RF Metrology - Tools and Process Capability

Technology for Productivity

POWER & REACTIVE GAS · VACUUM TECHNOLOGY · F
LEAK DETECTION · FLOW MEASUREMENT & CONTRO
PRESSURE MEASUREMENT & CONTROL · CONTROL &
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
BIOPHARMECEUTICAL · VACUUM TECHNOLOGY · LEA
PRESSURE MEASUREMENT & CONTROL · FLOW MEAS
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE

This presentation will provide technical capabilities of the MKS V/I Probe family of RF metrology tools and discuss the data collection capabilities of the MKS Toolweb Blue Box. The discussion will also touch on using multivariate analysis tools on process data for fault detection.

Philip Schmitt / Mark Rousavy

8/9/04

Agenda

- Overview of VI Probe Product Family
- Technology Overview
- Data Acquisition and Analysis

V/I Probe® RF Impedance Analyzer

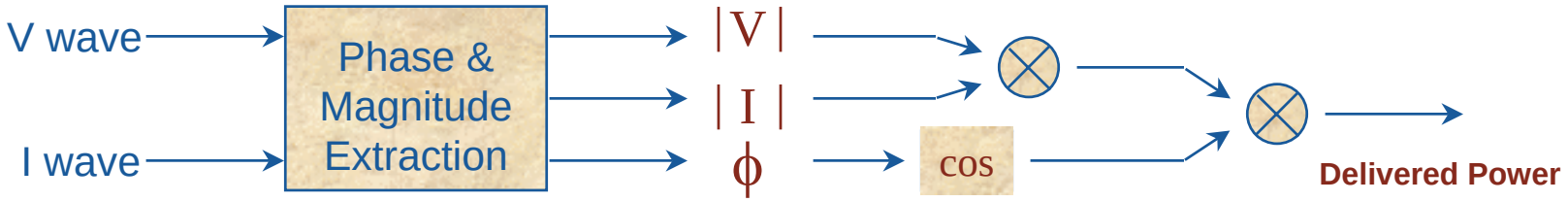
Non-intrusive, independent, real time, accurate measurement of load V, I and phase angle which monitors multiple frequencies at the same time

Real-time assessment of RF subsystem health
and
Ability to characterize key process applications to maintain and enhance process uniformity, control and consistency

V/I Probe® Impedance Analyzer

Measurement Parameters

- Basic Measurement Parameters
  - RMS Voltage
  - RMS Current
  - Phase relationship between Voltage & Current
  - Frequency
- Derived Measurement Parameters
  - Impedance (Z)
  - Forward/Reflected Power
  - Γ (Reflection Coefficient)
  - Load Power(VICos[Ø])
  - Reactive Power (VISin[Ø])
  - SWR and others

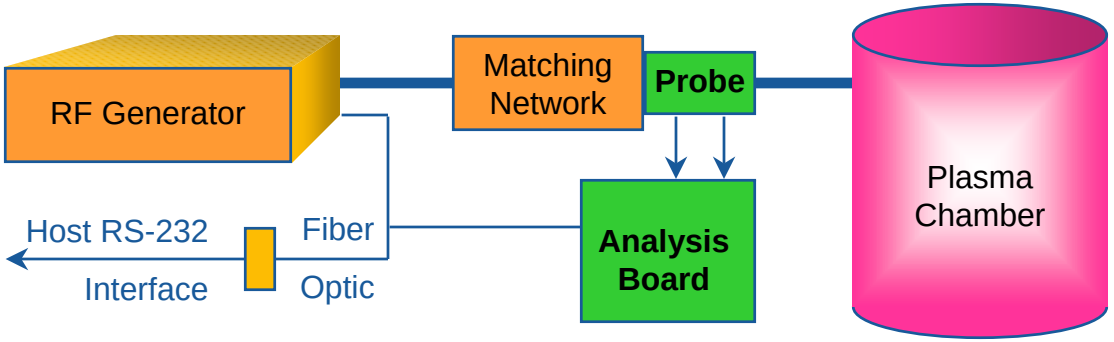


DSP Algorithm for Delivered Power Calculation

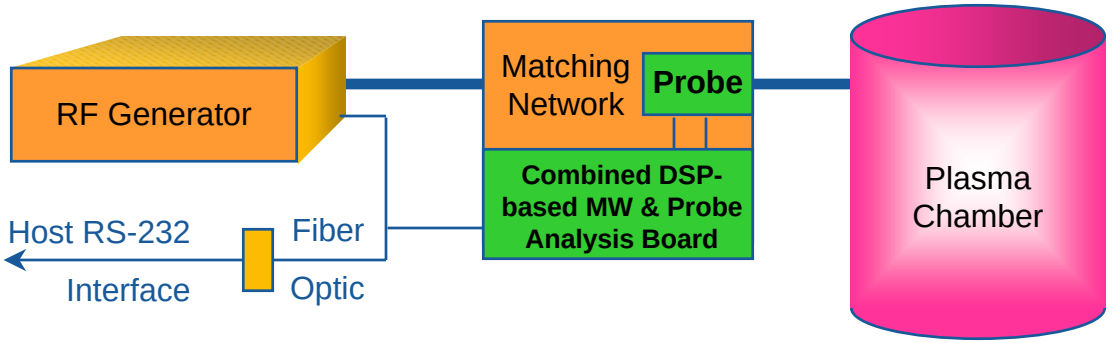
V/I Probe® Impedance Analyzer

Block Diagram and Installation

Standard Configuration



Optional Integrated Configuration



Overview of VI Probe Product Family

- 2 Types of VI Probes:
- ***Scanning*** – Monitors 1 frequency at a time over a user specified range
- ***Broadband*** – Monitors and tracks 2 fundamental frequencies and up to 5 harmonic frequencies for each fundamental (12 frequencies total) simultaneously

Typical Uses

- **Scanning VI Probe:**
  - Ideal for the single frequency applications (fixed frequency)
  - Capable of measuring Harmonics on higher power processes using sequential measurements
- **Broadband VI Probe:**
  - Ideal for multiple frequency chambers or processes
  - Enables tracking of up to 2 Fundamental frequencies
  - Enables real time simultaneous data collection of all monitored frequencies
  - Improved signal to noise performance on harmonics
    - Harmonic data used for end point detection, process and chamber finger printing, process and chamber SPC

Performance Comparison

		VI Probe 350	VI Probe 4100	VI Probe Broadband
RF	Frequency range	325kHz to 50MHz	600kHz to 100MHz	400kHz to 150MHz
	Frequency Monitoring	1 frequency at a time	1 frequency at a time	2 fundamental simultaneously Lower Frequency Range: <16MHz Upper Frequency Range: >16MHz
	Harmonic Monitoring			5 Harmonics for each fundamental
Fundamental	Voltage Repeatability	+/- 1%	+/- 1%	+/- 1%
	Current Repeatability	+/- 1%	+/- 1%	+/- 1%
	Power Accuracy (50 ohms)	+/- 1%	+/- 1%	+/- 1%
	Phase Accuracy	+/- 0.7 degrees	+/- 0.7 degrees	+/- 0.7 degrees
	Impedance Accuracy	+/- 1.5%	+/- 1.5%	+/- 1.5%
	Voltage Minimum (Meet Accuracy)	TBD	TBD	1.0 V
	Current Minimum (Meet Accuracy)	TBD	TBD	75 mA
	Voltage Dynamic Range (Full Scale, Meet Accuracy)	~60 dB	~60 dB	70 dB
	Current Dynamic Range (Full Scale, Meet Accuracy))	~60 dB	~60 dB	60 dB
	Frequency Accuracy	100 PPM	100 PPM	100 PPM
	Phase Sensitivity	+/- 0.7 degrees	+/- 0.7 degrees	+/- 0.7 degrees

Performance Comparison (con't)

		VI Probe 350	VI Probe 4100	VI Probe Broadband
Harmonics	Voltage Repeatability	+/- 1%	+/- 1%	1.00%
	Current Repeatability	+/- 1%	+/- 1%	1.00%
	Phase Accuracy	+/- 0.7 degrees	+/- 0.7 degrees	+/- 1.0 degrees
	Impedance Accuracy	1.50%	1.50%	+/- 2.0%
	Voltage Dynamic Range	~ 60 dB	~ 60 dB	>70 dB
	Current Dynamic Range	~ 60 dB	~ 60 dB	> 60 dB
	Phase Sensitivity	+/- 0.7 degrees	+/- 0.7 degrees	+/- 0.7 degrees
Electrical	Phase Range	+/- 180 degrees	+/- 180 degrees	+/- 180 degrees
	Voltage Range (Working / Max)	2500 Vrms 10 kVrms	2500 Vrms 10 kVrms	4500 V rms 10 kV rms
	Current Range (Working / Max)	110 A rms 135 A rms	110 A rms 135 A rms	110 A rms 135 A rms
	Communication	RS-232	RS-232	RS-232, Ethernet

Note: Impedance accuracy for up to 90:1 VSWR Load (other loads possible, but may affect accuracy)

How Does It Work?
The Basics

Technology for Productivity

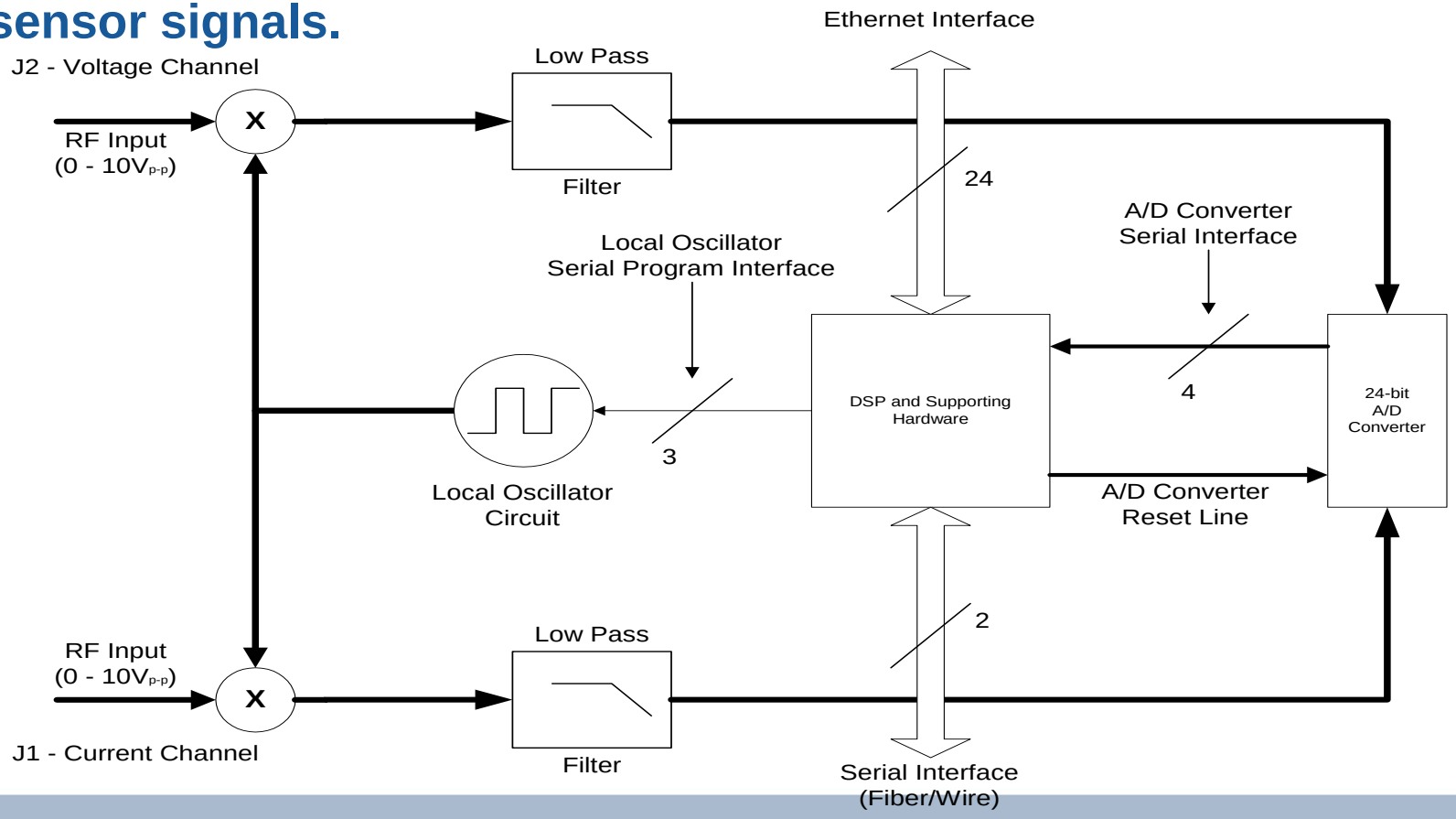
POWER & REACTIVE GAS · VACUUM TECHNOLOGY · F
LEAK DETECTION · FLOW MEASUREMENT & CONTRO
PRESSURE MEASUREMENT & CONTROL · CONTROL &
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
BIOPHARMECEUTICAL · VACUUM TECHNOLOGY · LEA
PRESSURE MEASUREMENT & CONTROL · FLOW MEAS
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE

Philip Schmitt / Mark Rousavy

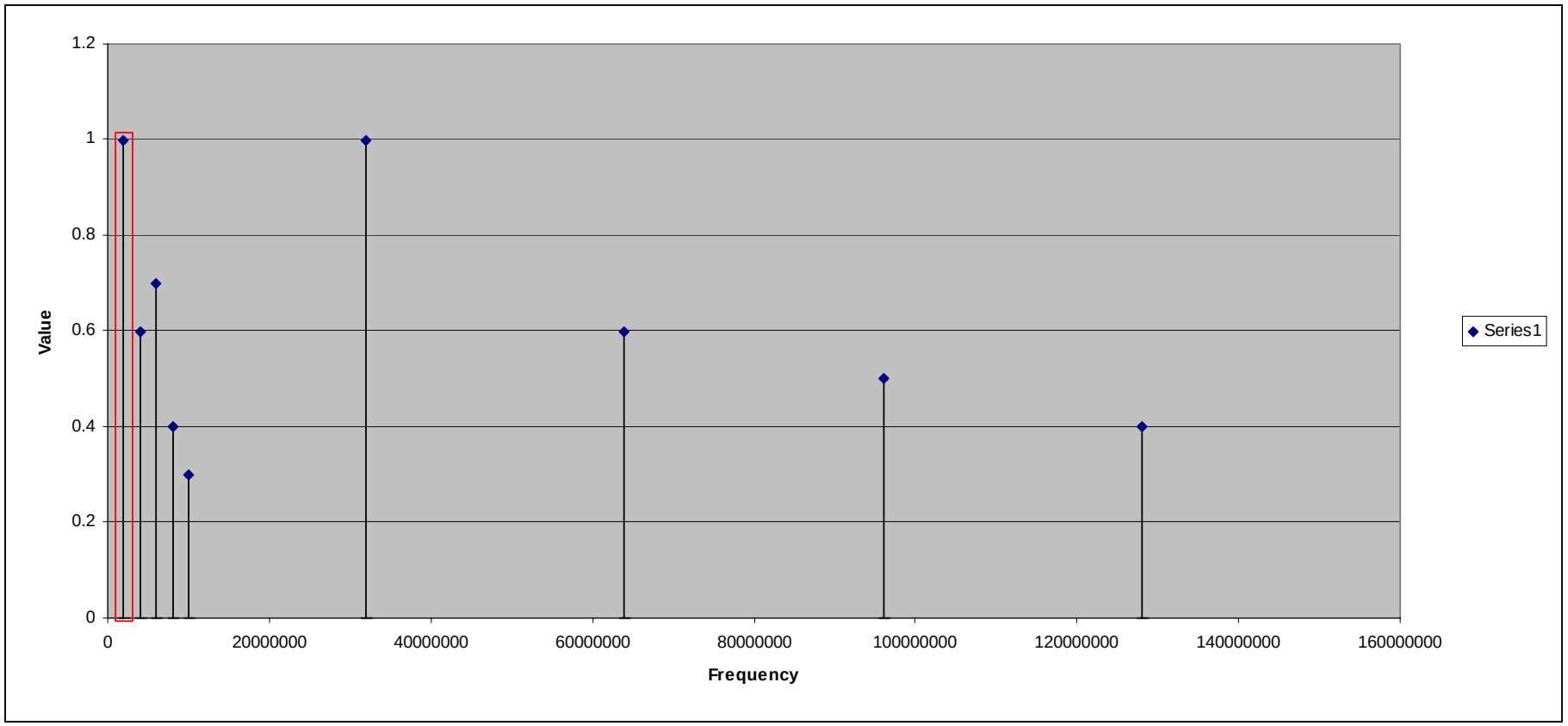
8/9/04

Frequency Scanning System

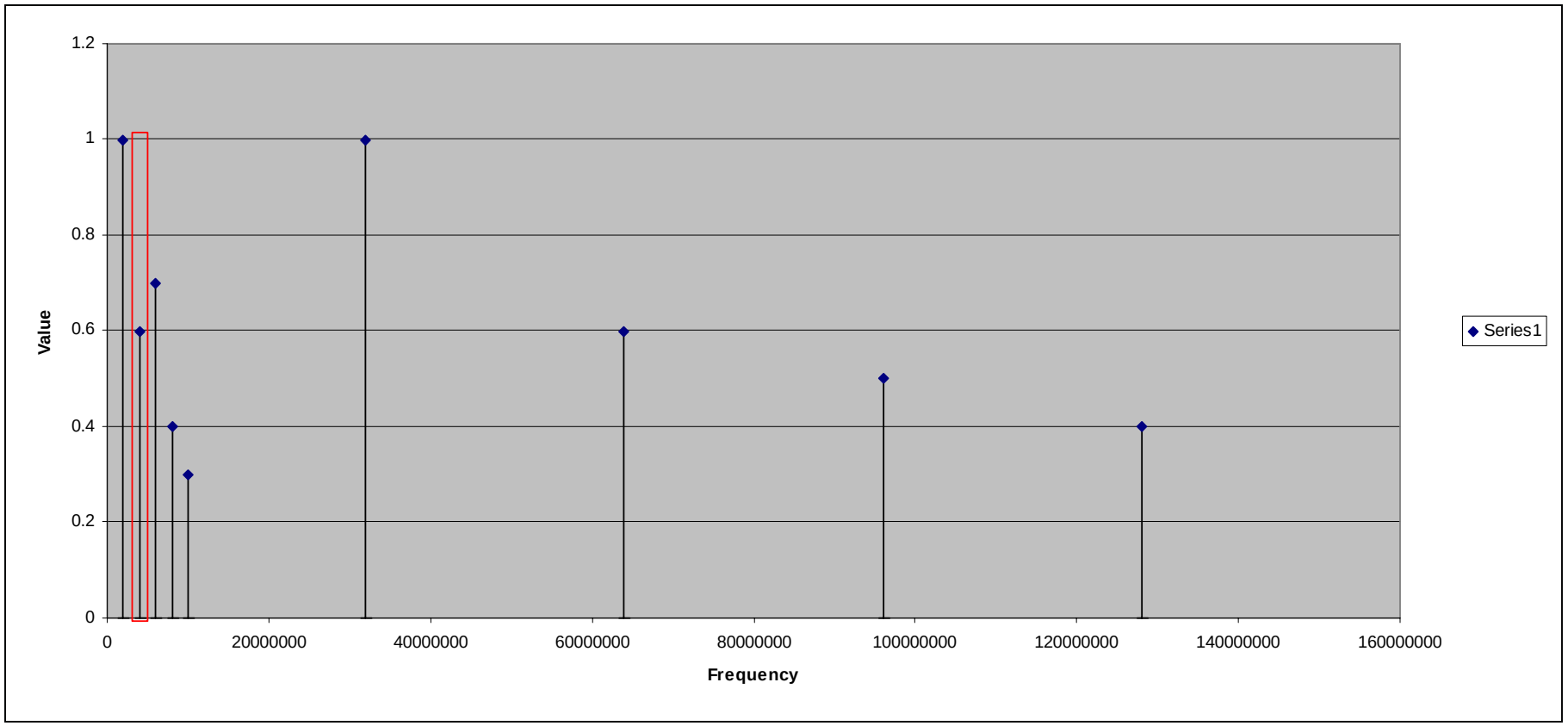
- **Utilizes a baseband mixing approach for processing of the RF sensor signals.**



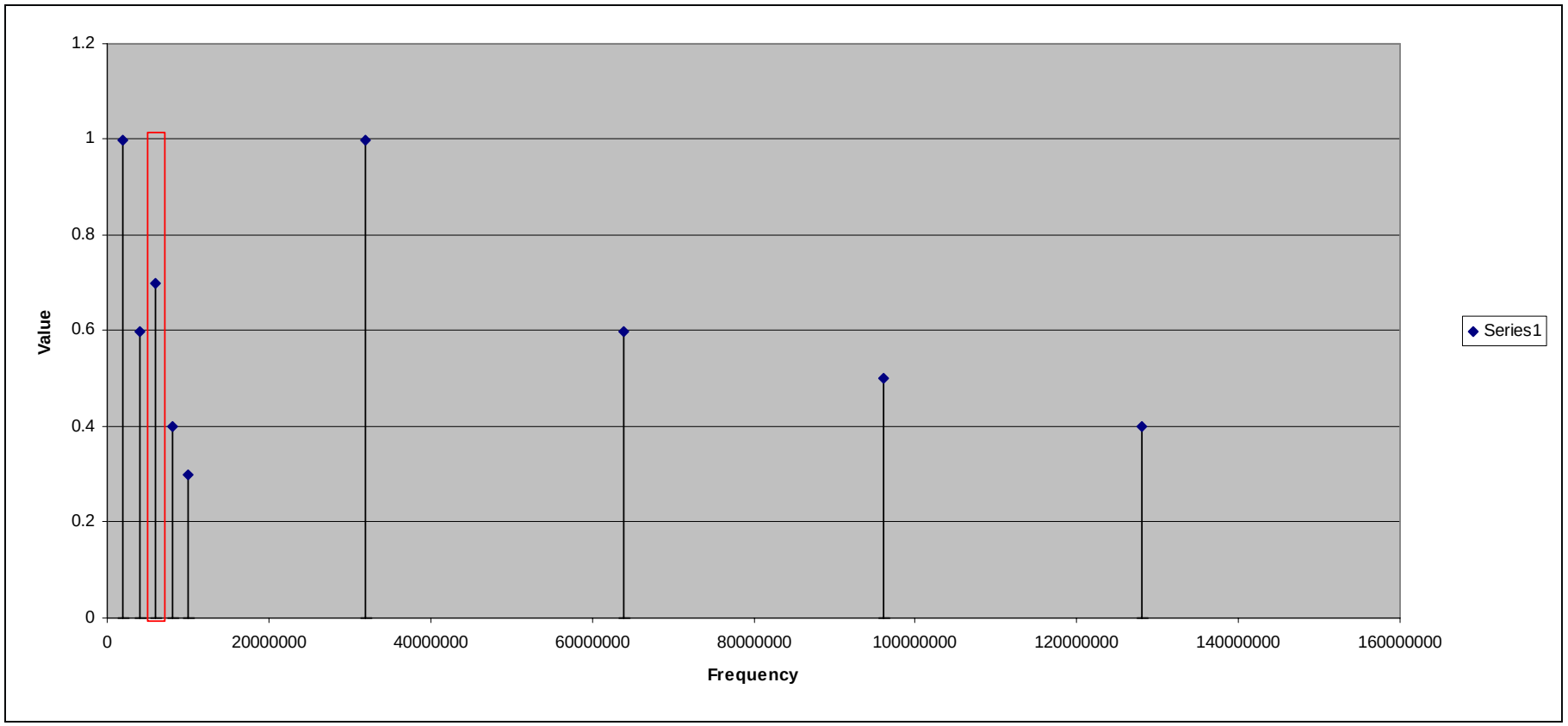
Scanning Spectrum



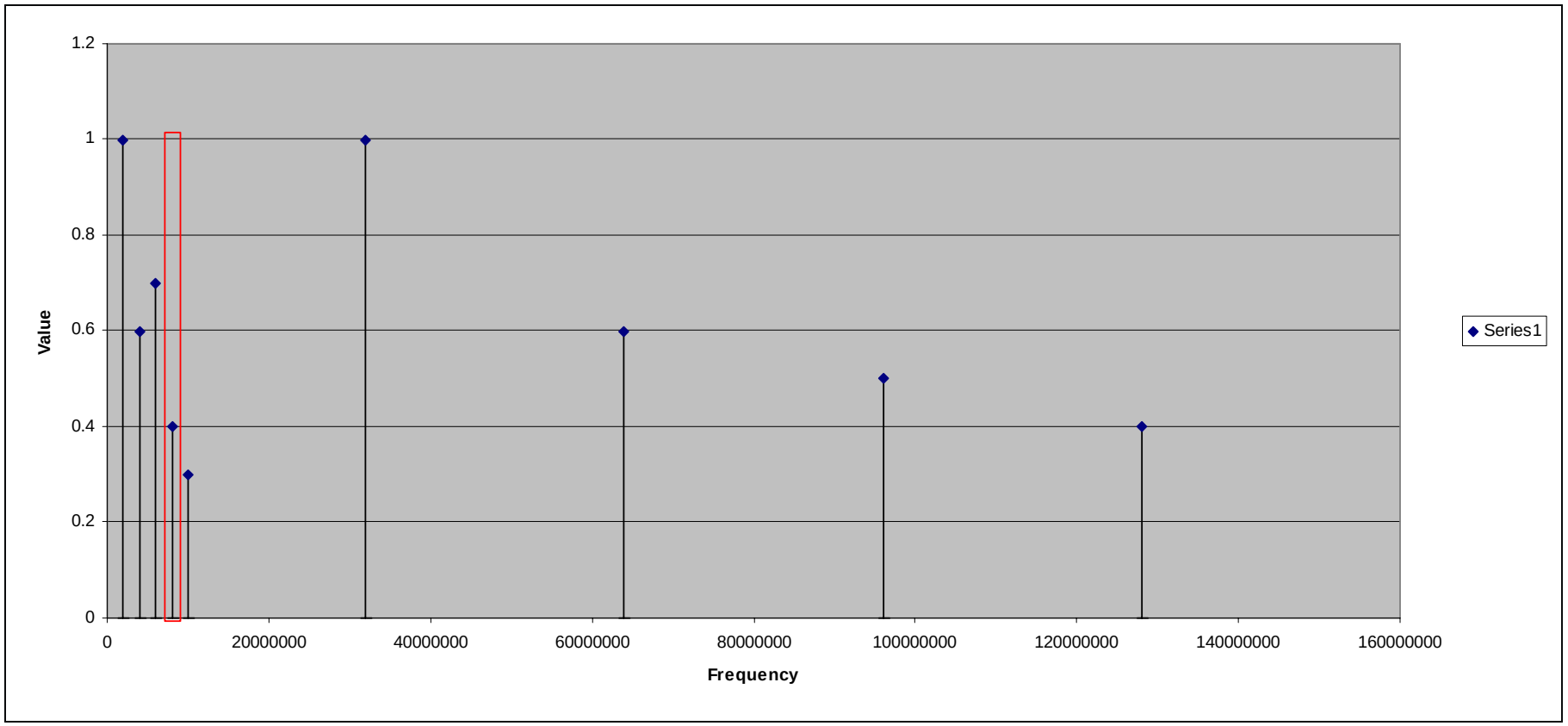
Scanning Spectrum



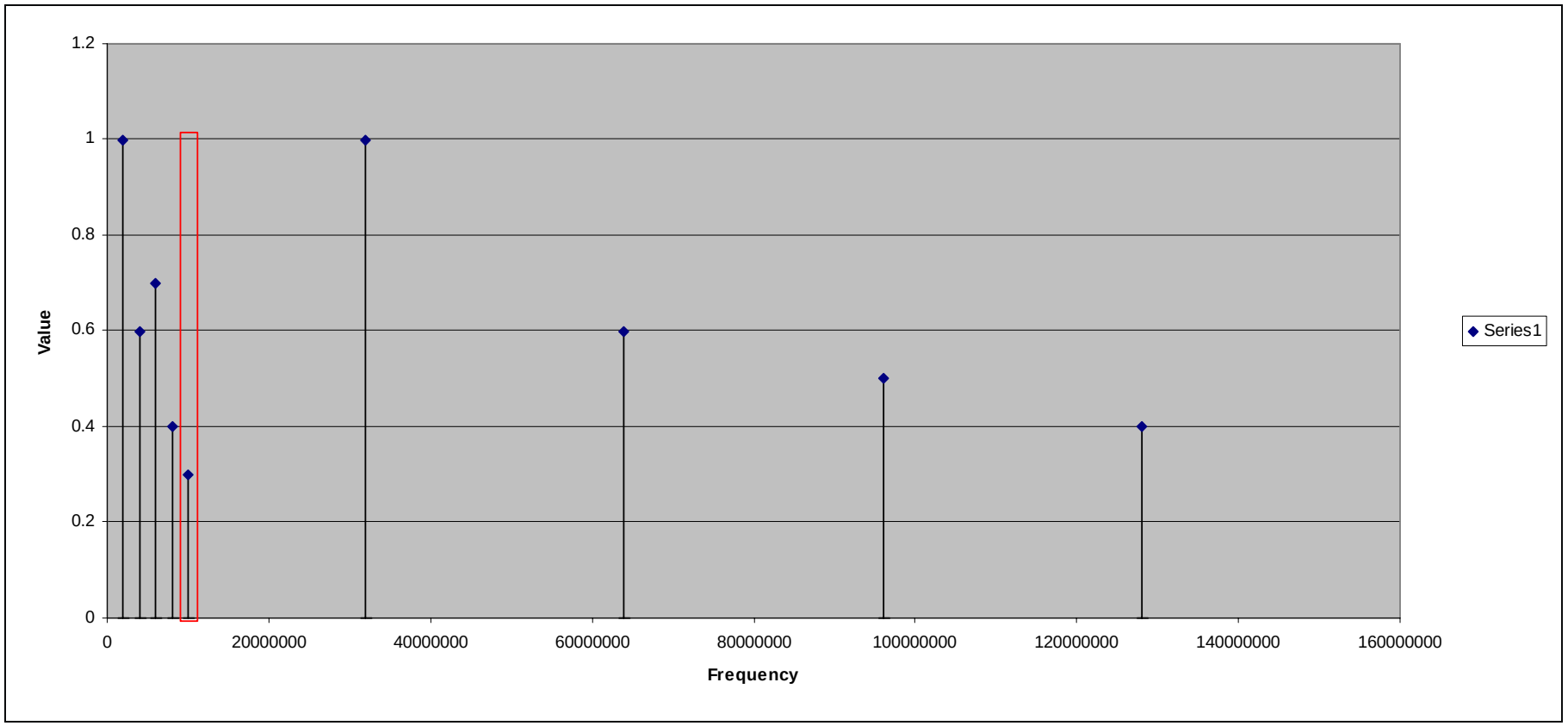
Scanning Spectrum



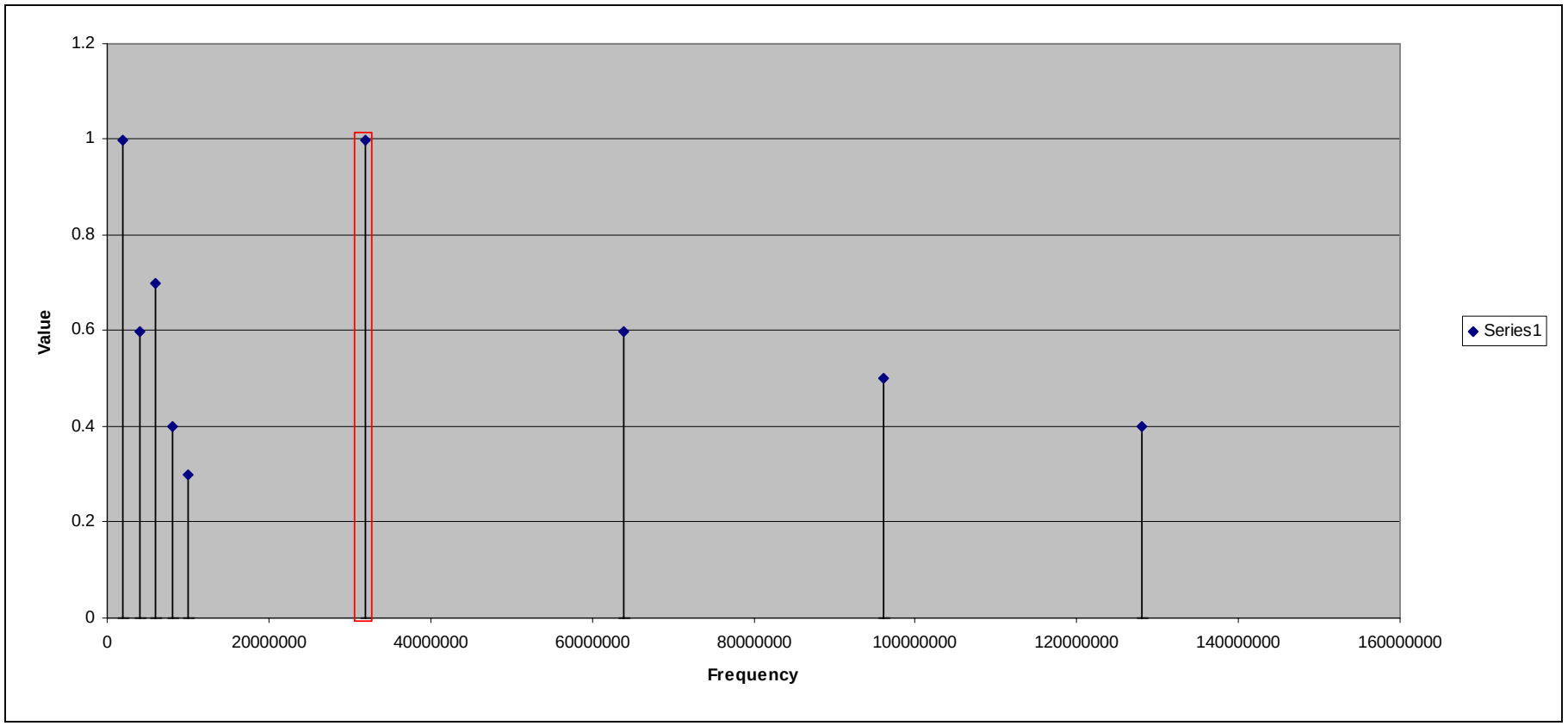
Scanning Spectrum



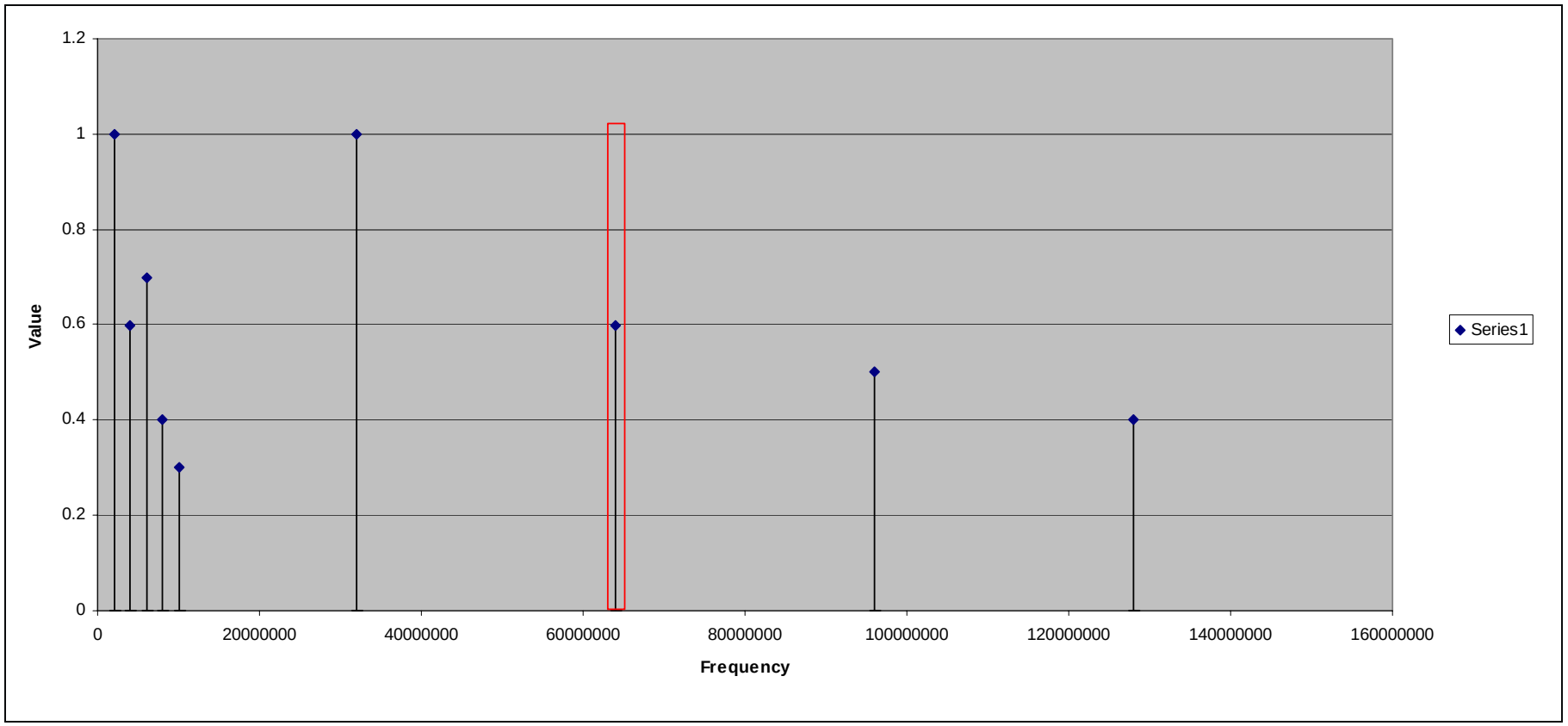
Scanning Spectrum



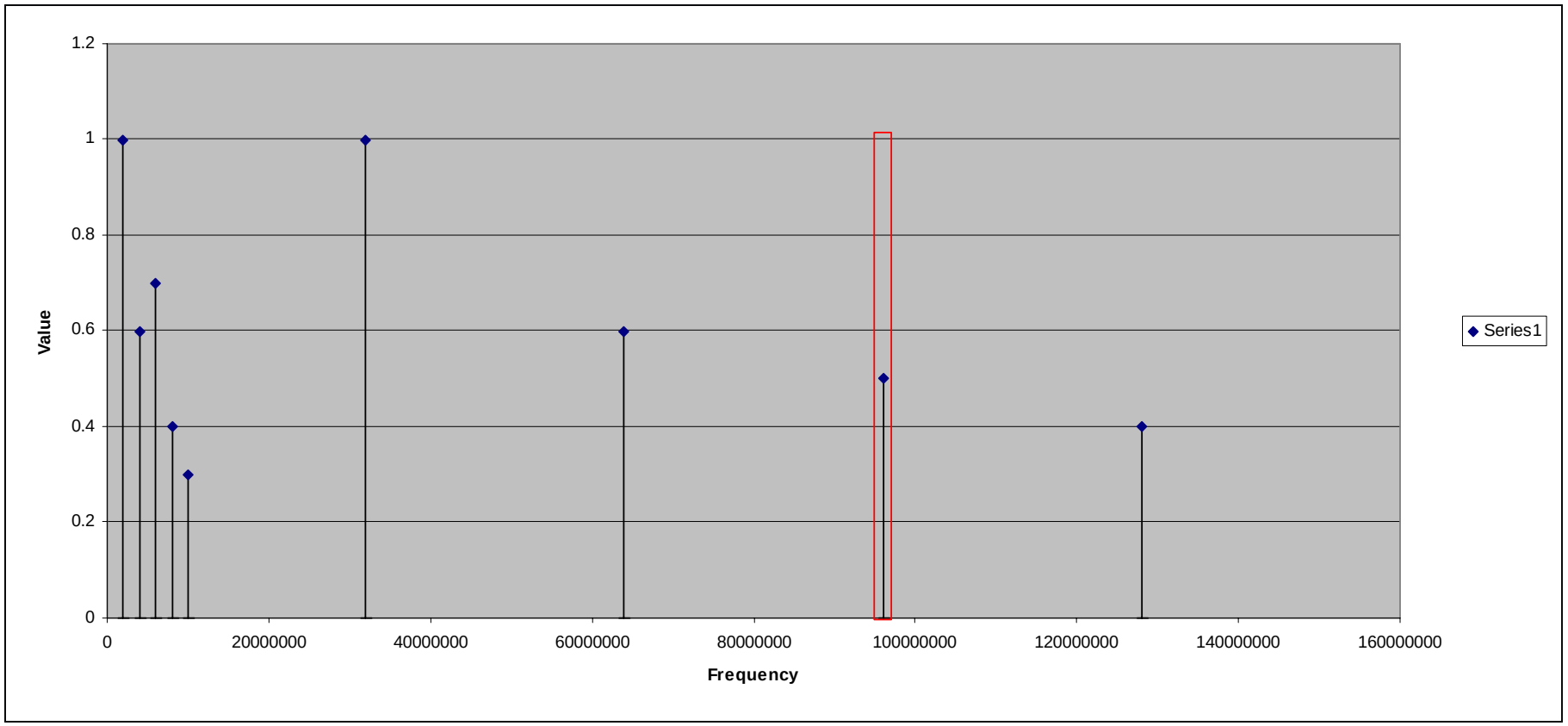
Scanning Spectrum



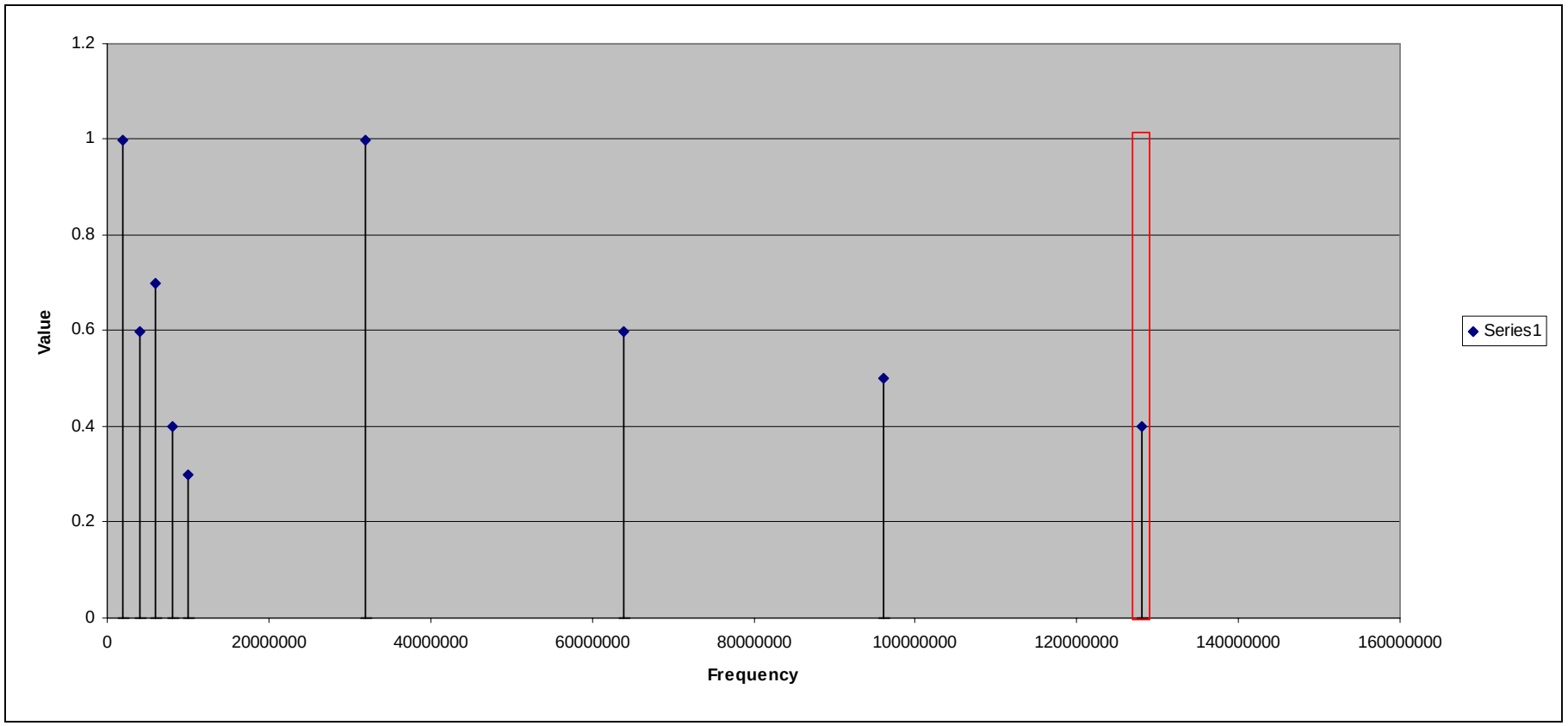
Scanning Spectrum



Scanning Spectrum



Scanning Spectrum



Problems of the Frequency Scanning

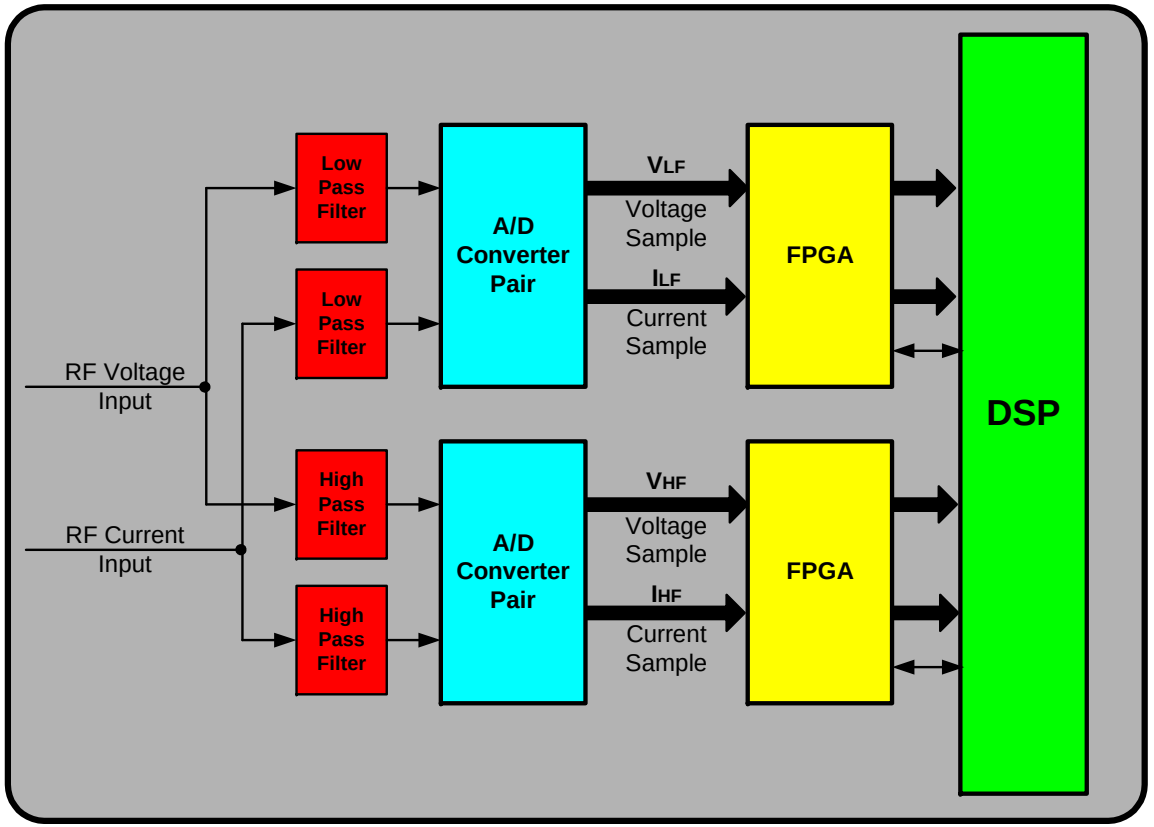
- Frequency tracking
- Sequential frequency processing
  - Slow data rate
- Poor SNR at harmonic

Broadband System Design Objectives

- Concurrently monitor multiple RF frequencies
- Autonomously track RF fundamental frequency(s) for frequency tuning systems transient detection and plasma instability
- Wider Bandwidth: 150 MHz
- Optimized front end attenuation for two fundamental frequencies
- Improved Harmonic signature analysis
- Improved sampling and data rate

Functional Diagram

Broadband Probe System

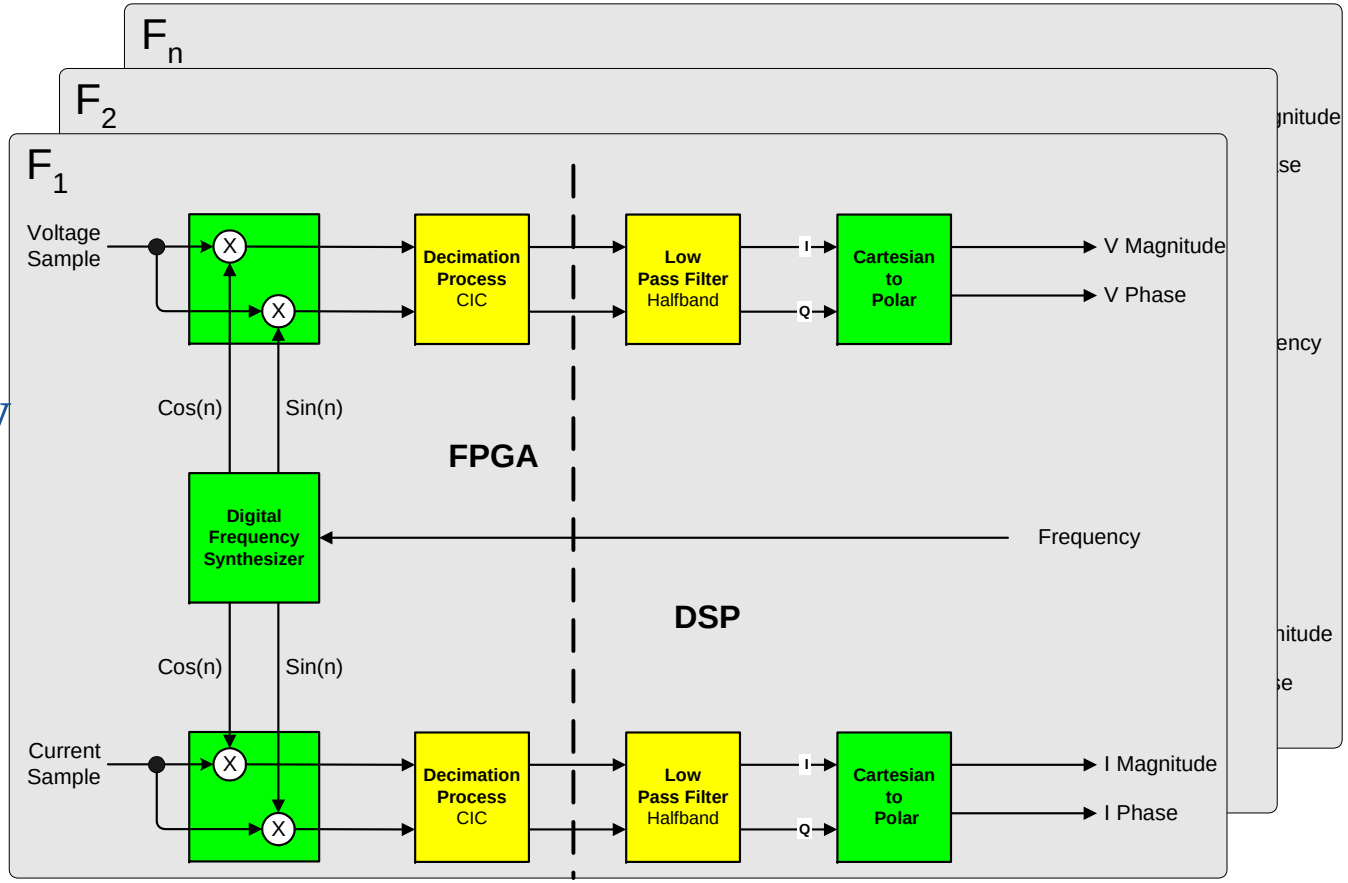


Signal Processing Architecture

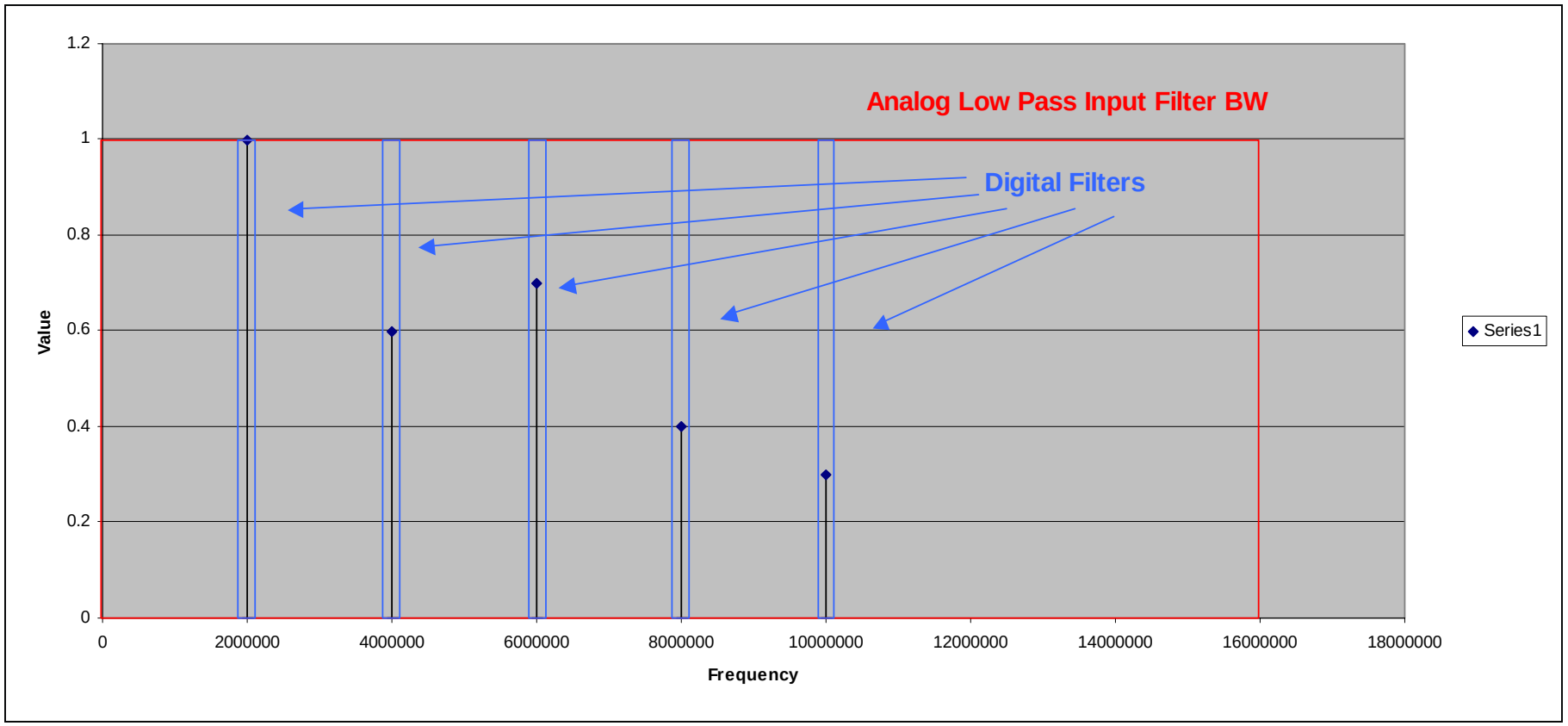
Broadband Probe System

1600 MOPS per frequency

1.28 TOPS in total

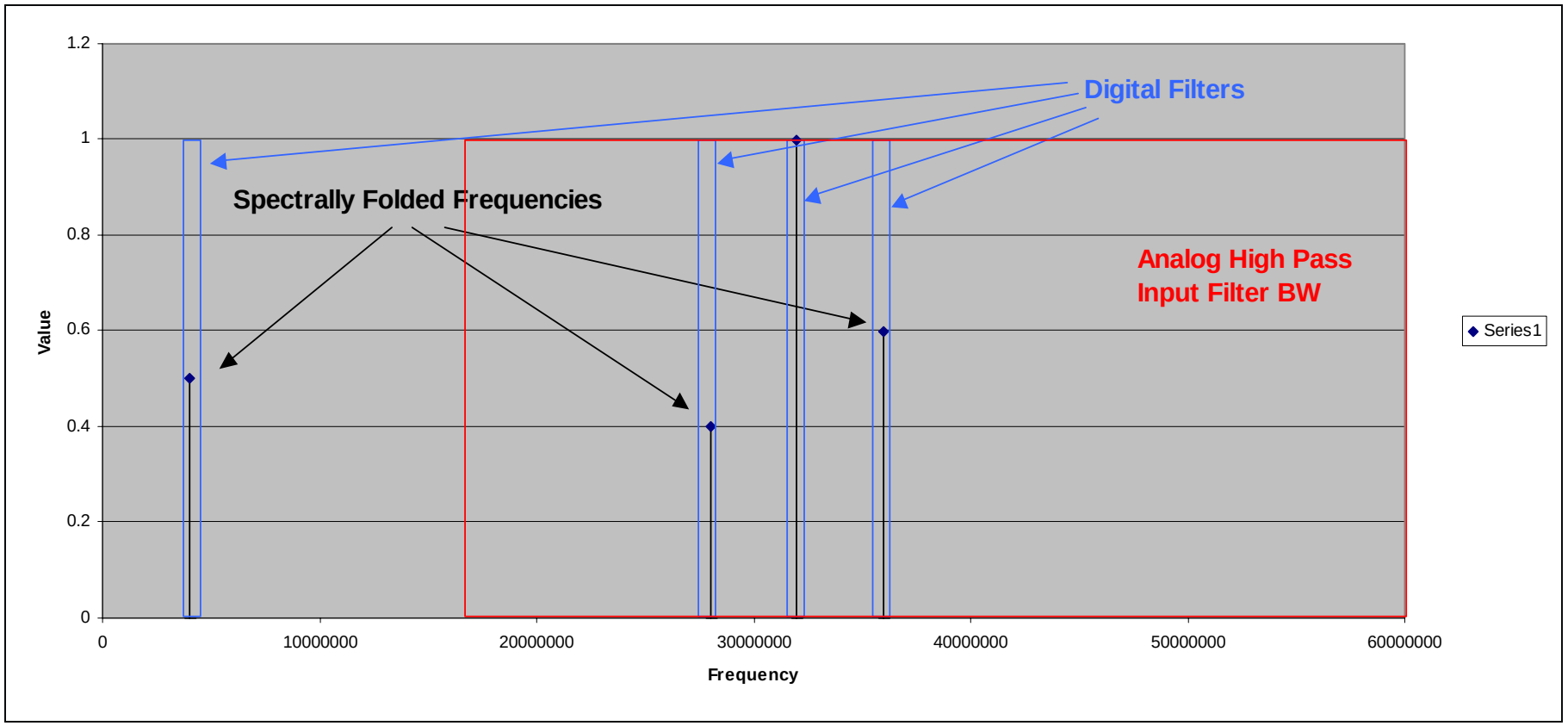


BB Spectrum Channel 1 (<16 MHz)



- Analog filter corner is dependent upon application

BB Spectrum Channel 2 (>16 MHz)

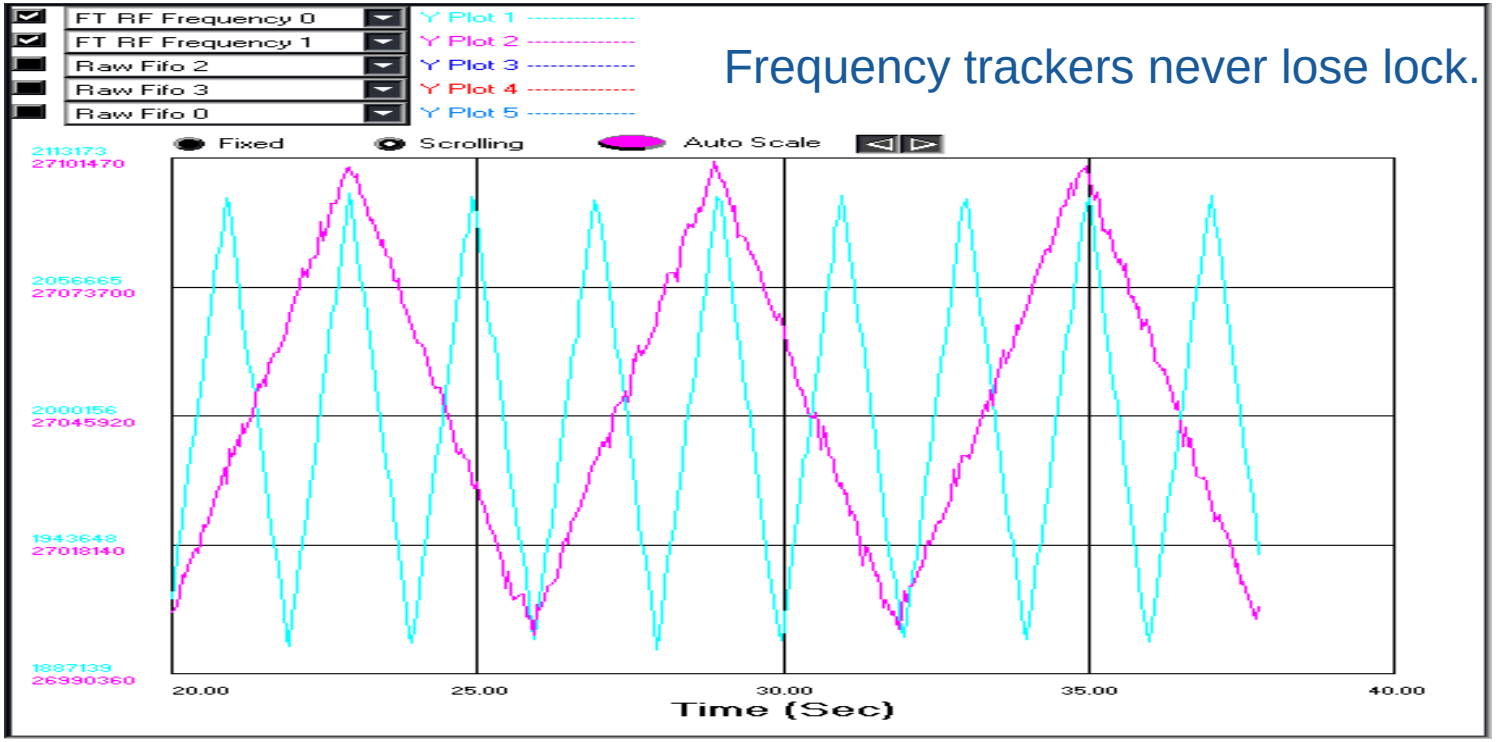


- Analog filter corner is dependent upon application

Key Features: Frequency Tracking

- Frequency tracking is accomplished by taking the derivative of the phase with respect to time.
- As the frequency varies, the frequency synthesizer is adjusted to maintain the position of the frequency in the digital filter's frequency response.

Frequency Tracking Active Load



Frequency trackers never lose lock.

- Dual Frequency tracking while RF sources are programmed to sweep.
- Performed while significant plasma transients (arcs) were occurring.

Other Key Features

- Scaleable Architecture
  - System delivered based on customer's specified features.
  - FPGA and DSP field upgrades to add customer features.
- Simultaneous operation of multiple communication ports.
- High speed sampling and data rate

Applications

- The VI Probe is
  - Sensitive to tool health
  - Sensitive to process
- Chamber Characterization
  - Fingerprinting v. SPC
  - Arc detection
- Advanced Process Control
  - Endpoint
  - Plasma uniformity
  - Impedance measurement for RF pulsing applications
  - Fast sampling for plasma diagnostics
  - Plasma closed loop control

Great Instrument! , But What do we do with the Data?

mks
Technology for Productivity

POWER & REACTIVE GAS · VACUUM TECHNOLOGY · F
LEAK DETECTION · FLOW MEASUREMENT & CONTRO
PRESSURE MEASUREMENT & CONTROL · CONTROL &
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
BIOPHARMECEUTICAL · VACUUM TECHNOLOGY · LEA
PRESSURE MEASUREMENT & CONTROL · FLOW MEAS
CONTROL & INFORMATION TECHNOLOGY · WAFER ME
CALIBRATION · INTEGRATED SUBSYSTEMS · MEDICAL
GAS ANALYSIS · BIOPHARMECEUTICAL · POWER & RE
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE
FLOW MEASUREMENT & CONTROL · PRESSURE MEAS
GAS ANALYSIS · CONTROL & INFORMATION TECHNOL
INTEGRATED SUBSYSTEMS · CALIBRATION · POWER &
REACTIVE GAS · VACUUM TECHNOLOGY · LEAK DETE

Philip Schmitt / Mark Rousavy

8/9/04

The Issue

- Modern APC strategies require that integrated RF metrology data be correlated in real time, with internal tool data *and* with Recipe, Lot-ID and Wafer number

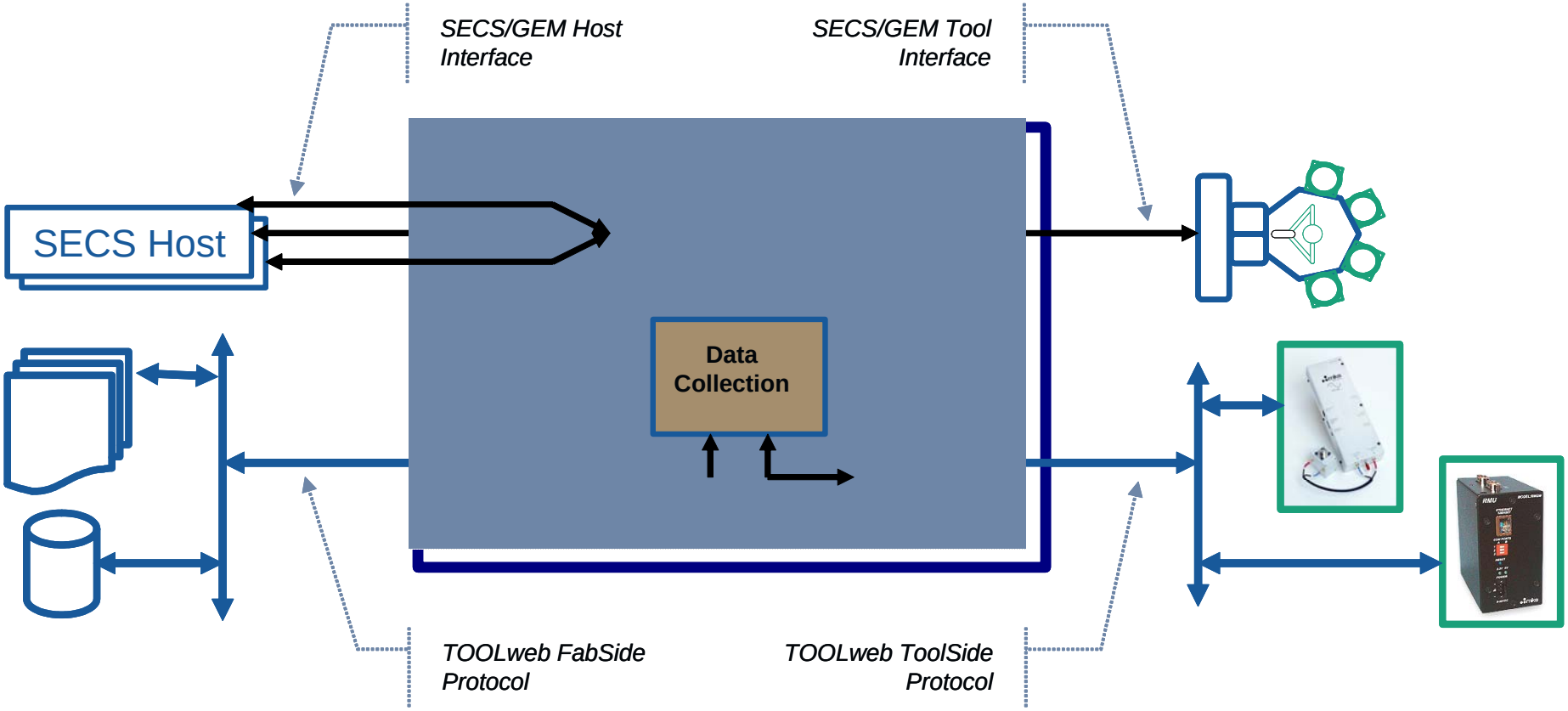
- However, most process tools support only a single SECS or HSMS connection- typically occupied by the factory host.

How to correlate RF metrology in real time with tool data to optimize the process?

TOOLweb™ BlueBox Solution

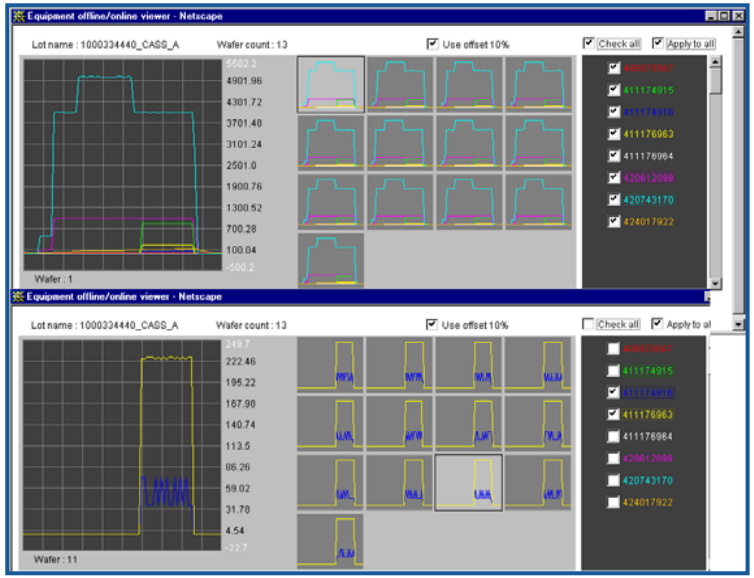
- The optimum solution for data sharing.
- Multiplexes the data from the process tool and sensors such as a VI Probe
- Communicates this data to the multiple applications and users, including the factory host.
- Open, flexible architecture guarantees easy integration into existing fab environments

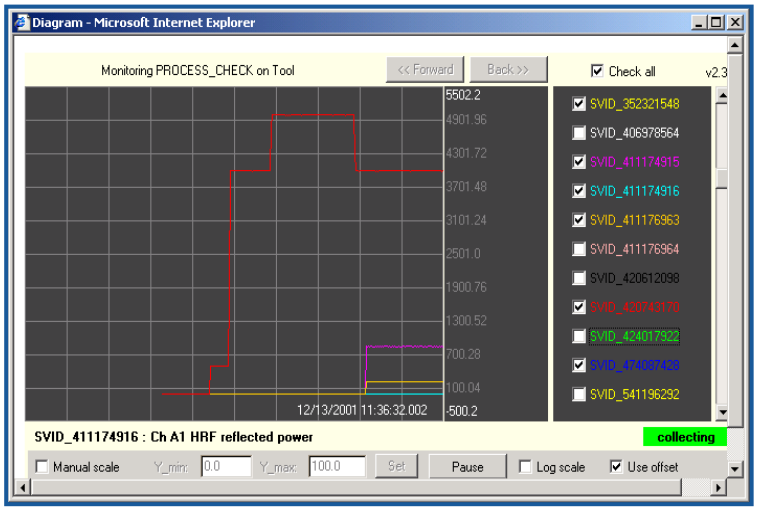
Data Flow Through Blue Box



Charts and Results

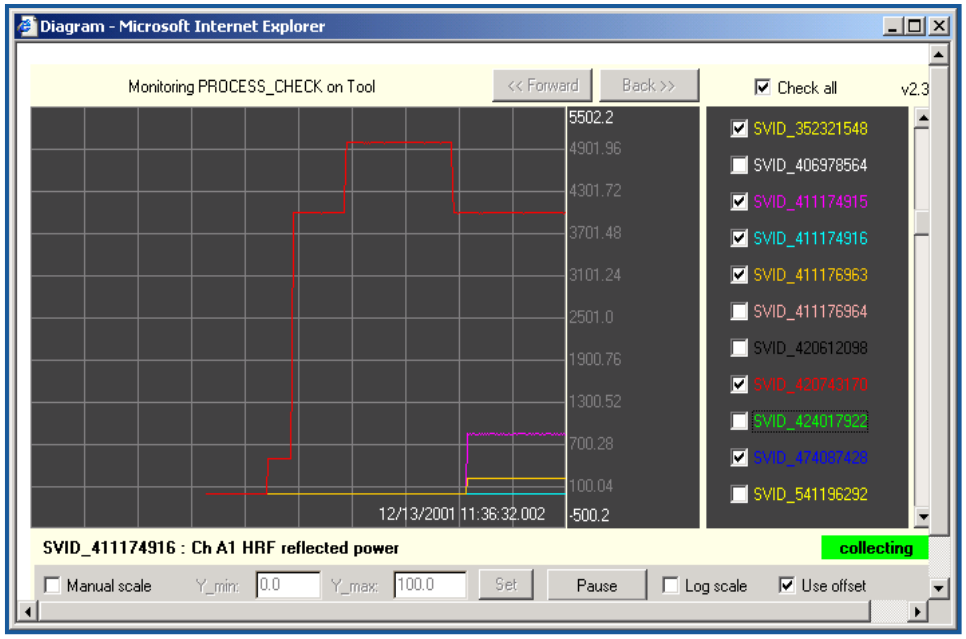
- Data from the Blue Box can be viewed in real-time or exported- including VI Probe data
- Data from VI Probe is viewed and analyzed offline
- Multivariate analysis is shown using VI Probe data in combination with tool sensor data.





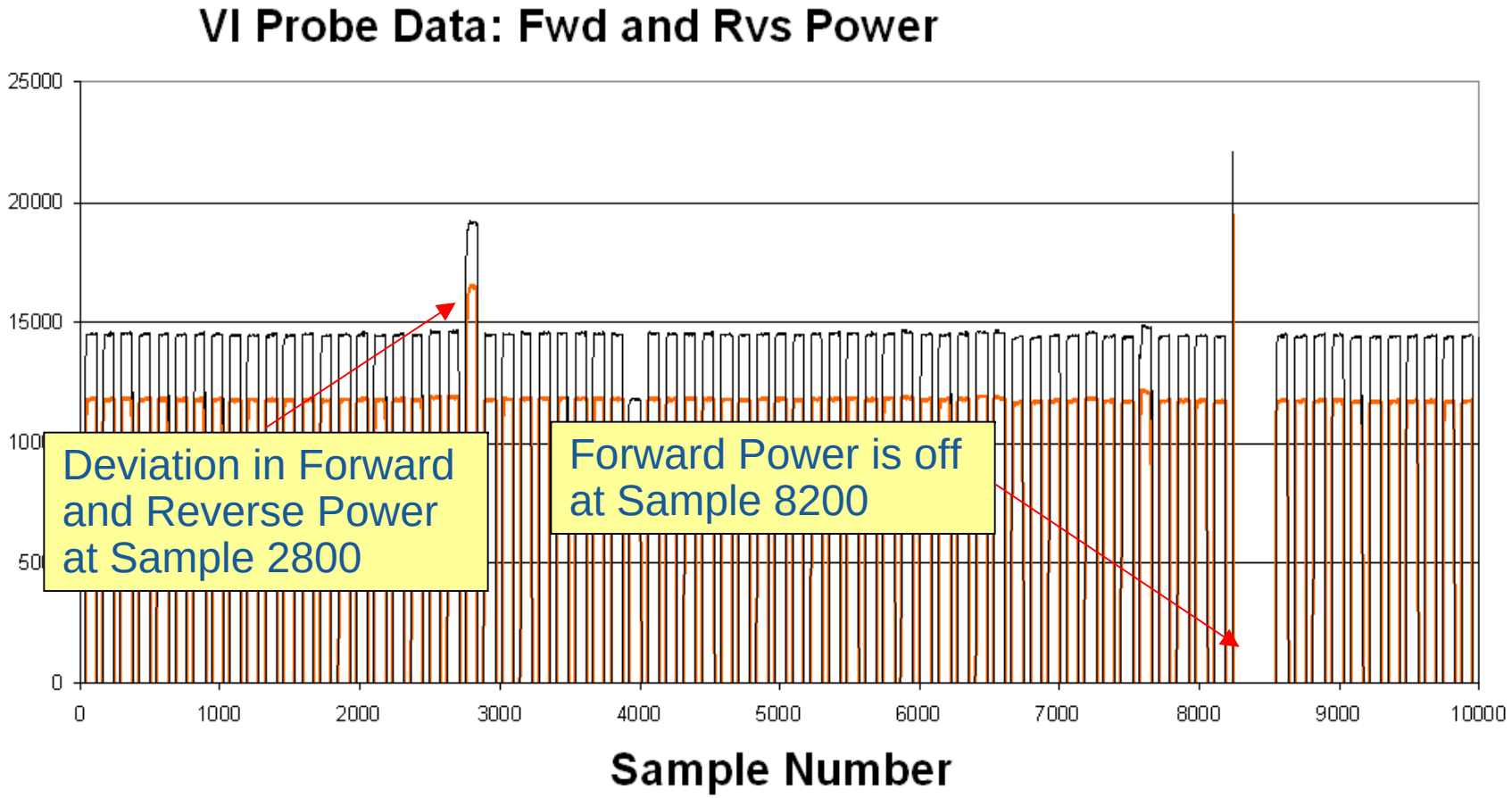
Real-time Data on Blue Box

Example of Real-time data streamed into the Blue Box.

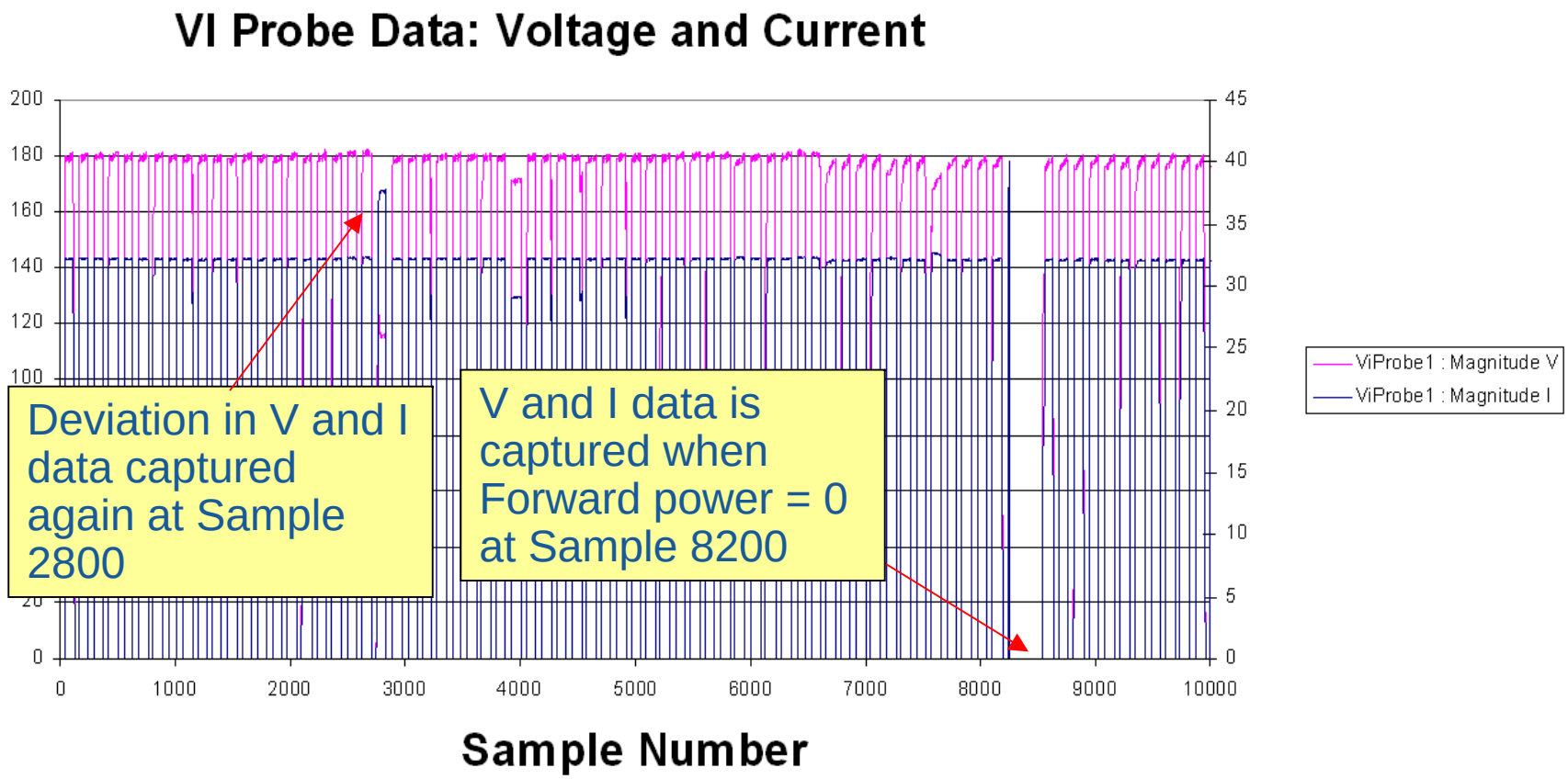


- Real-time selection of sensor(s) to view
- View variable by ID number or name
- Export raw data into several formats directly from Blue Box

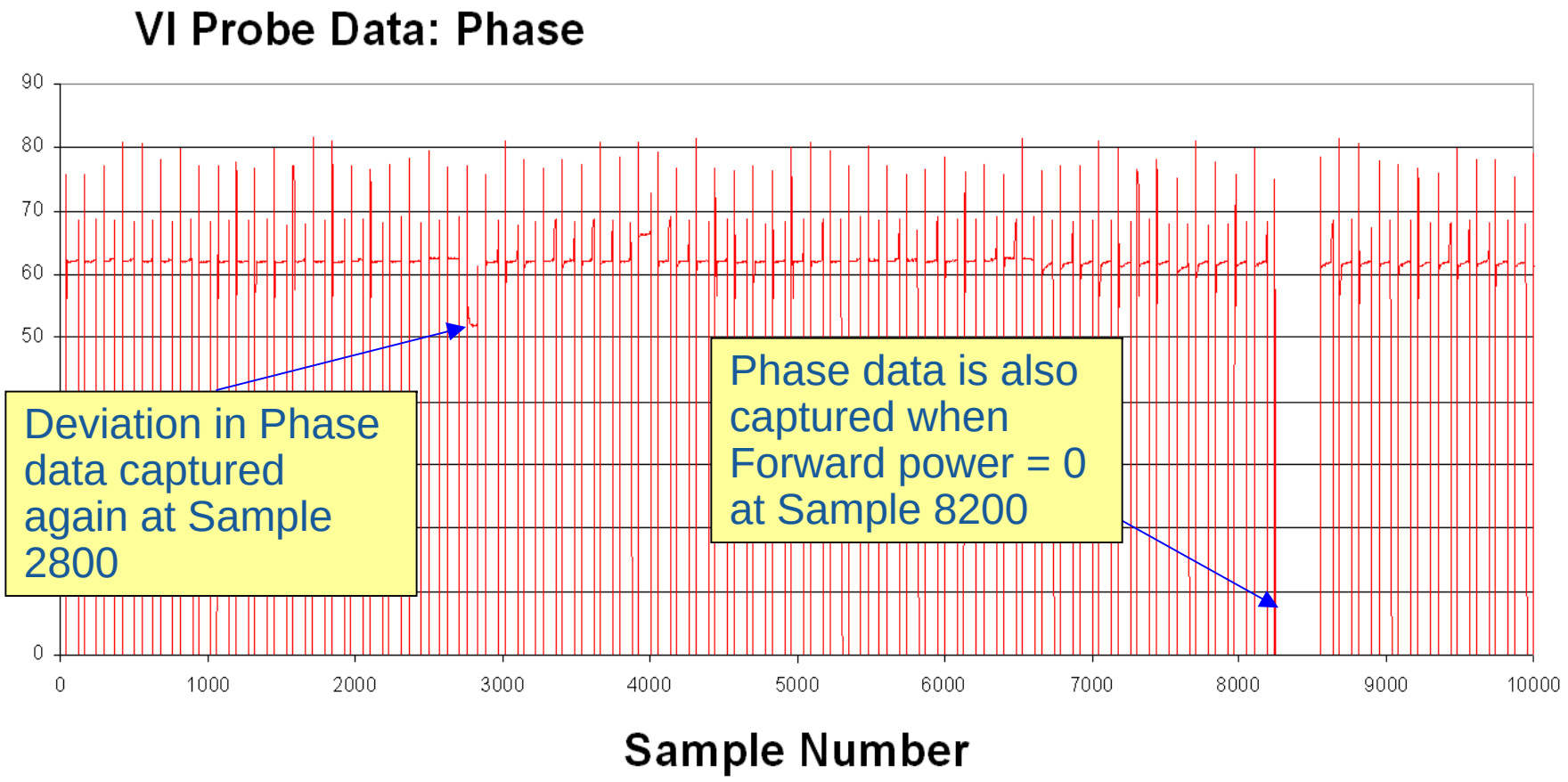
Example: VI Probe Data



VI Probe Data



VI Probe Data



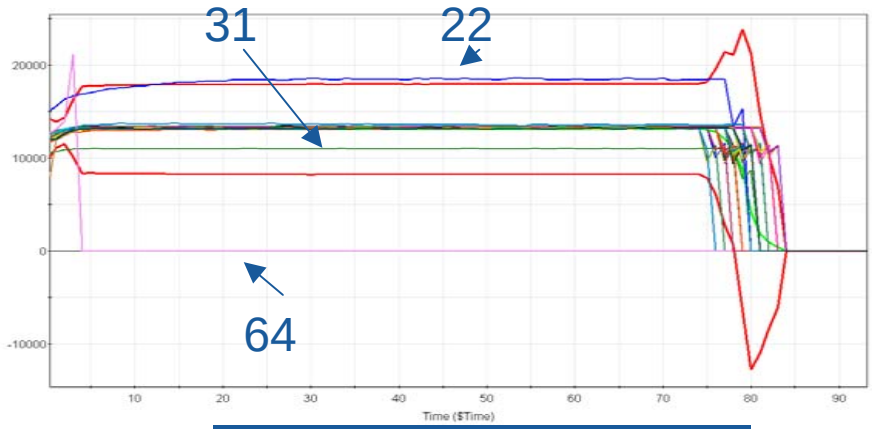
Combining VI Probe and Tool Data

- Blue Box collects data for applications such as TOOLweb Server and Simca-P+.
- Simca-P+ models use data obtained from the VI Probe and process tool.
- Once Simca-P+ models are created they can be run directly on the TOOLweb Server in real-time as the data is being streamed from the Blue Box

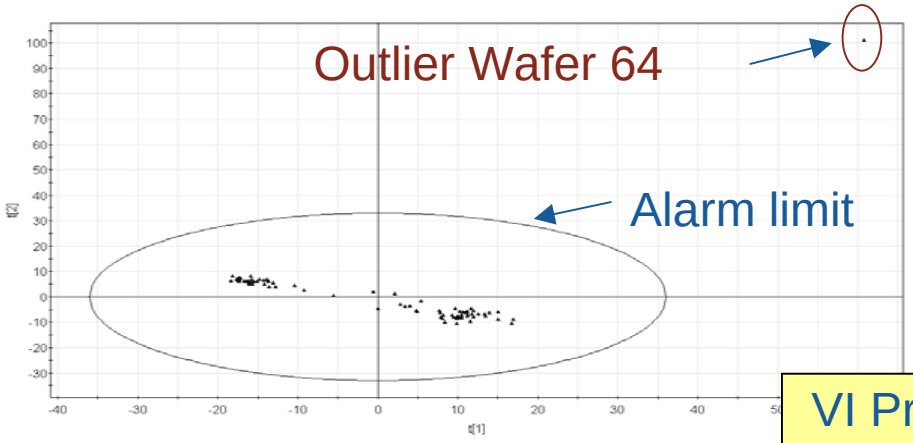
MVA of VI Probe & Tool Data

VI probe signals reveal that the outlier wafer 64 is due to RF turn off.

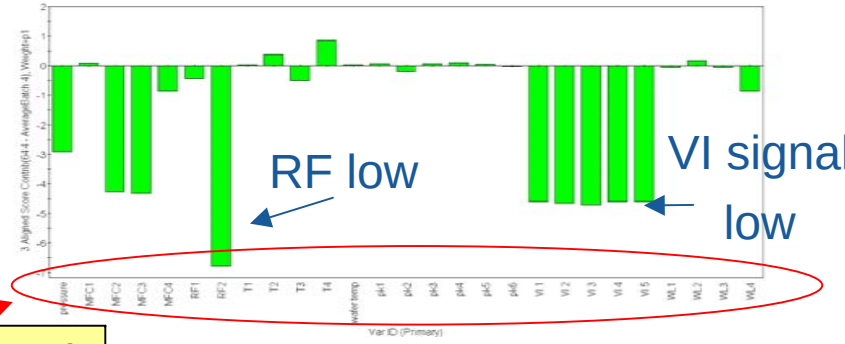
VI probe shows that wafers 22 and 31 are different from the others



VI Probe Variable Plot



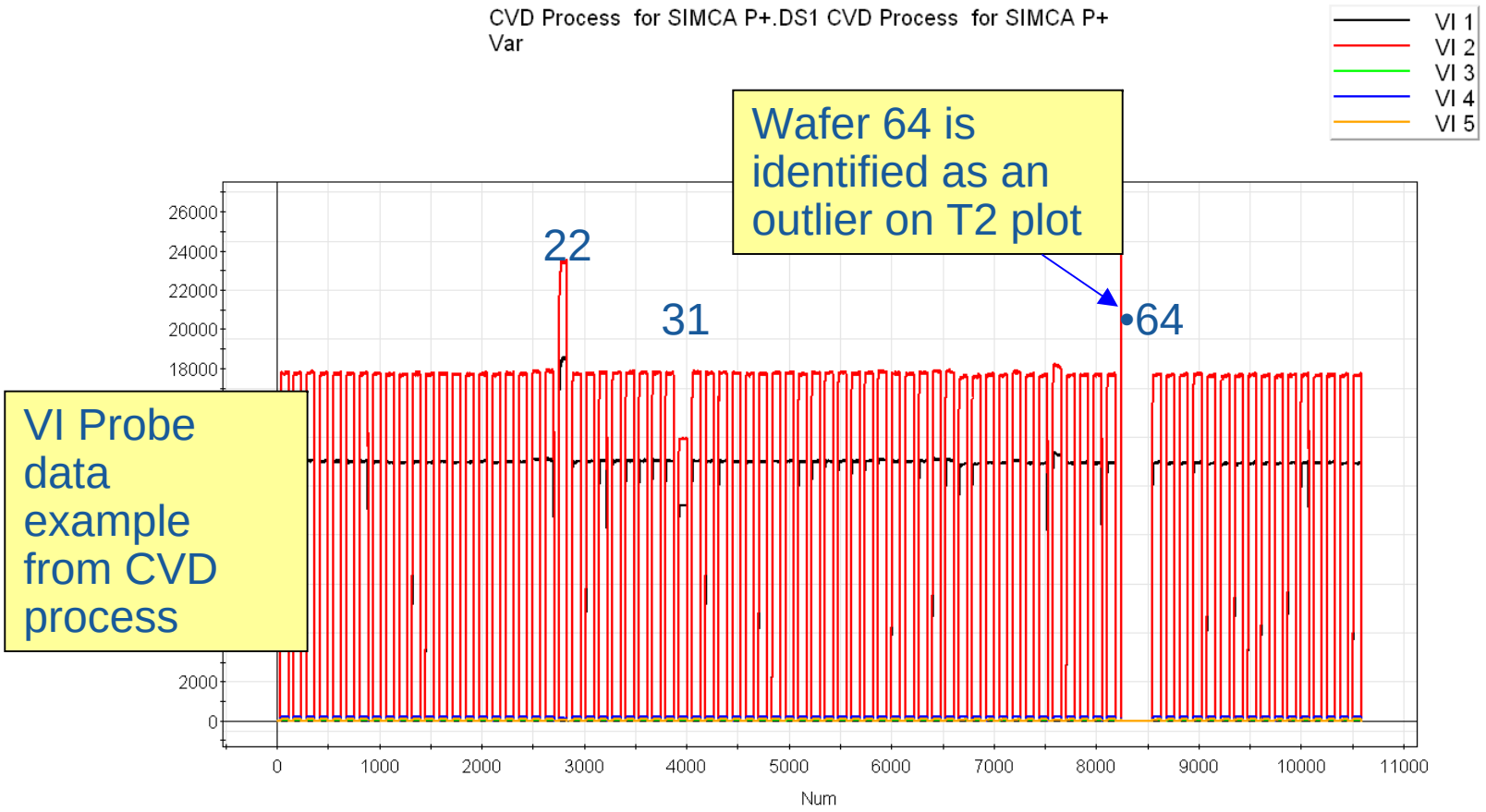
Score Plot



Contribution Plot

VI Probe and SVID data

Drill Down: VI Probe Signals



Conclusion

- Combined data from VI Probe and process tool:
  - Increases accurate fault detection in a process
  - Enables problem identification associated with specific wafers using multivariate analysis