

# Phase Noise 101: Basics, Applications and Measurements

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# Agenda

- Phase Noise Basics
  - What is Phase Noise?
  - Review: AM, PM and Phase Noise
  - The Theory and Mathematics of Phase Noise
  - Noise Sources that contribute to Phase Noise
- Phase Noise Applications
  - Radar
  - Digital Communications
- Phase Noise Measurements
  - Phase Detector Techniques
  - Reference Source/PLL Measurement Method
  - Frequency Discriminator Measurement Method
  - Cross-correlation
- Keysight Phase Noise Measurement Solutions
- Conclusion



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- **Phase Noise Basics**

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- **Phase Noise Applications**

- Radar
- Digital Communications

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- Frequency Discriminator Measurement Method
- Cross-correlation

- **Keysight Phase Noise Measurement Solutions**

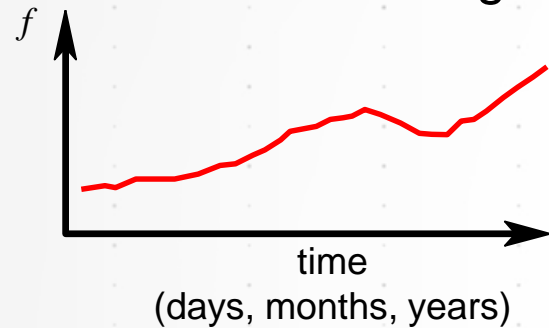
- **Conclusion**



# What is Phase Noise?

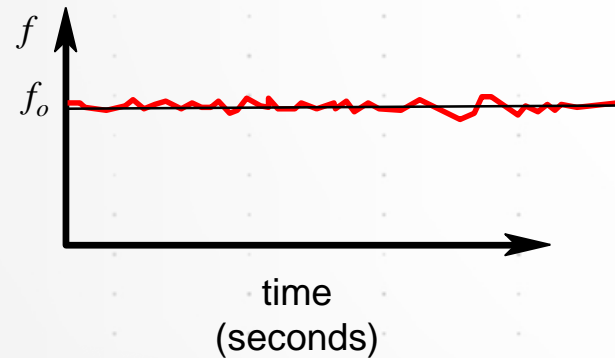
## FREQUENCY INSTABILITY

### Long-term Frequency Instability



- Slow change in average or nominal center frequency

### Short-term Frequency Instability



- Instantaneous frequency variations around a nominal center frequency

Phase noise is generally considered the **short-term phase/frequency instability** of an oscillator or other RF/microwave component

# What is Phase Noise?

## IDEAL VERSUS REAL WORLD SIGNALS

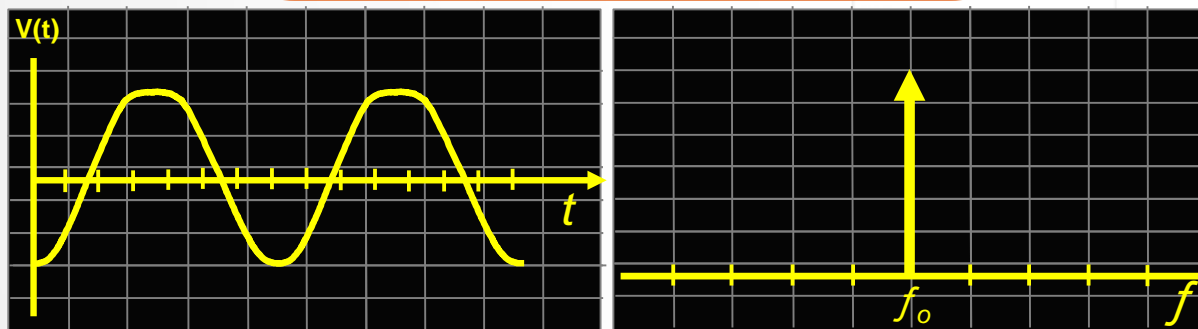
### Ideal Sinusoidal Signal

$$V(t) = A_o \sin(2\pi f_o t)$$

where

$A_o$  = Nominal amplitude

$f_o$  = Nominal frequency



Time

Frequency

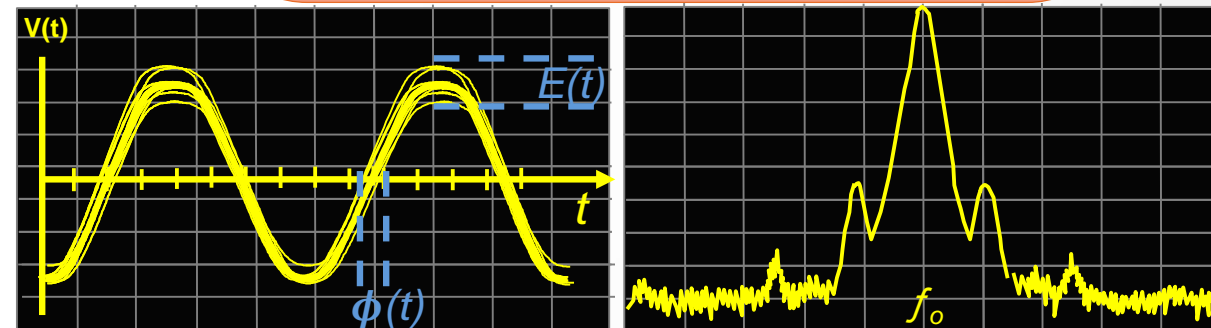
### Real Sinusoidal Signal

$$V(t) = [A_o + E(t)] \sin[2\pi f_o t + \phi(t)]$$

where

$E(t)$  = Random amplitude fluctuations

$\phi(t)$  = Random phase fluctuations



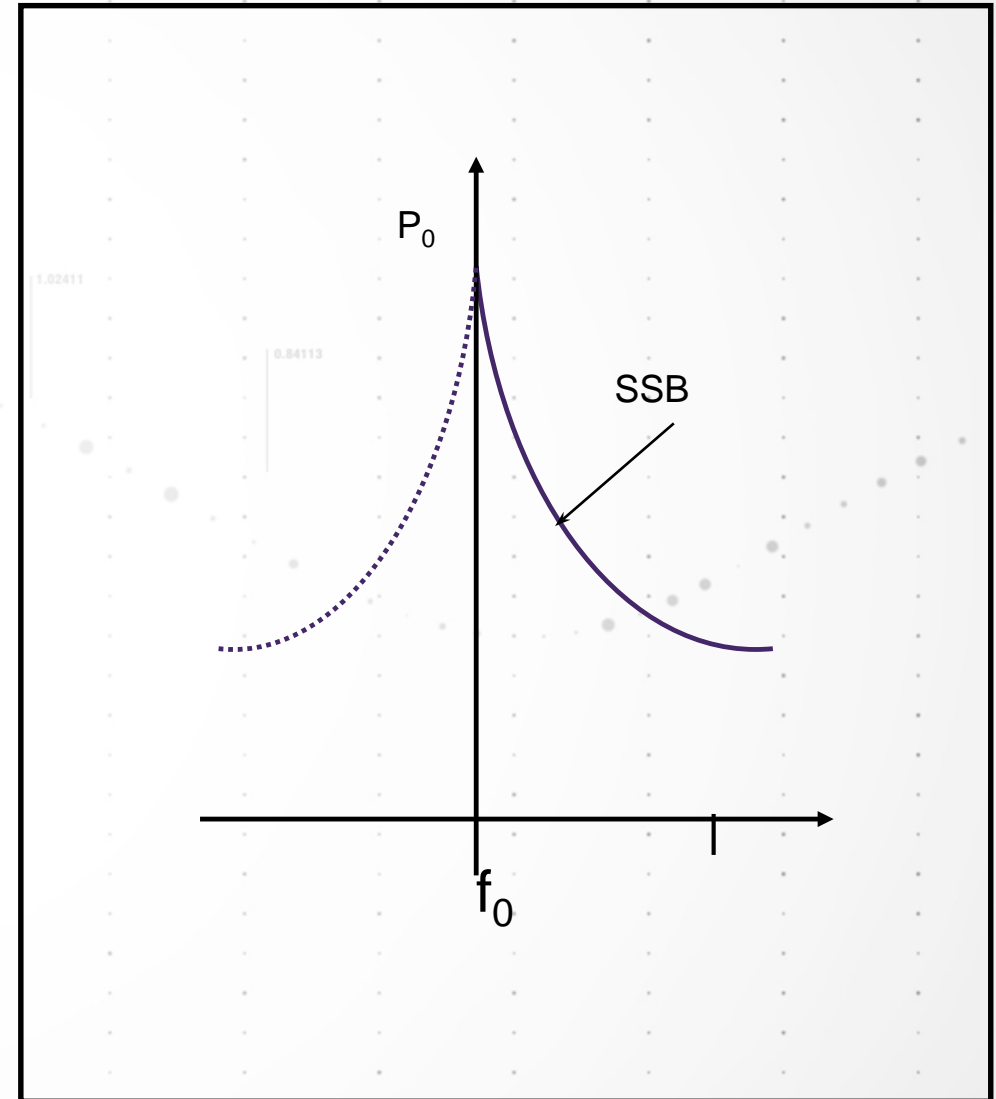
Time

Frequency

# What is Phase Noise?

## POWER SPECTRAL DENSITY OF NOISE SIDEBANDS

- Phase fluctuations of an oscillator produced by different random noise sources is phase noise
- This is just phase modulation with noise as the message signal
- We concern ourselves mostly with the frequency domain and in this realm, phase noise is simply the noise sidebands/skirt around the delta function representing a perfect oscillator at a fixed frequency that we would expect from theory
- Because phase modulation is symmetrical around a center frequency, we can measure a single noise sideband (SSB)



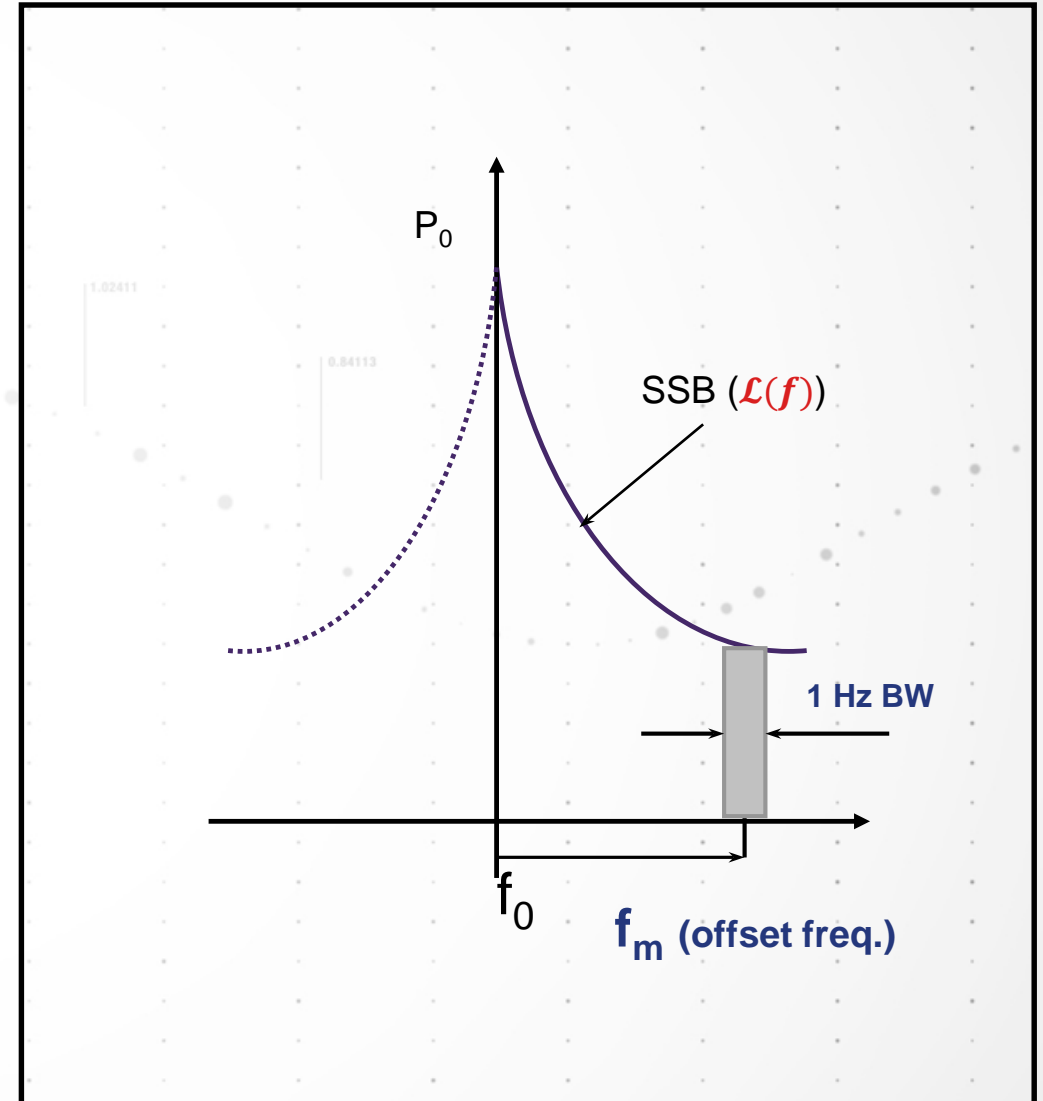
# What is Phase Noise?

## HOW TO DEFINE PHASE NOISE MEASUREMENTS

Three Elements:

- Upper sideband only, offset freq. ( $f_m$ ) from carrier freq.
- Power spectral density (in 1 Hz BW)
- Relative to carrier power in dBc

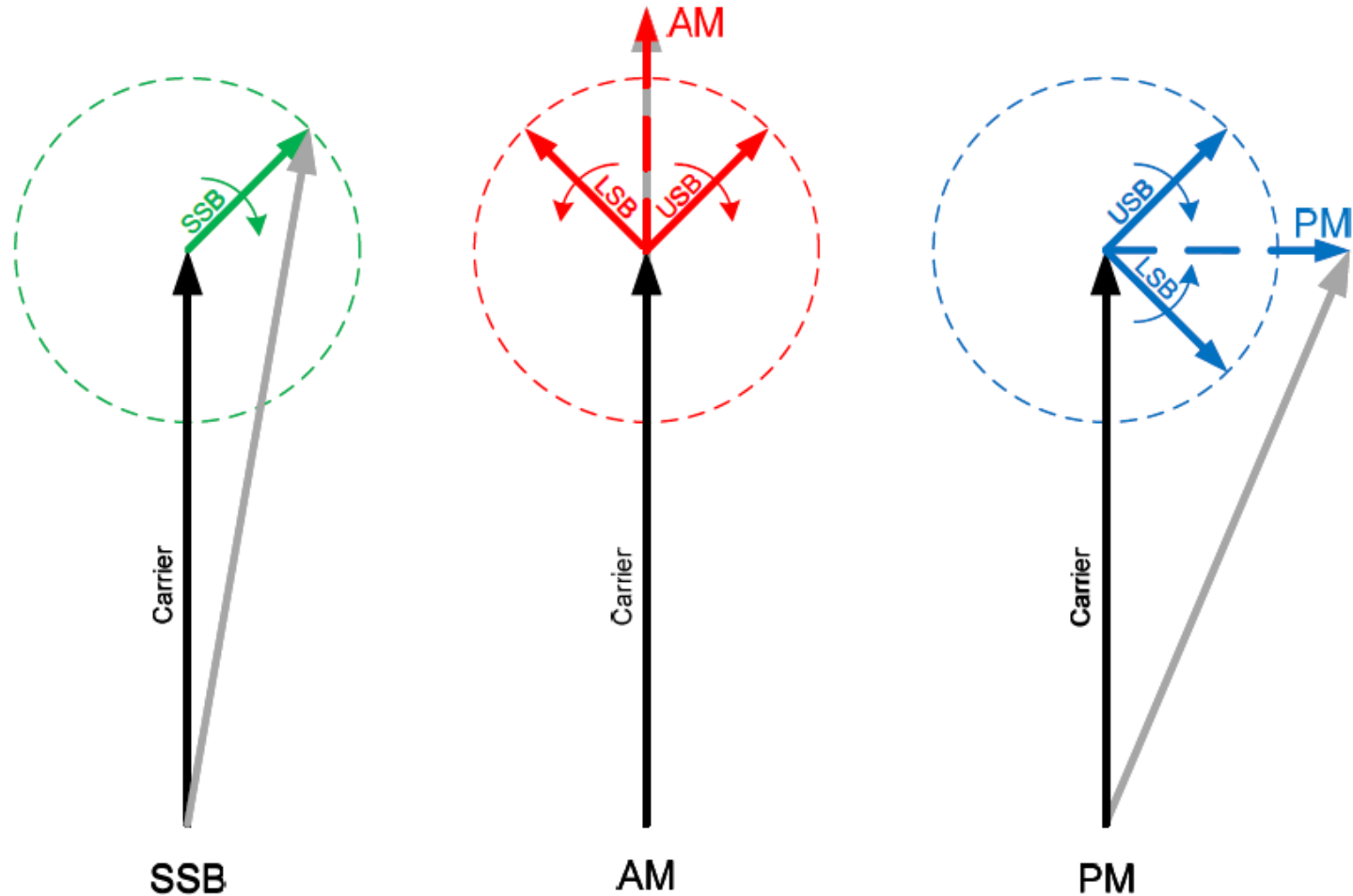
dBc/Hz @ offset freq.  $f_m$



# Modulation Basics Using Phasors

## AMPLITUDE, FREQUENCY AND PHASE MODULATION

- **Phase noise is a modulation noise**, so we will quickly review the basics of modulation
- Amplitude Modulation (AM) varies the envelope amplitude of the carrier frequency in direct proportion to the message signal
- Phase Modulation (PM) and its time derivative Frequency Modulation (FM) vary the phase/frequency of the carrier in direct proportion to the message signal
- On the right, we see phasor diagrams of the amplitude, phase and single sideband modulation (SSB). LSB is the lower sideband and USB is the upper sideband. The gray vector indicates the resultant of the carrier



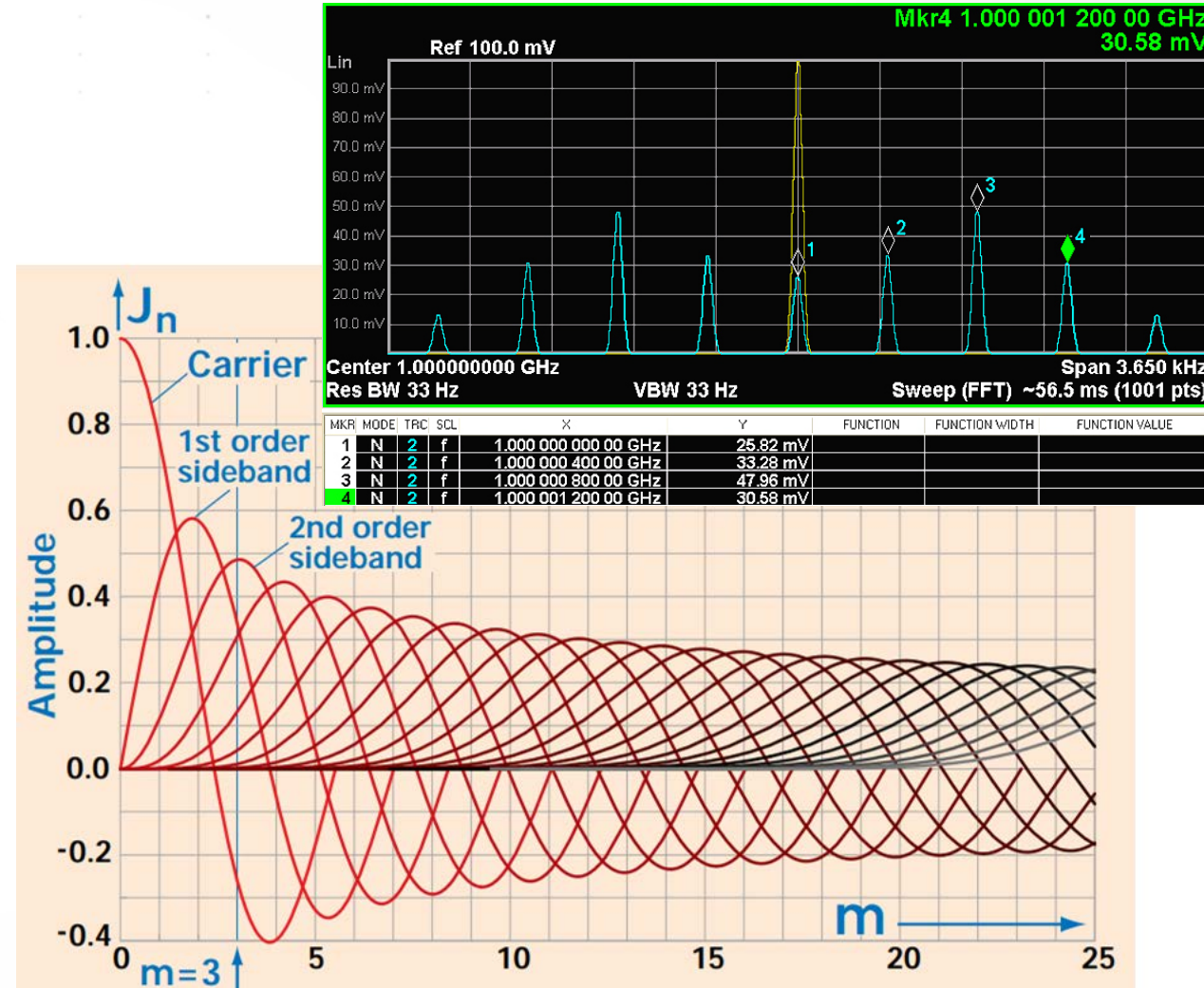
\*United States National Institute for Standards and Technology (NIST)



# Generalized Phase Modulation (PM)

## BESSEL FUNCTIONS OF THE FIRST KIND

- Since **phase noise is really phase modulation (PM) noise**, it is prescient to review PM/FM
- In the frequency domain, PM has an infinite number of sidebands and thus does not look like AM
- To determine the amplitude of these sidebands, one can use Bessel functions,  $J_n$  (at bottom right)
- On the horizontal axis, is the peak phase deviation ( $\phi_{pk}$  also called  $m$  and Beta,  $\beta$ ) of modulating signal and the vertical axis is the amplitude of the sidebands
- As an example, if we let  $\phi_{pk} = m = 3$  and draw a vertical line (in blue), the intersection of this line with all the Bessel functions at that point will give us the amplitudes of the sidebands
- On the top screen capture, we can see these sideband amplitudes as viewed on a spectrum analyzer



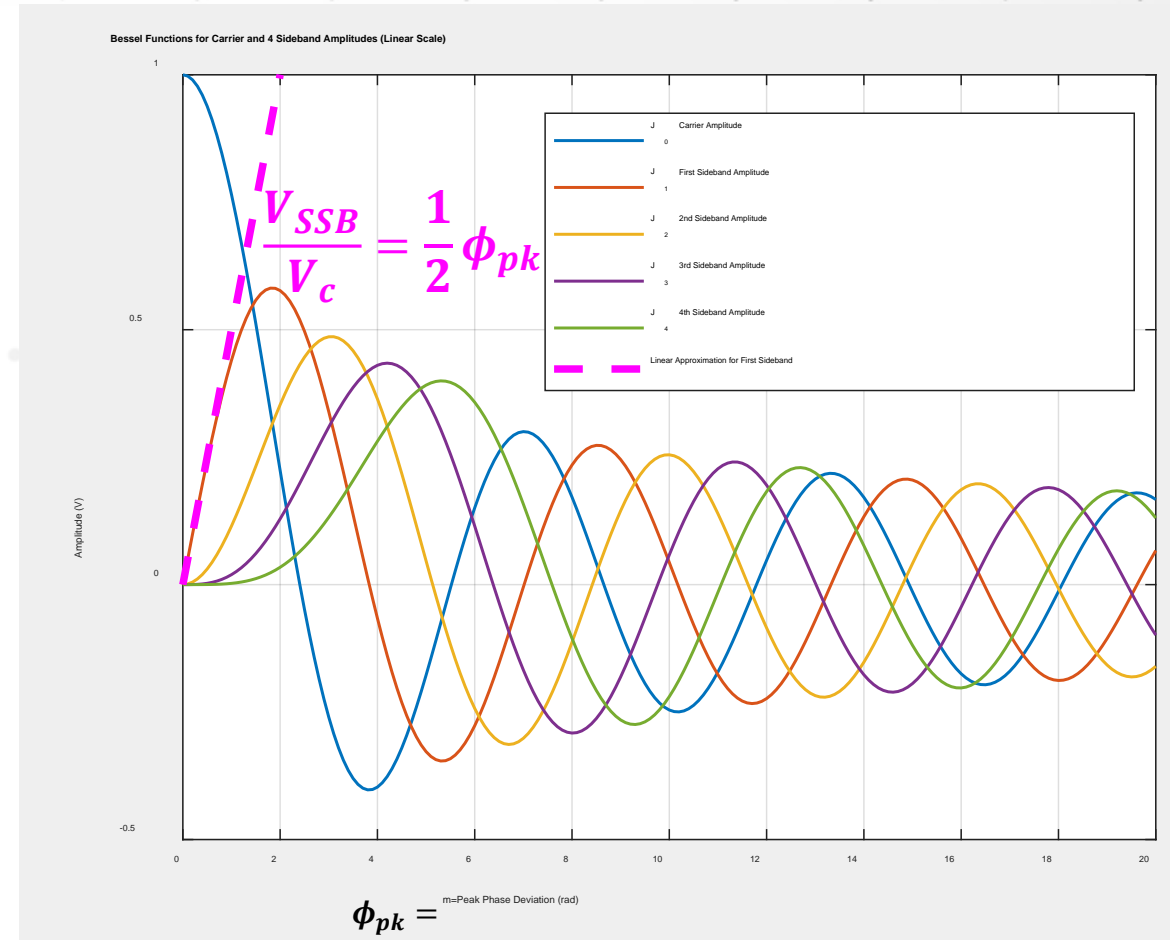
# Deriving Phase Noise from Narrowband PM

- We can use the Bessel functions to go the other way: **measure the relative amplitude (power) of a sideband to the power of the carrier in the frequency domain and obtain rms phase deviation**
- At small  $\phi_{pk}$  (narrowband PM), the first sideband (Bessel function  $J_1$ ) is almost linear with slope  $\frac{1}{2}$  and the carrier ( $J_0$ ) has a value of 1.0 and is constant. The ratio of the SSB voltage to the carrier voltage is equal to half the **peak phase deviation**:

$$\frac{V_{SSB}}{V_c} \left( \frac{V}{V} \right) = \frac{1}{2} \phi_{pk} \text{ (rad)}$$

- Converting the peak phase deviation to a **power ratio**:

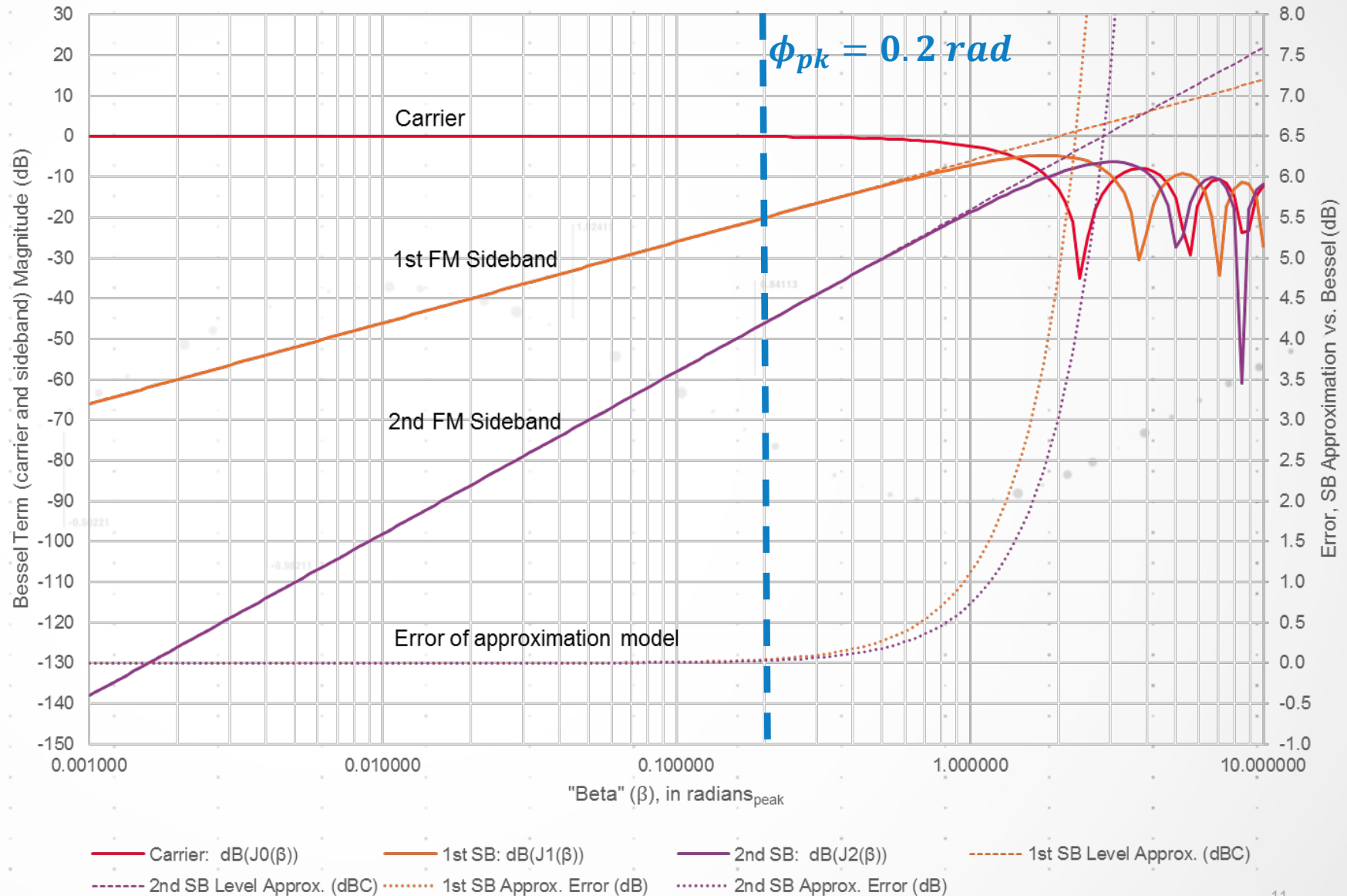
$$\frac{P_{SSB}}{P_c} \left( \frac{W}{W} \right) = \left( \frac{V_{SSB}}{V_c} \right)^2 = \left( \frac{1}{2} \phi_{pk} \right)^2 = \frac{1}{4} \phi_{pk}^2 \text{ (rad}^2\text{)}$$



# Narrowband PM

- If  $m = \beta = \phi_{pk} \leq \frac{1}{5} \text{ rad}$ , we actually have **narrowband PM**
- If we plot the Bessel functions that we just saw on a log-scale, we can more easily see peak phase deviations ( $m = \beta = \phi_{pk}$ ) this small
- If we draw a vertical blue line at  $m=0.2$ , we see that only the carrier and 1<sup>st</sup> sideband with have appreciable amplitude – the other sidebands are highly attenuated more than -50 dB down from the carrier

FM Carrier & Sideband Levels vs. Beta  
Bessel Function (1st kind), order 0, 1 & 2 on LOG plot with SSB approximations and associated error



# Deriving Phase Noise from Narrowband PM

## RMS PHASE FLUCTUATIONS & DEVIATION

- From PM theory, we know the phase of the carrier will vary with amplitude of the sideband (message) signal
- Because we use a sinusoid as the sideband message (SSB) signal we can relate peak phase to rms phase:

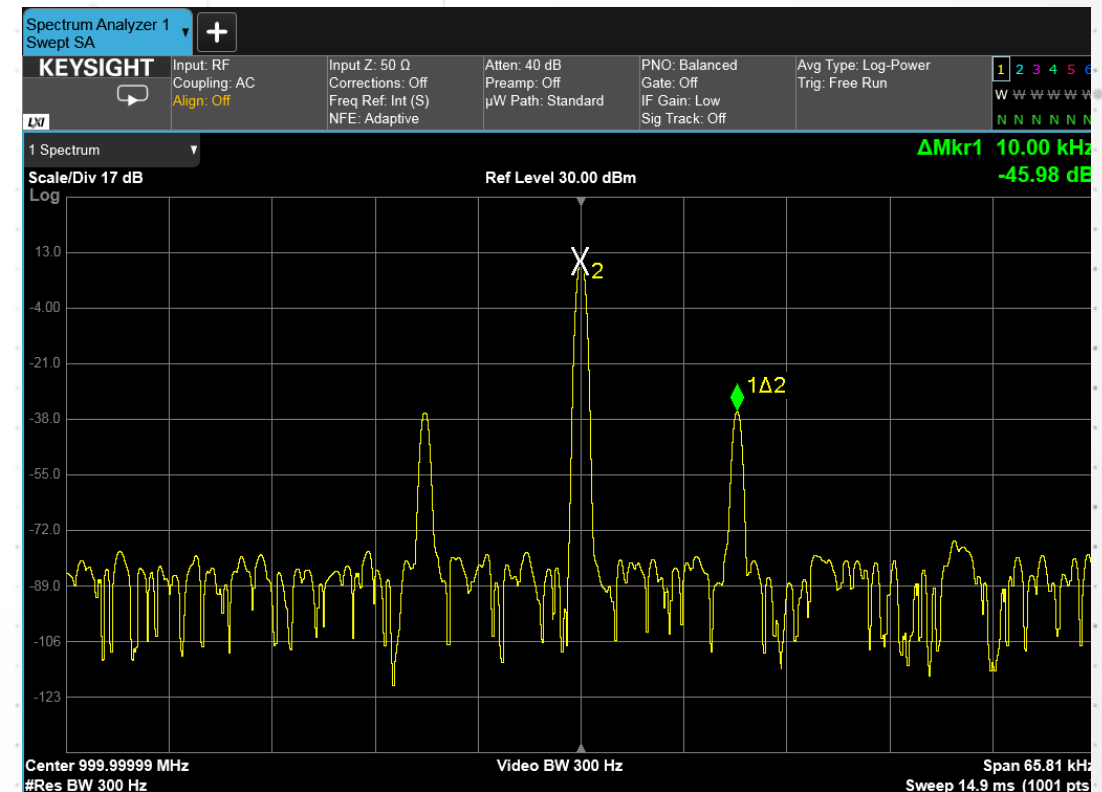
$$\phi_{pk} = \sqrt{2}\phi_{RMS}$$

- Now we can see that the **rms phase fluctuations** can be obtained by just measuring the ratio of the power of the sideband to the power of the carrier (at right a SA with a delta power measurement):

$$\frac{P_{SSB}}{P_c} = \left(\frac{1}{2}\phi_{pk}\right)^2 = \frac{1}{4}(\sqrt{2}\phi_{RMS})^2 = \frac{1}{2}\phi_{RMS}^2 \text{ (rad}^2\text{)}$$

- Taking the square root and thus converting the power ratio to an **RMS phase deviation**:

$$\sqrt{2\frac{P_{SSB}}{P_c}} = \phi_{RMS} \text{ (rad)}$$



# Deriving Phase Noise from Narrowband PM

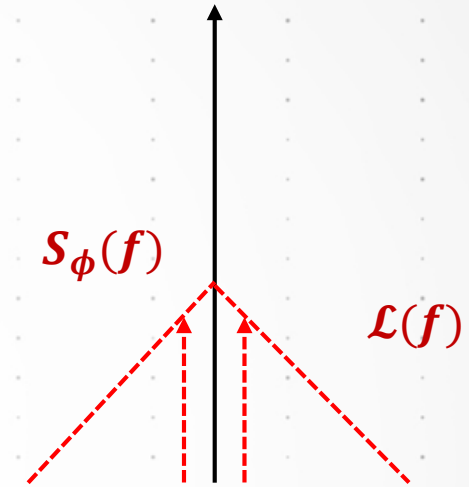
## RMS PHASE FLUCTUATIONS AND PHASE NOISE

- Previously the message signal (with two sidebands) was a sinusoidal tone
- If we now replace the sinusoidal tone with a noise signal (and associated noise BW) we get a continuous spectrum about the carrier with a **spectral density** in units of power per unit of bandwidth (dBm/Hz)
- We can convert the rms phase fluctuations into a spectral density by dividing by the bandwidth of the noise sidebands:

$$S_{\phi}(f) = \phi_{RMS}^2 \left( \frac{1}{BW} \right) \left( \frac{rad^2}{Hz} \right)$$

- Phase modulation is a symmetric process so we only need to measure either the upper or lower sideband. The upper noise sideband is called **phase noise or  $\mathcal{L}(f)$** :

$$\mathcal{L}(f) = \frac{S_{\phi}(f)}{2} = \frac{\phi_{RMS}^2}{2} \left( \frac{1}{BW} \right) \left( \frac{rad^2}{Hz} \right)$$





# Deriving Phase Noise from Narrowband PM

## INTEGRATED PHASE NOISE

- We can integrate single sideband phase noise  $\mathcal{L}(f)$  over the measurement bandwidth from  $f_{start}$  to  $f_{stop}$  (this is known as the **single sideband integrated phase noise**):

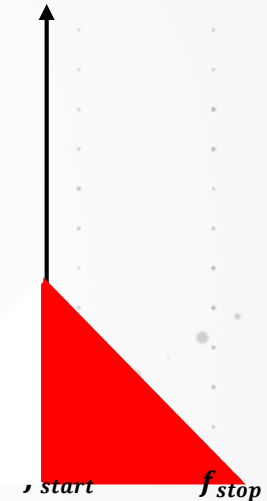
$$\frac{\phi_{RMS}^2}{2} = \int_{f_{start}}^{f_{stop}} \mathcal{L}(f) df \quad (rad^2)$$

- If we multiply this result by two (or integrate both phase noise skirts), we get the **RMS phase fluctuations** ( $\phi_{RMS}^2$ ) back (this is also known as **double sideband integrated phase noise**):

$$\phi_{RMS}^2 = 2 \int_{f_{start}}^{f_{stop}} \mathcal{L}(f) df \quad (rad^2)$$

We can now use the integrated single sideband phase noise to calculate the **RMS phase deviation**:

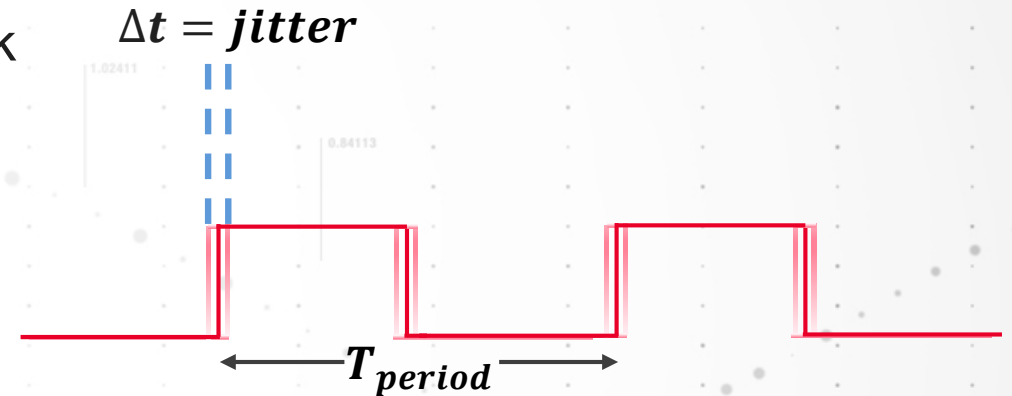
$$\phi_{RMS} (rad) = \sqrt{2 \int_{f_{start}}^{f_{stop}} \mathcal{L}(f) df}$$



# Deriving Phase Noise from Narrowband PM

## PHASE NOISE & JITTER

- In the time domain, rms phase deviation is called **jitter**
- Frequently, people concerned about jitter deal with clock signals, and thus are more concerned about measuring square wave type signals as opposed to the sinusoids we've been dealing with
- To relate rms phase deviation to jitter, we can use the following mathematical relation:



$$\text{jitter}(\text{seconds}) = \frac{\phi_{RMS}}{2\pi} [T_{\text{period}}(\text{seconds})] = \frac{\phi_{RMS}}{2\pi f_c}$$

Percentage of total angular period affected by rms phase noise

Carrier signal period (time) –same as  $1/f_c$

# Log Scaled Phase Noise

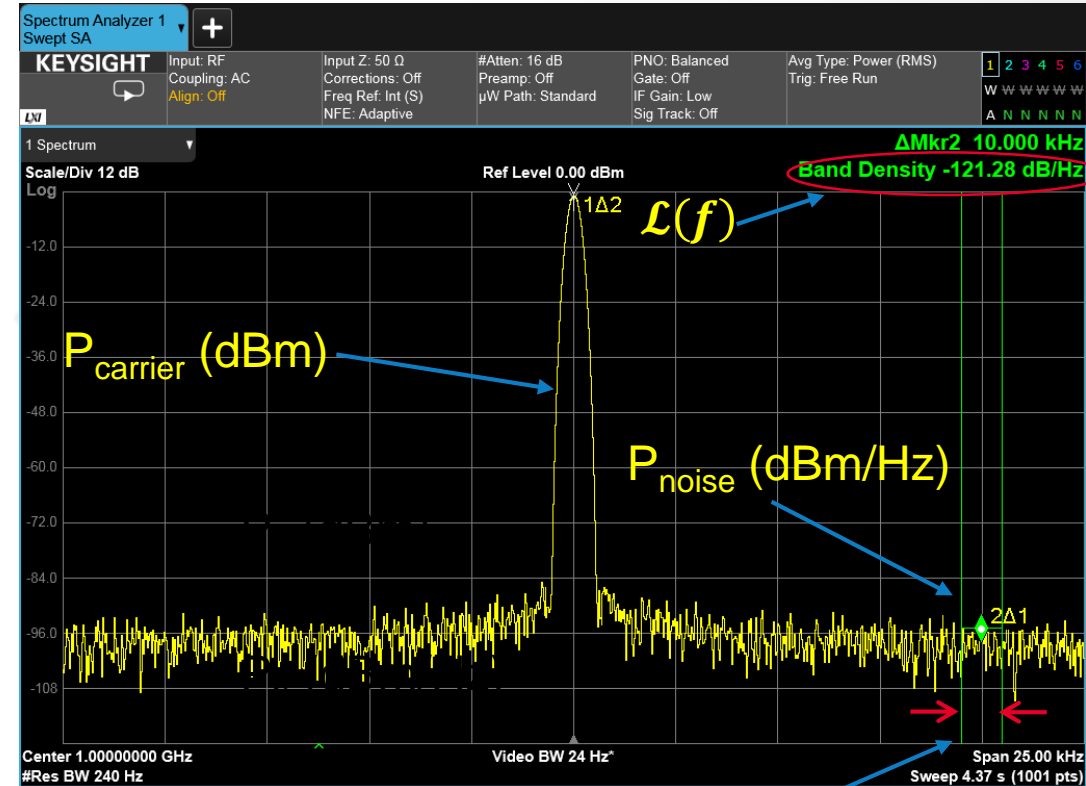
## PHASE NOISE ON A SPECTRUM ANALYZER

- As we saw before, single sideband phase noise  $\mathcal{L}(f)$  is a relative power measurement –we measure the power density of the noise sideband **relative to the power of the carrier**:

$$\frac{P_{SSB}(W/Hz)}{P_c(W)} = \frac{1}{2} \phi_{rms}^2 \frac{(rad^2)}{Hz} = \mathcal{L}(f) \frac{(rad^2)}{Hz}$$

- These ratios (relative power measurements) are suited quite well to spectrum analyzers –which measure signals using a log-transformed power scale
- Context matters because  $\mathcal{L}(f)$  is used for both linear units and log-transformed phase noise (in **dBc/Hz**)
- The log scale (dB) allows us to replace the division of the carrier with subtraction and gives us units of dBc/Hz

$$\mathcal{L}(f) = P_{noise} \text{ (dBm/Hz)} - P_{carrier} \text{ (dBm)} = -121.28 \text{ dBc/Hz}$$



1 kHz measurement bandwidth using noise density marker (generally normalized to 1 Hz)



# Phase Modulation (PM) vs. Amplitude Modulation (AM)

## MATHEMATICAL DERIVATION OF NARROWBAND PM

- Phase noise ( $\mathcal{L}(f)$ ) is a **phase phenomenon** –it is simply the phase modulation (PM) of a carrier signal with a noise message signal
- Deriving narrowband PM mathematically will show the extreme similarities between AM and PM

$\phi(t)$  = a time varying random noise signal with randomly varying frequency & amplitude  
 $\cos(\omega_c t)$  = ideal carrier sinoidal signal from oscillator  
 $\cos(\omega_c t + \phi(t))$  = real signal with phase noise on it

Recall:  $\cos(\alpha + \beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta)$

where:  $\alpha = \omega_c t$  and  $\beta = \phi(t)$

Small Angle Approximations:  $|\phi(t)| < \frac{1}{5}$  rad (narrowband modulation) so:  $\cos(\phi(t)) \approx 1$  and  $\sin(\phi(t)) \approx \phi(t)$

Result:

$$\cos(\omega_c t + \phi(t)) = \cos(\omega_c t) - \phi(t)\sin(\omega_c t)$$

noise that modulates the **phase** of the carrier becomes an **amplitude** modulation of the carrier!

# Phase Modulation (PM) vs. Amplitude Modulation (AM)

## AM VS NARROWBAND PM ON SPECTRUM ANALYZER

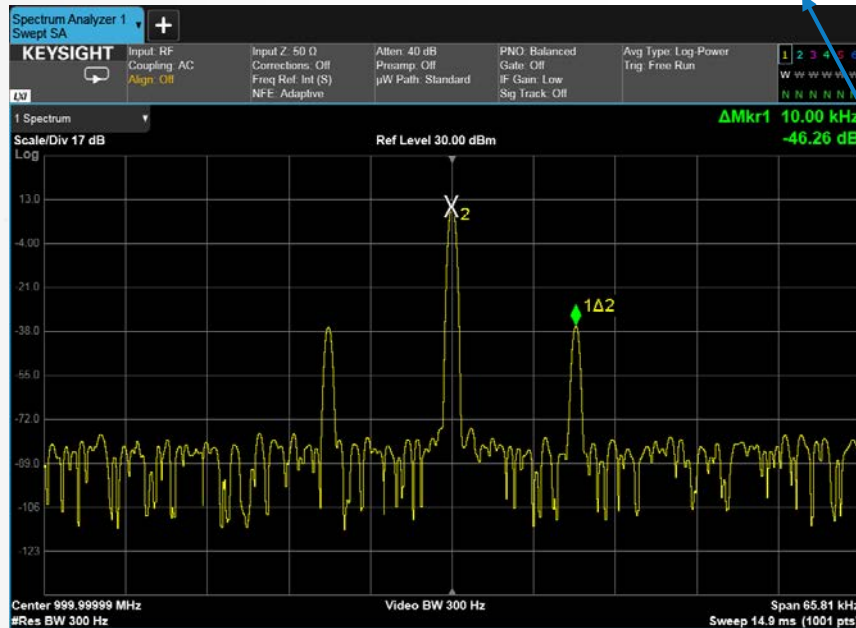
- Now we compare double sideband (DSB) AM with the narrowband PM signal with  $\phi(t)$  as the message/modulating signal:

**DSB AM:**

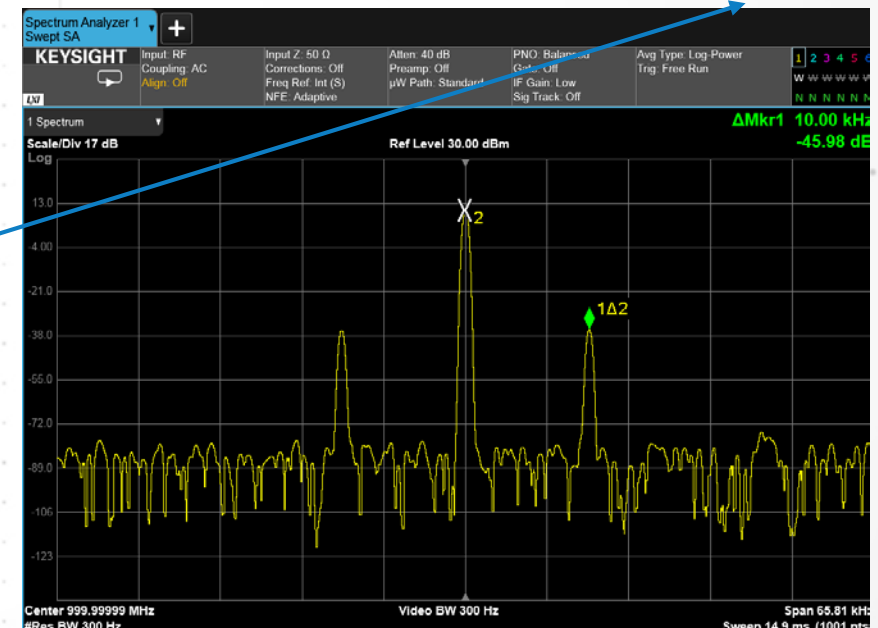
$$[1 + \phi(t)]\cos(\omega_c t) = \cos(\omega_c t) + \phi(t)\cos(\omega_c t)$$

**Narrowband PM:**

$$\cos(\omega_c t + \phi(t)) = \cos(\omega_c t) - \phi(t)\sin(\omega_c t)$$



\*DSB AM signal with 0.8% modulation index, AM Rate=10 kHz



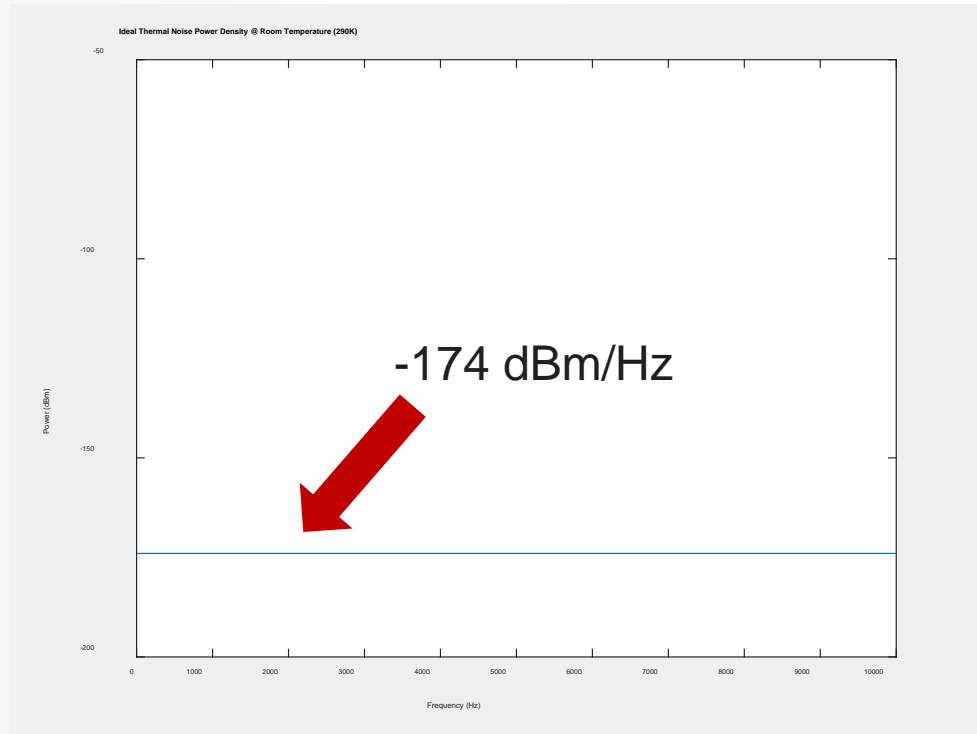
\*Narrowband PM signal with  $\Delta\phi_{pk} = \frac{1}{5}$  rad index, PM Rate=10 kHz

The difference between the two is just a phase shift!

- Because a spectrum analyzer shows magnitude spectrum, AM and narrowband PM look identical –therefore **we need to remove the AM component** to accurately measure only the phase noise component of total noise

# Types of Noise Contributing to Total Phase Noise

## THERMAL NOISE (JOHNSON-NYQUIST NOISE)



Thermal noise is “white” –the same magnitude (-174 dBm/Hz)- at all frequencies

$k$  = Boltzman’s constant

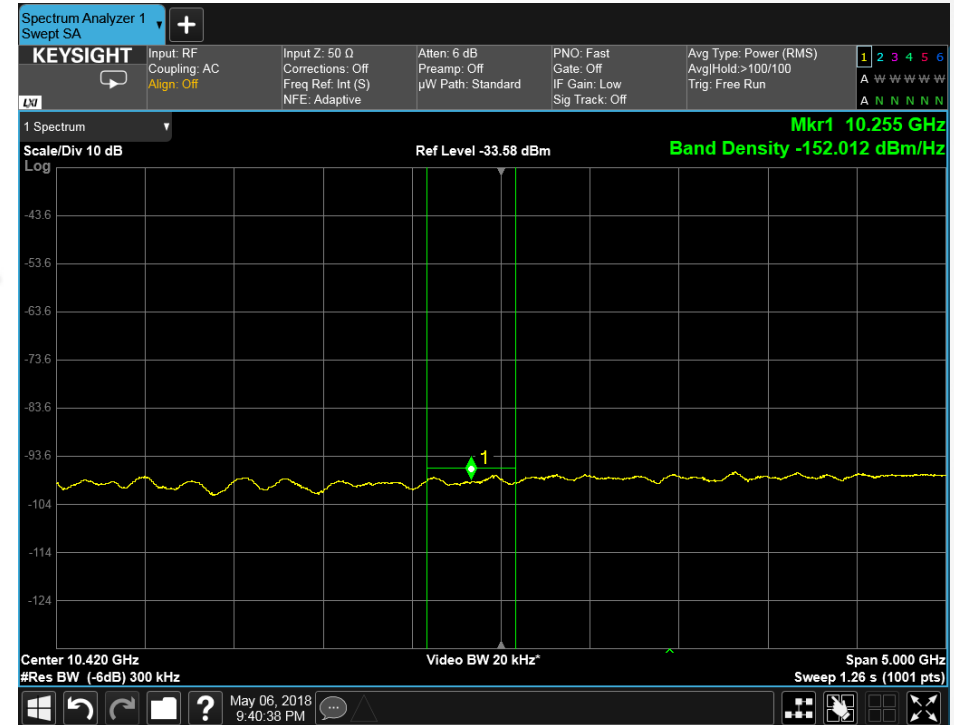
$T$  = Temperature (K)

$B$  = Bandwidth (Hz)

$N_p = kTB$

For  $T = 290K$ :

$$N_p = -204 \frac{dB(Watts)}{Hz} = -174 \frac{dBm}{Hz}$$



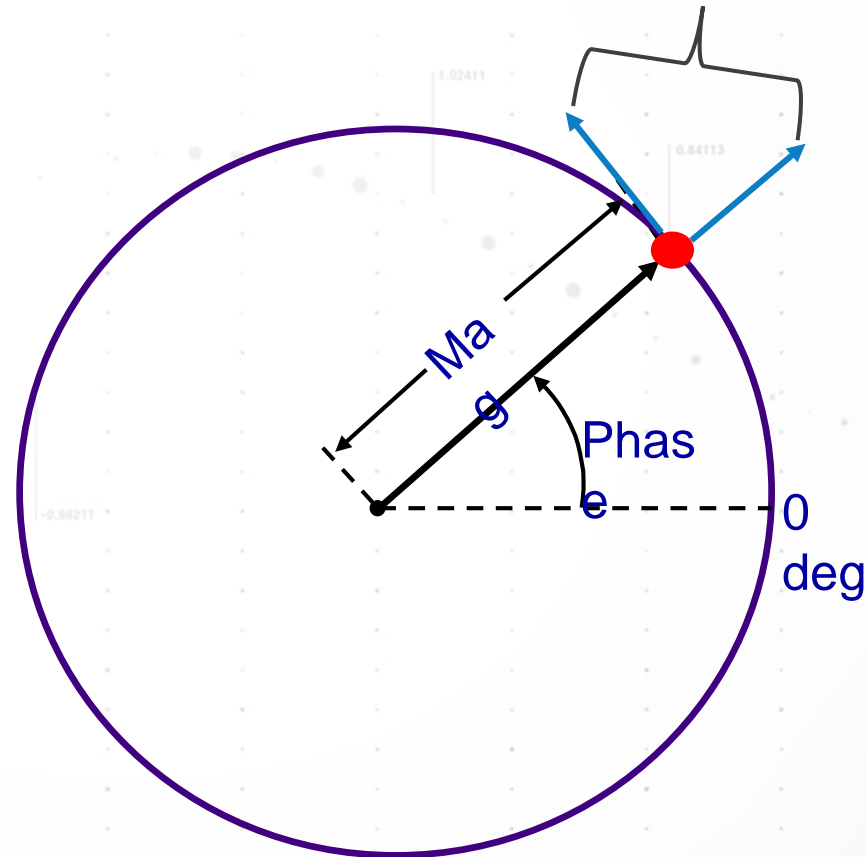
Displayed Average Noise Level (DANL) of a signal analyzer is thermal noise plus the signal analyzer’s own internal noise

# Types of Noise Contributing to Total Phase Noise

## AM AND PM CONTRIBUTE EQUALLY TO NOISE POWER

- If we look at a signal in the complex domain, we see that there are two degrees of freedom: one for phase and one for amplitude
- Equipartition of power tells us that both of these degrees of freedom will contribute equally to our total noise power
- This means that although total thermal noise is commonly known to be -174 dBm/Hz, if we subtract out the amplitude noise component, the phase noise component of thermal noise is 3 dB lower at -177 dBm/Hz

Phase and amplitude components of noise vector together constitute **two degrees of freedom**



# Types of Noise Contributing to Total Phase Noise

INPUT SIGNAL LEVEL DICTATES DYNAMIC RANGE

$$\mathcal{L}(f) = P_{\text{noise}} \text{ (dBm/Hz)} - P_{\text{carrier}} \text{ (dBm)}$$

- As we can see above, **phase noise is a relative measurement**: a noise-to-carrier ratio in **dBc/Hz**
- This means that our sensitivity is actually dictated by the input power level of the carrier (or input) signal
- For example, as we can see on the right, with a 30 dBm input signal, we can actually achieve a -207 dBc/Hz measurement until we are constrained by the **absolute level** of the thermal phase noise floor dictated by kTB (-177 **dBm/Hz**)

Theoretical kTB limits to phase noise measurements for various input (carrier) signal levels

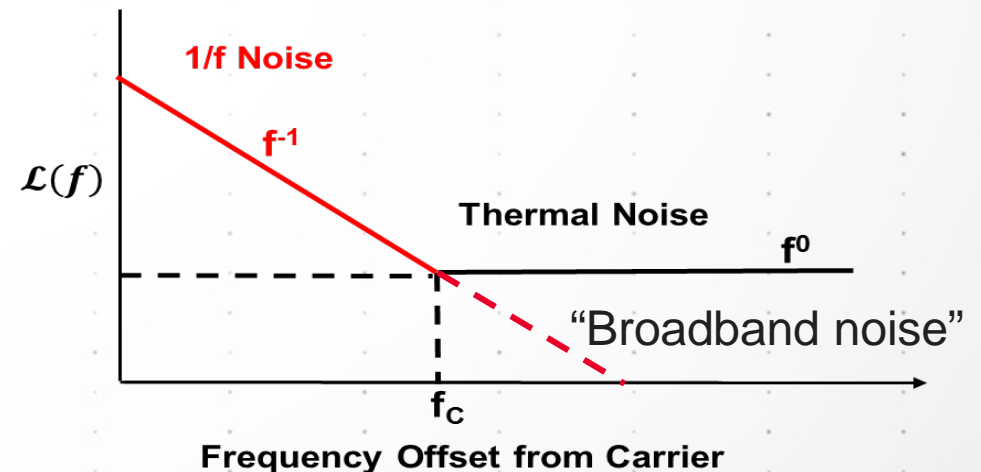
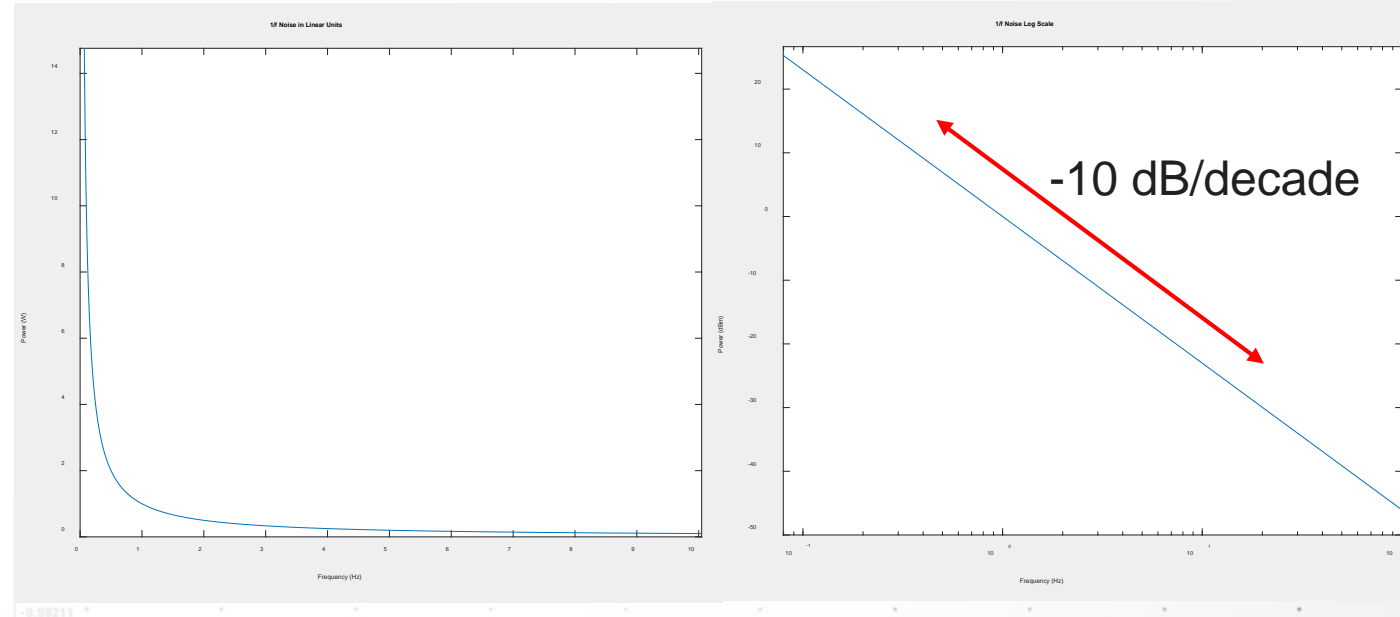
$P_{\text{carrier}}$ (dBm)	$\mathcal{L}(f)$ dBc/Hz
+30	-207
+20	-197
+10	-187
0	-177
-10	-167
-20	-157

Total Noise Power (kTB) =  $P_{\text{noise}}$  (kTB) = -174 dBm/Hz  
Phase Noise and AM noise equally contribute  
Phase Noise Power (kTB) = -177 dBm/Hz

# Types of Noise Contributing to Total Phase Noise

## 1/F & THERMAL NOISE

- In addition to a thermal noise floor that has an approximately constant magnitude as a function of frequency, nearly all electronic devices exhibit a type of noise that is inversely proportional to frequency ( $1/f$ )
- In oscillators,  $1/f$  is a “modulation” noise that wouldn’t exist in absence of device electronics (unlike thermal noise)
- On a Bode plot (log scaled power and frequency axis), it has the easy to use property of **decreasing by 10 dB/decade**
- $1/f$  noise meets the thermal noise floor at the  $1/f$  corner frequency, beyond which point thermal noise dominates (called broadband noise)
- Noise sources that are a higher order negative power of frequency dominate closer to the carrier

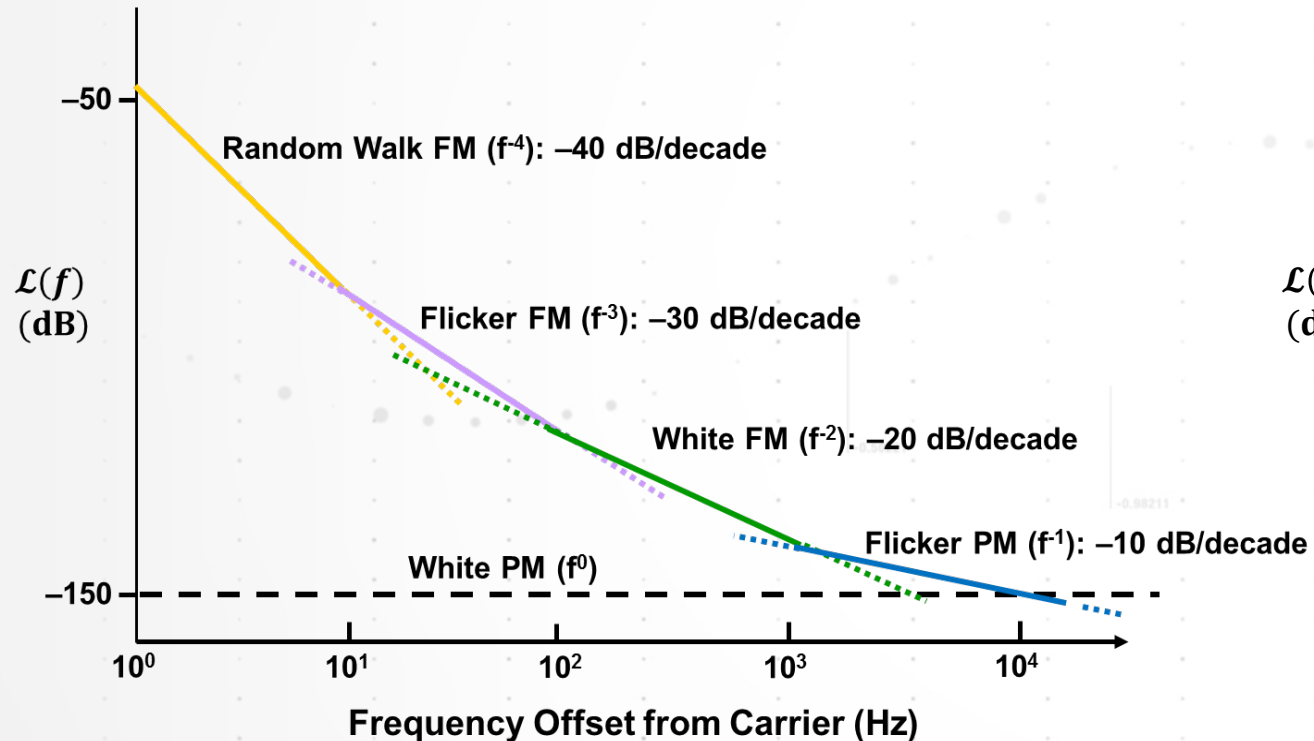




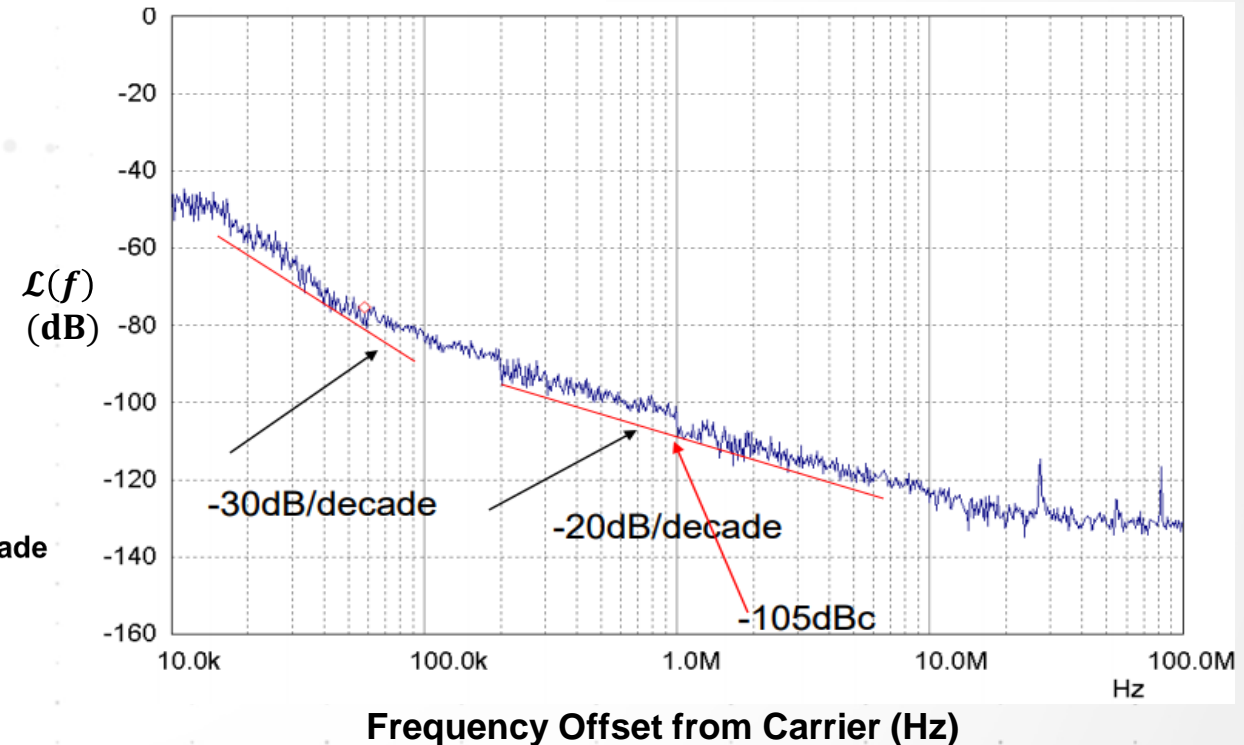
# Types of Noise Contributing to Total Phase Noise

ALL POWER-LAW NOISE PROCESSES IN AN OSCILLATOR

## Theoretical Noise Processes



## Real Noise Processes in VCO



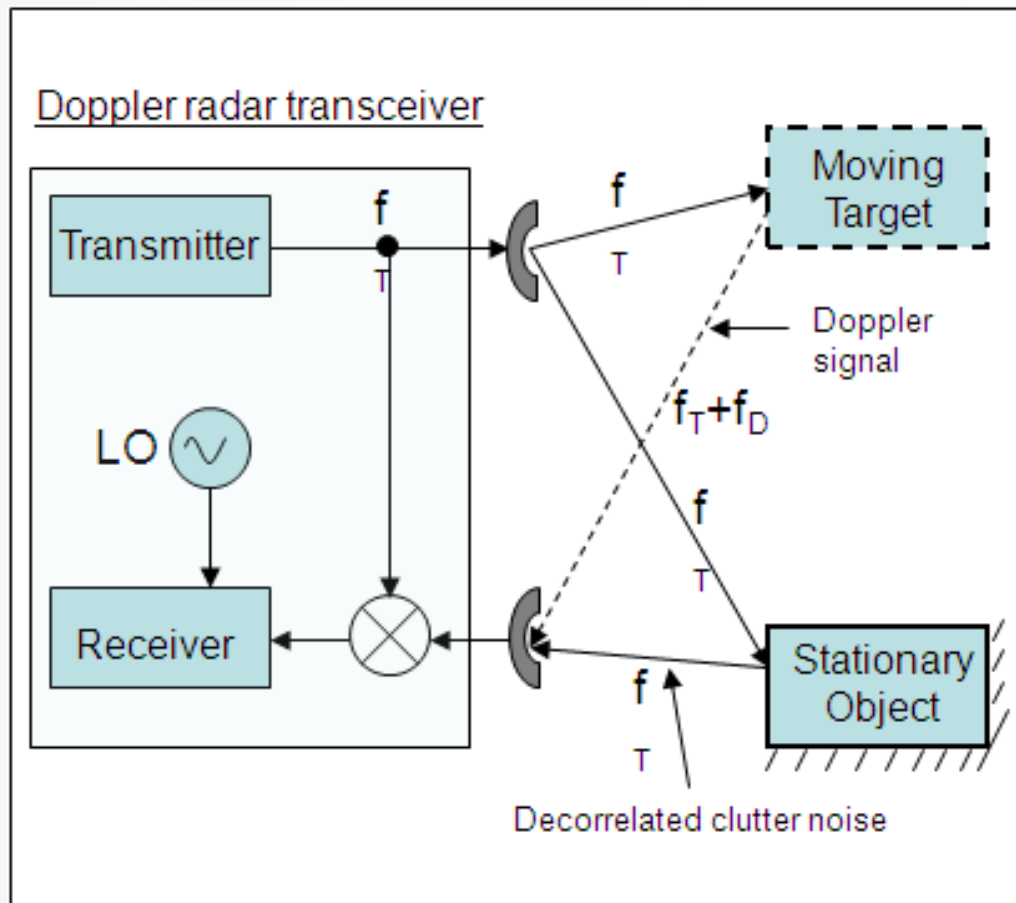
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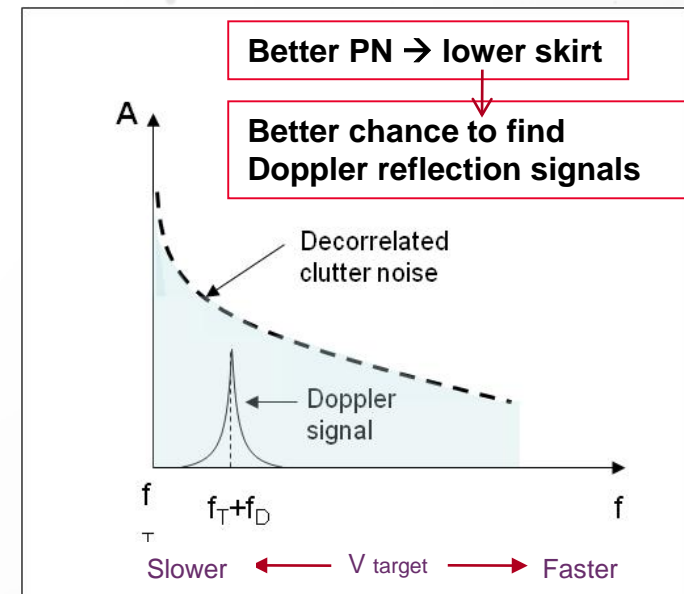




# Importance of Phase Noise in Radar

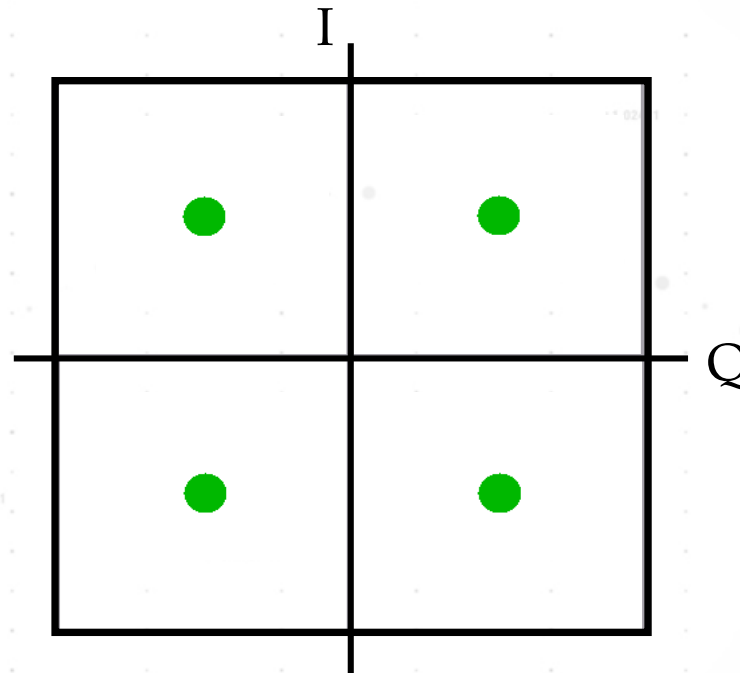
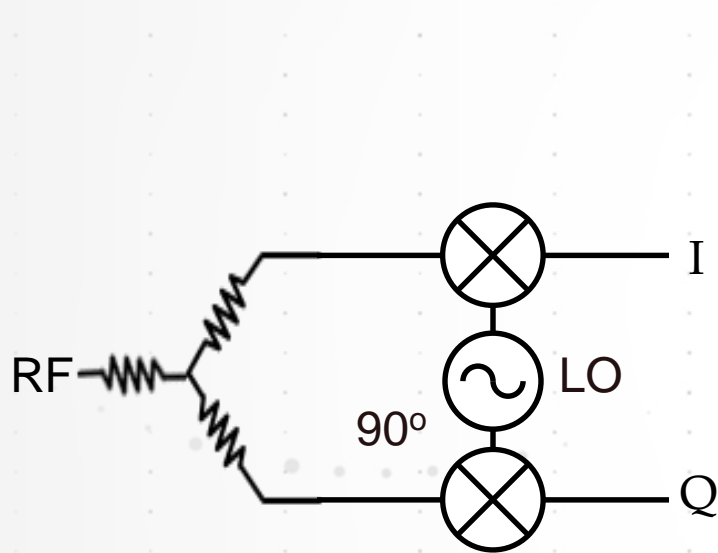


Highest performance radar transceiver designs demand the best phase noise to find moving targets, fast or slow

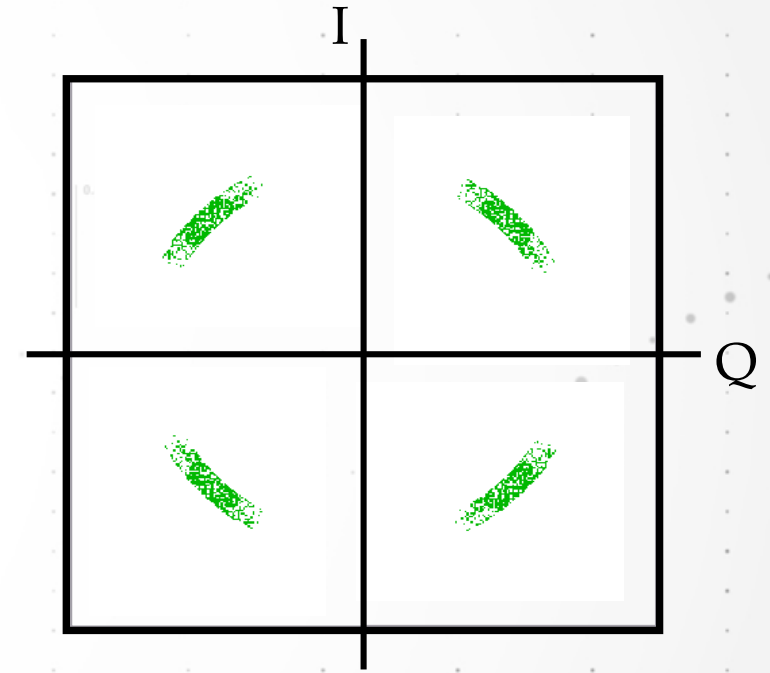


# Importance of Phase Noise in Digital Communications

## QPSK EXAMPLE



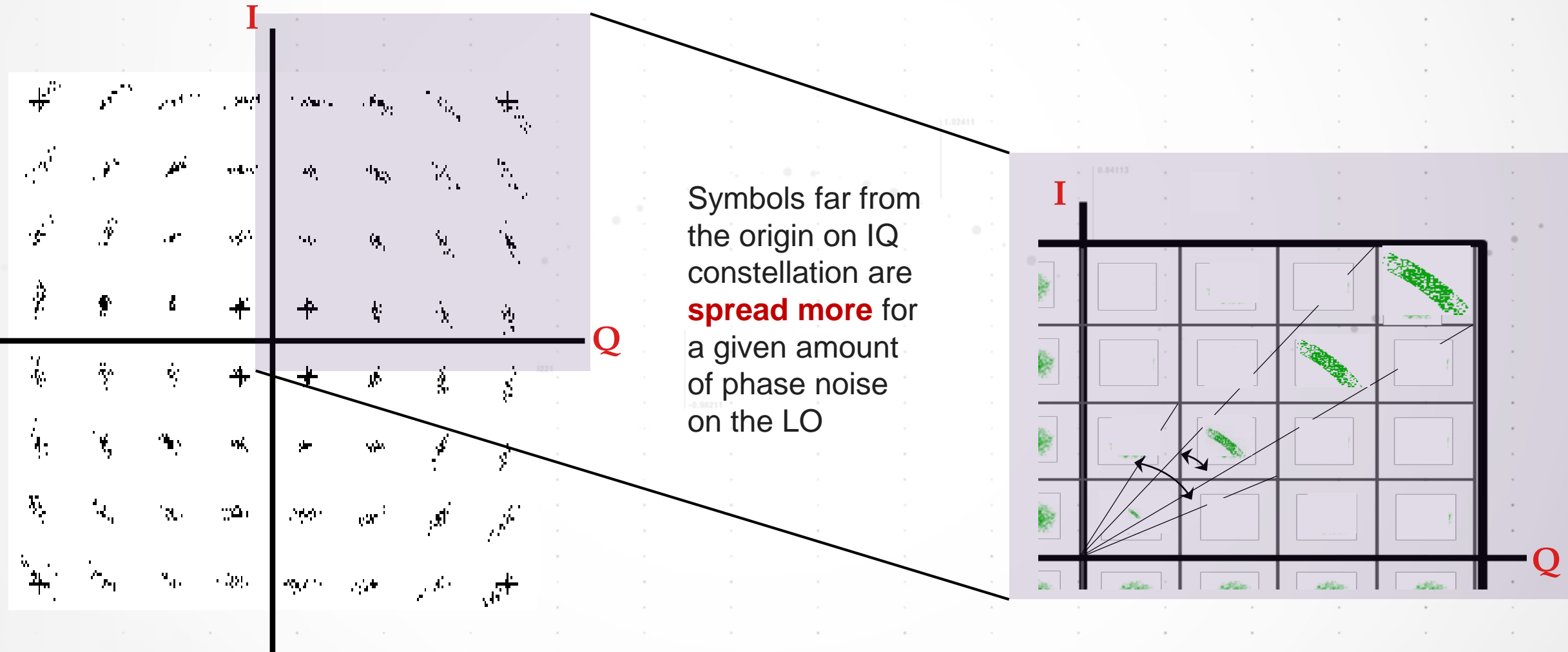
Ideal QPSK constellation



**Degraded phase noise**  
QPSK constellation

# Importance of Phase Noise in Digital Communications

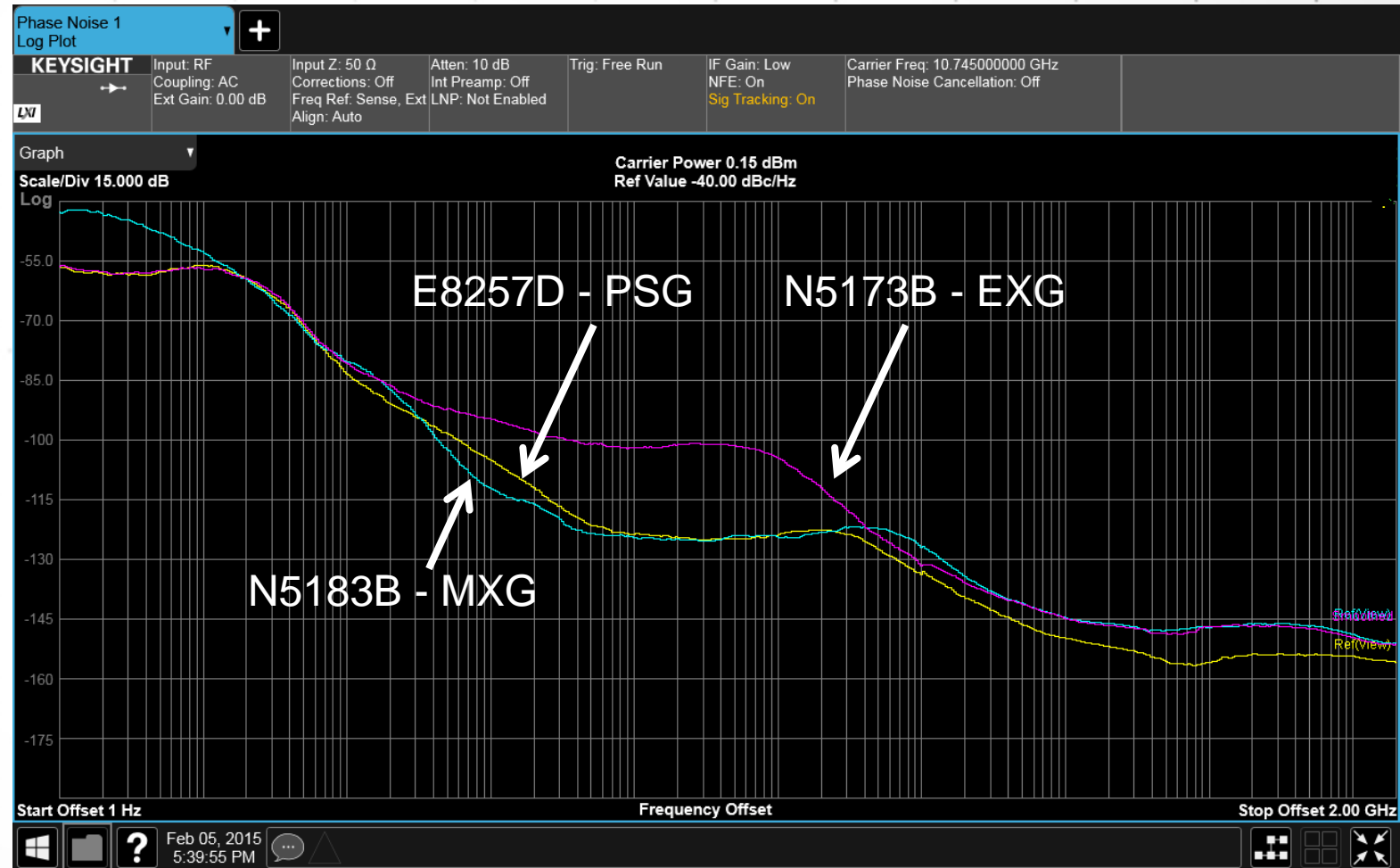
## 64QAM EXAMPLE



# Importance of Phase Noise in Digital Communications

## SIGNAL SOURCE AS LOCAL OSCILLATOR

- 3 Keysight signal generators' phase noise performance is shown at right
- Phase noise comparison done at a center frequency of 10 GHz
- We will see that using these signal generators (sources) as LOs for a larger system has a definite impact on EVM performance



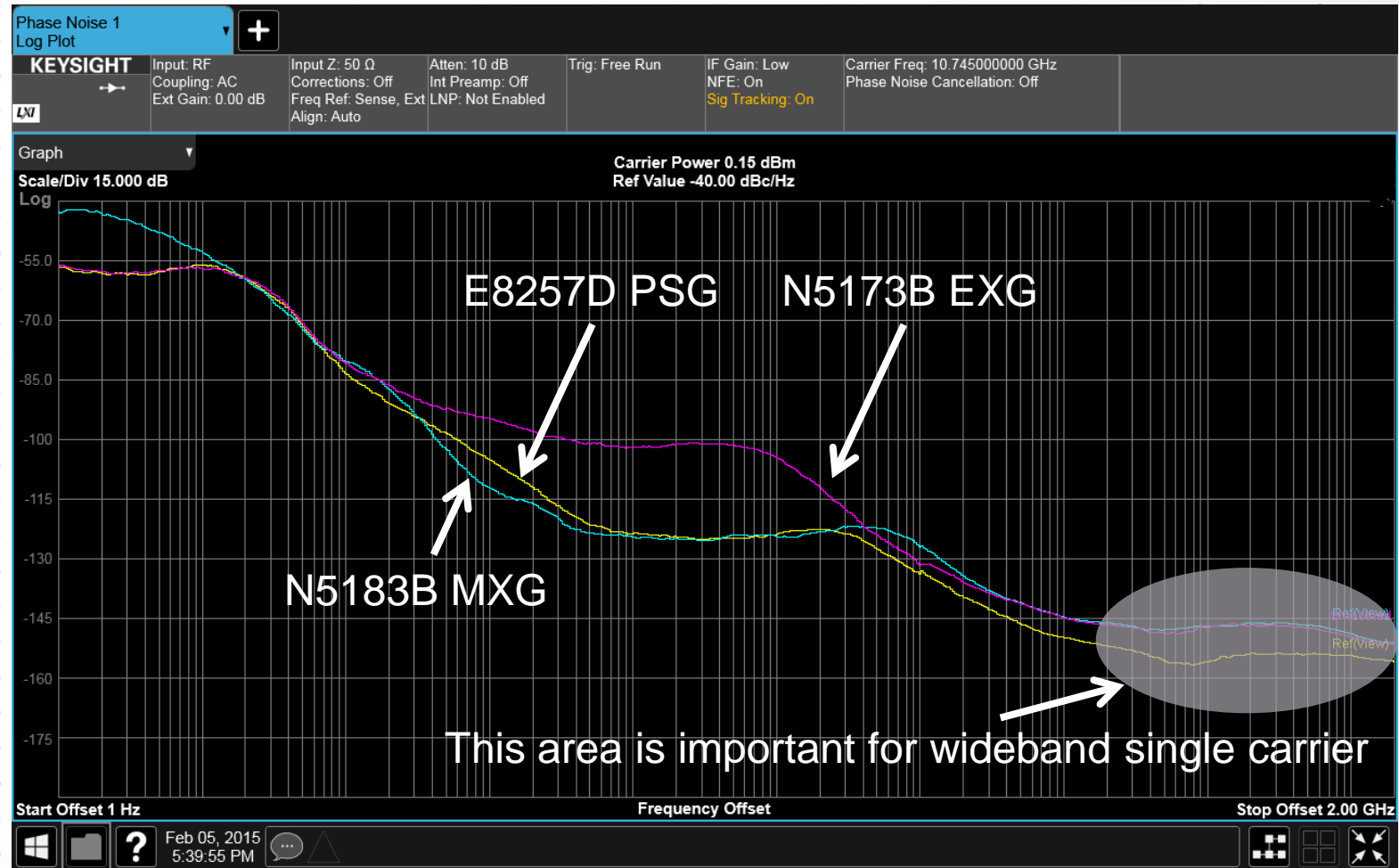
\*All sources have the best phase noise option (UNY) (applies to PSG & MXG)

\*\*Scale is 15 dB / div

# Importance of Phase Noise in Digital Communications

## SIGNAL SOURCE AS LOCAL OSCILLATOR

- For multicarrier modulation systems (OFDM), close-in phase noise matters most
- Close-in and far-out phase noise performance is one of the main performance metrics that differentiates high-end signal generators from lower end signal generators
- The far out phase noise of a device is also known as broadband noise
- For extremely wideband single carrier modulation (e.g. 1 GHz BW for satellite applications) this far out phase noise performance can affect the EVM of the signal generator



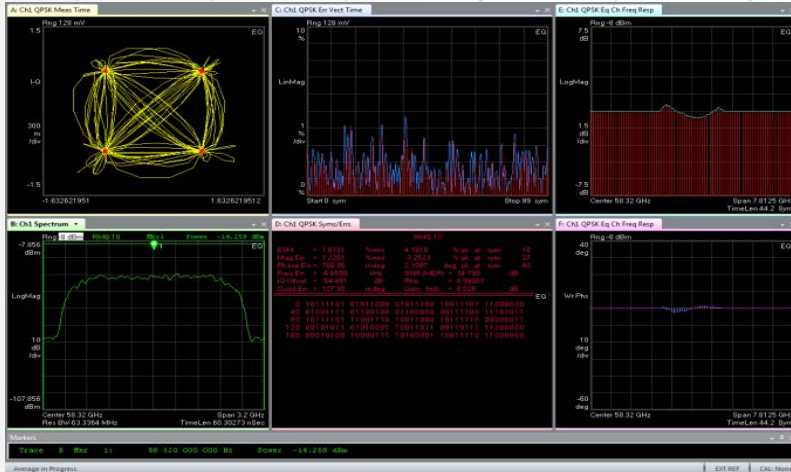
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# Importance of Phase Noise in Digital Communications

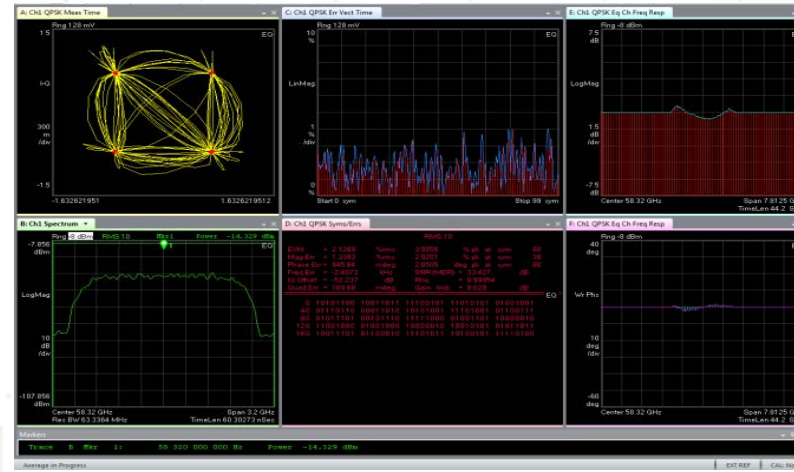
## SIGNAL SOURCE AS LOCAL OSCILLATOR

PSG is LO



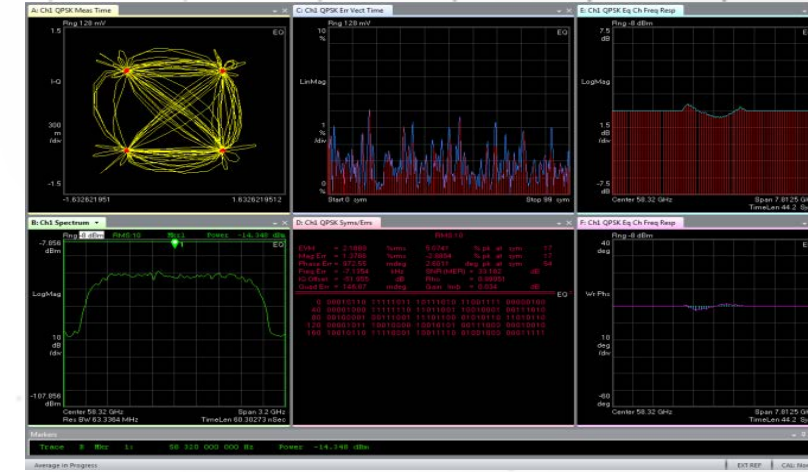
EVM = ~1.8%

MXG is LO



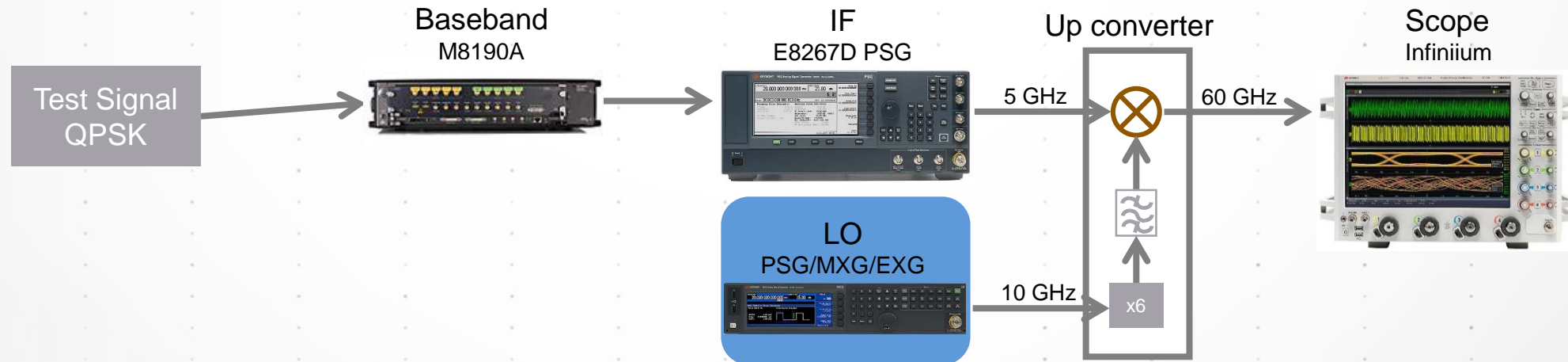
EVM = ~2.1%

EXG is LO



EVM = ~2.1%

### Test configuration

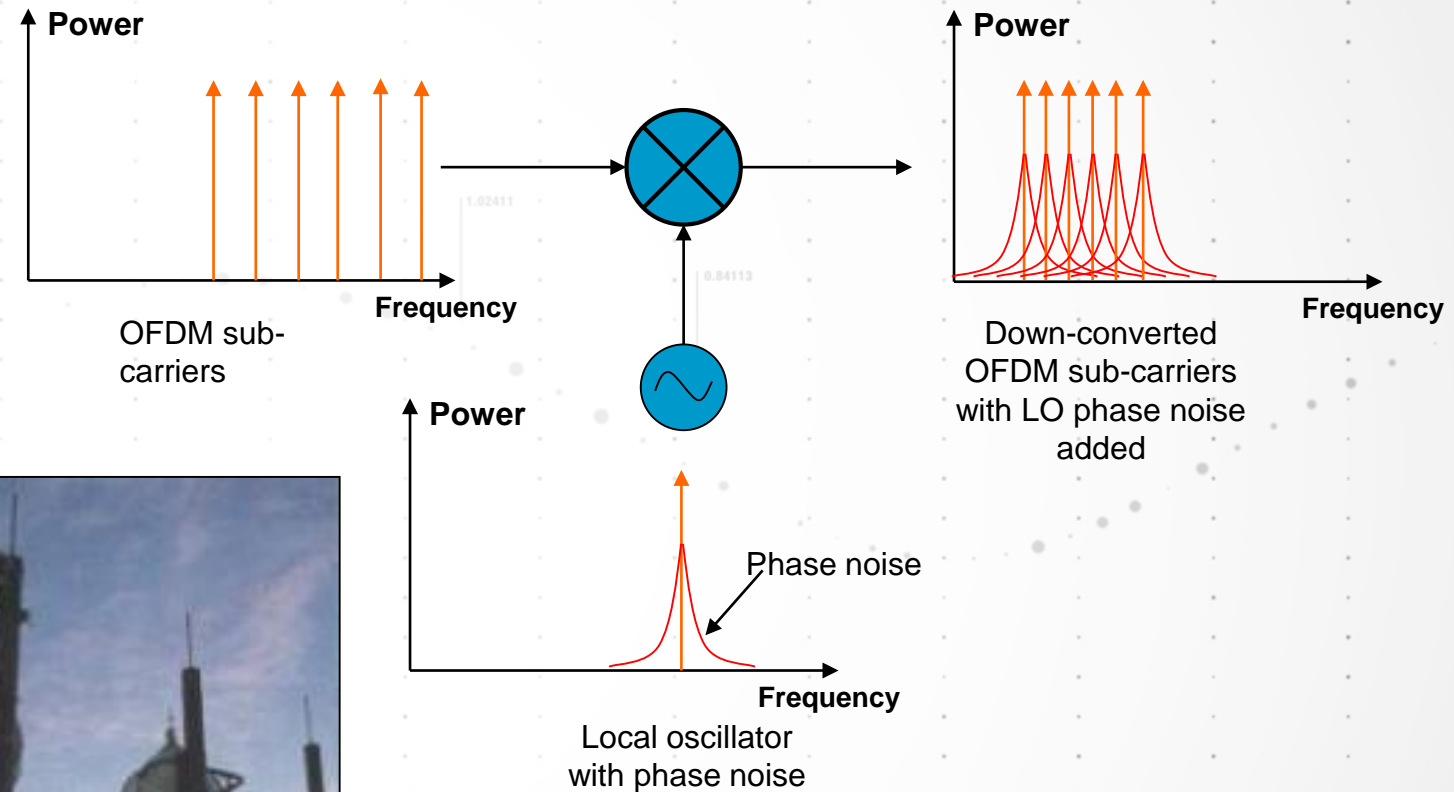




# Importance of Phase Noise in Digital Communications

## OFDM EXAMPLE

- LTE uses OFDM with many subcarriers –each spaced at 15 kHz
- Lower (better) phase noise of the LO in a receiver or transmitter **improves each sub-carrier's resolution and thus EVM performance**
- Unlike our previous use case with wideband single carrier modulation, OFDM requires **extremely good close-in phase noise performance**



# Agenda

- Phase Noise Basics
  - What is Phase Noise?
  - Review: AM, PM and Phase Noise
  - The Theory and Mathematics of Phase Noise
  - Noise Sources that contribute to Phase Noise
- Phase Noise Applications
  - Radar
  - Digital Communications
- **Phase Noise Measurements**
  - Phase Detector Techniques
  - Reference Source/PLL Measurement Method
  - Frequency Discriminator Measurement Method
  - Cross-correlation
- Keysight Phase Noise Measurement Solutions
- Conclusion

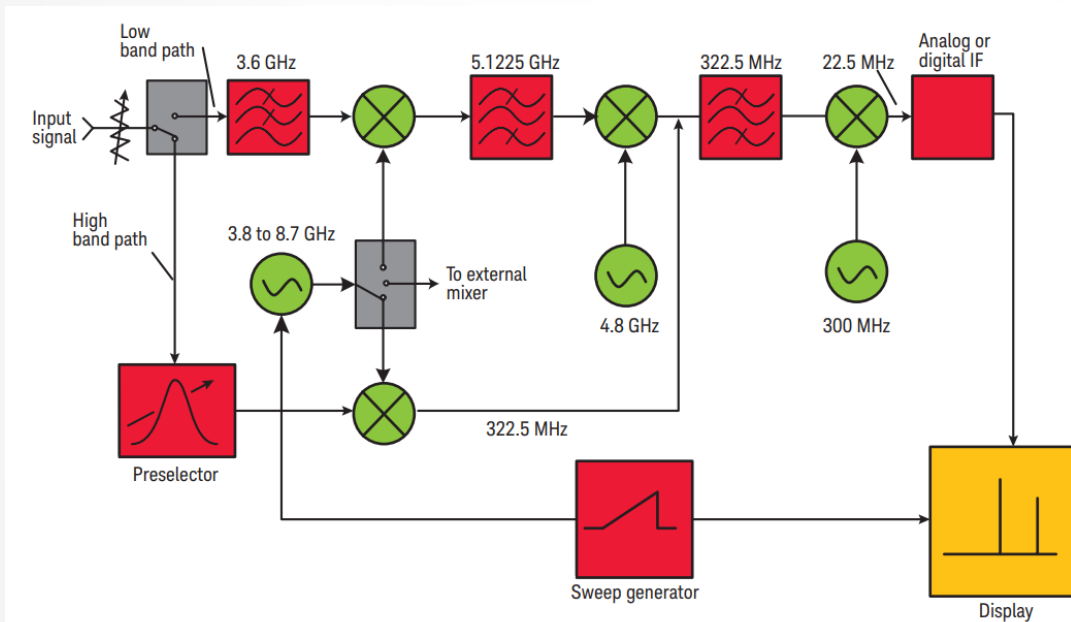




# Measuring Phase Noise

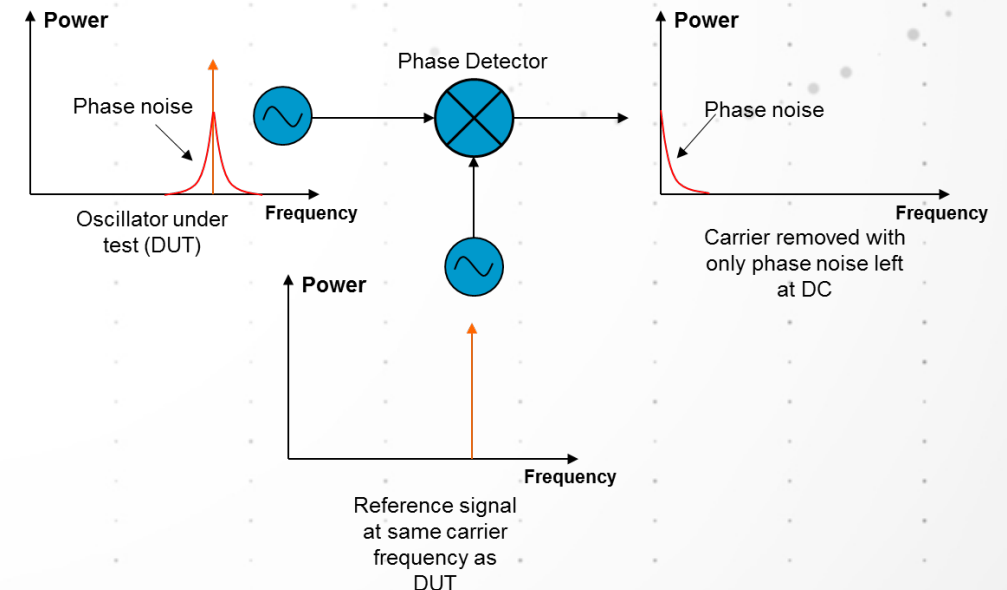
## Direct Spectrum Method

- By sampling the carrier, the direct spectrum method (as employed in signal analyzers and some phase noise systems) is able to immediately get amplitude and phase information
- This method is far less sensitive (lower performance) than the carrier removal method



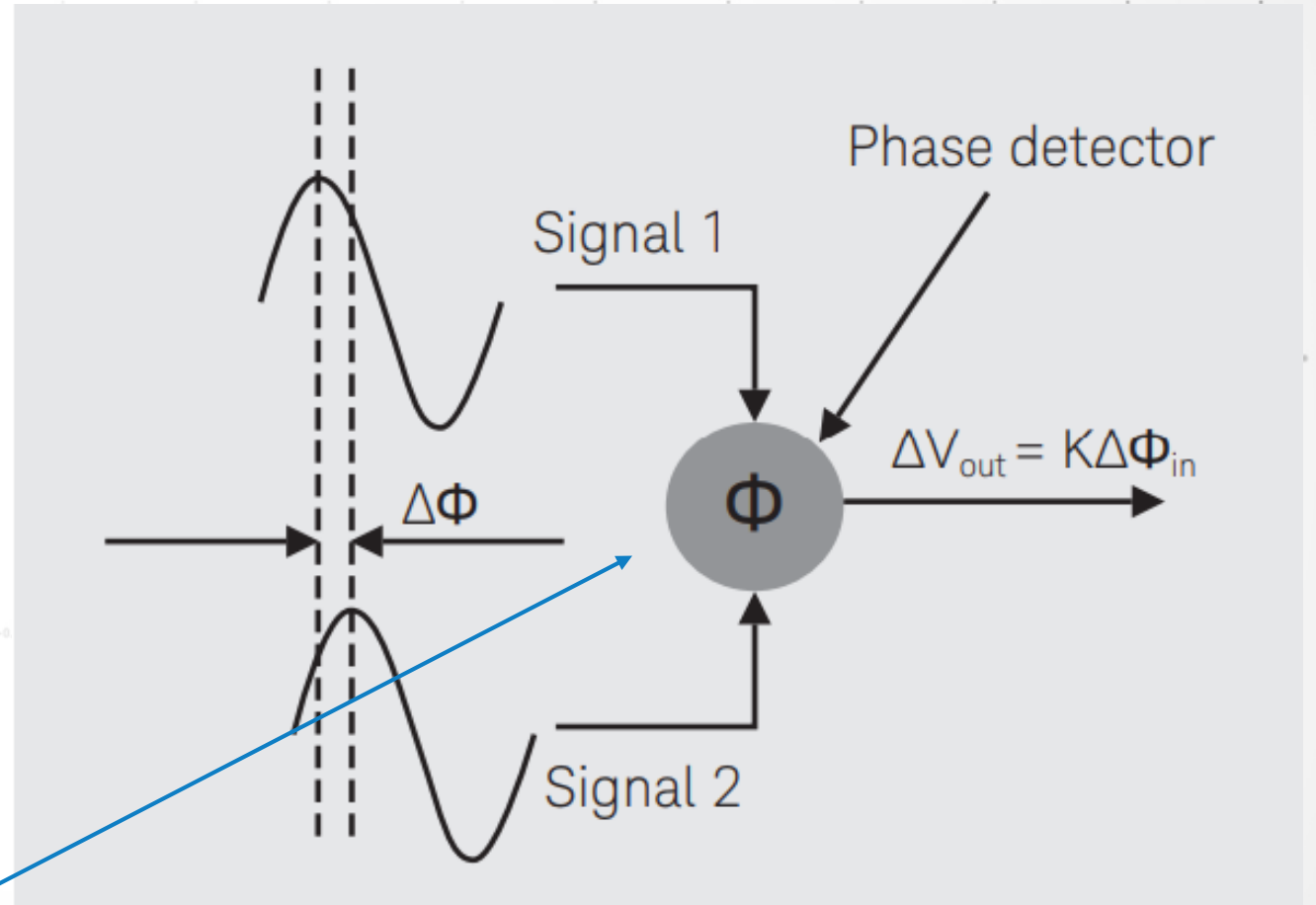
## Carrier Removal

- Increased sensitivity is obtained by nulling the carrier and then measuring the phase noise of the resulting baseband signal
- Both the frequency discriminator and the PLL/Reference Source methods discussed next use carrier removal with **phase detectors**



# Phase Detector Techniques

- Both the frequency discriminator and reference source/PLL method use a phase detector as the heart of the measurement system
- A phase detector takes two input signals and compares their phase
- The output of the phase detector is just a voltage that is proportional to the phase difference of the two signals (delta phase)
- The constant of proportionality, called K is in units of volts per radian (V/rad) and must be measured



**$\Delta\phi$  to Voltage  
Converter ("Phase Detector")**

# Double Balanced Mixer as a Phase Detector

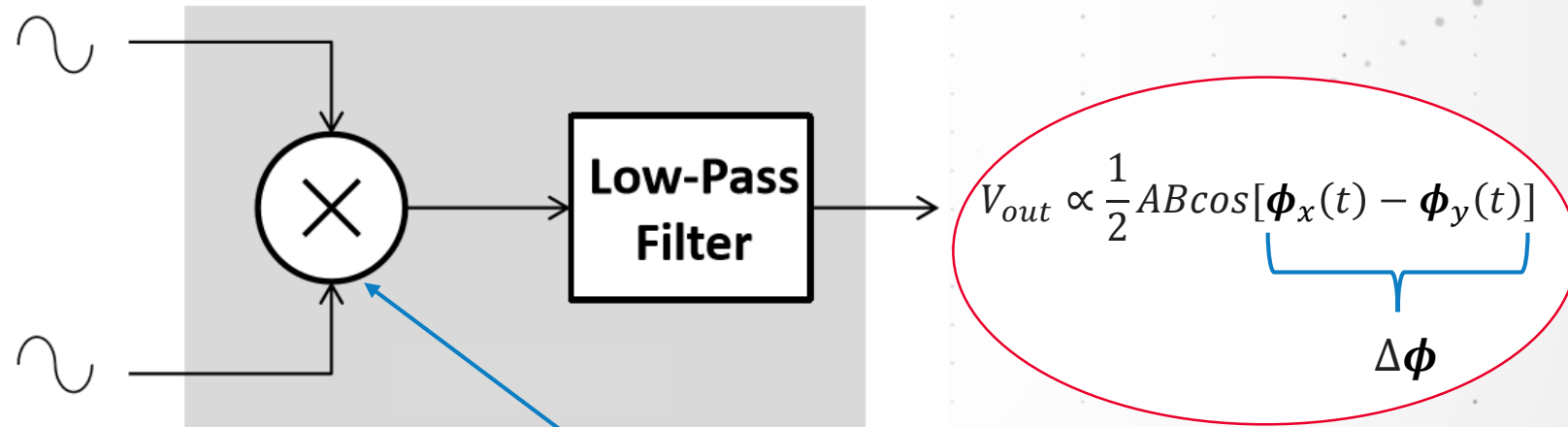
## THE MATHEMATICS

- Double balanced mixers produce sinusoids at the sum and difference frequencies of two input signals  $x(t)$  and  $y(t)$
- If both signals are at the same frequency, we get 0 Hz (DC) and a high frequency term that goes away via low pass filtering (LPF)
- After the LPF, we get only a DC term that varies in amplitude as a cosine function of the delta phase of the two signals –this is a delta phase to voltage converter or **phase detector**

Product to Sum Identity:

$$\left. \begin{aligned} x(t) &= A \sin[\omega_0 t + \phi_x(t)] \\ y(t) &= B \sin[\omega_0 t + \phi_y(t)] \end{aligned} \right\} \times \left. \begin{aligned} &\frac{1}{2} AB \cos[\phi_x(t) - \phi_y(t)] - \frac{1}{2} AB \cos[2\omega_0 + \phi_x(t) + \phi_y(t)] \end{aligned} \right\}$$

LPF



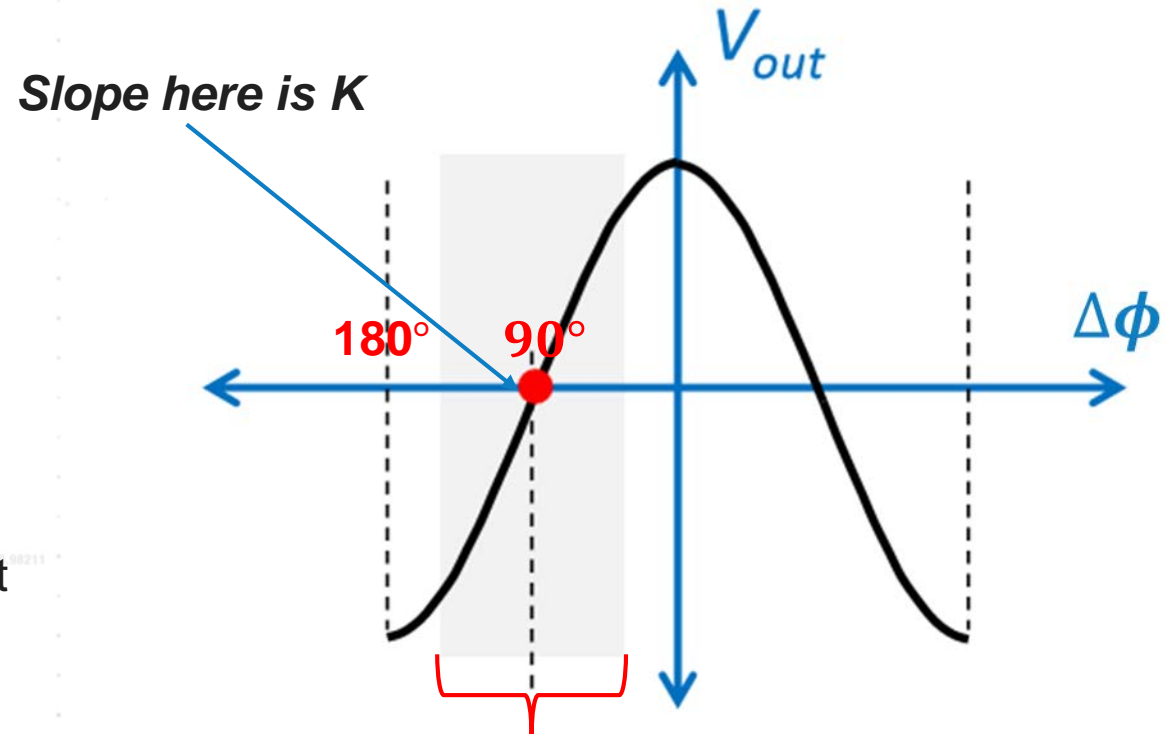
**$\Delta\phi$  to Voltage Converter ("Phase Detector")**

# Double Balanced Mixer as a Phase Detector

## IMPORTANCE OF QUADRATURE

- The phase detector's cosine output voltage ( $\cos(\Delta\phi)$ ) is non-linear and we would like to linearize it so that we can get a linearly proportional relationship between delta phase and output voltage
- We notice that if both input signals to the phase detector are 90 degrees offset, the output voltage is 0V
- As we increase or decrease the delta phase about 90 degrees (**quadrature point**), the output voltage is approximately linear
- We have now created a phase detector! After characterizing the proportionality constant,  $K$ , we now get an output voltage that linearly varies with the delta phase

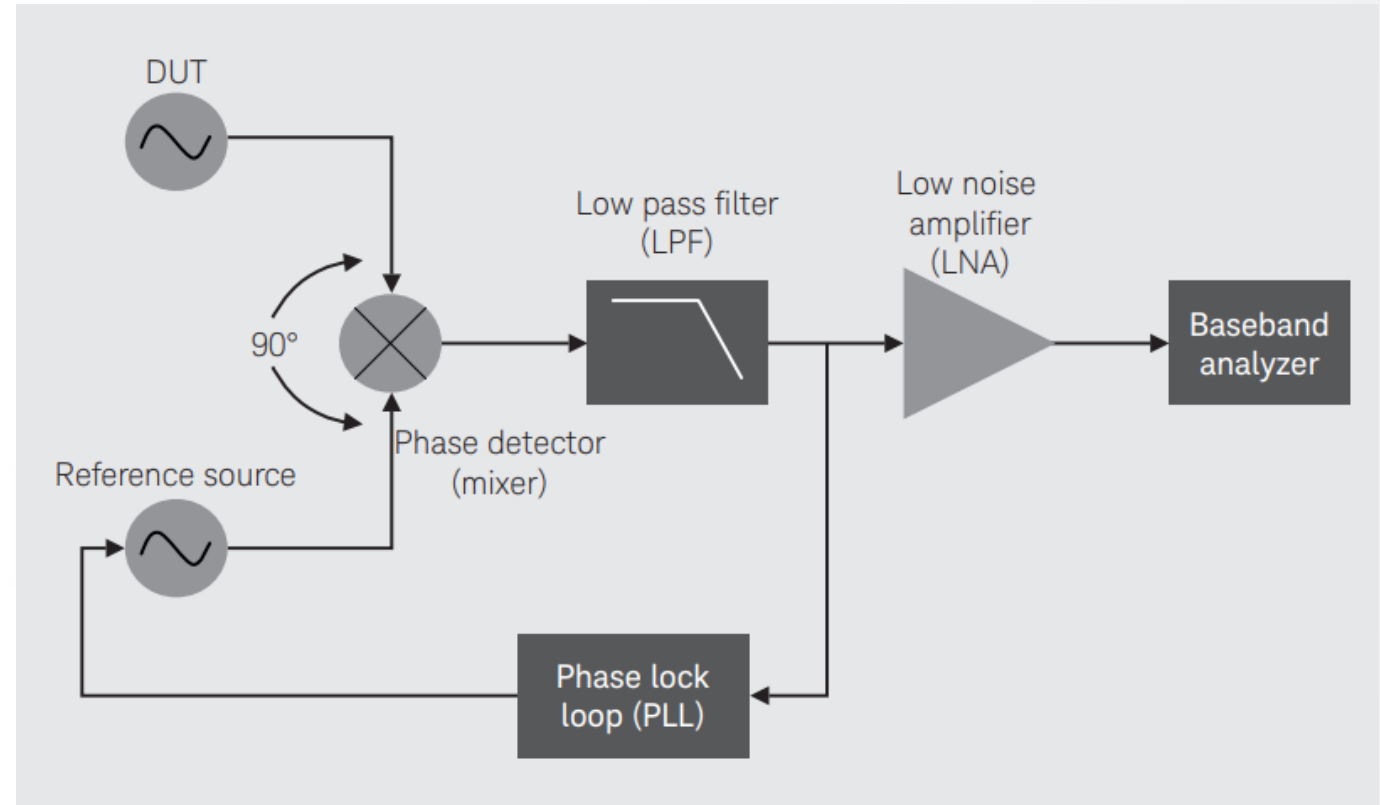
Phase Detector Output Voltage vs. Delta Phase



**Piecewise Linear Region about quadrature ( $90^\circ$ )**  
where  $V=K\Delta\phi$

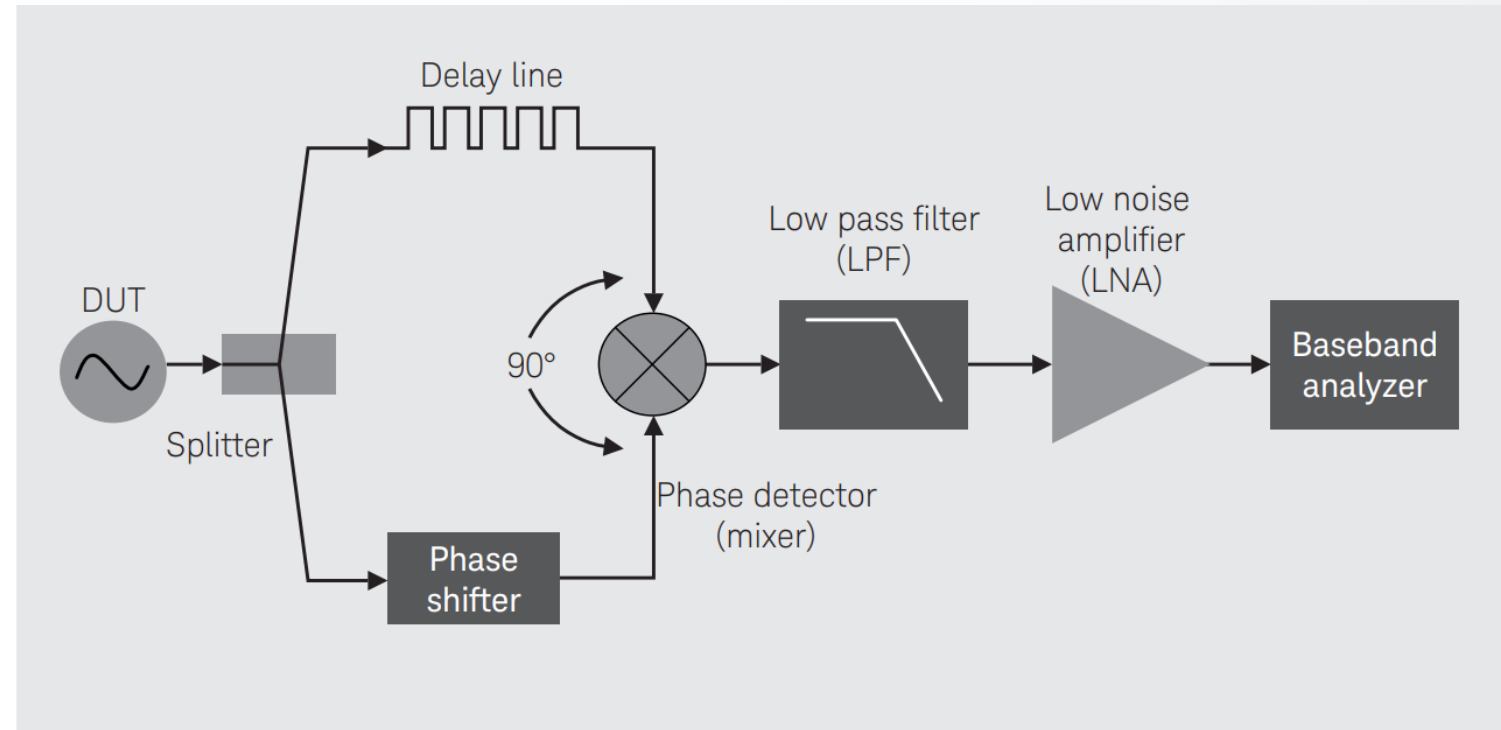
# Reference Source/PLL Method for Absolute Measurement

- An absolute phase noise measurement means that we are measuring the DUT (oscillator usually) phase noise performance directly –inclusive of the reference source used
- This is a 1-port measurement
- The Reference Source/PLL method is a phase detector technique that uses a Phase Locked Loop System (PLL) to set and keep both our DUT and reference sources in phase lock at 90 degrees offset (quadrature) so that we keep the phase detector in the linear region
- We are limited by the noise floor of the phase detector itself if we have a perfect reference



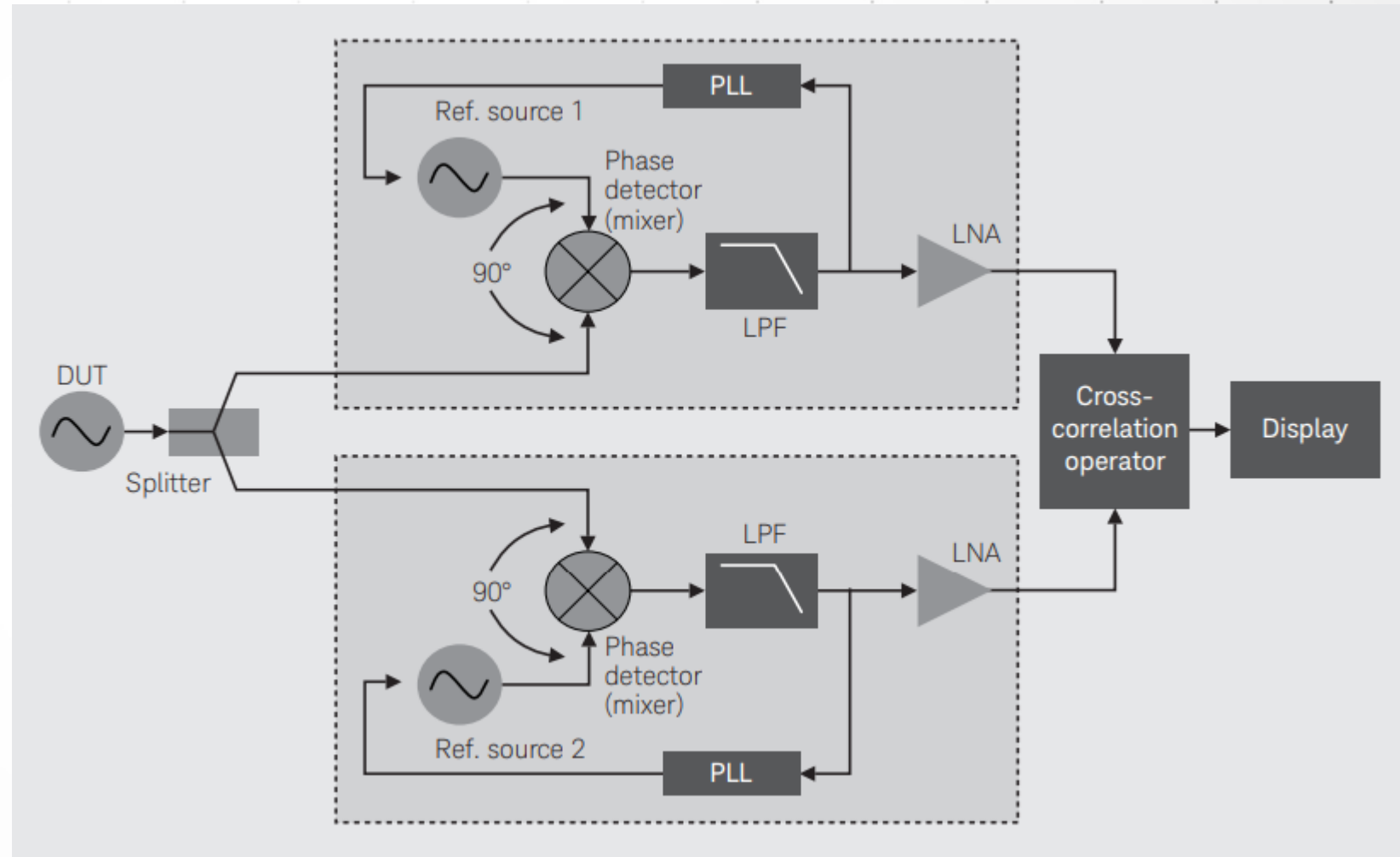
# Frequency Discriminator Method for Absolute Measurement

- This method is an absolute (1-port) measurement that also uses a phase detector
- Signal from the DUT is split into two paths
- The signal in one path is delayed relative to the other path
- The delay line converts frequency fluctuations into phase fluctuations
- The delay line or phase shifter is adjusted to put the inputs to the mixer in quadrature
- The phase detector converts phase fluctuations into voltage fluctuations which are analyzed on the baseband analyzer



# Cross-Correlation Technique

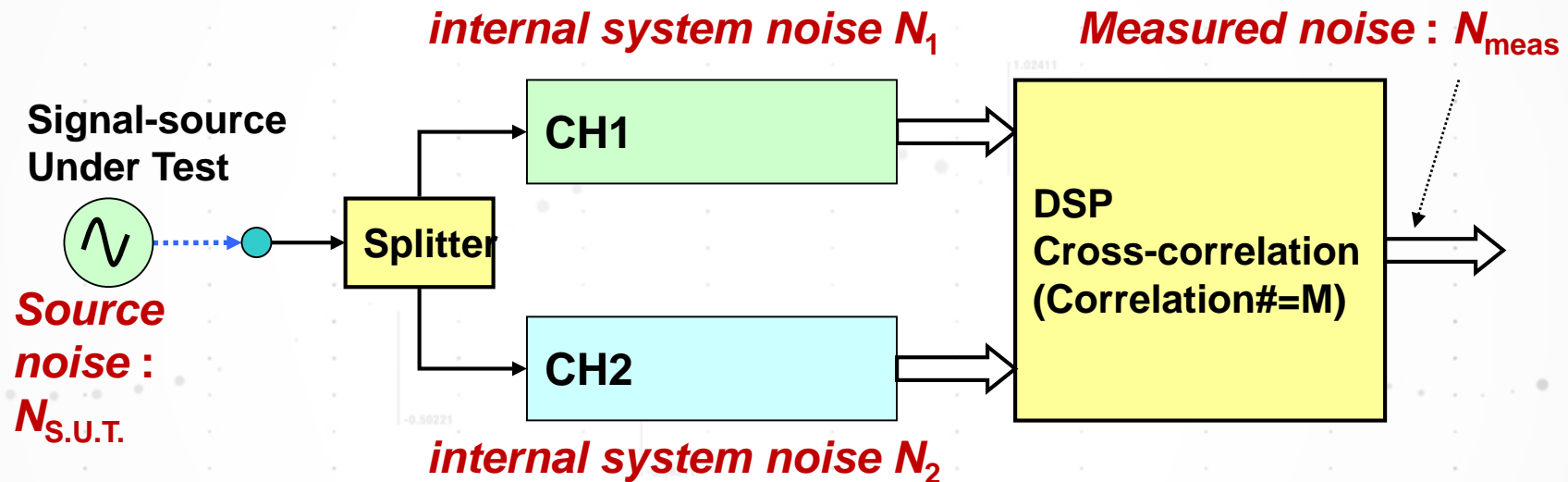
- With two phase detectors and two references (2 channels), we can further improve our phase noise floor
- There are now 2 channels that are uncorrelated, so we can remove the noise added by the references given enough time (we'll quantify this next)
- The DUT signal is common to both channels and is thus perfectly correlated and kept as our measurement result





# Cross-Correlation Technique

## TIME VERSUS PERFORMANCE IMPROVEMENT



$$N_{meas} = N_{S.U.T.} + (N_1 + N_2) / \sqrt{M} \quad \text{Assuming } N_1 \text{ and } N_2 \text{ are uncorrelated.}$$

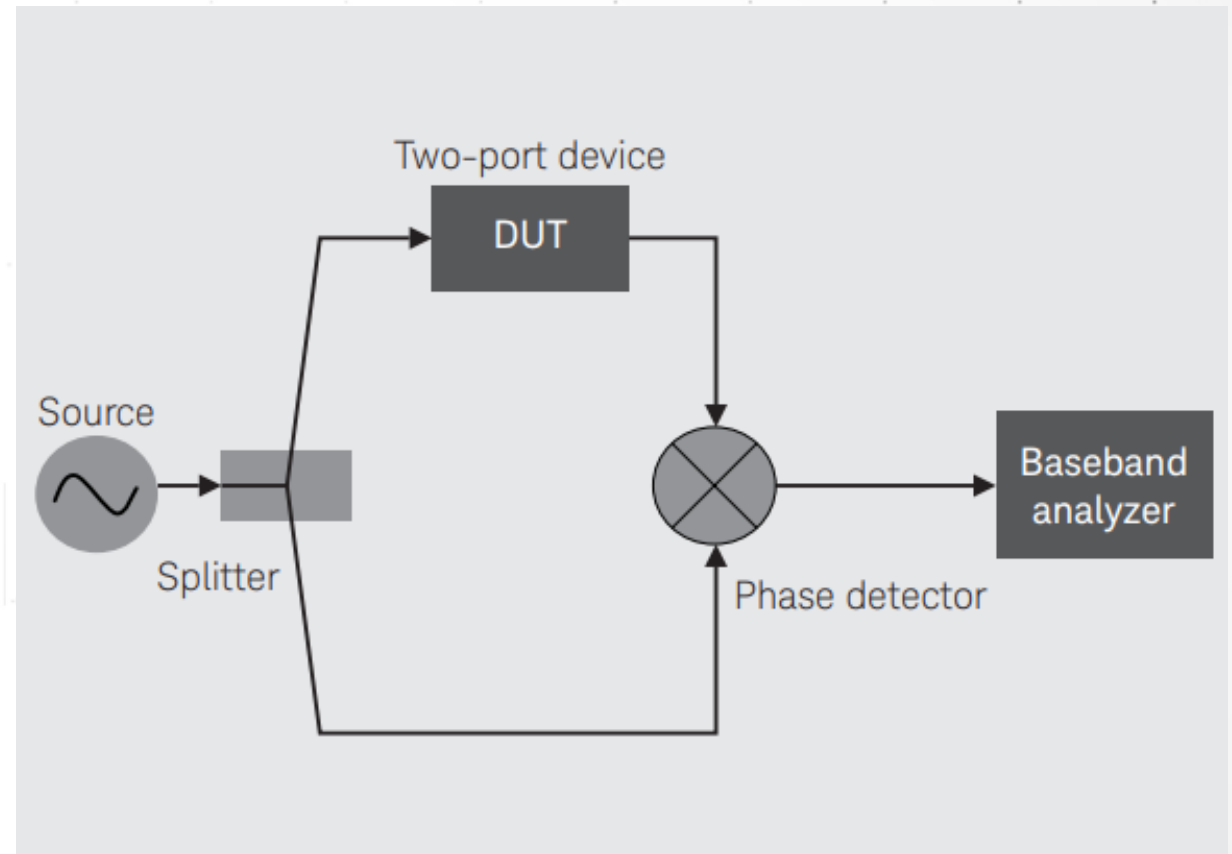
<b>M (number of correlation)</b>	<b>10</b>	<b>100</b>	<b>1,000</b>	<b>10,000</b>
<b>Noise reduction on <math>(N_1+N_2)</math></b>	<b>-5dB</b>	<b>-10dB</b>	<b>-15dB</b>	<b>-20dB</b>



# Residual Phase Noise Measurements

## RESIDUAL MEASUREMENTS USING A PHASE DETECTOR

- Can think of it as a **completely different class** of measurement from absolute phase noise measurements
- Is the “additive” or residual noise added to an electronic signal and so is often performed on a two port device like an amplifier
- Reference source doesn't make a difference to residual measurements because it is perfectly correlated at both ports of the phase detector and will cancel –leaving only the additional phase noise added to the signal by the DUT



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# Direct Phase Noise Measurement On SA

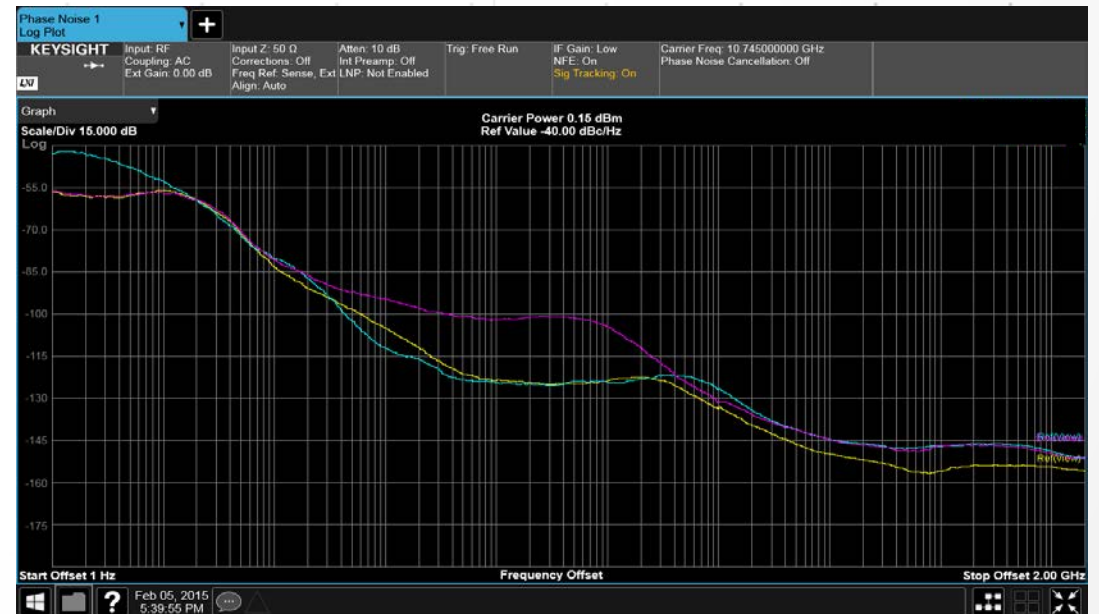
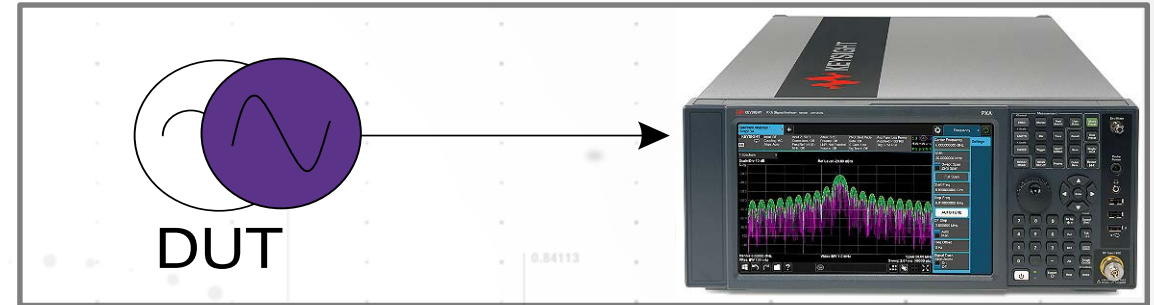
## PHASE NOISE APP ON X-SERIES ANALYZERS

### Pros:

- Easy to configure and use
- Quick phase noise check
- Log plot
- Spot frequency (PN change vs. time)
- rms PN, rms jitter, residual FM
- X-Series phase noise application automates PN measurements

### Cons:

- Uses less sensitive direct spectrum method
- Limited by SA internal PN floor
- Caution: On vintage spectrum analyzers, AM noise cannot be separated from PM noise. In today's modern signal analyzers, the AM component is removed



N9068C X-Series Phase Noise Application

# Keysight E5052B Signal Source Analyzer

## CROSS CORRELATION SYSTEM W/ BUILT IN REFERENCES

- The Keysight E5052B incorporates
  - A two-channel cross-correlation measurement system to reduce measurement noise
  - Can be configured as:
    - Two-channel normal phase noise (phase detector) PLL system
    - Two-channel heterodyne digital discriminator system
- Provides excellent phase noise measurement performance for many classes of sources and oscillators
- Well suited for free running oscillators

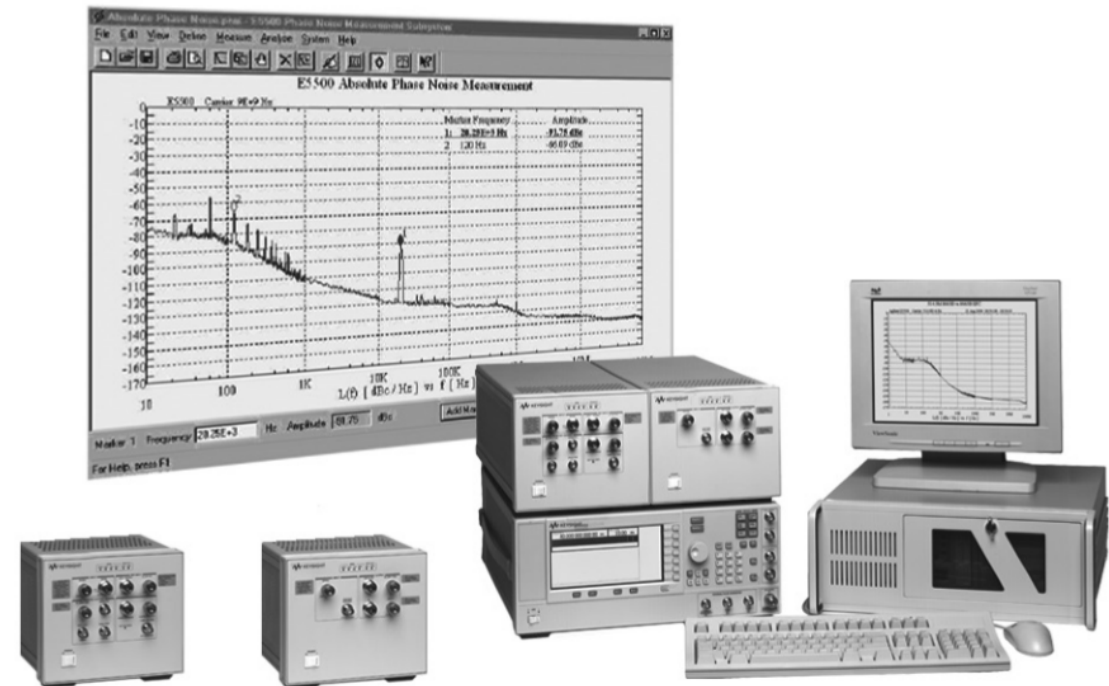




# Keysight E5500 Phase Noise Measurement System

## GOLD STANDARD PHASE DETECTOR BASED SYSTEM

- The E5500 system can be configured as:
  - A reference source/PLL system
  - A frequency discriminator system
  - For absolute and residual phase noise measurements
  - For pulsed phase noise measurements
- System is complex, but allows the most measurement flexibility and best overall system performance
- Can use any reference sources for the best possible absolute phase noise measurements



# Summary

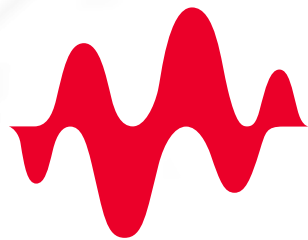
- With the increased data requirements of today's digital radios in Satellite and 5G as well as increased sensitivity requirements of modern radar systems, phase noise has taken on added importance to RF/microwave and systems engineers
- Understanding phase noise and its sources can be complicated and is a full-time profession for some engineers
- Determining the best method of phase noise measurement can be bewildering, but all common test solutions are well documented and Keysight applications experts are available to assist and answer your questions
- In general, one solution does not fit all applications or all users
- Keysight provides a great breadth of phase noise measurement equipment that is tailored to today's demanding measurement requirements



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**Thank you!**



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