Impedans PLASMA MEASUREMENT

Octiv VI Probe - theory of operation

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The Octiv VI probe is an advanced RF voltage and current sensor, which can provide real-time information on complex loads. Real-time information the Octiv provides includes voltage, current, phase, power and impedance on all harmonics of a chosen frequency simultaneously, as well as transmission line parameters such as forward power, reflected power, standing wave ratio (SWR) and reflection coefficient. The Octiv sensor was designed to meet the need for post-match voltage and current measurements in RF excited plasma processes.

Plasma processes are used in a wide range of industries. The plasmas are formed by passing an RF current through a low pressure gas. Often the plasmas are generated from multiple frequencies in order to control the plasma density and energy. Pulsed plasmas are also being used to better control the energy and quality of the etch process. The RF impedance of the plasma and the quality of the power delivered are important factors that now need to be monitored to ensure the process is running correctly.

Anatomy of the Octiv

The Octiv comprises of a small section of transmission line, voltage and current "pick-ups", analogue signal conditioning circuits, ADCs, digital processing logic and a micro controller.

The RF signal going through the small section of transmission line is sensed using capacitive and

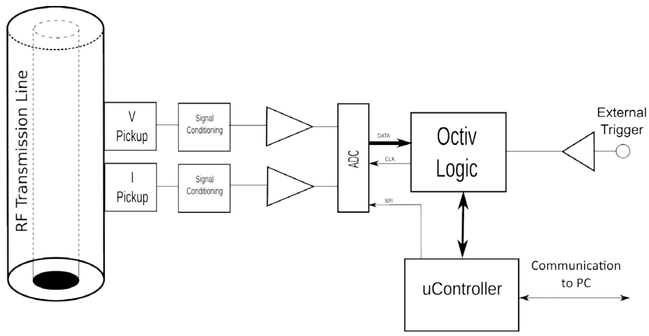

Figure 1. Octiv sensor block diagram.

inductive pick-ups to extract signals for the line voltage and current respectively. The pick-ups provide a low voltage signal compatible with the Octiv system electronics. These signals are digitized and processed digitally within the Octiv Logic circuit.

The Ocitv Logic uses a Fast Fourier Transform (FFT) to convert the signals from time-domain to the frequency domain. The Octiv Logic uses a patented[1] spectrum averaging technique to isolate and perform noise reduction on up to 5 chosen frequencies and their harmonic components. This averaging technique also retains phase information between harmonics, which is required to reconstruct the RF waveform.

The micro-controller retrieves the data from the Octiv Logic as each block of averaging is complete, which occurs approximately every 10 ms.

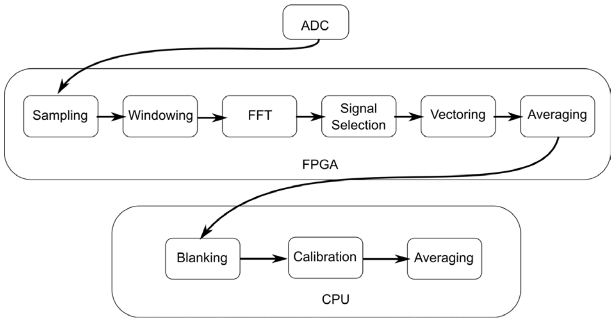

Figure 2. Flow for digital signal processing.

The micro-controller then applies scaling and calibration factors to the data to convert the processed digital values to real world voltage and current values. The controller will perform further averaging and report data at the requested rate.

The Octiv Logic performs the high speed portion of the digital signal processing. The data is organized into blocks of samples that represent approximately 5 micro-seconds of signal. Each block is then processed; signal windowing is applied to the sample data before performing the FFT to reduce spectral spreading.

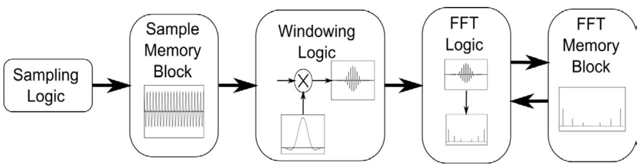

Figure 3. FFT is performed on blocks of sampled data

When the FFT is complete the Octiv Logic uses a look-up or "instruction" table to determine which portions of the FFT are to be searched in order to locate fundamental frequency signals. The fundamental signal is recognised as the largest signal in the defined frequency area. The location of the fundamental signal is then used to determine where to look in the FFT data for the subsequent harmonics. The signal instruction table is populated according to user frequency and harmonic selections.

The micro-controller relays these requirements to the FPGA. After data for each requested frequency has been extracted from the FFT memory the results are vector rotated so that the fundamental voltage signal vector is aligned with the real axis (i.e. zero phase). This gives a reliable reference on which subsequent V and I vectors can be averaged.

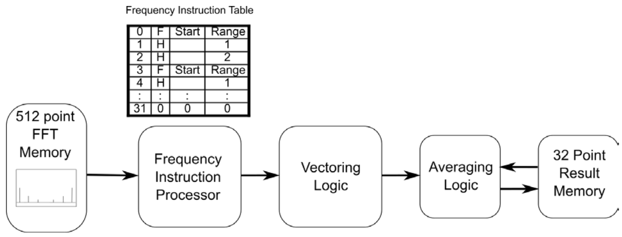

Figure 4. Octiv Logic block diagram

Frequency Agility

The Octiv sensor is capable of following fast frequency changes in RF signal. As previously discussed the Octiv analyses the RF data in blocks, where the block covers approximately 5 µs of signal. Each block is analysed independently and the values for harmonics of the signal of interest are extracted from the FFT data block and averaged with corresponding values extracted from previous FFT data blocks. When the RF frequency is changed, the fundamental signal will appear in a different location on the FFT but will remain inside a predefined "search area". The new fundamental location is used to calculate where the signal harmonics are located. The extracted signal values are averaged as before with the with previous selected signal values. Changes in frequency cause the signal to spread in Fourier space, where the power becomes distributed across the frequencies according to the time spent at those frequencies. This will be observed in the Octiv FFT data when the signal frequency is changing beyond the sensors frequency agility range. The Octiv algorithm selects the peak signal in the range and due to signal being distributed over FFT bins, will report a lower than expected result. The frequency agility range is affected by the block time and the signal windowing used. The configuration used in the Octiv sensor yields a frequency agility range of up to 10 KHz/µs.

Pulse Mode

Pulsed RF sources are being used more frequently in Plasma reactors. The Octiv sensor is capable of providing voltage and current data with resolutions down to 1 us. The Sensor achieves this by using gated block sampling to implement averaging similar to "boxcar averaging" technique. The same time slot within the RF pulse is averaged over successive pulses.

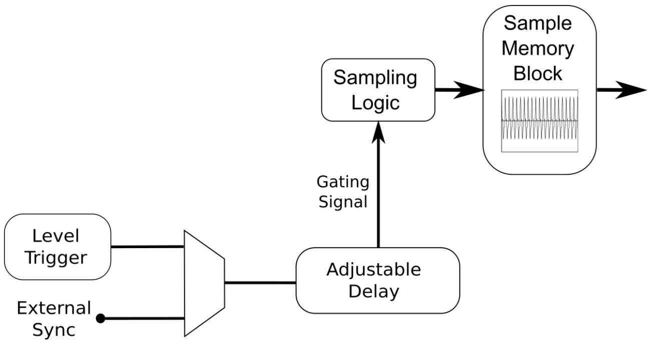

Figure 5. Block sampling logic is gated, synchronised to pulse.

This is achieved by having a gating signal synchronised to the RF pulse, which is used to control when a block of data starts sampling. The time slot within the RF pulse can be selected by setting an adjustable delay as shown in Figure 4.

Pulse Profile

The Octiv software can build a RF pulse profile by sweeping the adjustable delay time through the RF pulse period.

Pulse Trending

The Octiv software provide a trending mode for pulsed RF signals. This uses the "boxcar average" technique described above to select and trend a single time-slot with the RF pulse.

References

[1]Paul Scullin, Michael Hopkins,. Impedans Ltd., (2014). *Analysing RF signals from a plasma system*. WO2014016357 A3.