Long-Pulse Integrator Testing with DIII-D Magnetic Diagnostics

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EAGLE HARBOR TECHNOLOGIES

Introduction
Eagle Harbor Technologies (EHT), Inc. has developed a high-gain integrator for magnetic diagnostics that meets ITER specifications including integration time and integration error limits. EHT has conducted testing of this long-pulse integrator at DIII-D with existing DIII-D magnetic probes. The EHT long-pulse integrator was operated for several hours up to a full day. During a single period of EHT integrator operation, DIII-D was pulsed multiple times. The multiple pulses from the DIII-D magnetic diagnostics can be clearly resolved in the integrator signal output. The results are compared to DIII-D measurements. EHT also operated the long pulse integrator in High Dynamic Range Mode (HDRM), which effectively allows for a dramatic increase in measurement bit depth for higher resolution signal acquisition with the same diagnostic and digitizers presently available on DIII-D. Additionally, EHT has tested a new microprocessor and FPGA-based digitizer, which can be included on the integrator PCB, for a single board magnetic diagnostic solution.

Short Pulse Integrator
EHT has completed the development and characterization of the short-pulse integrator. The frequency response (gain), droop, and drift characterizations are shown below. The gain curve is normalized for frequency (since integrators fundamentally have a 1/f gain vs frequency dependence). The integrator had a 100 Ω input termination resistor and 50 Ω to ground on each side (total 50 Ω input impedance). The signal was from a Tektronix function generator or a BNC data pulser, coupled through an isolation transformer to prevent the integrator from ringing due to signal asymmetry. The gain graph was consistent across all tested RC times: 33 μs, 2 μs, and 500 ns.

Long Pulse Integrator
EHT has developed a long-pulse integrator that exceeds the ITER specification of 70 nVs/s. This also implies that if the ITER drift specification remains constant as pulse length increase the EHT integrator will be able to support long pulse operation over the one hour ITER requirement and has the possibility of being able to run continuously to ultimately support a fully continuously operating burning plasma reactor.

Long Pulse Integrator Signal Fidelity Testing
It is challenging to produce a signal that will not introduce a minimum DC offset into the integrator. To have an accurate drift measurement, it was necessary to develop a signal source that could produce a signal that, when integrated, would be guaranteed to return to zero or not provide a characteristic offset to the integrated signal.

The signal source is shown in the figure. When the LED drives the photodiode, current flows clockwise through the circuit, developing a voltage across the termination resistor R2, which is integrated. As current flows, C1 and C2 are charged. Once the LED turns off and there is no more photocurrent, the capacitors discharge through R1 and R2. Because the capacitors must start and end at the same voltage, the current through (and voltage across) R1 must integrate to zero. This produces a signal that goes up and then comes back down to zero for integrator testing.

This circuit was used to test the signal fidelity if the integrator re-zeroing transition occur while the input is non-zero or has a high dV/dt. The data shown here has been corrected so it returns to zero after 100 s. The end result is that there is no significant change to the integrator drift as a result of a non-zero input or high dV/dt signal.

Conclusion
EHT has successfully developed and commercialized a short-pulse integrator that can operate stability for several hundred seconds, which meets the needs of fusion science machines today. To date, EHT has deployed over 400 channels to laboratories around the country with support of this grant as well as commercial sales. This program has led to the development of a high-dynamic range integrator, which can improve bit-depth and vastly improve the measurement of small signals. To support the needs of future machines in the long-pulse and burning plasma era, EHT has developed a long-pulse integrator that exceeds the ITER specifications and has been tested on the fusion science experiments of today (DIII-D and HIT) in preparation for tomorrow.

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Further Information
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