Zurich Instruments

Advanced electrical characterization with the state-of-the-art lock-in amplifier

Dr. Romain Stomp, Principal Application Scientist

Company profile

- Founded in 2008, 180+ people, 25+ nations
- Headquarters in Zurich, Switzerland
- Offices in China, USA, Germany, Korea, Japan, France, India
- Part of Rohde & Schwarz since 2021

Zurich Instruments

A company of scientists for scientists.

Zurich Instruments

What do we do?

experience LabOne

Hardware

- Adequate speed
- High sensitivity
- Low noise
- High resolution

+

Software

- Efficient workflows
- UI & APIs
- Functionality & features
- Value added over time

→

Instruments

- Quantum control systems
- Lock-in Amplifiers
- Boxcar Averagers
- Impedance analyzers

The software is the instrument

Digital signal processing: Many tools in one box

500 kHz &
5 MHz

50 – 200 MHz

600 MHz

1.8 GHz

8.5 GHz


Lock-in


Scope


Spectrum


Sweeper


Imaging


PID


PLL


AWG


Boxcar

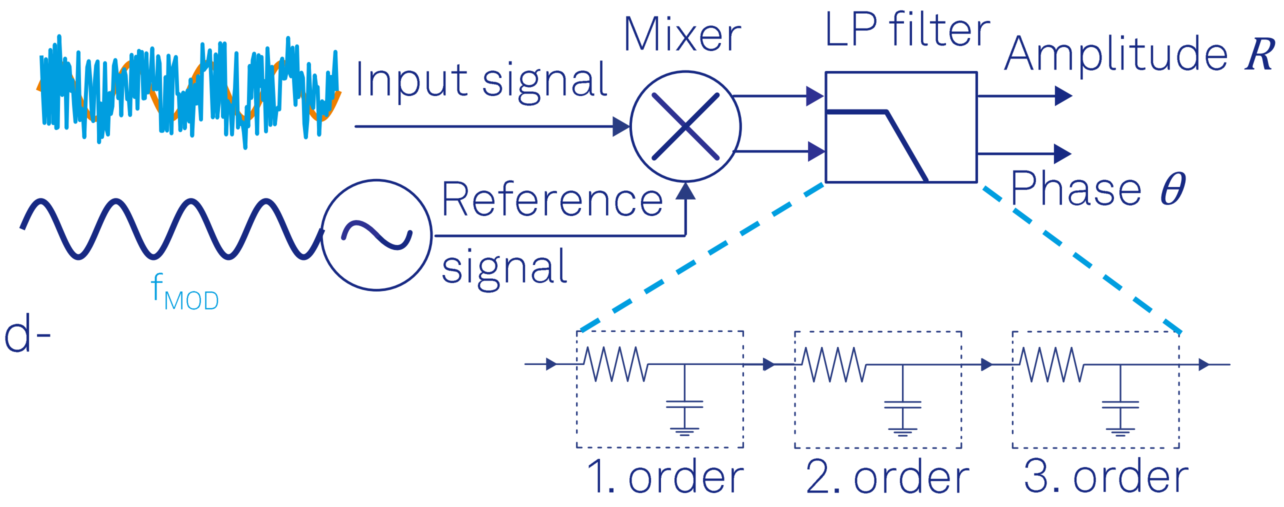
How to recover a periodic signal?

Lock-in Amplifier working principle

How does it work?

1. Multiply the signal with the reference (Shift from DC to f_{MOD})
2. Apply a low pass filter

→ Overall transfer function similar to a band-pass filter



Three parameters to set:

- Modulation frequency f_{MOD}
- Filter bandwidth *BW*
- Filter order

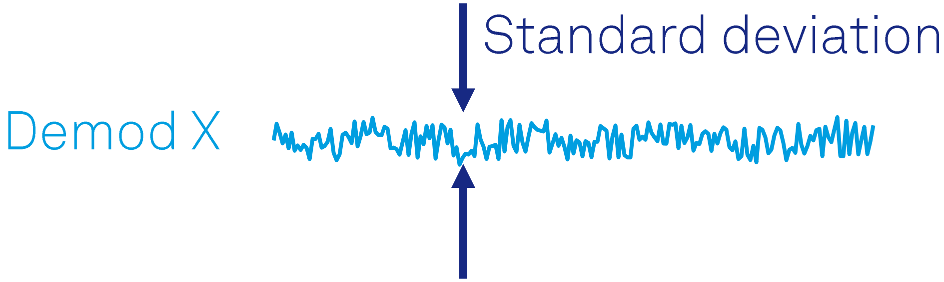
→ Sensitive to signals 1M times smaller than any spurious signal

Measuring Noise Spectral Density

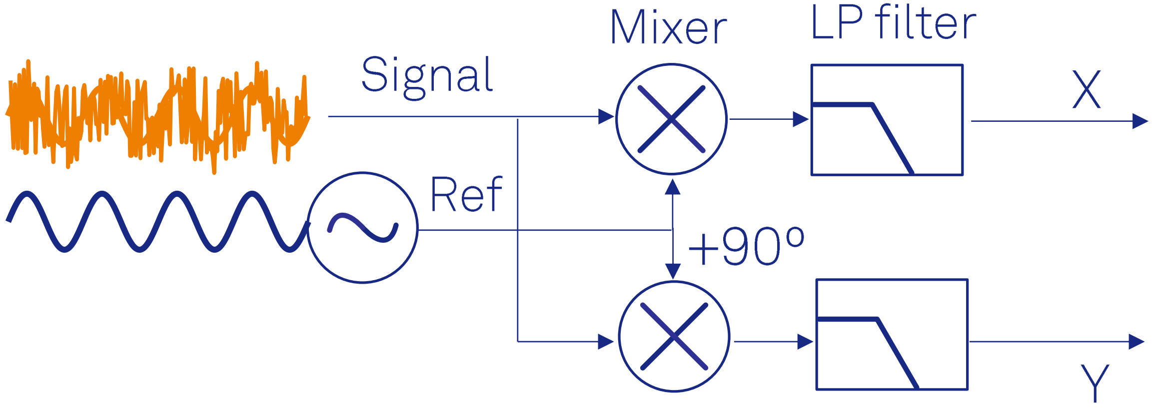
Lock-in Detection

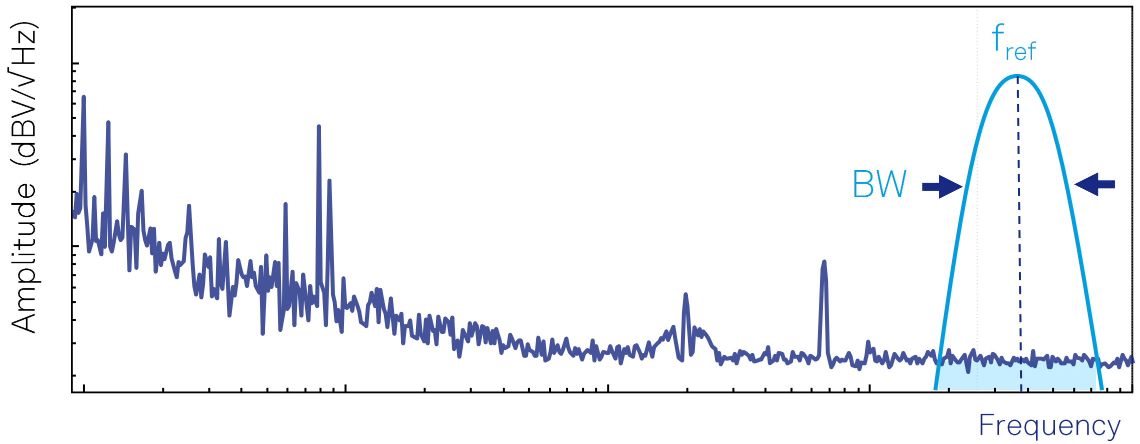
Step by Step

1. Demodulate at a frequency f_{ref}
2. Record the result X or Y
3. Repeat the measurement many times



4. Calculate the standard deviation
5. Normalize by the measurement bandwidth
6. Repeat for different frequencies





Measuring Noise Spectral Density

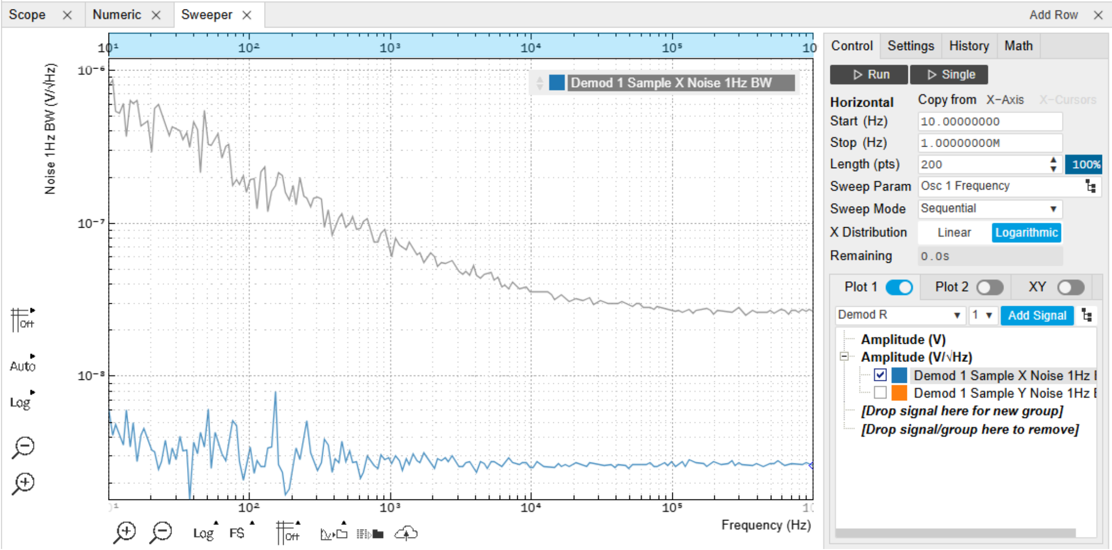
Lock-in Detection

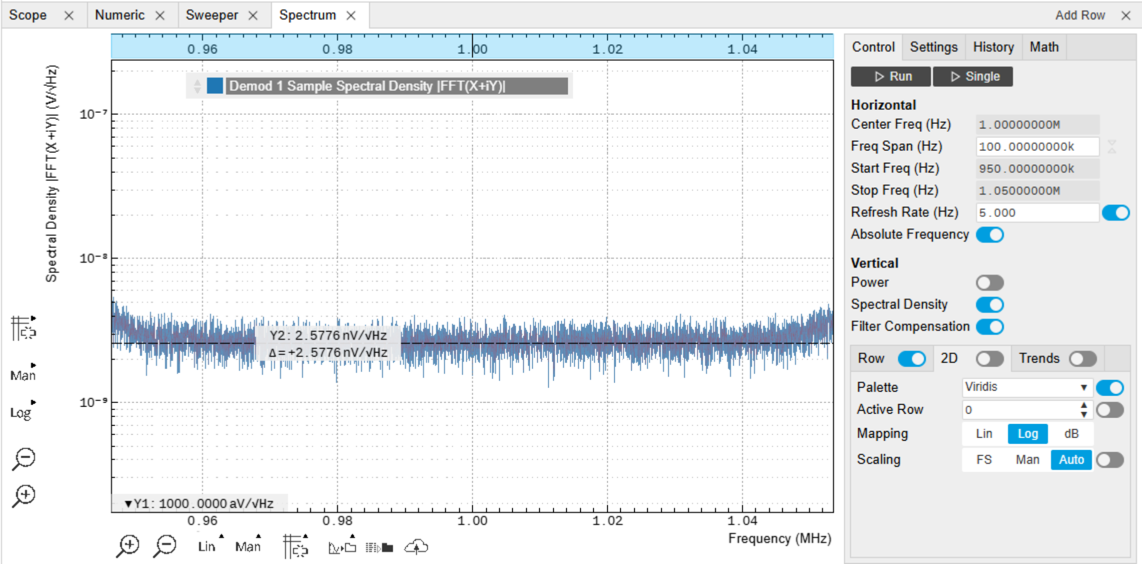
Noise Amplitude Sweep

- Automatic sweep of different frequencies
- Automatic spectral density calculation

Spectrum analysis

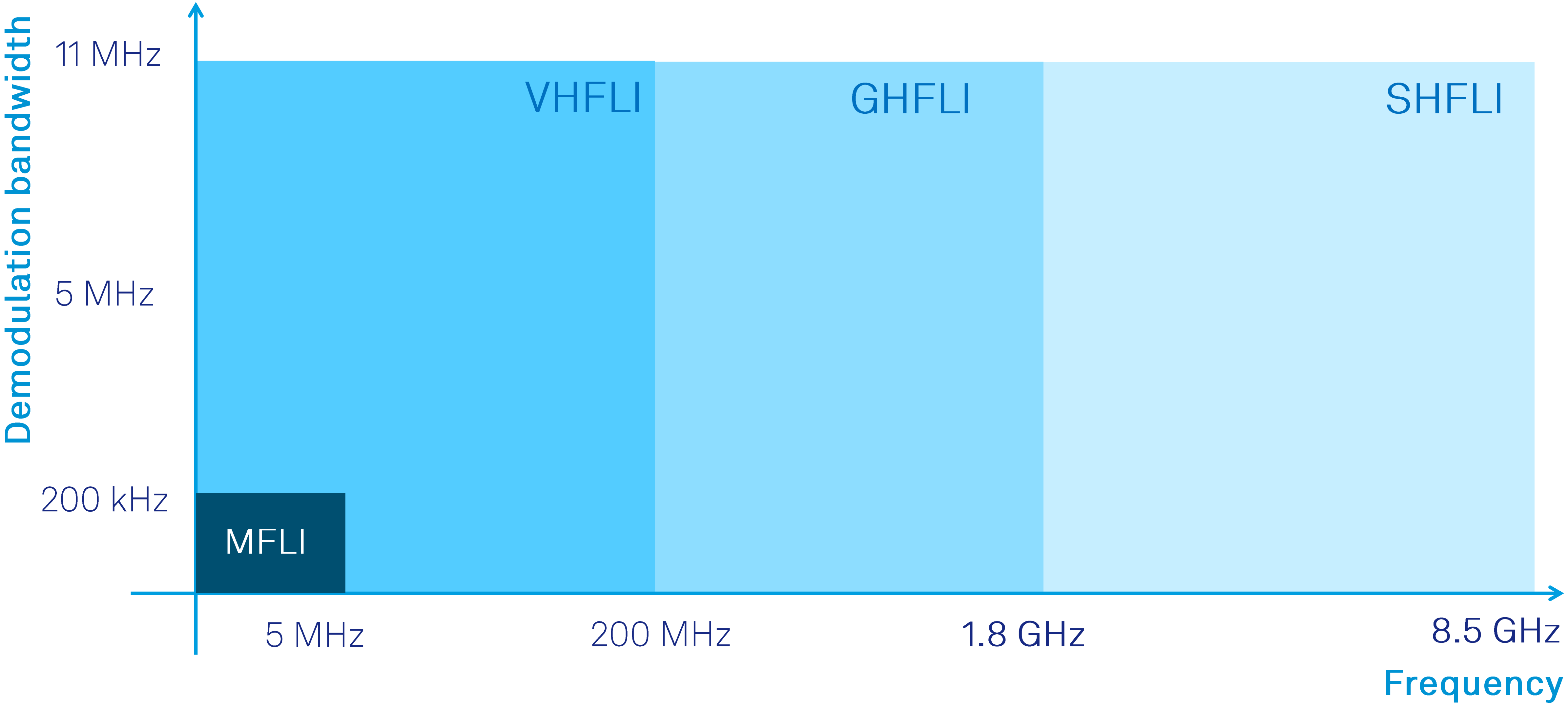
- Demodulation at one fixed frequency
- FFT of the demodulation result
- Automatic spectral density calculation and filter compensation

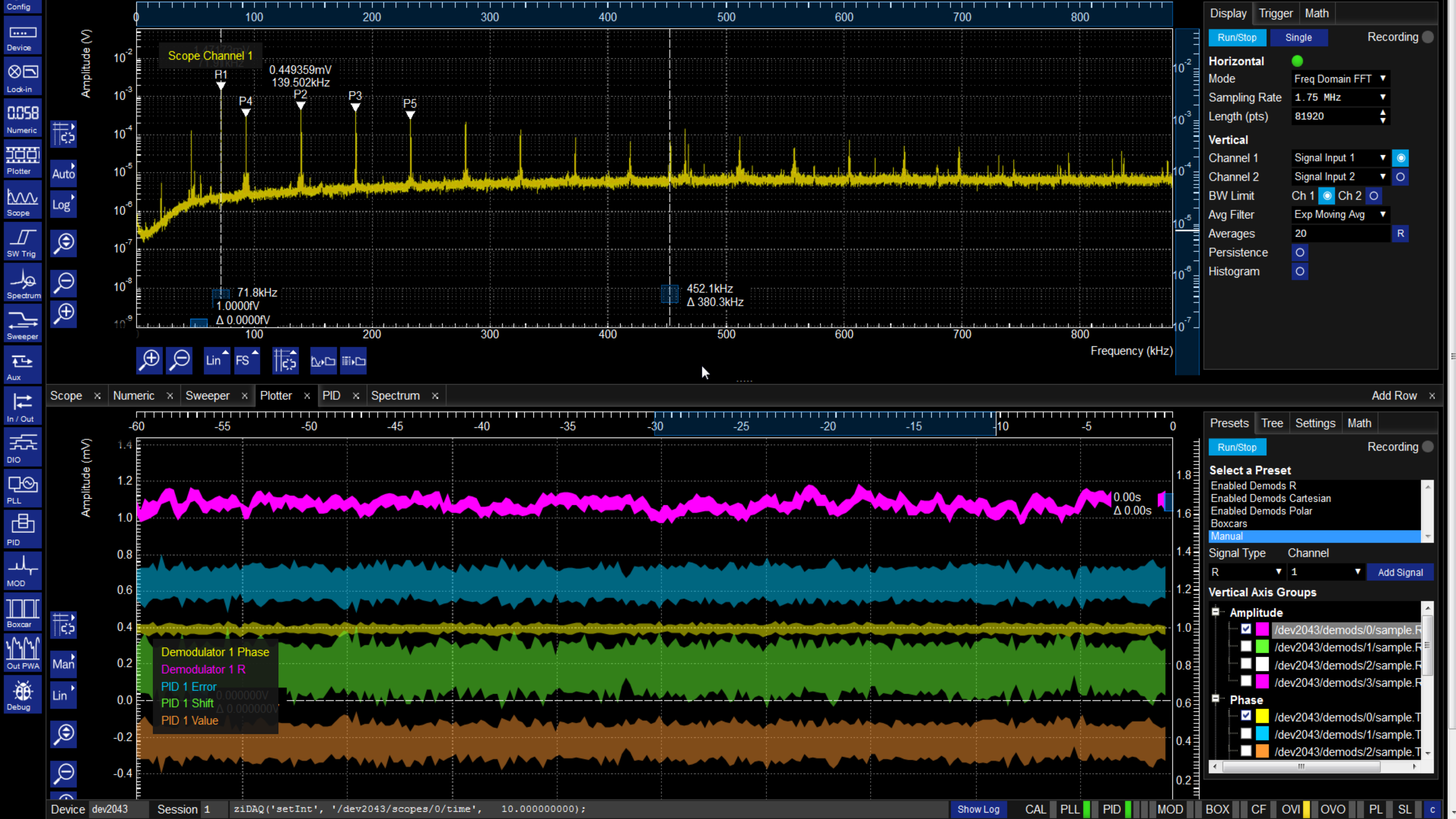




Sensing vs Making Sense

A wideband detection



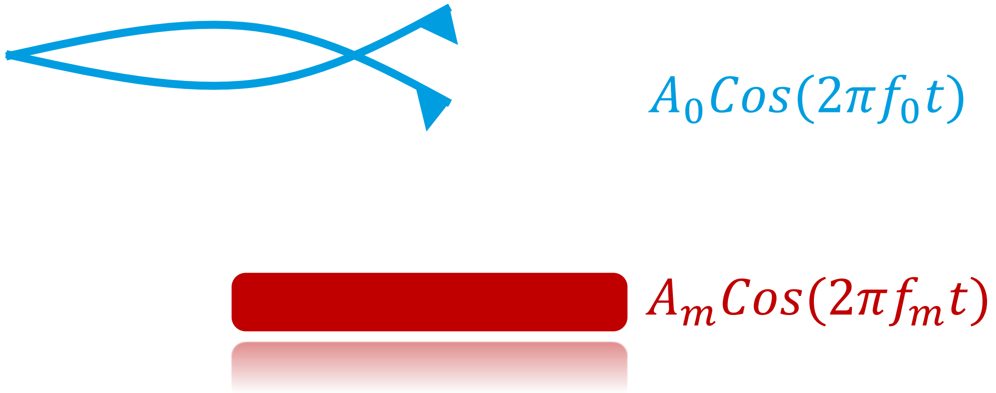


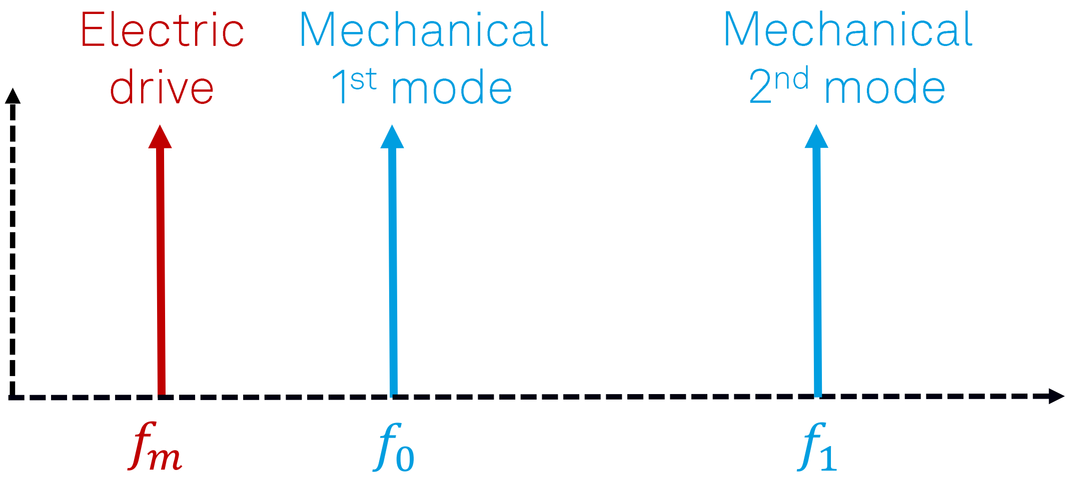
Config
Device
Lock-in
Numeric
Plotter
Scope
SW Trig
Spectrum
Sweeper
Aux
In / Out
DIO
PLL
PID
MOD
Boxcar
Out PWA
Debug
Scope Channel 1
Amplitude (V)
0.449359mV
139.502kHz
P1
P2
P3
P4
P5
71.8kHz
1.0000fV
Δ 0.0000fV
452.1kHz
Δ 380.3kHz
Frequency (kHz)
Auto
Log
Lin
FS
Display
Trigger
Math
Run/Stop
Single
Recording
Horizontal
Mode
Freq Domain FFT
Sampling Rate
1.75 MHz
Length (pts)
81920
Vertical
Channel 1
Signal Input 1
Channel 2
Signal Input 2
BW Limit
Ch 1
Ch 2
Avg Filter
Exp Moving Avg
Averages
20
Persistence
Histogram
Scope
Numeric
Sweeper
Plotter
PID
Spectrum
Add Row
Amplitude (mV)
Demodulator 1 Phase
Demodulator 1 R
PID 1 Error
PID 1 Shift
PID 1 Value
0.00s
Δ 0.00s
Man
Presets
Tree
Settings
Math
Select a Preset
Enabled Demods R
Enabled Demods Cartesian
Enabled Demods Polar
Boxcars
Manual
Signal Type
Channel
Add Signal
Vertical Axis Groups
Amplitude
/dev2043/demods/0/sample.R
/dev2043/demods/1/sample.R
/dev2043/demods/2/sample.R
/dev2043/demods/3/sample.R
Phase
/dev2043/demods/0/sample.T
/dev2043/demods/1/sample.T
/dev2043/demods/2/sample.T
Device
dev2043
Session
1
ziDAQ('setInt', '/dev2043/scopes/0/time', 10.000000000);
Show Log
CAL
PLL
PID
MOD
BOX
CF
OVI
OVO
PL
SL

Electro-mechanical systems

Electrostatic actuation of mechanical resonator

- Apply various frequency mixing scheme
- Rely on electro-mechanical coupling
- Same principle works for SPM, MEMS or opto-mechanical systems





Electro-mechanical systems

Electrostatic actuation of mechanical resonator

- Apply various frequency mixing scheme
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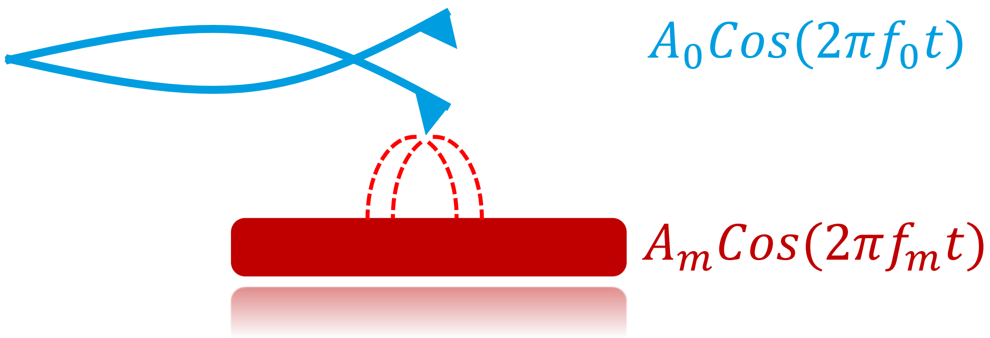
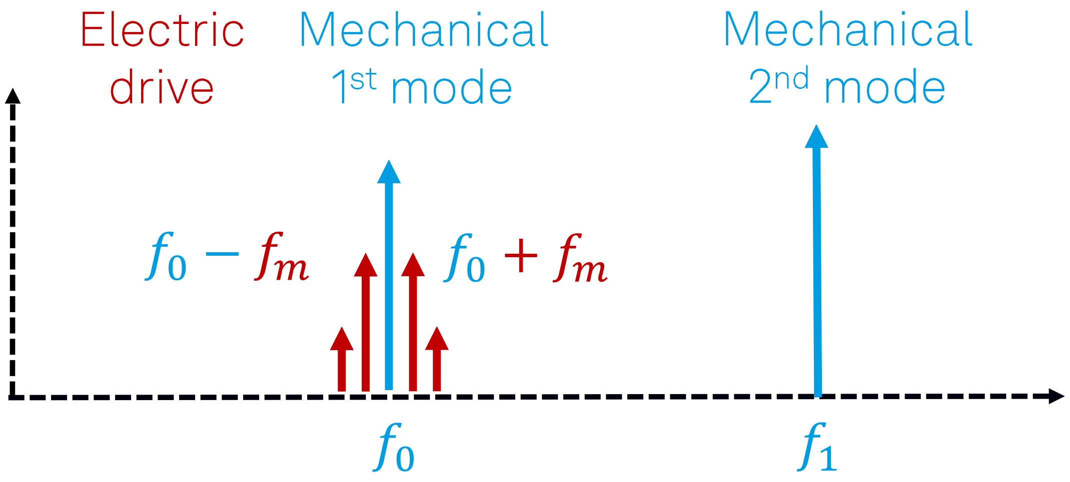
→ Sideband generation

→ Frequency Modulated carrier which can lead to so called FM-KPFM (Kelvin Probe)

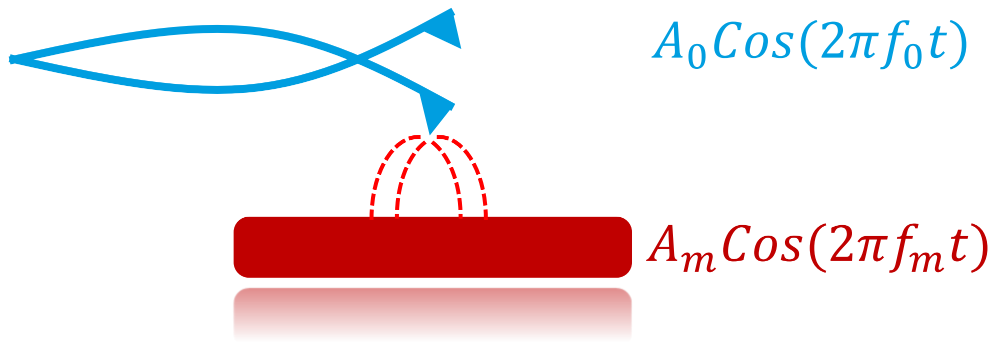




Heterodyne Kelvin Probe Force Microscopy (KPFM)

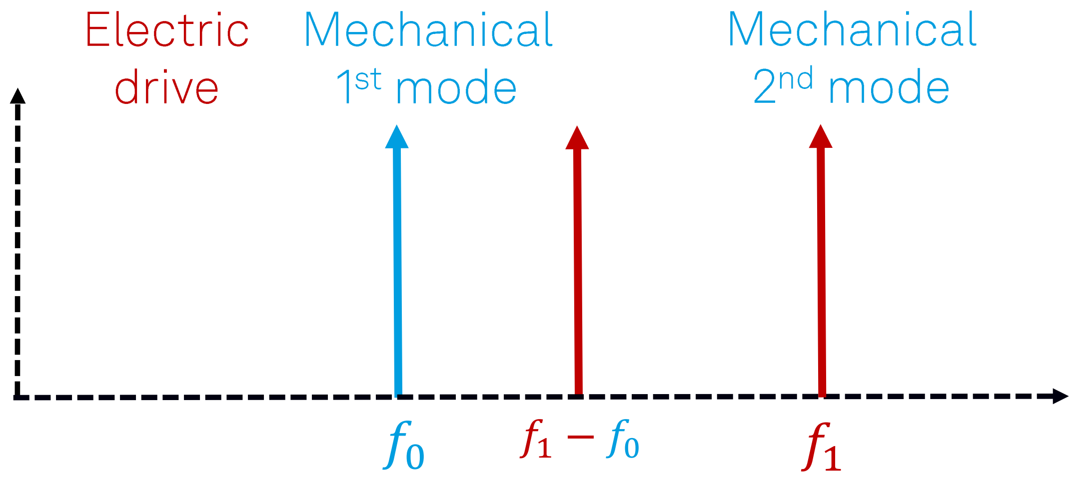
Electro-mechanical frequency mixing

- Still rely on electro-mechanical coupling
- But now the right sideband *(f_0+f_m)* is conveniently located at *f_1*
- Topography and electrostatic measurements benefit from 2 different eigenmodes



→ Heterodyne mode

→ "projection" of electric mode to higher mechanical eigenmode



The Lock-in Amplifier Power Horse

Freedom to innovate

From DC to 200 MHz

Current input

Mechanical drive (multifrequency)

Voltage input

Electrostatic drive (AC+DC)

The Lock-in Amplifier Power Horse

State-of-art analog and digital performance

Speed & measurement bandwidth

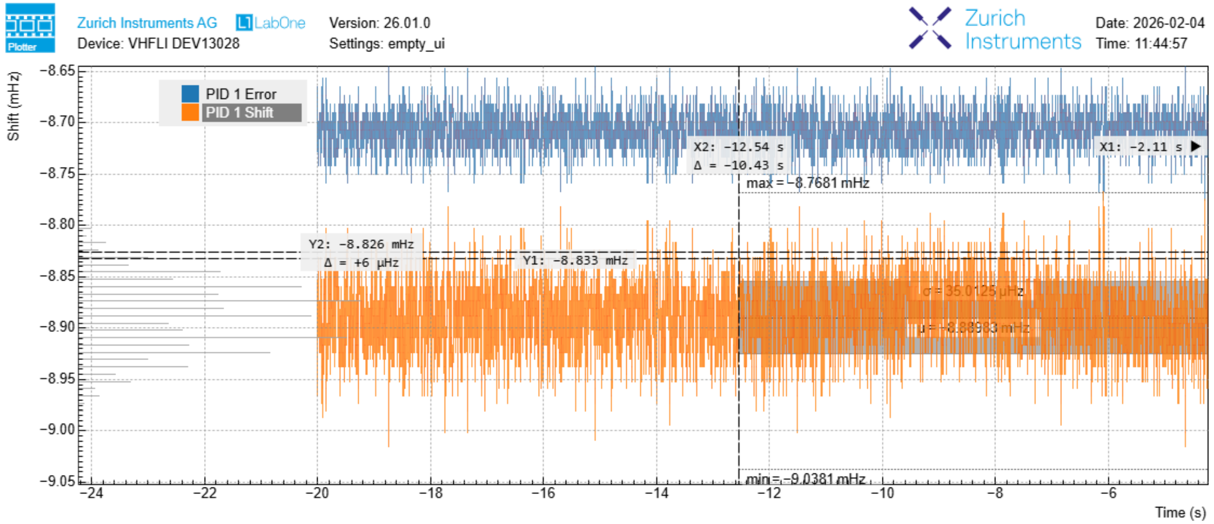
- 14ns time constant
- 2MSa/s data rate (up to 25MSa/s in Burst)

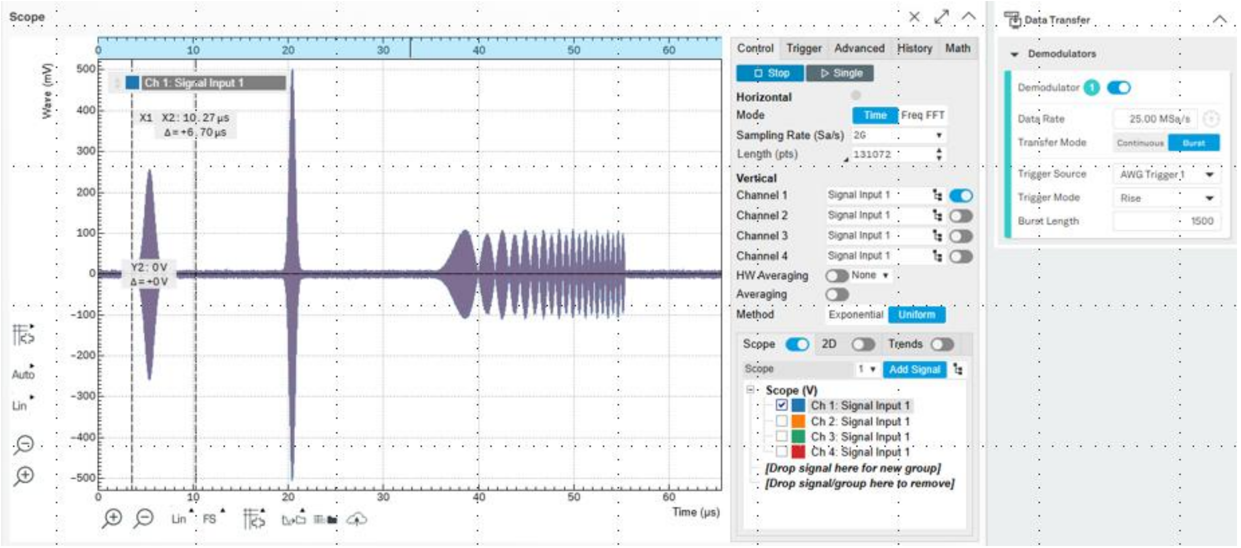
Ultra-low noise performance

- 3 nV/√Hz input noise
- 6 µHz frequency resolution in closed-loop

The Timeline Module

- CW & Pulsed modes in one box
- Orchestrate acquisition
- Arbitrary Waveform Generation





The Timeline Module

The timing hub of LabOne

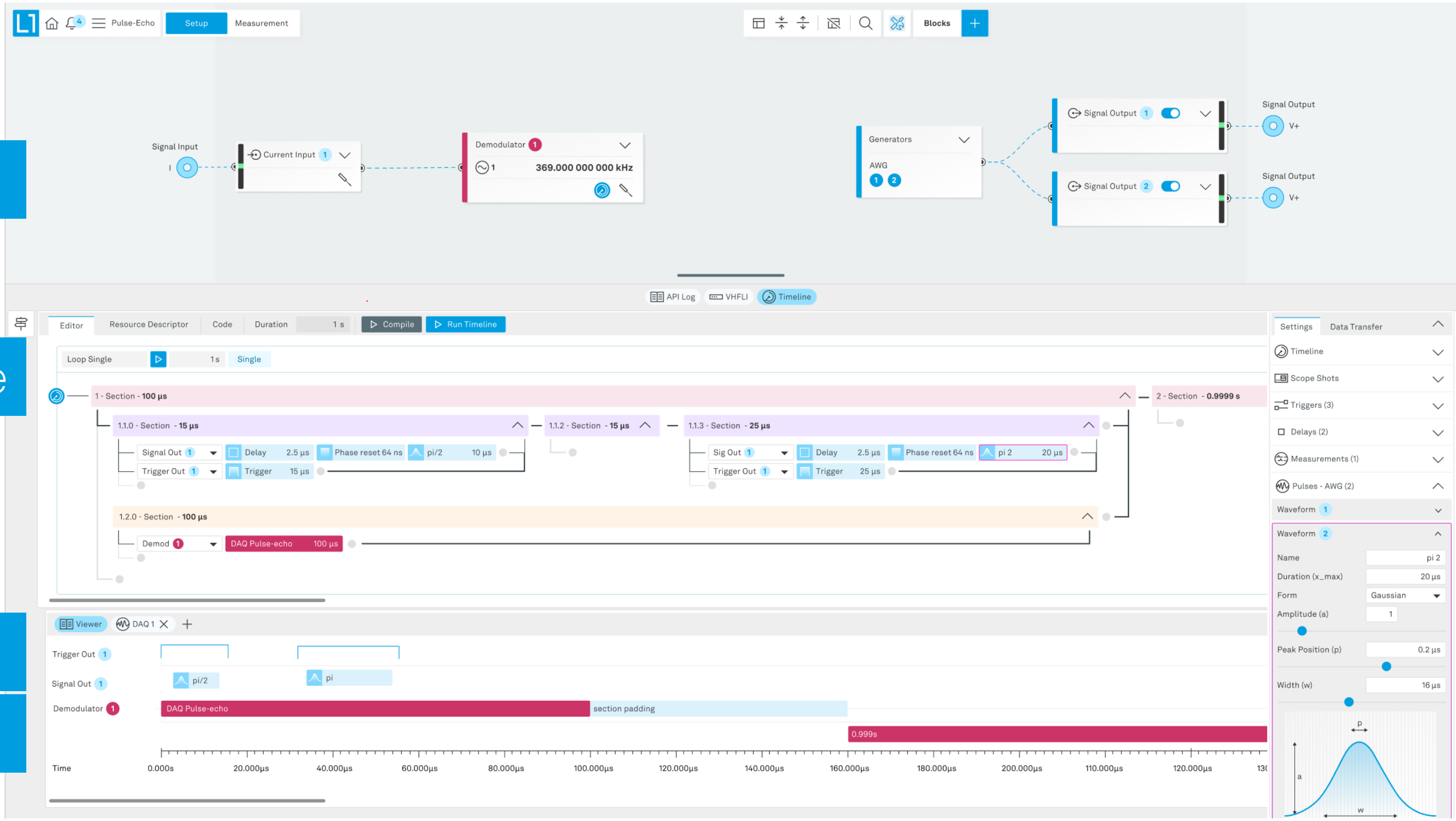
- Build and implement continuous wave and pulse measurement schemes
- Seemlessly coordinate pulses, triggers, measurements – all from a single interface

Setup

Orchestrate

Monitor

Measure



AWG

The Lock-in Amplifier Power Horse

A wealth of applications

Noise Analysis

→ Scope, Spectrum Analyser, Gaussian noise distribution, noise amplitude sweep, transient data capture

Sensors

→ Sensor characterization, impedance measurements, phase-locked loop

Photonics

→ Spectroscopy, laser & interferometer stabilization, pump-probe techniques

Scanning Probe Microscopy

→ Advanced mulitfrequency and time-resolved modes

The MF platform

Not just a lock-in amplifier, but more

+

MF

IA
Impedance Analyzer Option

=

- Common LCR meters use a classical auto-balancing bridge to measure impedance. This is the commonly accepted method in the field

The MFIA is different

1. Based on MFLI Lock-In Amplifier -> high frequency bandwidth starting from 1mHz
2. No external PID feedback loop -> faster LCR mode measurements
3. DC-coupled input and 8-stage gain amplifiers -> both low & high impedance measurements

Technical Aspects – Accuracy and Precision

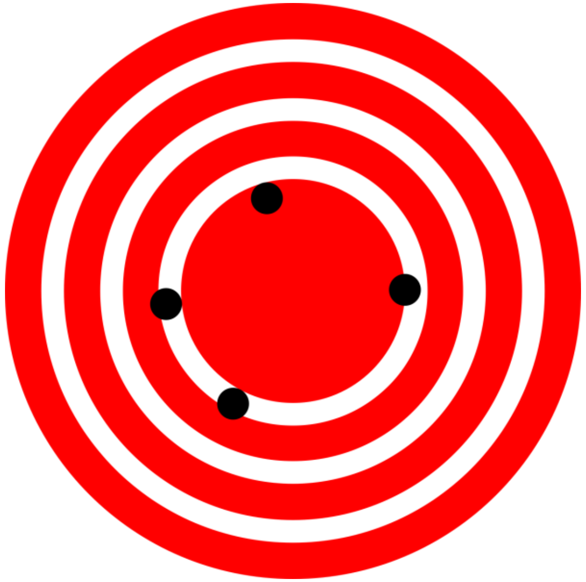
How to Achieve the Best Precision?

Accuracy has nothing to do with precision

- Only precision is affected by noise
- Compensation only corrects accuracy

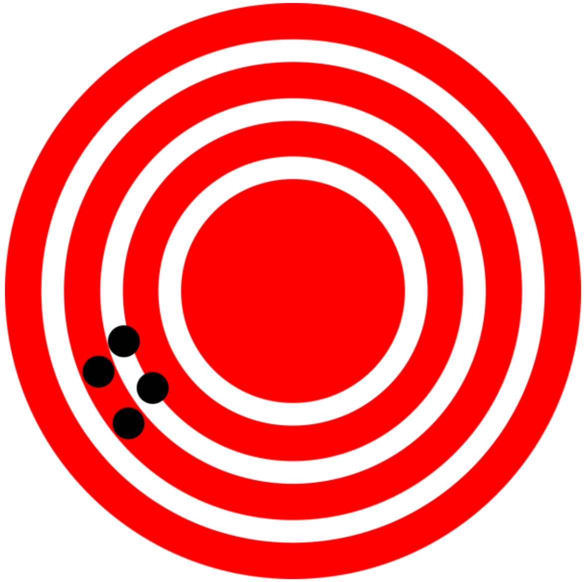
Ways to reduce noise:

- Remove noise sources
→ e.g. clean power supply
- Add noise insulation
→ e.g. Faradaic cage
- Use filtering circuit
→ e.g. RC circuit or RL circuit
- Digital filtering with adjustable bandwidth
→ Fast and precise numerical calculation



Accurate

Not precise



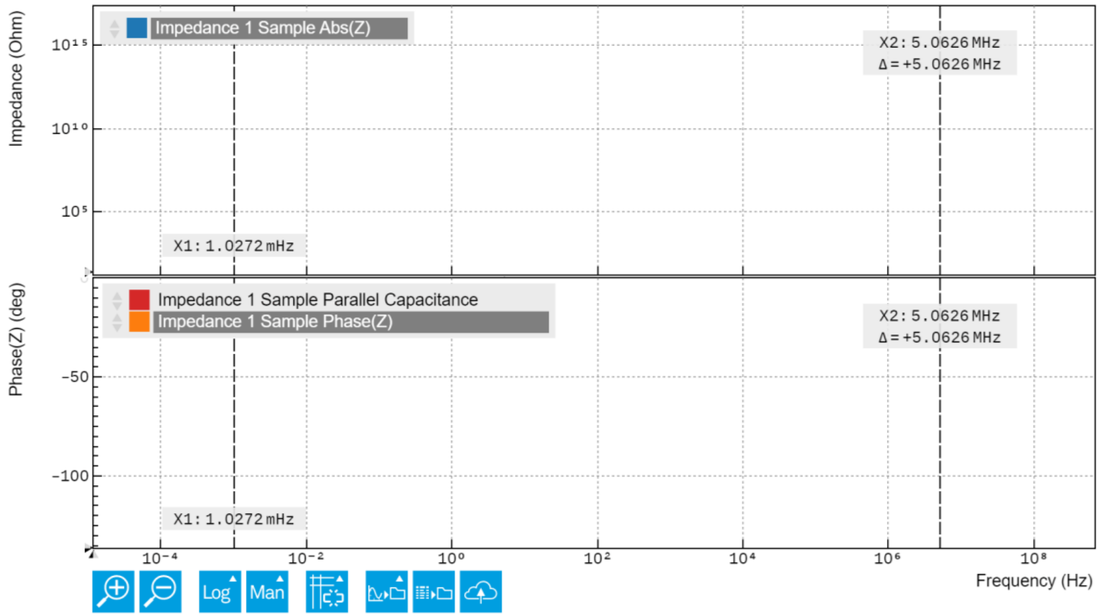
Precise

Not accurate

Image from Wikipedia

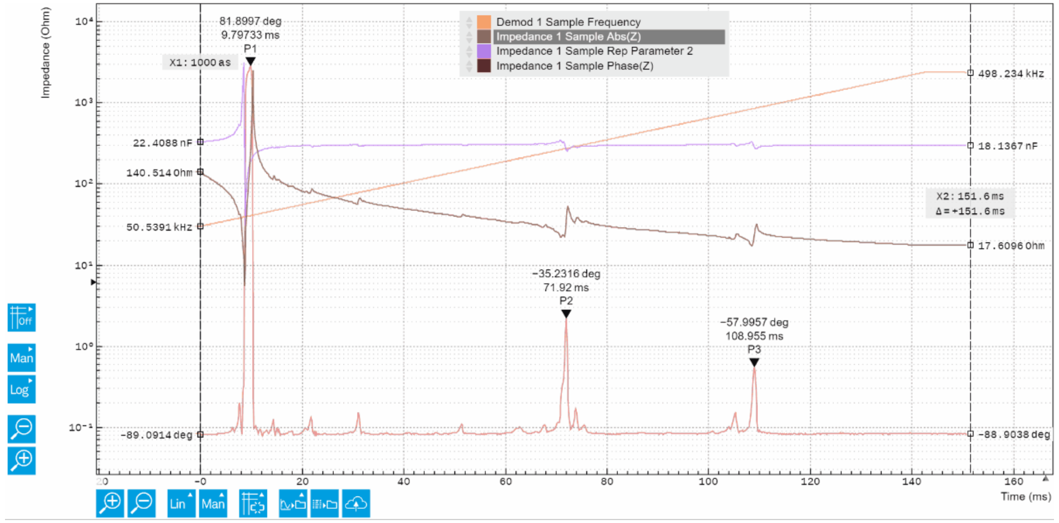
MFIA Applications
Material Characterization

- Measure broad impedance bandwidth – starting from mΩ and below to 1 TΩ and beyond
- Sweep from 1 mHz to 5 MHz seamlessly
- Measure impedance over full range thanks to eight current input ranges
- Sweep up to 100k points
- Compatible with any dielectric fixtures
- Current zone ranging: include 1 nA ranges to detect current down to 0.1 pA



1 mHz 5 MHz

MFIA Applications
Fast sweeps for ferroelectric characterization

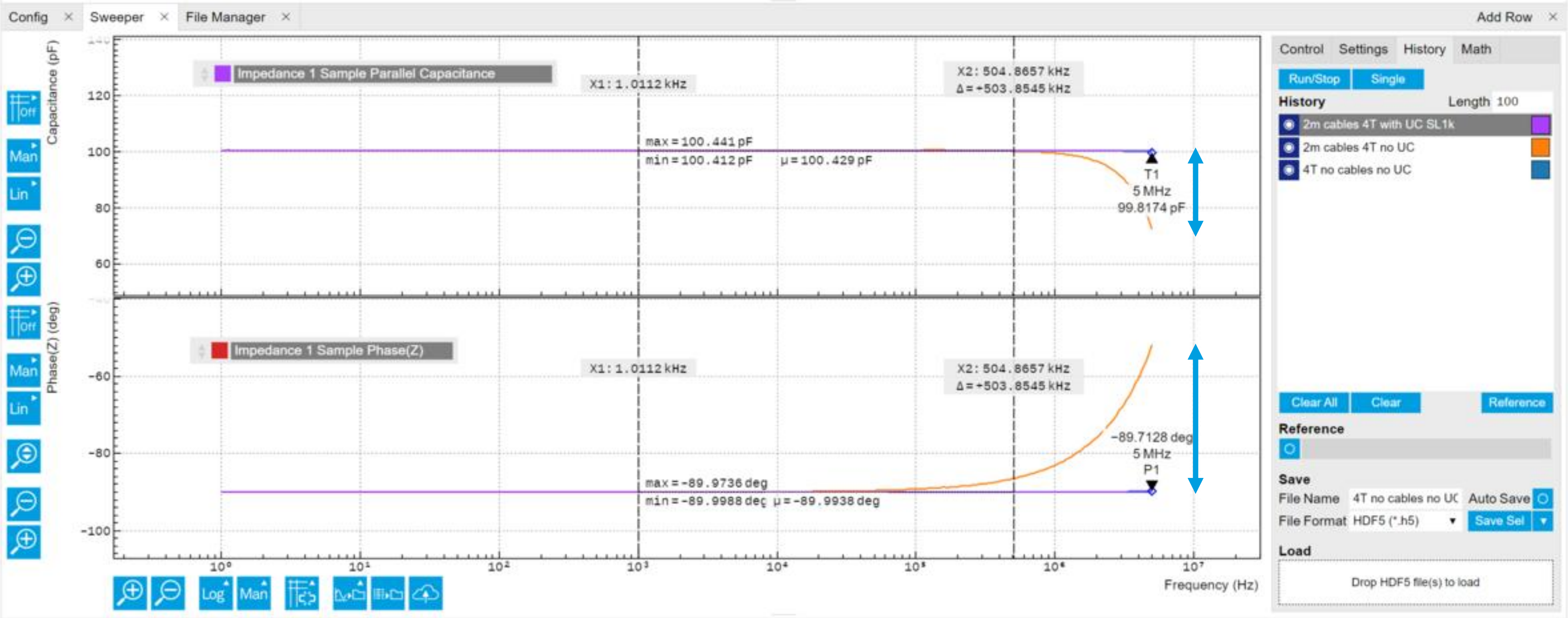


- Ability to measure fast with frequency-chirp sweeps, fast update rate
- Sweep 1000 data points in 300 ms
- Real-time feedback: requires MF-PID option

Technical Aspects – Accuracy and Precision

How to Achieve the Best Accuracy?

Applying a short-load compensation brings the phase back to ~-90 deg at even 5 MHz.



Technical Aspects – Accuracy and Precision

How to Achieve the Best Accuracy?

The MFIA boasts of 0.05% basic accuracy.

Common sources of 'systematic' error:

- Parasitic inductance (L) from cables
- Geometrical capacitance (C) of device
- Contact resistance (R)
- Gain error at high frequencies

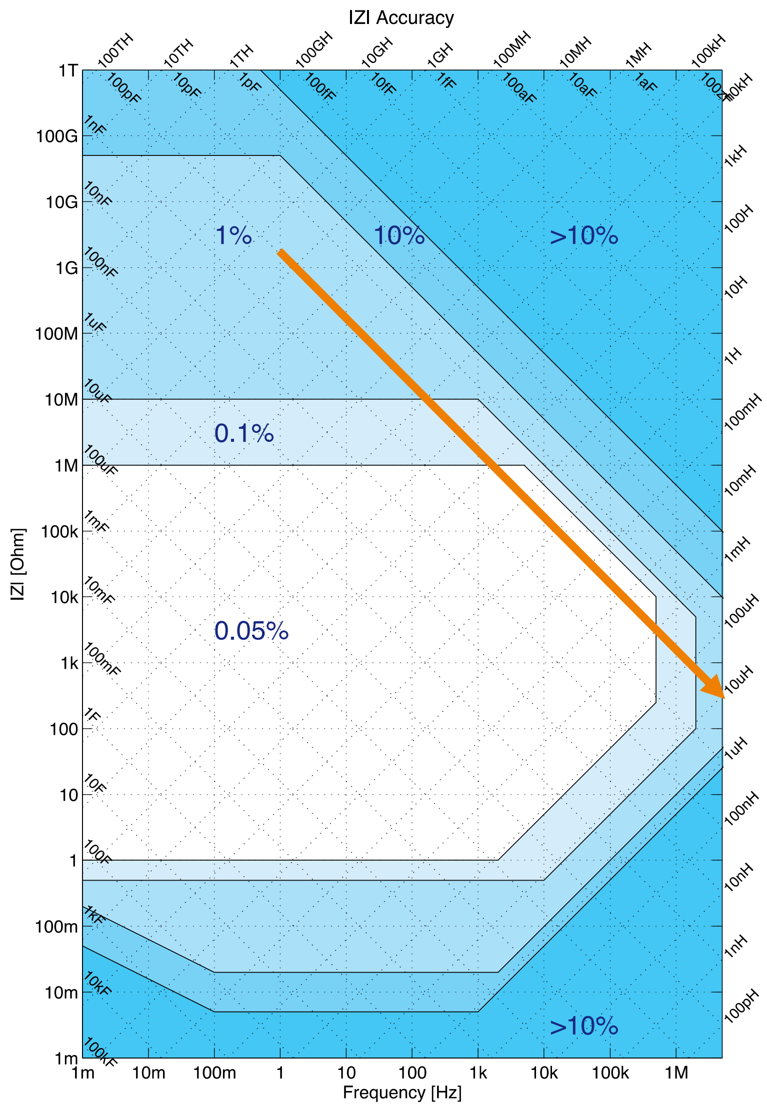
(Numerical) Solutions:

- Apply impedance compensation for all f

→ Short: Z baseline subtraction

→ Open: 1/Z (Y) baseline subtraction

→ Load: Z (and θ) scaling



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Ask us

We look forward to your questions!

Contact us today

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