Enlightened PLL Measurements

Using Newly-Available Real-Time Spectrum Analysis

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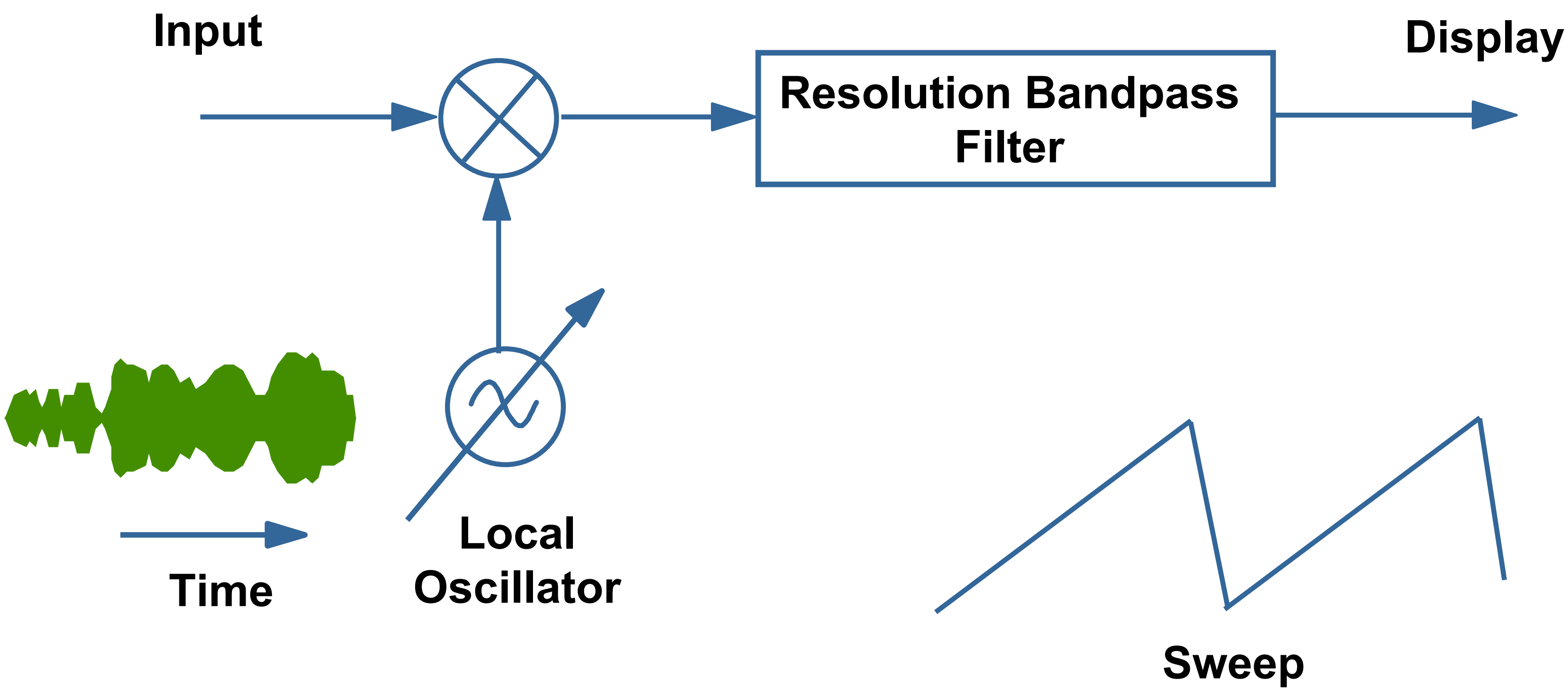
Outline

- Overview of Swept and Real-Time Spectrum Analyzers
- Overview of Phase Locked Loops
- Measurements of Phase Locked Loops
- Live Demonstration of PLL Measurements Using Real-Time Spectrum Analysis
- Summary and Conclusions

Overview of Swept and Real-Time Spectrum Analyzers

Traditional Swept Spectrum Analyzer Architecture



Limitations of Traditional Tools

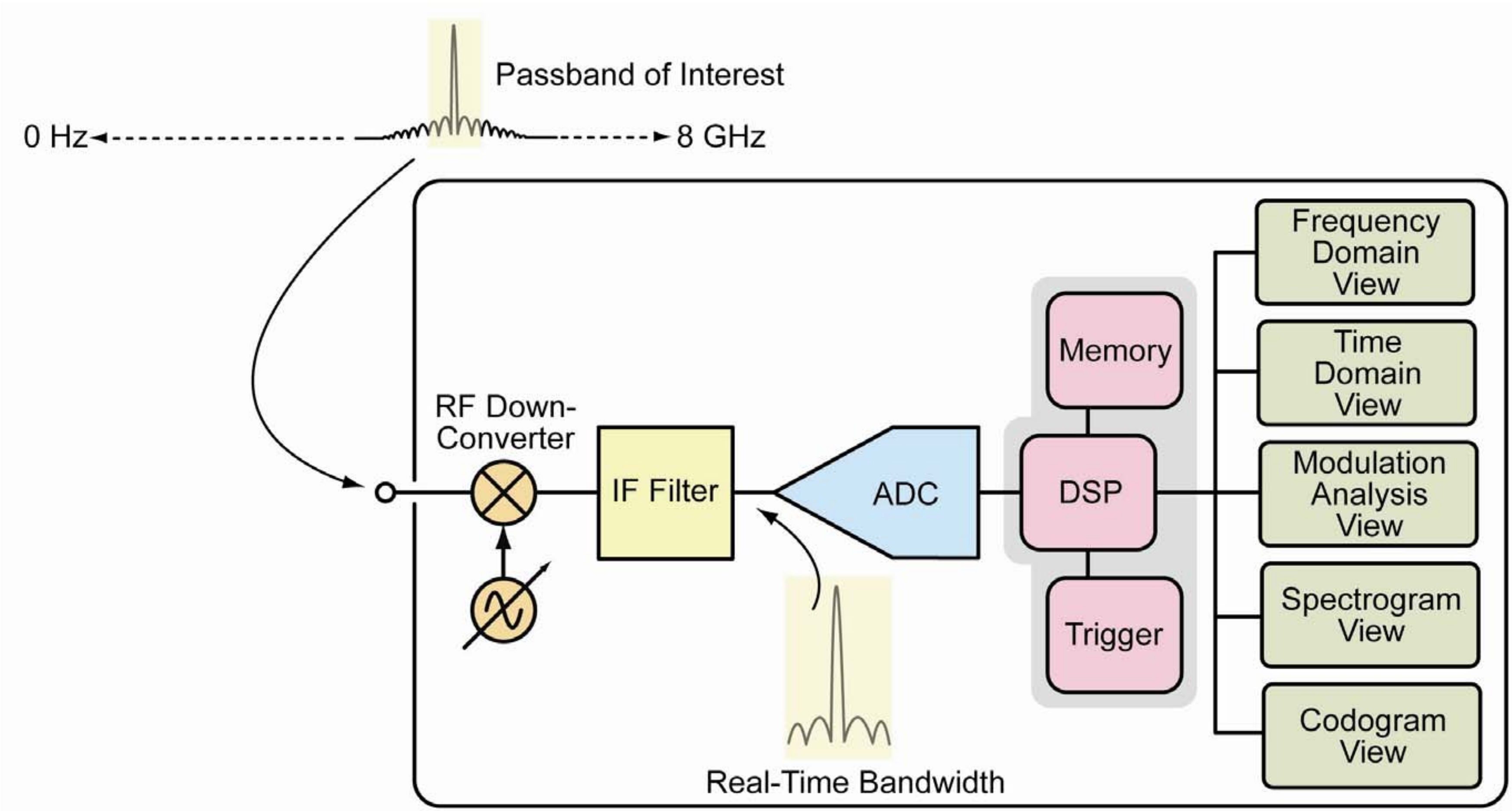
Traditional Swept Spectrum Analyzer Shortcomings

- Limited digital modulation analysis
- Limited triggering capabilities
- No time-history memory
- Single domain views
- Misses frequency changes over time

Traditional Vector Signal Analyzer (VSA) Shortcomings

- Poor RF performance
- Limited triggering capabilities
- Limited correlated views
- Misses frequency and modulation changes over time

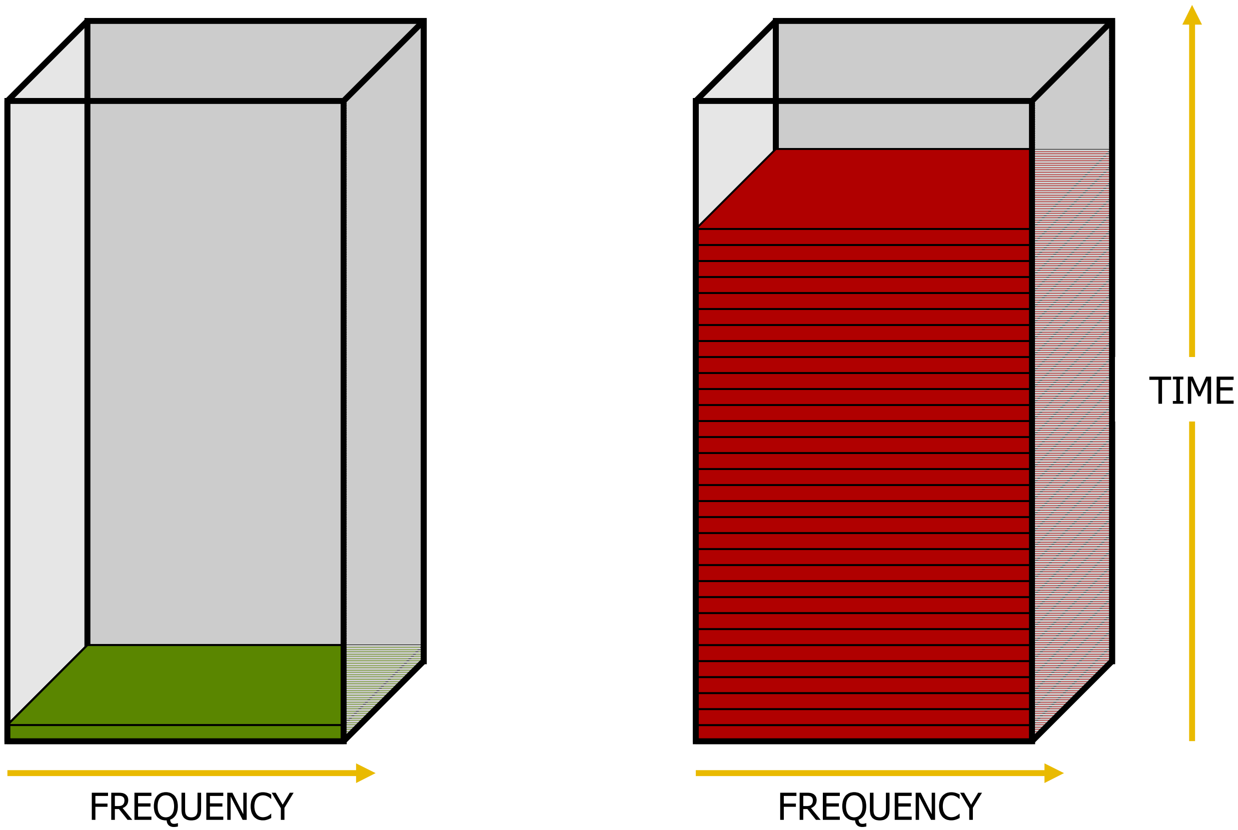
Real-Time Spectrum Analyzer Architecture



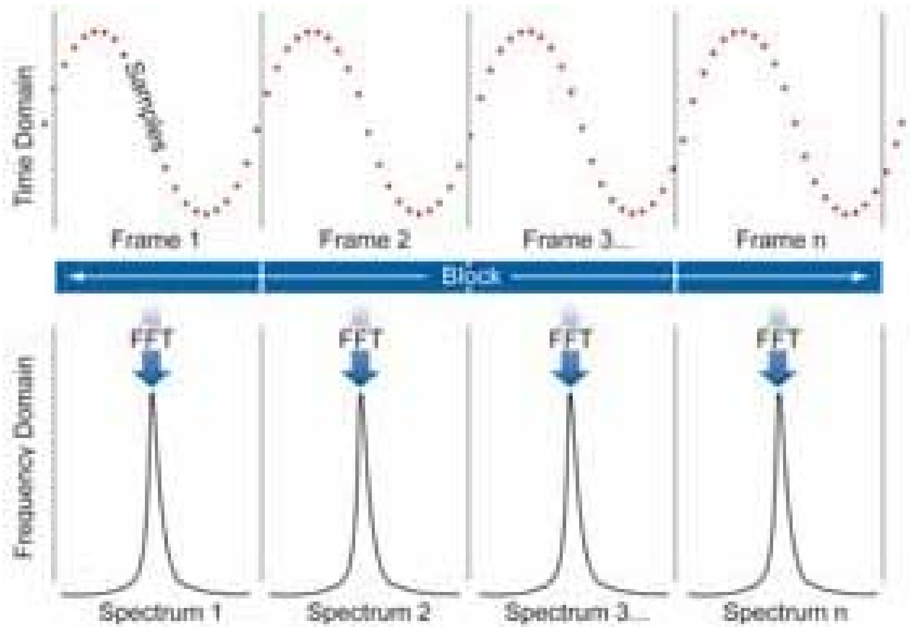
Swept vs. Real-time Seamless Capture

Swept Analyzers

Real-Time Analyzers



The FFT Transformation of the Signal



- Frame after frame, the time domain is converted to the frequency domain with the FFT

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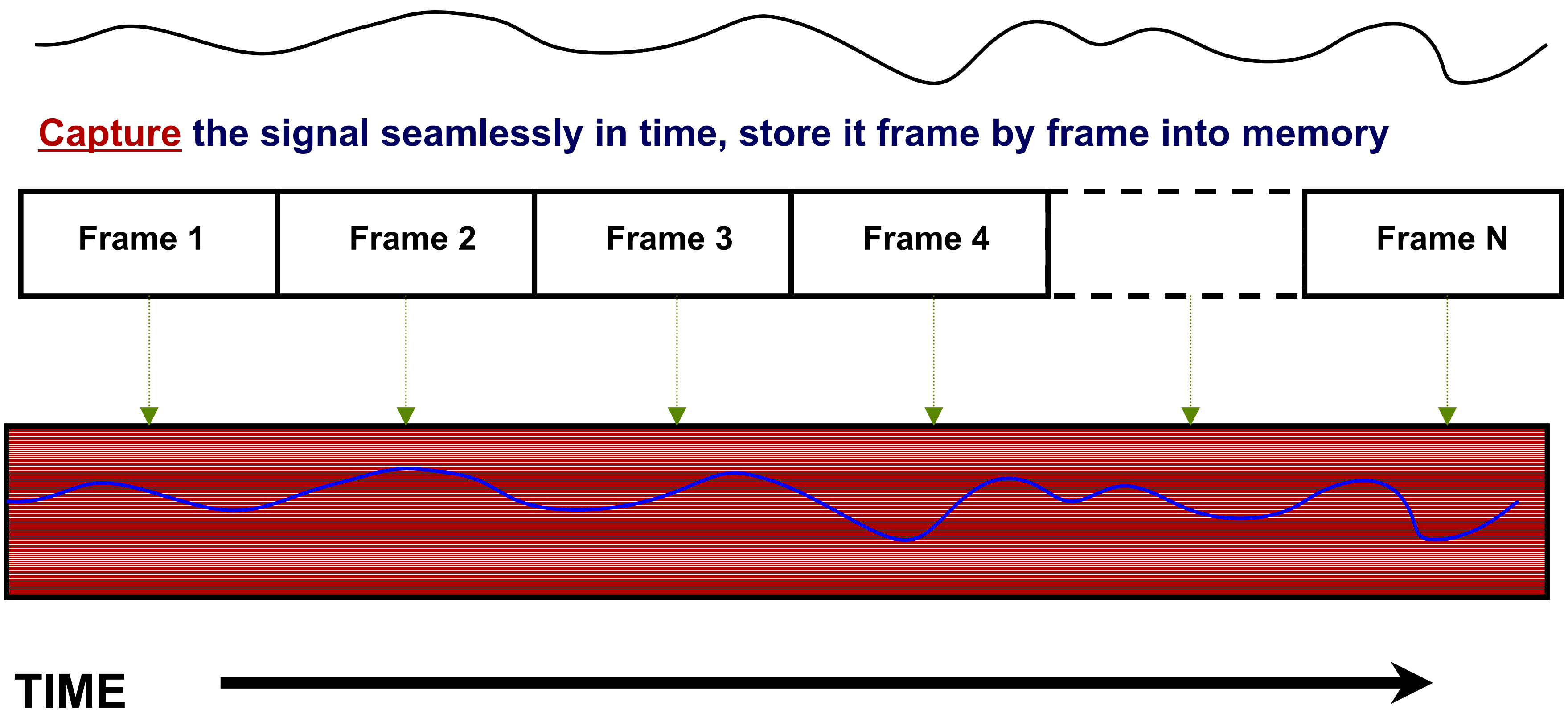
Real-Time SA

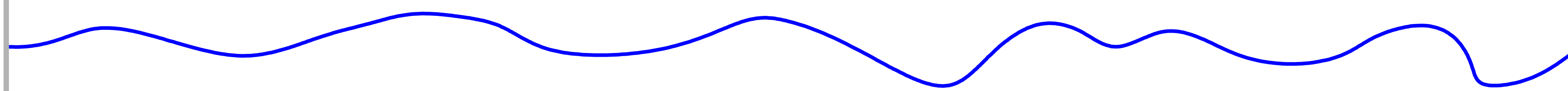
Trigger on an RF signal based on voltage, power, or frequency characteristics

Capture the signal seamlessly in time, store it frame by frame into memory

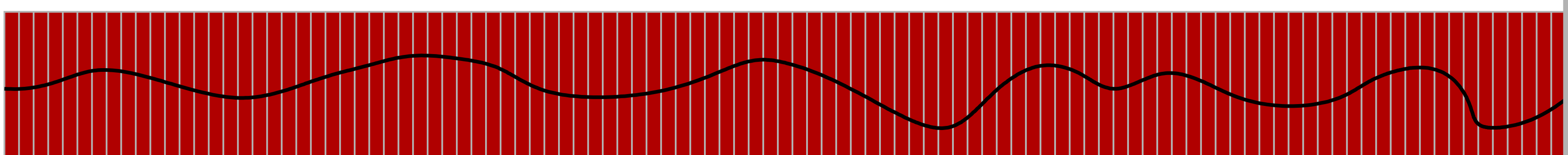


Real-Time SA – View of Modulation Domain

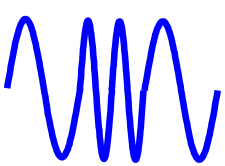
Trigger | on an RF signal based on power or frequency characteristics



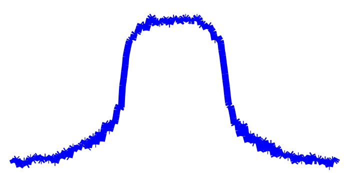
Capture | the signal seamlessly in time, into memory



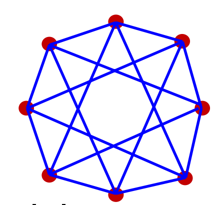
Analyze | the signal simultaneously in multiple domains



Time Domain

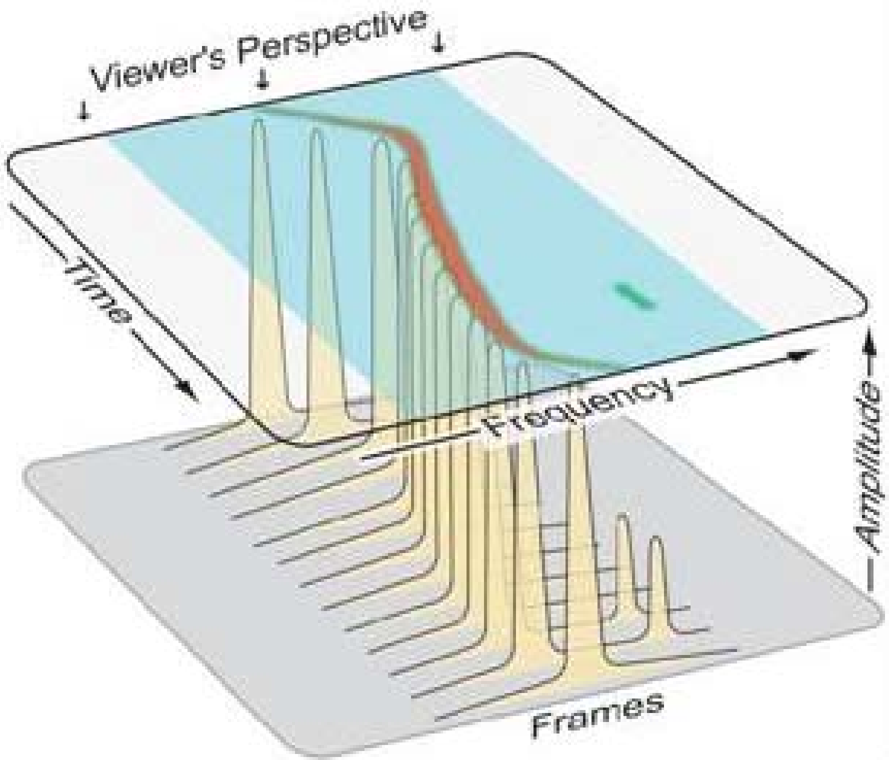


Frequency Domain



Modulation Domain

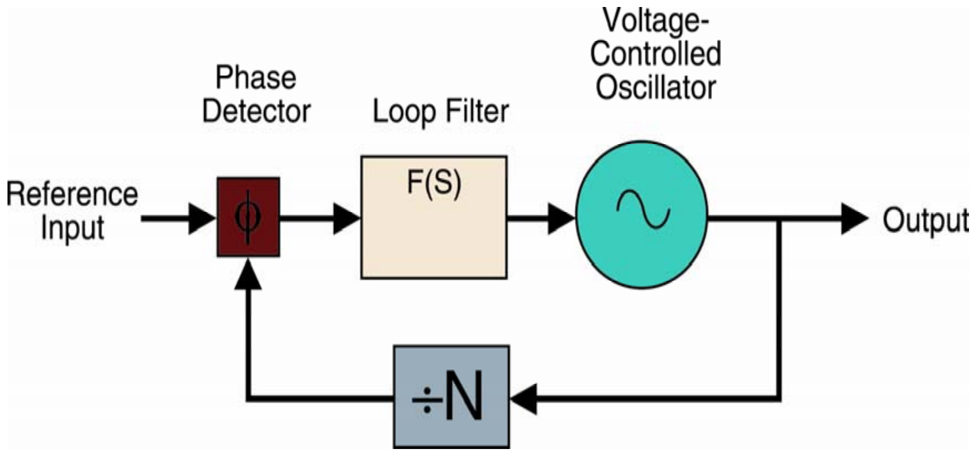
Seamless Capture and Spectrogram



- The spectrogram shows how an RF signal changes over time in the frequency domain
- Frequency is the horizontal axis, time is the vertical axis, and power is represented by the color of the trace

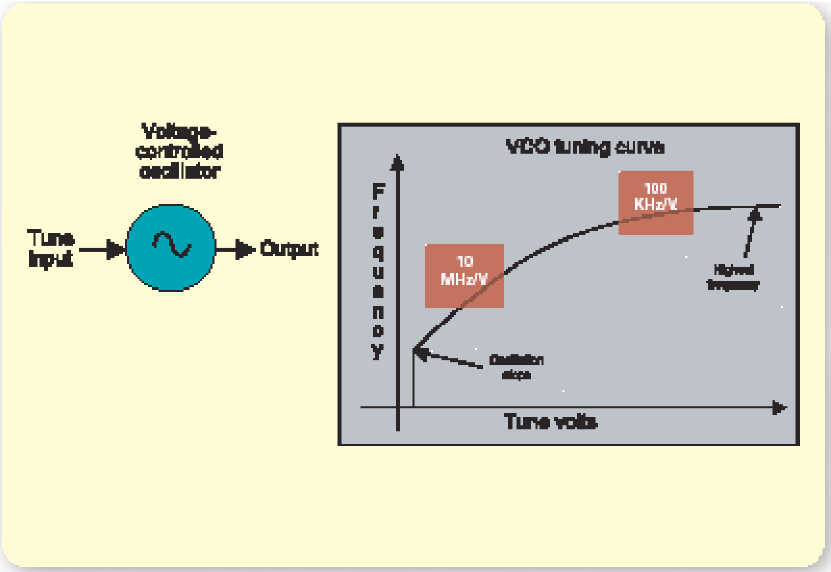
Overview of Phased Locked Loops (PLLs)

The Building Blocks



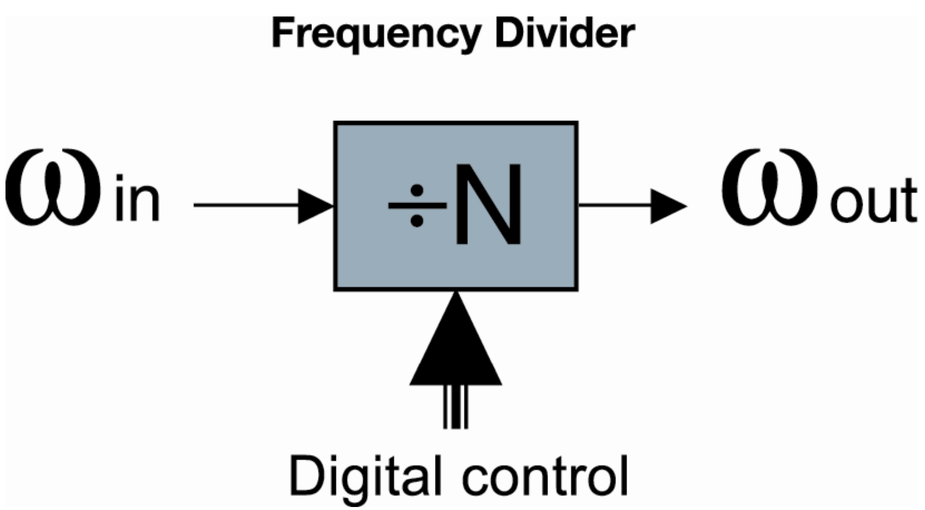
- PLL locks the phase of the output to N times the phase of the input
- PLLS behave linearly in the vicinity of lock
- Non-linear effects dominate when PLL is unlocked

Voltage Controlled Oscillator (VCO)



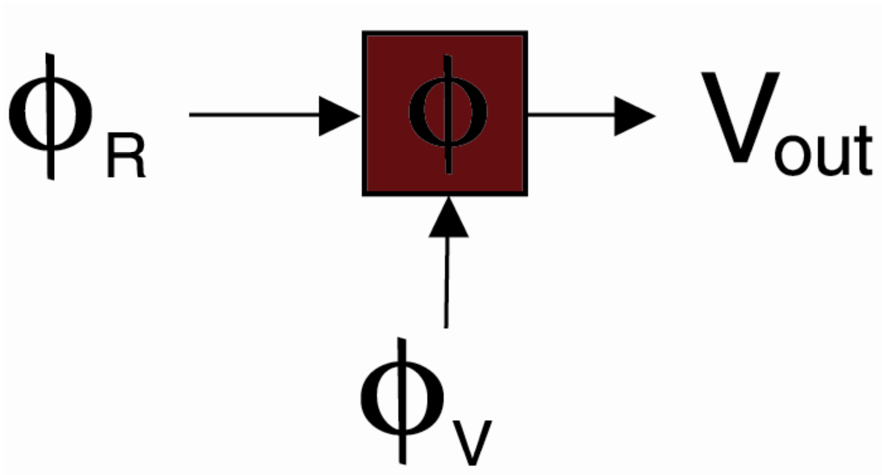
- VCO output signal is controlled through a tuning signal
- Tuning signal is typically a voltage, but it can be another variable (current, numerically, etc)
- VCOs are often non-linear, having tuning sensitivities that vary greatly
- Other non linear behaviors include:
  - Min/Max tune frequencies
  - Tune voltages where oscillations stop

Frequency Divider



- Typically a digital counter produces one output for every N inputs
- Both Phase and Frequency are scaled by the ratio N
- N is generally an integer, however Fractional-N techniques exists to provide ratios that are not whole numbers

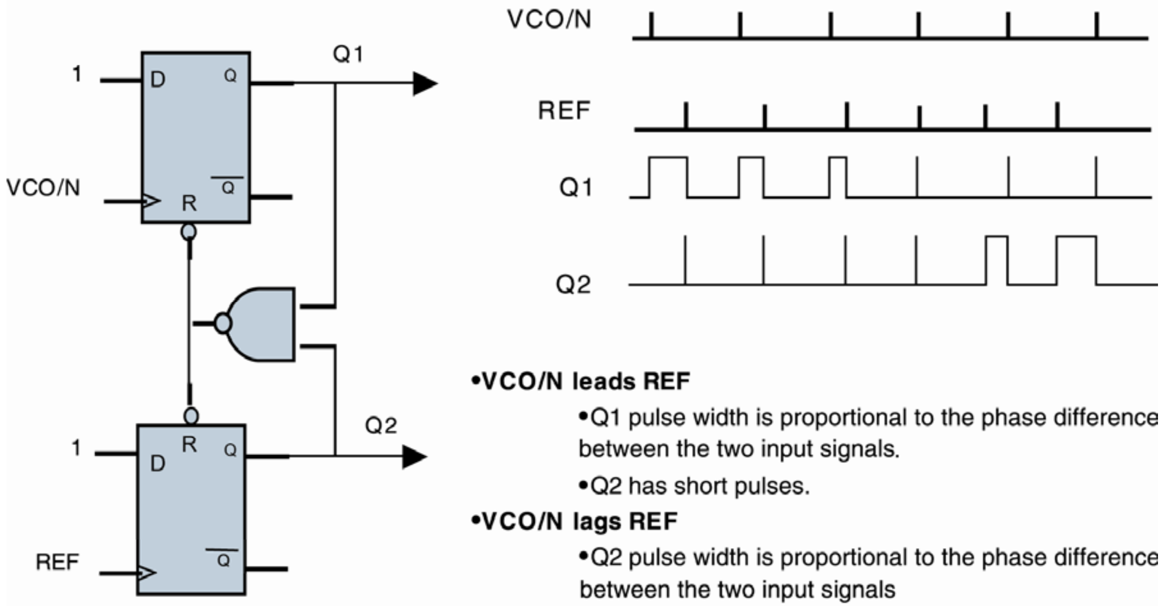
Phase Detector



- Produces an output that is proportional to the phase difference between two inputs signals
- Φ_R = phase of the reference signal
- Φ_V = phase of the VCO signal
- Vout = a signal that is proportional to the difference between Φ_R and Φ_V

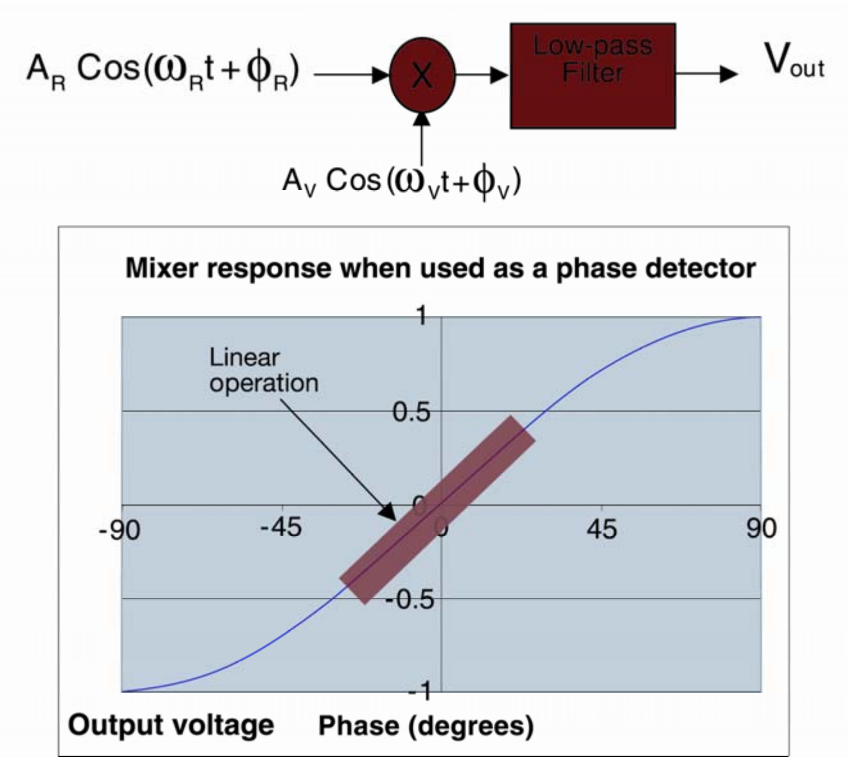
Phase Frequency Detector

Phase Frequency Detector Logic and Timing



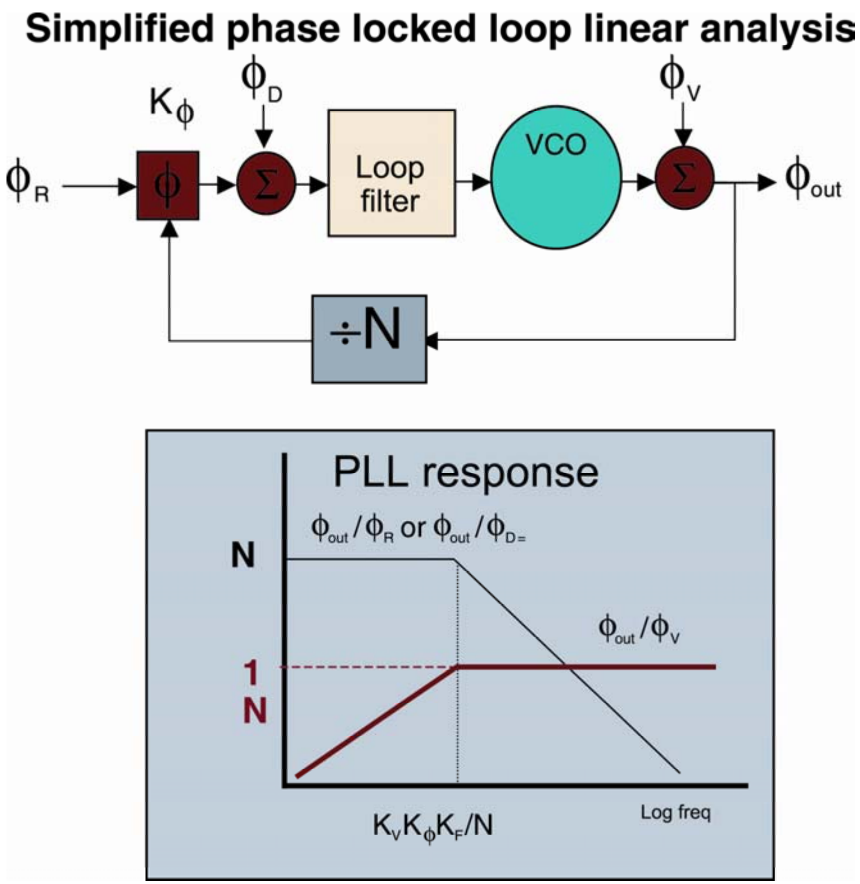
- **VCO/N leads REF**
  - Q1 pulse width is proportional to the phase difference between the two input signals.
  - Q2 has short pulses.
- **VCO/N lags REF**
  - Q2 pulse width is proportional to the phase difference between the two input signals
  - Q1 has short pulses.
- **VCO/N has a higher frequency than REF: Frequency steering down.**
  - Q1 is high except for occasional short glitches. Q2 is low except for occasional glitches.
- **VCO/N has a higher frequency than REF: Frequency steering up.**
  - Q2 is high except for occasional short glitches. Q1 is low except for occasional glitches.

Mixer Phase Detector



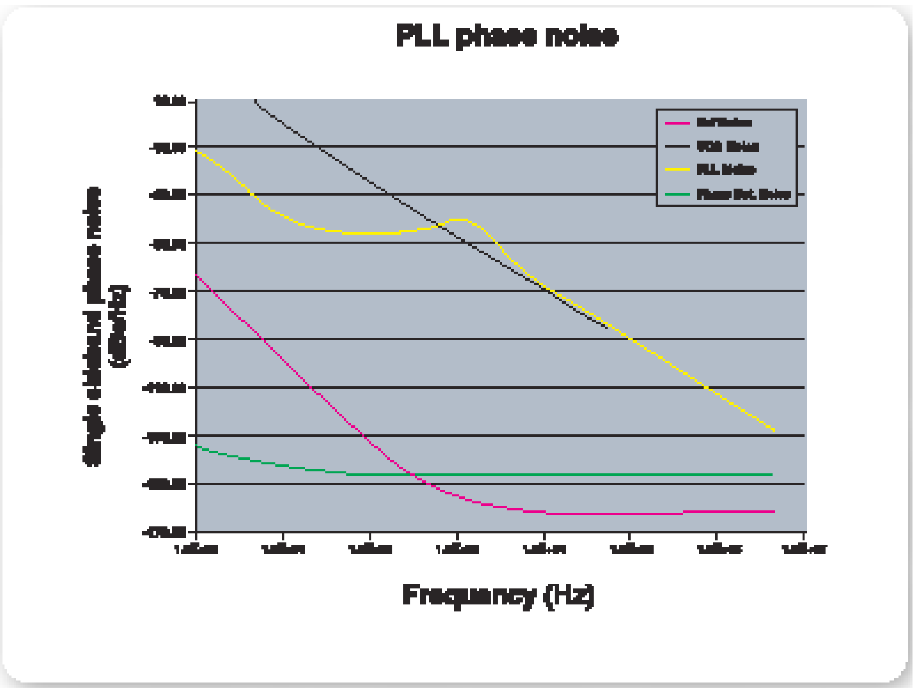
- Multipliers or Mixers can be used as phase detectors
- The output of the mixer is proportional to the sine of the phase difference between the inputs
- $V_{out} = K_{det} A_r A_v \text{Cos}(\Phi_R - \Phi_V)$
- K_{det} = mixer conversion gain
- A_r and A_v are the amplitudes of the input signals
- Φ_R and Φ_V are the phases of the two input signals

Loop Filter



- Loop Filters are used to tailor the PLL response to optimize:
  - Bandwidth
  - Switching speed
  - Settling time
  - Spurious levels, etc
- Loop filters often include integrators and therefore are subject to the same linearity concerns as other active devices

Linear Operation/Response

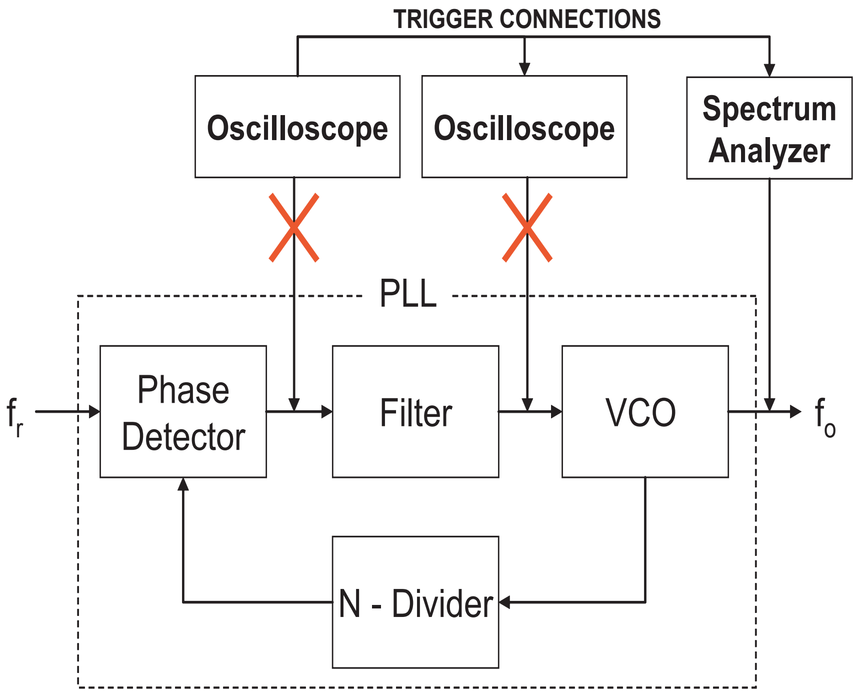


- All oscillators exhibit phase fluctuations
- PLLs can be used to improve the phase stability of oscillators
- The output of the PLL varies due to fluctuations in the reference, VCO and the signal applied to the Phase Detector
  - Phase Noise at low frequencies is dominated the reference signal and the signal applied to the phase detector
  - The VCO dominates the phase noise performance at higher frequency

Measurements of Phased Locked Loops (PLLs)

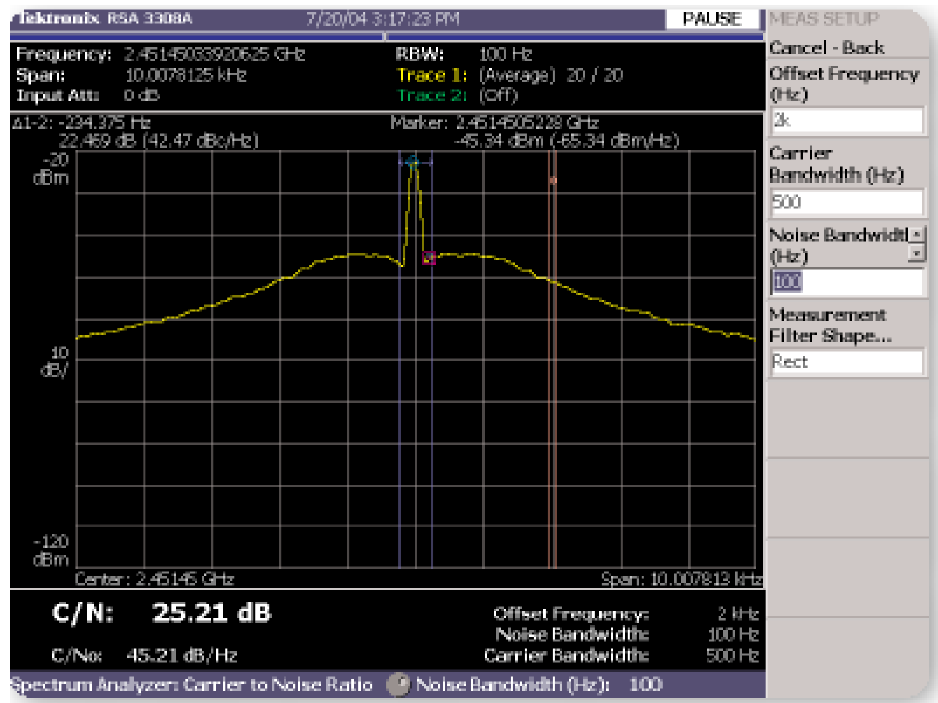
Limitations of Traditional Test Methods

- Traditional methods relied on sampling the signal at each node
- Higher levels of circuit integration limits access to individual nodes
- Traditional test equipment requires complex triggering arrangements
- Traditional methods do not provide time correlation between frequency and time domain



Phase Noise Measurements

- Phase Noise typically expressed as a ratio of sideband power in 1Hz BW to the signal power (dBc/Hz)
- Phase Noise is measured at specific offsets from the carrier frequency
- Measurement Example:
  - CF = 2.4515 GHz
  - Offset = 2 kHz
  - Noise Bandwidth = 100 Hz
  - C/N = 25.21 dB
  - C/No = 45.21 dB
- This traditional view only shows a single snapshot in time



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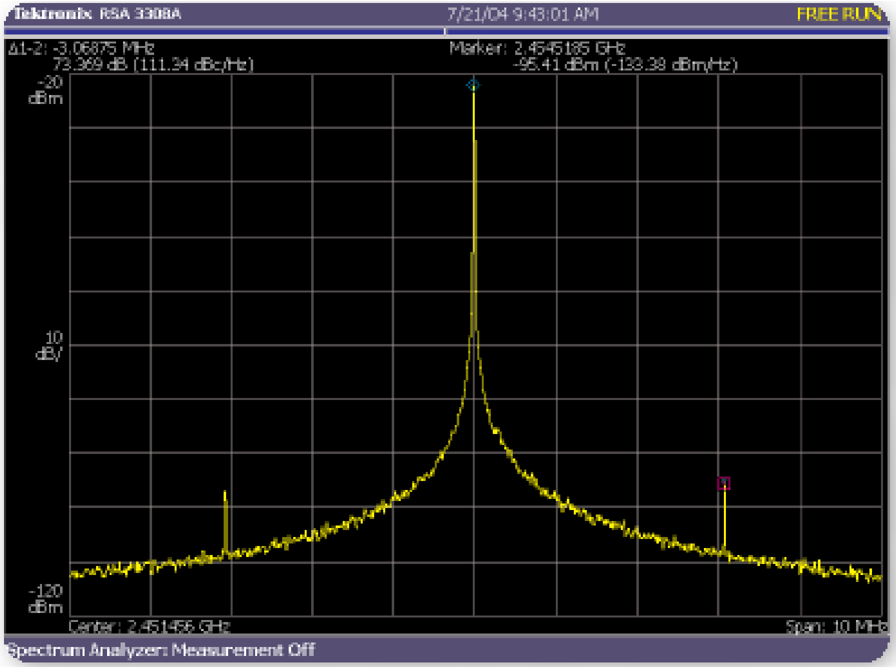
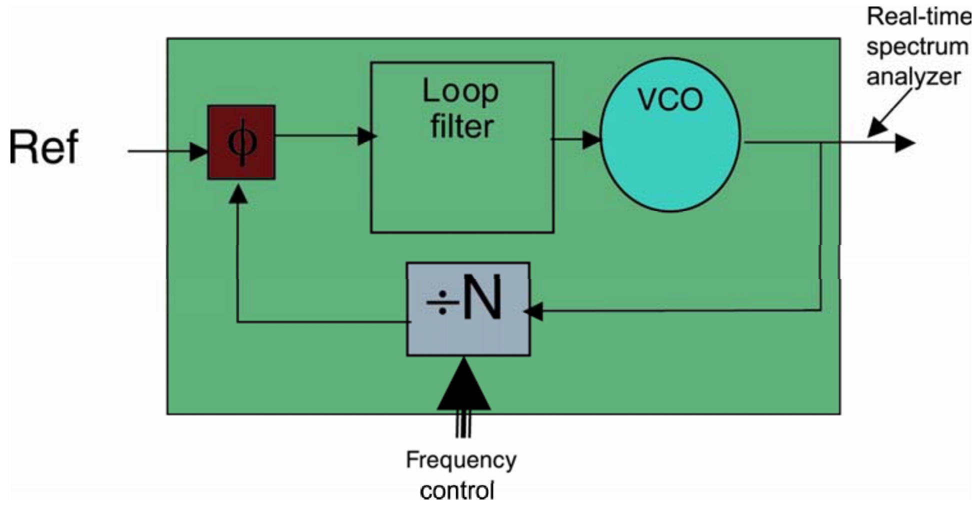
Spurious Signals

- There are many sources of spurious signals that can affect the output of a PLL
  - Switching circuitry
  - Power supply switching
  - Close by oscillators
  - IMD
- The reference signal can also generate spurious
  - These spurious signals are always at multiples of the reference signal
- The loop filter can be used to reduce spurious, but in the real world, they can never be eliminated
- This traditional view only shows a single snapshot in time

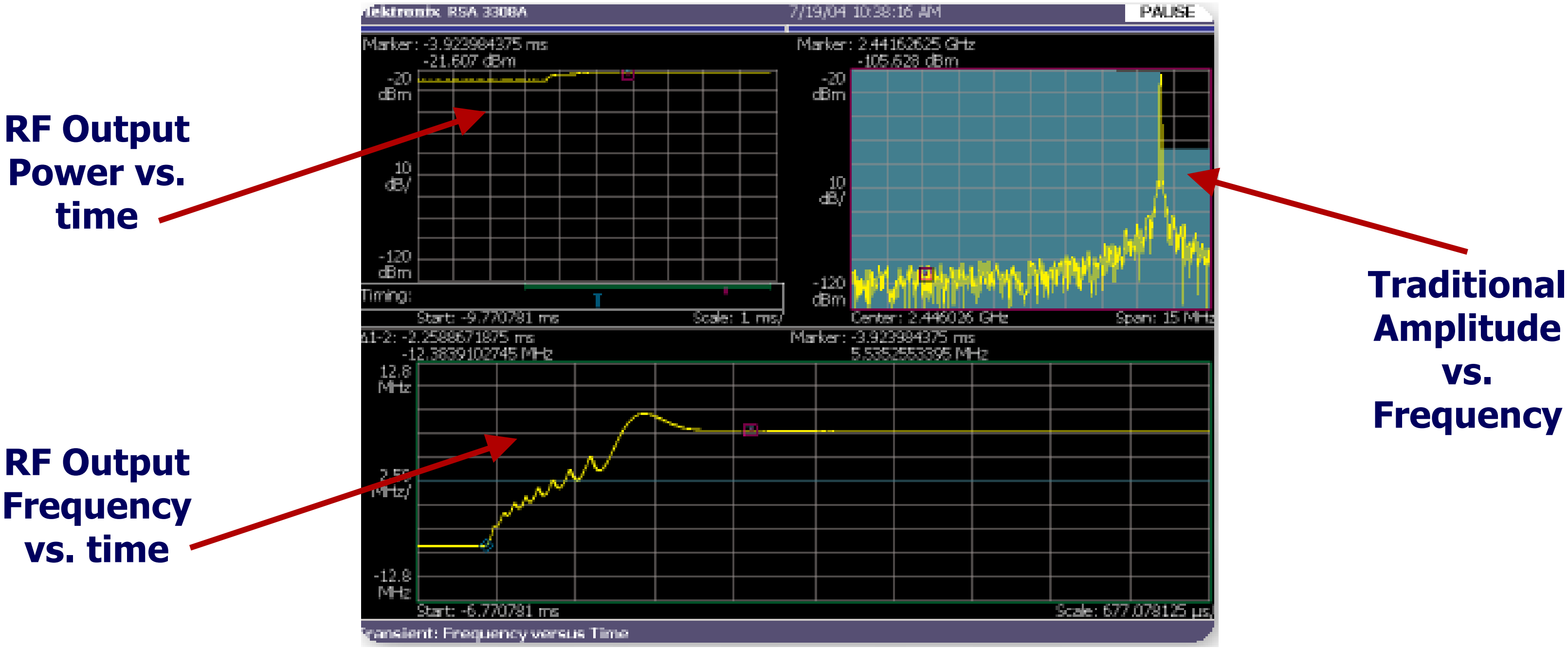


Non Linear Behavior



- During switching PLLs experience a lot non-linear behavior until the phase detector can close the loop
- Measurement of the switching transients requires time domain analysis
- Traditional methods required probing at each stage of the PLL, however this is not always possible with integrated PLL circuits

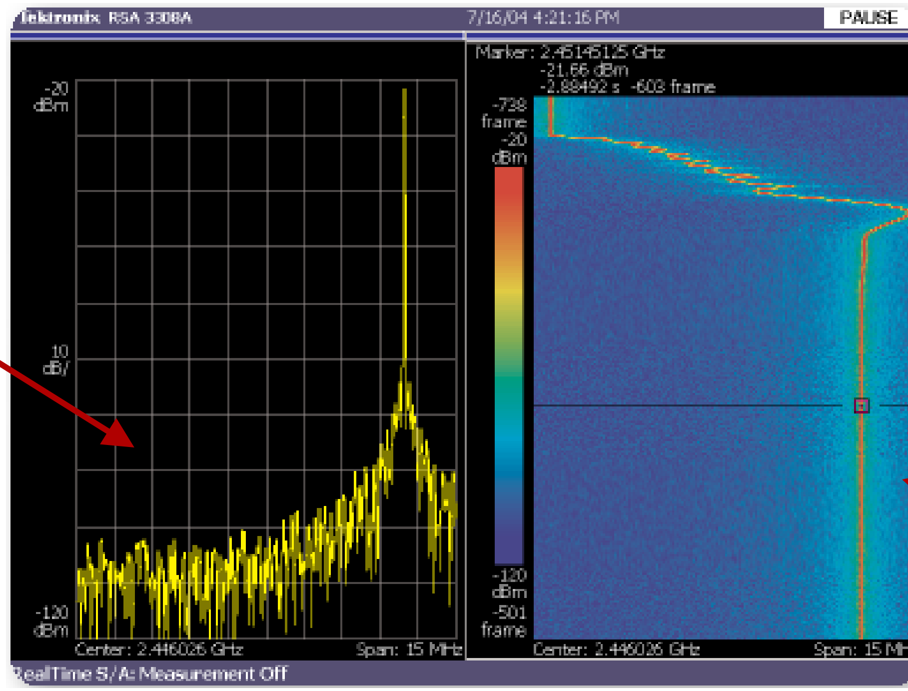
Capturing Transient Events, Using Real-Time SA



- Real-Time Spectrum Analyzers can capture the transient event by triggering the instant that the output of the PLL changes
- Capturing a seamless history of the signal enables the non-linear behavior to be analyzed in both the time and frequency domains

Frequency Changes over Time, Using Real-Time SA

Traditional Amplitude vs. Frequency

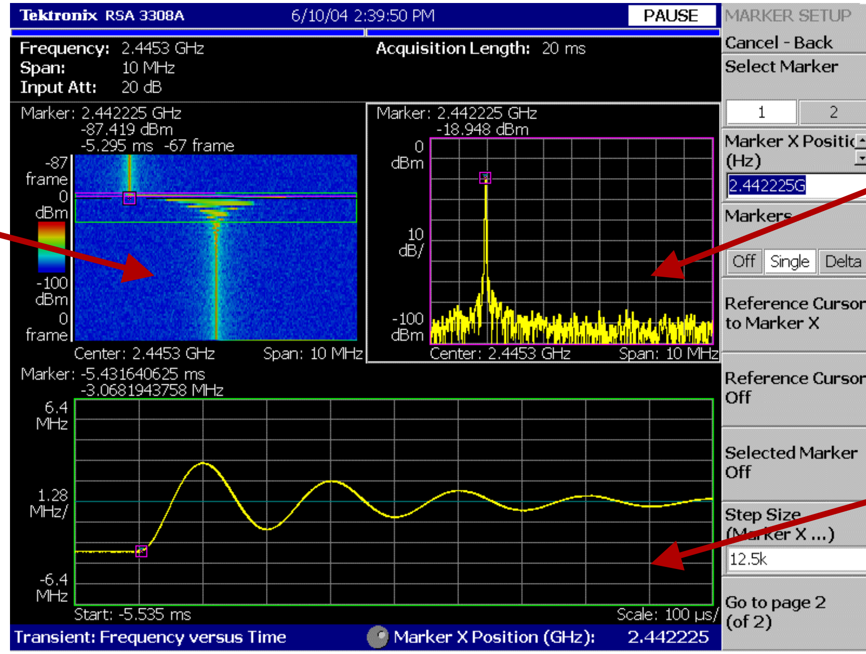


Frequency variation over time

- The dynamic frequency behavior of a PLL determines its spectral output
  - Understanding the spectral output before, during and after the transient event is important for designers
  - To minimize interference spectral mask requirements typically have to be meet at all times
- Viewing frequency changes over time is critical for designers of PLLs

Multiple Domain View, Using Real-Time SA

Transient response of step frequency change



Traditional Amplitude vs. Frequency

Frequency vs. time (settling time)

- Trigger the moment the PLL loses lock
- Real-Time seamless capture ensures no data is missing
- Analyze the single shot event completely with time correlated multi-domain views Increased levels of integration makes the analysis of linear and non linear behavior critical
- Analysis of the transient events in the time, frequency and modulation domains

Live Demonstration of PLL Measurements Using Real-Time Spectrum Analysis

Demonstration Prelude

- The PLL is one of the most common circuits in use today
- Technology trends in PLL development are leading to complex designs:
  - Increasing output frequencies
  - Higher output frequency stability
  - Faster settling time
  - Faster switching speeds
- Commercial demands are leading to the creation of smaller, lower cost PLL
  - PLLs are becoming more integration and are often just a “black box”

Demonstration Measurements

- Several different measurements must be made on a single shot event:
  - Frequency switching speed (Time Domain)
  - Frequency settling behavior (Time Domain)
  - Spectral purity/splatter (Frequency Domain)
  - Transient instabilities

- Repeatability measurements must be made on short, very frequent events
  - Output Frequency
  - Frequency settling time
  - Spectral purity
  - Spectral splatter

Summary
&
Conclusions

Summary & Conclusions

- Modern PLL circuits have limited access for monitoring
- Characterizing PLL's over both time and frequency provides the greatest insight to the circuits behavior
- Settling time in frequency agile systems is very critical for proper timing.
- The tools must be up to the tasks for timely and accurate results.
- Proper signal capturing and measurement are often more than half the battle.