Filtering Temperature Sensor Outputs for Power Dissipation Monitoring

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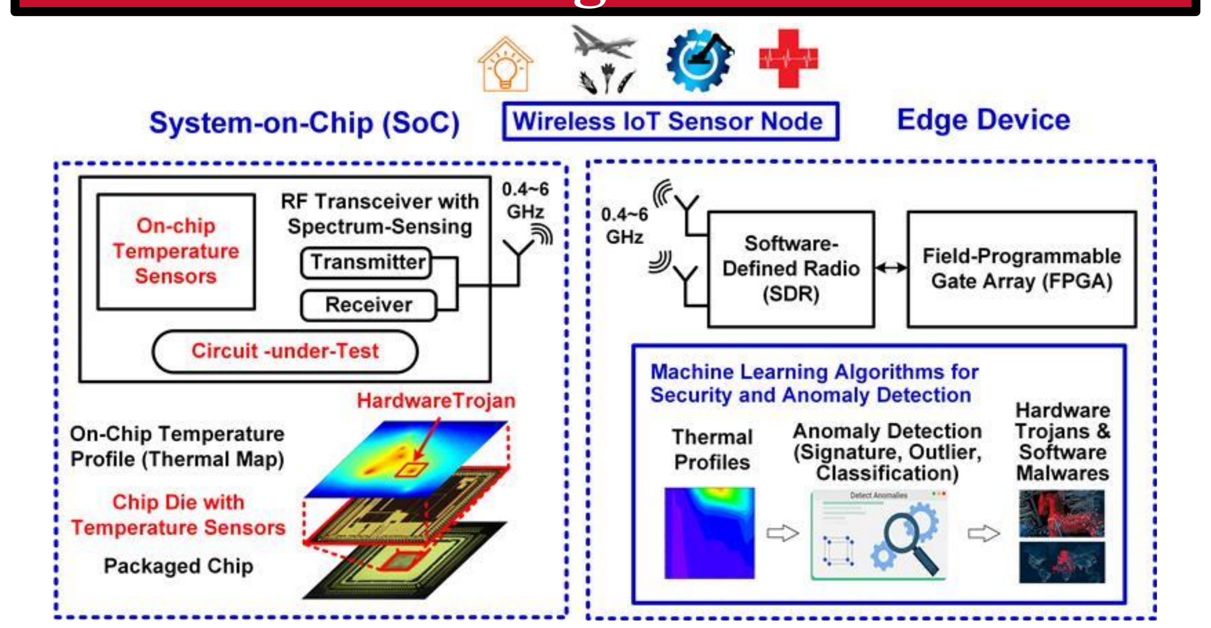
Abstract

With the development of the Internet of Things (IoT), Hardware Trojans (HT) pose threats to modern integrated circuits and electronic systems, compromising performance, causing system failure, or leaking sensitive information. Recently, a non-invasive anomaly identification approach and machine learning algorithm for HT detection using analog on-chip differential temperature sensors has been proposed. However, electronic noise can obscure the output signals from the temperature sensing front end, thus reducing the detection accuracy. In this project, we designed and experimentally validated an analog system that behaves as a low-pass filter to improve signal clarity. This system consists of an operational amplifier buffer, continuous time integrator with reset and inverting amplifier.

Background



Modern Internet of Things (IoT) systems are increasingly at risk from Hardware Trojans (HTs)—malicious changes to integrated circuits that can compromise functionality, leak data, or cause system failure. These threats are difficult to detect because they are small and often remain inactive under typical conditions. One of the proposed detection methods relies on analog temperature sensors and machine learning algorithms for anomaly detection, which is limited by the inherent electrical noise present.

This research investigates an analog integrator that functions as a low-pass filter to reduce noise before digitization. This would further enhance the detection capability for anomalous behavior. The integrator's simplicity, real-time performance, and compatibility with hardware systems make it a strong candidate for hardware security applications.

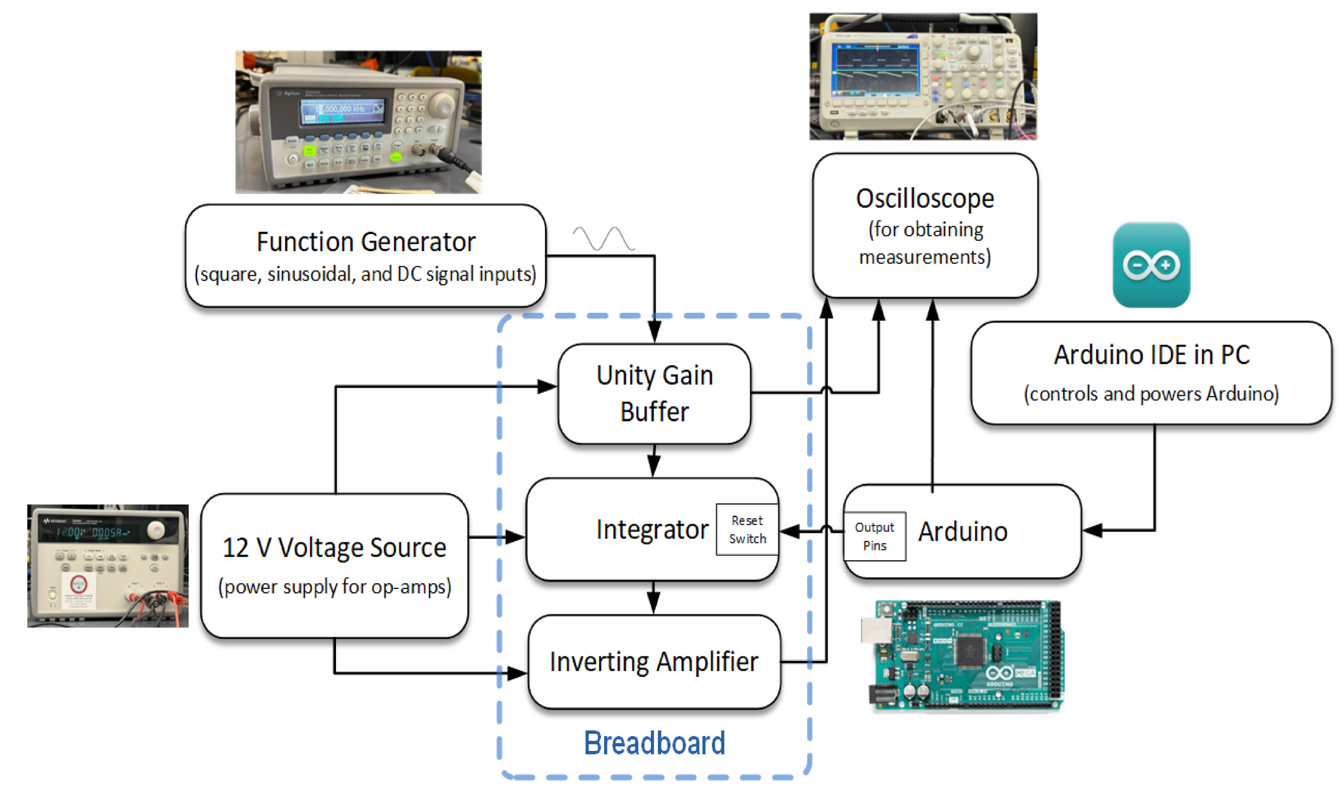
Experimental Methods

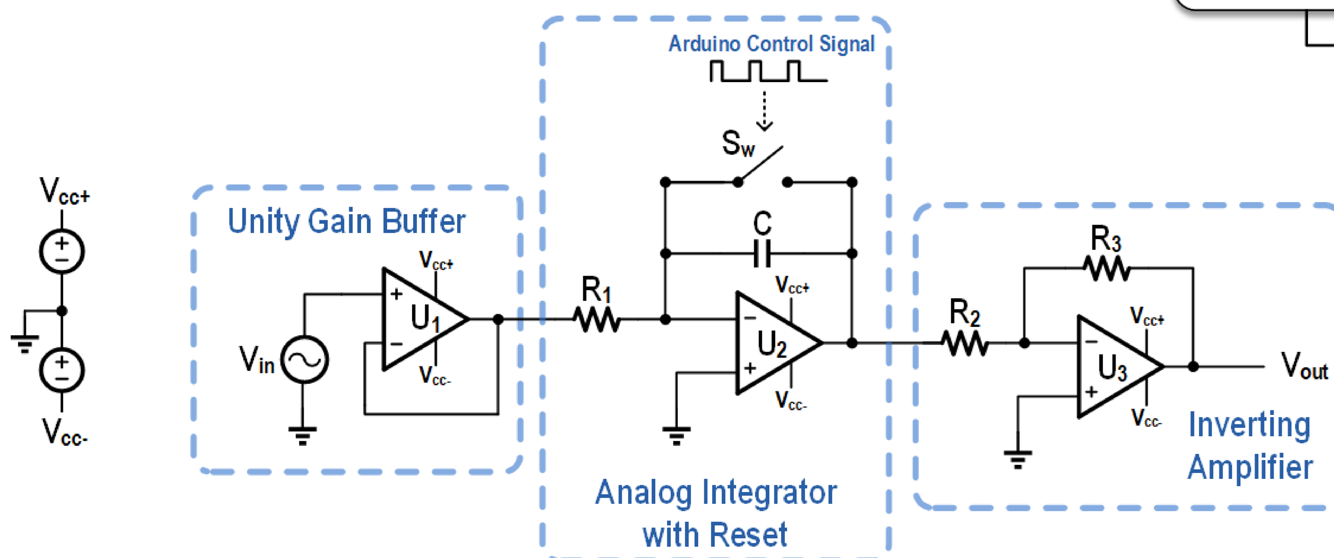
Software and Hardware used:

- Oscilloscope
- Analog Function Generator
- 12V DC Power Supply
- Multimeter
- Arduino Mega 2560 Rev3
- Arduino IDE
- LTspice
- LF411C Operational Amplifier,
- DG202B Quad CMOS Analog Switch

Activities:

We designed and built an analog integrator circuit to function as a low-pass filter. We simulated its behavior with input waveforms, then tested the real circuit using an oscilloscope to measure its output. The Arduino controlled signal switching and resets. Finally, we compared the measured results to theoretical calculations to confirm the circuit's filtering behavior.

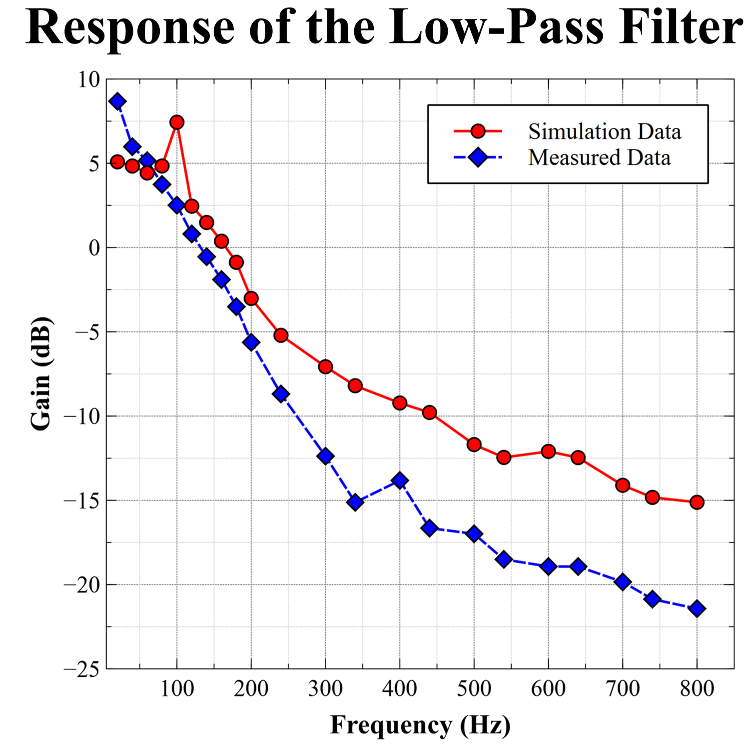


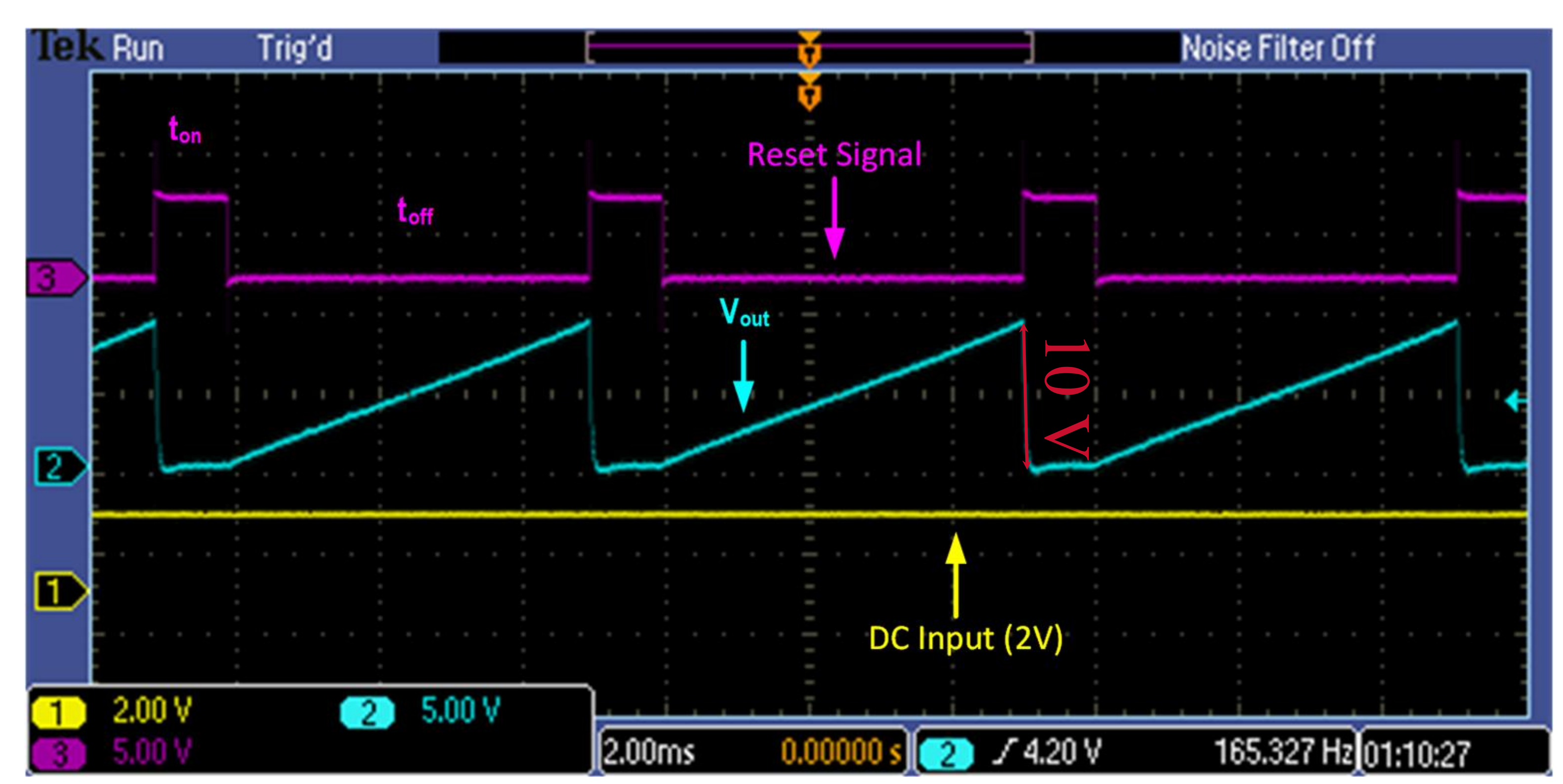


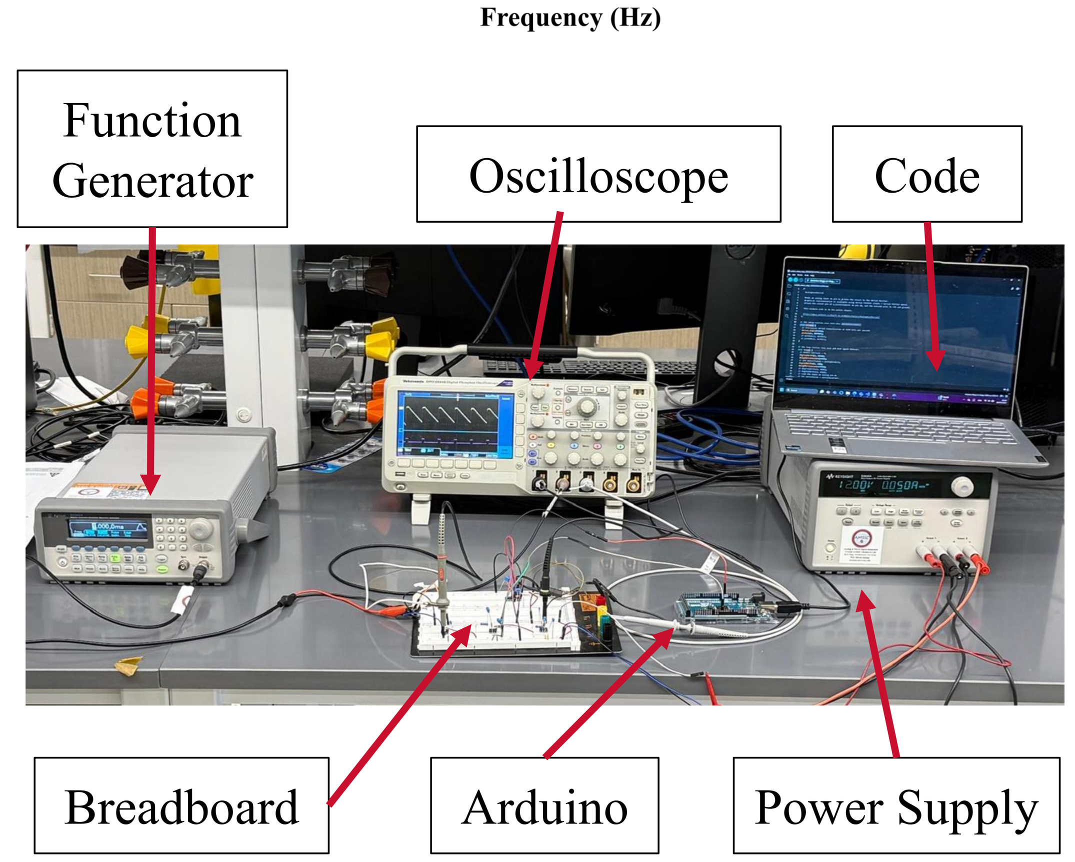
$$G_{total} = \prod_{i=1}^{3} G_i$$
$$= G_1 \times G_2 \times G_3$$
$$= 1 \times \left(-\frac{1}{RC}\int V_{in}dt\right) \times (-1)$$
$$= \frac{1}{RC}\int V_{in}dt$$

Results

Simulated vs. Measured Frequency Response of the Low-Pass Filter

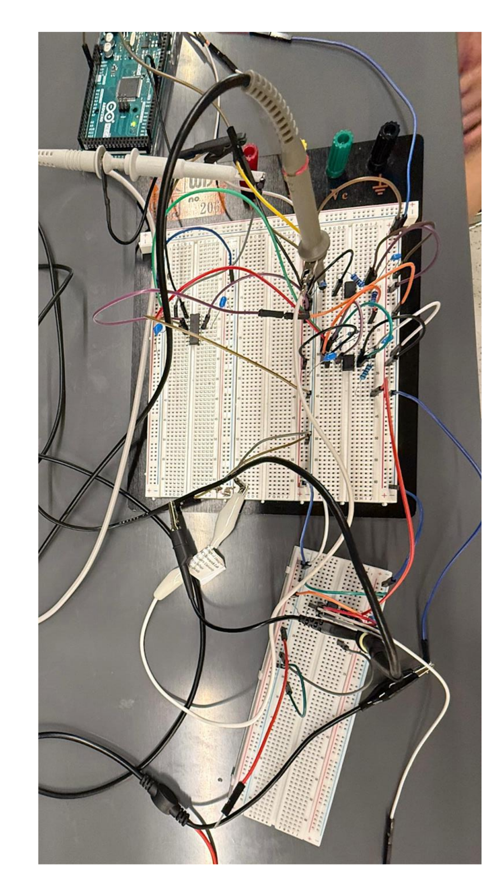






Low-Pass Filter:

- Our filter successfully filters out higher frequency signals
- The measured frequency response corresponds nicely with the simulated response
- Helps reveal subtle variations in the signals caused by HTs
- Provides smoother output with less noise, improving signal clarity before digital analysis



Conclusion and Future Steps

The measurement results demonstrate that the designed analog signal processing circuit behaves as an integrator and as a low-pass filter. These are validated from transient measurements. These outcomes are aligned with our original objective: to design, build, and test an analog circuit capable of integrating the output signal and filtering out noise. The broader implication is that analog techniques like this can enhance signal clarity and improve anomaly detection accuracy in hardware security applications. Moving forward, the next steps include evaluating the circuit's performance with temperature sensor data under various operating circumstances.

References

Gourousis, T., Zhang, Z., Yan, M., Zhang, M., Mittal, A., Shrivastava, A., Restuccia, F., Fei, Y., & Onabajo, M. (2023). Identification of Stealthy Hardware Trojans through On-Chip Temperature Sensing and an Autoencoder-Based Machine Learning Algorithm. *2022 IEEE 65th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 30–34. https://doi.org/10.1109/mwscas57524.2023.10405958

Mittal, A., Zhang, M., Gourousis, T., Zhang, Z., Fei, Y., Onabajo, M., Restuccia, F., & Shrivastava, A. (2024). Sub-6-GHz Energy-Detection-Based Fast On-Chip Analog Spectrum Sensing With Learning-Driven Signal Classification. *IEEE Internet of Things Journal*, *11*(14), 25033–25046. https://doi.org/10.1109/jiot.2024.3392428

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