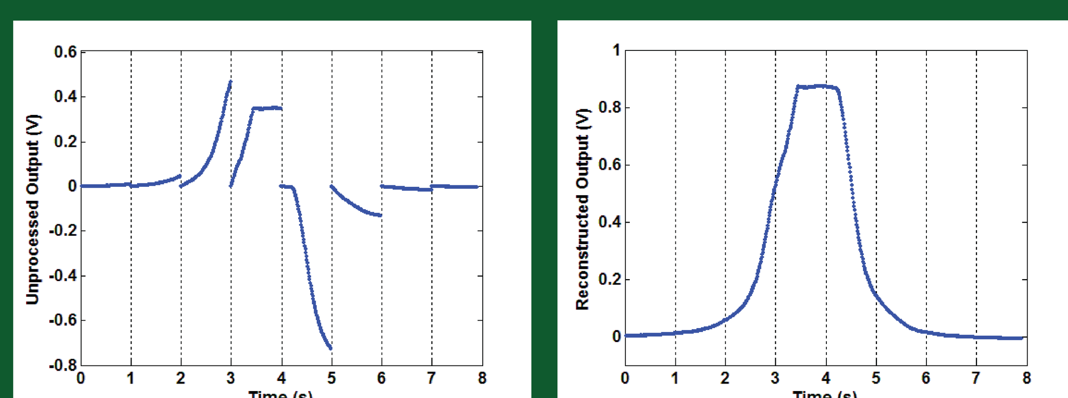
In-situ testing of the EHT high gain and frequency ultra-stable integrators

K. E. Miller; T. M. Ziemba; J. R. Prager; I. Slobodov; D. Lotz
kemiller@eagleharbortech.com
EAGLE HARBOR TECHNOLOGIES

Introduction:

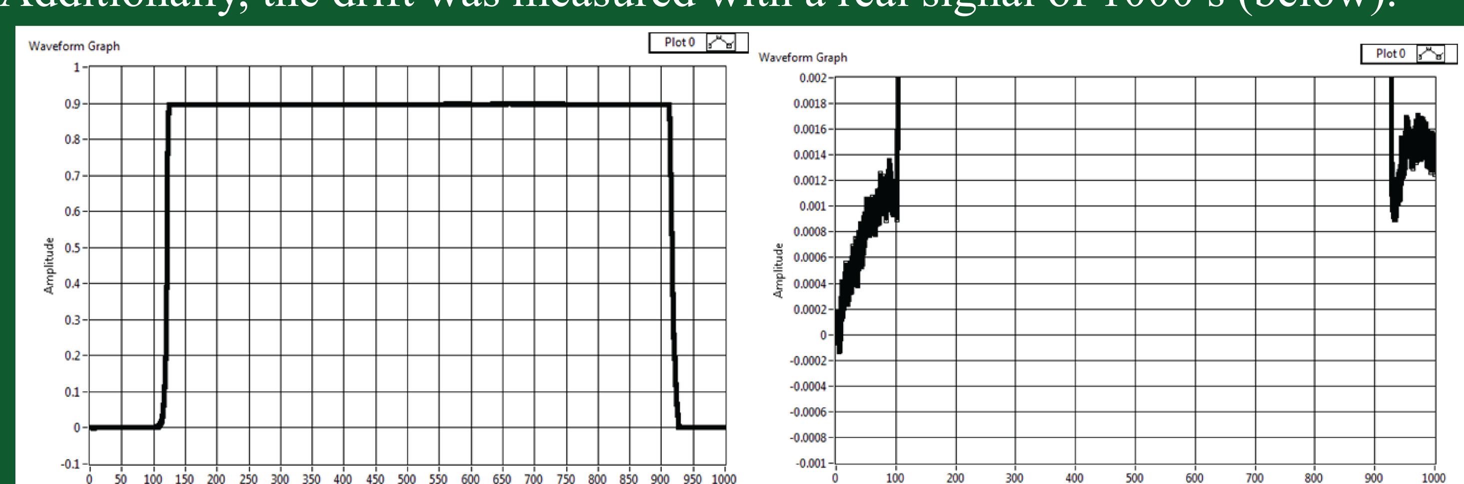
Eagle Harbor Technologies (EHT) has developed a short pulse integrator (up to 10 s) and a long pulse integrator (1000 s of seconds) for magnetic diagnostics. The long pulse integrator utilizes a digital circuit to quickly zero the integrator to maintain stability over long periods of time. The full signal can be reconstructed through post-processing or real time processing on an FPGA. In the past year, EHT has carefully characterized the integrator's performance including integrator drift (with inputs shorted and with signal), ground loop noise rejection, high frequency noise rejection, and common-mode noise rejection. The EHT integrator has been utilized by the HIT group in the HIT-SI3 experiment for magnetic field measurements. The integrator will be tested on magnetic diagnostics at DIII-D in Nov. - Dec. 2014.



Raw integrator signal (Left) and reconstructed signal (Right).

Integrator Testing (Bench):

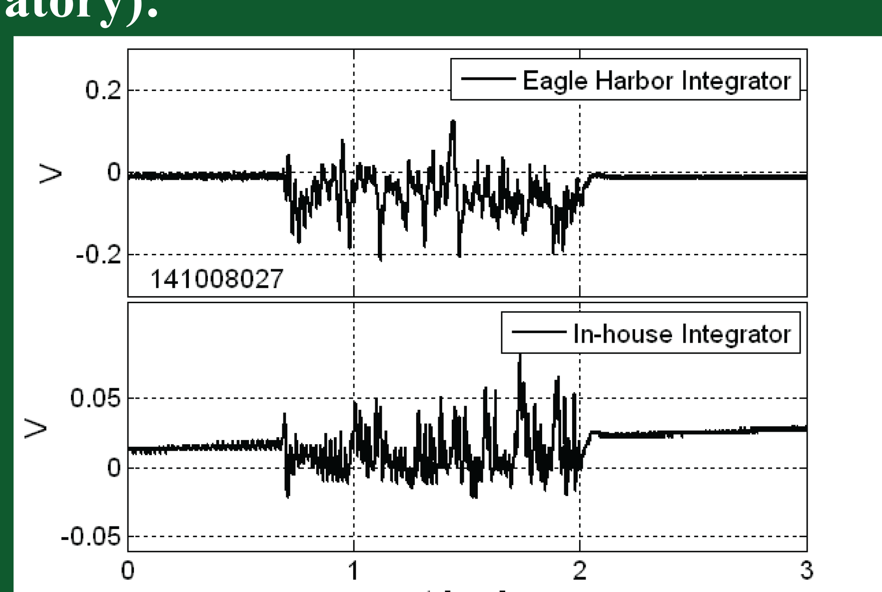
The long pulse integrator inputs were shorted. The integrator was operated for 3600 s. From several trials, the test measured a drift of 5.5 ± 2.2 mV. Additionally, the drift was measured with a real signal of 1000 s (below).



(Left) 1000 second real-time integrator test results with magnetic pickup loop. (Right) expanded scale showing approximately 1.5 mV drift error for the shot duration.

Integrator Testing (Laboratory):

The short pulse integrator has been tested at HIT-SI3 experiment (spheromak). Two magnetic pickup loops that are part of a chain probe were measured with the EHT and HIT integrator (figure). Here the low drift, low droop, and auto-zeroing can be seen in the upper figure. Additional testing will take place at DIII-D and HIT during the Phase IIB.



Comparison of EHT integrator (33 µs RC) and current HIT in-house integrator (100 µs RC).

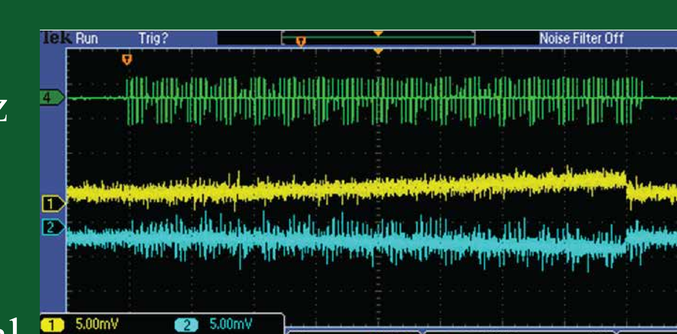
Ground Loop Noise Rejection:

Ground loops between the integrator and DAQ can produce crosstalk between the channels. Consider a signal (V_{sig}) into the DAQ along a BNC cable from the integrator. If the BNC cable is terminated with 50 Ω (R_T), then a current will flow and must return to the integrator through the ground shield of the BNC cable, which has real resistance (R). Half the current will flow back through the ground shield of second cable, and will produce an offset voltage V_{off} = ½IR. The optimal solution is to use a DAQ with differential inputs that do not tie to ground, avoiding the issue of currents returning through the ground of other channels.

Left: Circuit diagram showing induced currents generated by ground loops. Middle: Integrator channel perceived crosstalk error due to ground loop error. A 7 V signal on one channel (CH3) there is a 2 mV signal on a neighboring channel. Right: Lack of integrator channel perceived crosstalk error with differential probe termination.

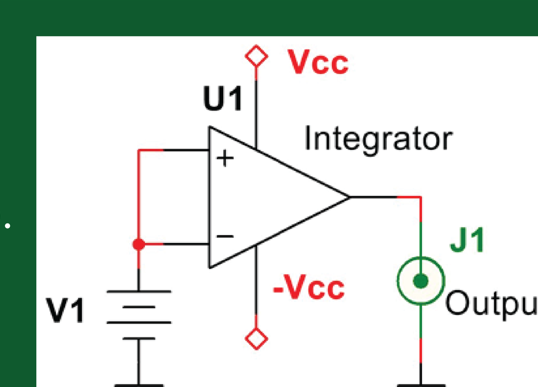
High Frequency Noise Rejection:

Testing used ±20 V (worst test case), 10 µs bursts of 1 MHz noise were repeated at 6 kHz for 20,000 iterations. The noise burst (shown on CH4) was applied to two channels of the short pulse integrator (CH1 & CH2). With shorted inputs over this timescale, the nominal integrator drift at this gain is less than 5 mV.


Differential probe measurement of integrator channel crosstalk error.

Common-Mode Noise Rejection:

For magnetic pickup loops located within the ITER reactor vessel, radiation induced common-mode current is a potentially significant issue (0.1 to 1 µA). Other experiment may also have the potential for generating common mode noise. ITER is expecting radiation-induced common-mode current on the pickup coils in the range of 0.1 to 1 µA, which is substantial and could affect the integrator drift error performance. The EHT integrator is inherently differential and should provide adequate common-mode noise rejection. To test the integrators for common mode noise, a DC voltage (1 V) was directly connected to both inputs of an integrator core. The output from J1 was less than 2 mV.

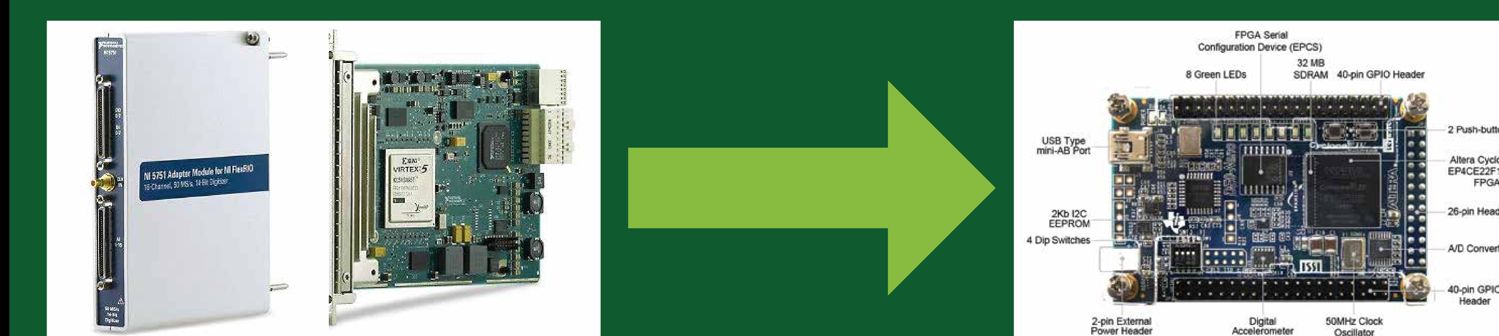


Left: Common-mode noise rejection test circuit diagram.

Phase IIB Objectives:

The goals to be accomplished during the Phase IIB program:

1. Lower the overall cost of the integrator/DAQ system to a level consistent with hardware budgets for small-scale validation experiments.
2. Develop software and communications packages for EHT integrator.
3. Validate the new EHT integrator on several plasma physics experiments.


Left: National Instruments PXIe digitizer and FPGA used for real time processing of integrator data. Right: During the Phase IIB, the digitizer and FPGA will be included on the EHT integrator PCB, which will significantly reduce the cost per channel.

Summary

EHT has developed a short pulse integrator, relevant for validation platform experiments and many tokamaks, and a long pulse integrator, relevant for burning plasma experiments like ITER. The long pulse integrator can be used in short pulse applications to improve the bit depth of the DAQ used to digitize the integrator signal. The characteristics of each integrator are summarized in the table below.

	Short Pulse	Long Pulse
Number of channels	16	8
Bandwidth	5 MHz	5 MHz
Drift error	< 10^{-7} V-s for 1 s	< 5×10^{-5} V-s for 3600 s
Gain (RC time constant)	1 µs to 100 ms	1 µs to 100 ms
Input impedance	50 Ω to 100 kΩ	50 Ω to 100 kΩ
Low output impedance	50 Ω	50 Ω
Stable operating time	10 s	---------
Input connectors	RJ45	RJ45
Output connectors	BNC, RJ45, VHDCI	BNC, RJ45, VHDCI

Left: Front (Upper) and back (Lower) panels of the EHT integrator short pulse. Right: Comparison of EHT long pulse integrator to previously published integrators and ITER specifications for drift error and run time.

Acknowledgments:

This work was supported by the U.S. Department of Energy (DE-SC000628). EHT would like to thank the HIT group at the University of Washington for in-situ testing of the EHT integrator on the HIT-SI experiment.

Further Information:

For more information on the EHT integrator or power supplies power supplies please visit our website (http://www.eagleharbortech.com) or email me.