Impedans
PLASMA MEASUREMENT

MODULI | RF SPECTROMETER

FOR NON-INVASIVE FAULT DETECTION AND CHAMBER HEALTH MONITORING

Moduli™ RF Spectrometer

Non-Invasive RF Harmonic sensor for plasma fault detection

Typical Frequencies

400 kHz, 2 MHz, 13.56 MHz, 27.12 MHz, 40.68 MHz, 60 MHz

Moduli RF Spectrometer

The RF Spectrometer is a radio-frequency (RF) detector that directly monitors the electrical state of a plasma from outside the plasma chamber. This is designed for end point detection and fault detection on production tools without the need for an in-line sensor in the RF path. It has demonstrated superior performance to optical techniques for low open area endpoint applications. It has also been proven to detect air leaks, wafer displacement and other serious plasma faults.

The RF Spectrometer is a non-invasive solution for plasma monitoring. This Radio Emission Spectroscopy (RES) tool can be placed anywhere outside the plasma source where small RF leakage is present – at a window port, for example. The antenna is split into two parts; an antenna pick-up which can be inserted within the chamber RF shielding manifold and the circuitry which remains outside. This allows measurement within the RF environment.

The antenna collects the electric and magnetic waveforms from the chamber and sends them to the acquisition unit, which extracts the RF harmonics. The harmonic spectrum is very sensitive to small changes in plasma impedance, a key indicator of process repeatability. Harmonic spectrum signatures are unique to specific plasma conditions and are very sensitive to small changes, allowing for accurate endpoint and fault detection.

Key Features

- Entirely non-invasive. The RF spectrometer antenna can be mounted at the OES fiber access point.
- API for extending software.
- Choice of 5 frequencies on a single sensor, measures multiple frequencies simultaneously.
- Frequency tracking to ± 10% of the fundamental frequency.
- Pulsed RF monitoring for multi-level pulsing and multiple frequencies simultaneously.
- Customizable form factor & multiple communication protocols.

Key Benefits

- Real-time plasma performance monitoring & production tool fault detection.
- Process endpoint capabilities with superior performance to OES for low open area ratios (< 1%).
- Only one sensor required for multiple frequency applications, saving significant cost.
- Customizable for seamless integration into your process equipment and control loop.
- Significant cost benefits through the enablement of fault detection and early intervention.
- Opto-RF sensor accessory to monitor optical RF waveform and harmonic spectrum.

Parameters Reported

Table 1: RF parameters measured by RF Spectrometer.

Parameters measured by the Moduli RF Spectrometer (many other RF parameters can be calculated and output on request)	
F_0	Fundamental frequency
F_N	Harmonic frequency number
V	RMS Voltage (magnitude) – [UNCALIBRATED]
I	RMS Current (magnitude) – [UNCALIBRATED]
Phase (θ)	Phase of the current relative to the voltage – [UNCALIBRATED]
P	Delivered power (V*I*cos**θ)** – [UNCALIBRATED]
P fwd	Forward power – [UNCALIBRATED]
P ref	Reflected power– [UNCALIBRATED]
Z complex	Complex impedance in the form R+Jx – [UNCALIBRATED]
Additional outputs	
Harmonic spectrum	Harmonic amplitude frequency spectrum

Specifications

Table 2: General Specifications

RF Spectrometer Specifications – General	
Antenna Power	5 Vdc, 4.1mm jack
Antenna Form Factor	[40 mm x 40 mm x 40mm] & custom
Antenna Communication	2 x SMA coaxial cables
Acquisition Unit Power Requirements	24 Vdc, 4.1mm jack
Acquisition Unit Interfaces	Micro USB, Serial, Ethernet
Acquisition Unit Protocols	USB, HTTP Web Service, EtherCAT, Ethernet/IP, others on request
Acquisition Unit Form Factor	[122mm x 70mm x 41mm]
Parameter Report Rate	USB: 125 S/sec max. Ethernet: 125 S/sec max.
Operating Temperature Range	10^0 C – 80^0 C

Table 3: Frequency Specifications

RF Spectrometer Specifications – Frequency	
# Fundamental Frequencies (F_0)	Choose 5 from the fundamental frequency range. Measures 5 simultaneously.
F_0 Range	$350\ kHz - 100\ MHz$
F_0 Specials	$40\ kHz$ & $162\ MHz$ models available on request
Harmonic Frequency (F_N) Range	$350\ kHz - 240\ MHz$
Frequency Resolution	$1\ kHz$
Frequency Accuracy	$\pm 1\ kHz$
# F_N	≤ 15 per fundamental (64 max.), ≤ 32 simultaneously
F_0 Modes	CW, CW with Tuning, Multi-level Pulsing with Tuning
F_0 Tracking Rate	10 *kHz/μs*
F_0 Tracking Range	$\pm$ 10% or $\pm$ 2 MHz, whichever is less

Table 4: Pulse Monitoring Specifications

RF Spectrometer Specifications – Pulse Profiling & Monitoring	
Pulse Profile – Standard Mode	
Acquisition Method	Boxcar average
Pulse Frequency Range	10 Hz to 100 kHz
Time Resolution	1 μs
Acquisition Time	> 1 second (pulse frequency dependent), average over many pulses
Pulse Level Monitor [# Time Frames]	2 per pulse period (more on request)
Pulse Level Monitor [Report Rate]	< 10 S/s (pulse frequency dependent)
Advanced Pulse Mode for OEM Integration	
Acquisition Method	Instantaneous sampling within pulse period
Time Resolution for Data Sampling	3.5 μs
Minimum Pulse Width	3.5 μs
Data Sampling	Data samples can be averaged or taken individually at different pulse times
Data Report Rate	Every 200 μs moving to 10 μs with future firmware upgrades
Data Transfer Latency	200 μs min. @ 200 μs report rate 30 μs min. @ 10 μs report rate

Table 5: Impedance & Phase Specifications

RF Spectrometer Specifications – Impedance & Phase	
Phase Range	$\pm 180^0$
Phase Resolution	0.02^0

Note: Phase only available when both the voltage and current channels are locked.

Table 6: Optical APD Specification

RF Spectrometer Specifications – Opto-RF APD Module	
Supply Voltage	+12 V ± 0.1 V
Max. Incident Light Level	10 mW
Operating Temperature Range	$0 – 50^0$ C
Spectral Response Range	400 – 1000 nm
Photosensor Diameter	0.5 mm
Frequency Range	50 kHz – 1 GHz
Gain Stability	5 % (25^0 C ± 10^0 C)
Dimensions	28 x 50 x 60 mm
Weight	120 g

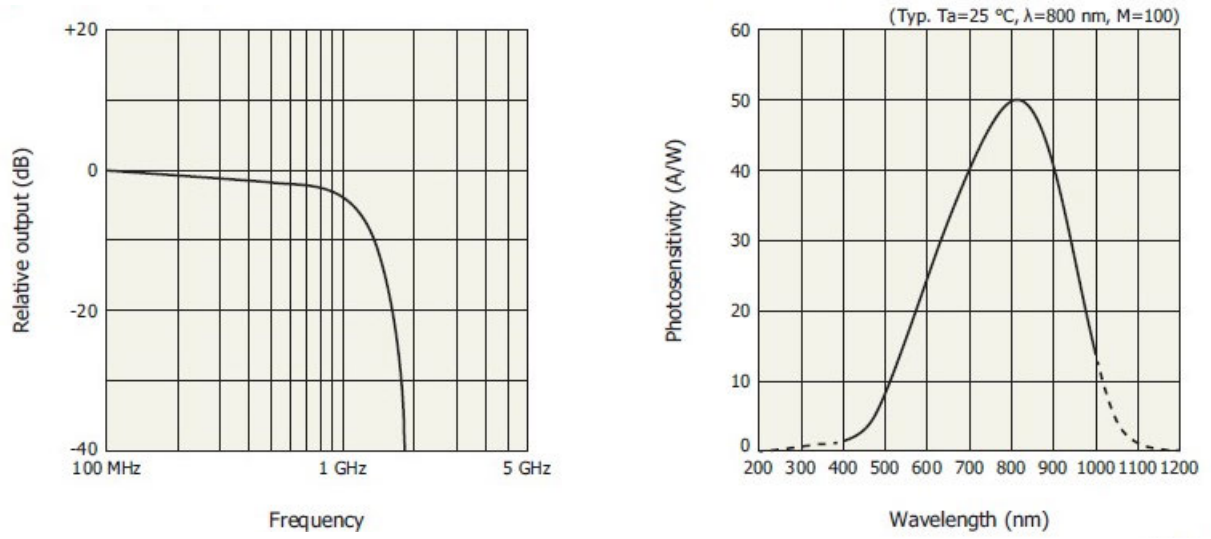

Figure 1: Frequency response and spectral response of the APD module.

New Era of Plasma Monitoring

Plasma Impedance Monitoring (PIM) is the future of process control. The plasma impedance is sensitive to every change in the plasma chamber – wafer misplacement, air leaks, chamber wall condition and other faults. It is also sensitive to both clean and etch processes, giving a strong endpoint signal. The RF Spectrometer is an indirect plasma impedance monitor – it monitors the radio frequency harmonics which are emitted by the plasma and respond non-linearly to changes in plasma impedance. Each harmonic reacts in a unique way to plasma changes, allowing for unique characterization of various plasma faults. Etch endpoint for open area ratios down to 0.5% have been demonstrated with plasma harmonic monitoring, succeeding where OES techniques fail.

Low Cost of Ownership

Each sensor can cover five fundamental frequencies. The RF spectrometer has the widest measurement range for voltage and current on the market. Measurement repeatability is maintained over the entire range.

Cost Benefits

Enormous cost benefits can be achieved through integration of the RF spectrometer with your FDC system. Cost savings are achieved through accurate endpoint detection, general RF health diagnosis, fault detection and chamber impedance deviation monitoring – all of which, if not detected early, can result in scrapping of valuable wafers or substrates. By using the harmonic spectrum as a baseline for a recipe you can be sure that the plasma state is as desired. By using changes in that spectrum as a fingerprint for different faults, production downtime due to faults is minimized.

Advanced Communication features

The spectrometer comes equipped with a wide variety of communication options. USB or Ethernet connectivity is used to interface with the software suite. USB, TCP/IP, EtherCat, EtherNet/IP and serial protocols are available to communicate directly with the sensor.

Novel Opto-RF Detector

The standard Moduli RF Spectrometer product includes an antenna to detect the RF radiation emanating from the plasma chamber electrically. The light emitted by the plasma is also modulated by the RF excitation power. An wideband avalanche photo diode (APD) is offered as an accessory to monitor the RF spectrum through the optical emission. The APD module has gigahertz frequency response and has an optical bandwidth that covers the visible spectrum. The APD module provides a voltage output that is compatible with the acquisition unit detector. This provides a novel dimension in which to probe the plasma and is similar to phase resolved optical emission spectroscopy (PROES) technology developed in recent years but at a fraction of the cost.

Dimensional Drawings – RF Antenna Module

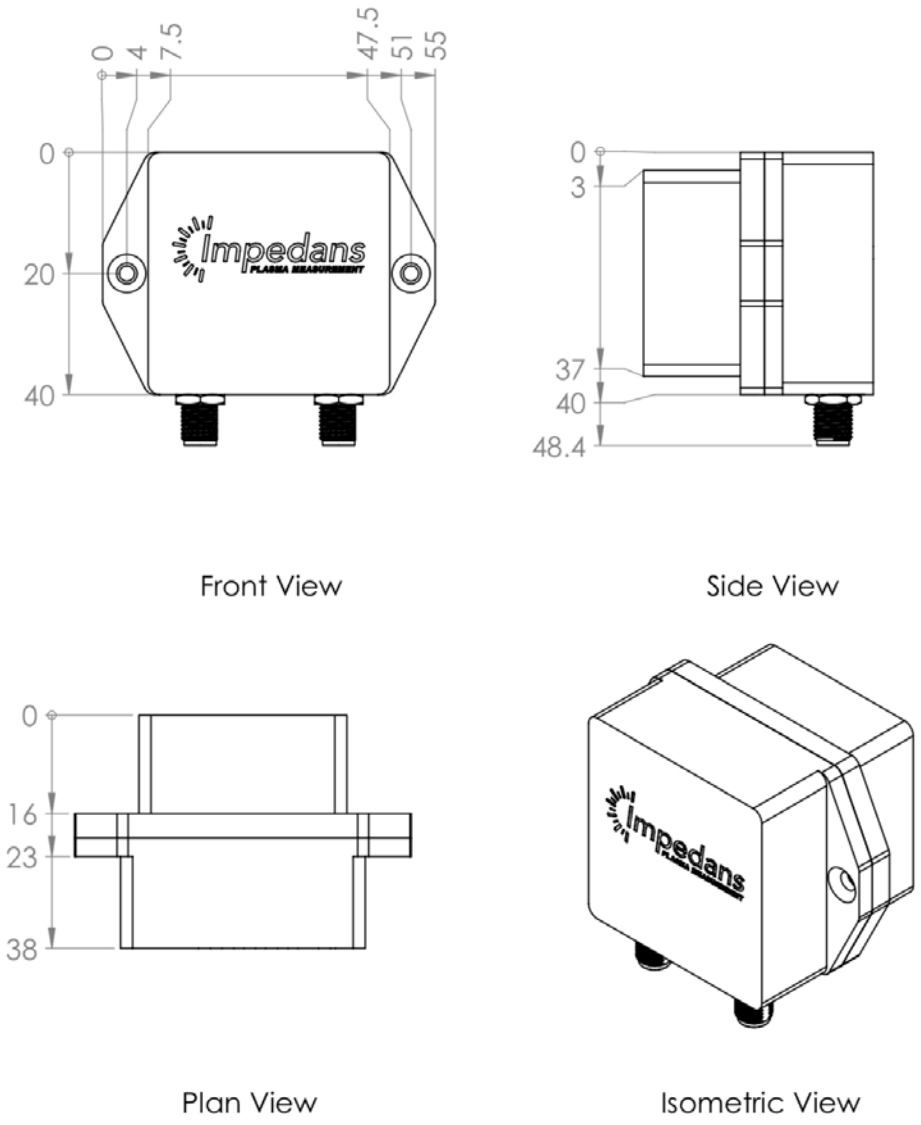

Figure 2: Dimensional drawings of RF Spectrometer antenna. All dimensions are in mm.

Dimensional Drawings – APD Module

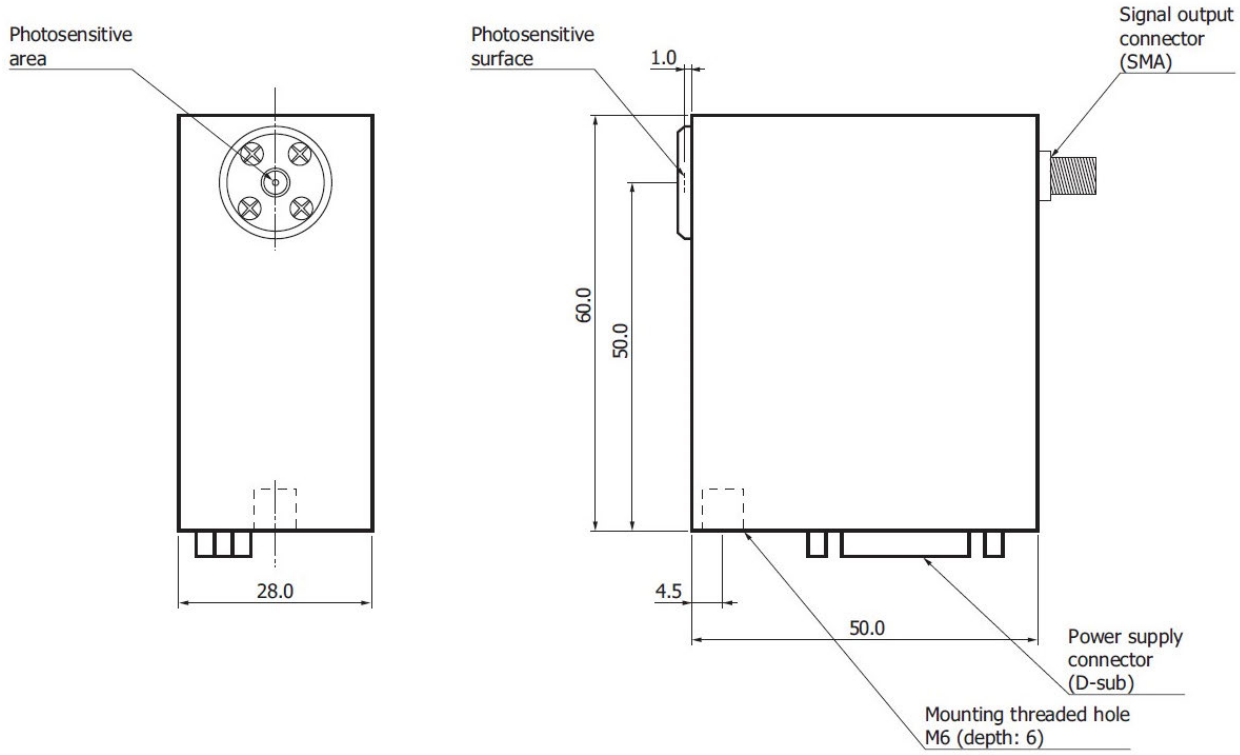

Figure 3: Dimensional drawing of the APD module. All dimensions are in mm.

Dimensional Drawings – Data Acquisition Module

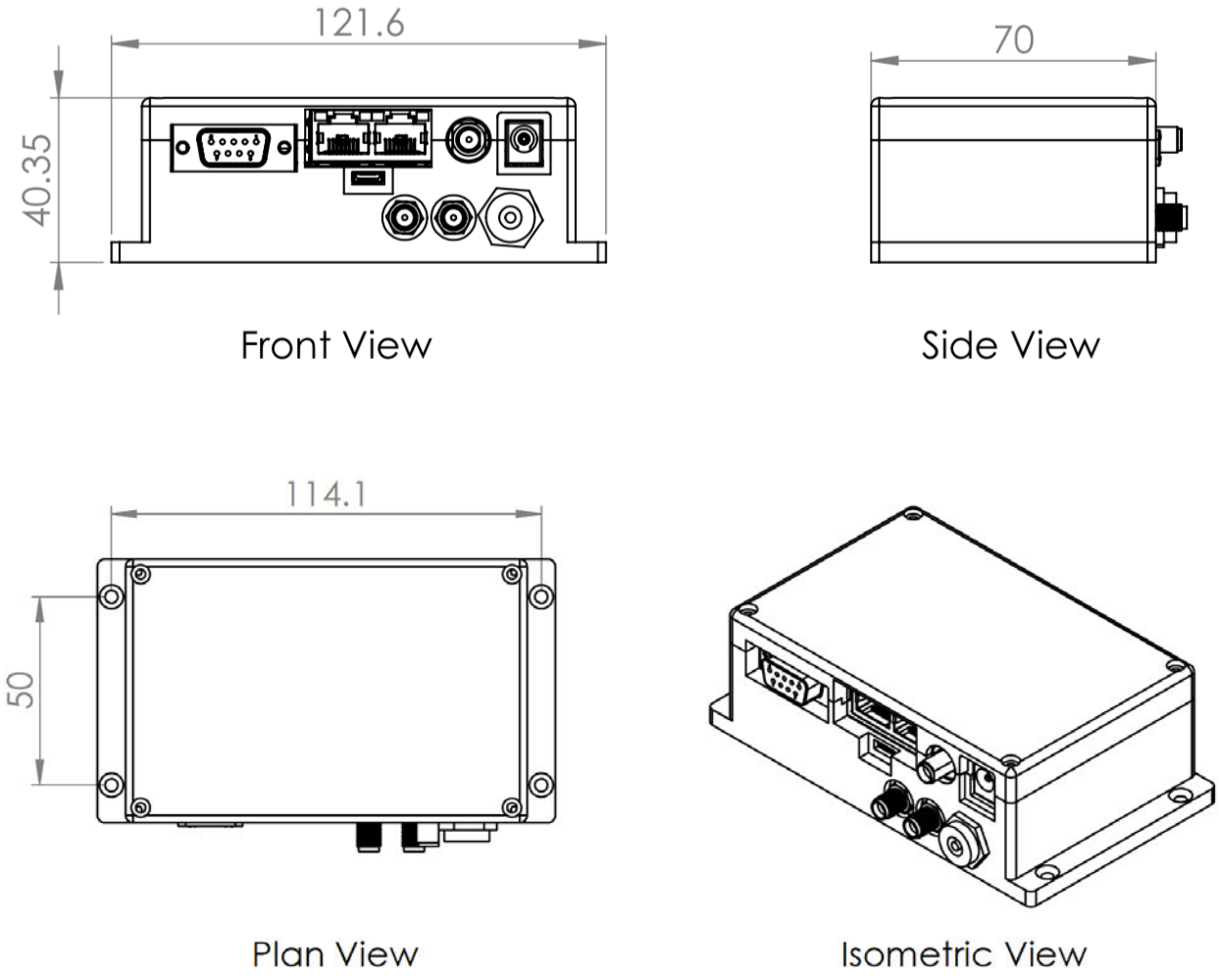

Figure 4: Dimensional drawings of RF Spectrometer acquisition unit. All dimensions are in mm.

Installation Example

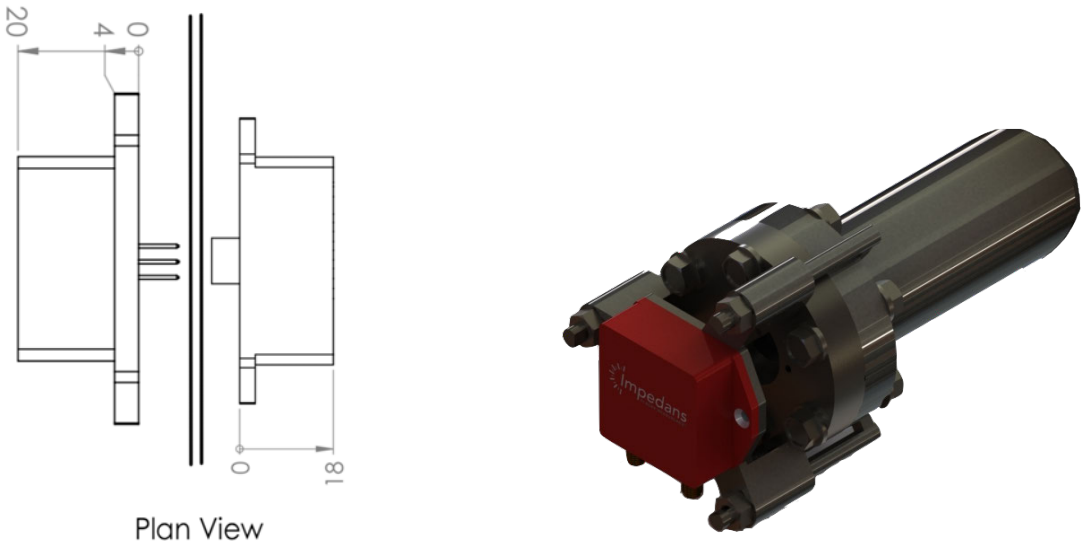

Figure 5: Two installation examples (a) the antenna mounted through the RF shield wall. The pick-up board connects through the wall via a 3-pin connector (b) the antenna mounted outside the optical window.

Software Display

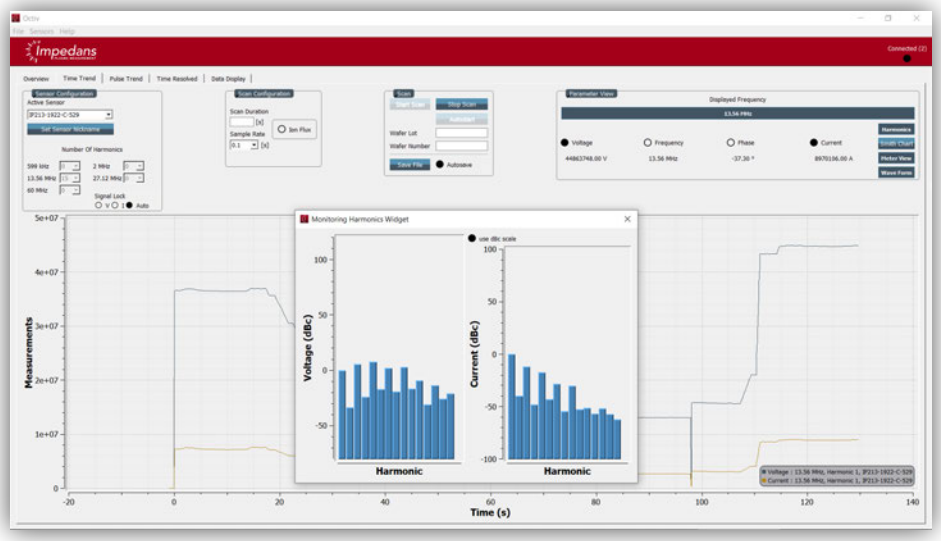

Figure 6: Example of the Harmonic view.

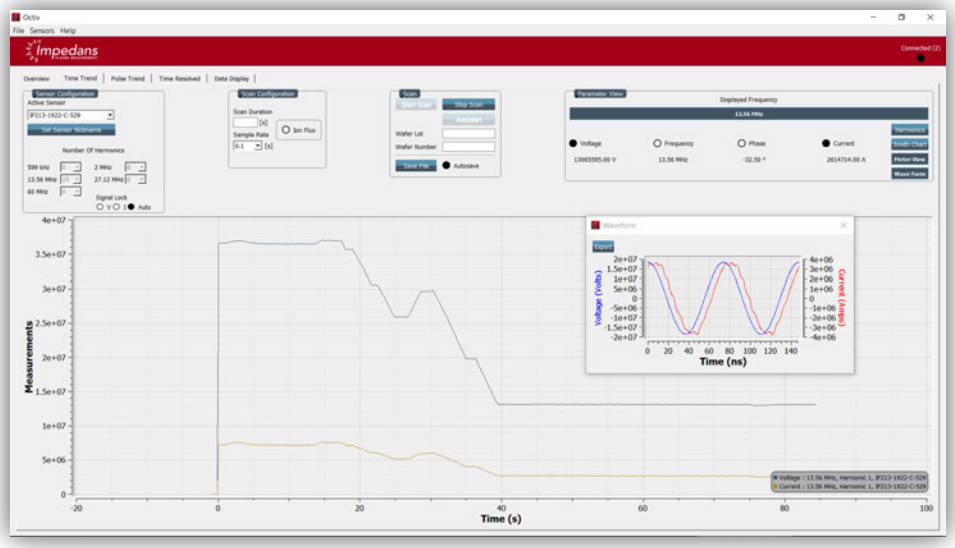

Figure 7: Example of the waveform view.