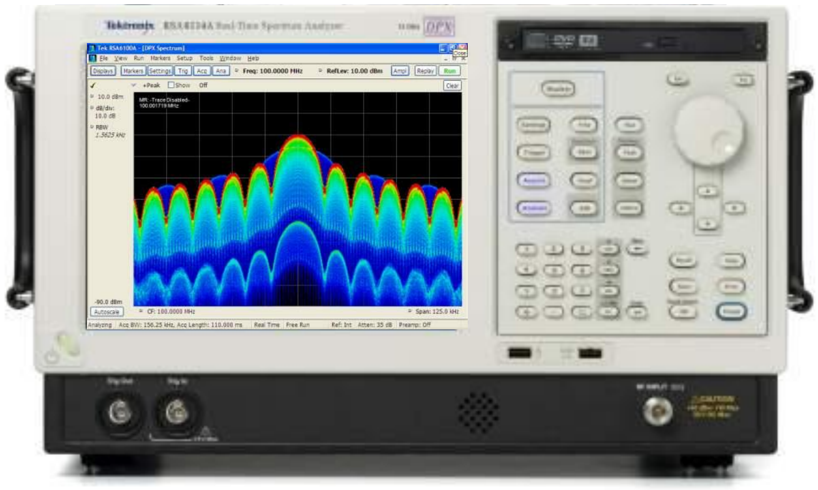
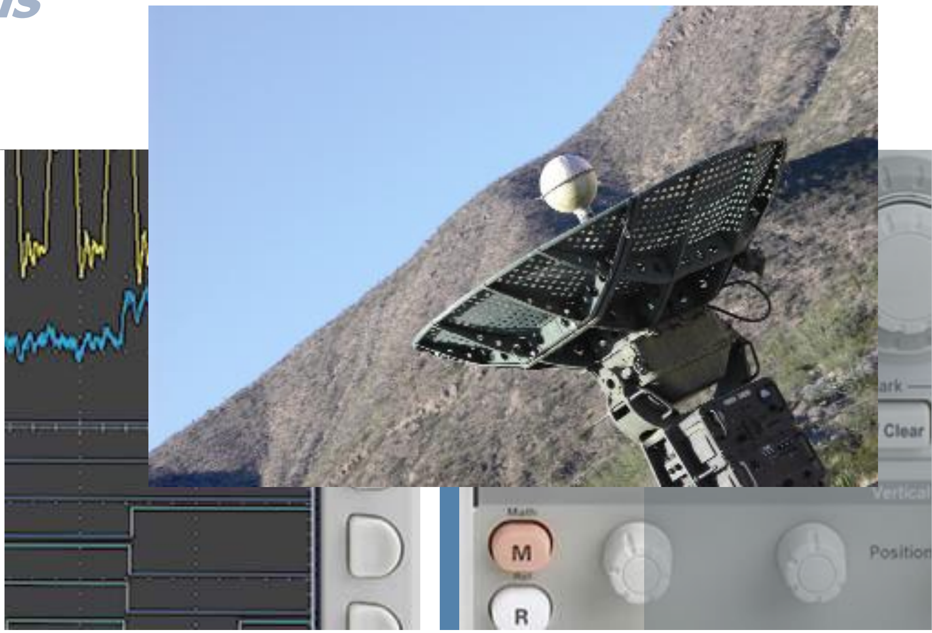
Advanced RADAR / EW

Characterization & Troubleshooting

Using Real Time Spectrum Analysis





Presented by:
Alan Wolke, W2AEW
RF Application Engineer

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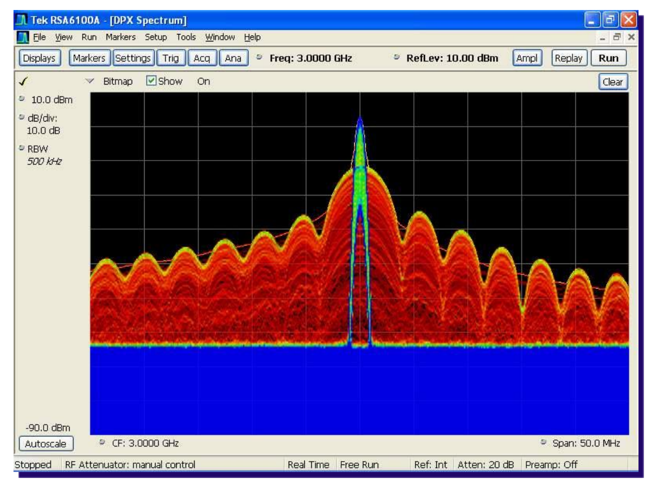
Agenda

- Introduction to RADAR Principles
  - Types of Radar
  - Signal Characteristics and Tool Selection
- What Is Real-Time
  - Viewing “live RF”
  - Triggering on RF phenomenon
  - Real-Time Signal Analysis
- Advanced RADAR Characterization & Troubleshooting
  - Complex Radar/EW visibility
  - Radar/EW signal Trigger & Capture
  - Radar Pulse Characterization
  - Deep dive into:
    - Pulse Compression
    - Pulse Demodulation
    - Chirped pulses and IPR / Time Side-lobe analysis



- Q & A

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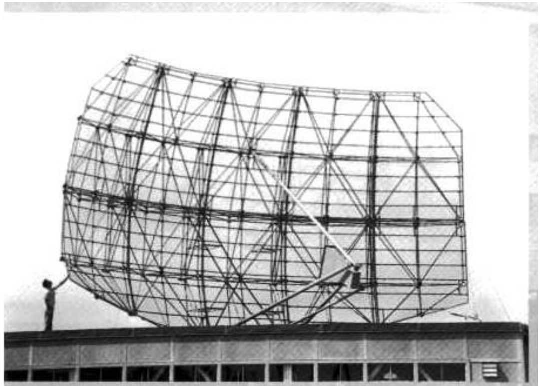
Types and Applications of RADAR

- Continuous Wave “CW”
  - Usually Bi-Static and ground based
  - Can not measure range
  - Usually used for long-range surveillance (i.e. Distant Early Warning, or DEW)
- FM-CW
  - Adds FM modulation to the signal which allows for ranging
- Passive Radar
  - Uses ambient radiation such as radio signals, cellular signals and other radars
  - No transmit signal of its own, very stealthy



Full-size Sentinel radar antenna on the roof of Building C at Lincoln Laboratory, circa 1955. The man at left shows the scale of the antenna.

Model of the Sentinel radar, a long-range Doppler-capable automatic-alarm radar operating at 600 MHz, 3-kW average power, part of the DEW Line system, 1955.

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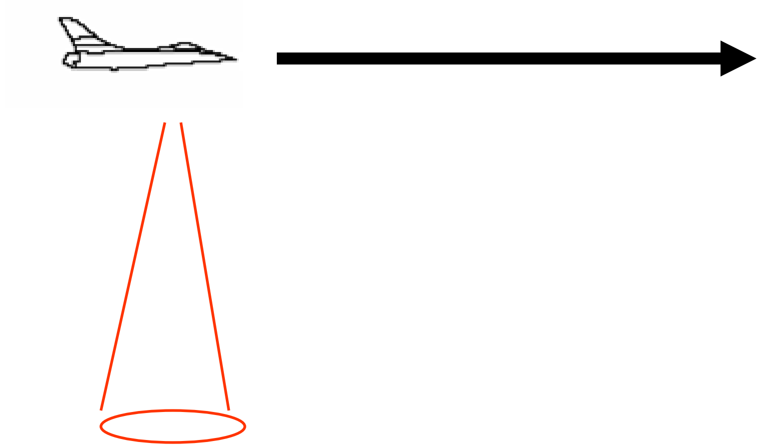
Types and Applications of RADAR –

- Pulsed Radar
  - Moving Target Indicator (MTI)
    - Long range, low PRF
    - Detect and track small (~2m^2) moving targets at long distances (~30km) by eliminating ground clutter (or chaff)
    - Not concerned with velocity, “just tell me if something is moving”
  - Pulsed Doppler
    - High PRF to avoid “blind speeds”
    - Shorter “unambiguous” range (~15km), high resolution, detailed velocity data
    - Airborne missile approach warning, Air Traffic Control, medical applications (blood flow)

Types and Applications of RADAR – cont'd

- Synthetic Aperture radar (SAR)
  - Antenna aperture determines spatial resolution. A larger aperture results in greater spatial resolution
  - Movement of the transceiver (plane) scans the target (ground)
  - DSP integrates results of multiple into a single larger (synthetic) aperture, improving spatial resolution
  - Huge DSP processing required

- Inverse SAR (ISAR)
  - Movement of the target does the work
  - Movement of the target is scanned multiple times by the stationary transiever
  - Huge DSP processing required



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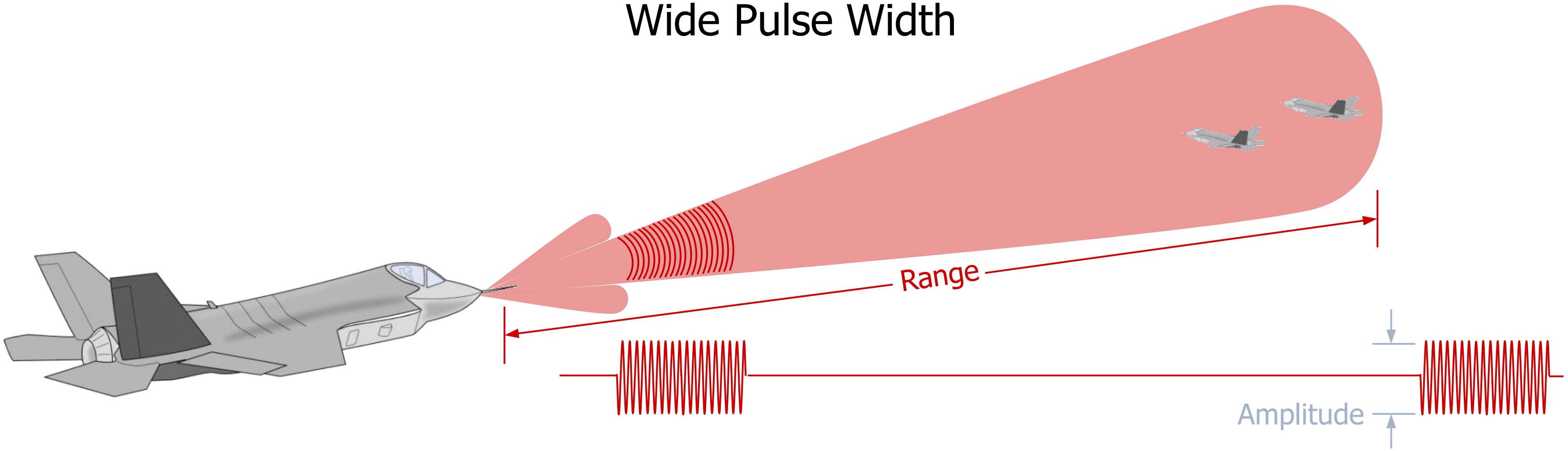
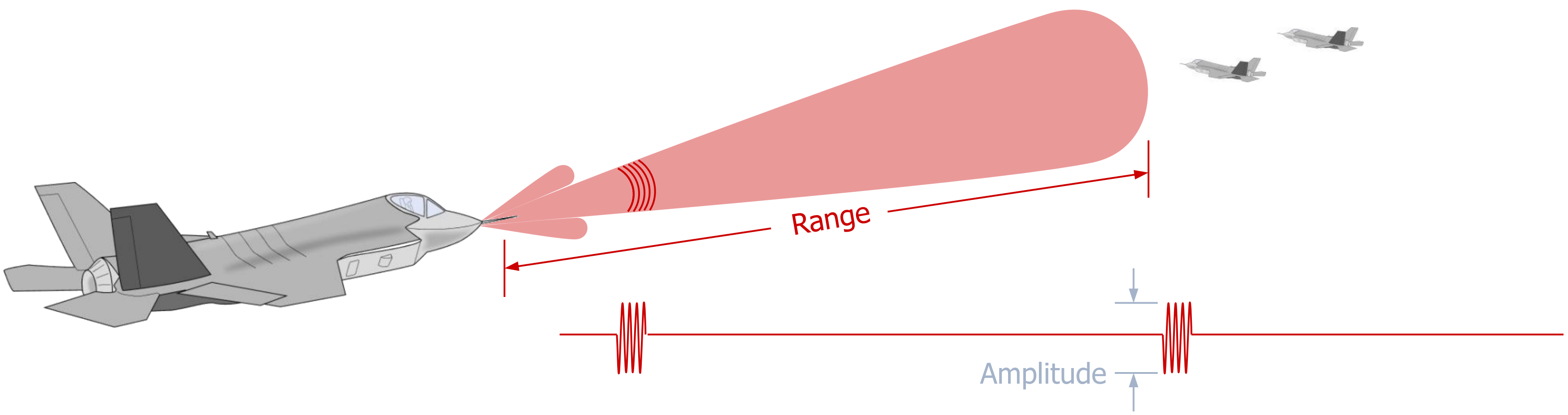
Range Versus Resolution

Wide Pulse Width

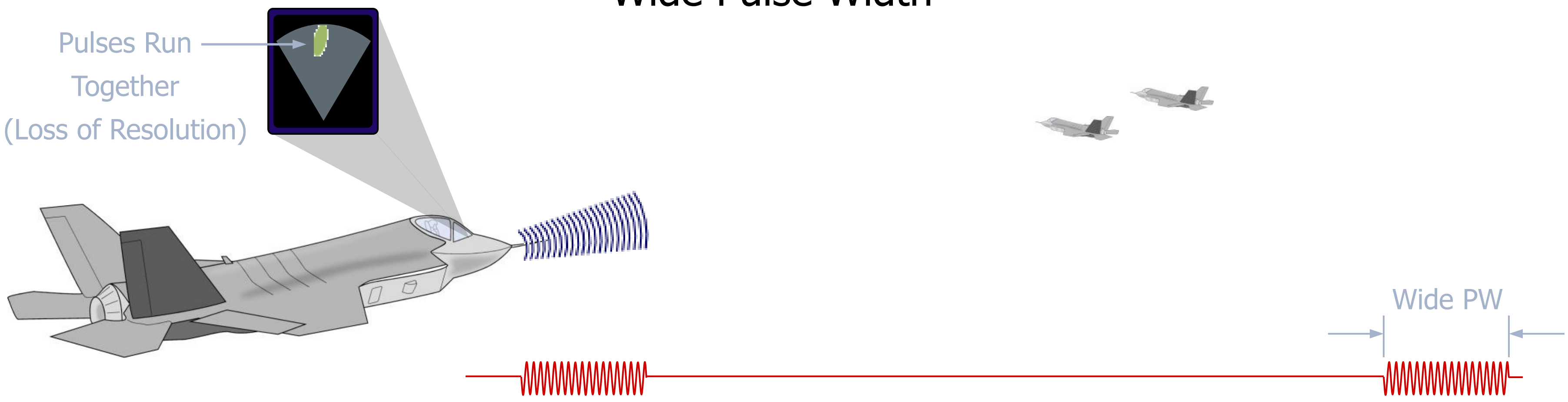


Narrow Pulse Width

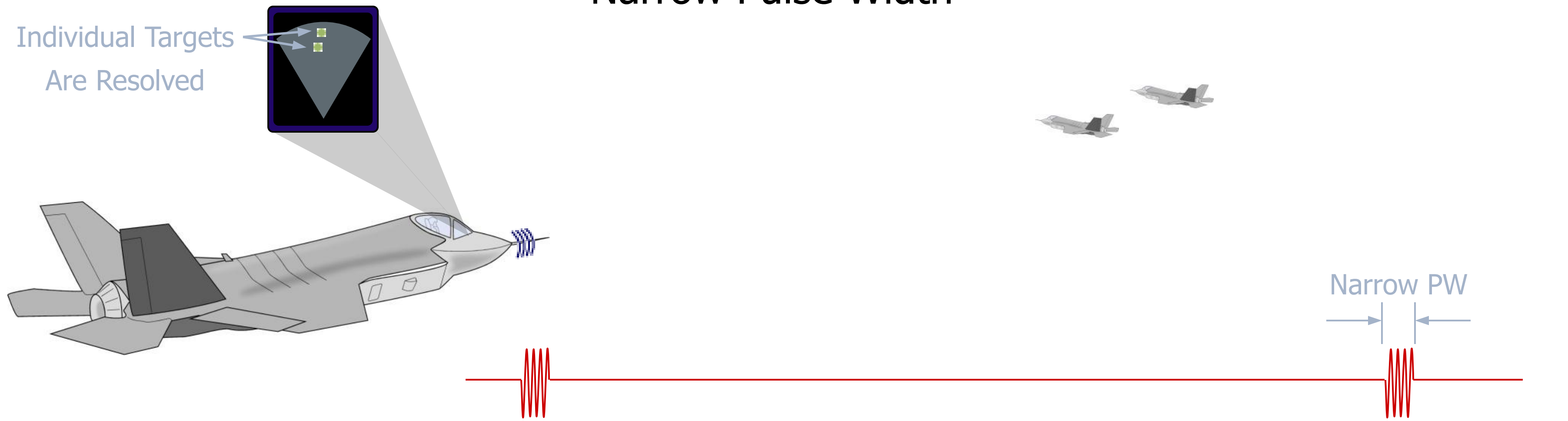


Radar Resolution

Wide Pulse Width

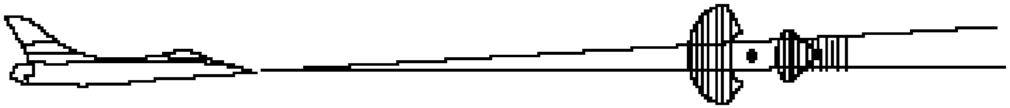


Narrow Pulse Width



Why Use Pulse Compression?

- **PW determines resolving ability (small is better) - BW ~ 1/PW**



- **PW affects average power (absolute range, large is better)**

$$P_r = \frac{P_t G_t A_r \sigma}{(4\pi)^2 R_t^2 R_r^2}$$

- Pulse compression allows use of a long pulse (for long range) while maintaining good resolution

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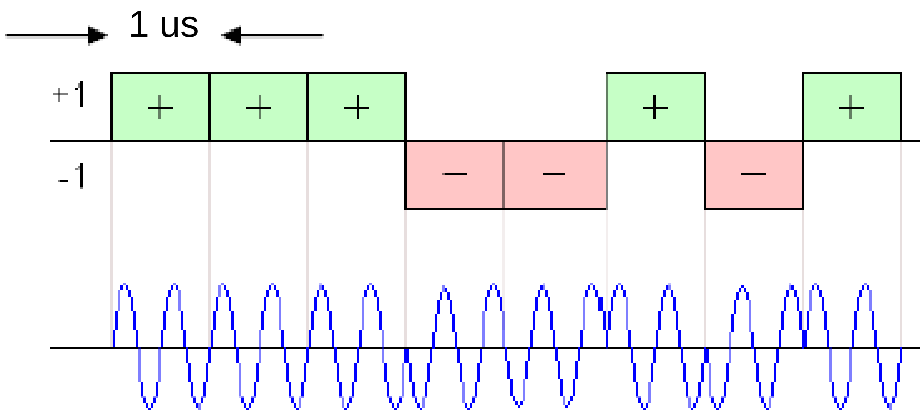
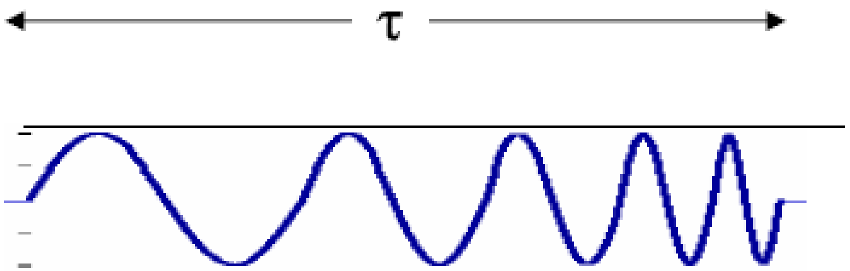
Pulse Compression – Techniques





Phase Coding

Bi-Phase

Barker, Pseudorandom
Golay

Poly-Phase

Frank, Welti, P4

or

Frequency Modulating "Chirping"

Linear or Non-Linear
Stepped

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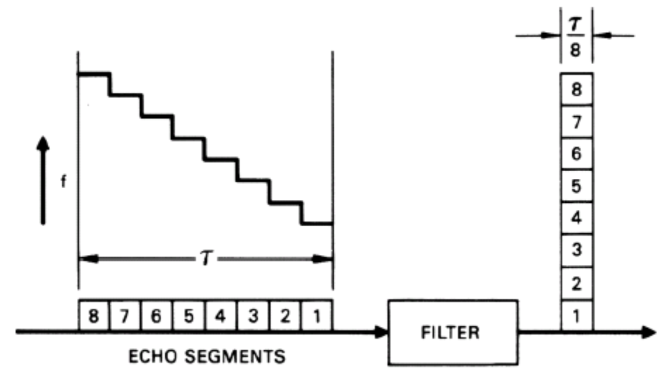
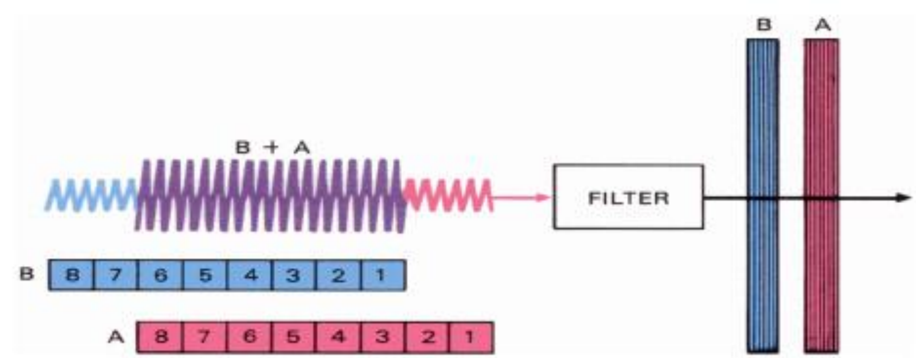
Pulse Compression

- Radar systems that use modulation within the pulse are referred to as "pulse compression" radar systems.
- The compression occurs in the receiver, not the transmitter
- Each echo segment has a unique frequency or phase component, allowing the receiver to discriminate time within a single pulse
- The most common is linear FM ("chirped")

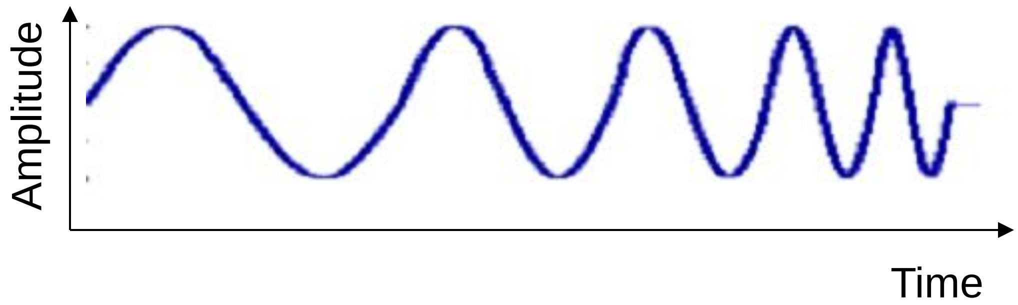


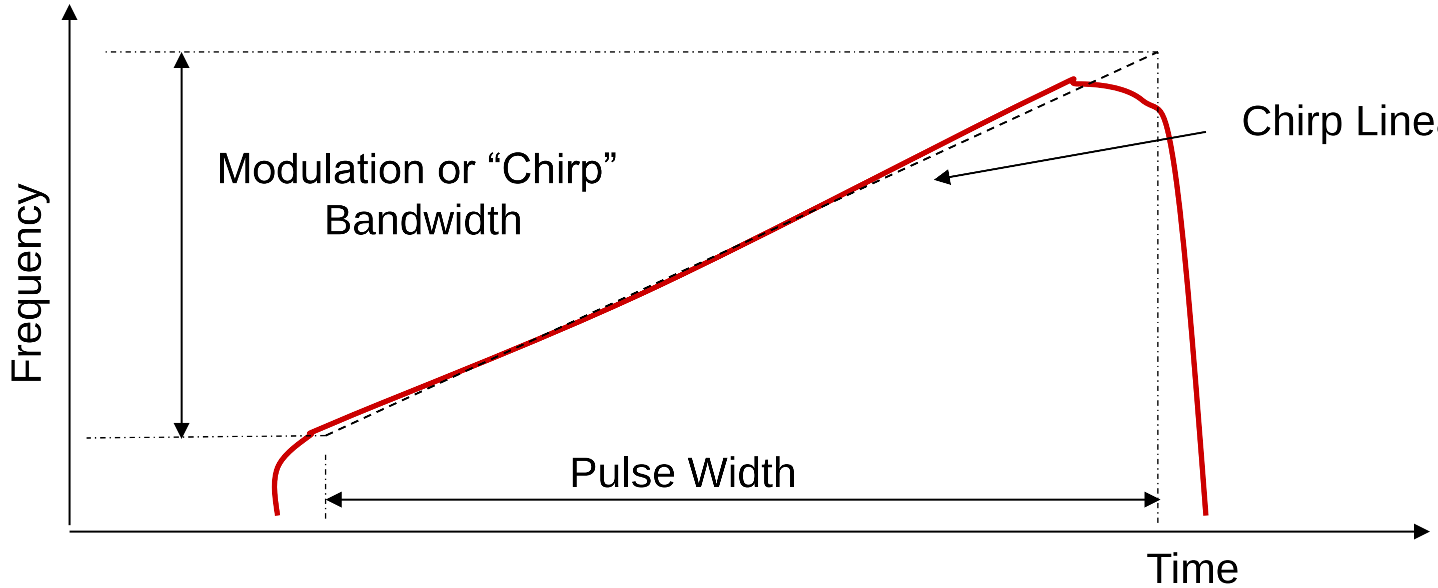


Echoes from closely spaced targets, A and B, are merged but, because of coding, separate in output of filter.

Pulse Compression- LFM "Chirp"

- RF frequency of the pulse continuously changes over the pulse duration in a linear ramp





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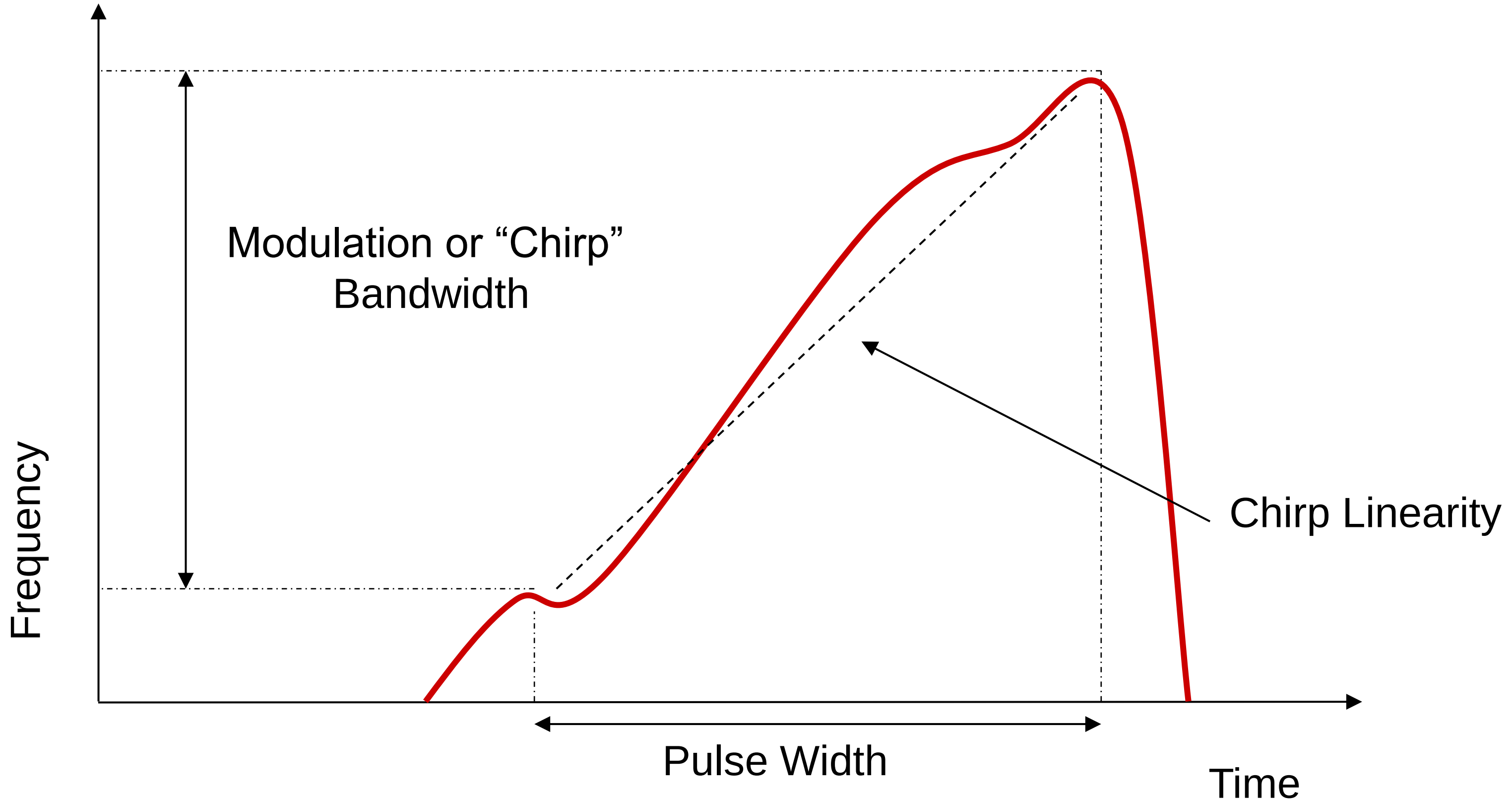
Frequency Modulated Pulse – Key Parameters



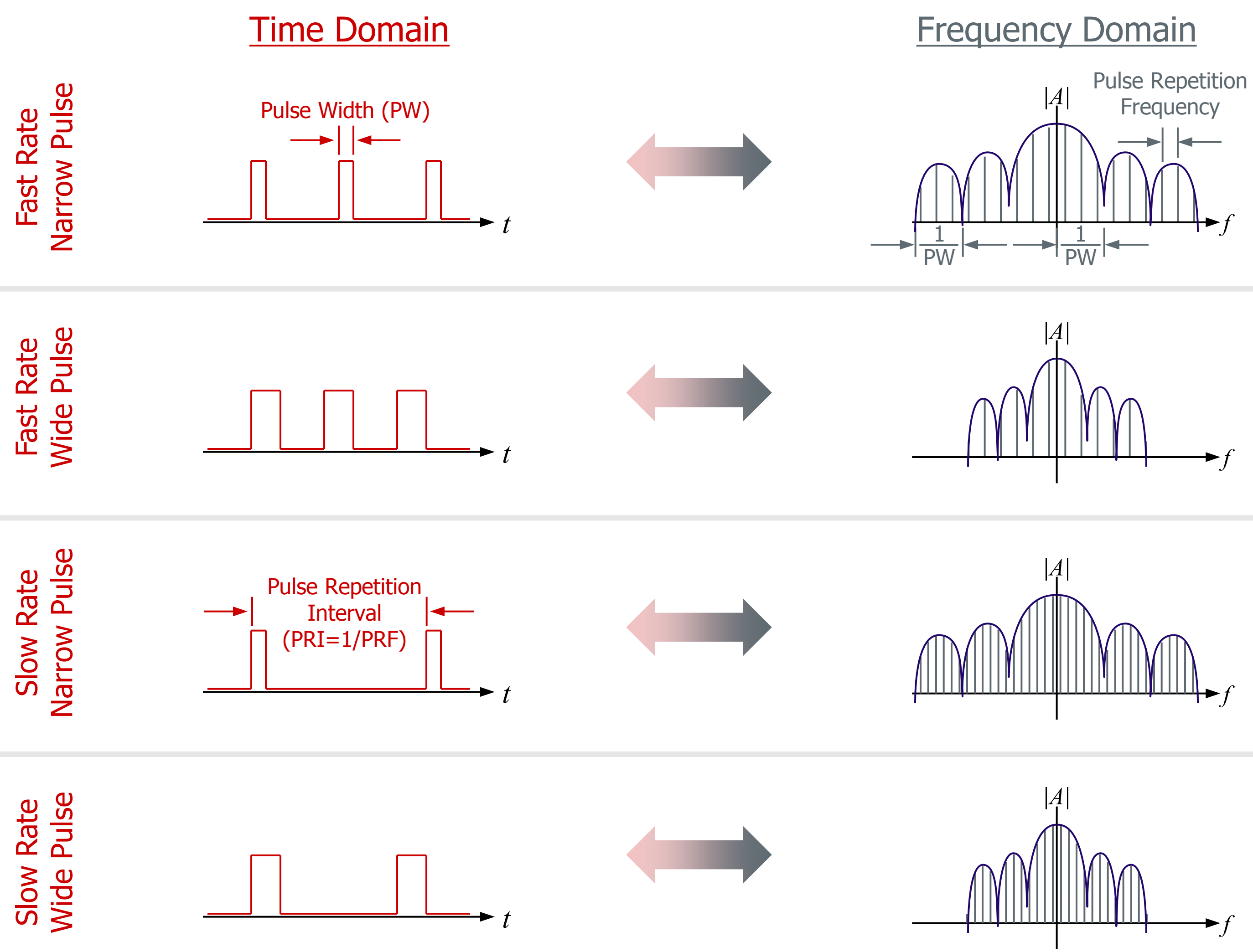
- Non-linearities in the chirp cause distance and speed errors in the radar

Key Understanding of Pulse Compression

- Compressed pulses are Transmitted longer in time, not shorter
- Compression is occurring in the Receiver
- Benefit is to achieve higher radar resolution with same peak transmit power
  - Distinguish between multiple targets in close proximity
- Higher resolution achieved by how much pulse signal BW and frequency resolution you have
- DSP techniques can be used for further gains…
  - Digital modulation – BPSK, QPSK

Overview and Tool Selection

Pulse Parameters: Time & Frequency Correlation, Bandwidth



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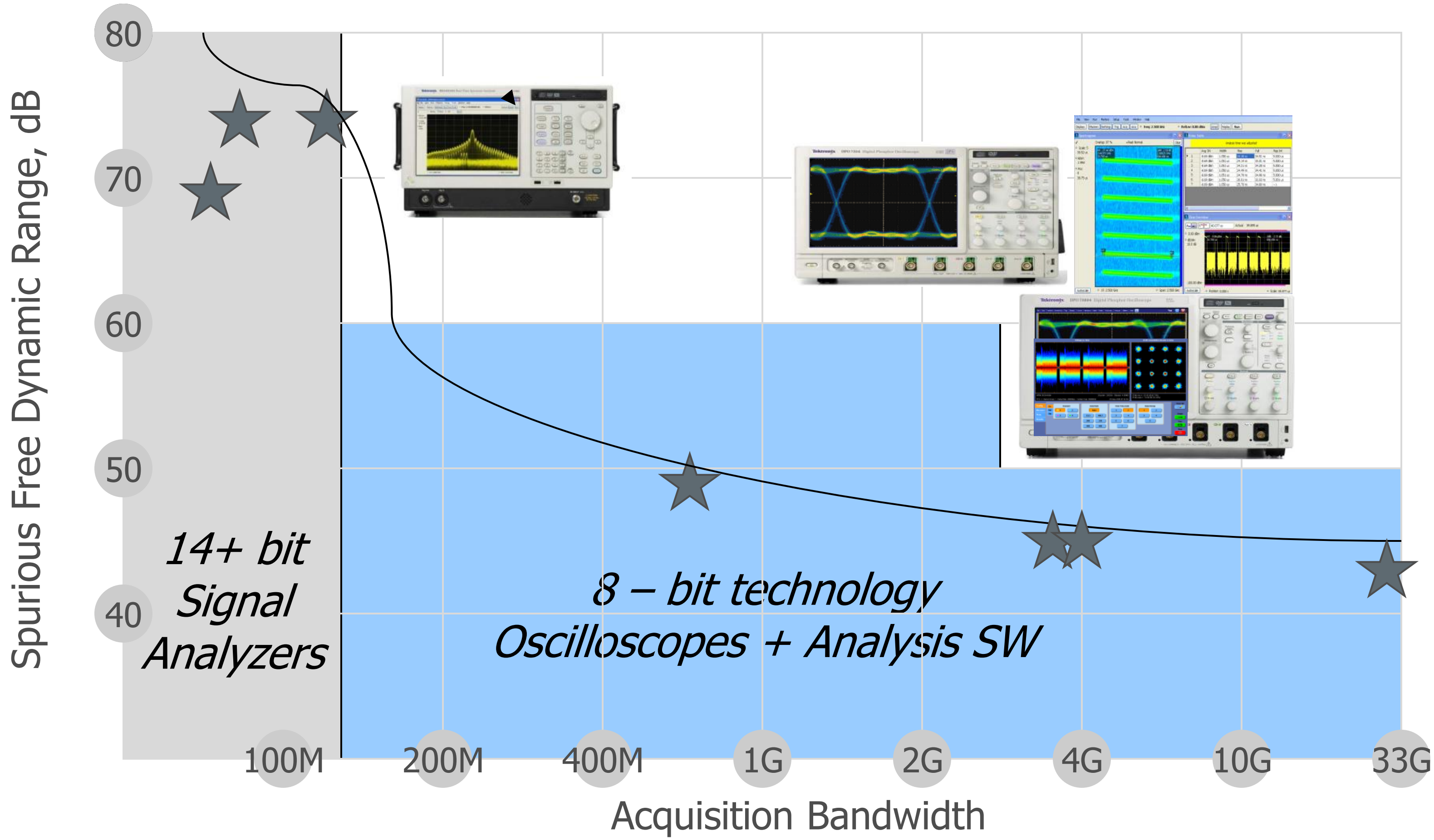
Overview and Tool Selection
Analysis Tools for Radar

Industry Leading Tools for Bandwidth/Dynamic Range



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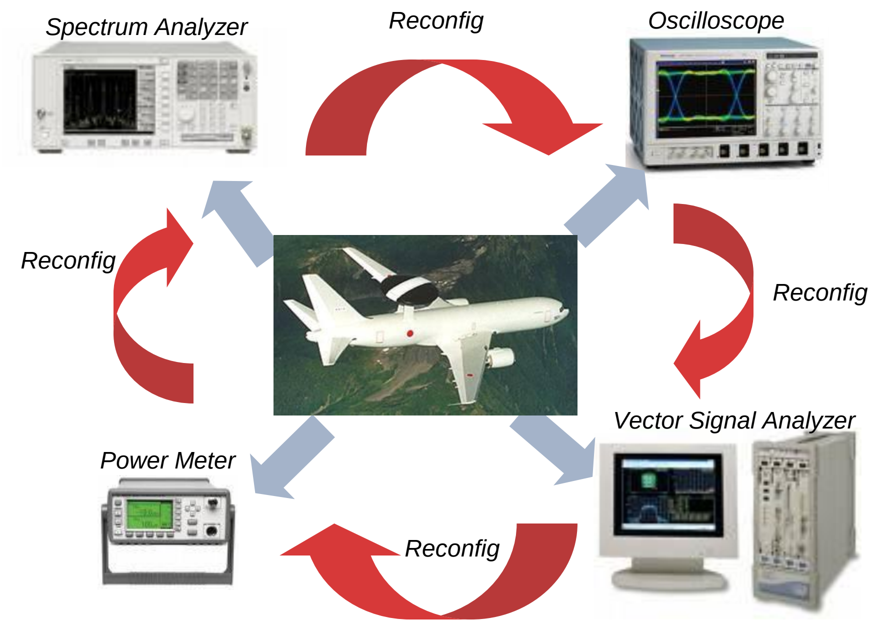
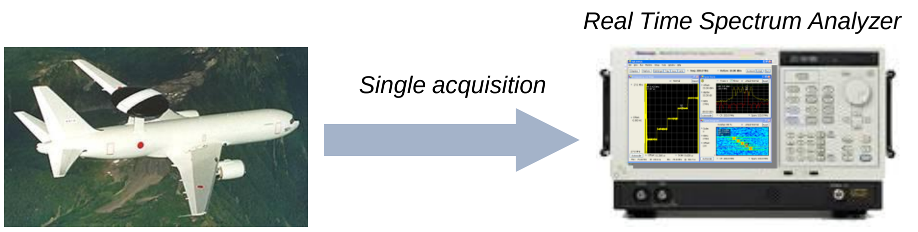
Analyze - Multi-Domain Analysis Reduces Test Times

- Traditional Radar Test
  - Spectral Occupancy, Spurious, PW, PRI
  - Special Modulations
  - Pulse Characteristics (rise time, droop, overshoot)
  - Peak and average power
- Multiple test configurations
  - Configuration changes take time
- Multi-Domain Analysis Benefits
  - Many test types on ONE acquisition
  - No re-configuration of equipment
  - Test multiple parameters with one unit
- Time Savings
  - Discovery and Triggering
  - Unique “Replay” analysis options
  - Fast narrow-RBW searches
- *TIME is MONEY*
  - Reduced test time
  - Reduced equipment needs





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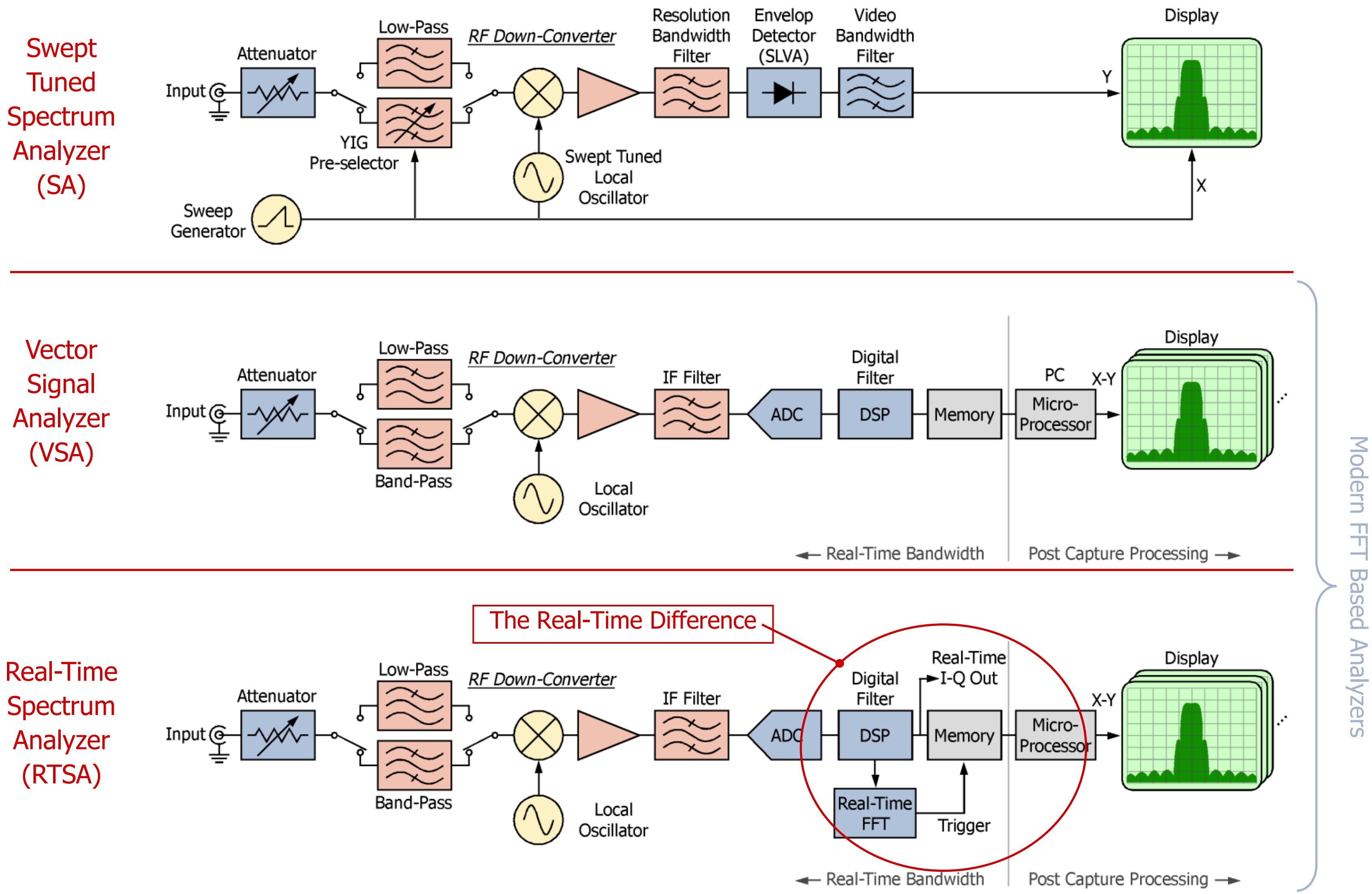
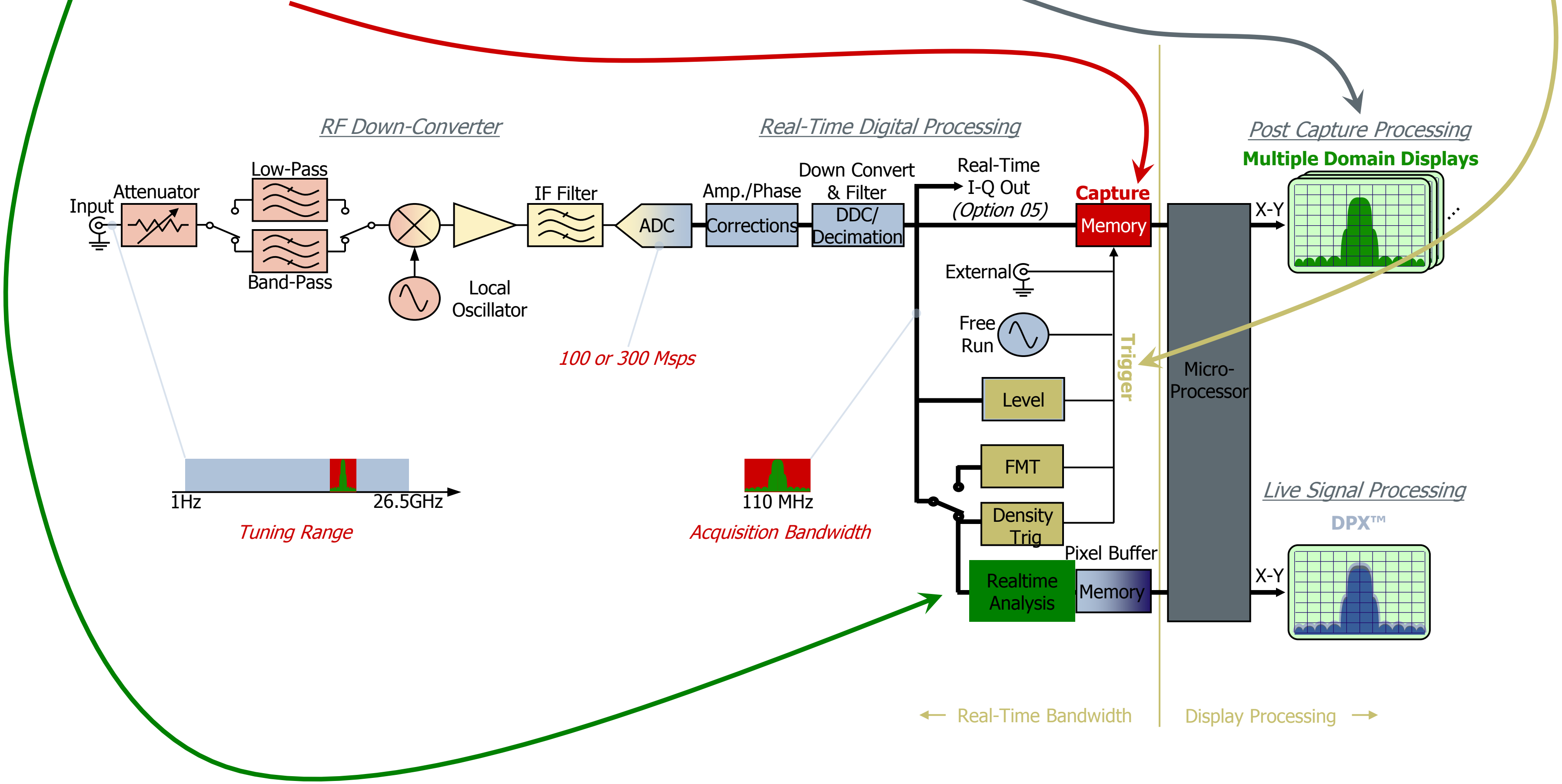
Simplified Analyzer Block Diagrams

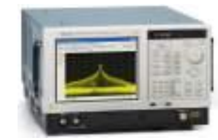


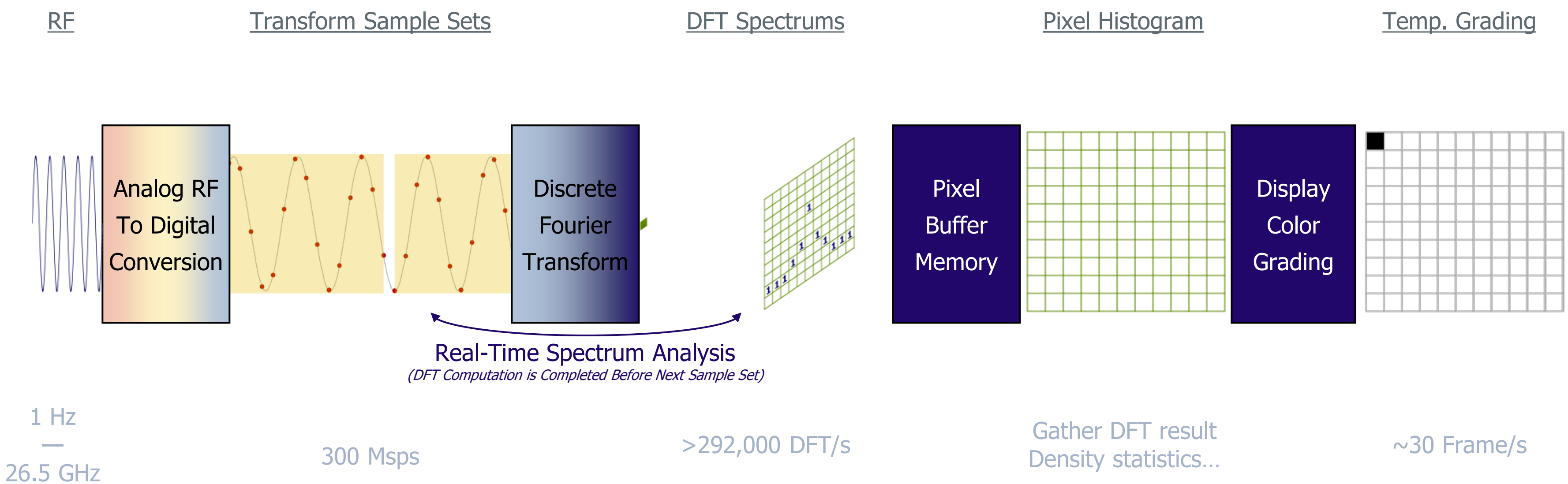
Real-Time Spectrum Analysis: Simplified Block Diagram

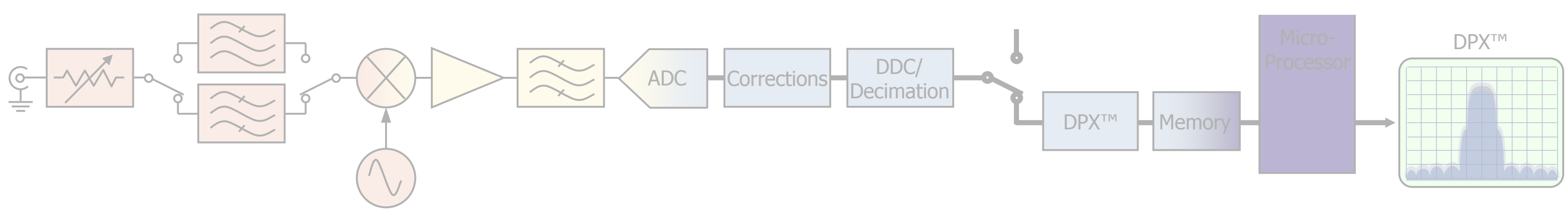
- ***Discover*** with DPX™, ***Trigger*** in powerful ways
- ***Capture*** signals into memory, ***Analyze*** in Multiple Domains



The Real-Time Spectrum Transform Engine







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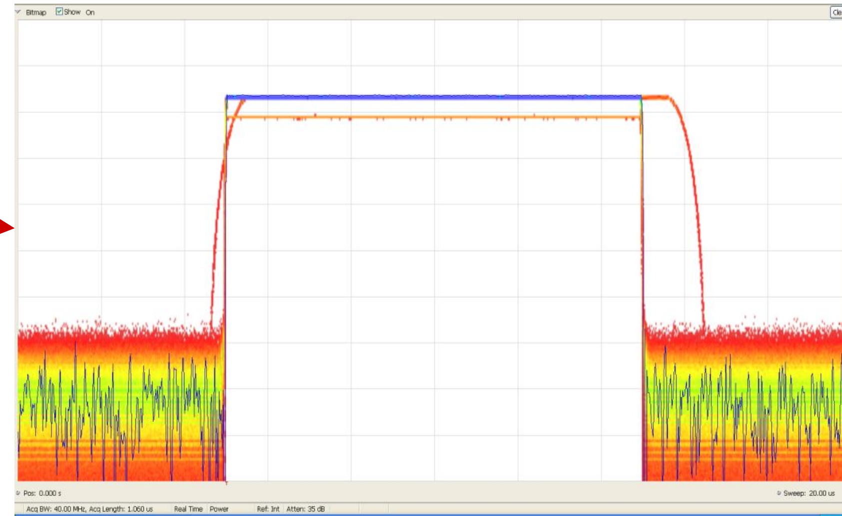
Demonstration of Real-Time Spectrum Analysis

- Live RF signal observation – see what your receiver is seeing!
  – See RF signals in a way that you've never seen before
  – See signals "under" other signals, signals in the noise floor
  – Observe interaction of multiple RF sources
- Unmatched Wideband RF Signal visibility
- Unmatched infrequent event POI – infrequent carrier frequency glitch
  – DPX™ shows you the infrequent glitches that drive you crazy
  – Arms you with the knowledge to debug…

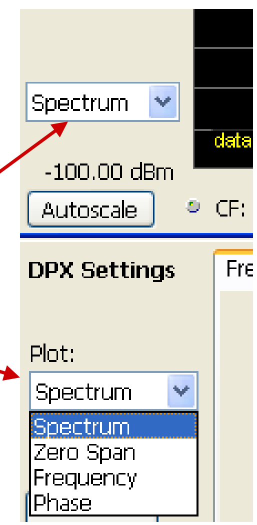
More Real-Time Display modes…

- Real-Time applied to other domains…
- Zero-Span (pictured)
  - Show Amplitude vs. Time LIVE!
  - 50,000 waveforms/sec
  - CATCH infrequent events others miss
  - User selectable BW
- Frequency vs. Time
  - Show Frequency Deviation vs. Time
  - Live frequency discriminator
  - Helpful with Freq Edge Trigger…
- Phase vs. Time
  - Live Phase deviation vs. Time



Accessible via Drop-Down

…in DPX Display
or
…in DPX Settings



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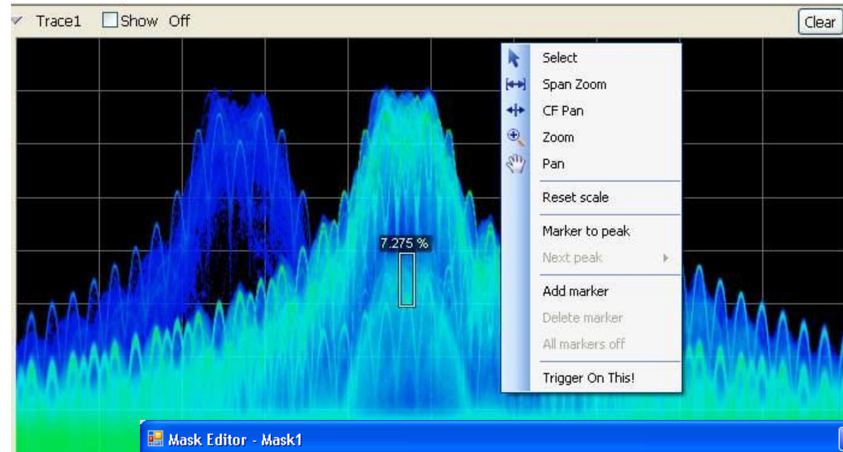
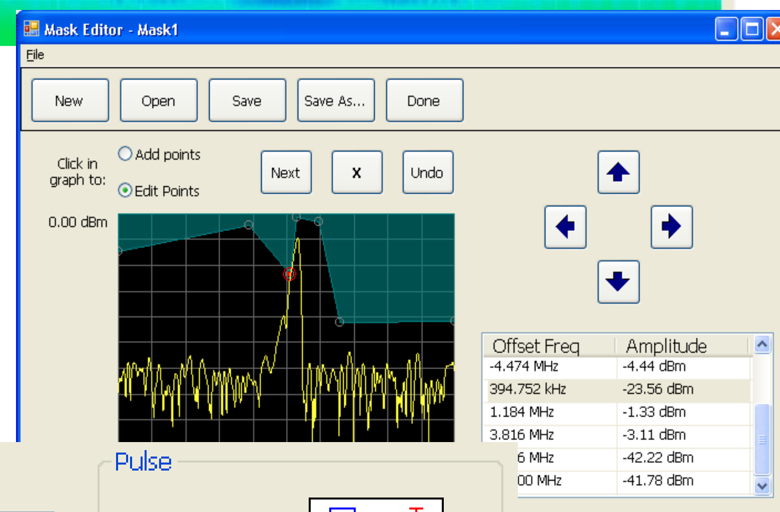
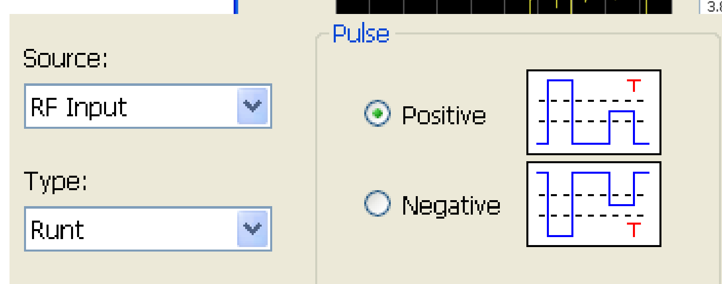
Powerful *Triggering* Features

- **Density Trigger**
  - *Trigger on This!*
  - Signals under signals, etc.
- **Frequency Mask Trigger** (FMT)
  - Flexible Amplitude/Frequency discriminating trigger
  - Simple mask creation on Spectrum, up to 500 points
- **Power/Amplitude Trigger**
  - Full SPAN or band-pass filtered
  - Adjustable threshold/polarity
- **Runt Trigger**
  - Trigger on Pulse Amplitude variations
- **External Electrical Trigger**
  - Two electrical trigger inputs
  - Independent or Gated

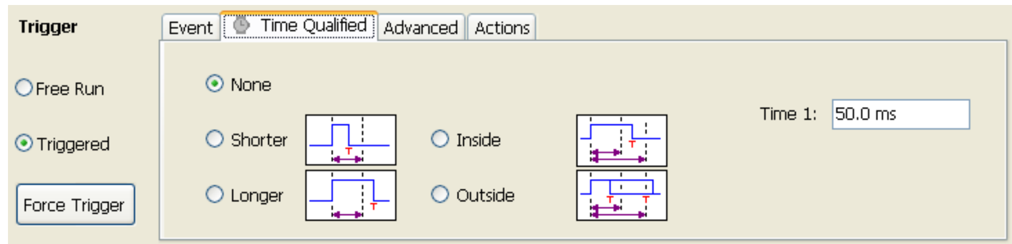






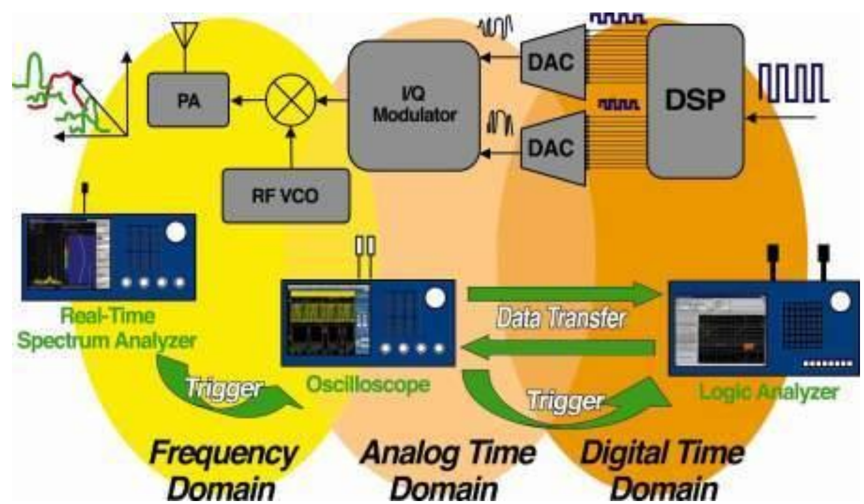
Advanced Trigger Functions

- **Time Qualified Triggering**
  - Apply to ANY trigger mode/event
  - Trigger on specific event durations



- **Save on Trigger**
  - IQ Data
  - Image

- **Cross-Trigger Capabilities**
  - Trigger RSA from Scope or LA
  - Scope or LA triggered from RSA
  - RSA Triggers Arbitrary Waveform Generator



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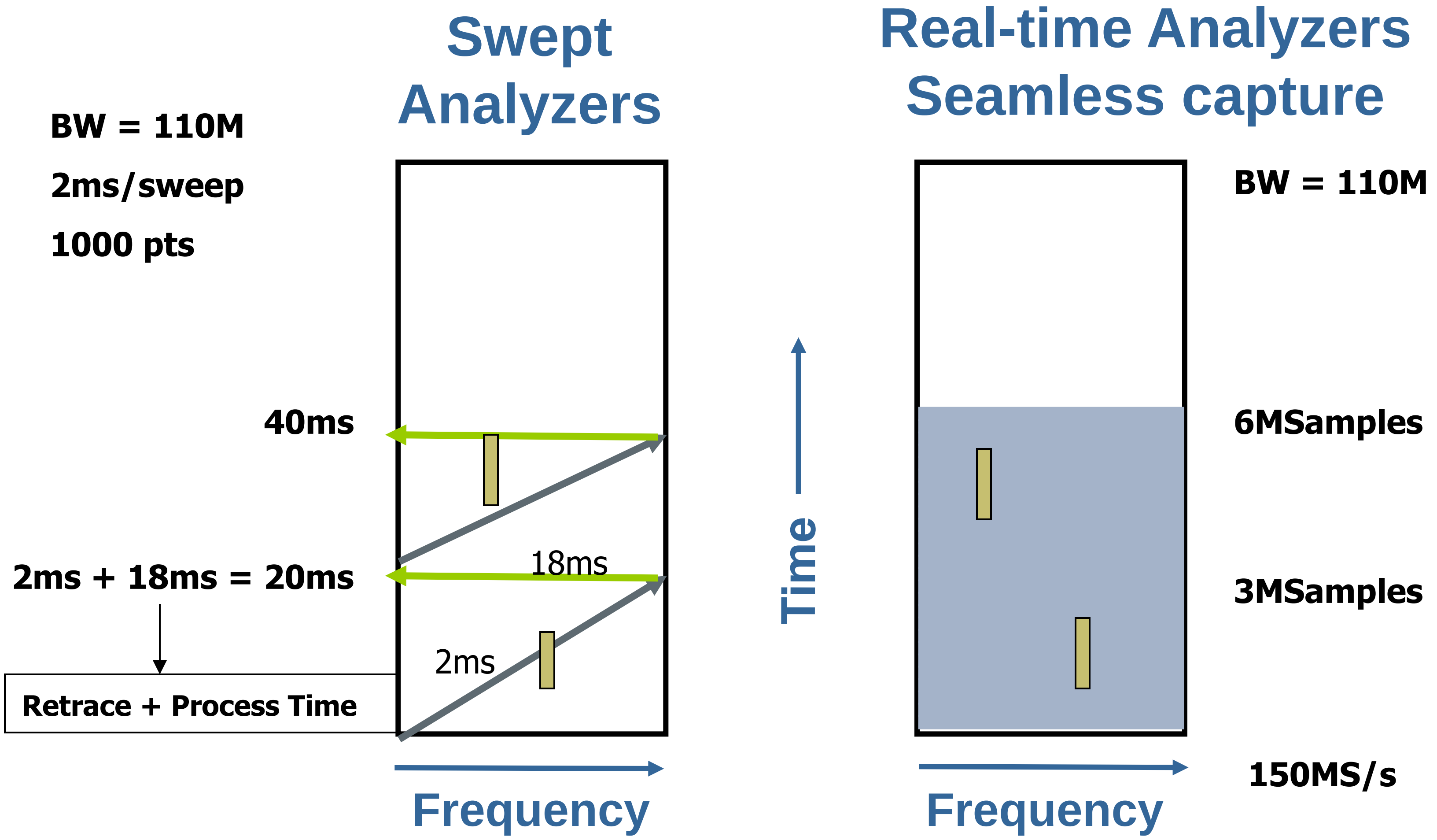
Swept vs. Real-time Seamless ***Capture***



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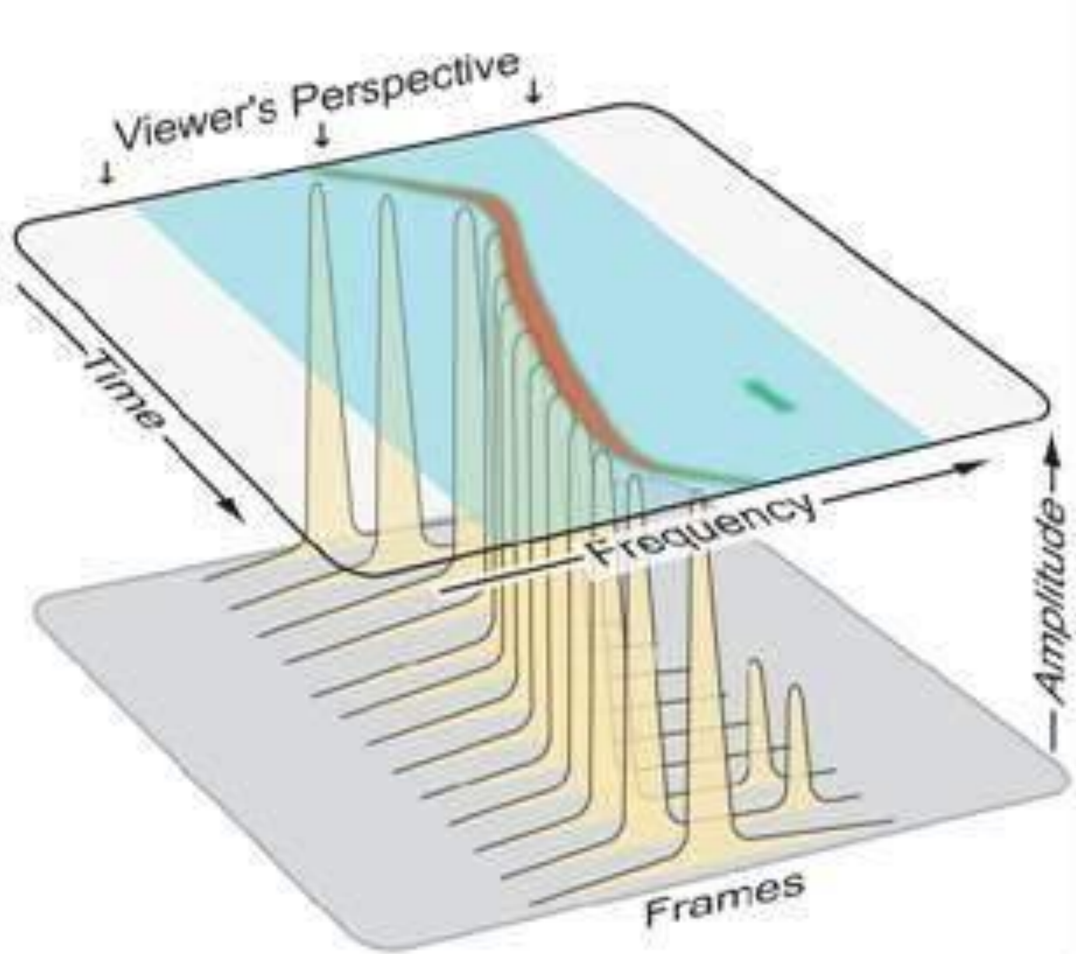
Seamless Capture and Spectrogram

- 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



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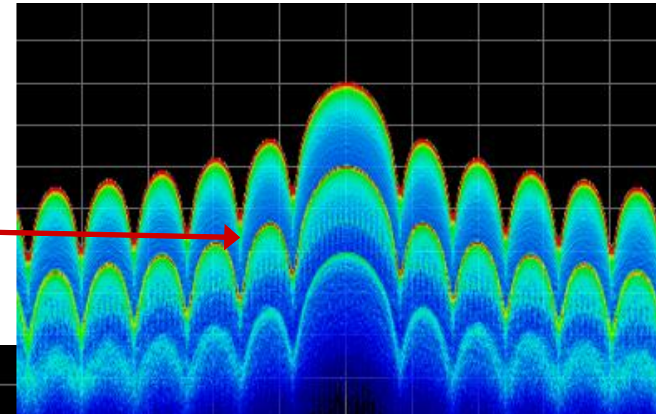
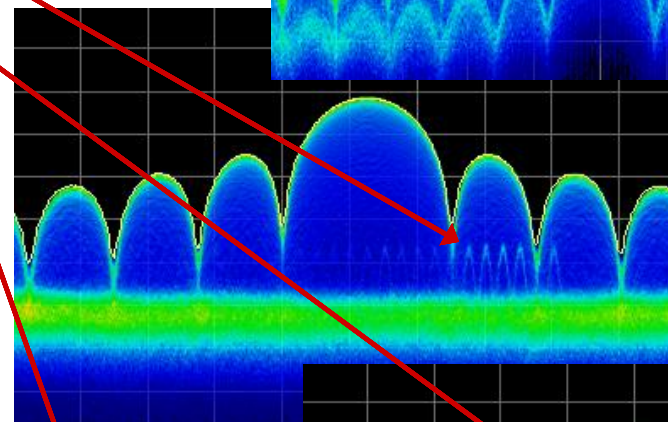
Trigger, Capture, Analyze Demos

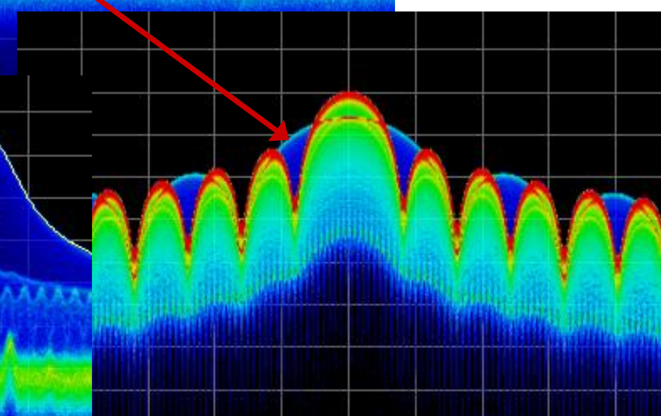
- Frequency Mask Trigger
  - Trigger on change in spectrum of signal
  - Capture and Analyze in multiple domains
- Spectral Density Trigger
  - “point and shoot” triggering on frequency hop
- Trigger on signals under signals
  - Trigger on things that nothing else can!
- Runt & Time Qualified Triggers
  - Trigger on mal-formed pulses
  - Trigger on specific pulse widths and repetition intervals

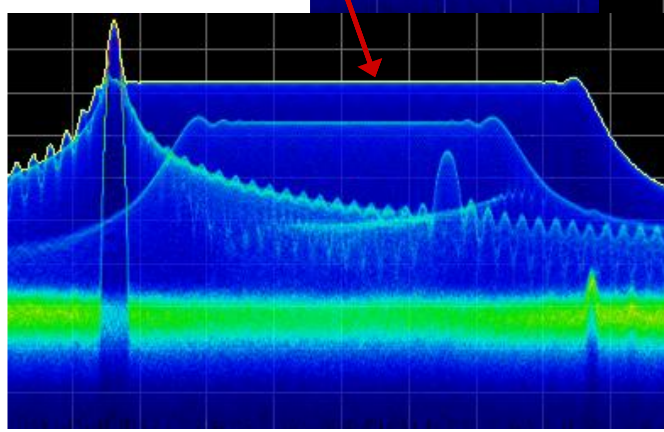
Troubleshooting Radar Systems

- The **Real-Time** Difference
  - See multilevel activity
  - See what interferers are hiding
  - Catch those infrequent glitches
  - Debug and understand complex signal behavior
- Powerful Triggering to capture the events
- Comprehensive Multi-domain analysis for pulsed signals









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Analysis of a "Live" RADAR signal…

- DPX provides valuable insight
  - See spectrum of pulses
  - See spectrum of noise between pulses
  - Observe anomalies in the spectrum…
- Capture and Analyze pulses quickly…
  - Look at multiple domains to understand pulse characteristics
  - Zoom in to check pulse trends and pulse characteristics
  - Multiple displays help to uncover the anomalies

…But there's more….

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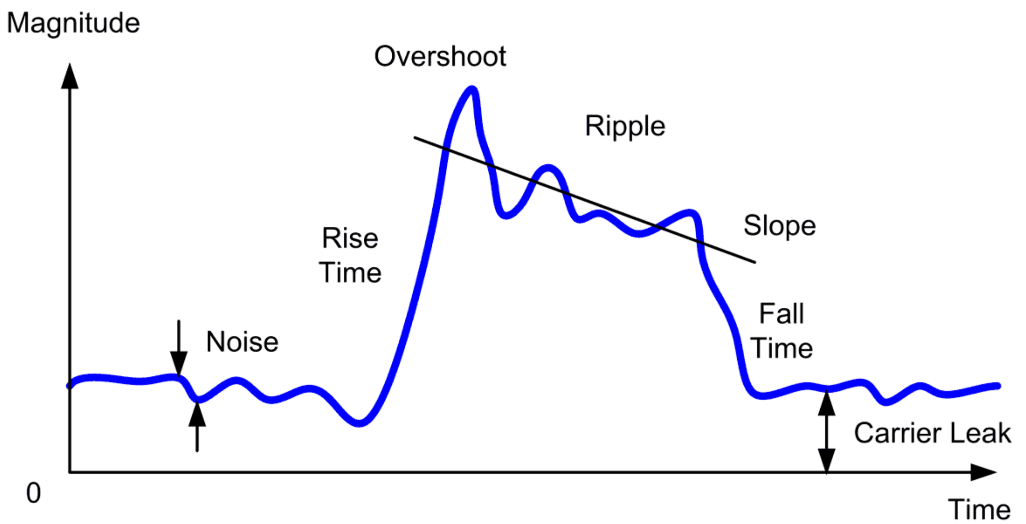
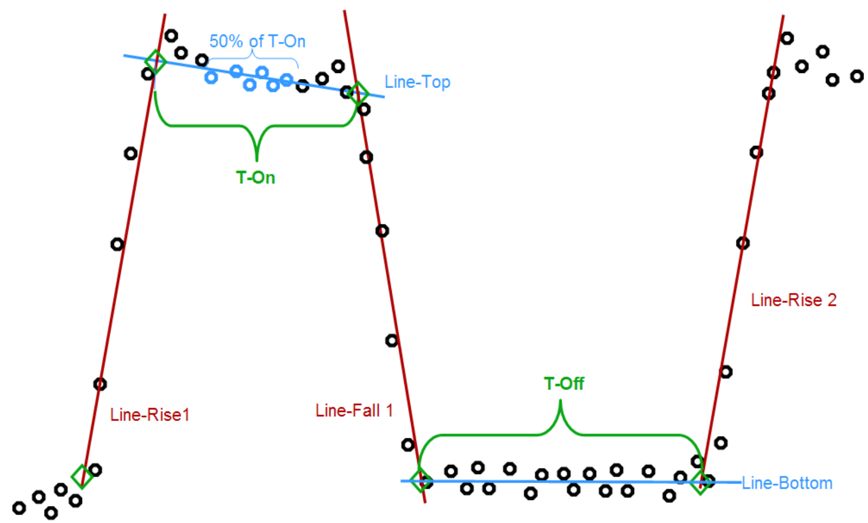
Setting Measurement Parameters



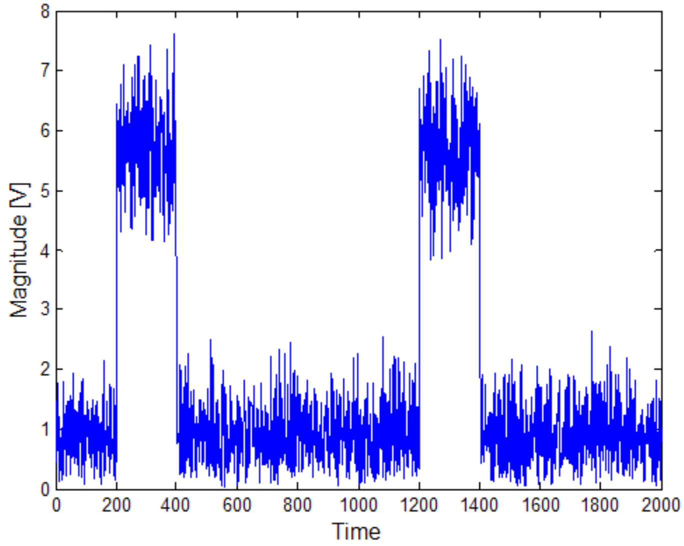
- Measurement Filter
- Bandwidth
- Power threshold
- Minimum OFF time
- Number of Pulses

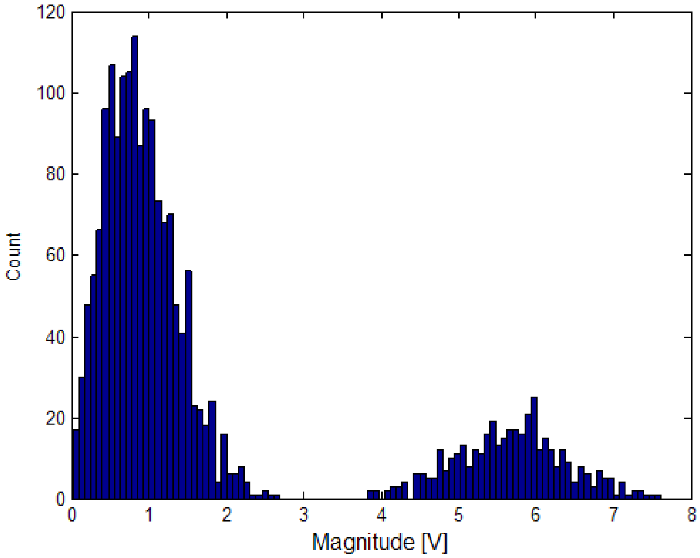


Automatic Measurement: Theory of Operation
Finding the Pulse

- Magnitude Histogram

  – Clean Pulses with good signal to noise ratio have bi-modal histogram





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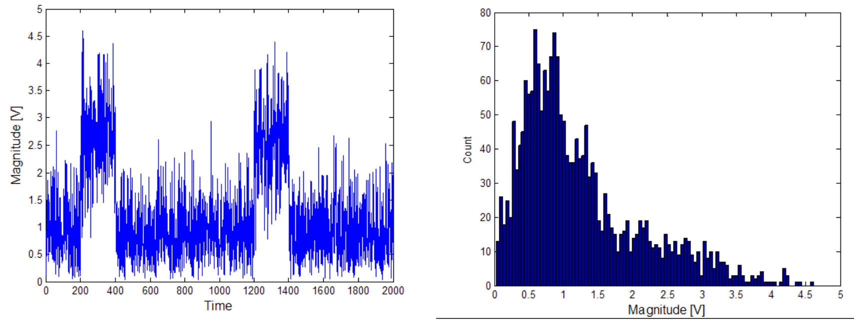
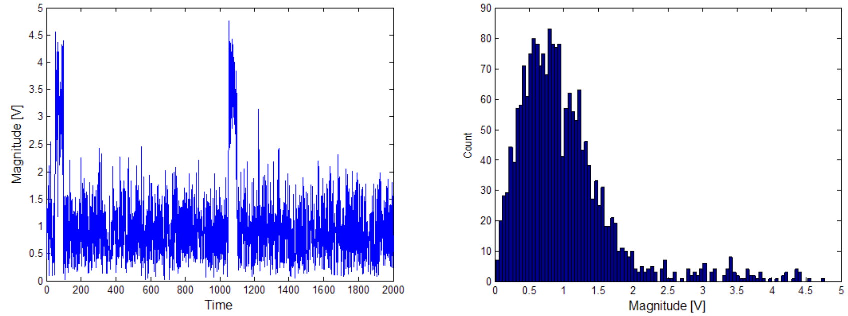
Automatic Measurement: Theory of Operation
Finding the Pulse

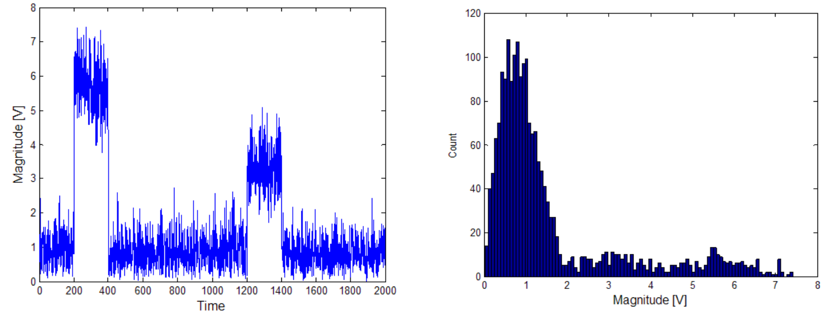
- Potential problems with Magnitude Histogram
  – Not all pulse patterns fit this detection method
  – Poor S/N



  – Narrow Pulses

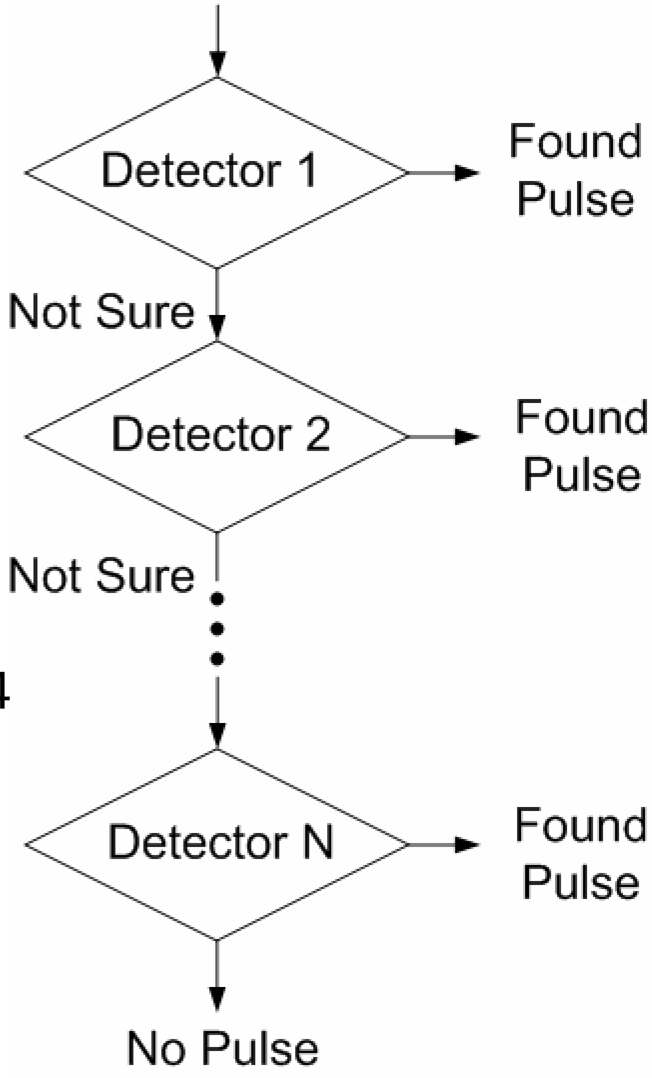


  – Variable Levels

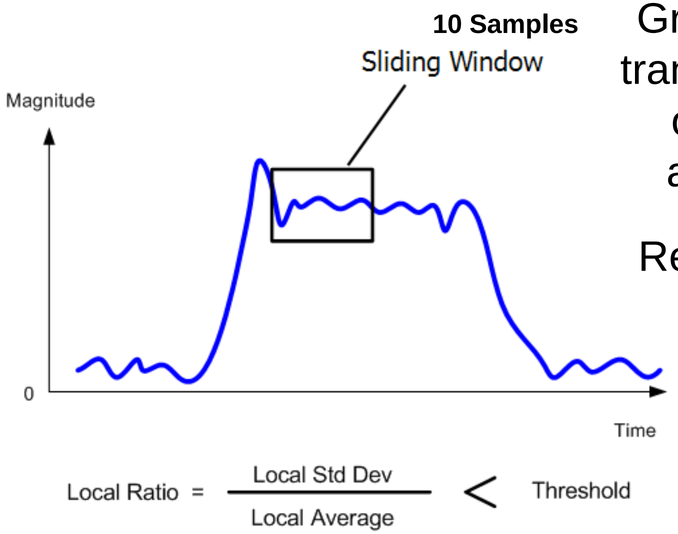


Automatic Measurement: Theory of Operation
Finding the Pulse

- Method 1: Magnitude Histogram
- Method 2: Local Statistics
- Method 3: Moving Average
- Noise Histogram – preparation for method 4
- Method 4: Least Squares Carrier Fit

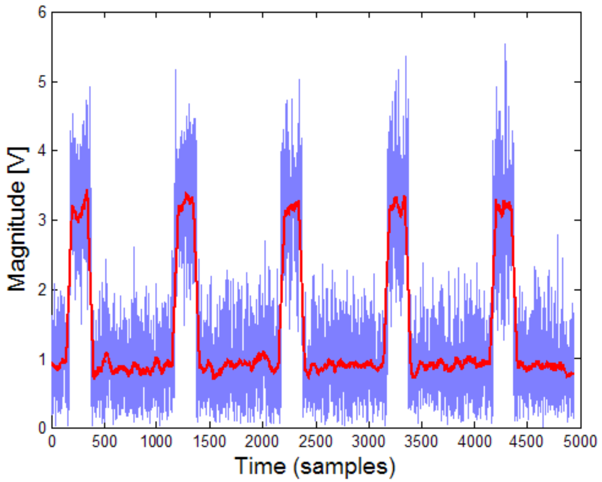


Automatic Measurement: Theory of Operation
Finding the Pulse



Great for slow transition times, or multiple amplitudes

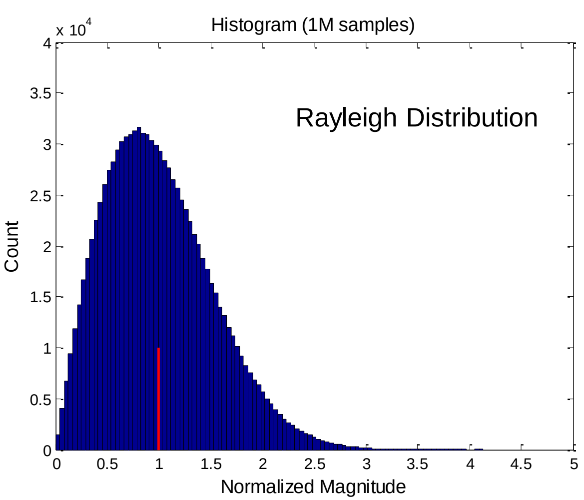
Requires high SNR



Moving Avg great for low SNR

Poor for narrow pulses

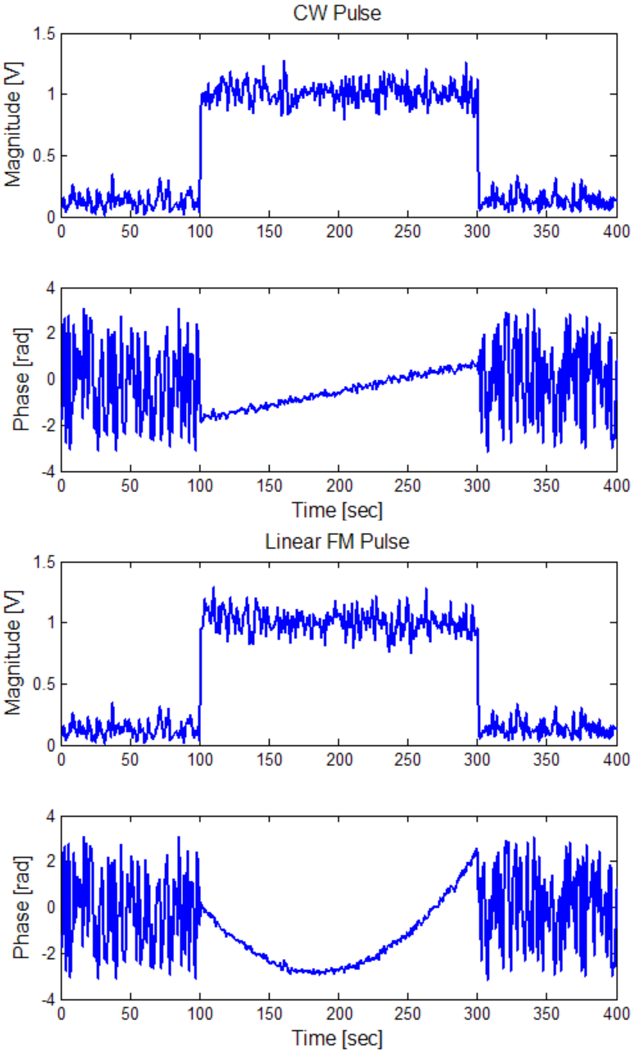
- Finding RF Carrier Amplitude
  - Magnitude Histogram (Method I)
  - Local Statistics (Method II)
  - Moving Average (Method III)
  - Noise Histogram
  - Least Squares Carrier Fit (Method IV)



Preparation for last method

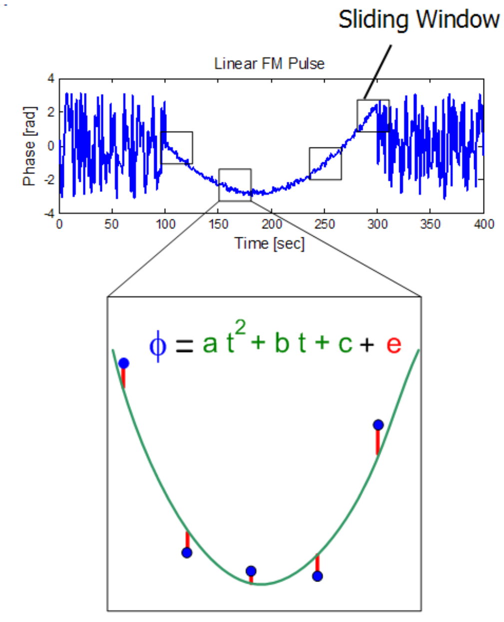
Automatic Measurement: Theory of Operation
Finding the Pulse

- Method 4: Least Squares Carrier Fit
  - CW Pulse
    - Linear phase vs time
  - Linear FM Chirp
    - Parabolic phase vs time



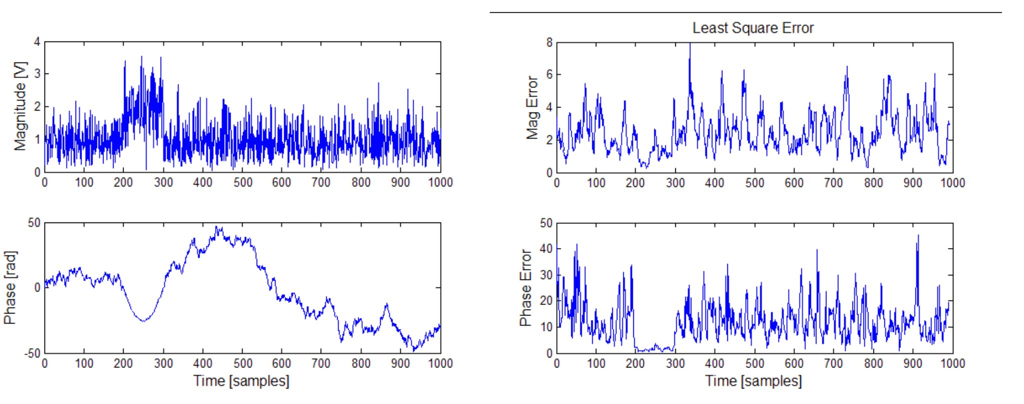
Automatic Measurement: Theory of Operation
Finding the Pulse

- Method 4: Least Squares Carrier Fit
  - Fit to Chirp



$$\text{Squared Error} = \sum e^2$$

  - Low SNR



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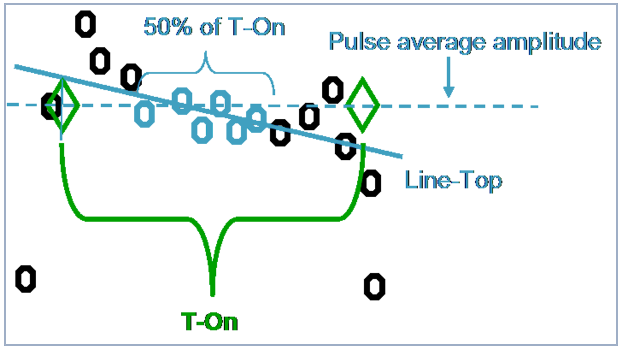
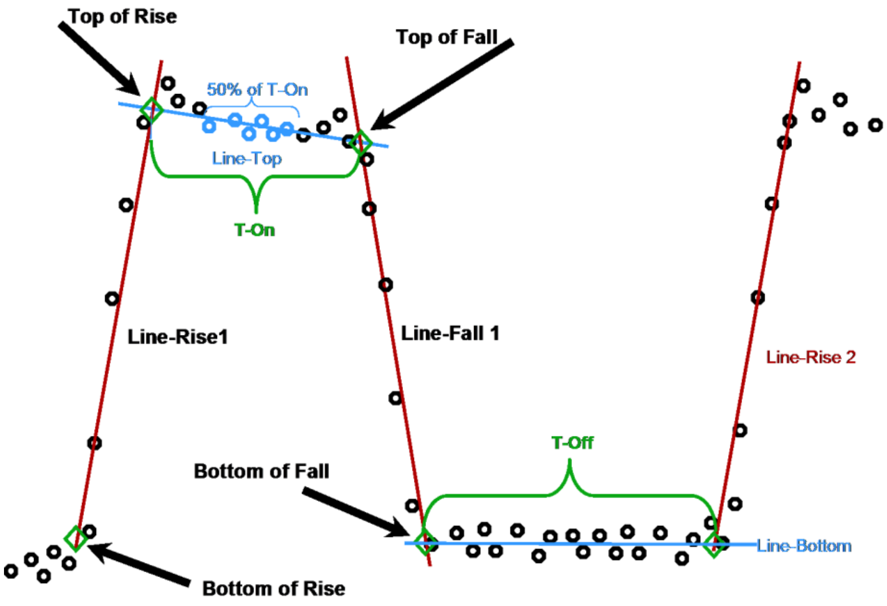
Automatic Measurement: Theory of Operation
Finding the Cardinal Lines and Points for Measurement

- Defined by parameter settings





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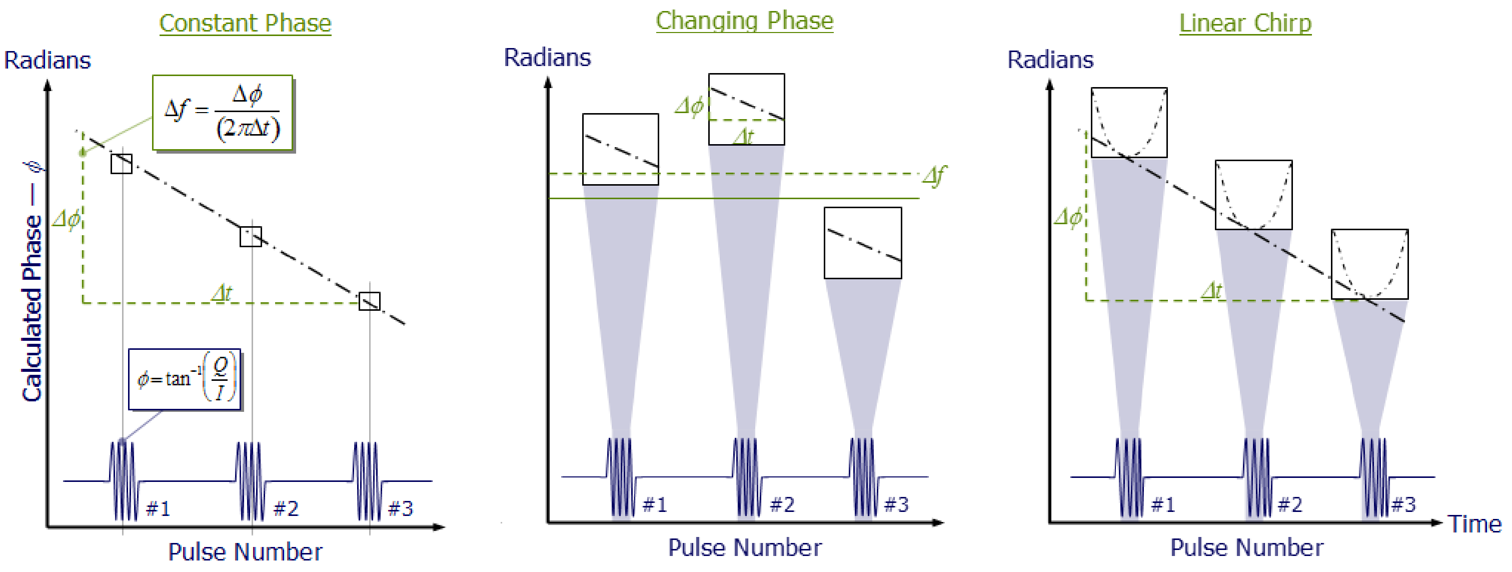
Automatic Measurement: Theory of Operation

Estimating Frequency

- Basic Methods



- Phase Changes Between Points Relate to Frequency Error (pulse modulated generator, phase coherent)
- Pulses with Changing Phase are Averaged for Frequency Error (generator turned on/off/on, does not maintain phase)
- Chirped Pulses Exhibit Parabolic Phase: Can Be Curve Fitted
- If the signal frequency is known, it can be manually entered

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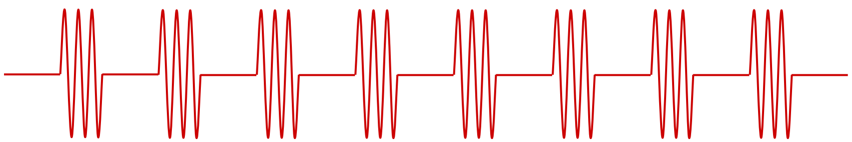
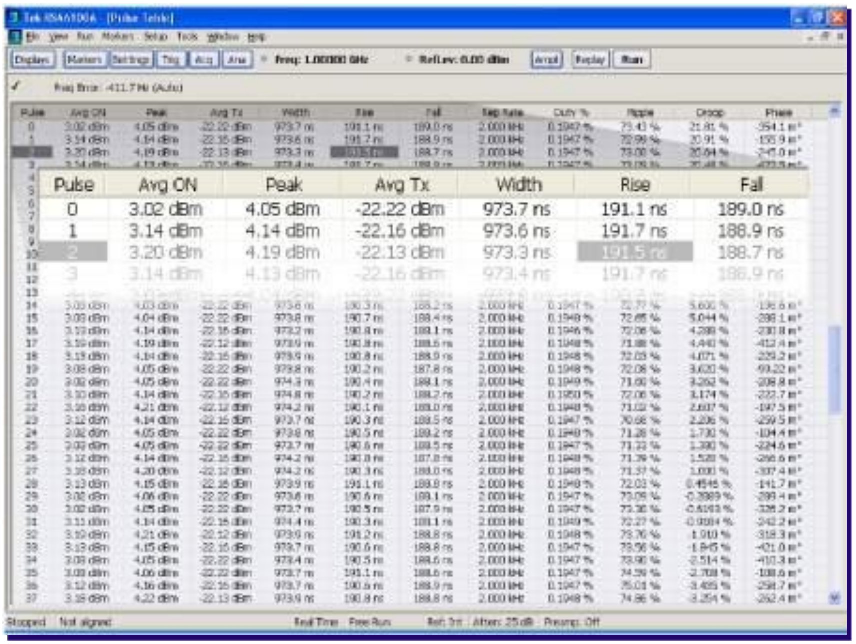
Radar Pulse Characterization

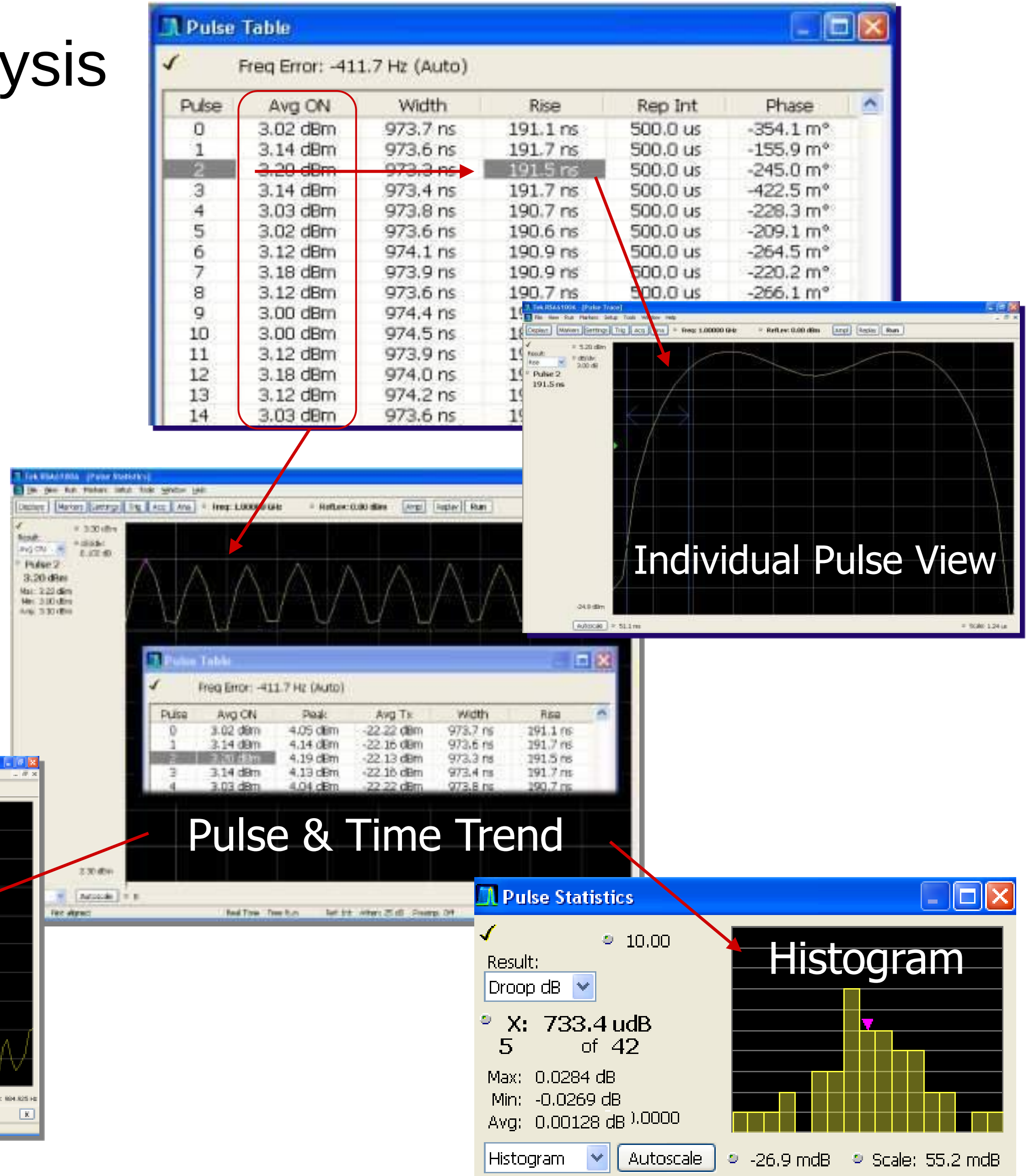


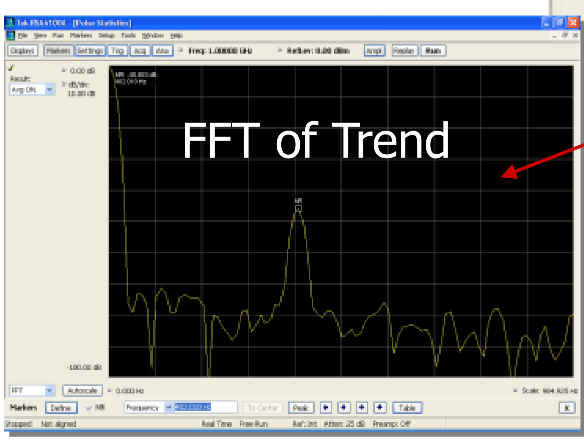


- Pulse Measurement Suite
- Automatic Pulse Measurements
- Identifies & Characterize Pulses
- Eliminates Manual Measurement
- Builds a Pulse Table of Results
- 27 Pulse Parameters
- Characterize up to 10,000 pulses

Pulse Parameter Analysis

- Pulse Table Measurements
- 27 Pulse Parameters
- View Graphical the Pulse Trace
- View Trend for Parameters
- Analyze Parameter Trends





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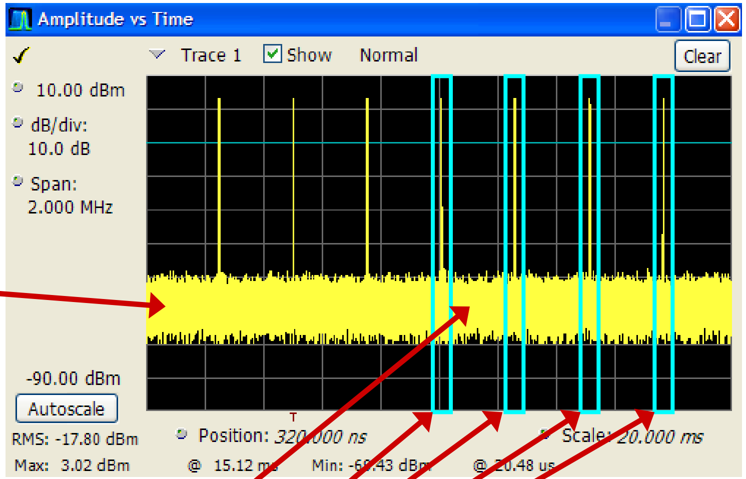
Demonstration of Pulse Characterization

- Hot Wheels™ RADAR
  - Complete Pulse Characterization
  - Individual Pulse Measurements
  - Pulse Trend Measurements
- Trends can uncover problems
  - Such as periodic or deterministic variations of pulse parameters
  - Such as slow amplitude variations…

Advanced Acquisition for RADAR Pulses

- Acquisition Memory is filled quickly by:
  - Capture of low duty cycle pulses…
    …and short pulses (due to wide BW)
  - Most of the data is useless noise between the pulses
  - Wasteful of memory and compute time



- *Time Segmented* Acquisition mode solves this!
  - Setup acquisition to capture single pulse (or group of closely spaced pulses)
  - Trigger and capture only the pulses
  - **Don't** store the noise between the pulses…
    …but remember how much time goes by
  - **Store** the time-stamped, captured pulses sequentially in memory

- Pulse Suite can handle up to 10,000 pulses using this technique

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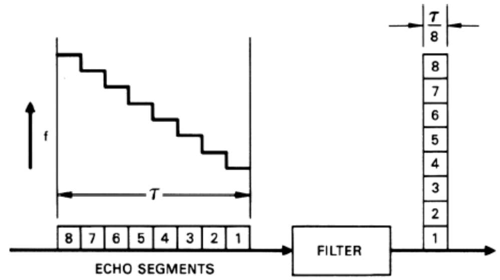
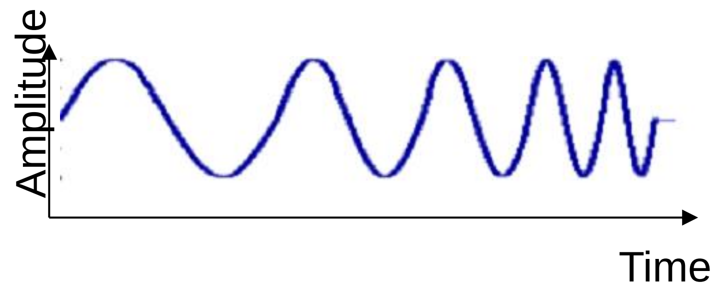
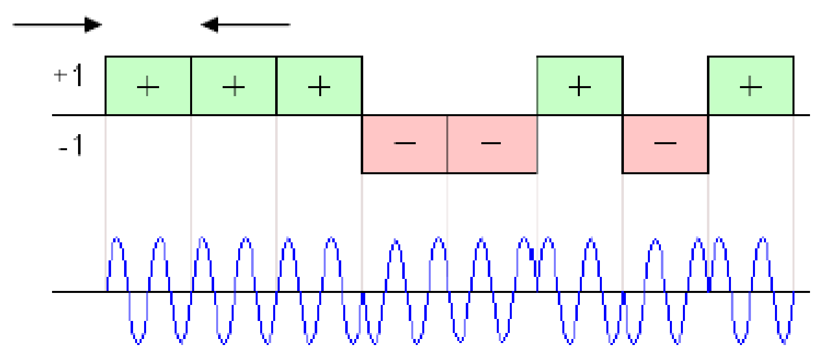
RADAR Pulse Compression Techniques

- Transmitted Pulses are Modulated
  - Frequency Modulation
    - Stepped FM, sequential or random
    - Linear FM, non-linear FM (chirps)
  - Phase Modulation
    - Biphase, using coding such as Barker, Golay, etc.
    - Polyphase, like QPSK, etc.
    - Stepped phase changes
- Special Filters in the Receiver compress the pulses
  - Matched filters
  - Phase correlation
- ***Advanced analysis easily demodulates and characterizes these pulses***
  - ***Including LFM linearity/error, and***
  - ***Time Sidelobes – more on this coming up….***







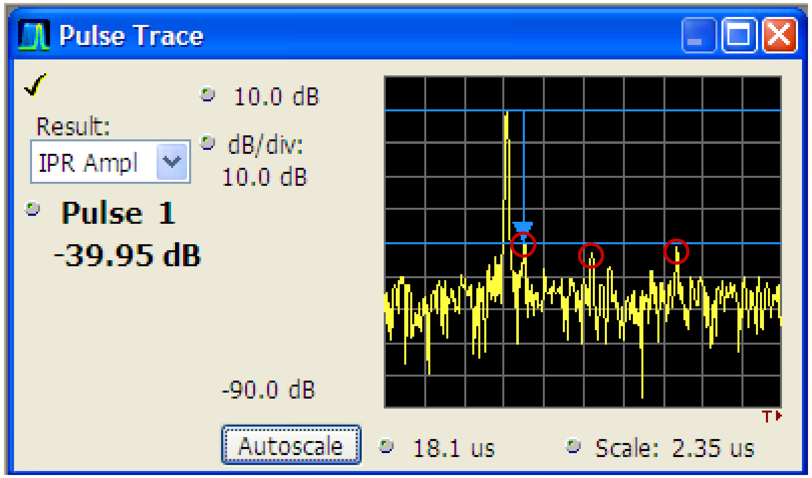
Demonstration of Compressed Pulsed Analysis

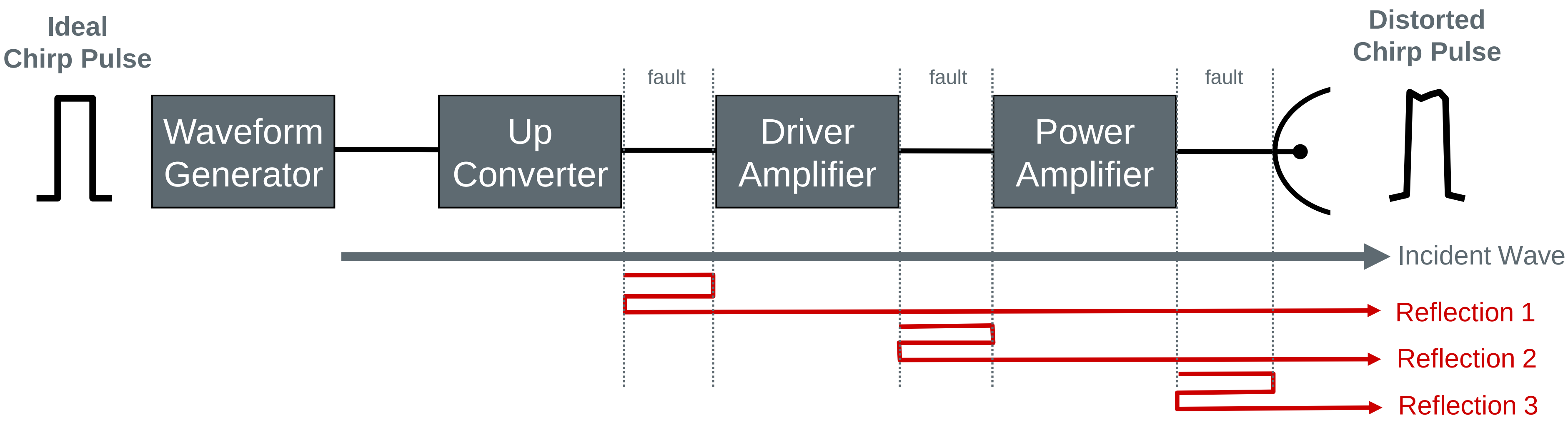
- Quickly examine modulated pulse characteristics
  - Frequency hopping (stepped FM)
  - Phase hops

- A deeper look at Linear FM Pulses (Chirps)
  - Live Spectrum shows you the big picture
  - View spectrums, frequency, amplitude vs. time
  - Pulse suite shows great detail
    - Frequency and Phase Deviation in the pulse
    - Frequency and Phase Error from ideal
  - Segmented Memory to capture more pulses quickly
  - Trend, Histogram and FFT…

Sources of Reflections…
…can be within the Radar system

- These "overlapping" signals can analysed with Impulse Response (IPR)
- Also commonly known as Range-Time Side Lobe Measurement





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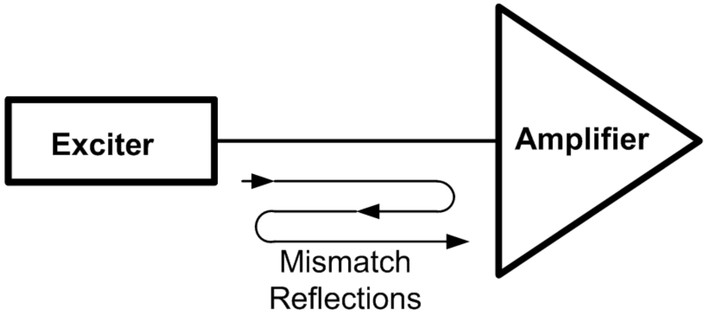
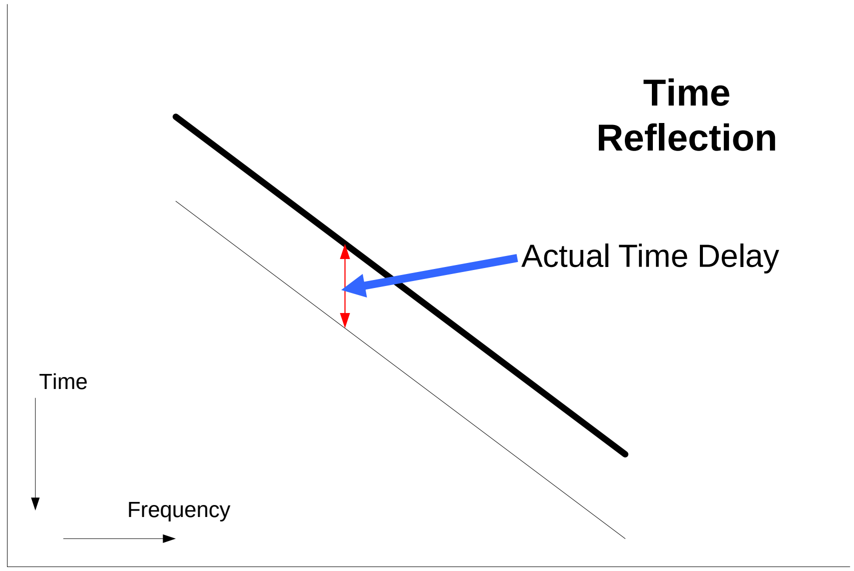
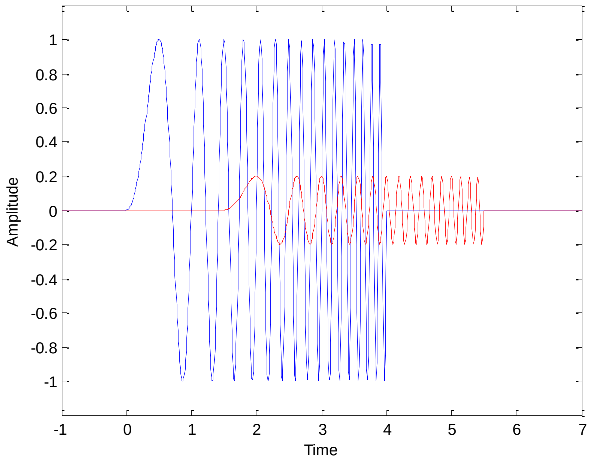
LFM Chirp With Defects - Reflections

- A time-delayed copy looks just like a second target,



Spectrogram View





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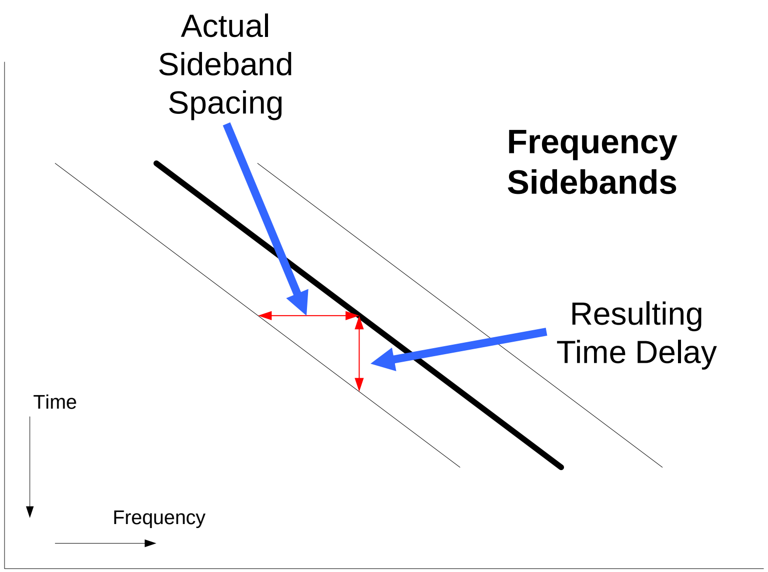
LFM Chirp With Defects – incidental modulation

- Modulation sidebands look like a reflection

Spectrogram View



- The Sidelobe spacing in time is equal to:
- The Modulating Frequency
- Multiplied by the inverse of the Chirp Slope
  - F_d is the chirp width
  - T_d is the chirp time

$$\Delta T = F_m \left(T_d / F_d \right)$$

Impulse Response or Time-Sidelobe - Just What Is It ?

- Impulse Response Measurement
  - Traditionally a Network Analyzer measurement
    - The name is a holdover from network Analyzers
  - The NA sweeps a network or amplifier across Frequency
  - It Measures the output of the network
  - Transforms the Frequency Result into the Time Domain

- Time-Sidelobe Measurement
  - Same thing, Same Math. Alternate Name.
  - This name more represents what a radar experiences with the defects that this finds

- Analyzer makes the Measurement on Radar Output
  - This measurement usually Requires a Swept input.
  - The analyzer uses the Chirp of the Radar itself.

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Impulse Response or Time-Sidelobe – What Is it Good For ?

- Many Transmitted Defects cause errors such as
  - Reduced Resolution
  - Reduced Effective Power (Reduced Range)
  - Interference to Other Services

- Errors can cause Apparent Multiple Returns for Each Pulse
  - Actual Reflections Inside the Transmitter
  - Frequency Sidebands
    - These cause separate returns only for a chirp pulse

- These Require a Conversion to Time Domain to Measure
  - Hence, the *Impulse Response (Time-Sidelobe)*

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LFM Chirp Impulse Response

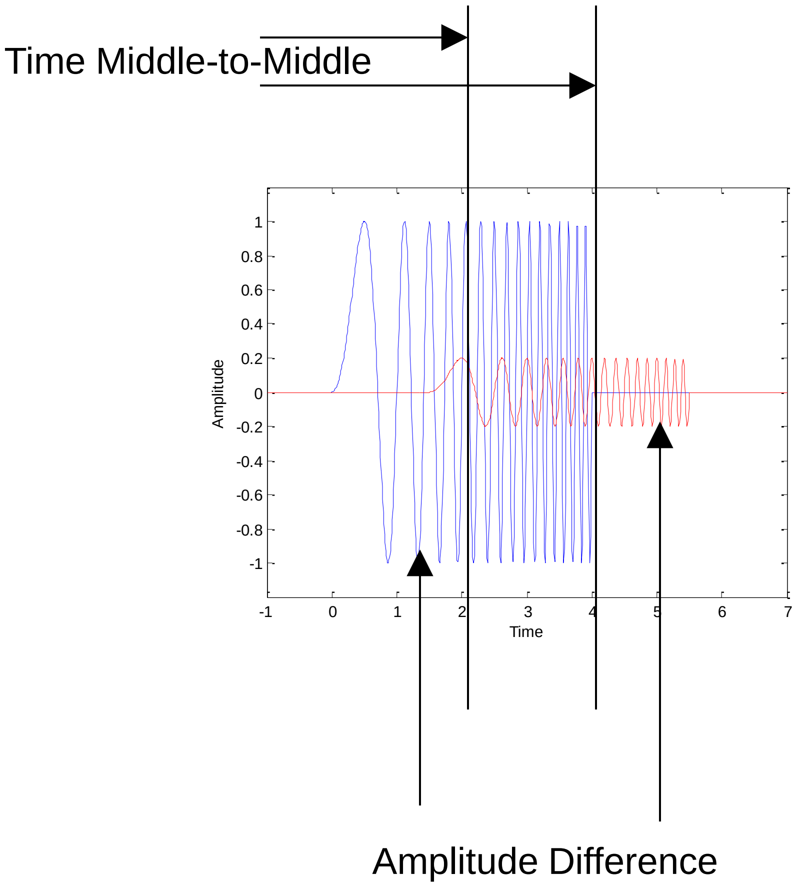
- Usually thought of as a Time-Domain Measurement of the Input-to-Output Transfer Response of a Network. Such as a Filter or Amplifier

- Time-Domain measurement of a Frequency-Domain Chirp

- Like a TDR measurement

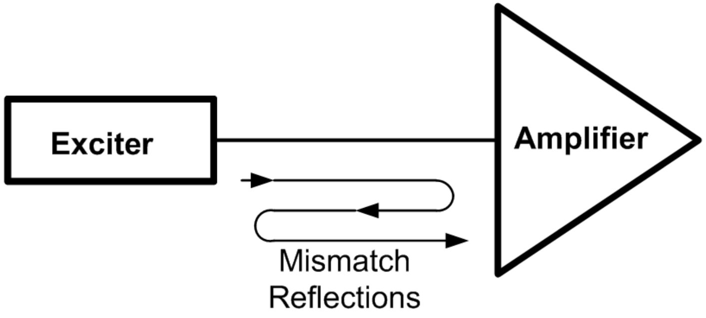
- Like a swept Correlation
  - (look for copy)

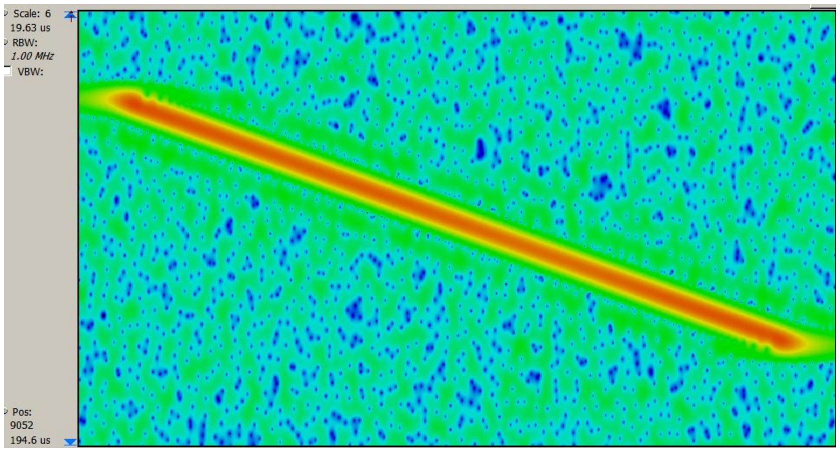
- Reflections (Time Sidelobes)
  - Undesired Modulations
  - or non-Linearities

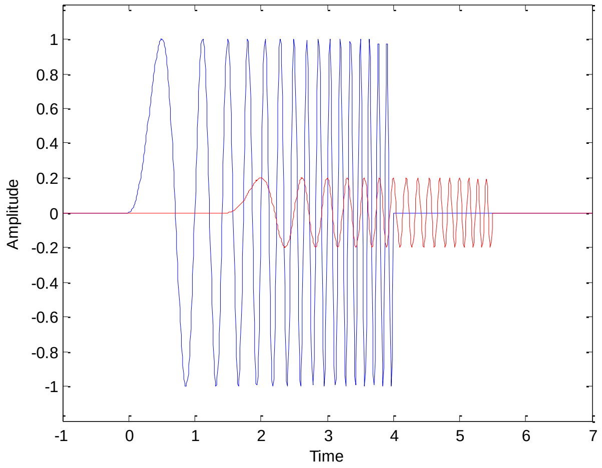


LFM Chirp Impulse Response

- Basic Concept: Time = 1/Bandwidth
  - This is the limitation on time resolution
- Why not Other Ways?
  - F-v-T can't work for overlapped signals
  - SG can't compare the two signals & FFT Frame length limits time resolution
  - IPR shows time and amplitude together







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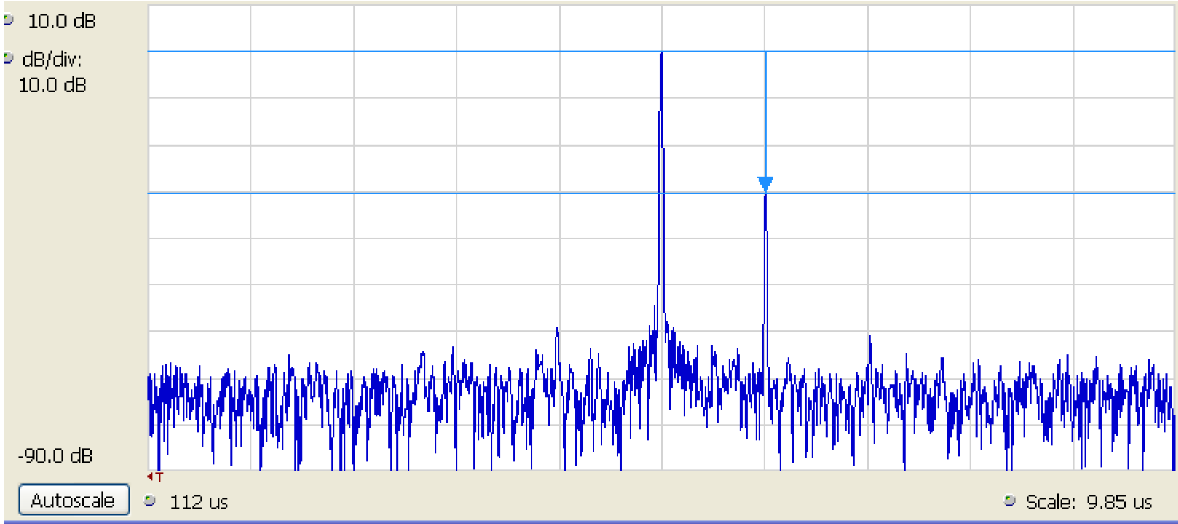
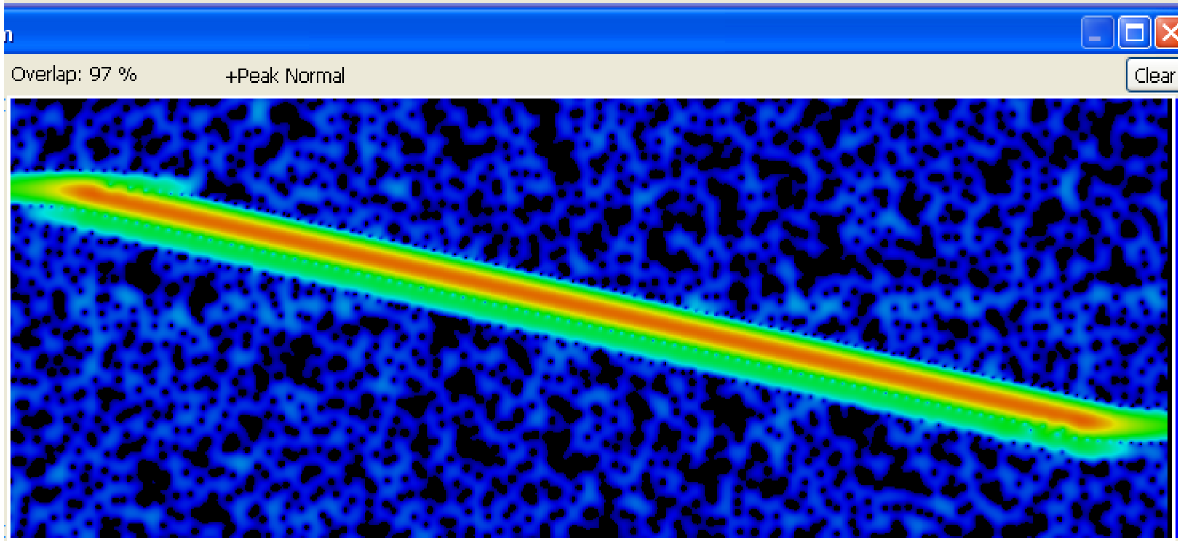
Impulse Response vs. Spectrogram

- LFM Chirp
  - 100 MHz wide
  - 1 us delayed reflection
  - 30 dB below main
- IPR shows it clearly
  - 10 us full scale
  - 100MHz gives
- Spectrogram
  - FFT Frame = **30 us**
  - RBW = 1 MHz





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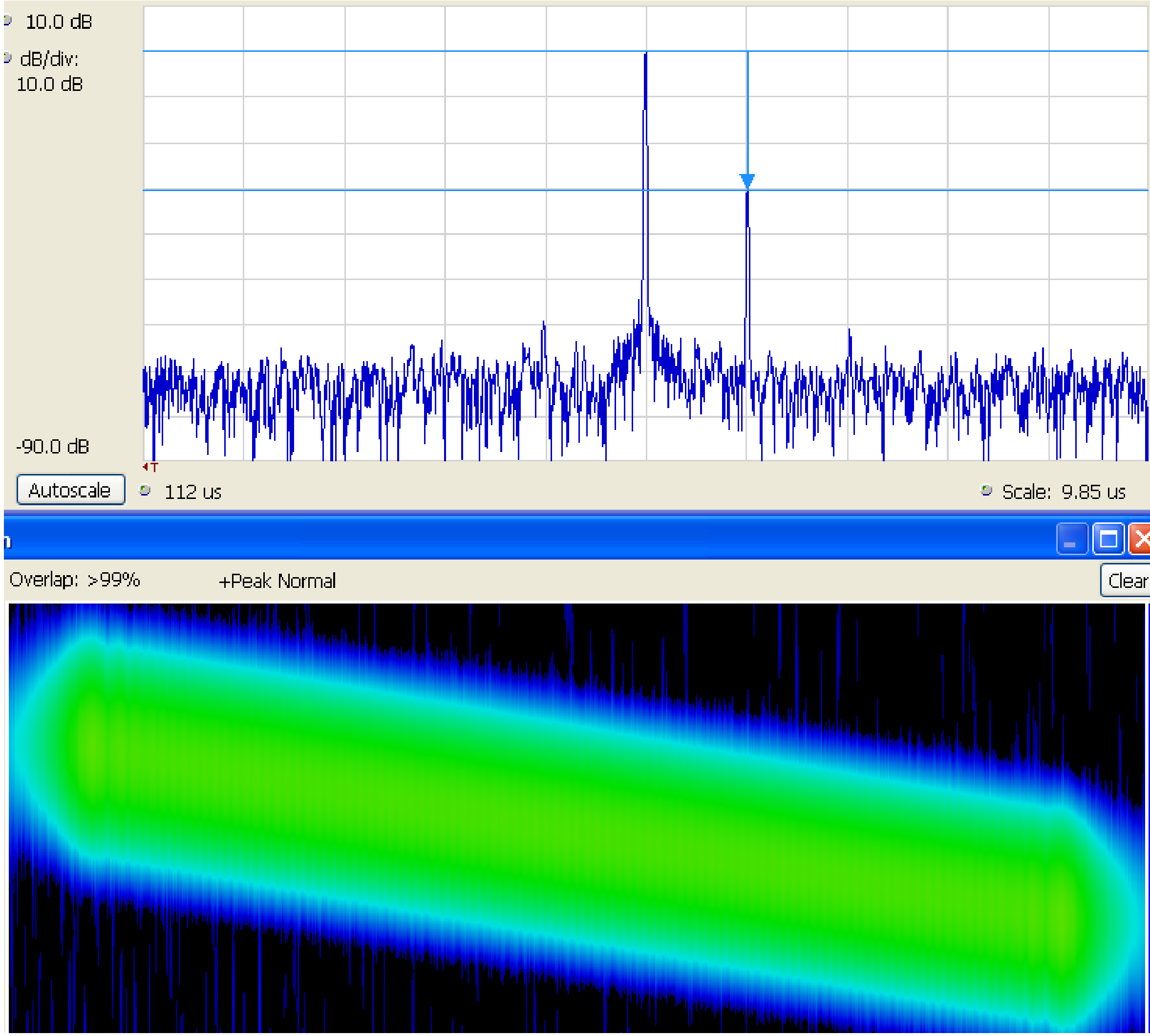
Impulse Response vs. Spectrogram

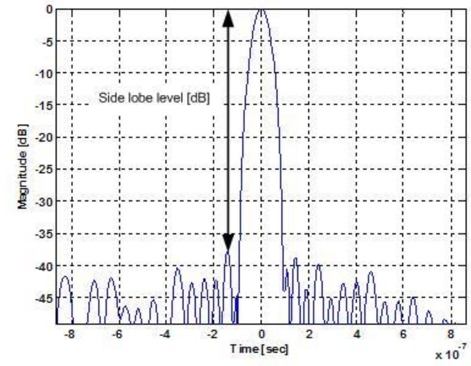
- Reducing the RBW to 100kHz will not reduce the FFT Frame length.
- So how does the IPR measurement do it?

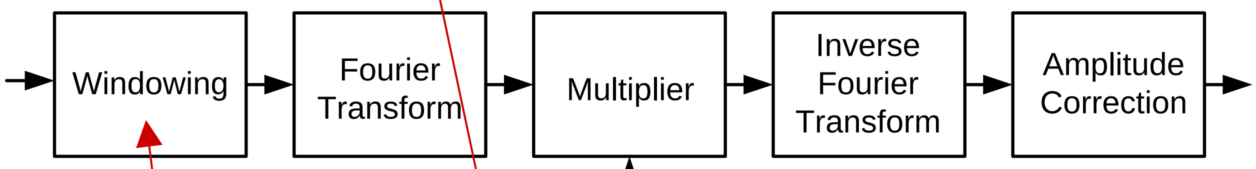


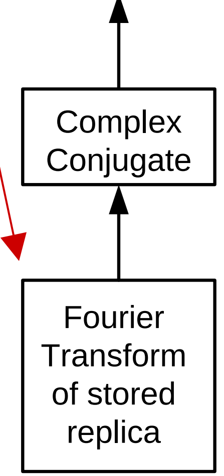
LFM Chirp Impulse Response - How it is done

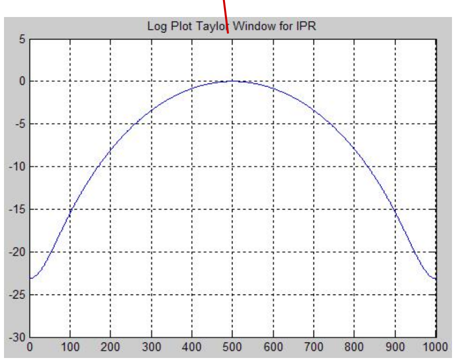
- Time Window (Taylor)
  - Narrow Main Lobe
  - Better Time Resolution
- FFT , De-Chirp, IFFT
- Estimated or User-Entered Chirp Parameters (for De-Chirp)

- Amplitude vs. Time plot

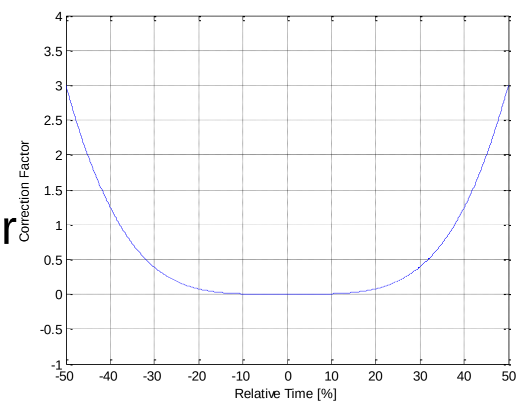








- This corrects for offset of Side Lobe



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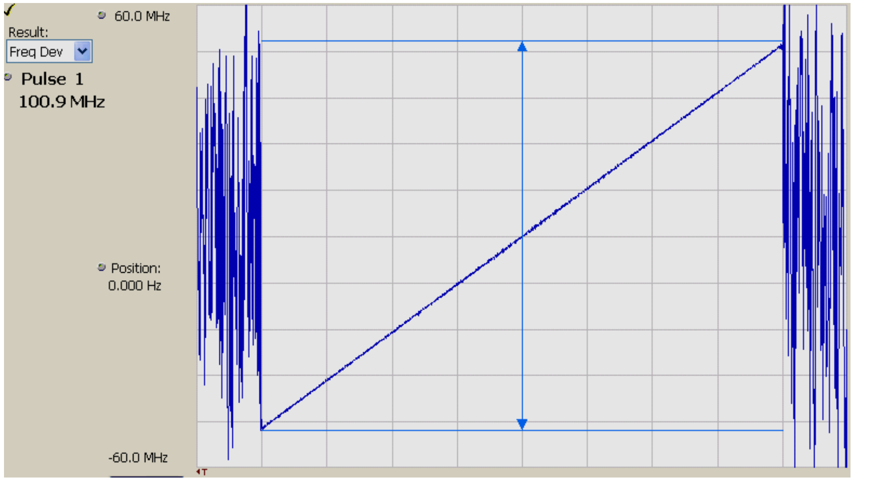
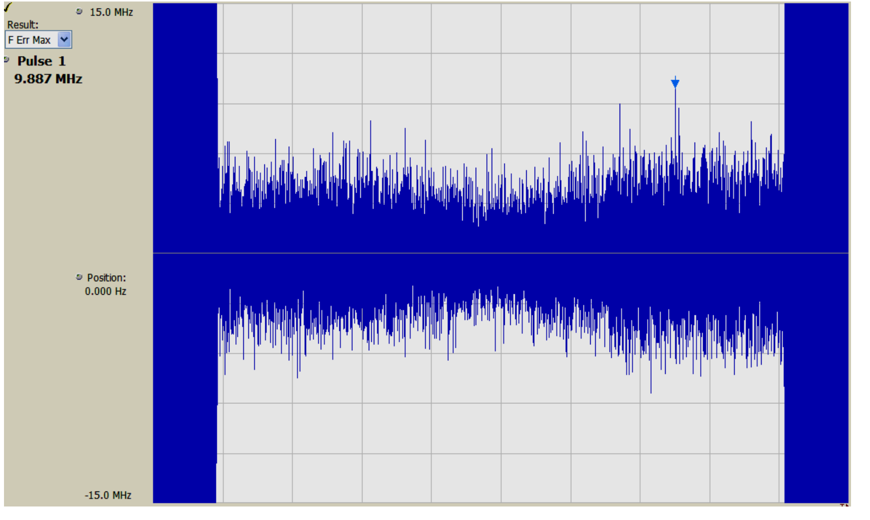
Impulse Response vs. Frequency Error

- Frequency plot
  - Simply look at the line
  - Is It Straight?
  - No Detail Visible



- Frequency error
  - More detailed
  - But has noise
  - Cannot see any AM



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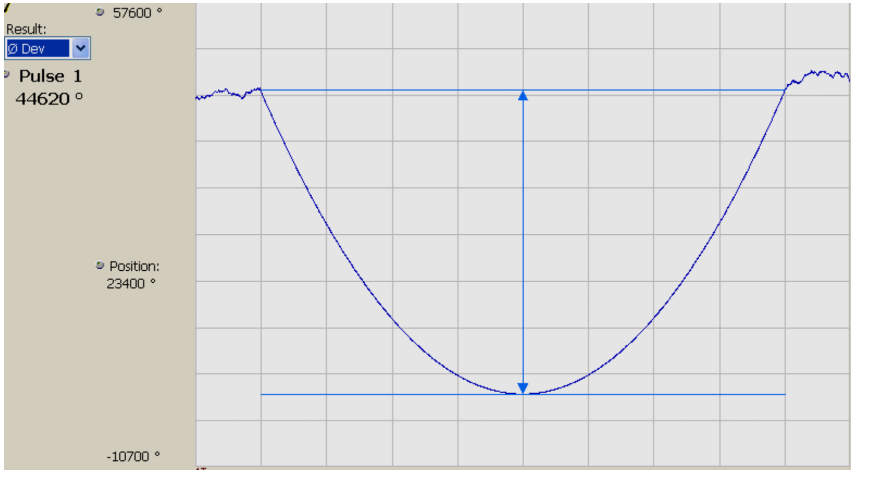
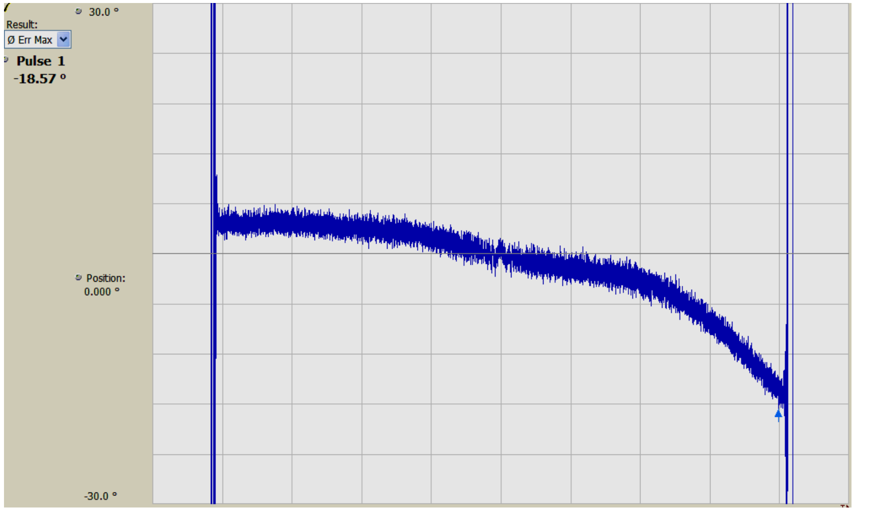
Impulse Response vs. Phase Error

- Phase plot
  - No Detail here Either



- Phase error
  - The Most Sensitive for Phase/Freq
  - Still No indication of AM



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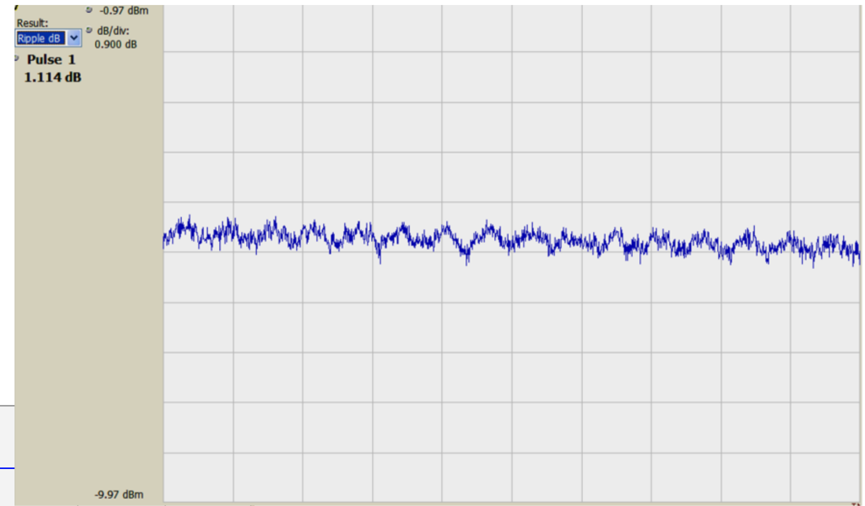
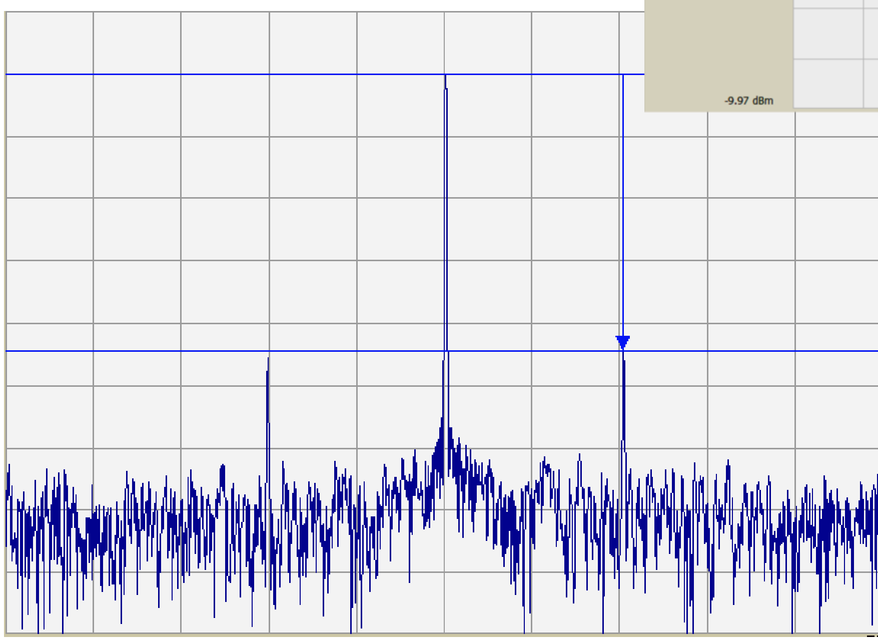
Impulse Response vs. Amplitude Plot

- Magnified Amplitude (Ripple) Plot

- Shows noisy periodicity, but not very measurable

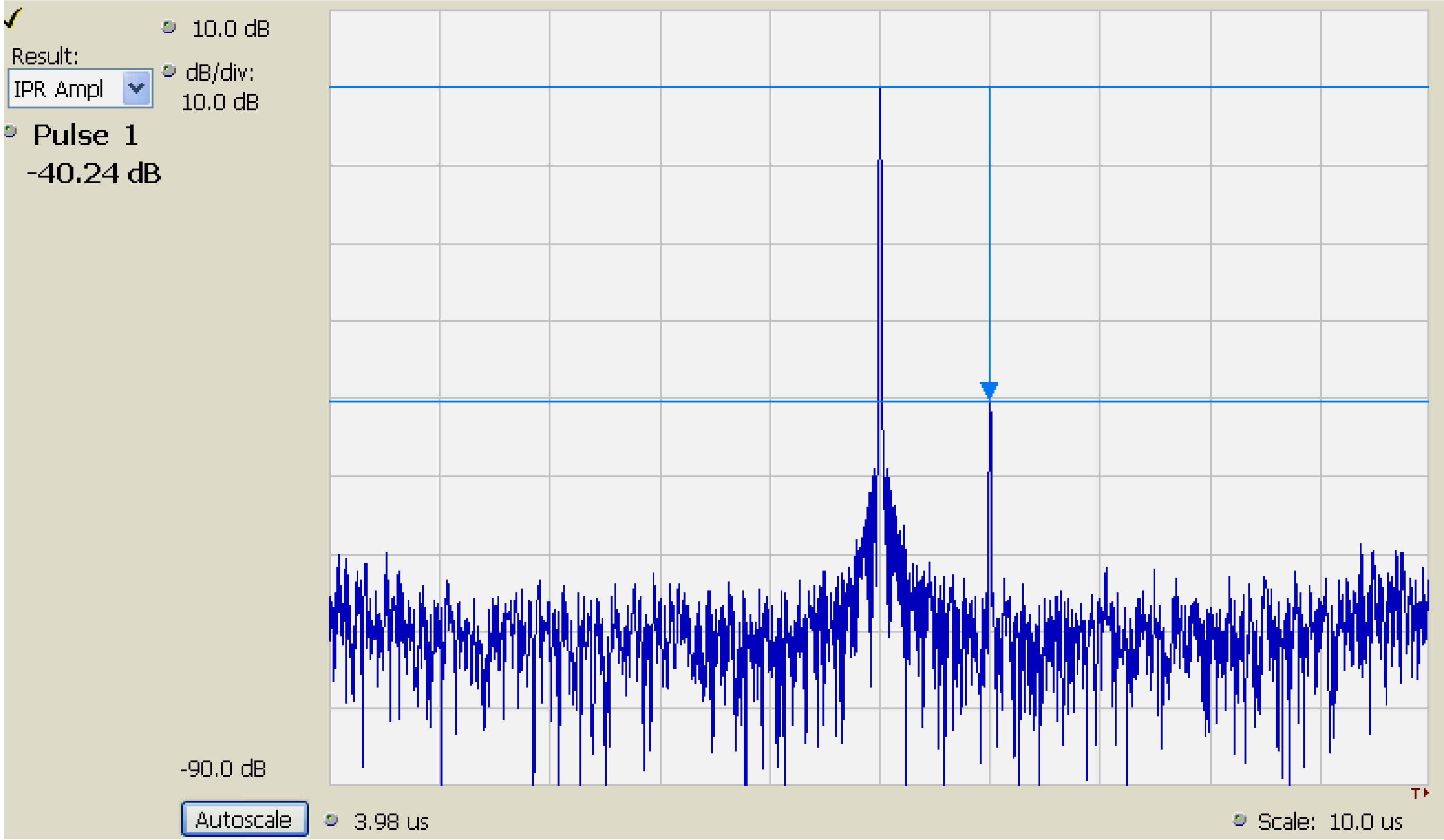




Compare to IPR

Impulse Response

- Time-Domain Plot of the Compressed Chirp
- Shows Main lobe and “Time Side lobe”
- -40 dB
- 1 us Delay

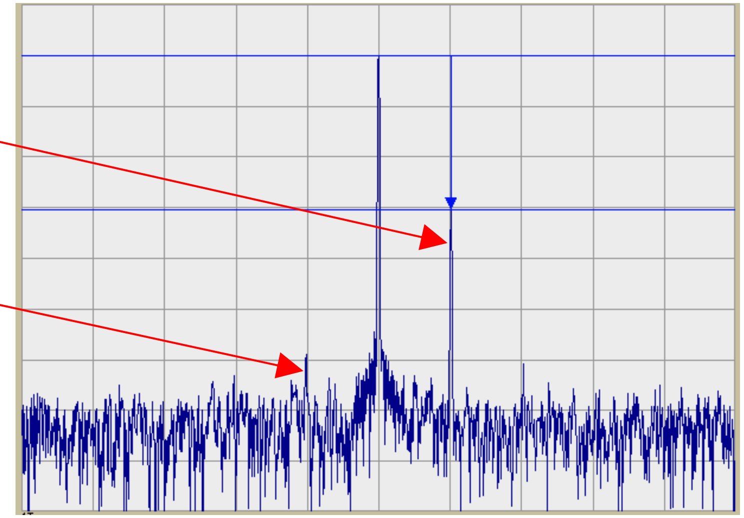


Impulse Response

- 100 MHz wide chirp
- 1 us Reflection
- 15 MHz FM
- 20 MHz AM

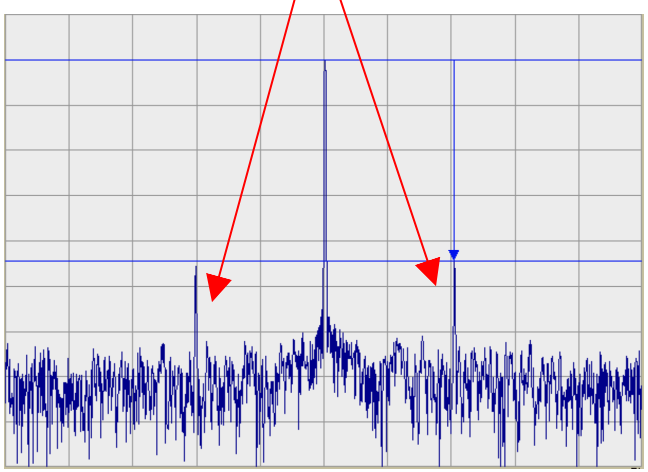
Side Lobe from reflection is on one side only

Small lobe on other side from Intermodulation

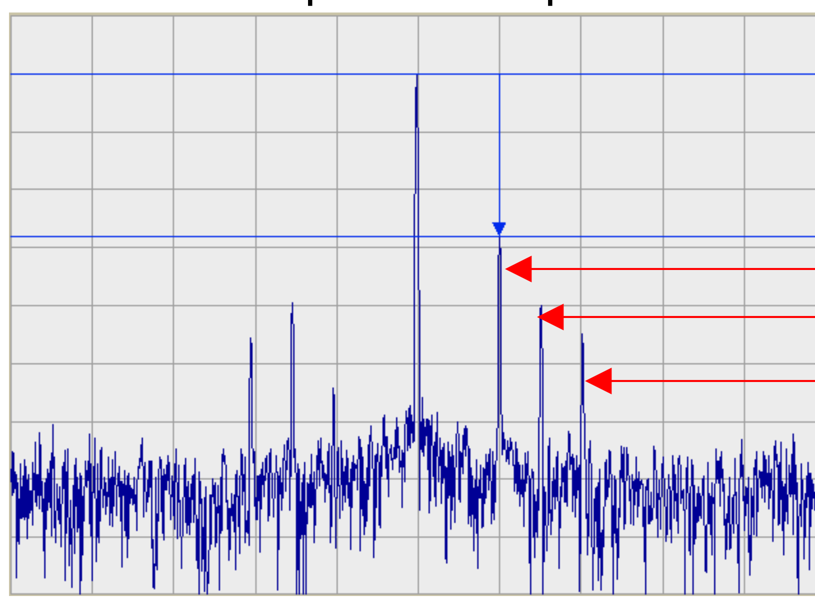


$$\Delta T = F_m ({}_d / F_d)$$

Incidental AM on chirp has equal Side Lobes on both sides



One chirp with Multiple defects



Reflection

FM

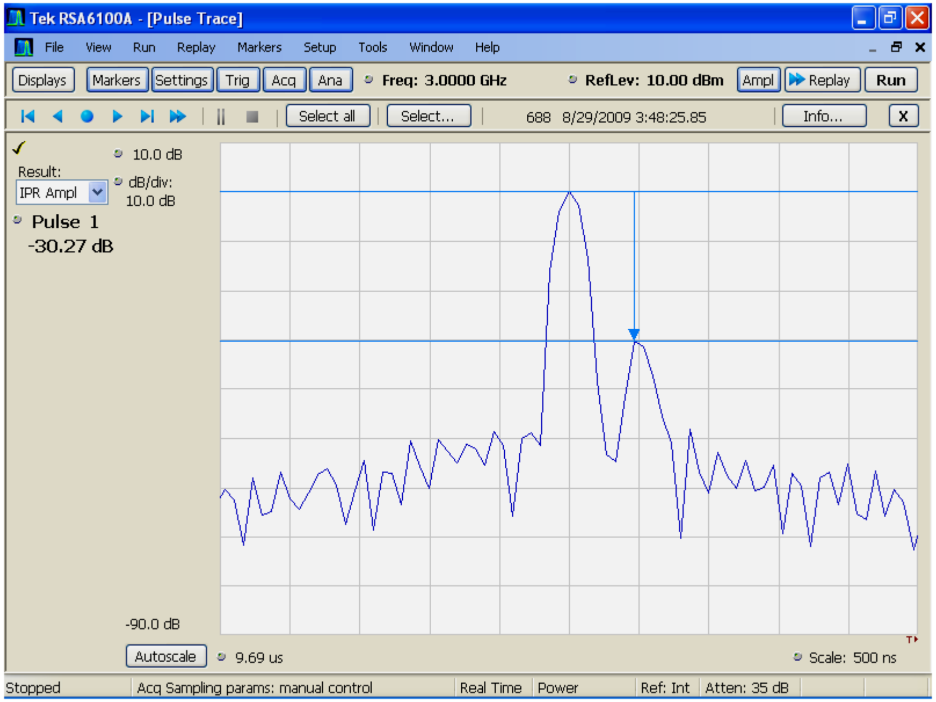
AM

Demo of IPR / Time Sidelobe Measurements

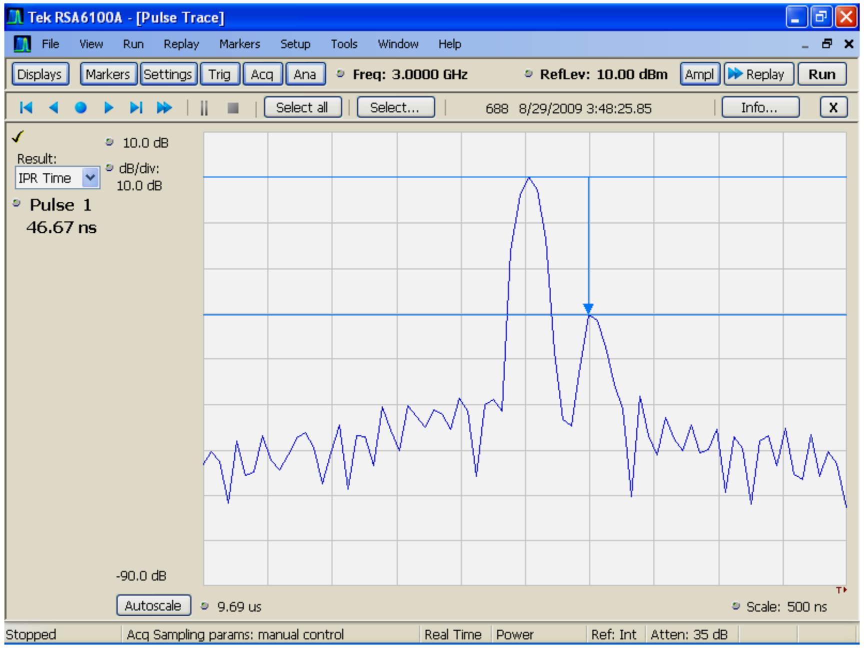
- Chirp Pulse Reflection defects
  - Difficult or impossible to see with Spectrograms or Demodulation
  - IPR measurements easily show defects
    - Low level reflection (delayed copy)
    - Incidental AM and FM modulation

Impulse Response

- Readout in dB for "Quality"



- Readout in Time for Diagnostic



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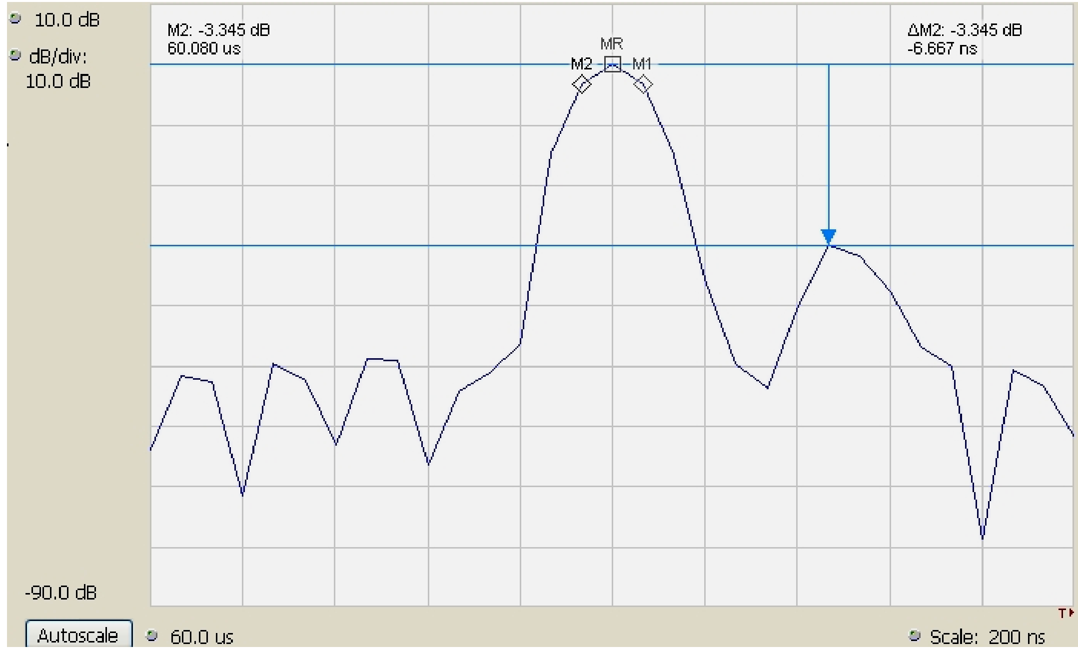
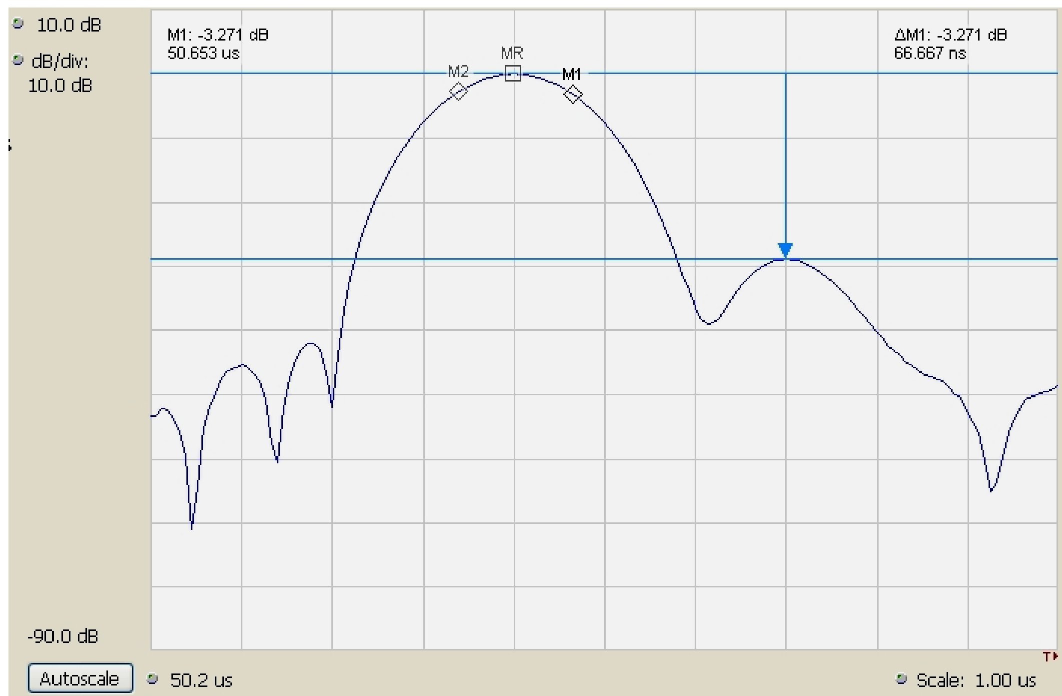
Impulse Response

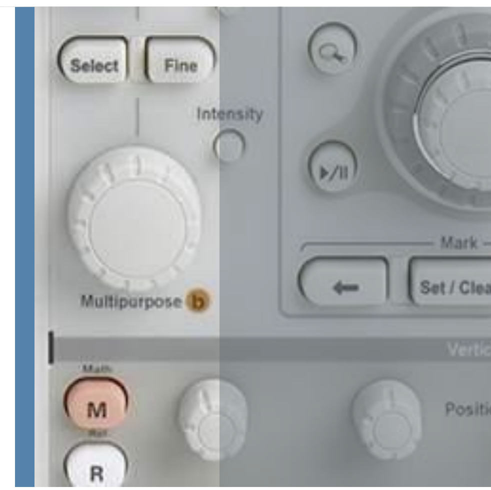
- Time = 1/Bandwidth
  - (altered by Window function)
- 100 MHz Wide Chirp
  - 14 ns wide at -3 dB
  - 50ns wide at -40 dB
  - shown at 200ns screen with 50 ns reflection
- 10 MHz Wide Chirp
  - 140 ns wide at -3 dB
  - 400 ns wide at -40 dB
  - shown at 1000ns screen with 300ns reflection





Thank You!

Any Questions?



RTSA – Discover… Trigger… Capture… Analyze!!!

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