of the source noise will cancel and only the residual noise of the DUT will be measured.

Configuration for frequency translating devices



- RMS noise of both devices is measured
- Measurement sets an upper limit on the noise of each DUT
- A three-device comparison determines the noise of each DUT

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Slide 13

If the DUT is a frequency-translating device (ie, a divider, mixer, multiplier, or PLL synthesizer, etc.) then one DUT must be placed in each of the two phase detector paths to maintain equal input frequencies. The resulting noise measured will be the RMS sum of the noise added by both devices. Although the noise of one device cannot be separated from that of the other device with a single measurement, the noise measured will be the maximum noise of either device, and at any particular offset frequency the noise of one of the two devices will be at least 3 dB lower. If a more precise determination is required, a third DUT must be measured against the other two DUTs. The data from each of the three experiments can then be processed by the HP 3048A three-source comparison software to separate the noise of each individual DUT. If one DUT is appreciably lower noise (approximately 3 to 6 dB lower) than the other DUTs, its lower noise performance will still be indicated although its added noise cannot be accurately separated from the higher noise of the other devices.

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Steps for making residual phase noise measurements

1. Define measurement.
   - Select measurement type: "Phase noise measurement without phase locked loop"
     - Establish offset frequency range.
   - Define instrument parameters.
     - Carrier frequency.
     - Detector input frequency.
     - Select ~~external~~ detector.
   - Select calibration option.
   - Define measurement block diagram.
   - Define plot parameters.
2. Measure
   - Connect DUT and external hardware.
   - Measure calibration data.
   - Measure noise data, interpret results.

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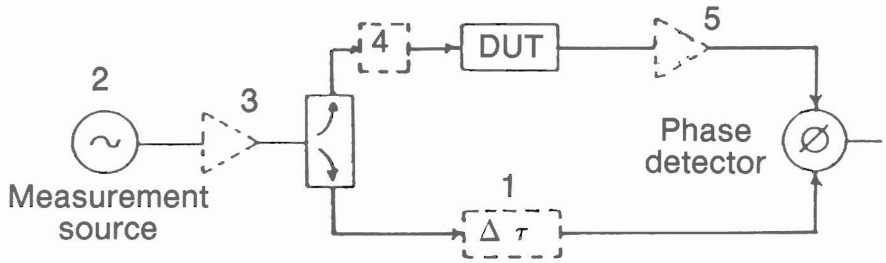
Slide 14

There are five basic steps to define a new measurement completely. Once the measurement is defined, one may proceed with the measurement.

Calibration and measurement guidelines



1. Minimize the difference in phase delay between paths
   Source noise attenuation is equal to:
   $$\text{Att(dB)} = 20 \log [2\sin (\pi \times f \times \tau)]$$
   where: f = carrier offset frequency (Hz)
   τ = time delay difference (sec.)
2. Whenever possible, all power should be supplied by the source.
3. If source produces insufficient power, place amplifier between source and power splitter.
4. Adjust input power to the DUT with attenuator.
5. If DUT produces insufficient power, place amplifier between DUT and phase detector.

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Slide 15

The time delay difference in the two paths between the power splitter and the phase detector must be kept to a minimum. The attenuation of the source noise is a function of the offset frequency, f, and the delay time τ, where: Att(dB) = 20 log$|2 \sin (\pi f \tau)|$. Note: at $f=1/(2\pi\tau)$ the attenuation of the source noise goes to 0 dB, and at $1/(2\tau)$ there is a 6 dB gain.

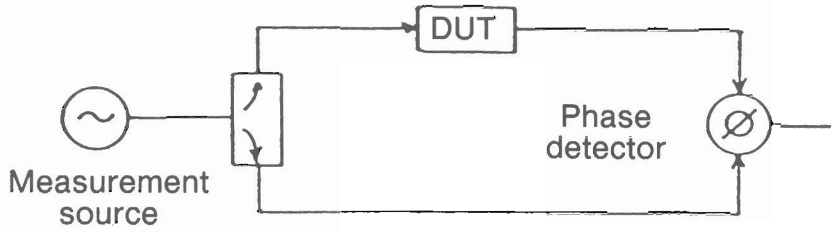
Whenever possible, all power necessary to drive the phase detector should be supplied by the source. If the source cannot supply sufficient power to drive the phase detector, an amplifier should be placed between the source and power splitter so its noise is correlated at the phase detector.

An amplifier must be used between the DUT and phase detector in cases where the power out of the DUT is insufficient to produce an adequate system noise floor. This amplifier should provide:

- Lowest possible noise figure with the greatest dynamic range.
- Only enough gain to provide the required signal levels. Amplifiers operating in gain compression are vulnerable to multiplicative noise problems which can mix the baseband noise of the active device or power supply around the carrier.
- Minimal sensitivity to power supply noise.

Signal levels must be kept as high as possible at all points in the setup to minimize degradation from the thermal noise floor.

Calibration and measurement guidelines (continued)



6. Source AM noise:
   - DUT phase noise may degrade from AM to PM conversion
   - Measurement data may degrade from insufficient AM rejection in phase detector
7. Source PM noise:
   - Short time delay DUTs require good broadband phase noise
   - Long time delay DUTs require good close-in phase noise
8. Shield all components from RFI
9. Prevent mechanically-induced phase fluctuations
10. Use semi-rigid cable between all components

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Slide 16

The source used for residual phase noise measurements must be low in AM noise. AM noise can cause AM-to-PM conversion in the DUT. Also, the mixer-type phase detector only provides about 20 to 30 dB of rejection to AM noise in a phase noise measurement.

The source's phase noise requirements depend on the delay characteristics of the DUT. Devices with short time delays: amplifiers, dividers, mixers, multipliers, etc., require sources with a good broadband noise floor. HP 8640B and HP 8642A/B Signal Generators have good broadband noise floors. Devices with large time delays or high "Q" devices such as crystal or SAW resonators, require sources which have good close-in phase noise, such as the HP 8662A and the HP 8663A Signal Generators.

Thoroughly shield all components in the test setup from RFI to prevent noise degradation through external coupling.

Prevent mechanically-induced phase noise (soft foam rubber is very useful for shock-mounting phase-sensitive components).

Use semirigid cables with tight connectors to prevent noise from thermal or mechanical distortions of the cable.

Residual phase noise calibration methods

1. User entry of phase slope
2. +/− DC Peak sensitivity
3. Beatnote method
4. Double-sided spur
5. Single-sided spur

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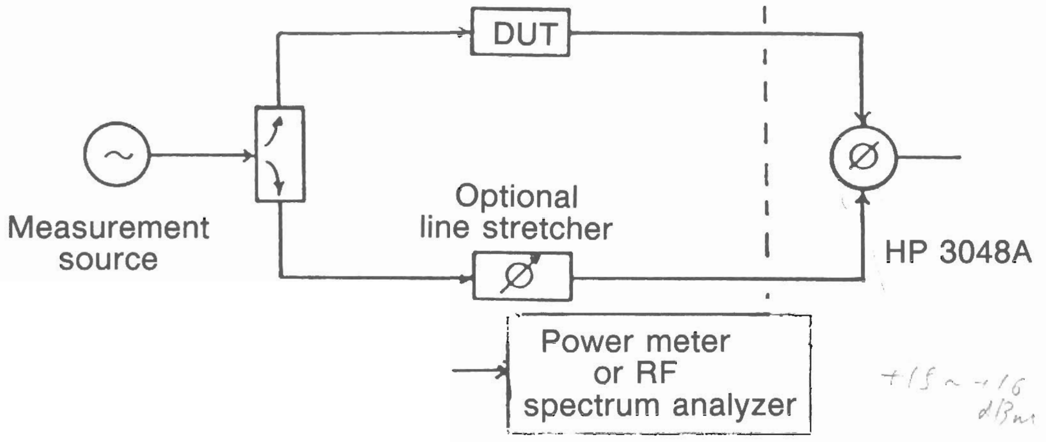
Slide 17

There are five calibration methods supported by the HP 3048A for residual measurements.

User entry of phase slope



1. Measure LO and RF power at the phase detector
2. Locate RF drive level on Phase Detector Sensitivity Graph
3. Enter phase slope
4. Establish quadrature
5. Measure noise data, interpret results

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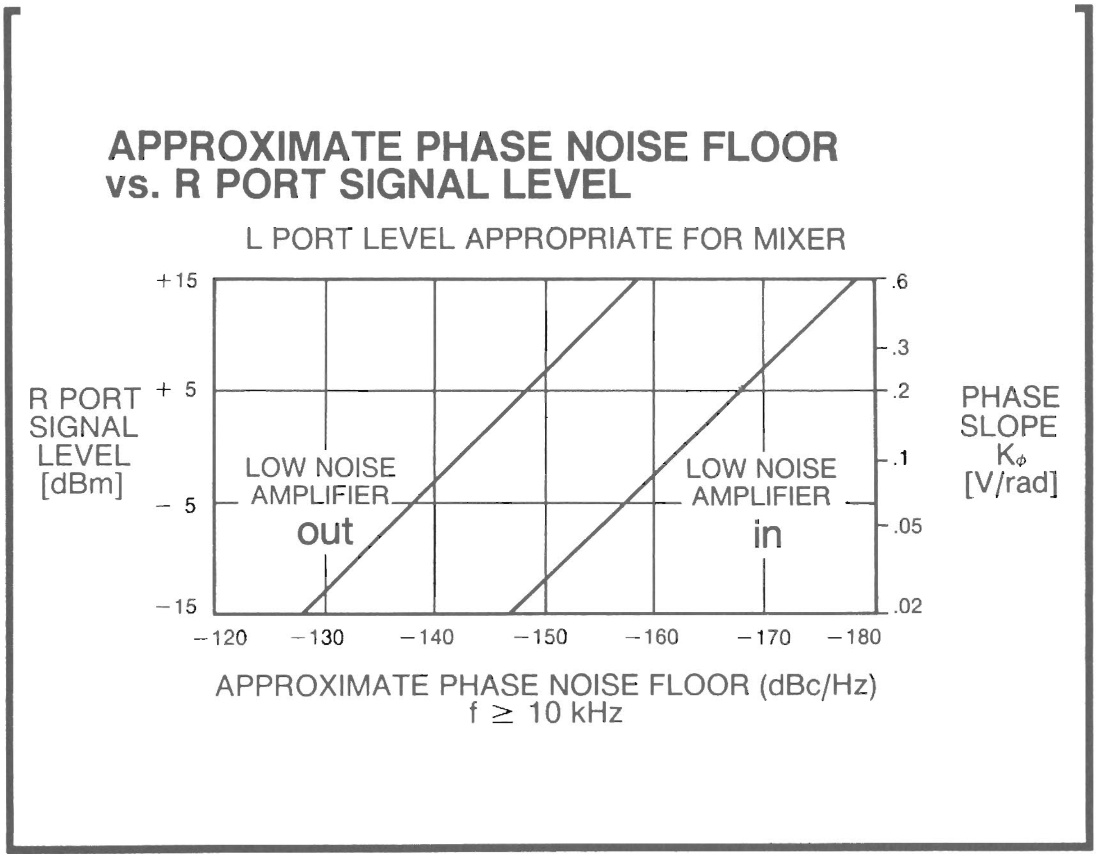
Slide 18

User Entry of Phase Slope is the easiest and fastest method of calibration, particularly in cases of unchanging power levels supplied to the phase detector. It requires little additional equipment—only one RF source and an RF power meter (for manual measurement of drive levels into the phase detector). It is the fastest method of estimating phase slope and noise floor to verify other calibration methods and to check available dynamic range. It is, however, the least accurate of the calibration methods and does not take into account the amount of power at harmonics of the signal. It also does not take into account power which may be generated by spurious oscillations, which cause the power meter to measure much more power than is present at the pahse detector frequency.



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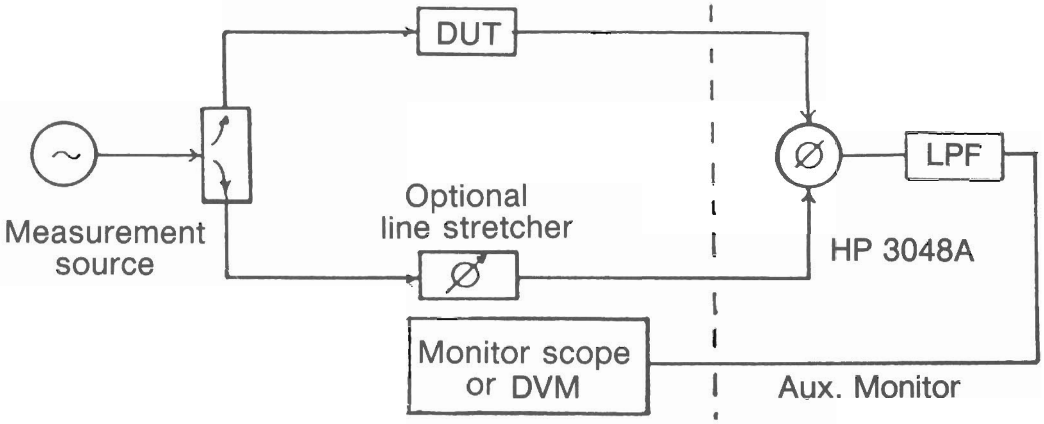
Slide 19

To determine the phase detector constant, K_ϕ (V/radian), locate the RF drive level on the left side of the graph and enter the corresponding phase slope, K_ϕ, read from the right-hand side of the graph. It is useful to note the approximate system noise floor read from the bottom of the graph.

(Note that the graph assumes that the LO port is operating at the appropriate level for the phase detector. The low frequency phase detector requires a LO drive of +15 to +23 dBm; the microwave phase detector requires a LO drive of +7 to +10 dBm.)

+/− DC Peak Sensitivity



1. Measure LO and RF port power at the phase detector.
2. Adjust for positive peak voltage at phase detector output, and measure.
3. System calculates phase slope

where: K_ϕ phase slope $= (+V_{peak} - -V_{peak})/2$

4. Establish quadrature
5. Measure noise data, interpret results.

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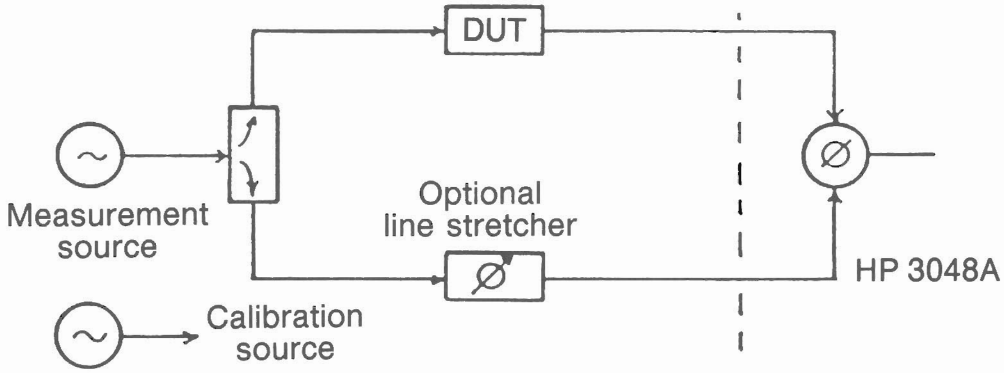
Slide 20

+/− DC Peak is an easy method of calibration requiring little additional equipment—only an RF source and an adjustable phase shifter capable of tuning the phase detector through its positive and negative peak voltages. This method also has the advantage of measuring the phase detector gain in the actual measurement configuration. This method, however, does not take into account the amount of phase detector harmonic distortion relative to the measured phase detector gain, therefore the phase detector must operate in its linear region. This method also requires manual adjustments to the source and/or phase shifter to find the phase detector's positive and negative output peaks.

Beatnote method



1. Measure LO and RF port power at phase detector.
2. Measure power out of one side of power splitter (then terminate in 50Ω).
3. Set calibration source to measured level and adjust frequency for beatnote.
4. Measure calibration constant, remove calibration source.
5. Establish quadrature.
6. Measure noise data, interpret results

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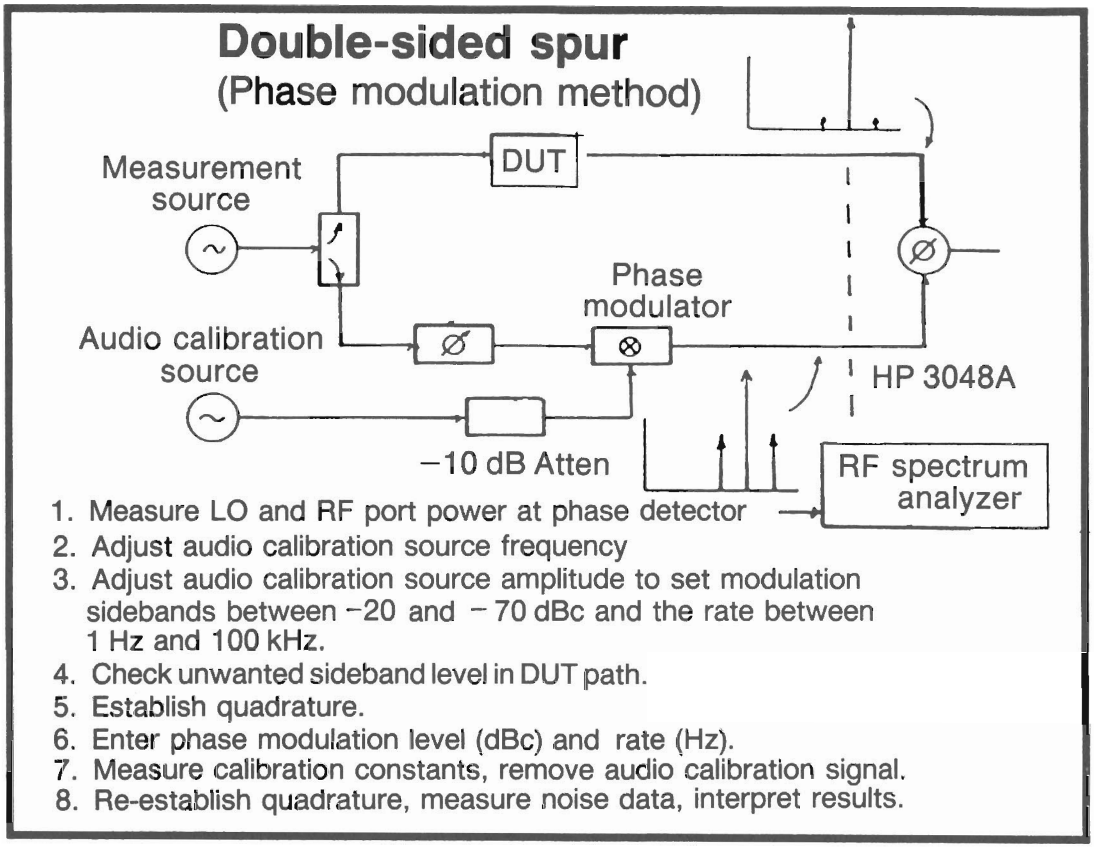
Slide 21

The Beat Note Method is both more complex and more accurate than the preceding two methods. It is simple and it takes into account the harmonics of the phase detector and all nonlinearities thereof. It does not require an RF spectrum analyzer, however it requires two RF sources separated by 1 Hz to 40 MHz at the phase detector. The calibration source output power must be manually adjusted to the same level as the power splitter output it replaces (requires a power meter).



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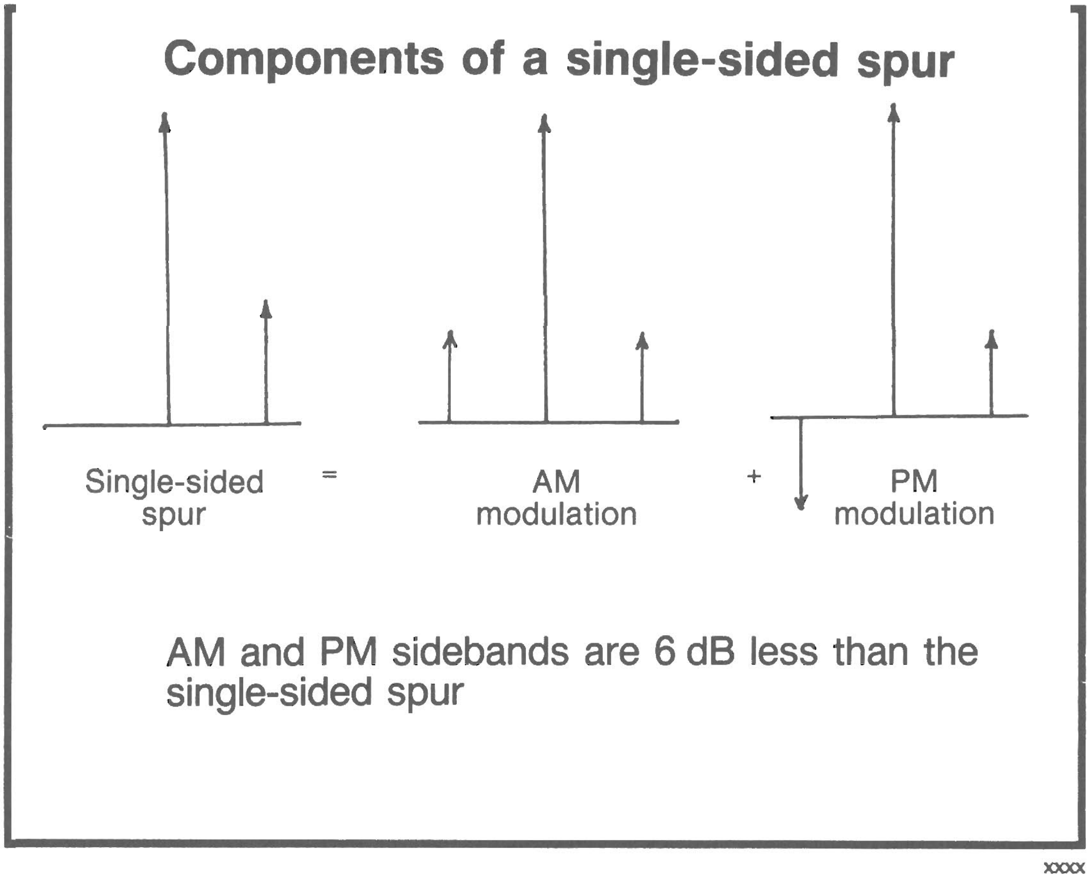
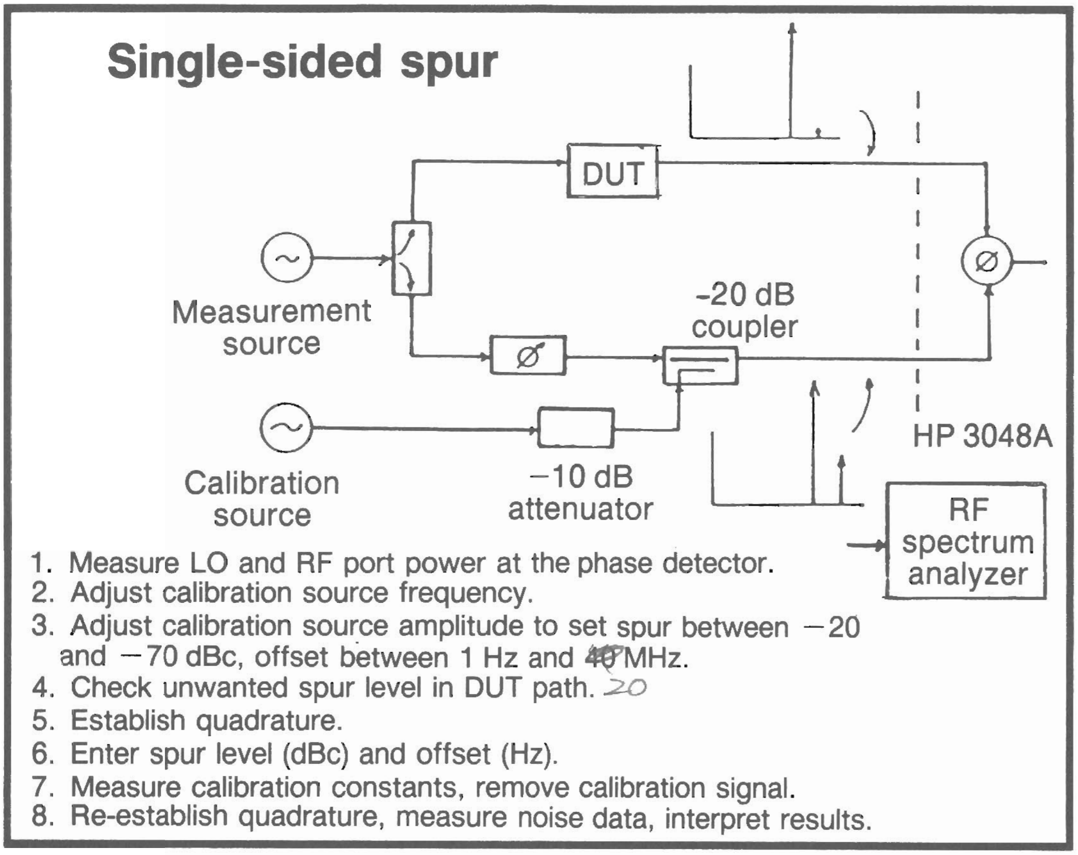
Slide 22

The Double-Sided Spur or Phase Modulation method of calibration requires only one RF source; however, it requires an RF spectrum analyzer for manual measurement of PM sidebands. It also requires an audio calibration source, and a phase modulator which operates at the desired carrier frequency. Calibration is done under actual measurement conditions, so all nonlinearities and harmonics of the phase detector are calibrated out. This is one of the most accurate methods of calibration.



Slide 23

A single-sided spur produces AM and PM sidebands of equal amplitude. Each of the sidebands is 6 dBc less than the original spur.



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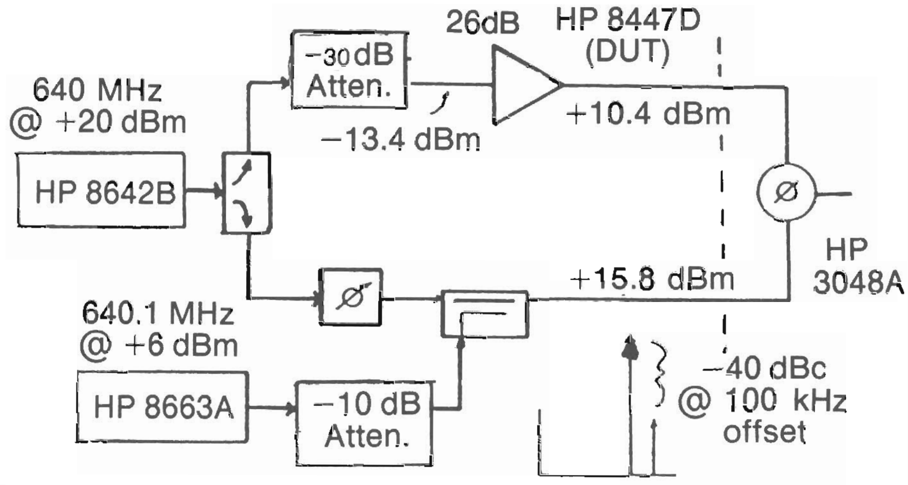
Slide 24

The Single-Sided Spur calibration method is done under actual measurement conditions and all nonlinearities and harmonics of the phase detector are calibrated out. This method requires two RF sources which must be between 1 Hz and 40 MHz apart in frequency. It also requires a coupler to couple in the calibration spur and an RF spectrum analyzer for manual measurement of the signal-to-spur ratio and the spur offset frequency. This method is extremely accurate, provided that the AM rejection of the phase detector is at least 20 dB.

Example: Amplifier noise (using the single-sided spur calibration method)



Note:

- Source provides all power required for phase detector.
- DUT input power adjusted with an attenuator
- Quadrature obtained with a phase shifter

Slide 25

The residual noise measurement of an amplifier can reveal two very important pieces of information:

1. The signal-to-noise ratio or dynamic range of the amplifier. The signal-to-noise ratio is a measure of the amount of noise the amplifier will contribute to the overall system noise floor during actual operating conditions.

Example(continued):

Amplifier large signal noise figure

A large signal equivalent noise figure for phase noise calculated from the amplifier input power and $\mathcal{L}$(f) data

where:

$$NF(dB) = \mathcal{L}(f) + P_i + 174\ dB_{w/Hz} + 3\ dB$$

Input power

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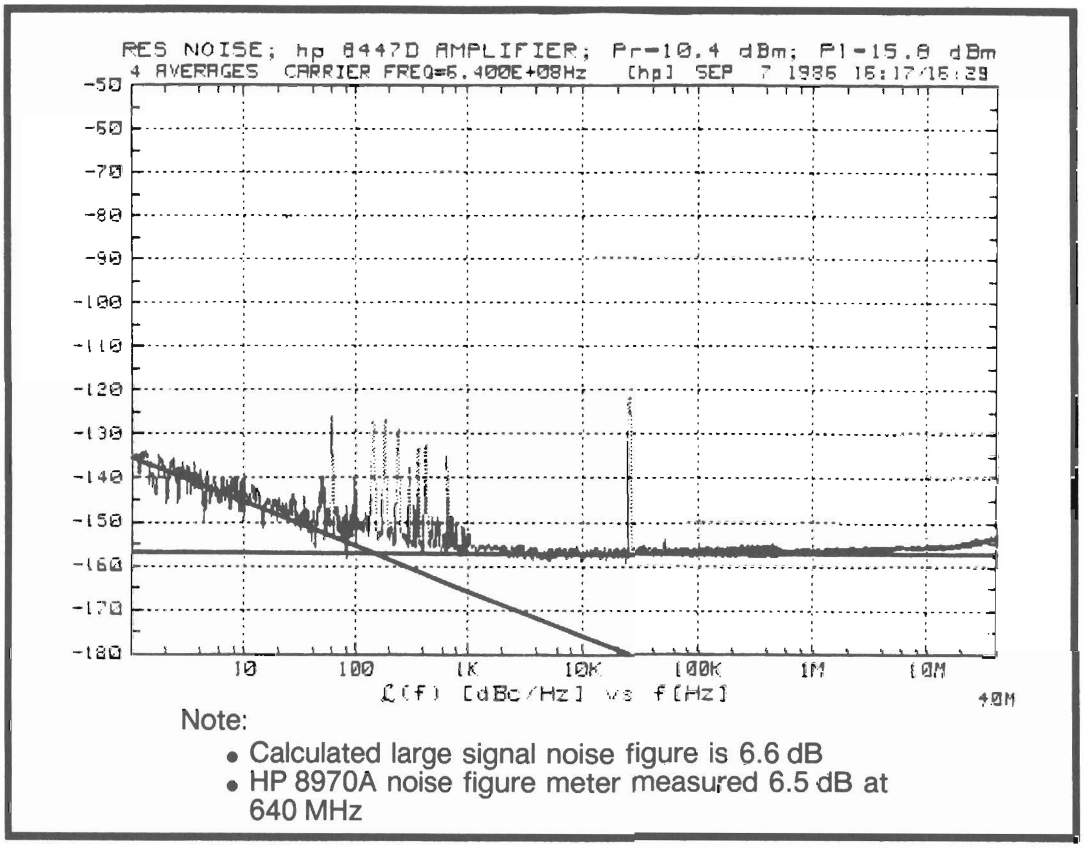
Slide 25A

2. The noise figure of the amplifier, which can be calculated from the amplifier input power, and $\mathcal{L}(f)$ data, at any measured offset frequency.

The noise figure is measured under actual large-signal conditions. It includes the multiplicative noise mixed around the signal by the nonlinearity of the active device in the presence of a large signal. The small signal noise figure measured on a noise figure meter may vary greatly from the large signal measurement. As the input power increases, the active device starts to operate nonlinearly and the noise figure increases. This effect may appear with signal levels 10 dB below the 1 dB compression point.

NOTE: It is important that the DUT power supply be well filtered to prevent low frequency noise from entering the DUT and degrading the performance from multiplicative noise.



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Slide 26

The amplifier, measured at 640 MHz, with a phase detector gain of .399V/radian appears well-behaved. There are no major discontinuities in the graph, and all the spurs are below −120 dBc. The noise floor is at about −157 dBc/Hz at 10 kHz offset, with a −139 dBc/Hz, 1 Hz intercept.

At −13.4 dBm input power and 100 kHz offset, the calculated large signal noise figure is 6.6 dB. The noise figure measured by an HP 8970A noise figure meter was 6.5 dB at 640 MHz. In this case, at this input level the amplifier is still operating in its linear range.

−157

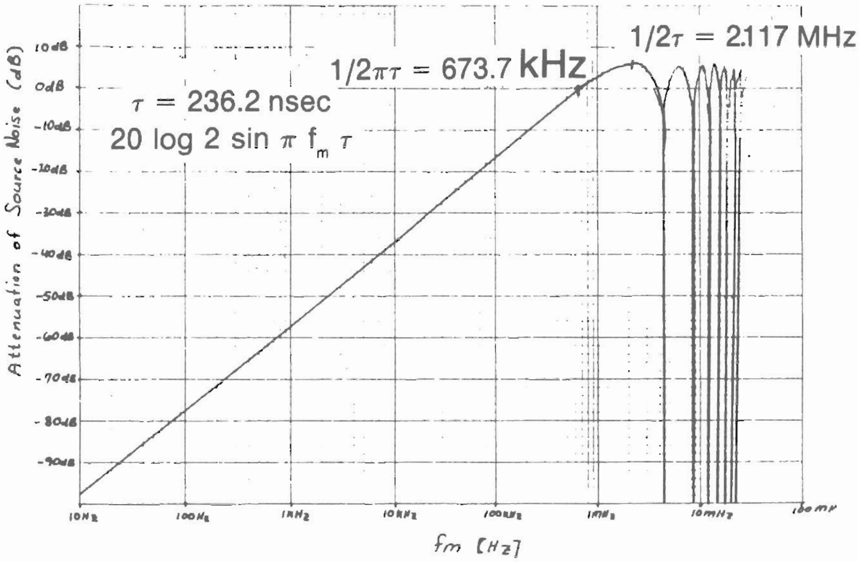
−13.4+3 + 174 − 157

157

17

= −10.4 + 17 = 6.6

Example: Measurement of a device with large time delay (τ)



Source attenuation vs. offset frequency for a 236 nS delay

Special considerations of long delay devices:

- Amplification following DUT
- Decorrelation of source noise

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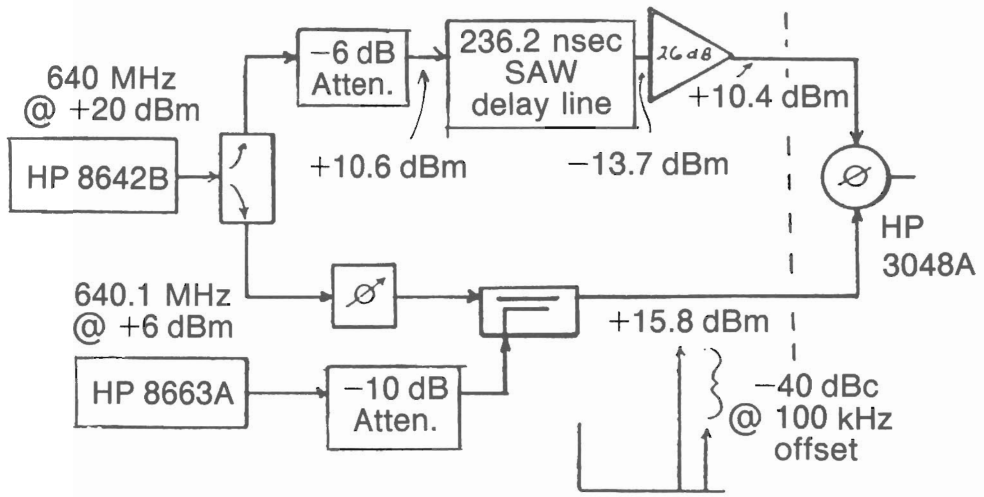
Slide 27

Measurement of a device with long delay usually has two special considerations:

1. Delays exceeding 1 μsec tend to have a large amount of signal path loss associated with them. This loss makes it necessary to follow the DUT with a low-noise amplifier.
2. The long delay will decorrelate the source noise. At $1/(2\pi\tau)$ the source noise will be completely decorrelated, and at $1/(2\tau)$ there is an actual increase of source noise by 6 dB. The source noise will be periodic in the region beyond $1/(2\pi\tau)$. The noise peaks are the sum of the source and DUT noise. The bottom of the nulls is the residual noise of the phase detector and measurement system.

Measurement setup:



- Source provides all power required for phase detector
- DUT input power adjusted with attenuator
- DUT inadequate to drive phase detector
- Test setup noise floor is measured to sort out DUT noise from the rest of the test setup
- Attenuator compensates for DUT loss in setup measurement
- Adjust phase shifter to compensate for DUT phase drift

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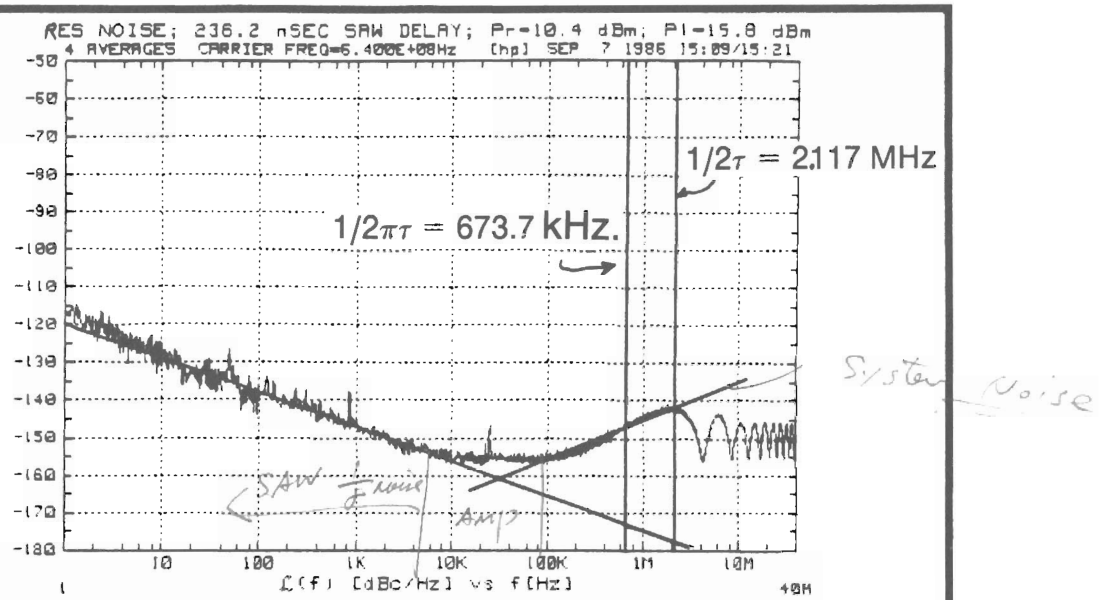
Slide 28

The DUT output is inadequate to drive the phase detector, so an amplifier has been added. It is necessary to measure the amplifier's noise under this operating condition to ensure it does not limit the measurement. The attenuation of the DUT must be known or measured and an attenuator substituted for the DUT when measuring system noise floor.

An HP line stretcher was used to obtain and maintain quadrature. The phase shift through this SAW delay line is very sensitive to temperature change, and it drifts with time. It was necessary to adjust the line stretcher very slowly during the measurement to maintain quadrature. A sudden movement in the phase correction will look like phase noise close to the carrier and invalidate that data.



1. SAW delay line characteristics (measured at 640 MHz, with a phase detector gain of .413 V/rad): All spurs less than 10 dB out of the noise, −155 dBc/Hz noise floor at 10 kHz offset, 1 Hz intercept of −118 dBc/Hz
2. Typical SAW delay line 1/f noise between 1 Hz and 4 kHz
3. Approaches system noise floor between 4 kHz and 200 kHz
4. Source noise decorrelation beyond 200 kHz

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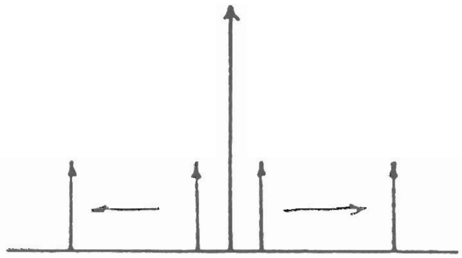
Slide 29

The SAW delay line appears to be very well-behaved. The floor region between 4 and 200 kHz approaches the test system noise floor. Data in this region is being degraded by insufficient dynamic range of the test setup. This problem may be remedied either by operating the DUT at a higher output level to increase its output signal-to-noise ratio, or by using an amplifier with a lower noise figure. The test setup noise floor must be 10 dB below the measured noise to ensure less than a .4 dB measurement error.

The region beyond 200 kHz is a very good example of the periodic nature of source correlation. At $1/(2\tau)$ noise is almost exactly 6 dB higher than the phase noise of a typical HP 8642A at that offset and carrier frequency. The noise nulls are at the measured test system noise floor.

AM and PM modulation properties

- Modulation sidebands constant with increasing modulation frequency
- Phase detector and AM detector gain constant for all modulation frequencies of interest
- Phase detector and AM detector calibration constant may be measured at a single modulation frequency.



*PM modulation properties for deviations <.2 radians

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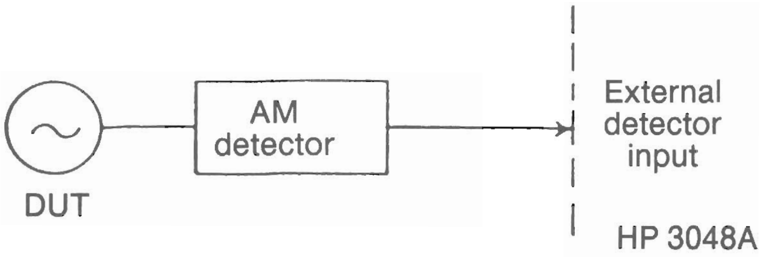
Slide 30

AM noise measurements are similar in principle to phase noise measurements. First, the AM detector sensitivity must be determined. Because of the nature of AM and PM modulation sidebands, system calibration need only be performed at one offset frequency and at one modulation frequency.

AM noise measurement system block diagram



1. Apply known signal to detector.
2. Measure detector output at baseband.
3. Calculate the transfer function between the known signal and the measured output.

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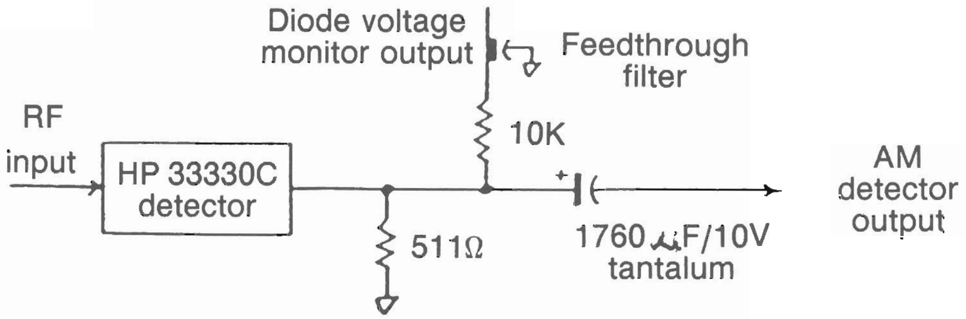
Slide 31

The AM noise measurement is a source-type measurement. The residual AM noise of a DUT can only be calculated by measuring the source's AM noise, then subtracting that from the measured output noise of the DUT. The noise floor of this technique is the sum of the noise floor of the source and the measurement system.

AM detector

AM detector schematic:



AM detector specifications:

detector type: low-barrier Schottky diode
carrier frequency range: 10 MHz–26.5 GHz
maximum input power: +23 dBm
minimum input power: 0 dBm
output bandwidth: 1 Hz–10 MHz

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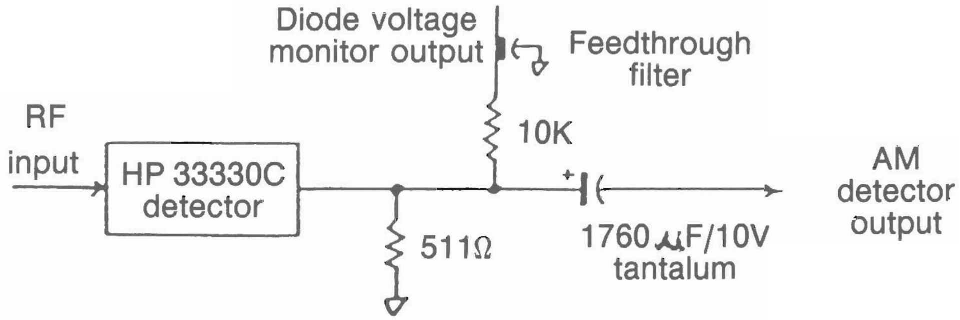
Slide 32

The AM detector consists of a low-barrier Schottky diode detector and a filter network.

AM detector schematic:



- Schottky will handle more power
- Point contact detectors have more bandwidth
- Blocking capacitor removes DC component
- Feedthrough limits measurements below 9 MHz
- Diode detector DC bias set by 511Ω resistor
- 50Ω AC load set by the system input
- Disconnect monitor port during noise measurements

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Slide 33

The detector is an HP 33330C Low-Barrier Schottky Diode Detector. The Schottky detectors will handle more power than the point contact detectors, and are equally sensitive and quiet.

The AM detector output capacitor prevents the dc voltage component of the demodulated signal from saturating the system's low-noise amplifier (LNA). The value of this capacitor sets the lower frequency limit of the demodulated output. The cutoff frequency can be decreased by increasing the value of the dc-blocking capacitor.

Carrier feedthrough in the detector may be excessive for frequencies below a few hundred megahertz. The LNA is protected from saturation by the internal filters used to absorb phase detector feedthrough and unwanted mixer products. This limits the maximum carrier offset frequency to 2 MHz for input frequencies of less than 95 MHz, and 40 MHz for carriers above 95 MHz.

The 511Ω load increases the detector bandwidth to greater than 10 MHz.

A high impedance monitor port is provided on the AM detector for measuring calibration constants. This port must be bypassed with a feedthrough capacitor to prevent noise from entering the main signal path. It must not be connected during the actual noise measurement.

Steps for making AM noise measurements

1. Define measurement.
   - Select measurement type: "AM noise".
     - Establish offset frequency range.
   - Define instrument parameters.
     - Carrier frequency.
     - Detector input frequency.
     - Select external detector.
   - Select calibration option.
   - Define measurement block diagram.
   - Define plot parameters.
2. Measure
   - Connect DUT and external hardware.
   - Measure calibration data.
   - Measure noise data, interpret results.

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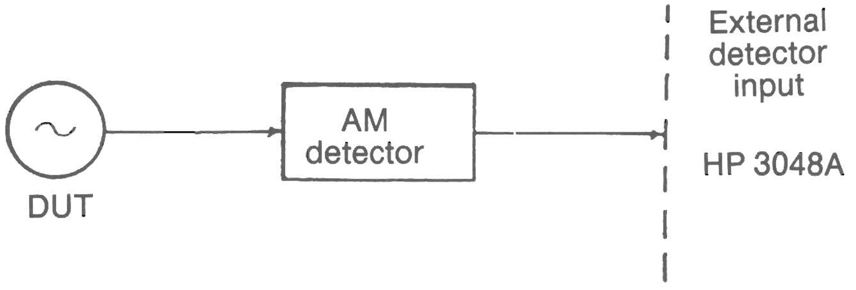
Slide 34

Steps to complete an AM noise measurement with the HP 3048A correspond to those of a phase noise measurement.

Calibration and measurement guidelines



- Shield all components from RFI
- Minimize ground loops between test system and AM detector.
- Prevent mechanically-induced AM fluctuations.
- Disconnect AM detector voltage monitor during measurement.
- The 1/f noise floor of the detector may degrade above +10 dBm.
- Broadband noise floor is best measured with about +20 dBm.
- If DUT produces insufficient power, place amplifier between DUT and detector.

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Slide 35

The AM detector must be well shielded from external noise, especially 60 Hz noise. The components between the diode detector and the test system should be packaged in a metal box to prevent RF interference. Also, the AM detector should be connected directly to the test system, if possible, to minimize ground loops. If the AM detector and test system must be separated, semirigid cable should be used to keep the shield resistance to a minimum.

Although AM noise measurements are less vulnerable than residual phase noise measurements to noise induced by vibration and temperature fluctuation, care should be taken to ensure that all connections are tight and that all cables are electrically sound.

The output voltage monitor on the AM detector must be disconnected from digital voltmeters or other noisy monitoring equipment before noise measurement data is taken.

The 1/f noise floor of the detector may degrade as power increases above +15 dBm. Noise in the 1/f region of the detector is best measured with about +10 dBm of drive level. The noise floor is best measured with about +20 dBm of drive level.

An amplifier must be used in cases where the signal level out of the DUT is too small to drive the AM detector, or is inadequate to produce a low enough measurement noise floor. In this case the amplifier should have the same characteristics as the amplifier used in phase noise measurements.

AM noise calibration methods

1. User entry of detector constant
2. Double-sided spur
3. Single-sided spur

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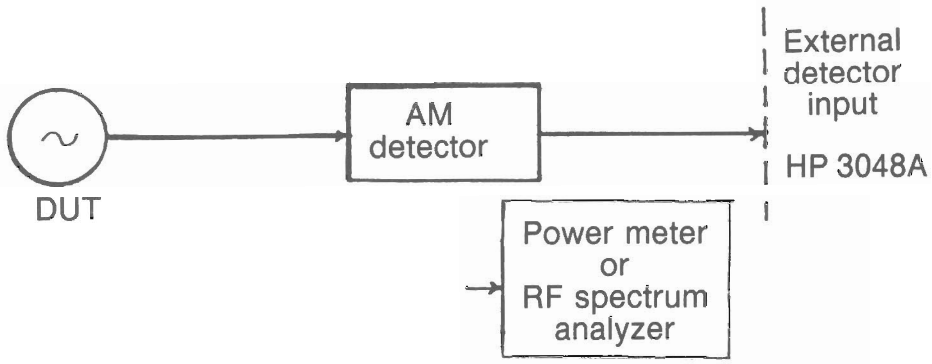
Slide 36

There are three calibration methods for AM noise measurement.

User entry detector constant, Method 1



1. Measure power applied to AM detector.
2. Locate power level on AM Sensitivity Graph, enter equivalent "phase slope".
3. Measure noise data, interpret results.

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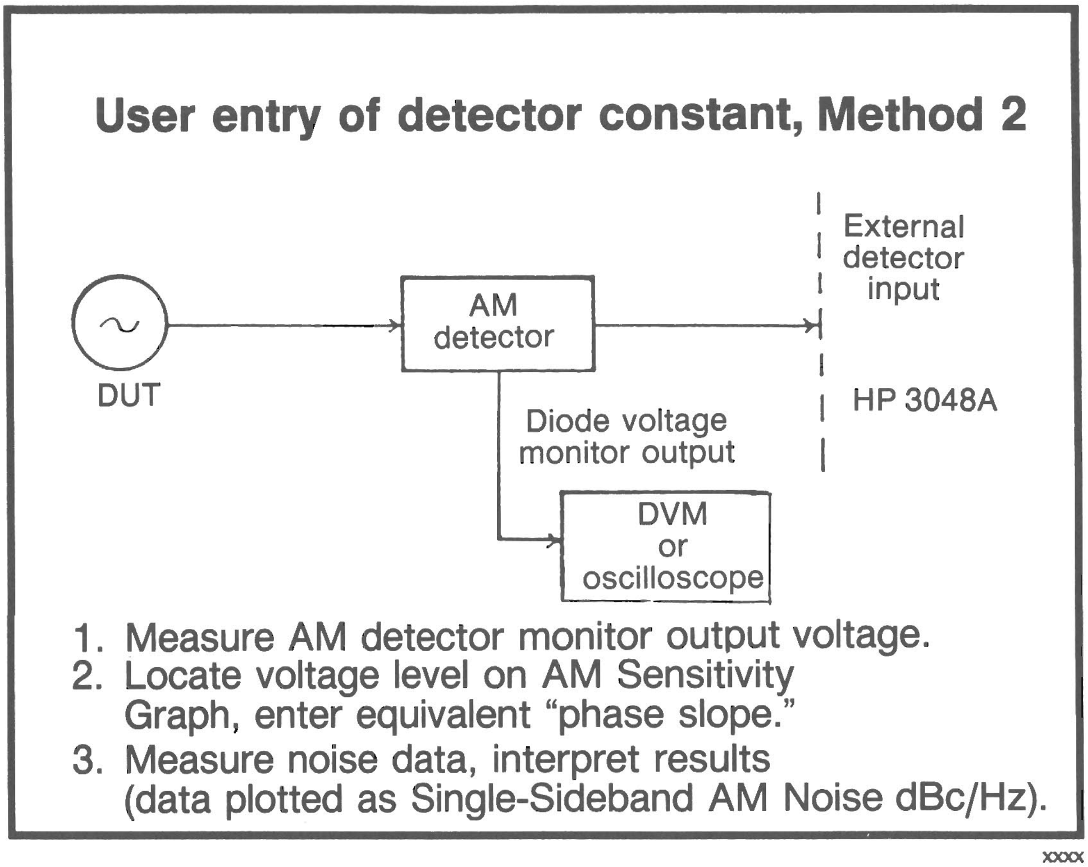
Slide 37

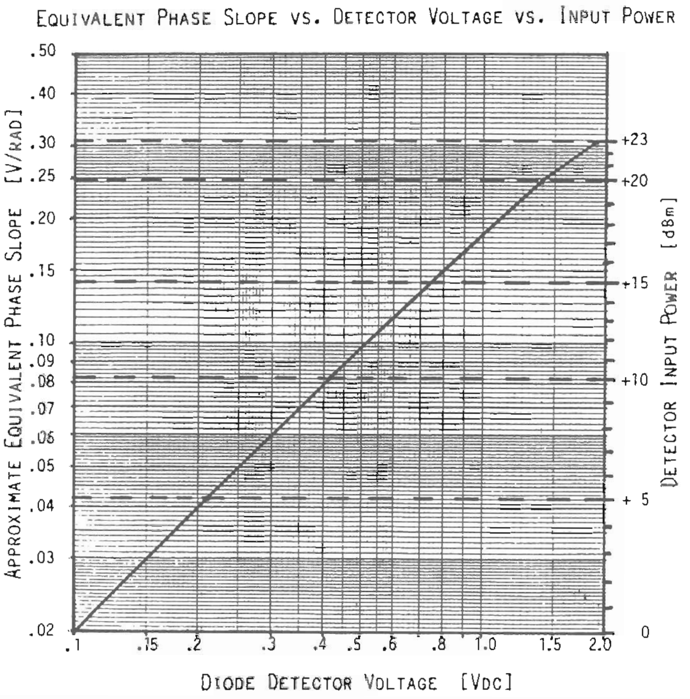
User Entry of the Detector Constant #1 is an easy method of calibration and requires only an RF power meter or spectrum analyzer to measure drive levels into the AM detector. It will measure the DUT without modulation capability and is the fastest method of calibration, particularly in the case of unchanging power levels supplied to the AM detector. It is an extremely fast method of estimating the "equivalent phase slope;" however, it is the least accurate of the calibration methods. It does not take into account the amount of power at harmonics of the signal, nor power which may be generated by spurious oscillations, causing the power meter to measure more power than is actually present at the desired frequency.



Slide 38

User Entry of the Detector Constant #2 is essentially the same as method #1 but requires either a voltmeter or an oscilloscope rather than an RF power meter or spectrum analyzer and measures the diode detector voltage at the AM detector's monitor output (must be disconnected during actual measurement). It is equally as fast as Method 1, especially with unchanging power levels supplied to the AM detector. It has the advantage of measuring the AM detector gain in the actual measurement configuration, and is an extremely fast method of estimating both the equivalent phase slope and the input power to the AM detector. It is, however, somewhat less accurate than the other calibration methods.

AM detector sensitivity graph



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Slide 39

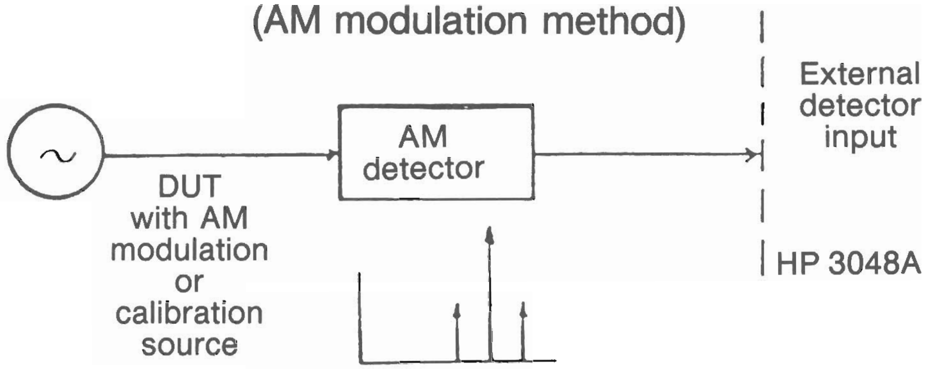
The AM detector sensitivity graph is used with the User Entry of Detector Constant examples 1 and 2.

In example 1, the AM detector drive level is measured and applied to the graph to determine the equivalent "phase slope."

In example 2, the diode detector's dc voltage is measured and located at the bottom of the graph. Moving up to the diagonal calibration line and over, the equivalent "phase slope" is read from the left side of the graph while the approximate detector input power can be read from the right side of the graph.

Double-sided spur

(AM modulation method)



1. Measure DUT power applied to AM detector.
2. If source under test does not have AM modulation, connect calibration source to AM detector RF input and adjust calibration source to DUT frequency and power level.
3. Otherwise, set modulation frequency.
4. Set AM modulation between .063 and 20% carrier-to-sideband is:

$$C/sb = 20\log(\%AM/100) - 6\ dB$$

5. Enter modulation frequency and carrier-to-sideband ratio.
6. Measure calibration constant, then reconnect DUT.
7. Measure noise data, interpret results.

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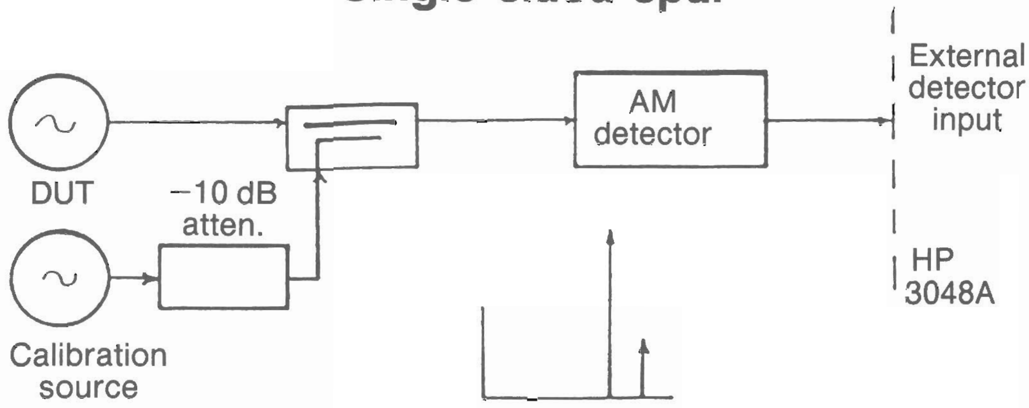
Slide 40

The Double Sided Spur or AM Modulation method of calibration is more complex and more accurate than the User Entry of the Detector Constant method. It requires a DUT which can be AM modulated or a calibration source which can be substituted for the DUT at the same frequency and power level.

If the AM modulation is precise, the carrier-to-AM sideband level may be calculated and entered into the test system. If not, it must be measured on an RF spectrum analyzer. Calibration is done under actual measurement conditions so all nonlinearities and harmonics of the AM detector are calibrated out.

Single-sided spur

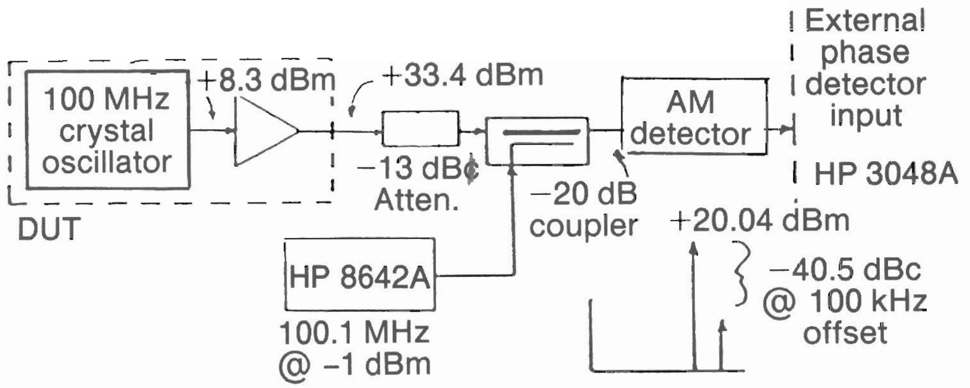


1. Measure DUT power applied to AM detector.
2. Connect −20 dB coupler output to RF spectrum analyzer.
3. Adjust calibration source spur frequency.
4. Adjust calibration source for spur between −20 and −70 dBc.
5. Reconnect AM detector, measure detector sensitivity.
6. Turn off calibration spur.
7. Measure noise data, interpret results.

Slide 41

The Single Sided Spur method of calibration is extremely precise and will measure a source without modulation capability; however, it requires a coupler and a calibration source to generate a calibration spur between 1 and 40 MHz from the carrier and an RF spectrum analyzer to precisely measure the signal-to-spur ratio and the spur offset from the carrier.

Example: Measurement of a source without AM modulation (using the Single-Sided Spur Calibration Method)



Note:

- DUT output attenuated to prevent detector damage.
- Calibration spur is −40.5 dBc at 100 kHz offset.
- Signal power must not significantly change when calibration spur removed.
- Detector power is +20 dBm for lowest detector noise floor.
- Blocking capacitor ensures zero volts on quadrature meter.

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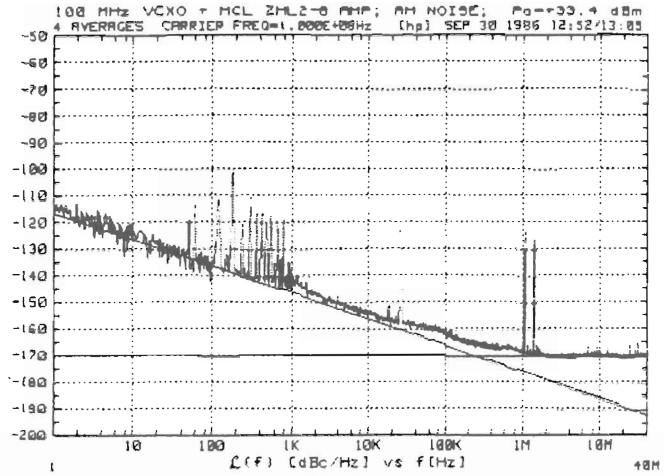
Slide 42

The Single-Sided Spur method is the most accurate calibration technique for sources without amplitude modulation capability. It requires that a single-sided spur be added to the signal. It can be shown that the single-sided spur is equal to amplitude modulation plus phase modulation, both with sidebands 6 dB below the single sideband spur. Since the AM detector is not sensitive to phase modulation, the PM sidebands are stripped away, and the AM sidebands are demodulated. The sensitivity of the AM detector is equal to the ratio of the recovered baseband signal to the singal-to-spur ratio minus 6 dB.

In this example, the DUT is a 100 MHz voltage-controlled crystal oscillator followed by a power amplifier with an output power of +33.4 dBm at 100 MHz.

The power of the DUT is greater than the maximum power rating of the diode detector. Thus, the output must be attenuated to less than +23 dBm, but still remain large enough to provide an adequate AM detector sensitivity, as detector sensitivity is directly proportional to the detector input power.

The AM detector is calibrated by adding a −40.5 dBc spur to the main signal via a −20 dB coupler. The spur has an offset frequency of 100 kHz. After the detector is calibrated, the spur is removed by setting the calibration generator output power to −140 dBm. This reduces the calibration spur to below the noise floor, while maintaining the impedance match of the coupler's coupled port.



Note:

- VCXO/power amp combination, measured at 100 MHz, with a "phase detector gain" of .264V/rad, has at least a −170 dBc/Hz noise floor at offsets greater than 1 MHz.
- Estimated system floor with Phase Detector Sensitivity Graph.
- Large 1/f region may be:
  - power amplifier 1/f noise.
  - diode detector noise.
- Spurs between 60 Hz and 1 kHz may be from a ground loop.
- Discontinuity at 1 kHz from unresolved 60 Hz spurs.
- RFI spurs between 1 and 2 MHz

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Slide 43

The crystal oscillator/power amplifier combination measured at 100 MHz has a noise floor of at least −170 dBc/Hz at offsets greater than 1 MHz. The system noise floor may be limiting this measurement. The system floor can be estimated by comparing the equivalent phase slope to the Phase Detector Sensitivity Graph.

The 1 Hz intercept noise is at least −116 dBc/Hz. The large 1/f noise region is probably due to one of two mechanisms:

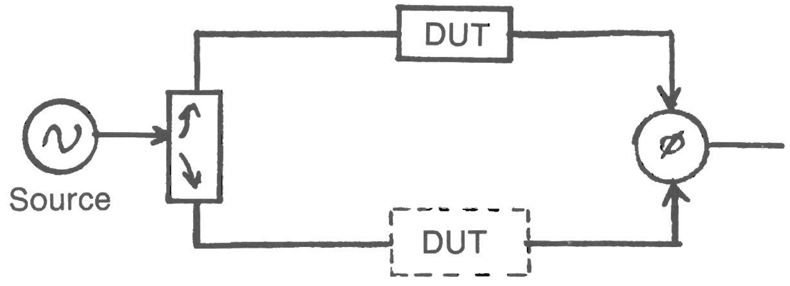
1. The noise of the power amplifier. This should be investigated by removing the power amplifier, and remeasuring the oscillator's AM noise.
2. The diode detector in the AM detector is operating at a very high power level to measure the noise floor performance. The high power may be degrading the 1/f performance of the detector. The 1/f region of the noise data should be remeasured with an additional 10 dB of attenuation placed before the AM detector, which will lower the input level to +10 dBm.

The spurs between 60 Hz and 1 kHz are due to 60 Hz line spurs, possible induced by a ground loop between the DUT and the test system.

The discontinuity at 1 kHz is caused by unresolved 60 Hz spurs. Spurs in the 1 to 2 MHz region are produced by the Shared Resource Management System multiplexer connected to the test system controller. This RFI can be greatly reduced by replacing the multiplexer with the new HP 50961A SRM coax adapter.

Conclusion

Residual phase noise measurement:



- Correlated source noise cancels.
- Source must have low AM noise.

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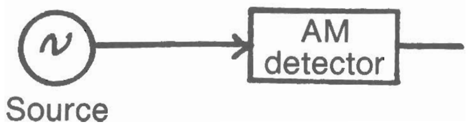
Slide 44

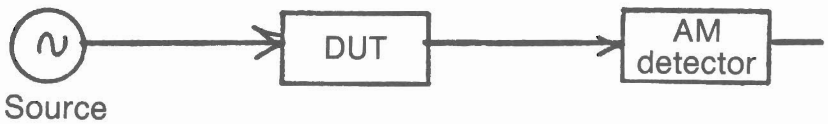
The source noise which is correlated between the two phase detector paths will cancel in the phase detector. Because of this cancellation of the source noise, the HP 3048A has a typical system noise floor of −180 dBc/Hz beyond a 10 kHz offset with a 1 Hz intercept of −145 dBc/Hz. This typical system noise floor will be maintained provided that sufficient signal power is supplied to the phase detector, the source noise does not become decorrelated, and the AM noise of the source does not dominate the measurement.

AM source noise measurement:



- An external AM detector will demodulate AM noise

AM residual noise measurement:



- DUT AM noise $\leq$ noise measured

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Slide 45

Measurement of AM source noise requires an external AM detector which can be easily constructed.

The AM noise of the DUT is equal to or less than the measured noise. If the source plus detector noise is less than the source plus DUT plus detector noise, then the measured result is the noise of the DUT.

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