Laser Modulation Techniques & Applications

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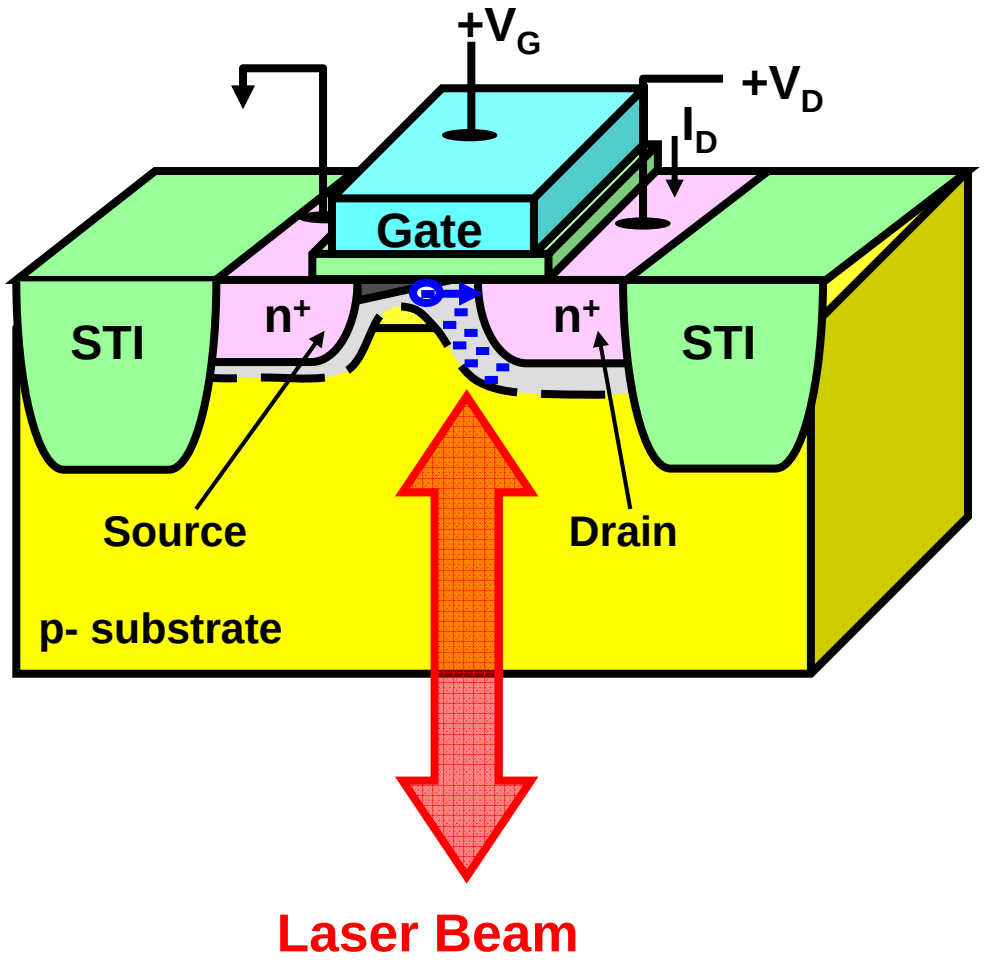
Agenda

- **Laser Voltage Probing (LVP)**
  - **Principles**
  - **Pulsed LVP (P-LVP) vs. Continuous Wave LVP (CW-LVP)**
  - **Laser Voltage Imaging (LVI)**

- **LVI Examples**

Laser Voltage Probing (LVP)



Reflected Laser Light Modulation due to:

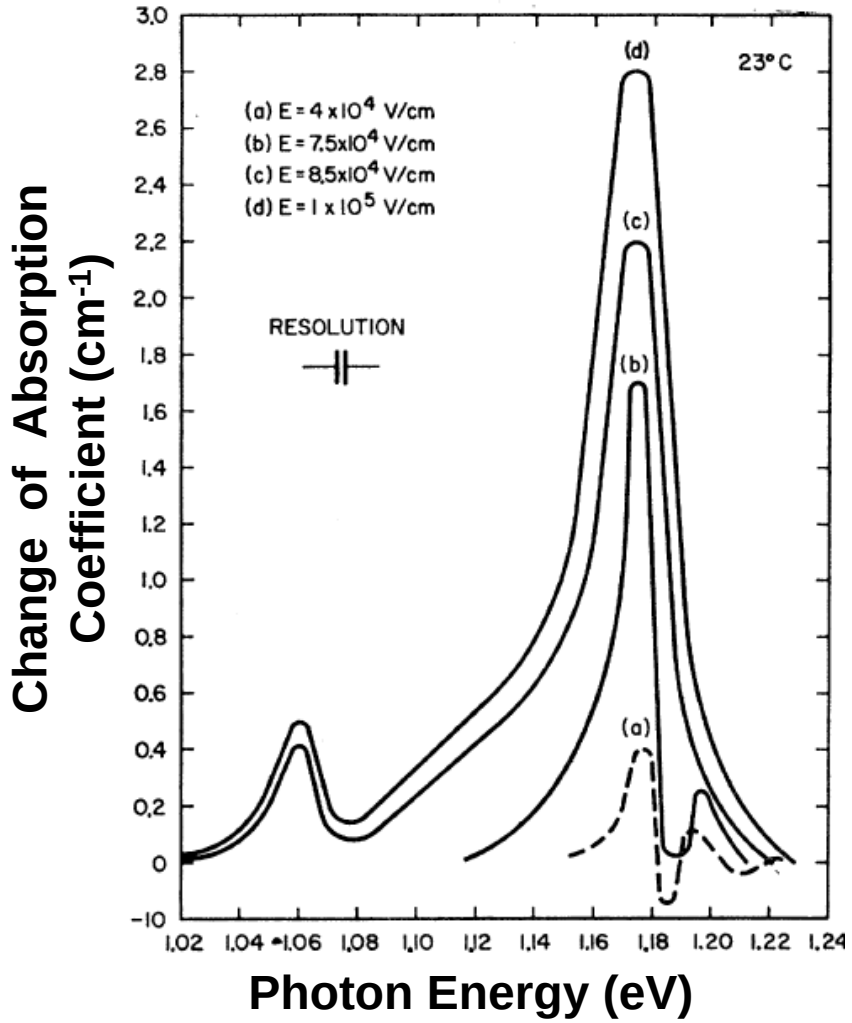
1. **Varying Electric Field in**
   - Pinch-off region
   - Drain-Substrate junction
2. **Varying Charge Density in**
   - Channel region
   - Drain-Substrate junction

Electro-Absorption Effects

"Franz-Keldysh Effect"

- For photon energy > Si band gap, electron-hole pairs are created

- High electric fields (>10^4 V/cm) reduces the "thickness" of this energy barrier to enable more pair formation
  - → Increases optical absorption
  - → Increases optical refraction



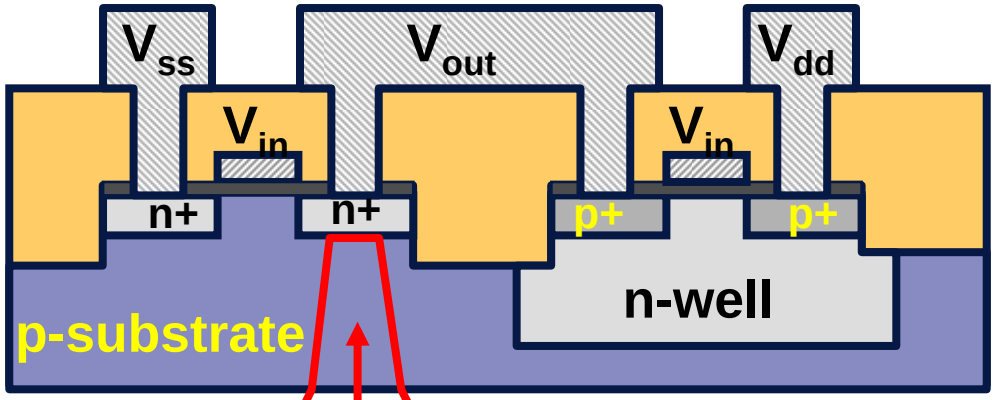
Wendland and Chester, 1965.

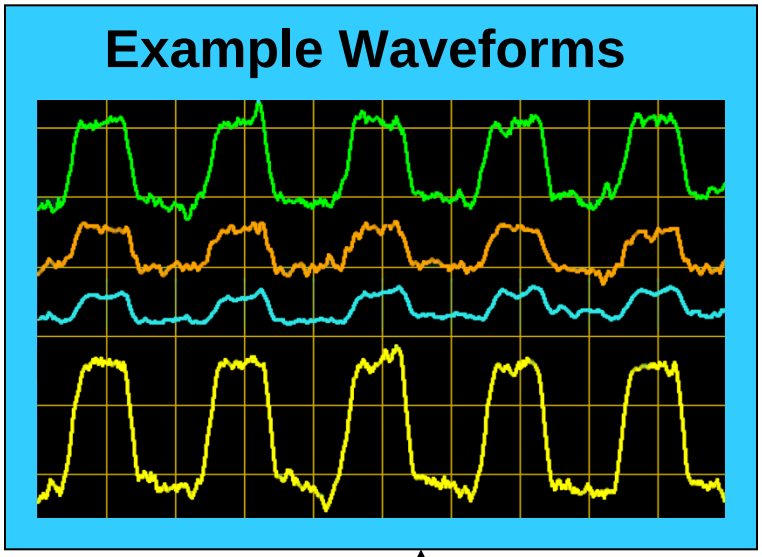
Relative Strength of Effects

- **Electric Field Effects – Electro-absorption**
  - 1st commercial laser voltage probers designed for these effects
  - In practice this contributes little to signal modulation

- **Charge Density Effects – Free Carrier Absorption**
  - Clearly the dominant effect
  - Confirmed in practice & by empirical characterization
    - U Kindereit, C Boit, U Kerst, S Kasapi, R Ispasoiu, R Ng, W Lo, **Micro Rel 48** (2008) 1322
    - U Kindereit, G Woods, J Tian, U Kerst, R Leihkauf, C Boit, **IEEE-TDMR 7** (2007) 19
    - U Kindereit, G Woods, J Tian, U Kerst, C Boit, **IEEE-IRPS 45** (2007) 526

Simplified Pulsed LVP Detection





Objective Lens

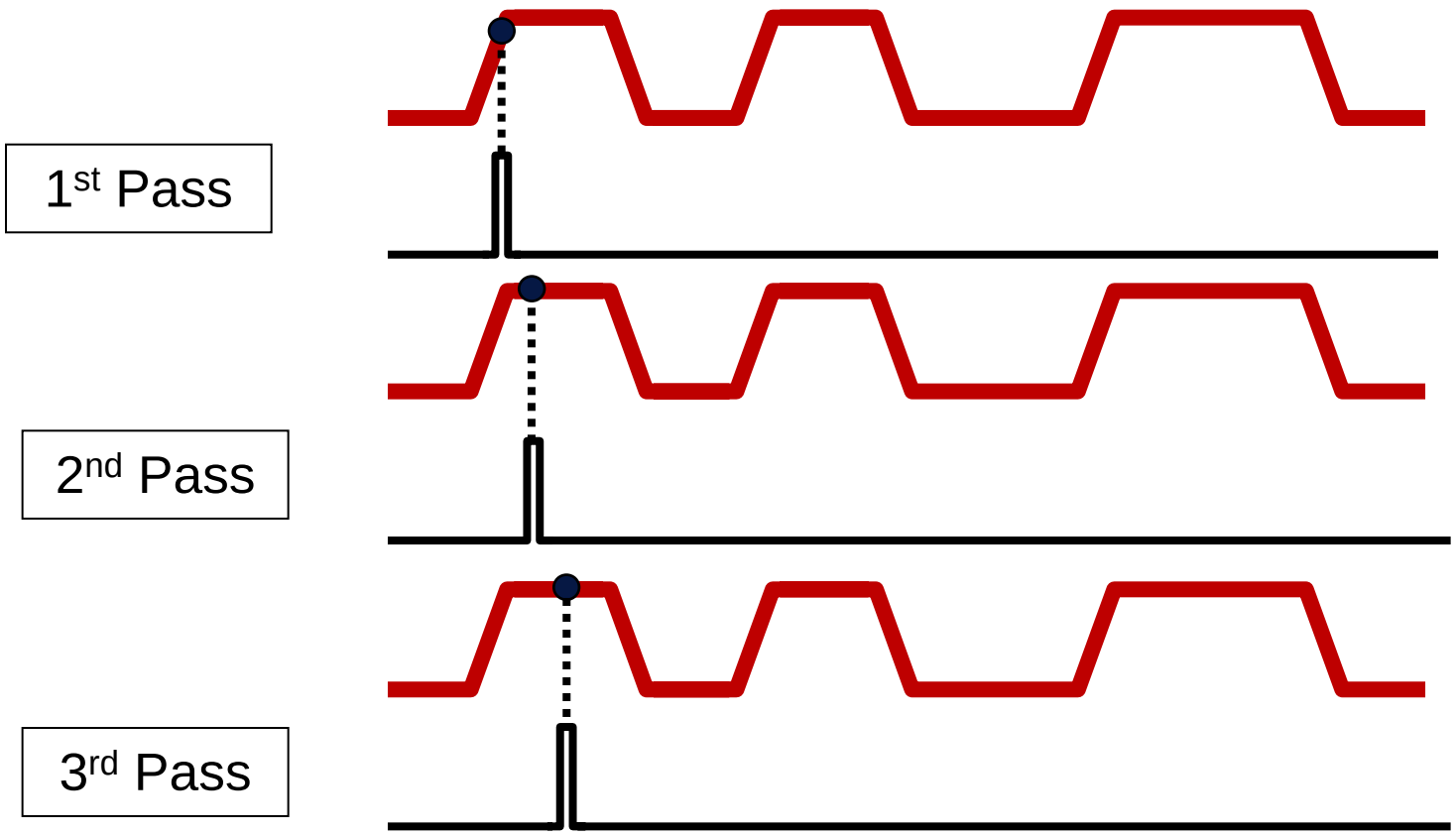
+

DAQ

Photo-Detector
Gated Integrator
ADC

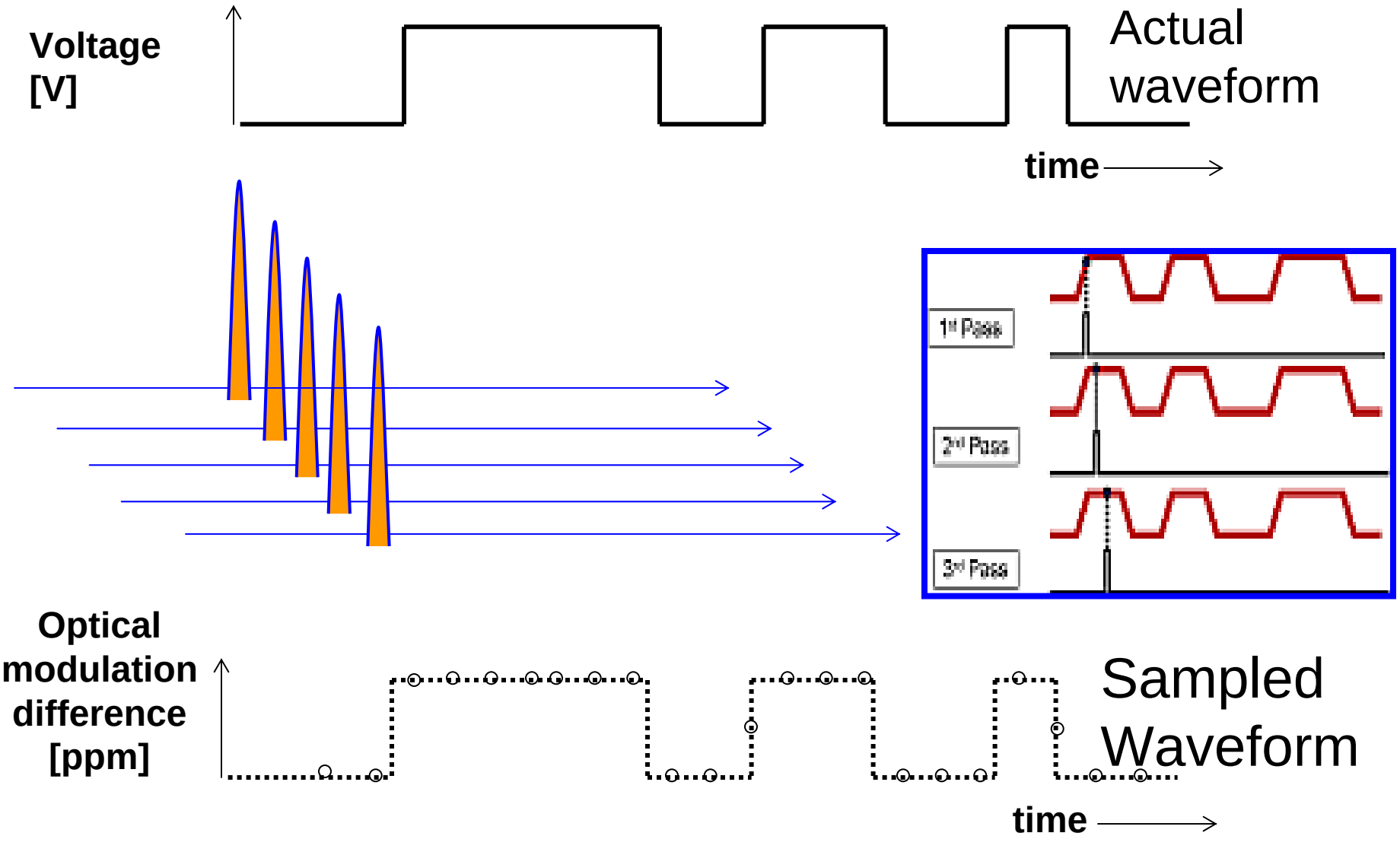
Mode-locked Laser
Wavelength: 1064 nm
Pulse width: 8 ps
Repetition rate: 100 MHz

Equivalent Time Sampling LVP



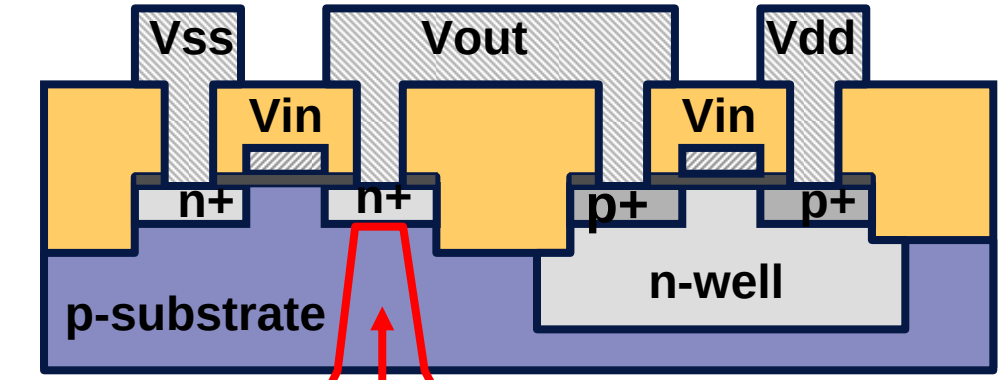
Waveform reconstructed from single measurements
(taken over multiple passes of the signal)

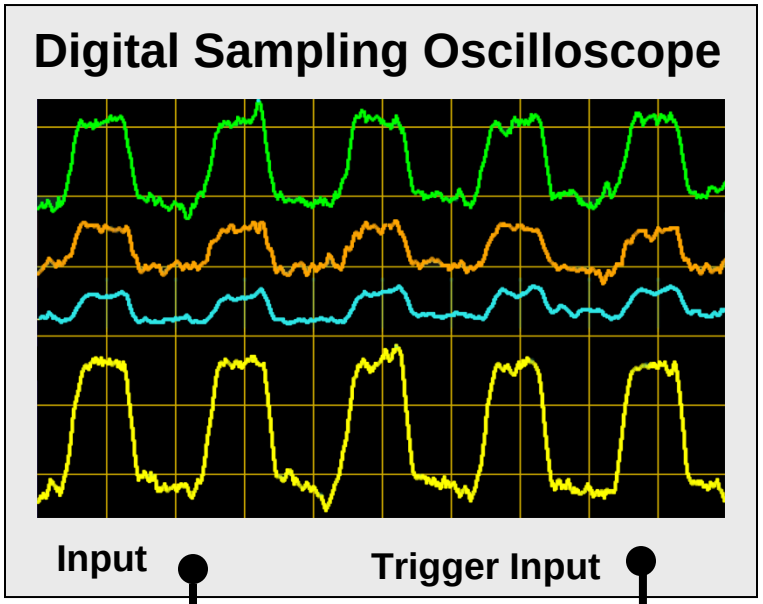
“P-LVP” Sampling Scheme



Simplified CW-LVP Detection

CW-LVP relies on a CW laser source, fast detection electronics & an external digital sampling oscilloscope





Objective Lens

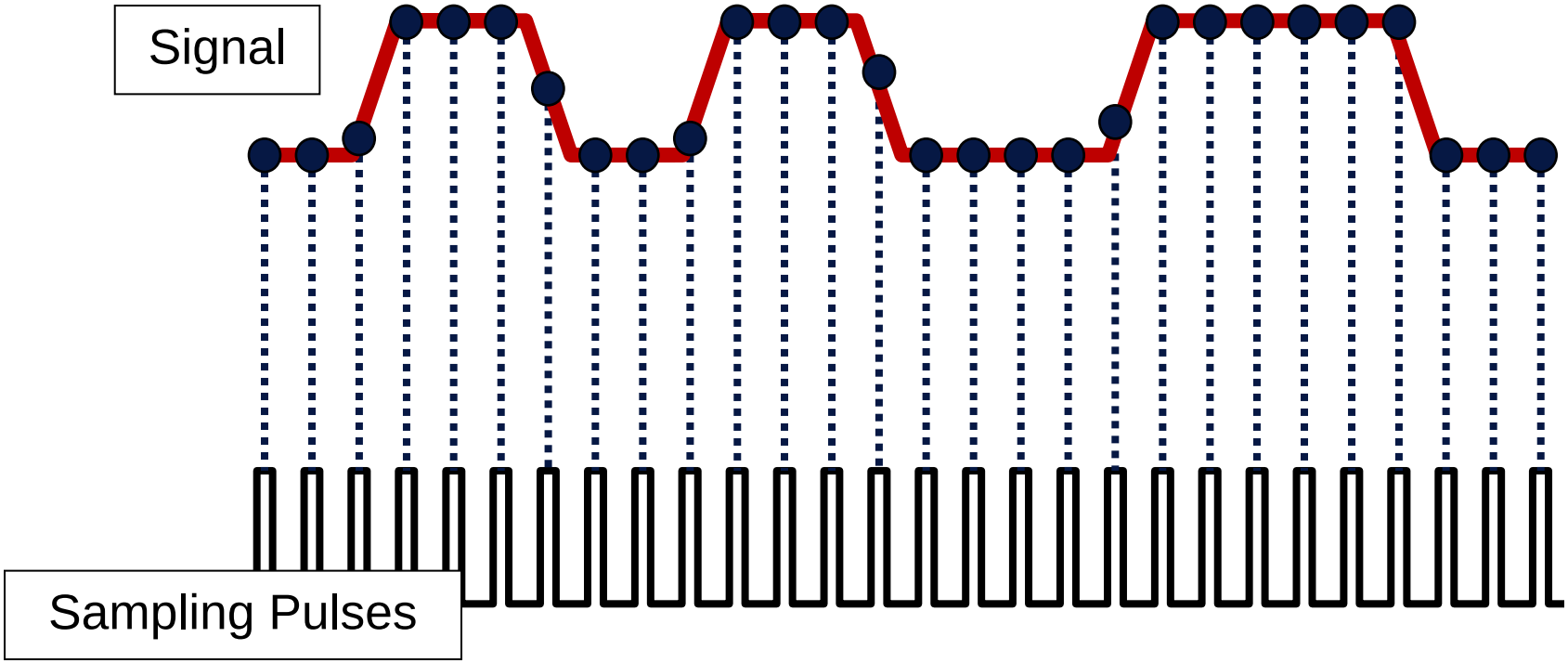
From Tester/DUT

Multi-GHz Photodiode RF Amplifiers

CW Laser

Wavelength: 1064/1340 nm

Real-time Sampling

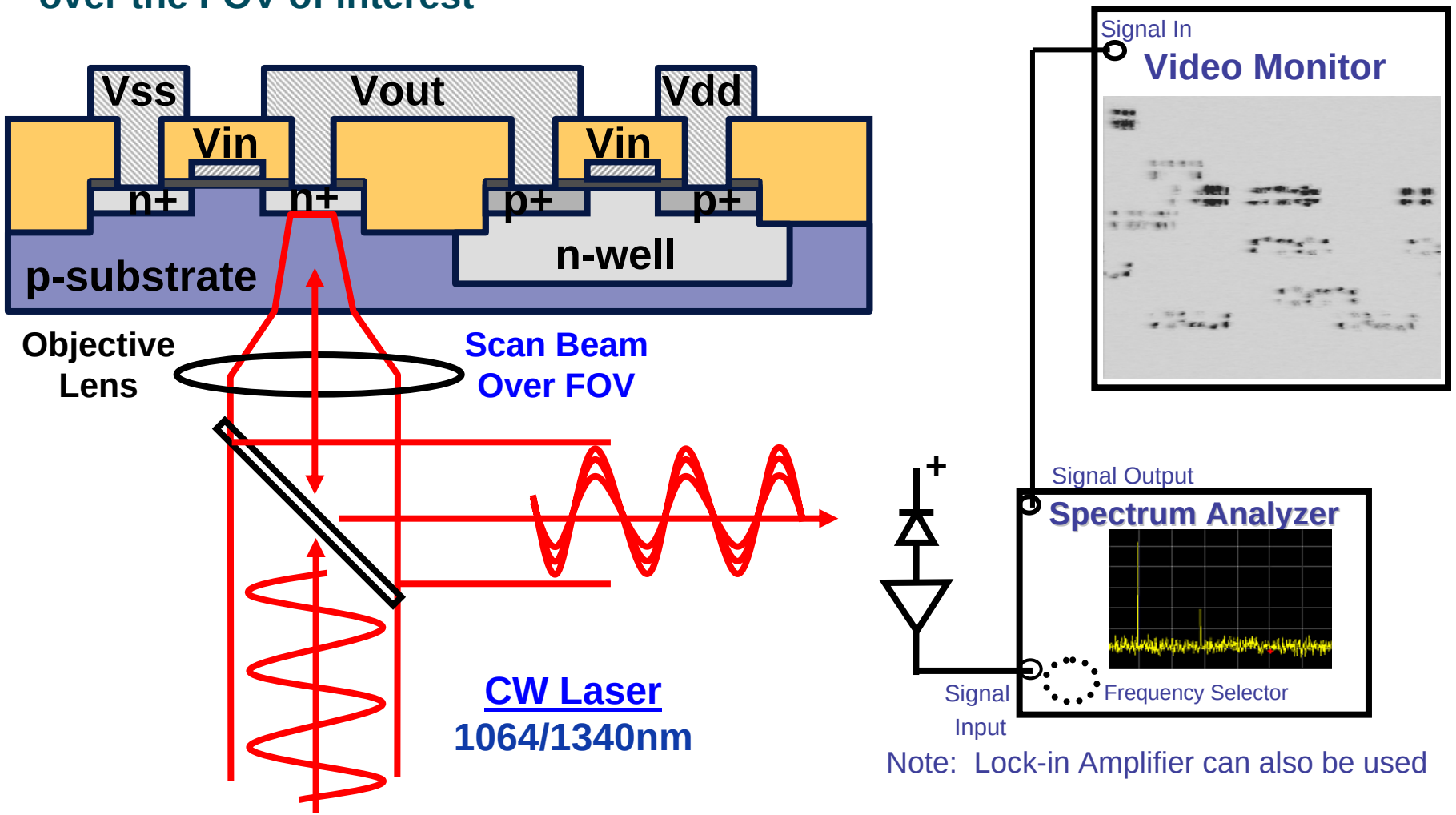


Waveform reconstructed from <u>multiple</u> measurements

(taken over single pass of the signal, averaging is still required over multiple loops)

Simplified LVI Detection Scheme

LVI is an image-based LVP scheme, detecting modulated light over the FOV of interest



Delivered laser power is 1-5 mW depending on objective lens. Low mag lenses require more power as signal is weaker because most of the reflected beam is from areas not changing at the chosen frequency.

Summary of Laser Modulation Techniques

	"P-LVP" Ruby	"CW-LVP" Meridian	LVI Meridian/Ruby
Laser Type	Mode-locked Laser: 1064 nm	Continuous Wave Laser: 1064nm, 1340nm	
Sampling Scheme	Equivalent-time Sampling	Real-time Sampling	
Bandwidth	>20 GHz	"few GHz"	
Data	"Voltage-like" Waveform	"Voltage-like" Waveform	Frequency Map
Primary Applications	Design Analysis & Characterization	Failure Analysis, Reverse Engineering, Security	

LVI Examples

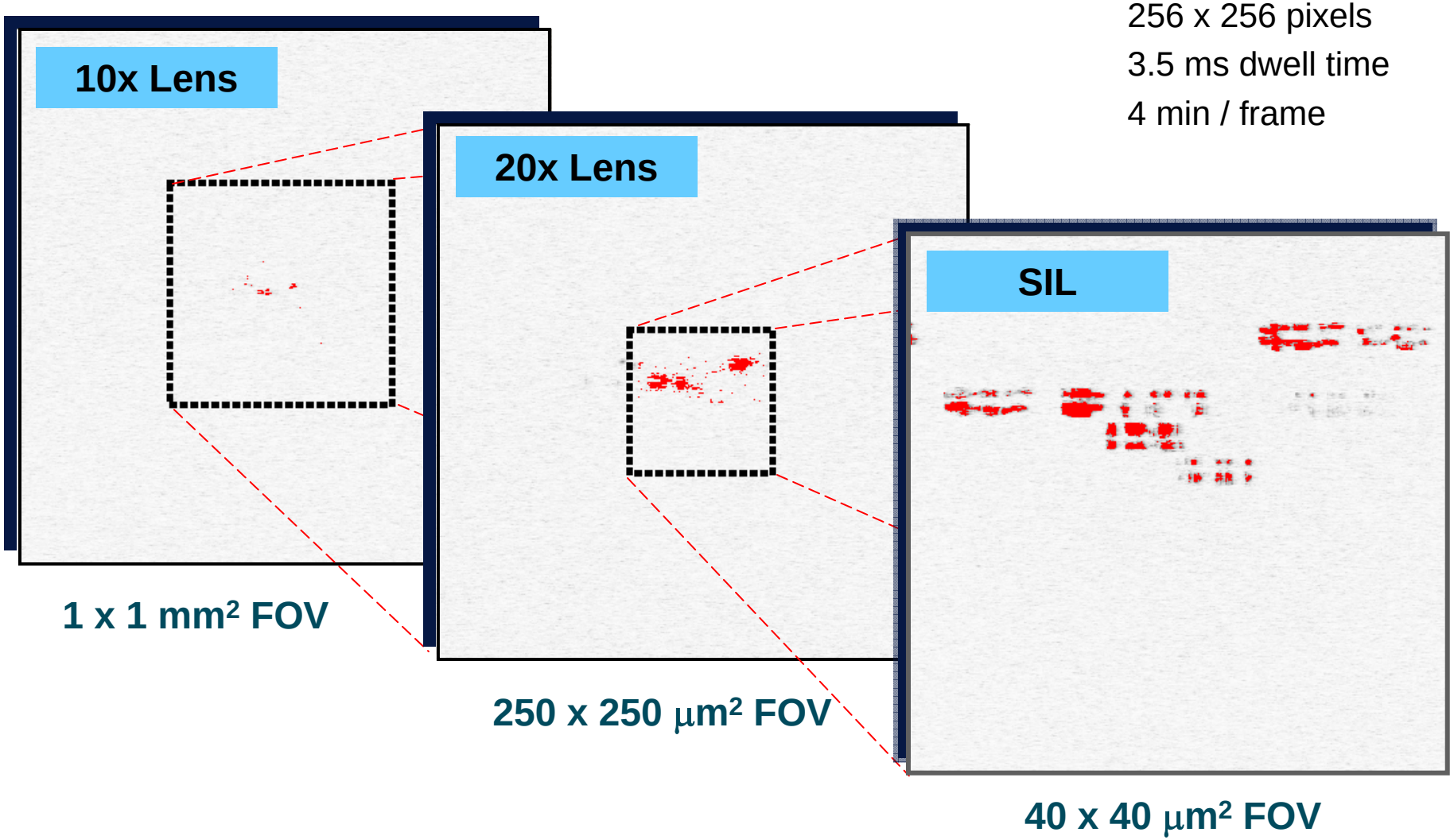
Zoom into identified electrical activity:

10 bit counter

256 x 256 pixels

3.5 ms dwell time

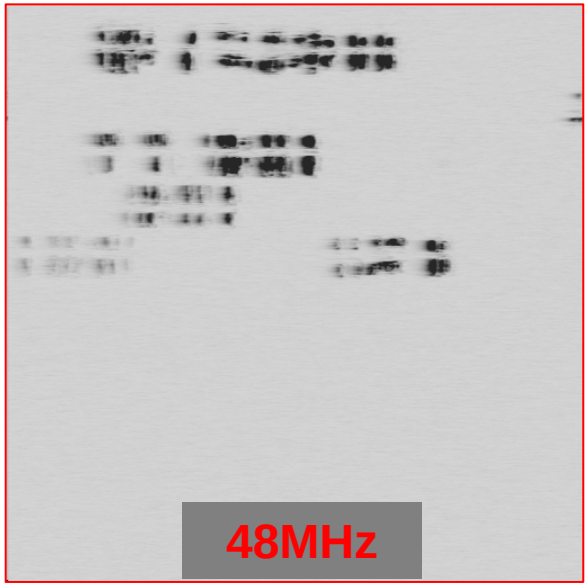
4 min / frame

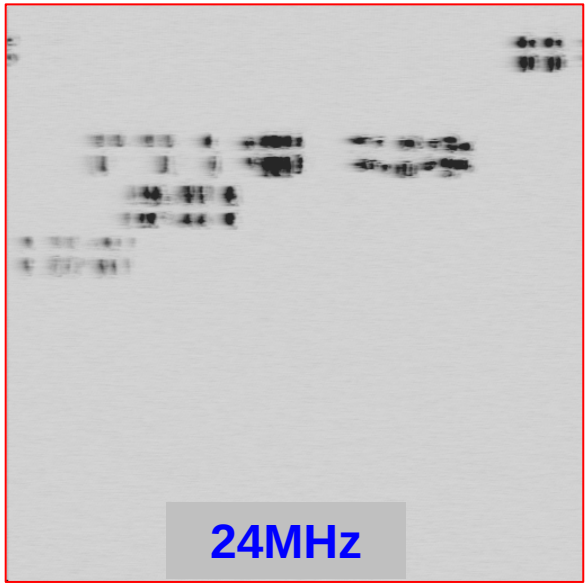


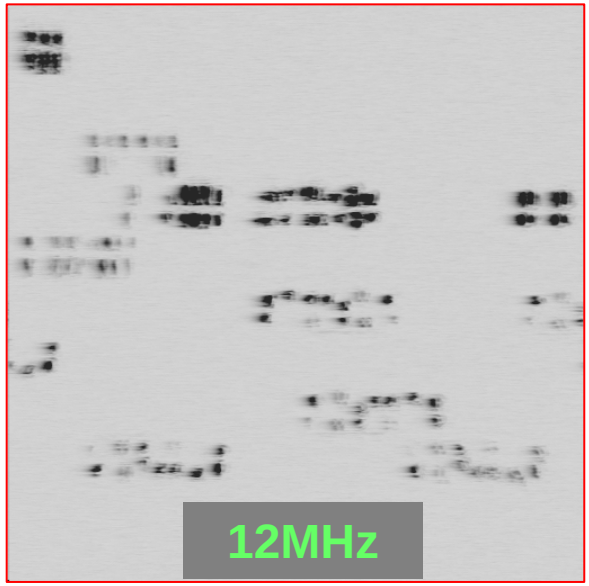
Equivalent acquisition time for each image regardless of field of view

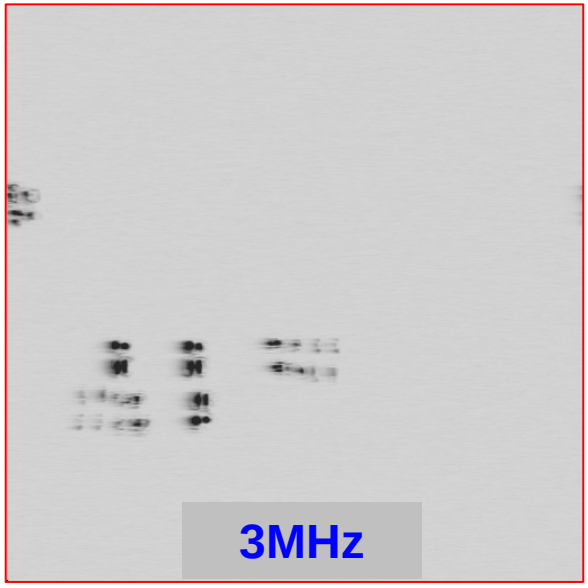
LVI Examples:

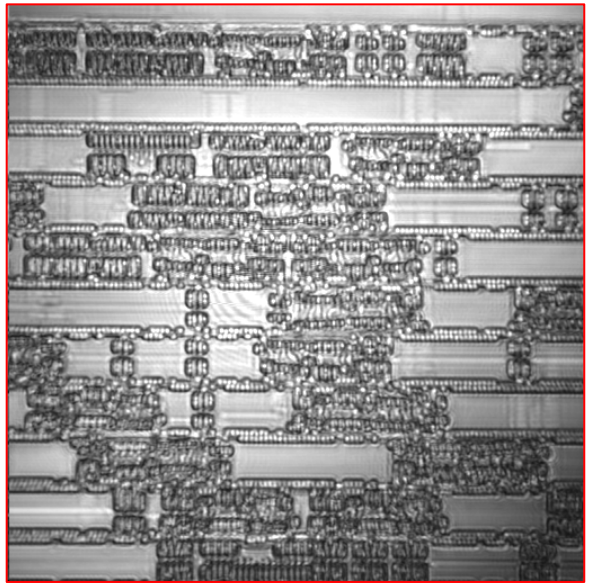
Functional Block with multiple Frequencies





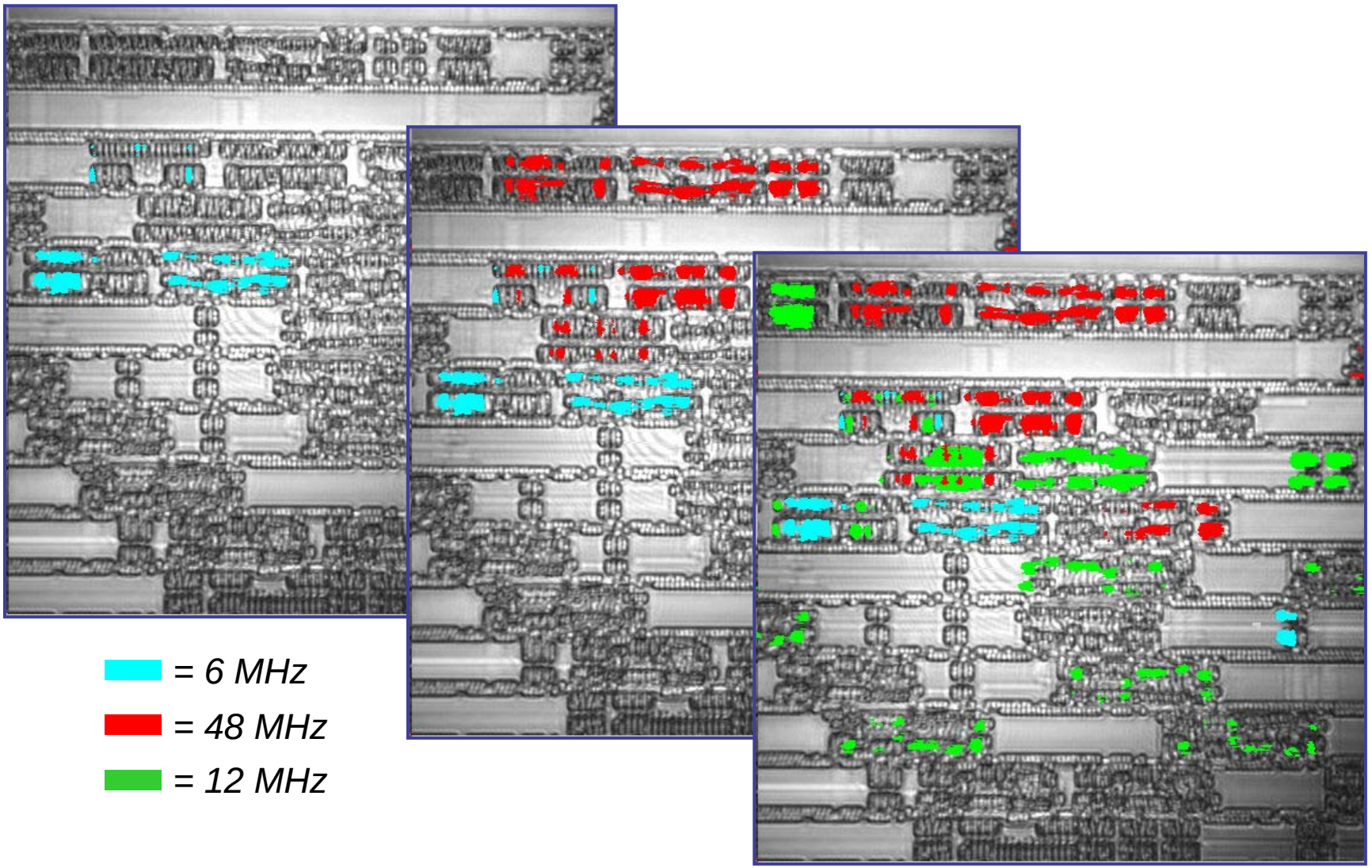






LVI Examples:

Multi-frequency LVI Overlay



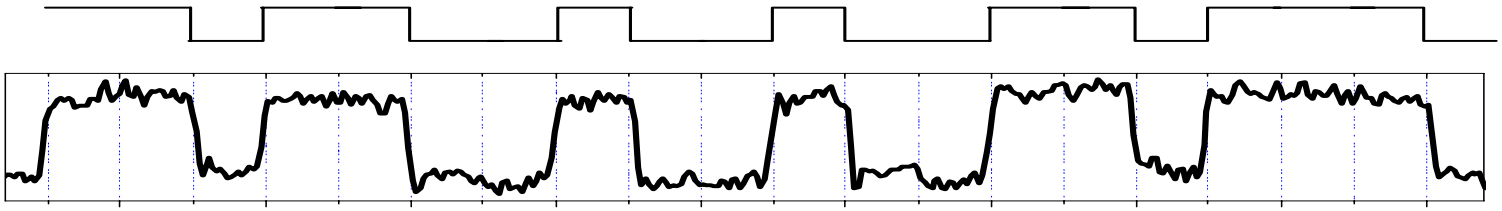
LVI Examples: Sensitivity to Non-Periodic Signals

DCG Systems

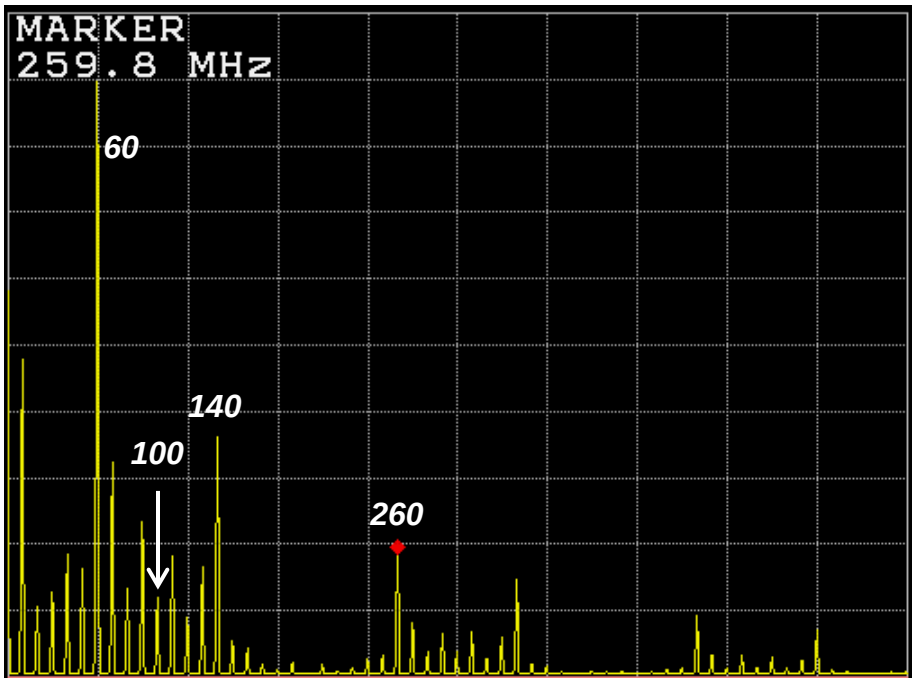
Waveform	Fourier Transform	LVI
100% periodic		
10101010101010101010		
60%		
11111111101010101010		
20%		
11111111111111111010	0 100 200 300 400 500 Frequency, MHz	

Data Stream with Complex of Frequencies

1 1 0 1 1 0 0 1 0 0 1 0 0 1 0 0 1 1 0 1 1 1 0



CW-LVP Waveform
50 ns/div



Frequency, MHz

Dominant frequencies:

10 MHz

60 MHz

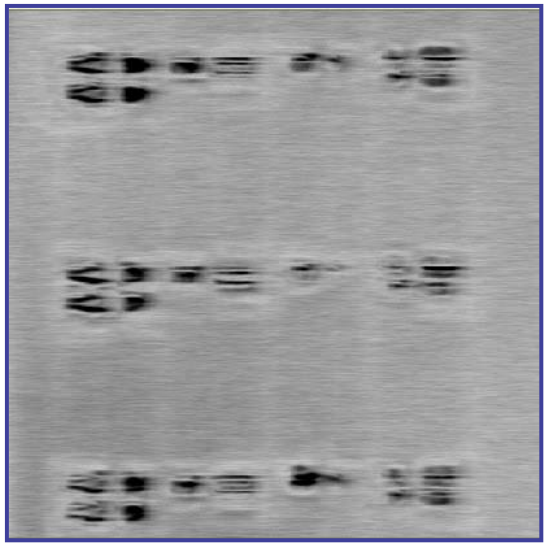
140 MHz

260 MHz

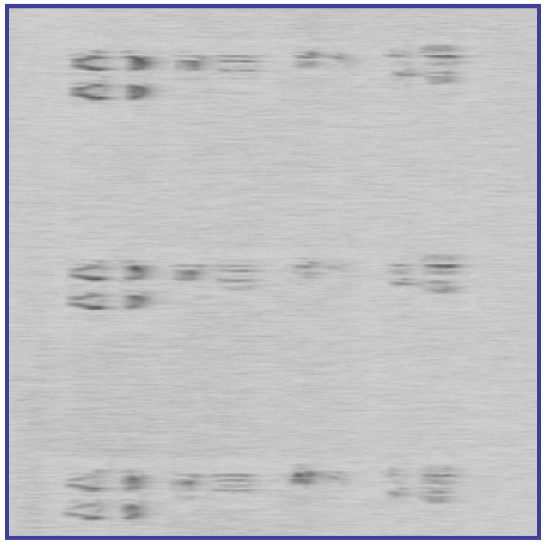
LVI Examples: Complex Signals

- LVI at several dominant frequencies

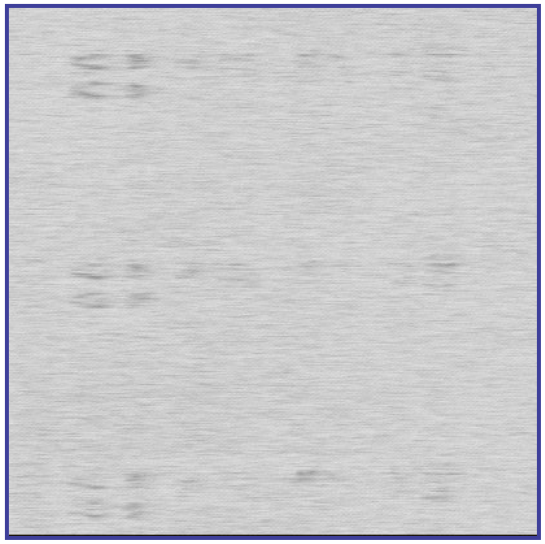
- FOV
  27 x 27 μm^2



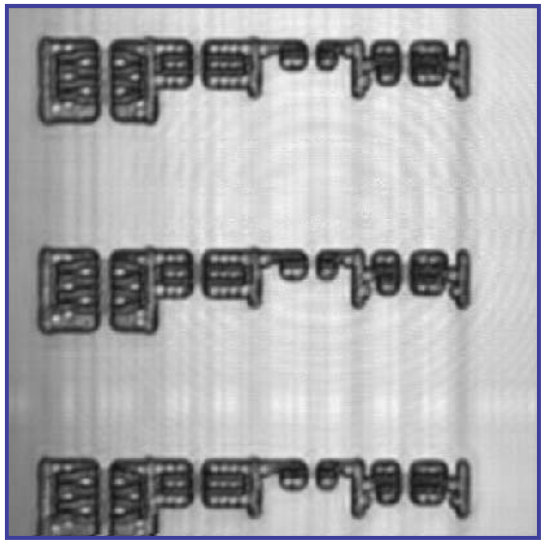
60 MHz



140 MHz



260 MHz



LSM Image

Discussion Summary

- Laser Modulation provides low V_{dd} sensitivity with new applications

- Laser Voltage Imaging (LVI) is a versatile global, image-based technique with applications in IC design debug, functional validation, optimization of LVP parameters, security & reverse engineering, signal tracing, scan chain debug, failure analysis….

- CW-LVP is a flexible optical probing scheme with few limitations
  - Limited accuracy when measuring high bandwidth edge timing
  - Reduced spatial resolution when operating at thermal laser wavelengths
  - Some invasiveness even with 1340 nm