Octiv Suite

INTRODUCTION

The **Octiv Suite** is part of a range of products which measure the parameters of plasma power delivery. These parameters include; real power; forward power; reflected power; impedance; voltage; current; phase angle; harmonics and ion flux. The Octiv Suite is also capable of reconstructing the waveforms of multiple fundamental frequencies simultaneously. The measurement functionality of the Octiv Suite extends to time-averaged, time-resolved and time-trend measurements.

Development of the Octiv Suite was necessary due to the over simplicity of its predecessor, directional coupler technology, which measured RF power. This technology, which was developed in the 1940's, measures a forward wave and reflected wave in a transmission line. By dividing the square of these figures by the transmission line rated impedance, the power forward and power reflected can be calculated. While this technology is still widely used in plasma monitoring, it has a number of technical limitations and only works when:

- The impedance range of the transmission line is limited
- The magnitude and phase of the forward voltage, reflected voltage and impedance is known for all frequencies

It is also noted that solely monitoring power is insufficient for modern plasma applications and knowledge of wafer parameters is necessary.

The development of technology such as the Octiv Suite is necessary because of the significance of knowing the exact shape of the current and voltage waveforms at the wafer surface. This can be achieved through the installation of a well characterised and calibrated VI probe after the match unit. As the complexity of the RF systems increases, such as in systems that are pulsed, multi-frequency and frequency tuned, the mounting of a VI probe becomes more critical.

When the voltage and current are monitored as complex parameters in the full frequency domain, power and other parameters can be measured in a large range of plasma applications. This brings a number of advantages:

- Line impedance can be determined
- Local waveform can be measured
- The waveform can be transposed onto the wafer surface

However despite these advantages, when measurements are taken in this manner, the data analytics process can become extremely complex.

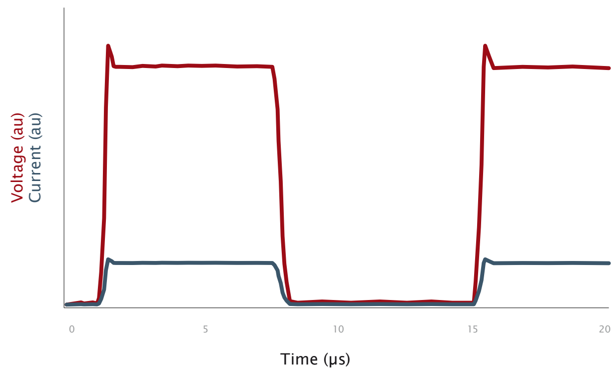

Figure 1: Pulsed time resolution

THEORY OF OPERATION

Figure 2 below shows how the **Octiv Suite** works to capture waveforms. A simple loop is used to pick up current from the RF magnetic field, with voltage from the E field being collected by a capacitor. Any imperfections in these pickups are calibrated out of the system. RF bias forces the capacitively coupled probe potential to the self-biased potential (more negative). By sending a pulsed RF bias the probe can be charged to the self-bias potential when it is 'on'. At 'off' periods, this potential can be discharged. This produces a voltage-current characteristic measurement similar to Langmuir probe results. This system is highly applicable to plasma deposition applications with insulating layers over the electrode/probe surface. The current and voltage measurements are turned into digital format with 14 bit accuracy. When this is fed into a field programmable gate array (FPGA), a one shot signal is collected in a few seconds.

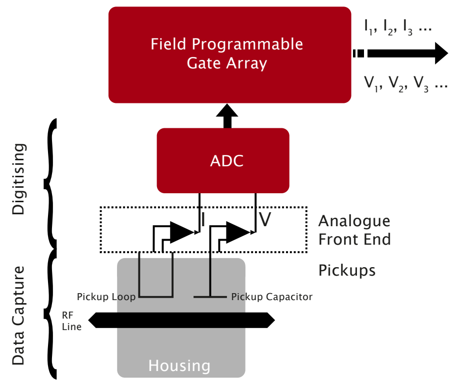

Figure 2: Octiv Suite waveform capture

Once this single shot is collected by the FPGA, a Fast Fourier Transform (FFT) is performed.

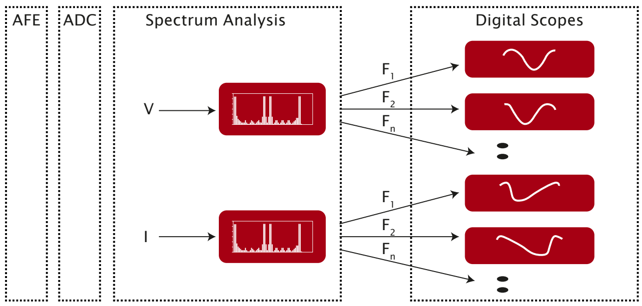

Figure 3: Octiv data analysis - FPGA

Following this process the digital oscilloscope is used. The frequency domain is now broken into ranges that are selected by the user. The strongest frequency in each range, **Fr**$_1$ and **Fr**$_2$, is now sought. Once all of the data is collected, it is sent to two or more digital oscilloscopes. One is activated at **Fr1** and the other at **Fr**$_2$. Extra frequencies are used if required. The procedure is repeated with the collection of a second data set, and the process follows the same pattern. No data is lost as it is all stored in the digital oscilloscopes.

RESULTS

The results displayed in Figure 4 below are the average magnitude (FFT) of the fundamental and first 4 harmonics of the voltage (V) and the current (I) at 13.56MHz. The blue data set represents the measurements from the Spectrum Analyser while the red data set represents the measurements from the triggered oscilloscope. These measurements are averaged over 100 data sets, which is approximately 1ms. It is noted that unwanted data such as noise, inter-modulation and aliased signals are cancelled in oscilloscope mode.

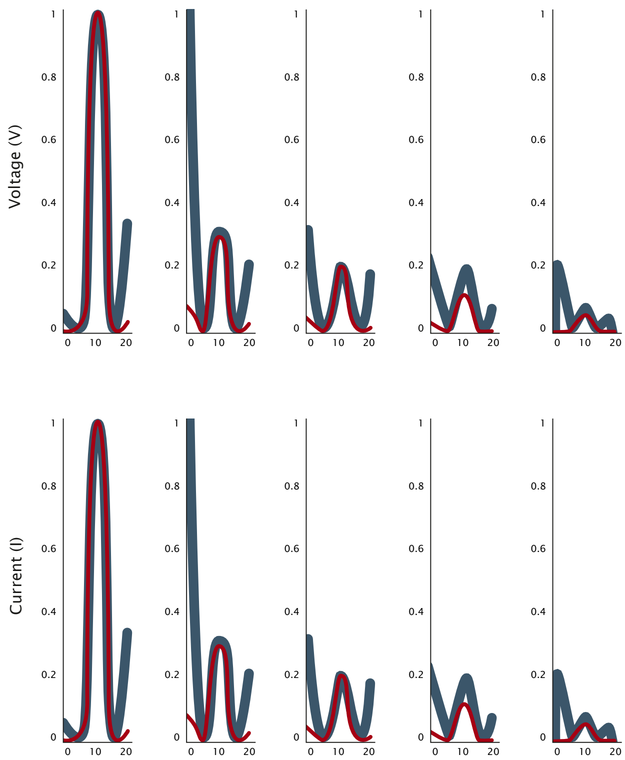

Figure 4: Typical VI results

The VI characteristic is determined by an algorithm displayed below. This algorithm is applicable at multiple time steps across the waveform for a variety of voltage resolutions.

$$I_{(t1)} = -I_p + v'\frac{R_p}{|z|} + v'\frac{C_{(t)}}{|z|}\left|\frac{dv}{dt}\right|_{v=v'}$$

Where $-I_p$ is the constant ion current to the electrode; $v'\frac{R_p}{|z|}$ is the step voltage electrode resistance at the measured impedance; $v'\frac{C_{(t)}}{|z|}$ is the step voltage time varying capacitance at the measured impedance and $\left|\frac{dv}{dt}\right|_{v=v'}$ is the time dependant voltage derivative.

The time steps and voltage resolution **v'** are displayed in the figure below. The voltage resolution determines the bin size of the voltage when measuring the voltage waveform. Each time step is representative of the time period the waveform takes to return to voltage **v'** having passed it previously. While the voltages are equal in magnitude, they are opposite in direction.

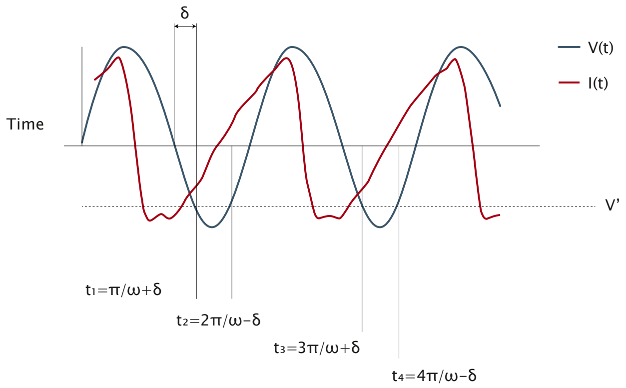

Figure 5: Time step and voltage resolution

Implementation of this algorithm across to voltage waveforms produces an IV curve similar to that shown in Figure 6. This sample data was taken at a capacitively coupled electrode in an ICP reactor. The ion flux extracted from analysis of this IV has been independently verified by Langmuir probe measurements.

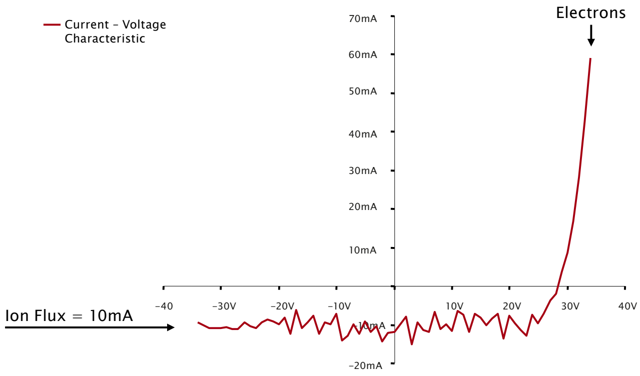

Figure 6: Typical VI curve obtained from **Octiv Suite**

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