Alfven VI Probe

RF Event Detector – Arc Detection and Pulsed RF Health Monitoring

https://impedans.com/alfven-event-detector

The Alfven VI Probe

Arc Detection and Pulse monitoring

The Alfven has two on-board algorithms that constantly process RF data with 1 microsecond resolution. The first is designed for detecting arcs within a plasma. The second monitors every single RF pulse and checks that each pulse is in spec

Parameters Measured:

- ✓ Voltage and current at the fundamental frequency
- ✓ Arcs ranging from sub-microsecond to 5000 microseconds long
- ✓ Categorizes arc types
- ✓ Pulse frequency, duty cycle
- ✓ Max, min, average pulse voltages and currents during the pulse-on time
- ✓ Checks every pulse for correct on time and cycle time, counts and reports “bad pulses”

Lab RFx Calibration

- ✓ Designed to work from the 50 Ohm region – it can see arcs when connected to the generator
- ✓ Quickly determine if arcing is the cause of an issue
- ✓ Pulse generator monitoring. Duty cycle deviations directly correlate with number of wafer defects, outside of a certain acceptable window
- ✓ Can sync with complex plasma recipes, changing its configuration automatically to monitor new pulse conditions and alarm appropriately for bad pulses
- ✓ It can automatically take regular “snapshots” of the pulses, reporting 5000 microseconds of pulses with 1 microsecond resolution
- ✓ Multi-level pulse monitoring

Key Features

Configurable Recipe
Configure the Arc adnd Pulse classification for each recipe step.

Microsecond resolution
1 μs resolution data reporting for arcs and atypical pulses

Multi-Level Pulsing
Measure Multi-level pulses (up to 3 levels) including pulse frequency and duty cycle

Customised Sensors
Special form factors for tool integration available, with power capabilities up to 90 kW

Process Summary
Gives summary of each process step including Max, Min and Average Voltages and Currents

Snapshot
Pulse Snapshot prevents the need for directional coupler to Oscilloscope setup.

Event Monitoring
Measure the number and severity of arcs in a process step

Advanced Software
Data collection and overlay made easy.

Technical Specifications

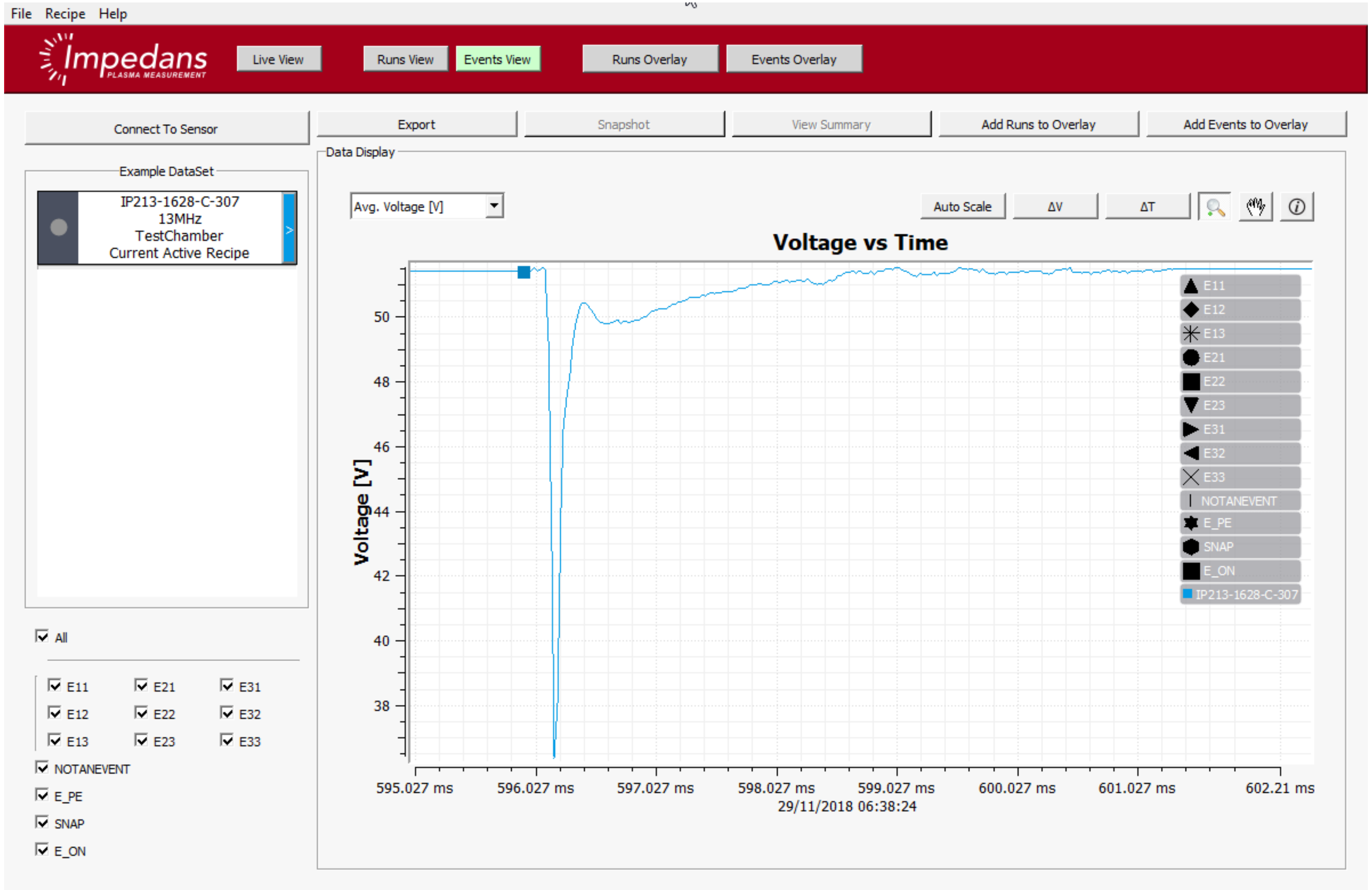
Parameters Measured	Range
Sensor Characteristic Impedance	50 Ohms as standard
RF Connectors	QC, EIA and custom options
RF Power Range @ 50 Ohms impedance	QC: 4 kW typical (connector dependent), B6N: 12 kW High Power: 30 kW & 90 kW
Operating Temperature Range	10 ^{o}C – 80 ^{o}C, calibrated versus temperature
Sensor Power Requirements	15-24 V DC, 0.5 A
Communication Interfaces	Micro USB, RJ45x2
Connectivity (Impedans Software)	USB 2.0, Ethernet
Communication Protocols (Standard)	USB 2.0, HTTP Web Service
Communication Protocols (OEM Options)	EtherCAT, EtherNet/IP
Parameter Report Rate	10 Samples/second
Onboard Data Storage	14 hours of average data plus up to 5000 atypical pulse or arc events
Voltage Range (Typical)	1850 V_{PK}, custom available up to 7 kV_{PK}
Voltage Resolution	0.1 V_{RMS}
Current Range	2.5 mA_{RMS} to 9 A_{RMS}, custom available up to 150A_{RMS}
Current Resolution	2.5 mA_{RMS}

Technical Specifications

Parameters Measured	Range
Pulse Frequency Range	5 Hz to 100 kHz
Pulse Timing Resolution	1 μs
Pulse Level Monitoring	Up to 3 levels (e.g. High - Low - Off)
Pulse Parameters Reported	Pulse Freq., Duty Cycle (of each level), Max & Min Pulse Voltage & Current, Pulse On Time, Pulse Period, number and percentage of incorrect pulses
Number of Recipe Steps	Max 40 Steps
Arc Duration Detection Range	1 – 5000 μs
Arc Amplitude Range (vs Moving average)	1% to 100%
Arc Categories	9 (3 time duration ranges x 3 amplitude change ranges)

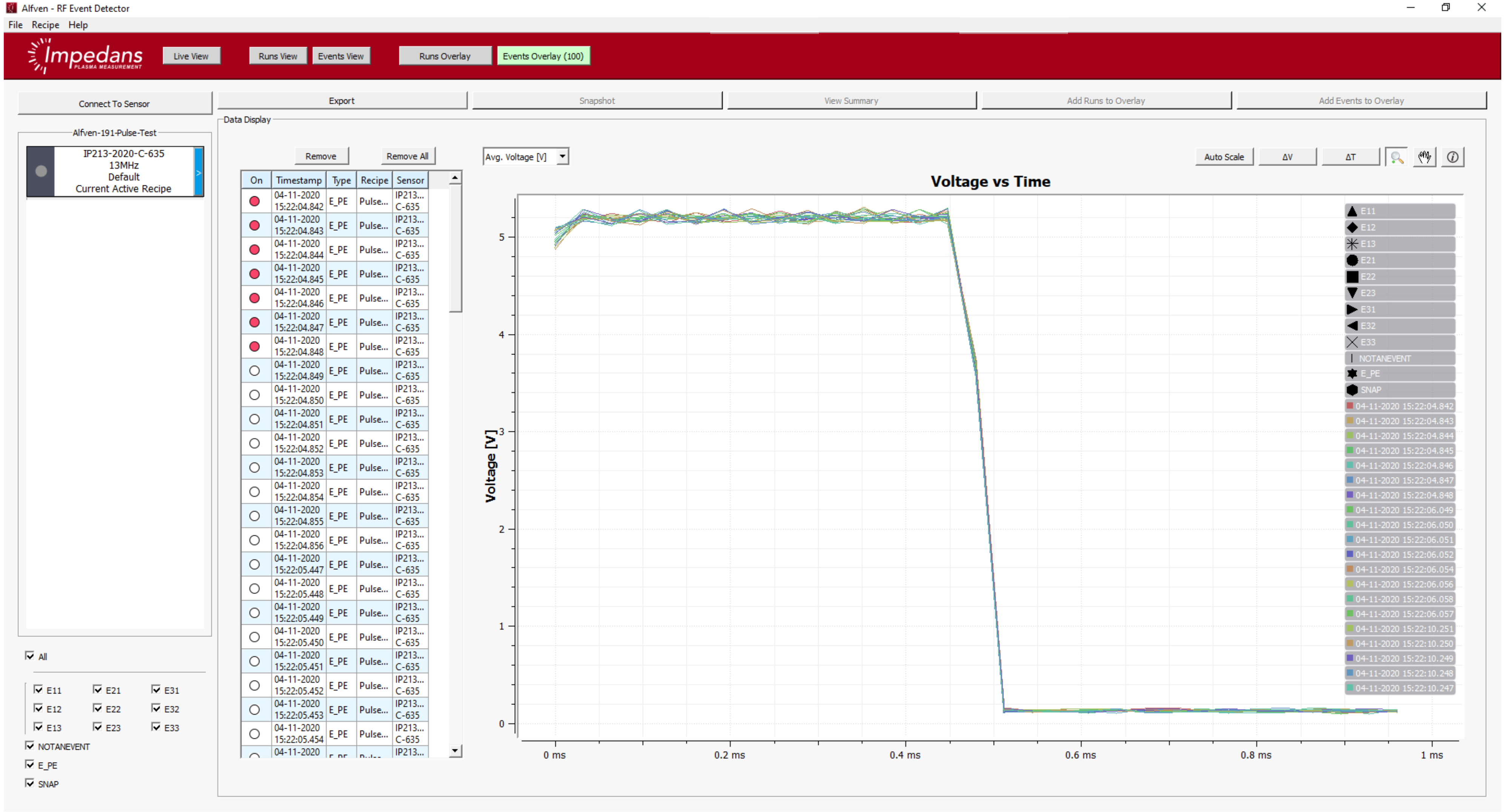
- ✓ Compatible with all tools in the RF frequency range. Has been used to resolve arcing issues on AMAT Endura, Lam FLEX e2300 etcher, TEL VIGUS etcher, TEL DRM and many others
- ✓ To arrange a technical discussion, contact support@impedans.com

Example Data: Arc Data



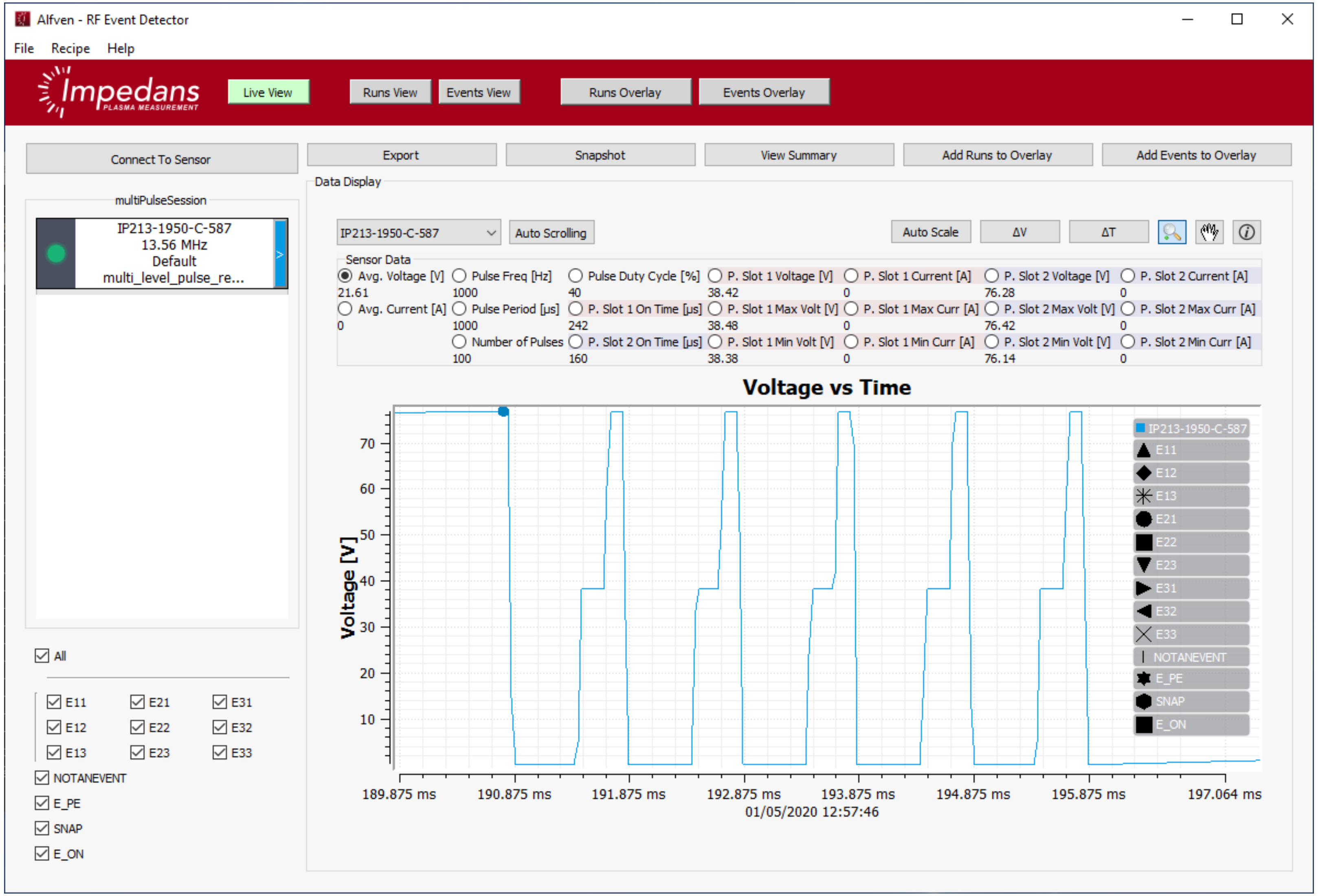
Example of Arc Data showing how the length of the arc is defined

Example Data: Pulse Data



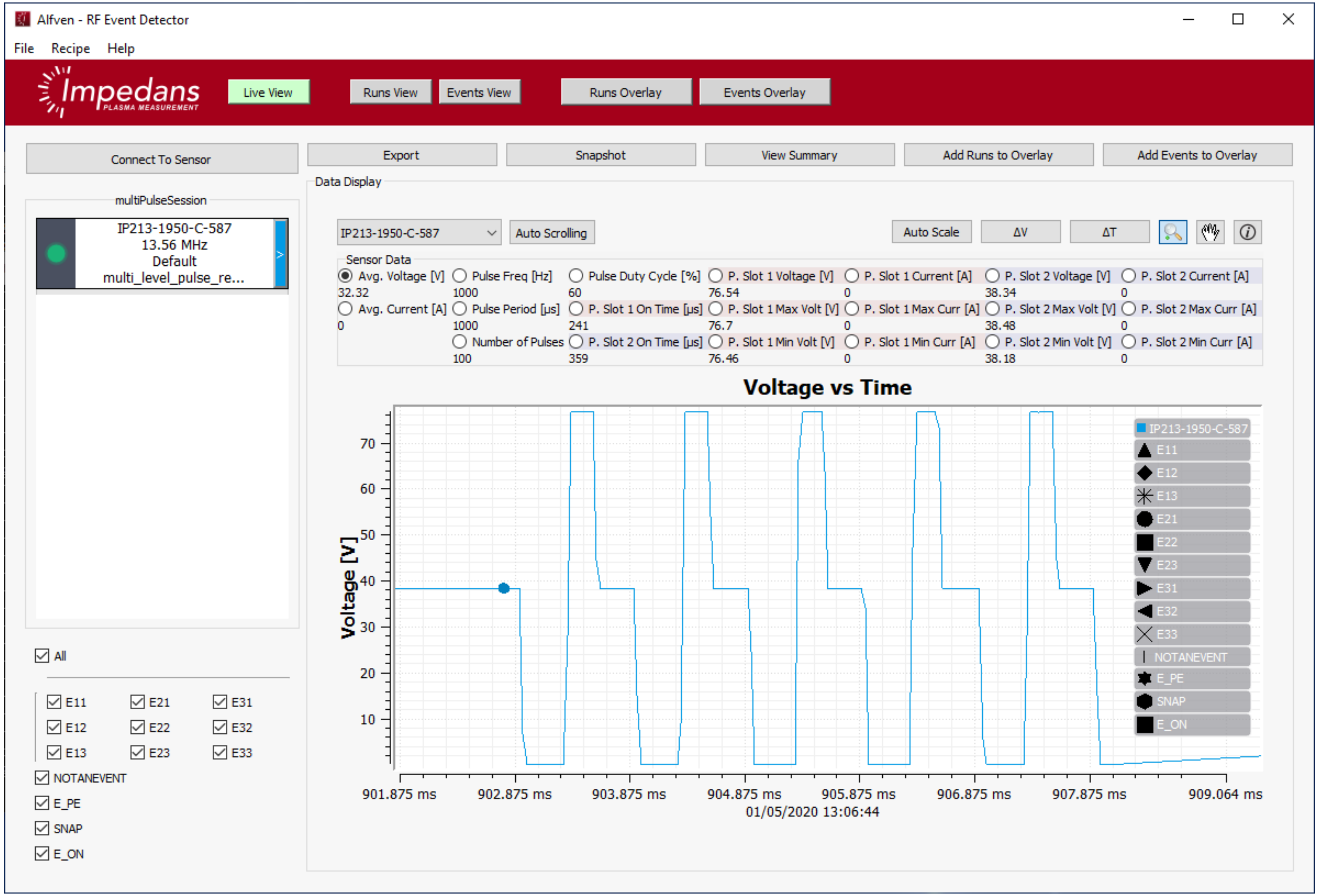
Example of a 1kHz 50% Duty Cycle Pulses overlaid to check for consistency

Example Data: Multi Level Pulse Data



Example of a Low – High – Off multi level pulse.

Example Data: Multi Level Pulse Data



Example of a High - Low – Off multi level pulse.

Example Data: Live Parameter View

Sensor Data

Avg. Voltage [V]	Pulse Freq [Hz]	Pulse Duty Cycle [%]	P. Slot 1 Voltage [V]	P. Slot 1 Current [A]	P. Slot 2 Voltage [V]	P. Slot 2 Current [A]
1.77	1000	50.3	3.38	0.05	0	0
Avg. Current [A]	Pulse Period [µs]	P. Slot 1 On Time [µs]	P. Slot 1 Max Volt [V]	P. Slot 1 Max Curr [A]	P. Slot 2 Max Volt [V]	P. Slot 2 Max Curr [A]
0.0260192	1000	503	3.4	0.051	0	0
	Number of Pulses	P. Slot 2 On Time [µs]	P. Slot 1 Min Volt [V]	P. Slot 1 Min Curr [A]	P. Slot 2 Min Volt [V]	P. Slot 2 Min Curr [A]
	100	0	3.36	0.05	0	0

Example of the Live Data being shown in the Alfven Software

Example Data: Summary Report

Data Display

Export ☑ Auto export Summary successfully saved in C:/Users/broph/Documents/Test Data/30mHz_weekend_Test/summaries/2021-02-19_09-57-14_1kHz.csv

	Step Name	Duration [s]	Frequency [Hz]	Avg Voltage [V]	Avg Current [A]	Pulses	Pulse Period [µs]	Pulse On Interval [µs]	Duty Cycle [%]	Pulse Frequency [Hz]	Max Pulse 1 Voltage [V]	Min Pulse 1 Voltage [V]	Max Pulse 1 Current [A]	Min Pulse 1 Current [A]
1	1	20	13560000	1.78	0.0260192	99	999.517	502	50.2242	1000.48	3.4394	3.40179	0.051	0.000253731
2	2	20	13560000	1.78	0.0260192	100	999.51	502	50.2246	1000.49	3.4392	3.4022	0.051	0
3	3	20	13560000	1.7801	0.0260192	100	999.485	502	50.2259	1000.52	3.439	3.4008	0.051	0
4	4	20	13560000	1.78	0.0260192	100	999.475	502	50.2264	1000.53	3.4388	3.4013	0.051	0
5	Live Data	20	13560000	1.78	0.0260192	100	1000	502	50.2	1000	3.44	3.4	0.051	0.051

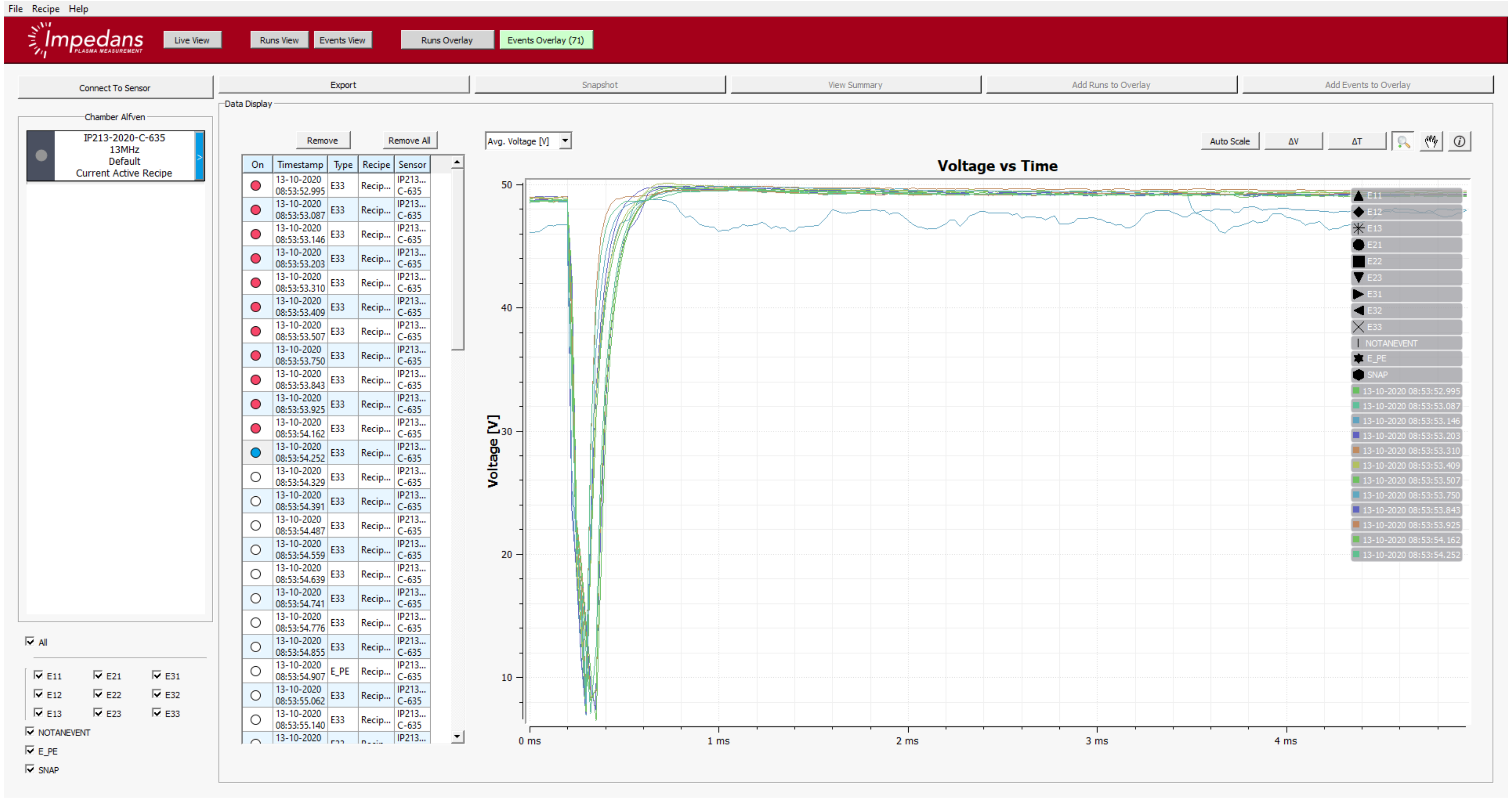
Data Display

Export ☑ Auto export Summary successfully saved in C:/Users/broph/Documents/Test Data/30mHz_weekend_Test/summaries/2021-02-19_09-57-14_1kHz.csv

	x Pulse 1 Voltage [V]	Min Pulse 1 Voltage [V]	Max Pulse 1 Current [A]	Min Pulse 1 Current [A]	Max Pulse 2 Voltage [V]	Min Pulse 2 Voltage [V]	Max Pulse 2 Current [A]	Min Pulse 2 Current [A]	Bad Pulses [%]	E11	E12	E13	E21	E22	E23	E31	E32	E33	E_PE
1	94	3.40179	0.051	0.000253731	0	0	0	0.000253731	1.0101	0	0	0	0	0	0	0	0	0	1
2	92	3.4022	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	9	3.4008	0.051	0	0	0	0	0	143	0	0	0	0	0	0	0	0	0	143
4	88	3.4013	0.051	0	0	0	0	0	20000	0	0	0	0	0	0	0	0	0	20000
5		3.4	0.051	0.051	0	0	0	0.051	100	0	0	0	0	0	0	0	0	0	100

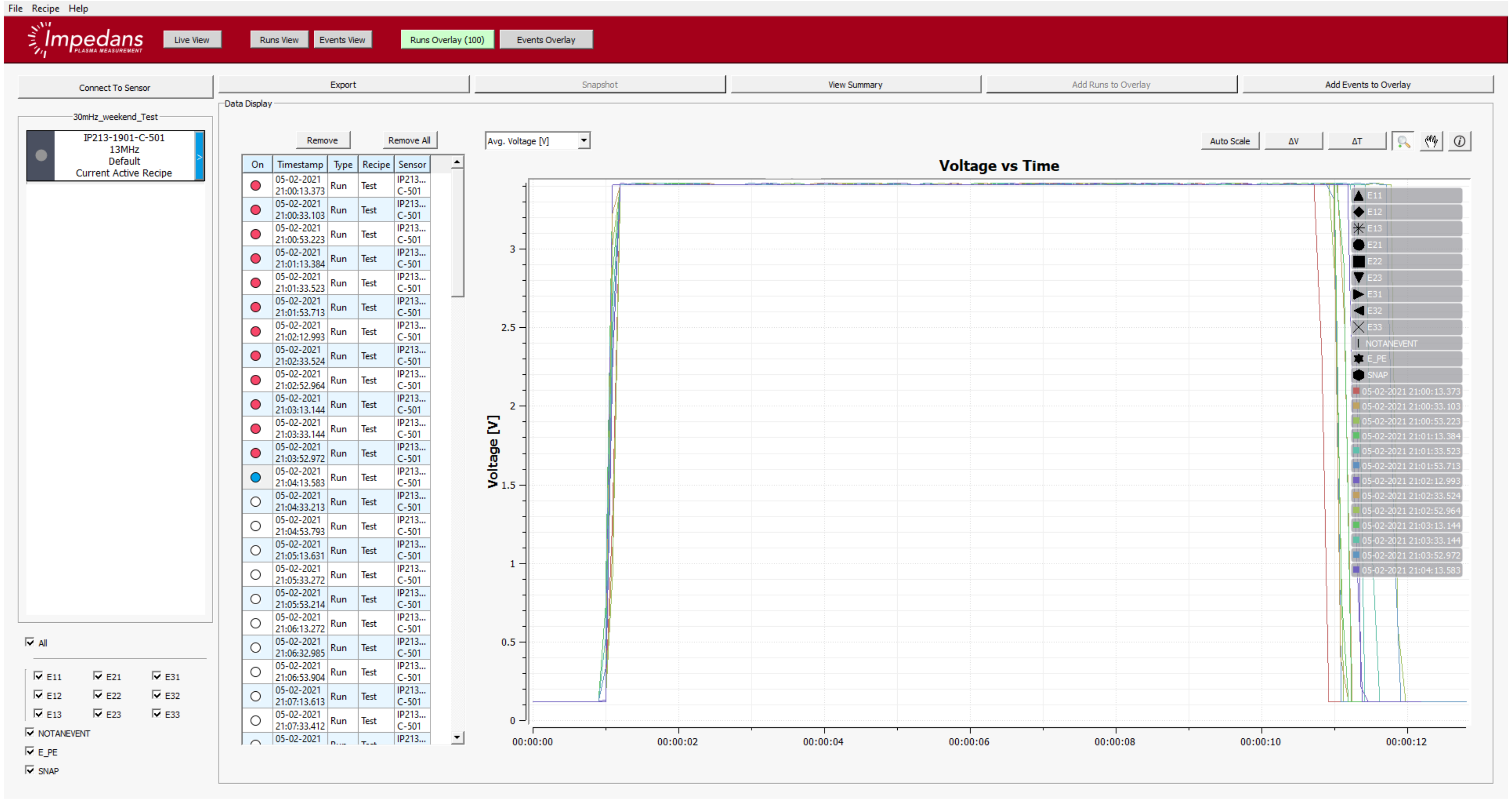
Example of the Recipe Summary using a multi-step recipe that included pulsing with finer acceptance levels in each step (100, 50, 10 and 1 µs for Pulse Period and the Pulse on-time)

Example Data: Event Overlay



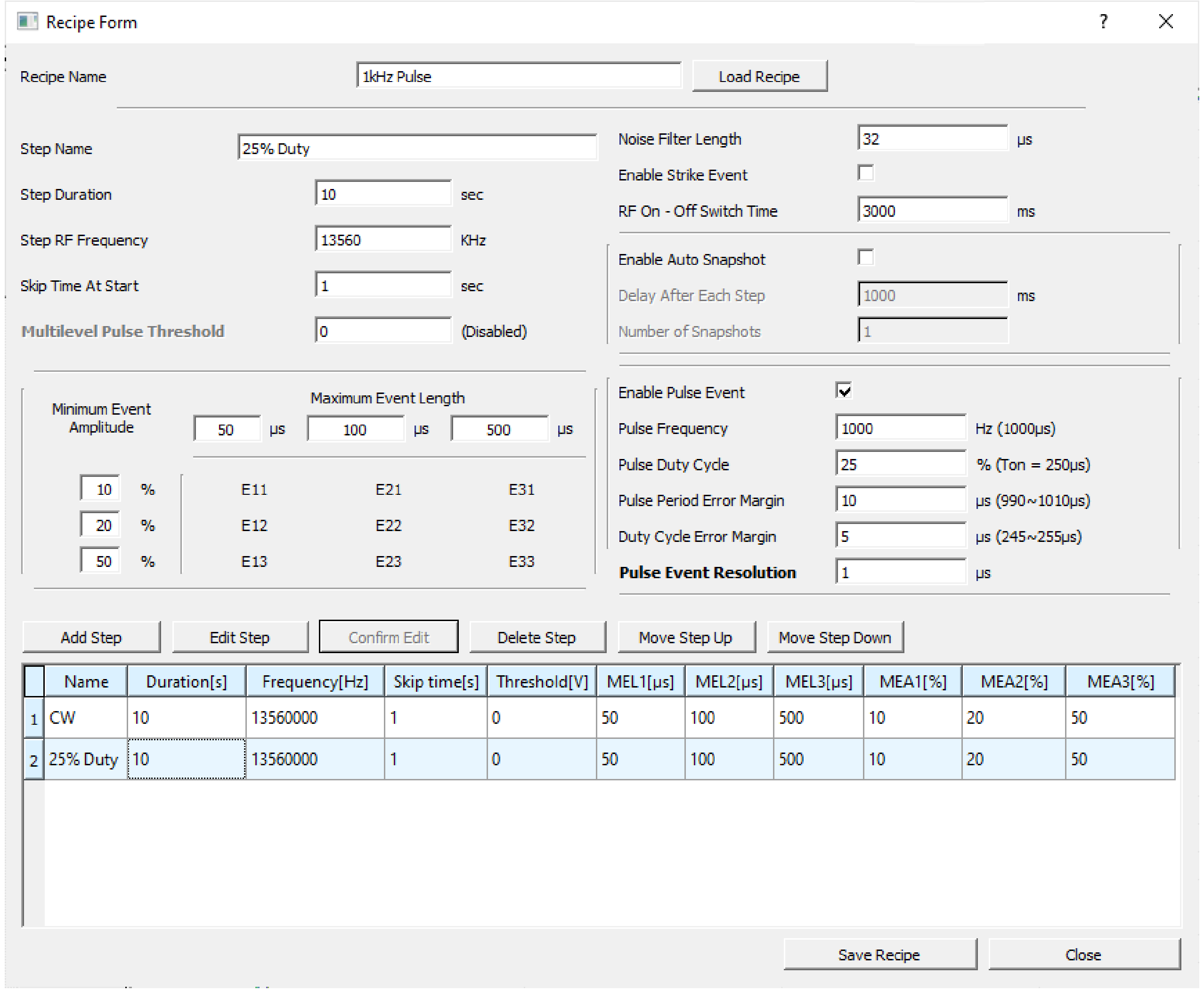
Example of Arc Data showing E33 (severe) Arcs overlayed.

Example Data: Run Overlay



Example of Run Data being overlayed to check for consistency of processes

Example Data: Recipe Creation


Recipe Form

Recipe Name: 1kHz Pulse [Load Recipe]

Step Name: 25% Duty

Step Duration: 10 sec

Step RF Frequency: 13560 KHz

Skip Time At Start: 1 sec

Multilevel Pulse Threshold: 0 (Disabled)

Noise Filter Length: 32 µs

Enable Strike Event: ☐

RF On - Off Switch Time: 3000 ms

Enable Auto Snapshot: ☐

Delay After Each Step: 1000 ms

Number of Snapshots: 1

Minimum Event Amplitude / Maximum Event Length: 50 µs, 100 µs, 500 µs

	50 µs	100 µs	500 µs
10 %	E11	E21	E31
20 %	E12	E22	E32
50 %	E13	E23	E33

Enable Pulse Event: ☑

Pulse Frequency: 1000 Hz (1000µs)

Pulse Duty Cycle: 25 % (Ton = 250µs)

Pulse Period Error Margin: 10 µs (990~1010µs)

Duty Cycle Error Margin: 5 µs (245~255µs)

Pulse Event Resolution: 1 µs

[Add Step] [Edit Step] [Confirm Edit] [Delete Step] [Move Step Up] [Move Step Down]

	Name	Duration[s]	Frequency[Hz]	Skip time[s]	Threshold[V]	MEL1[µs]	MEL2[µs]	MEL3[µs]	MEA1[%]	MEA2[%]	MEA3[%]
1	CW	10	13560000	1	0	50	100	500	10	20	50
2	25% Duty	10	13560000	1	0	50	100	500	10	20	50

[Save Recipe] [Close]

Example of the Creation of a Multi-Step recipe

Case Study

Impedans | CASE STUDY

Alfven™ 100 Event Detector

Pulsed RF plasma monitoring critical for 7nm and beyond

The Background

In recent years, pulsed RF plasma processes have been shown to improve etch selectivity, etch anisotropy and reduce feature damage in the semiconductor industry. Carefully selecting the pulse frequency and duty cycle allows for plasma chemistry selectivity and ion impact energy control, both of which are critical for the 7 nm node and beyond.

RF carrier frequencies typically range from 400 kHz to 60 MHz, modulated with pulse frequencies in the range of 100 Hz – 50 kHz. Duty cycles range from 90% down to a few percent, and the RF carrier frequency is sometimes adjusted for fast tuning. These together pose a unique diagnostics challenge for troubleshooting when wafer defects occur. For this, Impedans developed the Alfven 100, and this case study explores the pulse monitoring application designed to meet the needs of the semiconductor industry.

The Solution

The Alfven was integrated seamlessly into the 50 Ohm cable and monitored every single pulse with 1 microsecond resolution. Pulse frequency and duty cycle were compared with expected pulse parameters. Atypical pulses counted and reported to the Fault Detection and Control (FDC) system. A predetermined number of 'bad' pulses per process were allowed before action was taken.

Achievements:

- It was possible to identify when generators were on the verge of failing (due to increase in "pulse mis-firing")
- Alarm limits were determined for the acceptable levels of duty cycle shift before wafer defects would start to occur
- The Alfven significantly reduced troubleshooting time and labour for pulse issues, leading to increased tool up-time for better yields

The Challenge

The acceptable process windows for 7 nm and below are narrow, particularly for etch rates. Since the duty cycle controls the ion energies, small deviations in the average duty cycle over a process will result in a shift in ion energies and thus etch rate. This drift in the pulse on-time can be caused by many factors – misshapen pulses due to cable degradation, generator pulsing issues and generator calibration errors. Troubleshooting usually requires directional couplers and an oscilloscope, which are expensive, slow and inconvenient, and data analysis is labour-intensive. Even with all this equipment, pulse issues are intermittent, and recording every single pulse with an oscilloscope is not practical.

The Tool Integration Process

Impedans and the process engineers verified and compensated for the low-impact of the Alfven unit on the pulse waveform and power delivered to the match box through an adjustment of the 50 Ohm cable length. Then the Alfven was integrated with the FDC system using the simple Ethernet communication protocols available on the sensor.

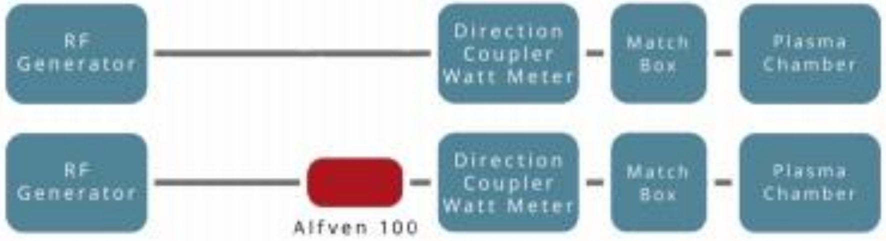


Fig 1: Once-off verification process to confirm the Alfven has no process impact

Data was accumulated with products being inspected in the usual manner. The number of 'bad' pulses was then correlated with the health of the product to determine how many could occur without adverse effects. Similarly, deviations in the average duty cycle for each process step were correlated with wafer defects for a process alarm.

*Click here for Alfven 100 brochure

Arc Management

Causes of arcs - 1) Poor Chamber Seasoning

- ✓ If chamber seasoning is incomplete, then some areas of the wall will be conducting and other parts insulating

- ✓ Or, if the coating is uneven, then in some areas the coating will be thin enough for breakdown to eventually occur through the dielectric material to the wall

- ✓ This type of arc is responsible for particle crea
- ✓ Aluminium particles are sputtered from the wall. These metal clusters collect many electrons, becoming “super-negative ions”. These particles collect above the plasma sheath, just above the wafer.

- ✓ When the plasma is off, they fall onto the wafer and will contaminate the next layer.

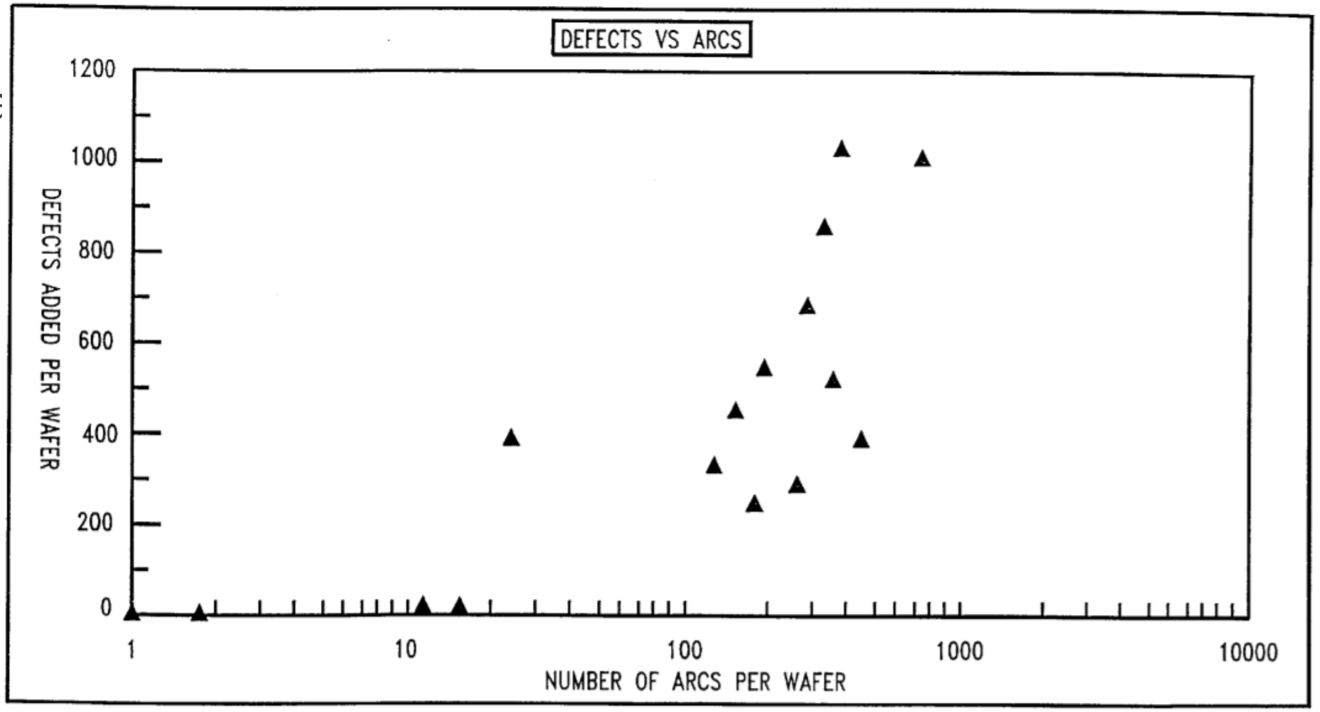


Figure ref: US Patent US5993615A 1999-11-30 Method and apparatus for detecting arcs

Causes of arcs - 1) Poor Chamber Seasoning

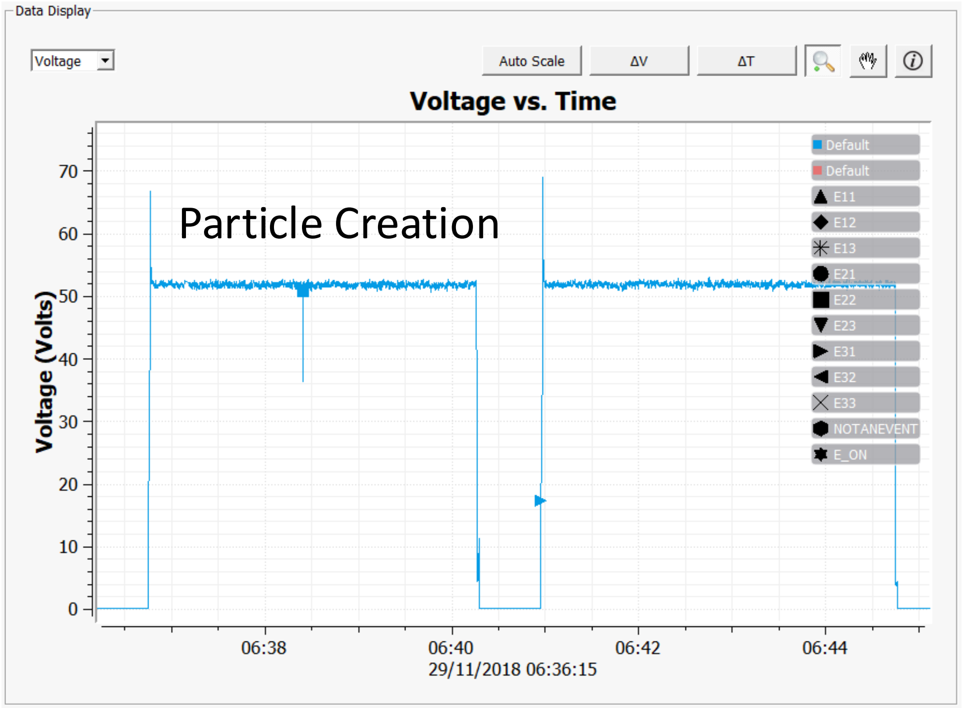
- ✓ The example in the graph was from a PECVD chamber with poor seasoning. It took multiple dummy wafers before it was allowed to run product, so the chamber would become correctly conditioned (multiple cycles)

- ✓ There are a few possible solutions

  A. Increase the duration of the seasoning step so the chamber is well coated. This may require an increase in the cleaning step duration.

  B. Introduce a pre-seasoning step, like an extra cleaning process. This is especially needed after the chamber has been opened, since there may be some water vapour on the surfaces

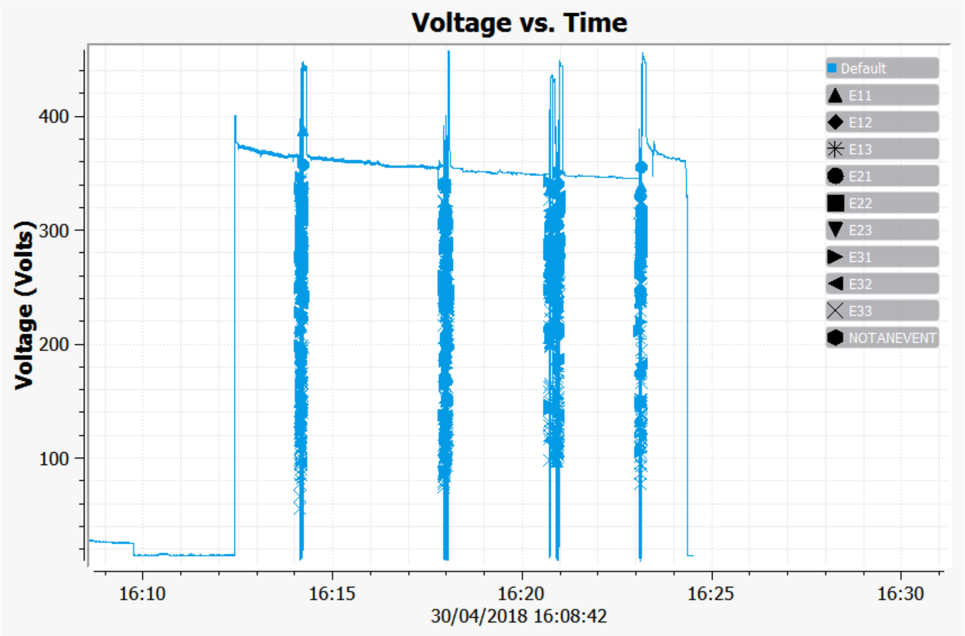
  C. To purge a system of left-over metal particles, put in a dummy wafer and run high gas flows for a few minutes. The particles will flow out of the system or be collected by the dummy wafer surface.



Causes of arcs - 2) Poor Grounding

- ✓ Poor grounding covers a number of arc causes

A. Poor chamber chassis earth connection. This will cause the chamber to “float” to a certain voltage near the plasma potential due to charge build-up. This charge will dissipate at random, causing arcing

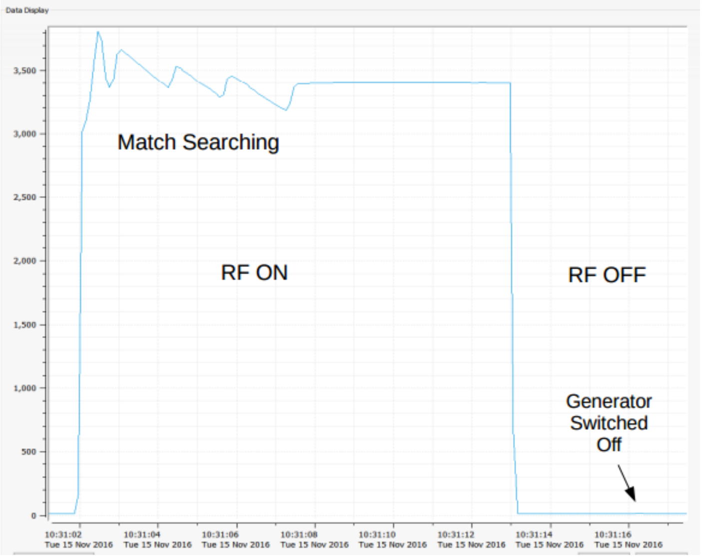


B. Poor wafer contact with the chuck, or poor wafer clamping.
   - ✓ This is particularly critical when a conducting layer is being deposited on an insulating layer. Charge will build up on the insulating layer until it breaks down to the nearest conducting surface (which may be through to a lower layer in the wafer itself).

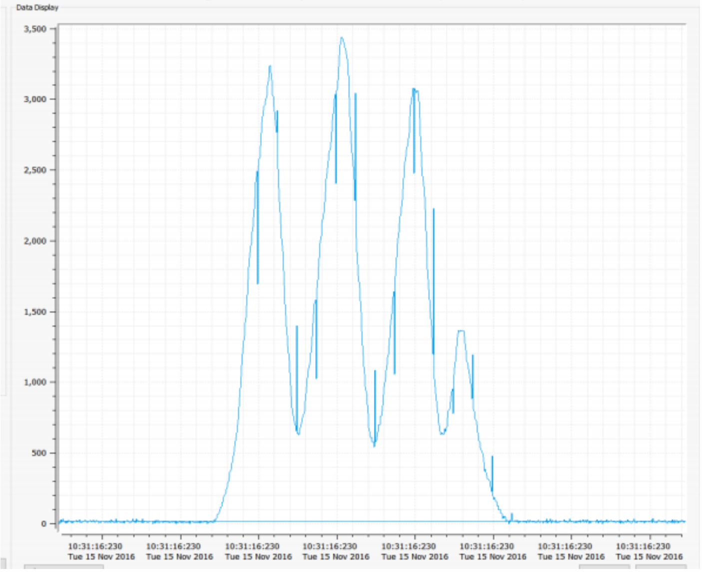
- ✓ Preventing these from happening simply requires good chamber maintenance.
  - ✓ Be aware that invisible oxide layers build up on the surface of metals in the chamber.
    - ✓ Connections to ground should be scrubbed free of oxides. RF travels on the surface of metals (“skin depth”), so clean the surface of ground connectors before attaching them.
      - ✓ Check braiding for damage and replace if necessary.

Causes of arcs - 3) Generator and Match Box

- ✓ Arcs can also be caused by faulty parts in the RF network.
- ✓ One example is this situation where products had burn marks if they were left in the chamber for too long after processing. If the product was removed immediately, there was never nay damage
- ✓ It was discovered that the generator was randomly outputting power even when the dial reading was zero – this was due to a faulty relay switch.
- ✓ Power would come on for a few hundred microseconds, causing thousands of volts across the wafer. The “ringing” in the microsecond data is typical of a power supply relay switch.
- ✓ A similar “ringing” with high voltages can be seen when the match box begins to fail. Arcs inside the match box capacitors cause very brief spikes in reflected power, which have an oscillating shape



Alfven spots that the RF ouput comes on back on for 400us while generator powers down. (RF is off)



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