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SEMICONDUCTOR PARTICLE DETECTOR BASED ON WORK FUNCTION MODULATION

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SESSION G10: DETECTORS, SENSORS, AND TRANSDUCERS

CREATING THE NEXT®

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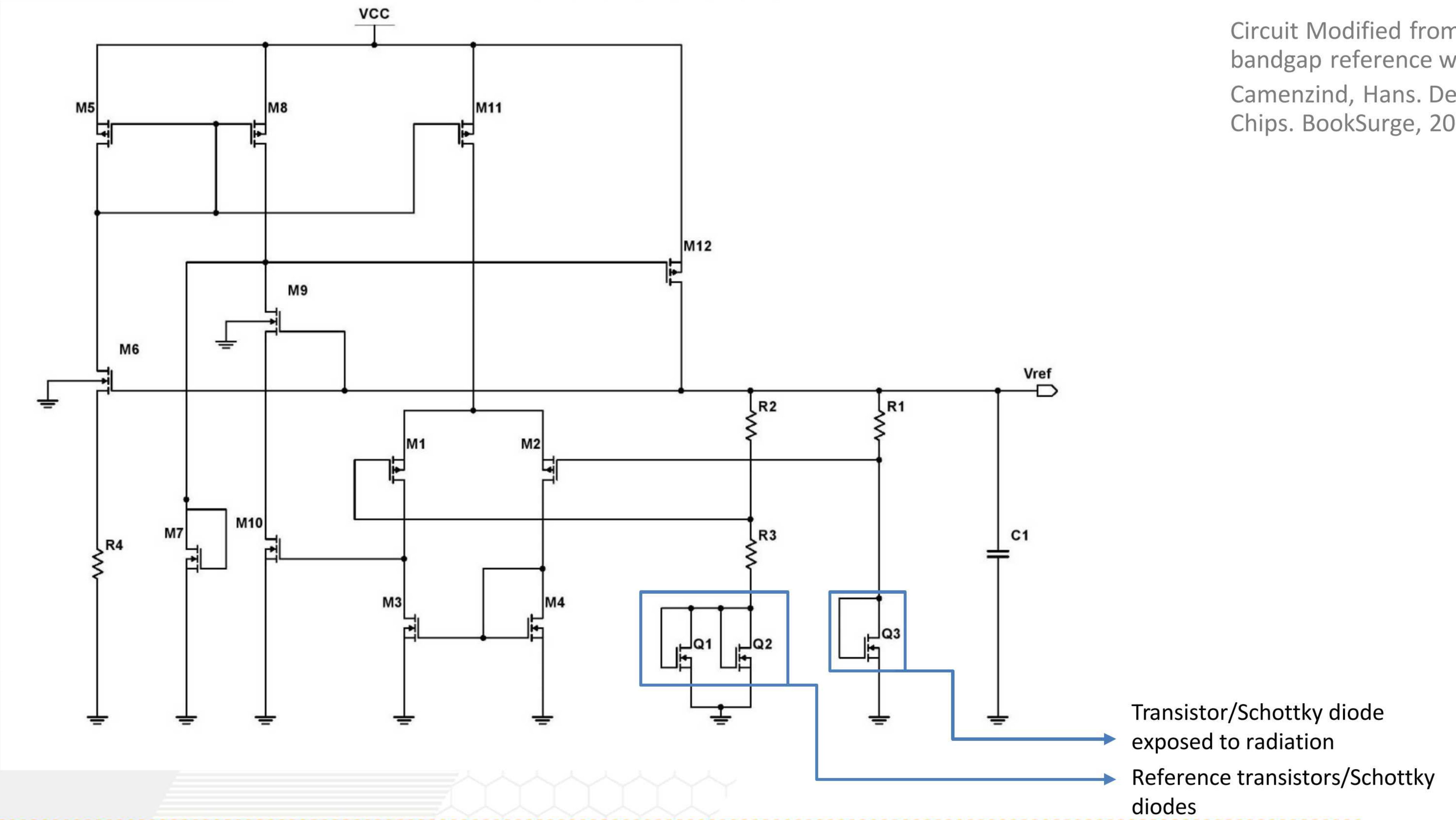
Project Objectives

- Energy transfer to crystal lattice generates primary knock-on atoms which create electron-hole pairs – record current to determine particle energy
  - Standard method of detection for solid-state particle detectors
- Utilize transient signatures in a solid-state detector to generate a new mechanism of particle detection
- Novel approach: record fluctuations in Schottky barrier height of a gallium nitride (GaN) Schottky diode to identify particle events
  - Circuit design: bandgap reference circuit that outputs Schottky barrier height
- Hypothesize that the signature of the fluctuations will be different for different types of particles
  - Focus on neutron detection, with comparison to alpha particles

Bandgap Reference (BGR) Circuit

- Goal of bandgap reference circuit: analog circuit whose voltage output equals that of the bandgap of the semiconductor being used
- Output of typical semiconductor devices is heavily temperature-dependent
- BGR circuit produces a constant output voltage independent of temperature variations, supply variations, and loading
- Bandgap reference adds components to cancel the effects of temperature, both PTAT and CTAT
  - PTAT – proportional to absolute temperature
  - CTAT – complimentary to absolute temperature
- Our bandgap reference circuit design provides an output voltage equal to the Schottky barrier height of a GaN Schottky diode, which is a stable baseline for observing output fluctuations due to particle events
  - Temperature independence important to lend confidence that fluctuations observed are *not* due to temperature variations

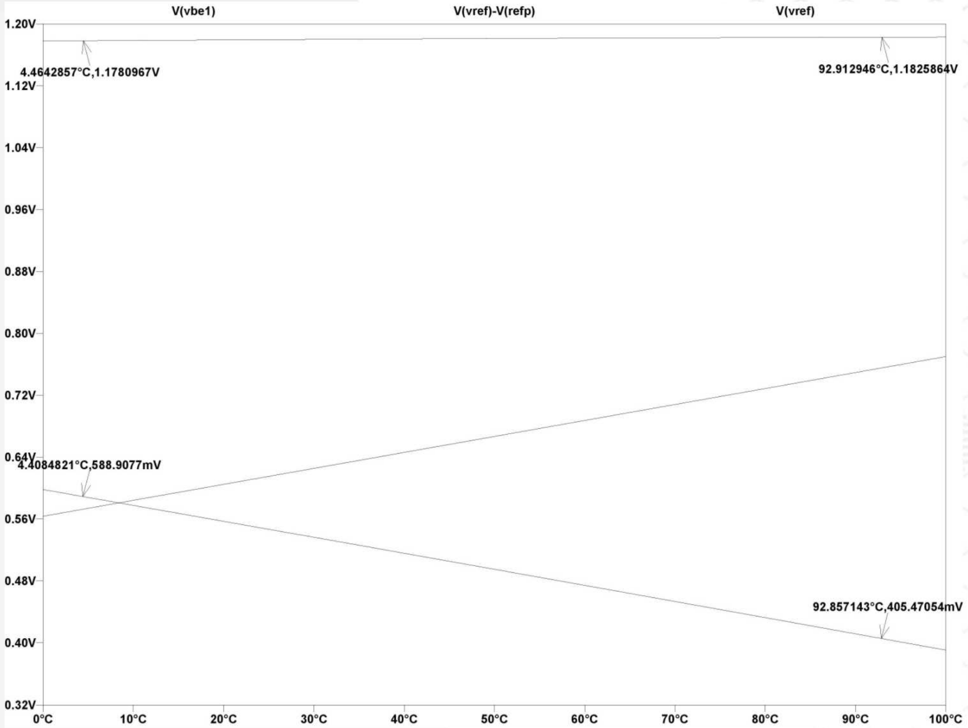
Bandgap Reference Circuit

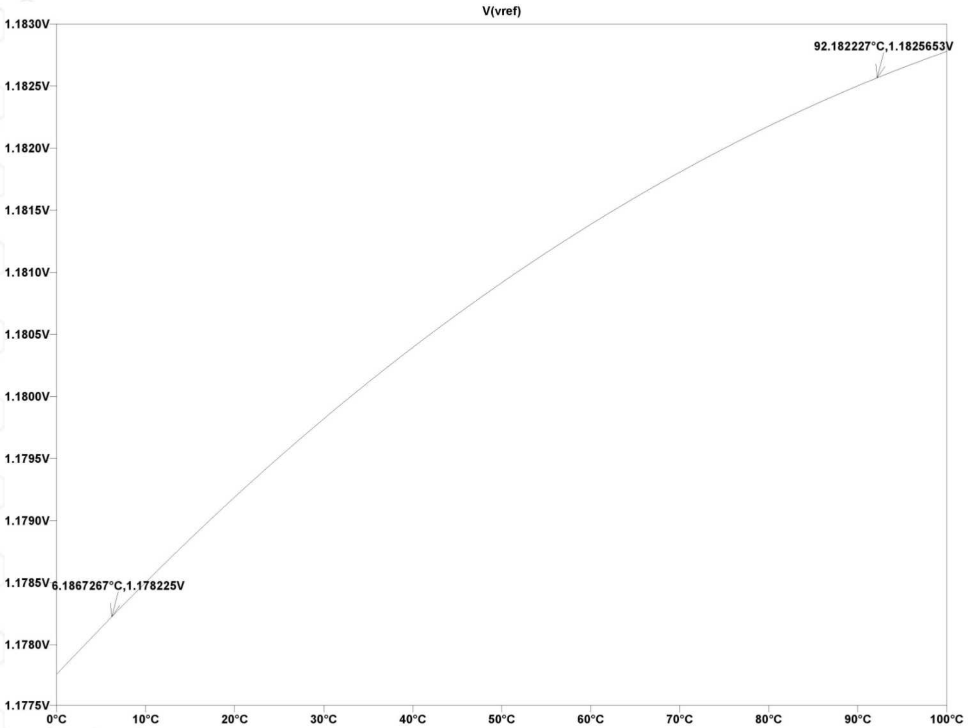


Circuit Modified from Fig 7-22, CMOS bandgap reference with substrate diodes

Camenzind, Hans. Designing Analog Chips. BookSurge, 2005.

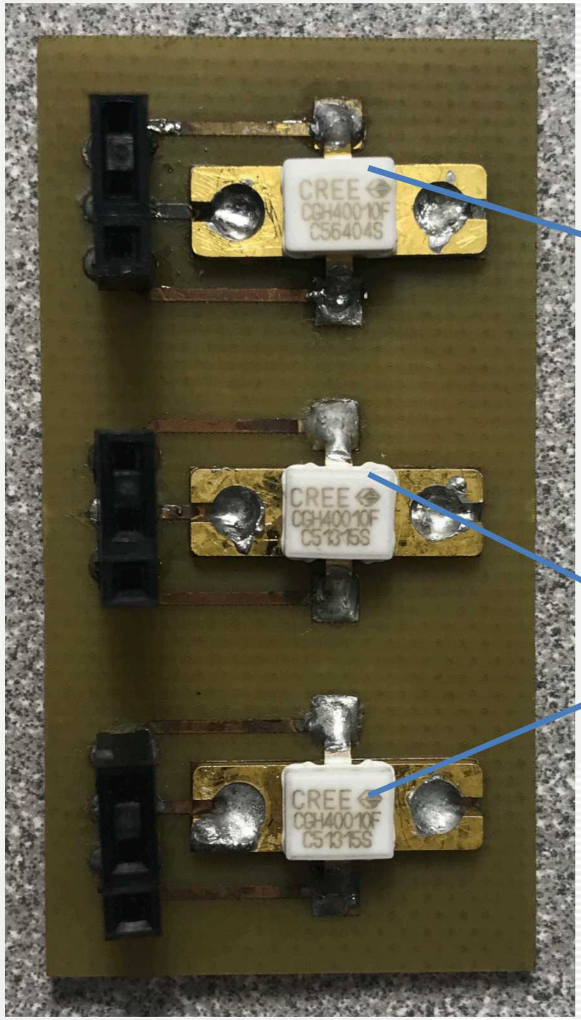
Temperature Response





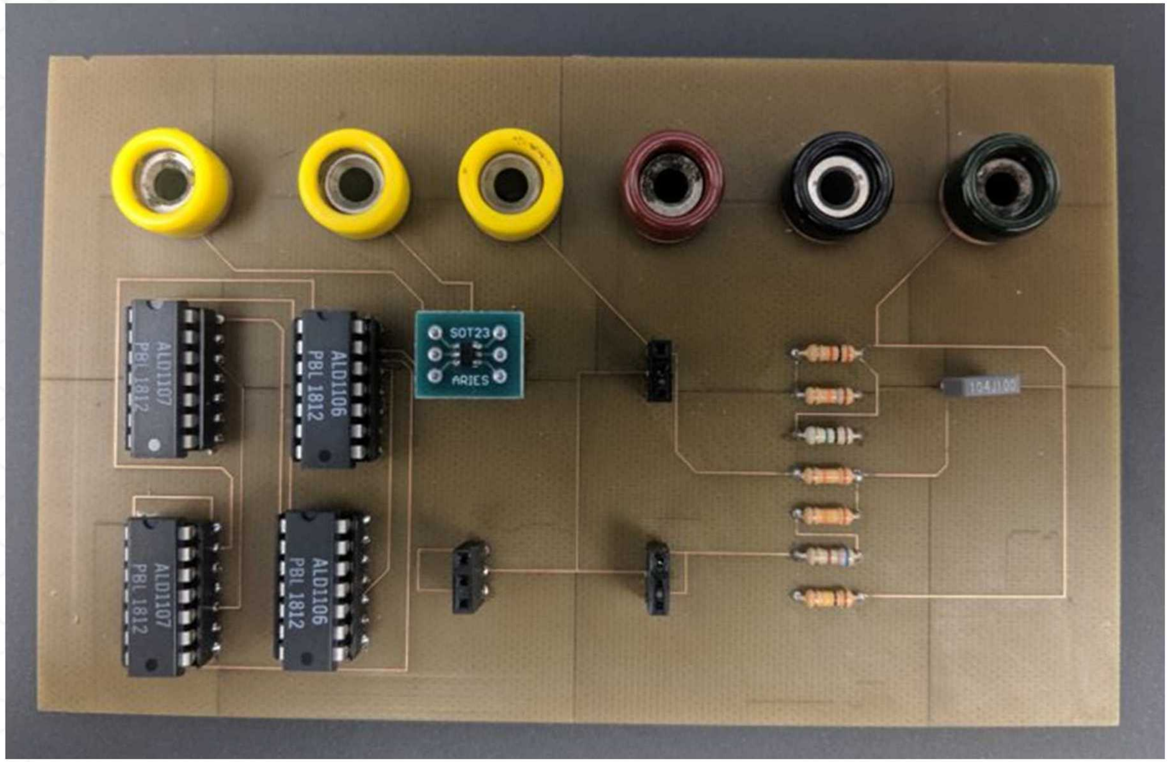
- Typical temperature dependence of a transistor -2 mV/°C
  - Our simulation: slope of Vgs is -2.07 mV/°C
- Typical slope of reference voltage is variation of 1.8% across 0°C to 100°C
  - Our simulation: slope of reference voltage is 50.76 µV/°C (0.365% change)

Bandgap Reference PCB



Transistor/Schottky diode exposed to radiation (corresponds to Q3 on schematic)

Reference transistors/Schottky diodes (corresponds to Q1 and Q2 on schematic)



PCB manufactured at Georgia Tech Interdisciplinary Design Commons

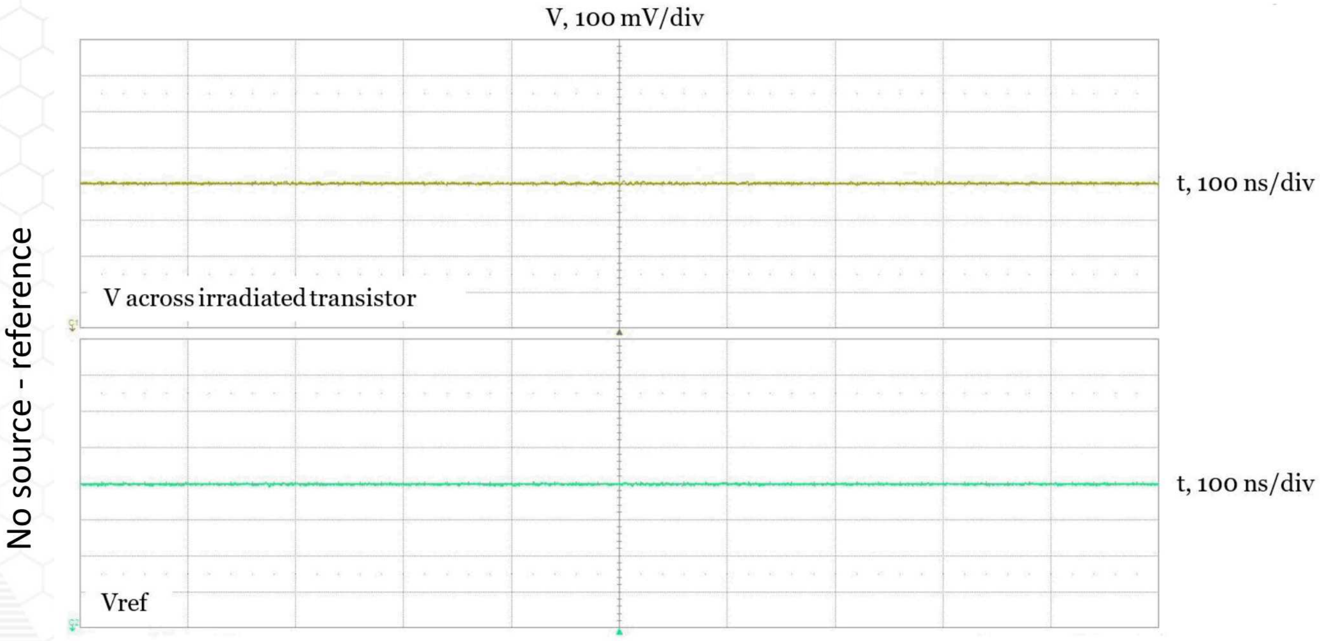
Circuit Irradiation Testing

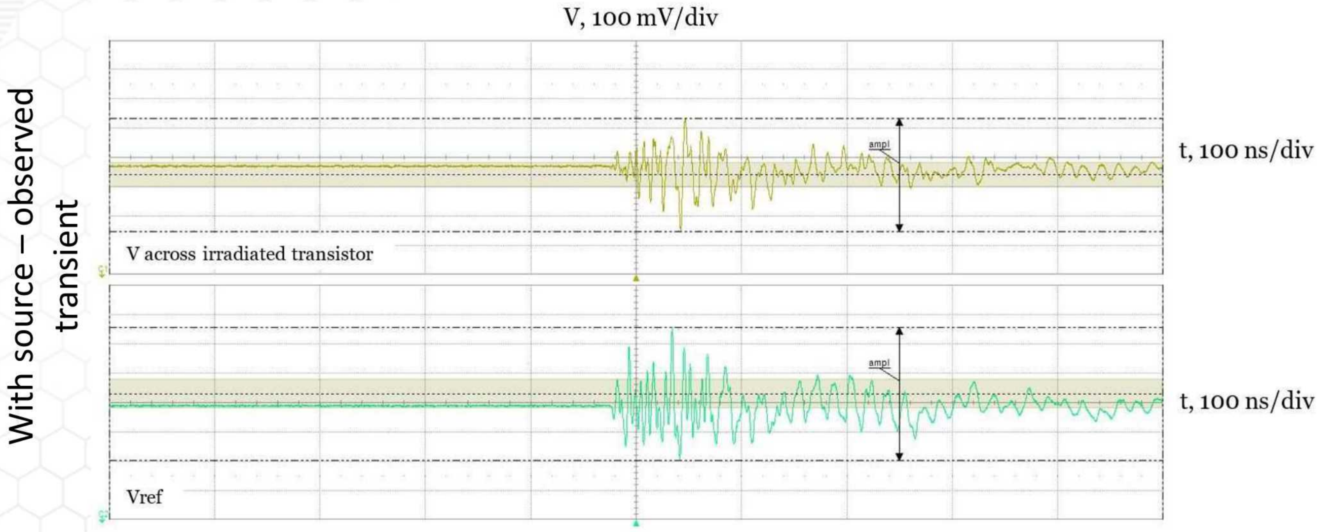
- Equipment
  - LeCroy Wave Runner 620Zi oscilloscope
    - 2 GHz max bandwidth, 20 Gs/s sample rate
    - Voltage resolution: 100 mV/div
    - Time resolution: 100 ns/div
  - Protek 3003B DC power supply set to +5V
  - PCB circuit board and transistor adapter

- Experimental details
  - Data collection was not continuous
  - Reference transistors were on the same board as the testing transistor – possible confounds in transient measurement, reference transistors may have been irradiated/source of signal
  - Operational amplifier not functioning correctly so was disconnected/not used

Neutron Source

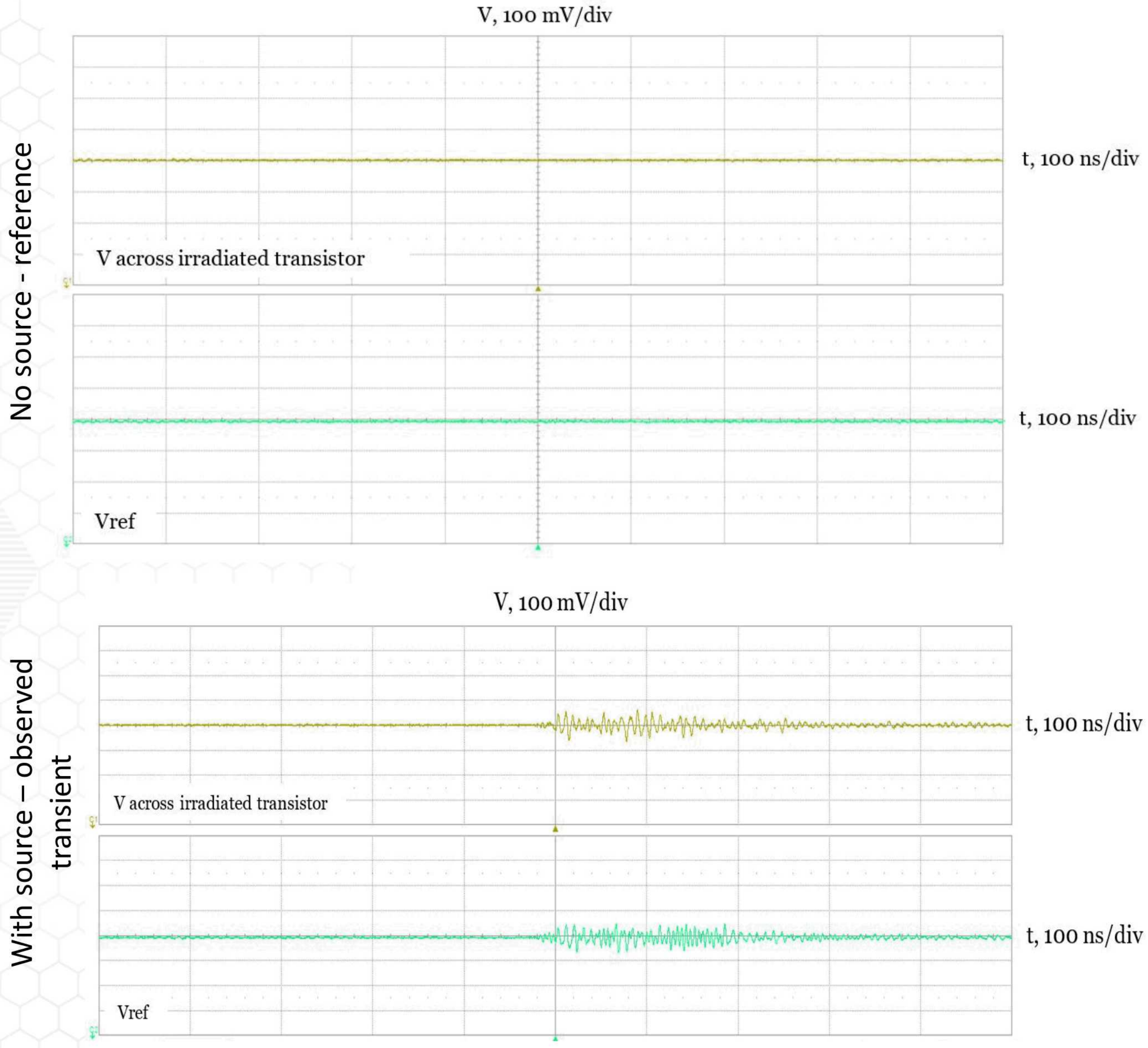
- Source: AmLi
- Approximately 1 decay per 17.3 ns interacting with the irradiated transistor at 1cm
- Time between potential events means transients could contain up to 12 neutron-device interactions
- Amplitude of transients
  - Average: 250 mV
  - Minimum observed: 100 mV
  - Maximum observed: 400 mV
- Decay time
  - Shortest decay observed: 350 ns
  - Longest decay observed: 500+ ns (limitation of scope)





Alpha Source

- Source: Am-241
- Approximately decay per 31.3 ms interacting with the irradiated transistor at 1cm
- Time between potential events leads to confidence of single-particle detection
- Amplitude of transients
  - Average: 150 mV
  - Minimum observed: 100 mV
  - Maximum observed: 400 mV
- Decay time
  - Shortest decay observed: 200 ns
  - Longest decay observed: 500+ ns (limitation of scope)



Conclusions

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- Designed a bandgap reference circuit that uses GaN semiconductor devices as a detector for neutrons
- Performed circuit simulations showing output stability across range of temperatures
- Produced and fabricated a prototype circuit board of the BGR circuit
- Irradiation testing of the fabricated PCB indicates
  - Output is low-noise under non-irradiative conditions
  - Transient signatures are observable
  - Difference in transients observed for neutron and alpha irradiation
- Upcoming work
  - Expand circuit modeling to include transient modeling
  - Additional irradiation experiments
  - Fabricating GaN device in Geant4 software to model the physics interactions occurring

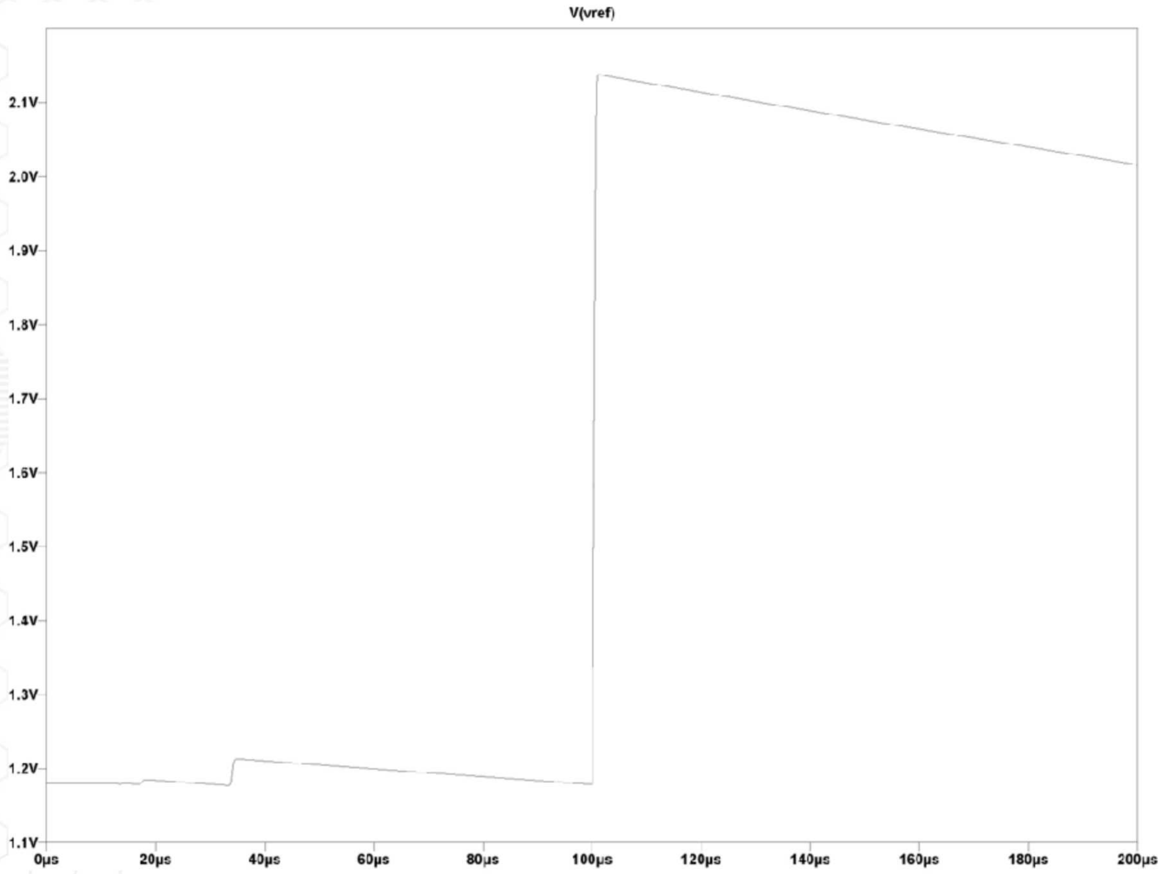
Extra Slides

Significance

- Current detectors are hampered by size and need for multiple stages
- Development of solid state particle detector that can measure energy and momentum would be a significant contribution to particle physics
- Small footprint
  - Application as a portable radiation detector
  - Implementation in current particle detectors for testing and experimental verification
  - Potential to create an array of devices for implementation in larger research experiments
- Potential applications include
  - More accurate dosimeter for protection of radiation workers
  - Utilization in an urban radiation detection network
  - In parallel with other detection techniques like optical radiation detection
  - In conjunction with other detectors for nuclear nonproliferation treaty verification

Transient Response Modeling

- Using data from preliminary testing (August 2018), the event is modeled as a current impulse in the transistor
- Initial simulations seem promising as the impulse is translated to the output voltage V_{ref}
- Simulation result details
  - Modeling was done with generic FET SPICE models before we had Cree models
  - Reference voltage returns to steady state much more slowly than predicted for unknown reason(s)



Transient Response of V_{ref}

Circuit Modeling Upcoming Work

- Recently received complete model for GaN HEMTs from manufacturer Cree
  - Incorporate these models into simulations
- Find and incorporate accurate device models for matched transistors in the circuit
- Continue implementation of transient response modeling
- Investigate why the operational amplifier stage not working in modeling or in experiment