Understanding Phase Noise Needs and Choices in Signal Generation

Ben Zarlingo, Allison Douglas
Agilent Technologies Microwave and Communications Division
This Presentation

Overview: Signal Generator Choices, Tradeoffs
When Phase Noise Matters
Example Calculation: Doppler RADAR
Example Calculation: OFDM EVM vs. Phase Noise
Getting the Most from the Resources You Have
Phase Noise can Matter:  • A Lot  • Some  • Not At All

Getting the Best Possible Performance
• Phase noise may be limiting parameter in meas. Or sys. performance

Balancing Phase Noise with Cost, Other Factors
• How to identify, quantify effects

Identifying When it’s Not Important

Phase Noise Tradeoffs
• Acquisition cost
• Switching speed
• Broadband noise
Frequency Stability: Short & Long Term
Terms, Measurements, Displays

Short Term Stability
• Short term = seconds
• Terminology: Phase Noise, Jitter
• $L(f)$ curves, integrated totals, spot measurements, jitter (p-p)
• Can be a function of both signal generator and frequency reference

Long Term Stability
• Long term = minutes - years
• Terminology: Accuracy, drift, aging
• Often determined by frequency reference

Understand Your System and its Sensitivity vs. Frequency
Pedestals, Slopes & Bumps: Signal Generator Architecture & Phase Noise

Example: Agilent PSG Microwave Signal Generator

E8257D with UNX typical SSB performance

Reference Section
Synthesizer Section
YIG Oscillator
Output section

Trace data shifted by -3 dB
Agilent E5500 Carrier: 10E+9 Hz No Spurs
17 Jul 2007 14:05:09 - 14:13:01

L(f) [dBc/Hz] vs f [Hz]

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Sig. Gen. Choices: Frequency Stability
Narrowing the Hardware & Software Choice

CW or “Analog” vs. Digital Modulation or “Vector”
• Phase noise performance choices may interact with other capabilities
  – Internal and/or external digital modulation
  – Pulse modulation
  – Internal/external software
  – Memory and/or real-time baseband signal generation
  – Power, distortion

Single-Loop vs. Multiple Loop

Phase Noise Performance Levels as Options

VCO (voltage-controlled oscillator) vs. YIG (yttrium iron garnet)
• Switching speed, phase noise, cost
Single vs. Multiple-Loop Architecture

Example: New Agilent X-Series (MXG, EXG)

![SSB Phase Noise @ 1 GHz Graph](image)

- MXG enhanced low phase noise option
- MXG standard
- EXG
Phase Noise vs. Frequency: Microwave & Millimeter

Generally Worse with Increasing Frequency
Not a Simple Relationship

Agilent PSG Microwave/Millimeter Signal Generator
Phase Noise vs. Frequency: RF Example

Agilent MXG RF Signal Generator (reduced phase noise opt.)
When Phase Noise Matters

Matters More
- OFDM
- Oscillator substitution
- ADC testing
- Doppler RADAR

Matters Less
- OFDM (matters more and less, depending on offset)
- Wideband single-carrier modulation
- Harmonic distortion testing
- ACPR testing
- Amplifier gain testing
Degrading Phase Noise for Signal Substitution

Simulate VCOs, Lower-Performance Synthesizers, Transmitters
Standalone (CW) or Added to ARBs incl. Modulated Signals
When “Representative” is Better than “Perfect”
Use Baseband Real-Time Processing
Selectively-Impaired Phase Noise Performance

- **User** sets \( f_1 \), \( f_2 \), and \( L_{\text{mid}} \)
- **Slope** -20dB/decade below \( f_1 \) and above \( f_2 \)

- \( f_1 = 5 \text{kHz} \), \( f_2 = 500 \text{kHz} \), \( L_{\text{mid}} = -80 \text{dBc} \)
- \( f_1 = 10 \text{kHz} \), \( f_2 = 1 \text{MHz} \), \( L_{\text{mid}} = -90 \text{dBc} \)
Adding Known Phase Noise Using FM Signal Modulated with Uniform Noise

Simple Technique for Uniform -20 dB/Decade

Result: Phase Noise -100 dBc/Hz at 10 kHz Offset

Configuration:

- Set up a signal generator for FM noise modulation:
  - FM enabled
  - FM deviation 500 Hz
  - FM waveform: uniform noise

- Ensure that noise of the signal generator with FM off is at least 10 dB less than the desired calibrated noise at a desired offset frequency, to ensure accuracy
Doppler Frequency Shift and Phase Noise Offset Frequencies

Doppler Frequency $f_d$:

$$f_d = \frac{2}{\lambda} \hat{v} \hat{R} = \frac{2f_0}{c} \hat{v} \hat{R}$$

Close-In (example: Airport Surveillance Radar)
- 100 mph, S-band (3 GHz) $f_d = 900$ Hz

Wider Offsets (example: Military Radar)
- Mach 1.5, X-band (10 GHz) $f_d = 33,000$ Hz
Also Consider Spurious Performance for RADAR and EW Applications

Noise and Spurious Effects

System Spurious Signals within the Receiver BW

\[ BW = \frac{1}{t} \]

\[ F_0, F_s_1, F_s_2 \]

\[ F_0 \pm F_{d1} \]
Estimating Required Phase Noise Performance

Example*
1 GHz Doppler radar
Doppler BW = 10 kHz
Target = 1 m²
Range = 100 km
Min Det Vr = 80 knots
Clutter visibility = 80 dB

Transmitter Noise Sidebands:
$L(f) < -120 \text{ dBc/Hz} @ 200 \text{ Hz offset}$

* See “Introduction to Radar Systems” by Skolnik
OFDM and Pilot Tracking

Pilots Shown in Time (I/Q) and Frequency
OFDM and Pilot Tracking

BPSK Pilots: Demodulation Reference, No Data Transmitted

Pilot Tracking “Tracks Out” Some Freq/Phase Instability

Instability Not Just Constellation Rotation, also FFT Leakage or Inter-Carrier Interference

No Pilot Tracking
Pilot Tracking Enabled
Common Pilot Error: Phase
Translating Phase Noise to EVM in OFDM

Assumptions

- Estimating effects of only phase noise and broadband (wide offset) noise
- Spurious and other nonlinearities are not significant
- Equalization effective in removing linear errors
- Pilot tracking is effective to ~10% of subcarrier spacing
  - Common phase error removed in demodulation

Example: WiMAX

- 10 kHz subcarrier spacing
- 10 MHz channel bandwidth
Example: Phase Noise Contrib. to EVM in OFDM

Error power calculated on log scale:

-95 dBc/Hz integ. over ~100 kHz & Convert SSB to DSB: add 3 dB
-95 dBc/Hz + 10\log(100\ kHz) + 3\ dB
EVM = -95\ dB + 50\ dB + 3\ dB
EVM = -42\ dB (conservative)

EVM is a function of integrated phase noise beyond tracking BW and inside channel BW (and correct SSB to DSB)
Meas. Example: Calc. EVM from Integ. Phase Noise

Measured EVM = -27 dB

Pilot tracking rolloff is gradual above ~30 kHz and expected EVM should be slightly better than -26.35 dB.

Band Power Markers
Integrate 30 kHz to 10 MHz
DSB phase noise: -29.35 dB + 3 dB = -26.35 dB (carrier = 0 dBm)

Measured EVM = -27 dB
Pilot tracking rolloff is gradual above ~30 kHz and expected EVM should be slightly better than -26.35 dB.
Signal Generation and Signal Analysis for Design & System Integration

Q: Generate with no phase noise or representative amount?
A: Yes, both
  – Understand ultimate performance and residual error (error budget)
  – Understand phase noise tolerance, design for “just good enough” performance

Q: Measure with pilot tracking enabled or disabled?
A: Yes, both
  – Even when tracked out, phase noise can reduce demodulation margins
Methods for Improving Signal Generator Phase Noise

Connect to a Low-Noise External Frequency Reference

Adjustment of the Reference Oscillator & VCO PLL Bandwidth

Use of Dividers at Lower Frequencies Instead of Heterodyne Mixing
Generating Lower Frequencies: Freq. Division vs. Heterodyne Mixing

Frequency division reduces the phase noise sidebands of the signal by a factor of 20 dB/decade or 6 dB/octave

- Example: Dividing by 4 reduces phase noise by 12 Db

Divider tradeoff: Maximum FM and PM deviations are reduced by the same factor as the division number

Heterodyne mixing provides fine frequency adjustment while retaining full bandwidth FM and PM

Heterodyne mixing tradeoff: Heterodyne mixing to lower frequencies provides no phase noise reduction
References, More Information

“Techniques for Improving Noise and Spurious in PLLs” Eric Drucker, Microwave Journal, May 2012


“Signal Generators Provide Perfect and Precisely Imperfect Signals” Ben Zarlingo, Microwave Journal, May 2012

“Reducing Phase Noise At Microwave and RF Frequencies” Agilent A/D Symposium 2011

“Testing Low-Noise Components in Pulsed or Moving Target Radars” Agilent A/D Symposium 2009

“Phase Noise Measurement Methods and Techniques” Agilent A/D Symposium 2012

“Radar & Electronic Warfare Threat Simulation” Agilent A/D Symposium 2011