Agenda

• Phase Noise Review

• Phase Noise Measurement Techniques
  – Direct Spectrum Analyzer
  – Phase Detector
  – Phase Detector with Cross-Correlation
  – Delay Line Discriminator
  – Digital Phase Demodulator

• Additive Phase Noise

• Pulsed Phase Noise

• AM Noise

• VCO Measurements

• Summary
What is Phase Noise?

• Ideal Signal (noiseless)
  \[ V(t) = A \sin(2\pi \nu t) \]
  where
  \[ A = \text{nominal amplitude} \]
  \[ \nu = \text{nominal frequency} \]

• Real Signal
  \[ V(t) = [A + E(t)] \sin(2\pi \nu t + \phi(t)) \]
  where
  \[ E(t) = \text{amplitude fluctuations} \]
  \[ \phi(t) = \text{phase fluctuations} \]

Phase Noise is unintentional phase modulation that spreads the signal spectrum in the frequency domain.
Phase Noise is equivalent to jitter in the time domain.
What is Phase Noise?

- **Absolute Phase Noise**
  1 Port – Produced by Signal Source

- **Additive Phase Noise**
  2 Port – Added by device (e.g. amp, up/down converter)
What is Phase Noise?

**AM Noise and Phase Noise on a Phasor Diagram:**

\[ V(t) = [A + E(t)] \sin(2\pi\nu t + \phi(t)) \]

- **\( A \)** (Amplitude Noise)
- **\( 2\pi\nu \)**
- **\( \phi(t) \)** (Phase Noise)
- **\( E(t) \)** (Amplitude Noise)
- **Noise\(_{rms}\)**
- Measured point at Time = t
What is Phase Noise?

kTB noise has equal contributions from Amplitude Noise and Phase Noise

Noise added by a device dominated by phase noise

Noise added by a device dominated by amplitude noise (AM)
Quantifying Phase Noise – Measurement Limits

• Since $kT\nu$ noise has equal contributions from AM and Phase Noise, theoretical measurement floor for each parameter is -177dBm/Hz

• Phase noise is expressed as dBc/Hz so the theoretical measurement floor becomes $-177\text{dBm/Hz} - P_{\text{signal}}$ (dBm)

• Example:
  • DUT with +20dBm output level can be theoretically measured as low as -197dBc/Hz

• In practice, instrumentation noise prevents measurements to these levels
Phase Noise
Important in Digital Modulation

Modulation quality (phase error, EVM) is degraded by phase noise

Increasing Phase Noise (16QAM)
Phase Noise
Digital Modulation Example – DOCSIS 3.1

- Cable internet standard is changing from 256QAM (single carrier) to 4096QAM (OFDM)
- Phase noise must be low enough to ensure <0.22% EVM (>53dB MER)

DOCSIS 3.0: 256 QAM
DOCSIS 3.1: 4096 QAM
Phase Noise
Important in Communication Systems Transmitters

Adjacent Channel Power

Phase Noise causes transmitter signal to leak into adjacent channels

Ideal LO

Real LO
Phase Noise
Important in Receivers

Sensitivity: Big interferer near the transmit channel

Large interferer mixes with LO energy spread by phase noise to produce a signal in the receiver IF – reduced sensitivity
Phase Noise
Important in Radar

Radar Applications – Moving Target Indication

\[ f_d = \frac{-2f}{c} v_r \]

- \( f = 10 \text{ GHz} \)
- \( v_r = 4 \text{ km/hr} \)
- \( c = 2.998e8 \text{ m/s} \)
- \( f_d = 74 \text{ Hz} \)

High phase noise in radar LO spreads clutter signal and masks desired low-level target response.
Phase Noise
Important in Digital Systems

High Phase Noise = High Jitter

Jitter peaks can cause transmitted symbol errors which increased bit error rate and limits usable data rate.
Quantifying Phase Noise

• Phase Noise Definition and Unit of Measure
• Residual Noise (Integrated Parameters)
  – Integrated Phase Noise
  – Residual PM
  – Residual FM
  – Jitter: Time and Frequency Domain Approaches
Phase Noise – Unit of Measure

- Phase Noise is expressed as $L(f)$ (L(f) is pronounced “script L of F”)
- $L(f)$ has units of dBc/Hz
- Old definition: $L(f)$ is the single sideband power due to phase fluctuations in a 1Hz bandwidth at a specified offset frequency, $f$, from the carrier
Narrowband Phase Modulation (CW)

• With low modulation index, virtually all sideband energy is in first sideband
• Sideband level is lower than carrier level

Phase deviation = 0.03 rad
Wideband Phase Modulation (CW)

- With high modulation index, energy is in higher sidebands and total sideband energy is larger than carrier energy
- dBc levels $>0$ are possible
- Old phase noise definition not meaningful with very high levels of phase noise

Phase deviation $= 2$ rad
Single Sideband Phase Noise
Region of Validity (per old Phase Noise Definition)

- Old phase noise definition:
  - Assumed phase noise energy in single sideband - not true for high phase noise
  - Required total phase deviation <0.2 rad (small angle criterion) for energy to be mostly in first sideband
- New definition includes ALL sideband energy – small angle criterion doesn’t apply

![Graph showing the region of validity](image-url)

- $L(f) > 0 \text{ dBC/Hz}$ is valid per new definition
- Small angle Criterion ($<\sim 0.2$ rad)
- $10 \text{ dB/decade}$
Phase Noise – Unit of Measure

- Phase Noise is expressed as $L(f)$ (L(f) is pronounced “script L of F”)
- $L(f)$ has units of dBc/Hz
- Old definition: $L(f)$ is the single sideband power due to phase fluctuations in a 1Hz bandwidth at a specified offset frequency, $f$, from the carrier
- New definition: $L(f)$ is defined as one-half the spectral density of phase fluctuations, $L(f) = \frac{1}{2} \cdot S_\phi(f)$ (IEEE STD 1139-2008)
Causes of Oscillator Phase Noise

Random Walk FM: Close to carrier, generally caused by environmental effects
Flicker FM: Related to active oscillator physical resonance mechanism, power supply noise
White FM: Related to passive resonator oscillators
Flicker $\phi$M: Related to noisy amplifiers and multipliers
White $\phi$M: Far from carrier, generally caused by broadband output amplifier noise

These contributors are present in varying degrees depending on the type and design of the oscillator

Residual / Integrated Noise

- Values calculated from integration of phase noise curve

- Integrated Phase Noise
  \[ \int L(f) \, df \] (dBc)

- Residual PM
  \[ \frac{180^\circ}{\pi} \sqrt{2 \int L(f) \, df} \] (deg or rad)

- Residual FM
  \[ \sqrt{2 \int f^2 L(f) \, df} \] (Hz)

- Jitter
  \[ \frac{1}{2\pi f_c} \sqrt{2 \int L(f) \, df} \] (sec)

<table>
<thead>
<tr>
<th>Residual Noise</th>
<th>Trace</th>
<th>Start Offset</th>
<th>Stop Offset</th>
<th>Int PHN</th>
<th>PM</th>
<th>FM</th>
<th>Jitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1.00 kHz</td>
<td>10.00 MHz</td>
<td>-77.45 dBc</td>
<td>10.85 m° / 189.39 μrad</td>
<td>544.60 Hz</td>
<td>30.14 fs</td>
<td></td>
</tr>
</tbody>
</table>
Jitter – Time Domain Approach

- Oscilloscopes measure jitter directly in the time domain, but the scope’s internal jitter (phase noise) limits sensitivity to the range of picoseconds.
- Some very high-end scopes can measure in the range of 100 femtoseconds, but are very expensive.
Jitter – Frequency Domain Approach (Phase Noise)

• Jitter: \[ J = \frac{1}{2\pi f_c} \sqrt{2 \int \mathbb{L}(f) df} \] Units of sec

- RMS Jitter can be calculated by integrating phase noise.
- Phase noise techniques can measure jitter with excellent sensitivity. Jitter measurements well below 10 femtoseconds (1 fs = 10^{-15} s) are possible (much more sensitive than an oscilloscope).
- Phase noise plot makes it easy to distinguish random and deterministic jitter (difficult using an oscilloscope).
- Only clocks can be measured, not random data streams.
The Phase Noise of a signal passed through an ideal multiplier (one that adds no noise) will increase since a given amount of phase deviation represents a higher fraction of the smaller signal period.

This is expressed by:

\[ \mathcal{L}(Nf) = 20 \log(N) \times \mathcal{L}(f) \]

- 2x \( \rightarrow \) phase noise increases by 6dB
- 10x \( \rightarrow \) phase noise increases by 20dB

Correspondingly, a frequency divider decreases the phase noise of a signal:

- \( \div 2 \) \( \rightarrow \) phase noise decreases by 6dB
- \( \div 10 \) \( \rightarrow \) phase noise decreases by 20dB
The Phase Noise of a signal passed through an ideal frequency mixer (one that adds no noise) will increase by the phase noise of the LO.

The phase noise increases whether the input signal is up or down converted.

This is expressed by: $L(f_{\text{out}}) = L(f_{\text{in}}) + L(f_{\text{LO}})$ (must add linear values, not dBc/Hz values)
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Direct Spectrum Analyzer

Simple setup, but how good is the measurement?
Direct Spectrum Analyzer

- Spectrum analyzer is a multistage receiver with multiple LOs.
- Each LO adds phase noise to the input signal – Measurement result is the sum of phase noise from DUT and all LOs.
- Full signal amplitude is present at every stage of the SA receiver – Measuring low level phase noise is limited by the SA’s dynamic range.
- SA minimum resolution bandwidth limits close-in offset.

![Diagram of Direct Spectrum Analyzer]

Spectrum analyzer is a multistage receiver with multiple LOs. Each LO adds phase noise to the input signal. The measurement result is the sum of phase noise from the DUT and all LOs. Full signal amplitude is present at every stage of the SA receiver, but measuring low level phase noise is limited by the SA’s dynamic range. The SA’s minimum resolution bandwidth limits close-in offset.
Direct Spectrum Analyzer
Manual Spot Noise Measurement

- Phase Noise Marker function corrects for ratio of RBW to 1Hz, 10log(RBW), and Effective Noise Bandwidth (ENB) of the RBW filter (typically <1dB)

- Must use proper detector and averaging type to get good measurement

- This technique is correct, but is the measurement accurate?
- What about the noise of the analyzer?
- What if we want a phase noise curve instead of a point measurement?
- What about AM noise?
- What if we want to measure closer than 1Hz to the carrier?
Direct Spectrum Analyzer

- Measurement sensitivity is limited by internal phase noise of spectrum analyzer
- Only way to validate measurement is to compare to SA phase noise specs
- Instrumentation noise always adds to measurement (error, not uncertainty)
- Would like SA phase noise to be at least 10dB lower than DUT phase noise

### R&S FSW Spectrum Analyzer Phase Noise from Data Sheet

<table>
<thead>
<tr>
<th>$L_{DUT} - L_{SA}$ (dB)</th>
<th>Meas Error (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.0</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>15</td>
<td>0.1</td>
</tr>
<tr>
<td>20</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Direct Spectrum Analyzer
Drifting DUT using traditional approach

- Measurement is done in half-decade spans
- Center frequency re-tuning done at start of each half-decade
- Measurement bandwidth is reduced for each half-decade making measurement less tolerant of drift
- Close-in offsets take longer to measure which gives the signal more time to drift
- Measurement error occurs if DUT drifts out of RBW filter
Direct Spectrum Analyzer
Drifting DUT using advanced IQ capture/DSP approach

- Measurement is still done in half-decade spans
- Signal is captured with wider IQ bandwidth in all half-decades
- Drifting signal stays within captured bandwidth
- Bandwidth reduction done in DSP
- Drift is tracked using digital PLL
- Even drifting signal is measured correctly
- Additional benefit: IQ capture approach also provides AM rejection
Direct Spectrum Analyzer – Summary

**Advantages**
- Fast and easy measurement setup
- High offset frequency range (up to 30GHz)
- Spectrum Analyzer can make many other signal measurements:
  - Harmonics
  - ACPR
  - Spurious emissions, etc.

**Limitations**
- Sensitivity is limited by phase noise of the internal LO’s in the instrument
- Sensitivity also limited by dynamic range since low level noise must be measured in the presence of the carrier
- Most SA’s cannot reject AM noise
- Lower offset frequency is limited to 1Hz due to minimum 1Hz RBW
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• Summary
Phase Detector

- Phase Detector converts phase fluctuations to voltage fluctuations
- Only Ref Source phase noise adds to signal’s phase noise
- Main carrier energy is removed by Phase Detector (PD) and LPF
- LNA and Baseband Analyzer measure noise signal with high sensitivity
- PD provides AM noise rejection
- Offsets closer than 1Hz can be measured (down to 0.01Hz)
Why offset DUT and Reference by 90°?

Phase detector most sensitive (most volts per degree) when nominal phase difference is 90°.
Phase Detector

- PLL bandwidth set as low as possible and still track DUT drift
- Phase noise at offsets below PLL loop bandwidth is suppressed by the PLL
- Measurement system applies inverse correction curve to measured values
- High uncertainty at low offsets more than 1-2 decades below loop BW
**Phase Detector**

- Phase detector approach has better sensitivity than direct spectrum analyzer method, but same relationship between DUT noise and instrument noise applies.
- Must check instrument phase noise spec to validate measurement.
- Still want at least 10dB margin, if possible.

**Phase Detector Diagram**

- **DUT**
- **PD**
- **Ref Source**
- **90°**
- **Target Margin**

**Phase Detector Table**

<table>
<thead>
<tr>
<th>$L_{\text{DUT}} - L_{\text{REF}}$ (dB)</th>
<th>Meas Error (dB)</th>
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<tbody>
<tr>
<td>0</td>
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<td>0.1</td>
</tr>
<tr>
<td>20</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Phase Detector

- Same presentation of results as with Spectrum Analyzer measurement.
- Phase Noise curve, Spot Noise, and Residual calculations are available.
- Spur detection algorithm displays and reports spurs separately (in dBc).

-132.1 dBc/Hz @ 20kHz offset

Spurs reported in dBc
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- Summary
Uncorrelated noise from Ref 1 and Ref 2 is suppressed by the cross-correlation function

- Ref Noise Suppression: 10dB for 100 CC, 20dB for 10000 CC
- DUT noise is common to both paths and is unaffected by cross-correlation
Phase Detector with Cross-Correlation

- Same presentation of measured data
- CC effectively reduces the phase noise of the reference source
- Improves sensitivity over single reference source by up to 20dB
Phase Detector Method – Summary

**Advantages**

- Carrier is suppressed so analyzer dynamic range is not a limiting factor as it can be with the spectrum analyzer method
- Measurements at very small offsets are possible (down to 0.01Hz)
- Phase Detector has inherent AM suppression
- Cross-Correlation improves the sensitivity of the test system
  - 10dB for CC=100, 20dB for CC=10000

\[
\text{cross corr improvement} = 10 \log_{10}(\sqrt{n})
\]

**Limitations**

- Restricted upper offset range (limited by bandwidth of baseband analyzer)
- Spectrum Analyzer is still necessary for measurement of other parameters:
  - Spurious Emissions, ACPR, Harmonics
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Delay Line Discriminator

- The delay line converts frequency fluctuations to phase fluctuations, then the phase detector converts the phase fluctuations to voltage fluctuations.
- No reference source required – good for noisy or drifting DUTs.
- Maximum offset limited to $\approx 1/(2\pi T)$ due to $\sin(x)/x$ term (max offset 1MHz for $T = 160$ns).
- Longer delay ($T$) gives better sensitivity, but reduces maximum usable offset.
- Longer delay line also has higher loss which reduces PD sensitivity.
- Manual adjustment of phase shifter over $180^\circ$ required for calibration.

Mathematical expression:

$$V = (2\pi T) \left( \frac{\sin(\pi f T)}{\pi f T} \right) K_{PD} \Delta f(t)$$
Delay Line Discriminator

\[ PD = (2\pi T) \left( \frac{\sin(\pi f T)}{\pi f T} \right) K_{PD}\Delta f(t) \]

- First measurement null occurs at \( f = 1/T \)
- Useful offset range up to \( f \approx 1/(2\pi T) \)
- Longer delay line gives better sensitivity, but reduces upper offset limit
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Digital Phase Demodulator

- Different approach to measurement with many advantages
  - Phase noise measured from demodulated PM
  - No phase detector or PLL – no loop BW correction, greatly simplified calibration
  - Easy measurement of **absolute**, **pulsed**, **additive**, and **pulsed additive** phase noise
  - Very low-noise Ref Sources and high-speed cross correlation to increase sensitivity
Digital Phase Demodulator

- Measurement speed improvement of >10x over traditional techniques
- High sensitivity measurement from 10Hz – 1MHz in less than 20s
- Can measure frequency offsets from 0.01Hz to 300MHz

Shaded gray area shows cross-correlation gain which indicates measurement floor for instant verification of measurement margin.
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Additive Phase Noise – Phase Detector

- Two-port DUT (e.g. amplifier)
- Source noise is correlated on both PD inputs – cancels out so only added noise of DUT is measured
- Manual adjustment of phase shifter over 180° required for calibration
- Phase detector may be external or internal to analyzer

* Phase shifter adjusted for calibration and set for quadrature during measurement
Additive Phase Noise – Digital Phase Demodulator

- Internal hardware automatically reconfigures when additive is selected
- No phase detector or need for quadrature – No phase shifter!
- Greatly simplifies measurement setup and calibration
- Internal Low Noise Synthesizer as DUT stimulus
- High speed cross correlation to increase sensitivity
Additive Phase Noise – Digital Phase Demodulator

- Internal Low Noise Synthesizer as DUT stimulus
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Pulsed Phase Noise – Phase Detector

- CW Ref Source causes DC shift at the PD when DUT pulse is off – must also pulse Ref Source in sync with DUT to keep output of PD at 0 volts
- Pulse edges of DUT and REF are not perfectly synchronized so switching transients will occur at pulse edges – PRF feedthrough
- LPF cutoff is too high to attenuate PRF feedthrough

Pulsed CW DUT

PLL (tracks DUT freq, maintains 90 deg offset)
Baseband Noise and switching transients
Low Pass Filter
LNA
Baseband Analyzer

Δφ=90°

Pulsed Ref Source

Pulsed CW DUT
Pulsed Phase Noise – Phase Detector

- PRF is LPF that attenuates PRF feedthrough
- PRF filter must have flat passband and sharp cutoff
- Different PRF filter required for every PRF frequency

**Diagram:**
- Pulsed DUT
- Pulsed Ref Source
- PLL
- PLL Low Pass Filter (sets loop BW)
- PD
- Δφ = 90°
- Low Pass Filter
- PRF Filter
- LNA
- Baseband Analyzer
- Pulsed Phase Noise Analyzer
Pulsed Phase Noise – CW Ref Source

- When DUT pulse is OFF the Ref Source causes a DC shift at the phase detector output.
- This DC level causes problems:
  - Even small DC voltage can saturate high-gain LNA
  - DC looks like frequency error to PLL – tracking issues
- To avoid these problems we must pulse the Ref Source in sync with DUT pulse.
Pulsed Phase Noise – Pulse Spectrum

- Spectrum of pulsed CW signal contains one line at the center frequency and many other PRF lines
Pulsed Phase Noise – Pulse Spectrum

- PRF filter is narrow to pass center line and attenuate all other PRF lines.
- Center line is lower than pulse level due to pulse desensitization: \(20 \times \log(\text{duty cycle})\)

\[
\frac{1}{\text{PW}} = 100\text{kHz}
\]

\[
\frac{1}{\text{PRI}} = \text{PRF} = 10\text{kHz}
\]

\[
A \times 20 \log\left(\frac{\tau}{T}\right) \quad \text{(pulse desensitization)}
\]

\[
\text{PRI (T)} \quad 100\text{us}
\]

\[
\text{PW (\tau)} \quad 10\text{us}
\]

\[
\text{Level (A)} \quad 10\text{dBm}
\]

\[
\text{Time}
\]
PRF Filter

- PRF must have flat passband out to PRF/2 but high attenuation at >PRF
- Difficult to achieve
Pulsed Phase Noise

- Max offset limited to PRF/2 for pulsed signals due to PRF lines
- Pulsed phase noise ~6dB higher at PRF/2 due to coherent combining

\[
\frac{1}{PRI} = PRF = 10\text{kHz} \quad \text{and} \quad \frac{0.5}{PRI} = 5\text{kHz}
\]
Pulsed Phase Noise – Digital Phase Demodulator

- Same block diagram as for CW phase noise measurements
- No phase detector so no need to pulse the reference sources
- PRF filter and PW gating are implemented in DSP to easily handle different PRFs
- Pulsed-Additive phase noise can also be measured without complex calibration required
Pulse Configuration Setup

- PW and PRI are automatically detected using zero-span measurement
  - PW is used to set measurement gate time
  - PRI is used to set maximum offset
Pulsed Phase Noise Measurement

- Measurement truncated to max offset of PRF/2
- Measurement time same as for CW
Pulsed vs CW Phase Noise Measurement

Pulsed measurements same as CW for offsets << PRF/2

Pulsed measurement higher than CW at PRF/2
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AM Noise Measurement – Diode Detector

• Recall the expression of a real-world sine wave:
  \[ V(t) = [A + E(t)] \sin(2\pi f t + \phi(t)) \]

• \( E(t) \) is the AM noise component

• AM noise is usually lower than phase noise – especially at close-in offsets

• AM Noise is traditionally measured using an external diode detector along with the baseband noise analyzer

• Calibration of the measurement is done using a signal generator with a known AM modulation index
AM Noise – Digital AM Demodulation

- Same block diagram – AM Noise measured from demodulated AM
- Much simpler setup with no need for detector diode or complicated calibration
- Permits simultaneous measurement of phase noise and AM noise
- High speed cross correlation to increase sensitivity
AM Noise – Digital AM Demodulator
AM Noise and Phase Noise

- Simultaneous measurement of AM Noise and Phase Noise
AM Noise, Phase Noise, and Total Noise

- Simultaneous measurement of AM Noise and Phase Noise with Total Noise
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VCO Measurements

- VCO measurements include:
  - Frequency vs. tune
  - Power vs. tune
  - Tuning sensitivity vs. tune
  - Supply current vs. tune
  - Spot noise vs. tune
VCO Measurements

- FSWP maximum/minimum voltage can be different tuning ranges
- $V_{\text{tune}}$, $V_{\text{aux}}$ and $V_{\text{supply}}$ can be swept
VCO Measurements

• Results
VCO Measurements

- Spot noise vs. tune

Different Offset Ranges
Digital Phase Demodulator – Summary

**Advantages**
- No PLL or compensation for noise suppression within loop BW required
- Much faster than other methods (for same sensitivity)
- Pulsed, Additive, and Pulsed Additive phase noise can be easily measured
- Phase Noise and AM Noise can be measured simultaneously
  - AM noise rejected in phase noise measurement (>50dB)
  - Phase noise rejected in AM noise measurement (>50dB)
- No complex calibrations required for AM and Additive phase noise
- Measurements at very small offsets are possible (down to 0.01Hz)
- Cross-Correlation improves the sensitivity of the test system

**Limitations**
- Additive phase noise frequency range limited to 18GHz (FSWP)
- Spectrum analyzer still required for other measurements such as ACLR, Harmonics, and Spurious (SA option available in FSWP)
# Measurement Technique Summary

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<thead>
<tr>
<th></th>
<th>Absolute</th>
<th>Additive</th>
<th>Pulsed</th>
<th>Pulsed-Additive</th>
<th>AM Noise</th>
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<tr>
<td></td>
<td>Limited sensitivity and close-in offset</td>
<td></td>
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<tr>
<td><strong>Phase Detector</strong></td>
<td><img src="check.png" alt="Check" /></td>
<td><img src="check.png" alt="Check" /></td>
<td><img src="check.png" alt="Check" /></td>
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<tr>
<td></td>
<td></td>
<td>Difficult cal required</td>
<td>PRF filter required</td>
<td>Difficult cal and PRF filter required</td>
<td>Detector diode and AM cal source required</td>
</tr>
<tr>
<td><strong>Delay Line Discriminator</strong></td>
<td><img src="check.png" alt="Check" /></td>
<td><img src="x.png" alt="X" /></td>
<td><img src="x.png" alt="X" /></td>
<td><img src="x.png" alt="X" /></td>
<td><img src="x.png" alt="X" /></td>
</tr>
<tr>
<td></td>
<td>Max offset limited by $\sin(\tau)/\tau$</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Digital FM/AM Demodulator</strong></td>
<td><img src="check.png" alt="Check" /></td>
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![Rohde & Schwarz Logo](logo.png)
Summary

• Phase noise is unintentional phase modulation on a signal that spreads the spectrum and degrades performance in many RF applications.

• Absolute Phase Noise can be measured using several methods:
  – Direct Spectrum Analyzer
  – Phase Detector (+ Cross-Correlation)
  – Delay Line Discriminator
  – Digital Phase Demodulator (+ Cross-Correlation)

• Traditional Pulsed PN, Additive PN, and AM Noise measurements require complicated setups with complex calibration schemes.

• Digital PM/AM Demodulation technique with very-low-noise reference sources makes Absolute Phase Noise, Additive Phase Noise, Pulsed Phase Noise, Additive-Pulsed Phase Noise, and AM Noise measurements with simple setup, no complex calibrations, and with state-of-the-art sensitivity and speed.

• VCO Measurements verify performance versus tune voltage.
Thank You!