Modeling and Simulation of Photodiode Circuits for Beam Emission Spectroscopy

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OBJECTIVE

- **Identify the parasitic component properties with greatest impact on circuit noise and gain.**
- **Determine the impact of alternative circuit designs on gain and noise characteristics.**

BACKGROUND

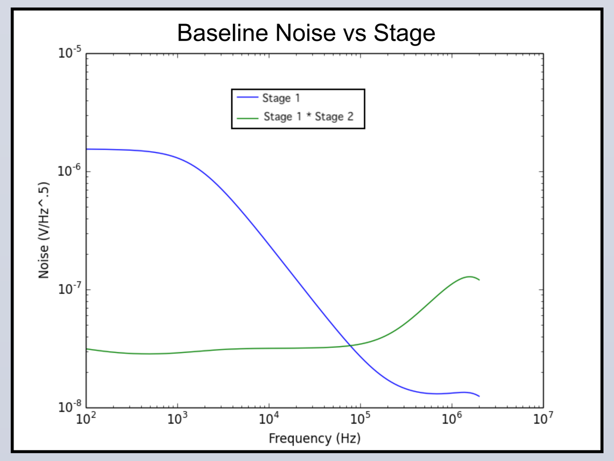
- Beam Emission Spectroscopy (BES) measures the emissions of collisionally-excited neutral beam particles. The emission is primarily sensitive to plasma density.
- The measurement is suitable for multi-point, spatially-localized observations of plasma turbulence and instabilities.
- W7-X requires a BES system similar to that installed on NSTX. This study's goal is to determine if certain changes to NSTX's system would have desirable effects.
- The changes studied include:
  - Replacing photodiode with a photodiode array
  - Eliminating the first amplifier stage's JFET
  - Altering the operating temperature
  - Replacing photodiode with new model photodiode
- Additionally, I studied which parasitic properties had the greatest impact on circuit performance.

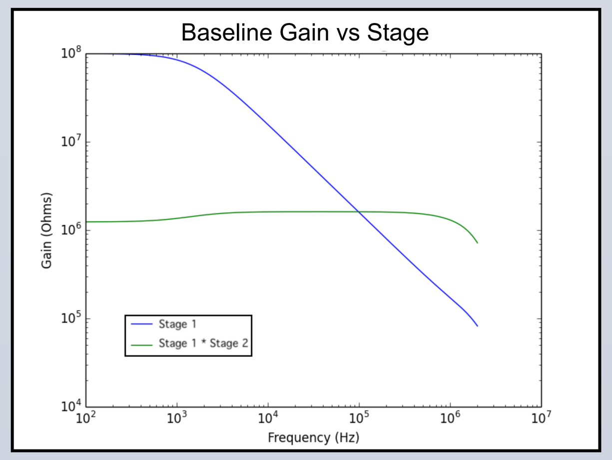
SIMULATION METHOD

- The simulations were performed using LTspice, which models Johnson, shot, and flicker noise.
- Photon noise was modeled using a Poisson distribution.
- I created a C++ command line tool to cross-compare data from multiple simulations.

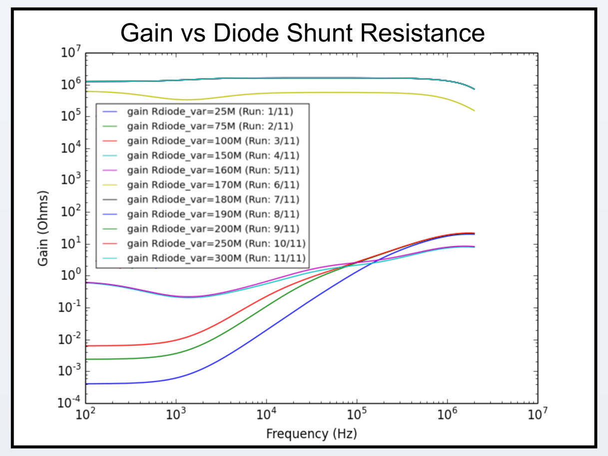
ORIGINAL CIRCUIT BEHAVIOR

- To establish a baseline, first the circuit was simulated by LTspice using a model for the circuit deployed on NSTX. The model accounted for shot noise, Johnson noise, and flicker noise.

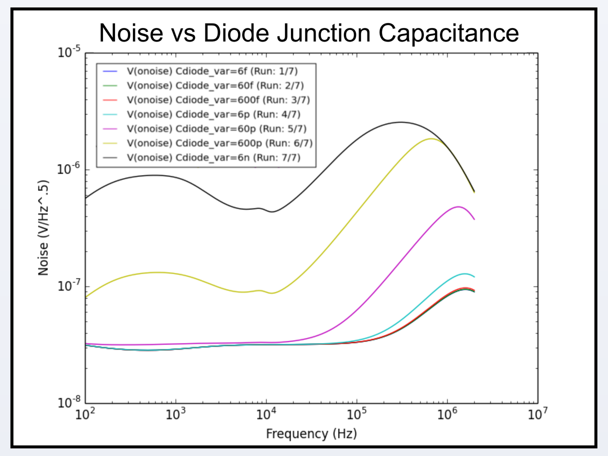




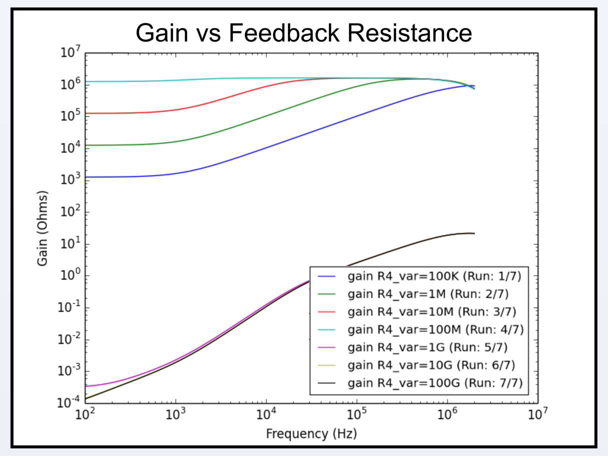
- An important feature of the original design is the flat frequency response.



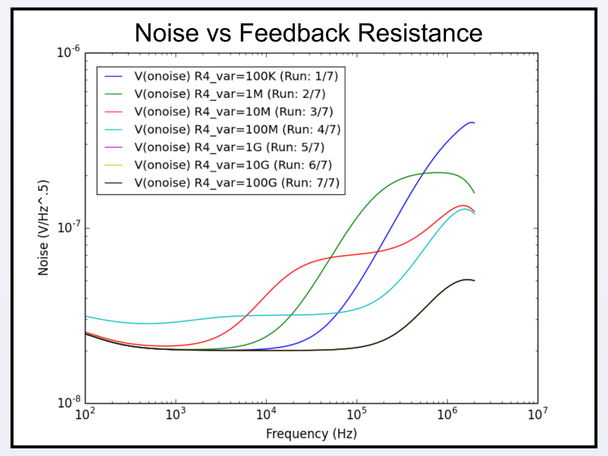
Gain drops off sharply between 160MΩ and 170MΩ.



Noise increases dramatically when the diode junction capacitance is greater than ~60pF.

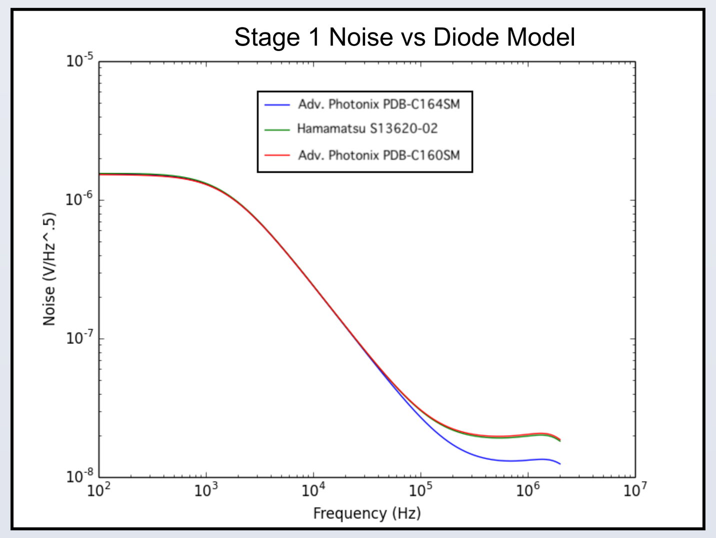


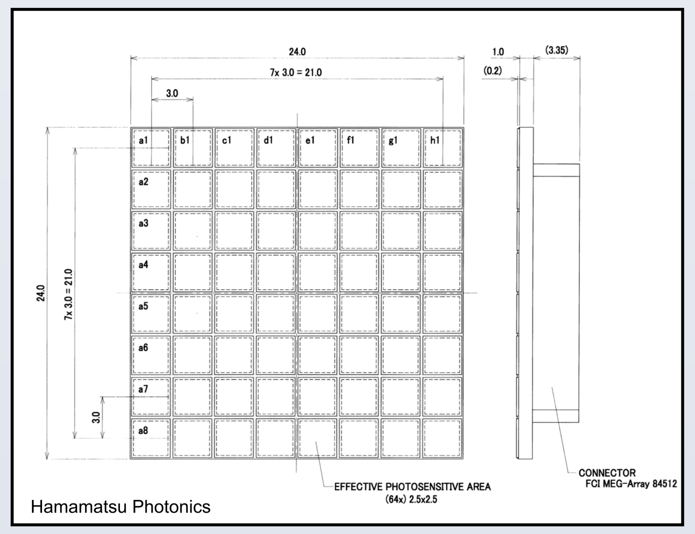
The expected behavior of higher gain with higher feedback resistances breaks down after a threshold where gain drops dramatically.



Noise is roughly proportional to gain, not feedback resistance.

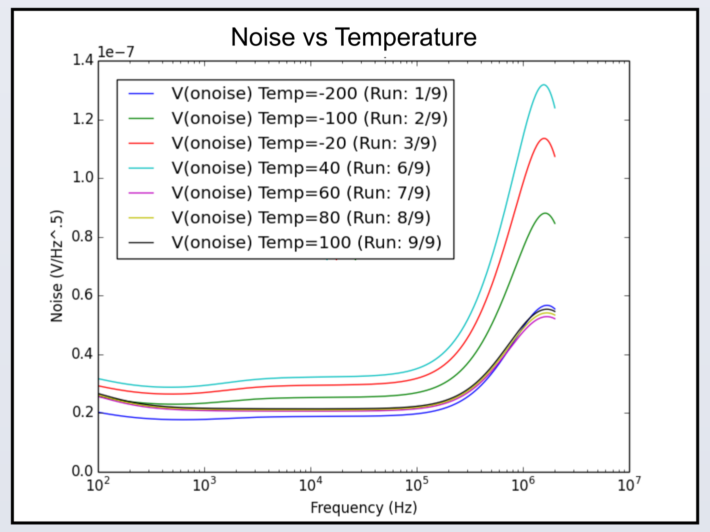
HAMAMATSU DIODE ARRAY





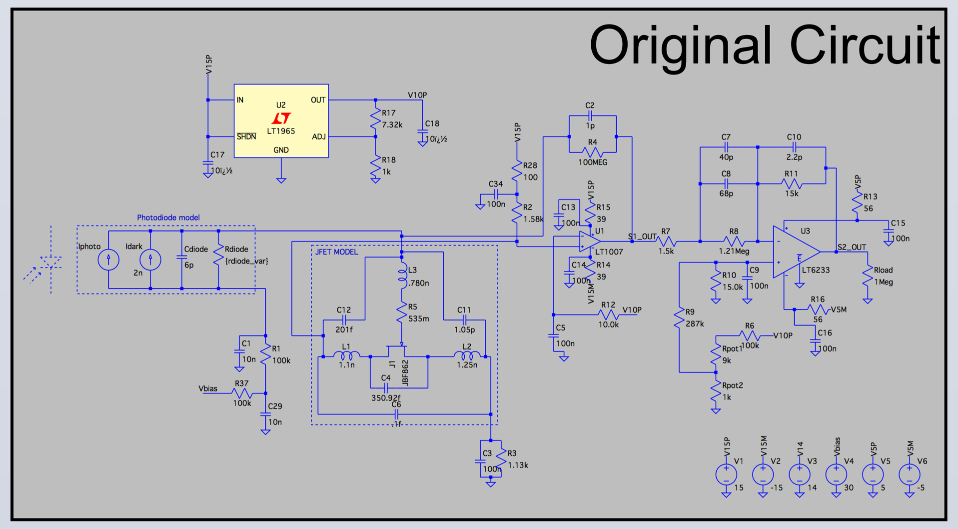
- Altering the circuit to use a photodiode array instead of individual photodiodes allows more detector circuits to fit on a single PCB.
- The primary differences between the Hamamatsu photodiode array and the original Adv. Photonix photodiode is a lower max bias voltage on the Hamamatsu diode and a higher junction capacitance at the max bias voltage.
- The gain was negligibly impacted by transitioning to the Hamamatsu photodiode.
- Noise increased, but only by a very small margin.

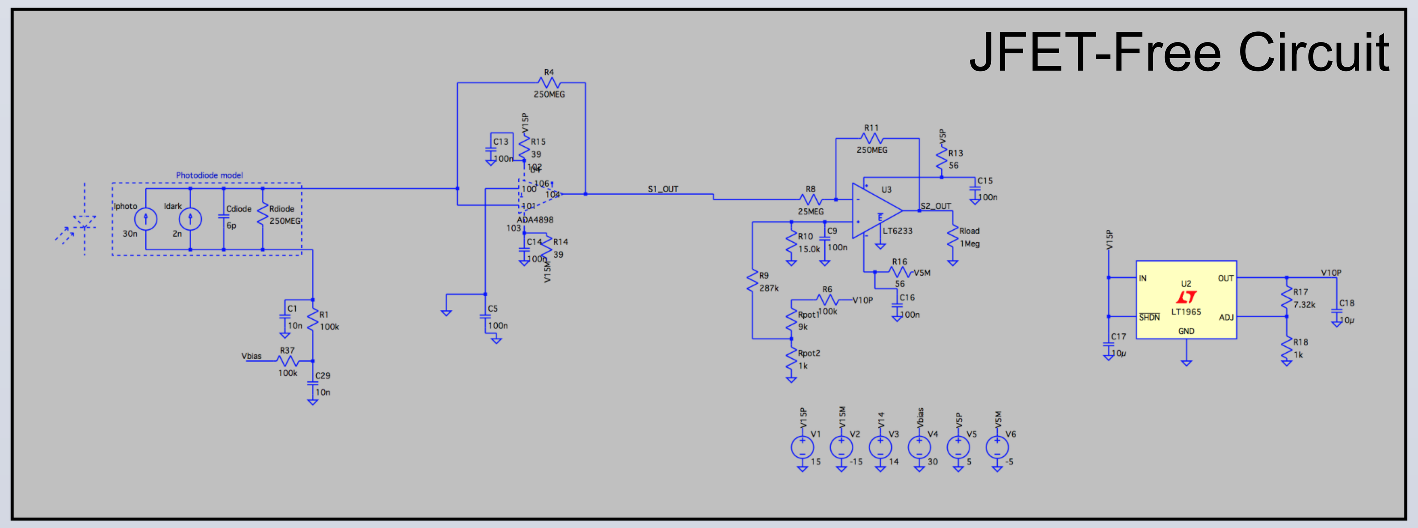
THERMAL EFFECTS

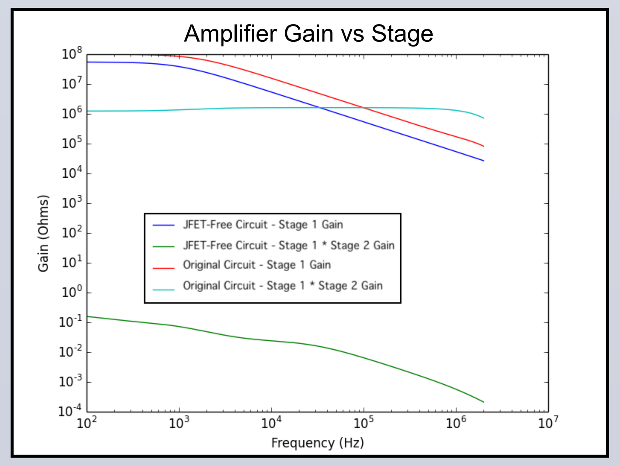


- The circuit's thermal dependence was analyzed by varying the global temperature from -200 C to 100 C and simulating the circuit with LTspice.
- Noise was seen to increase with rising temperatures, especially at high frequencies.
- Gain showed little temperature dependence.
- LTspice ignored important thermal effects such as the temperature dependence of the dark current.

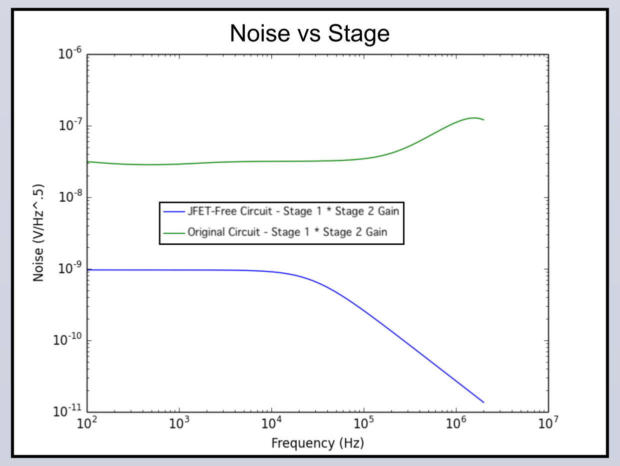
JFET-FREE CIRCUIT BEHAVIOR



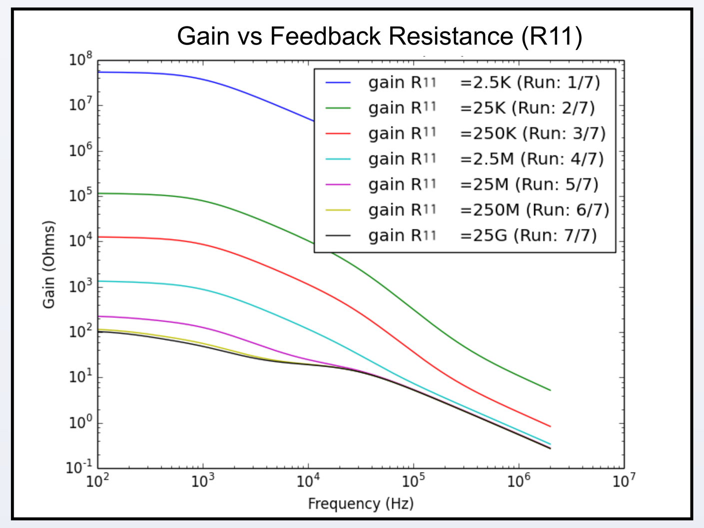




- First stage gain was higher than that of the unmodified circuit at low frequency, and lower at high frequency.
- LTspice shows below-unity gain in the second stage, making the circuit impractical.



- The noise performance was approximately the same for both the original and modified circuits' first stage amplifiers.



The JFET-free circuit's gain is reduced by increasing the feedback resistance.

CONCLUSIONS

- **Feedback resistance, diode shunt resistance, and junction capacitance strongly influence circuit gain & noise.**
- **Higher operating temperatures can increase circuit noise by more than a factor of 2, but has minimal impact on gain.**
- **Eliminating the JFET is feasible, but will require additional study.**
- **The Hamamatsu diode array's higher junction capacitance has minimal impact on circuit performance.**

ACKNOWLEDGEMENTS

- Dr. David Smith - U. Wisconsin Madison
- George McKee - U. Wisconsin Madison
- Matthew Kreite - U. Wisconsin Madison
- Lucas Morton - U. Wisconsin Madison
- U.S. Department of Energy
- Princeton Plasma Physics Laboratory - Summer Undergraduate Laboratory Internship (SULI)

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