Triple Langmuir Probe Circuit Response to Dynamic Loading

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Abstract

Recently, an array of Langmuir probes was installed in the divertor region of the National Spherical Tokomak eXperiment (NSTX) and has been successfully tested [1]. The array is backed by a custom designed electronics system that allows biasing the probes, collecting the signals, reducing noise and amplifying circuitry and is suited to operate both as a single Langmuir probe and as a triple Langmuir probe (TLP). While the probe data has been useful in understanding the plasma characteristics during steady plasma discharges in NSTX, certain modifications aid interpretation of the transient events (~ms scale) such as during Edge Localized Modes (ELMs). During high-flux transients, the bias circuit may drift from the nominal values before on-board control circuitry can respond. The details of the circuit, its response to dynamic loading and the resulting impact on signal interpretation is presented.

[1] M.A. Jaworski, J. Kallman, R. Kaita, H. Kugel, B. LeBlanc, R. Marsala, and D.N. Ruzic, "Biasing, acquisition and interpretation of a dense Langmuir probe array in NSTX," 18th Topical Conference on High Temperature Plasma Diagnsotics, 2010.

Problem Statement

- Understanding of the plasma edge and the control of edge conditions depend on measurements of local plasma parameters.
- The High Density Langmuir Probe (HDLP) array provides measurements of plasma parameters in the divertor region.
- While the temporal resolution of the triple probe offers the possibility to obtain time-resolved measurements during ELMs, the data analysis during ELMs is still troublesome. This is due to the effect of large transient currents on the bias voltage of the power supply.
- Although the power supply is regulated, sometimes, it might take few milliseconds for the power supply to recover the applied bias voltage. This makes the measurements unreliable.

High Density Langmuir Probe (HDLP) Array

• 99 Probe (3 x 33) array
• Signal acquisition for only 40 analog channels (limited by available resources)
• Each TLP biased by an individual circuit board which contains a regulated, isolating DC power supply

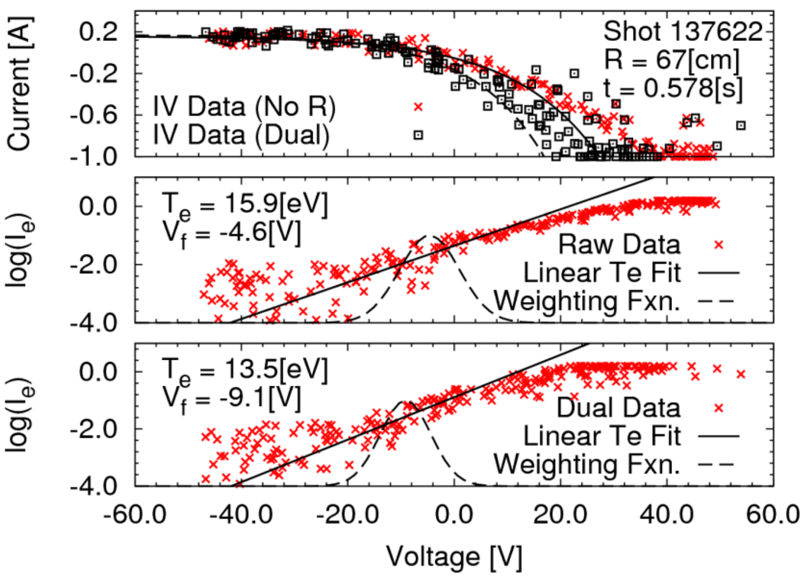
•Several key measurements including local n_e and T_e at outer divertor target.
•Probes can be run in various modes: triple, single swept,I_{sat}, floating
•Spatial resolution is 2.5 mm radially, and 7.5 mm toroidally
•DAQ and electronics allow for 500 K-samples/sec/channel simultaneously
•Additional probes to monitor scrape-off-layer currents directly
•Strike point could be determined from floating potential measurements and target plasma profiles

Approach

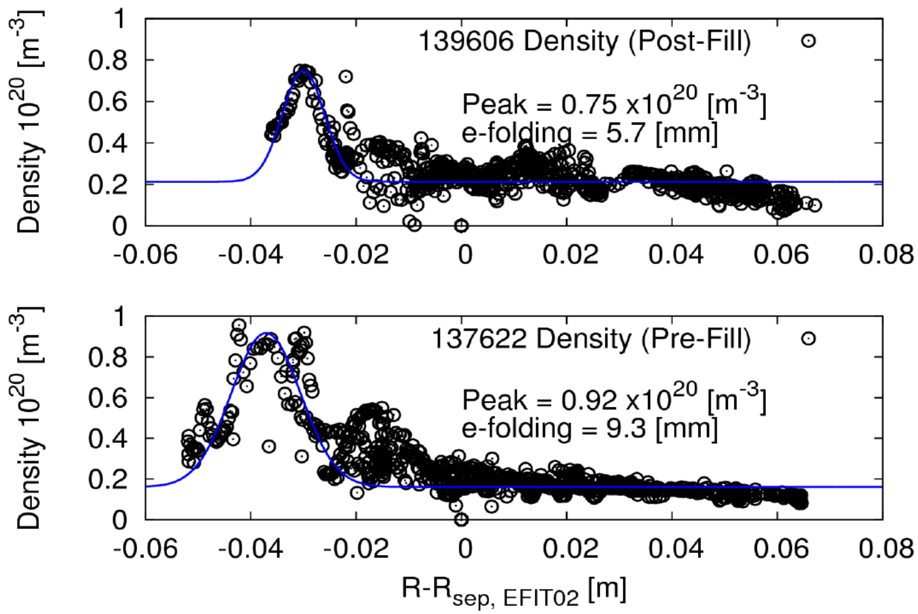
- Determine the behavior of the power supply during ELM like events on one TLP probe by modifying the circuit.
- Use Fourier Analysis to determine the Transfer Function of the power supply using the measurements obtained from the modified circuit.
- Use the obtained transfer function to determine the voltages on other probes based on their input currents
- Currently, we filter the data to ignore the data analysis during transients. However, the above mentioned approach may be useful in estimating the plasma parameters even in these complex cases.

Typical results from HDLP array

- Viewgraphs for HDLP array



Sample Probe data for NSTX Shot#137622.



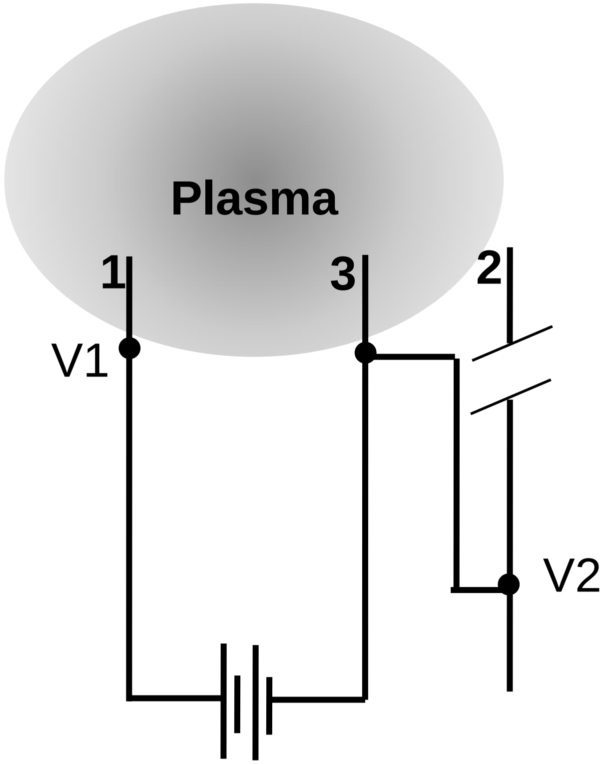
Variation of number density profiles for lithium post-fill and pre-fill conditions [Courtesy: M. Jaworski].

BP9.00042 : J. Kallman et. al. “Characterization of Effect of LLD on Edge Plasma Parameters using High-Density Langmuir Probe Array”

BP9.0052: M. A. Jaworski et. al. “Overview of NSTX divertor and plasma-material interactions diagnosis and modeling”

Circuit Modification to measure dynamic loading

- In order to obtain the plasma properties during ELMs, one needs to understand how the bias voltage is affected.
- The circuit is modified in such a way that instead of measuring floating potential on probe 2, V3 is measured as V2
- The difference in V1 and V2 gives the bias voltage, which is altered during an ELM like event



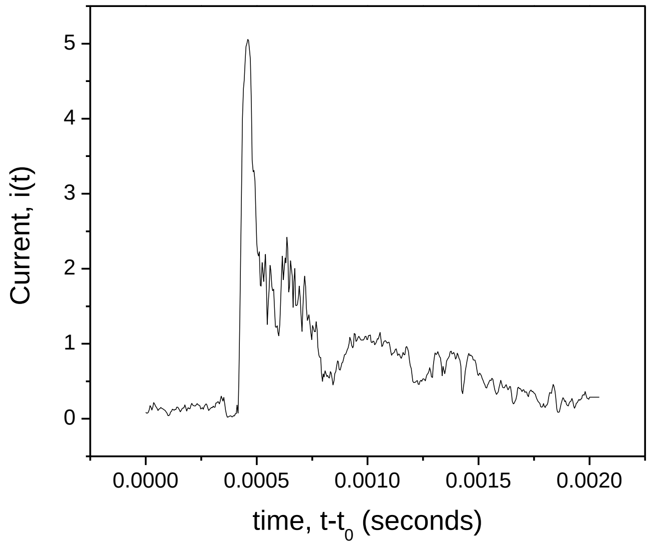
V3 is measured via V2

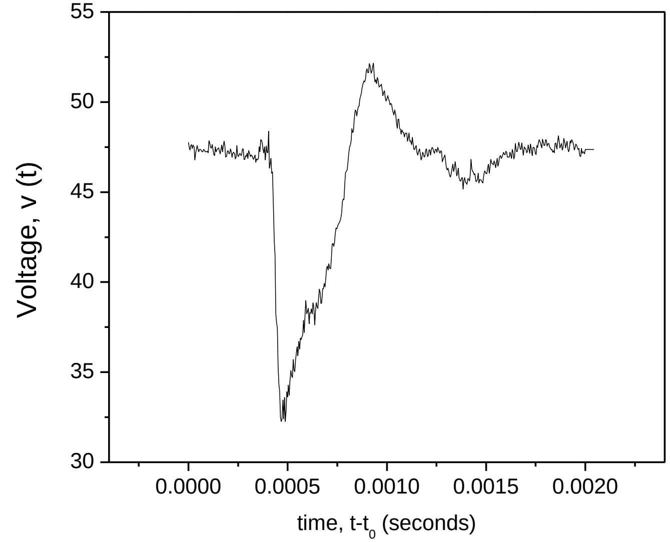
U_{bias} = V1- V2

- While the circuit modification provides a way to monitor the U_{bias}, it is not feasible to spend a digitizer channel for each TLP. The goal of the current work is to model this behavior and use that model for analyzing all the probes.

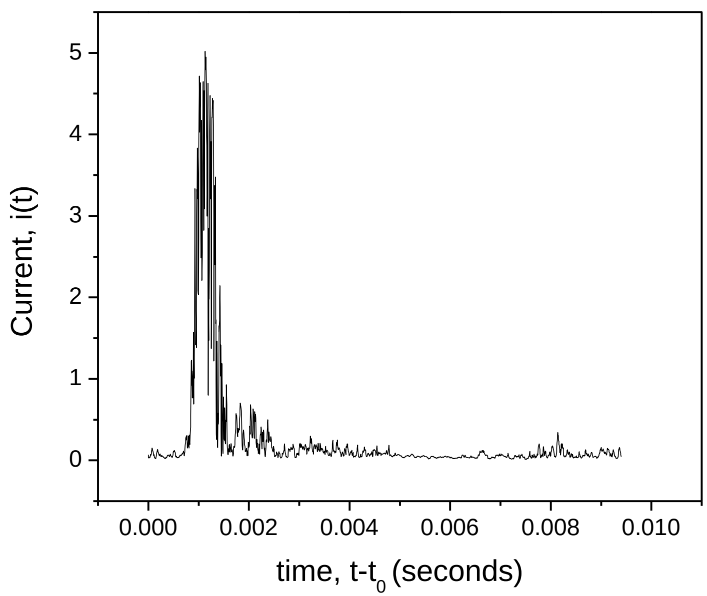
Response of Circuit due to ELM like event

- Shot #142255

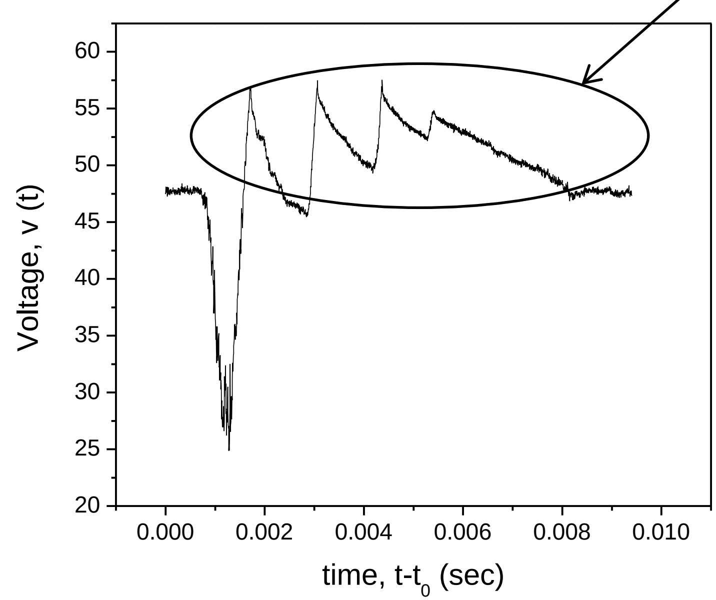




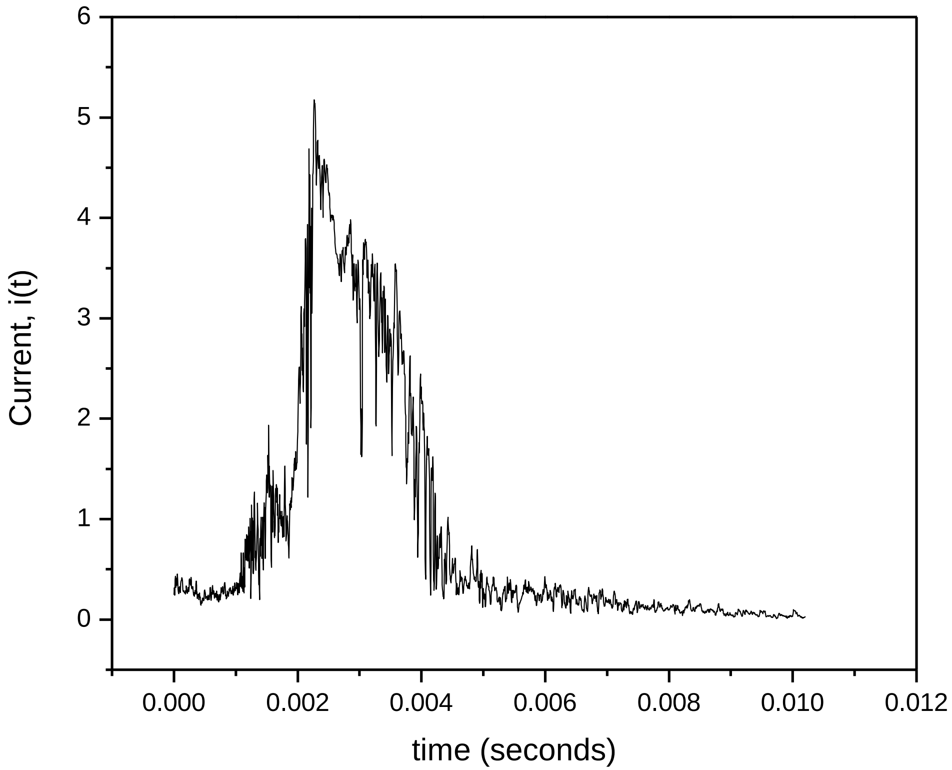
- Shot #142256

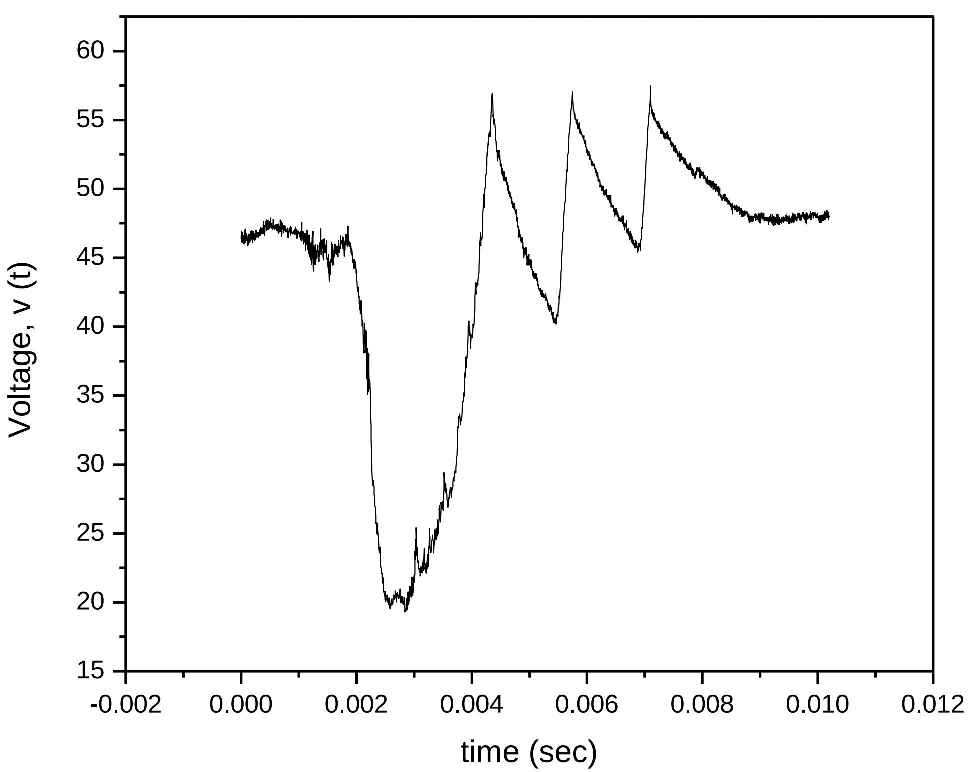


Non-linear circuit response



Does not have a Universal Transfer Function

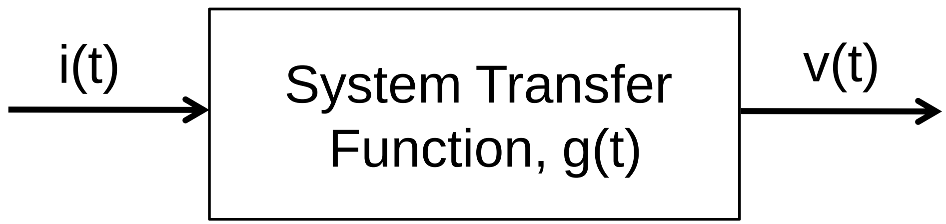




The response of the system strongly depends on the current waveform, i(t),(its amplitude, and duration) and so the transfer function strongly varies from shot to shot

Circuit Analysis

- Input- Current Signal, i(t)
- Output- Voltage response, v(t)
- Black box- Transfer function, g(t)

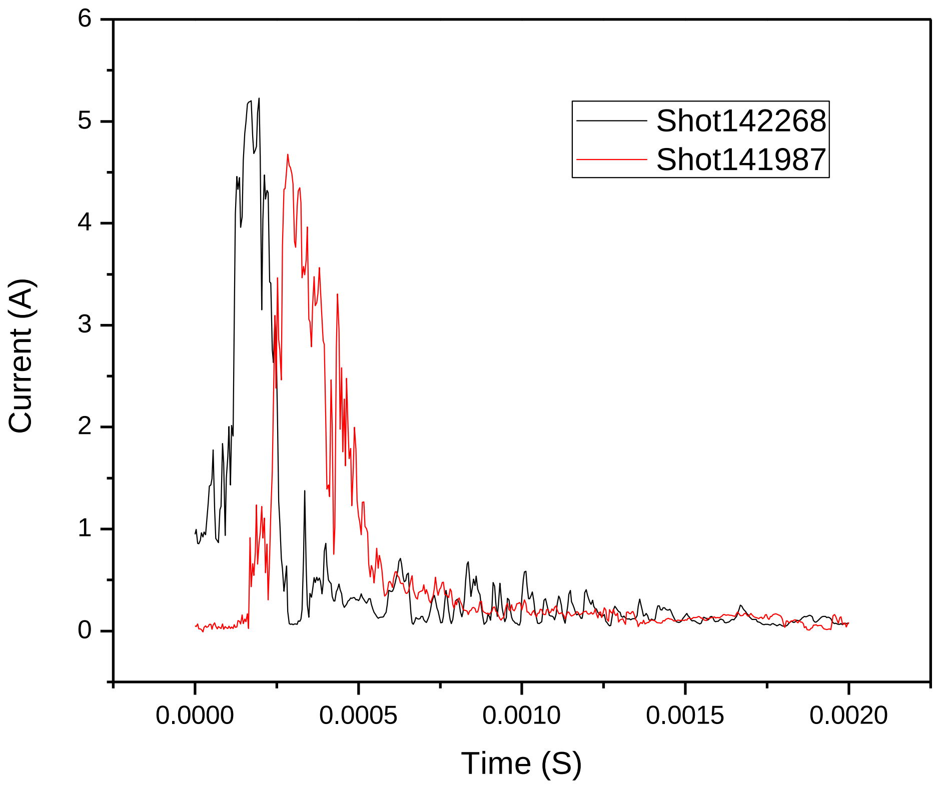


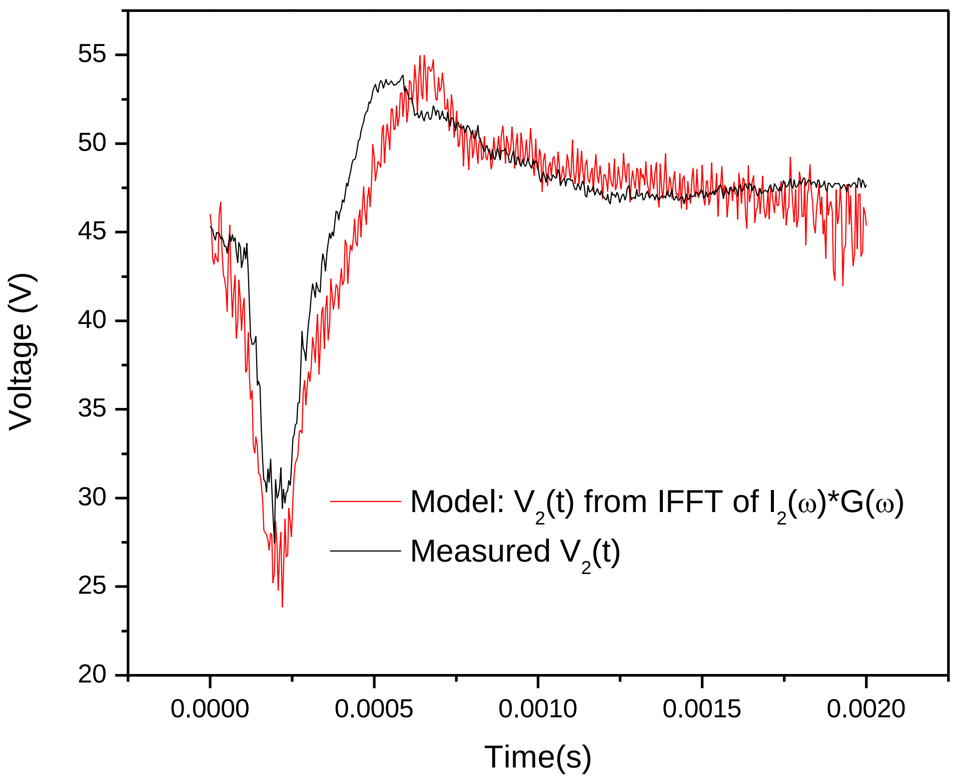
- Fourier Analysis

$$\Rightarrow \quad G(w) = \frac{V(\omega)}{I(\omega)}$$

Shots 142268 and 141987

- Determine transfer function, $G(\omega)$, of the system using shot 141987 data
- Under appropriate conditions, $V_1(\omega)/I_1(\omega) = G(\omega) = V_2(\omega)/I_2(\omega)$
- Use the obtained transfer function, $G(\omega)$, and the current signal of shot '142268' to predict the Voltage response
- Good agreement! This indicates that some pulses can have similar transfer function if their peak current value and FWHM of the current signal are similar





How to obtain plasma parameters

- Instead of measuring Voltage on all the TLP probes, one could use the transfer function determined from the modified circuit to determine U_{bias} and model the behavior that could be implemented on other probes.
- Let $i_n(t)$ be the current signal from probe 1 ($I_n(\omega)$ being the Fourier transform of $i_n(t)$), then $V_n(\omega)$ is obtained by using transfer function, $G(\omega)$ from modified board by the simple relation:

$$U_{bias}(\omega) = G(\omega) \cdot I_n(\omega)$$

where $n = 1,2...7$ represents each TLP measurement

$U_{bias}(t)$ can then be obtained from Inverse Fourier transform of $U_{bias}(\omega)$

$$U_{bias}(t) = \mathrm{IFFT}\,(U_{bias}(\omega))$$

Summary and Conclusions

- The circuit was modified to obtain the voltage response of the power supply during an ELM like or fast transient event
- The circuit response for dynamic loading was presented for few shots
- Fourier Analysis was used to determine the transfer function
- Under appropriate conditions, the transfer function of two independent shots was found to be similar
- For most cases, the transfer function was different for each shot. However, it might still be possible to obtain plasma parameters by using the transfer function obtained from the modified board and use it for other probes for the same shot.

Future Work

- Modify the probe circuit to prevent saturation of current signals acquired by the probes. This allows a comparison to be made for the analysis using the modeled transfer function described here.
- Modifications to the biasing power supply circuit externally to speed the transient response.
- Alternate approaches include adding an external capacitor to make the system more consistent (with the trade-off being the decrease in transient response time)
- IDL routine to automatically compute the plasma parameters during ELMs based on the modified circuit board