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Sandia National Laboratories

Georgia Tech Silicon-Germanium Devices and Circuits
School of Electrical and Computer Engineering

Response of Integrated Silicon Microwave *pin* Diodes to X-ray and Fast-Neutron Irradiation

Jeffrey W. Teng[1], D. Nergui[1], H. Parameswaran[1], N. E. Sepúlveda-Ramos[1], G. N. Tzintzarov[1], Y. Mensah[1], C. D. Cheon[1], S. G. Rao[1], B. Ringel[1], M. Gorchichko[2], K. Li[2], H. Ying[1,3], A. Ildefonso[4], N. A. Dodds[5], R. N. Nowlin[5], E. X. Zhang[2], D. M. Fleetwood[2], and J. D. Cressler[1]

1. School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250 USA
2. Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN 37235-1825 USA
3. HiSilicon, Co., Ltd., Shenzhen, Guangdong, CN
4. U.S. Naval Research Laboratory, Code 6816, Washington, DC 20375 USA
5. Sandia National Laboratories, Albuquerque, NM 87185 USA

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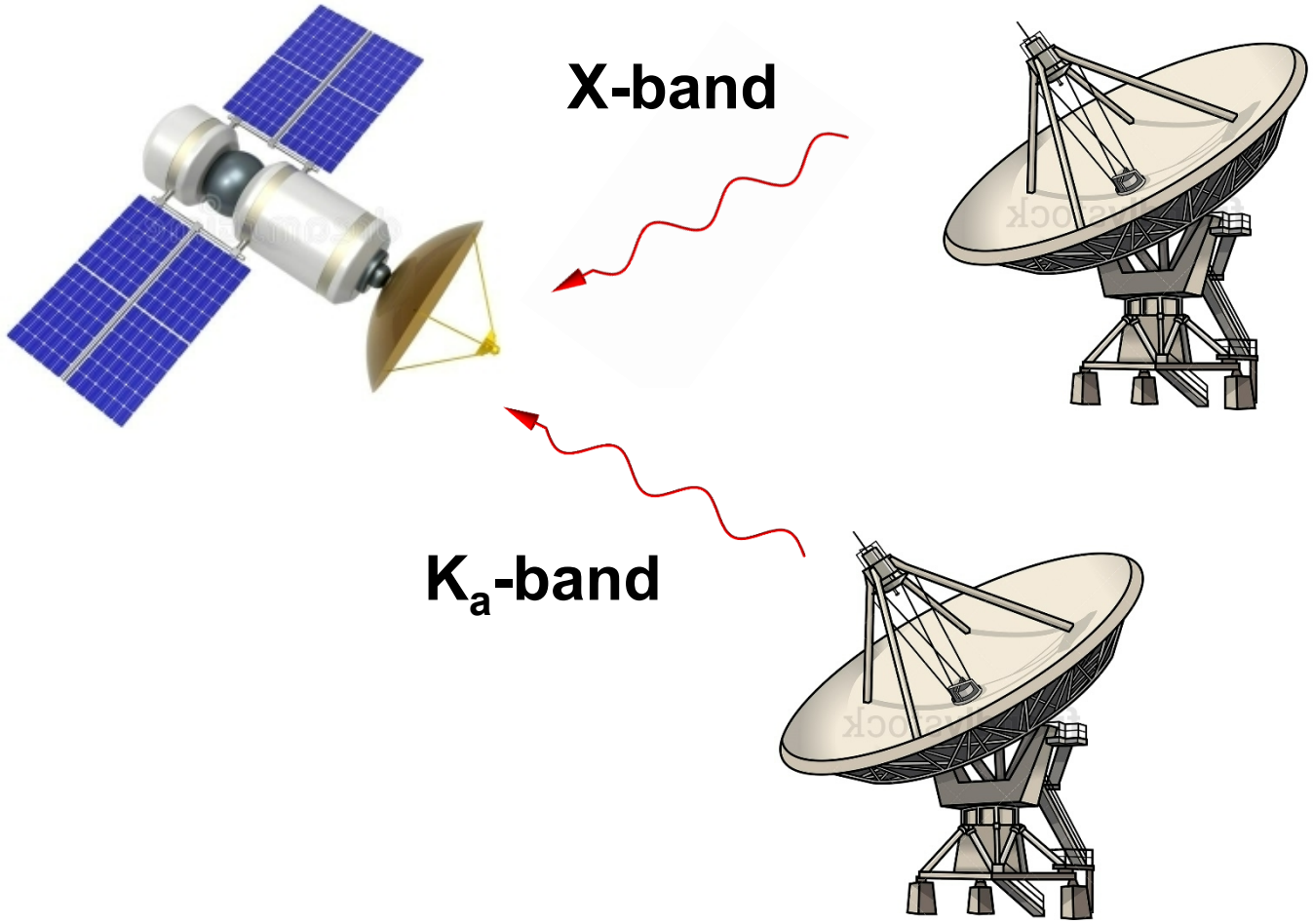
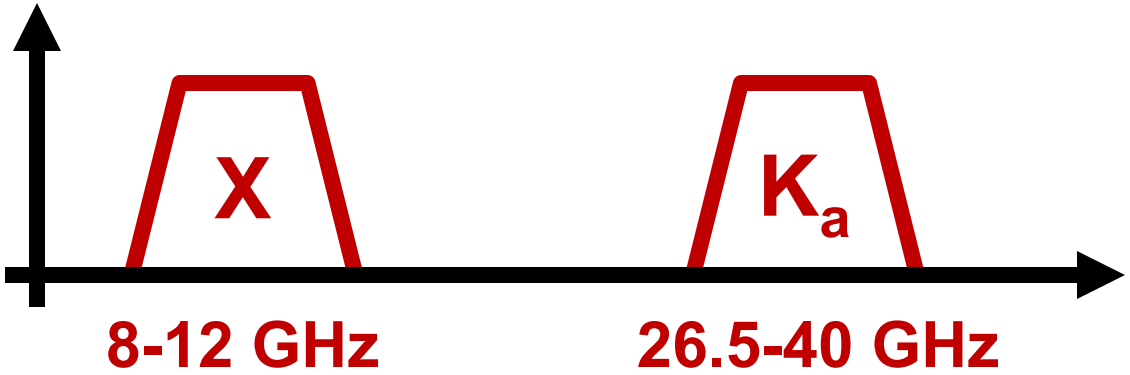
Satellite Communications Systems

- **Satellites Use Multiple Frequency Bands for Communications**

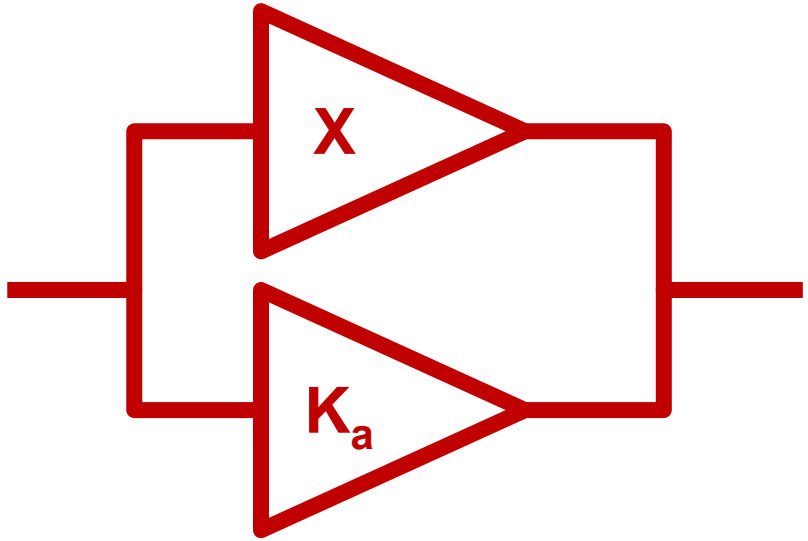


Reconfigurable Systems

- **Reconfigurability Enables Flexible Systems in One Footprint**
  - simultaneous multi-band solutions ➡ bulky and power hungry



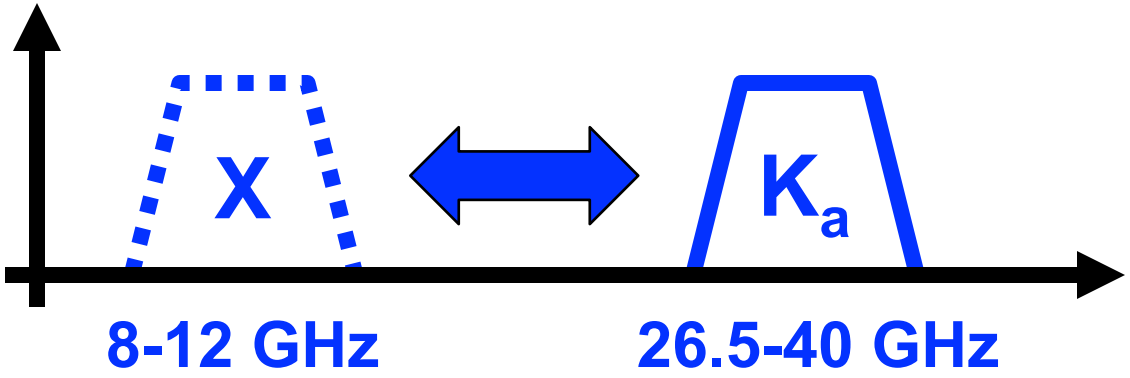
Satellite Communications Frequency



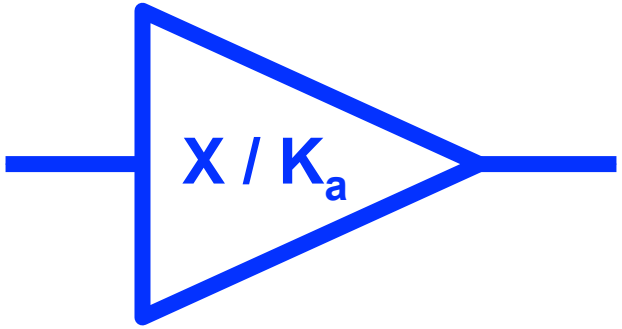
Two Front-End Amplifiers

Reconfigurable Systems

- **Reconfigurability Enables Flexible Systems in One Footprint**
  - frequency reconfigurability ➡ tuned performance across multiple bands



Satellite Communications Frequency



Single Front-End Amplifier

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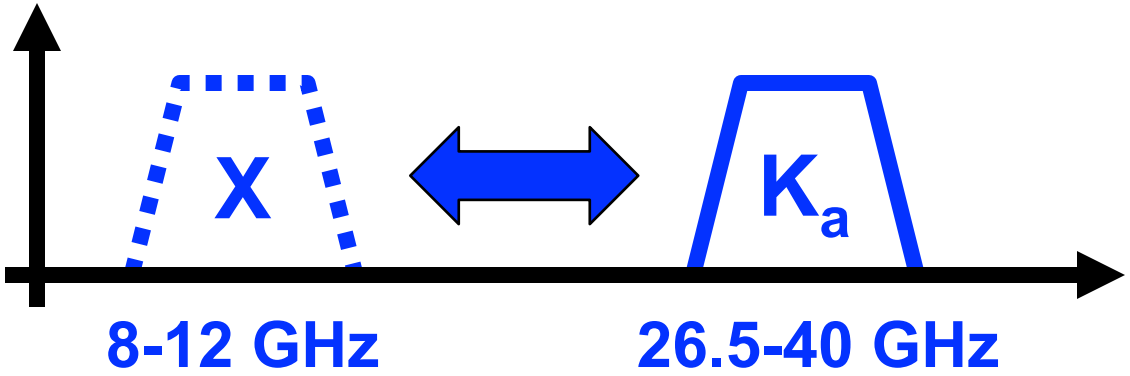
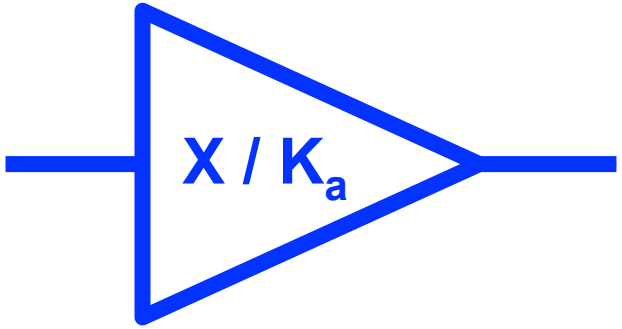


Satellite Communications Frequency

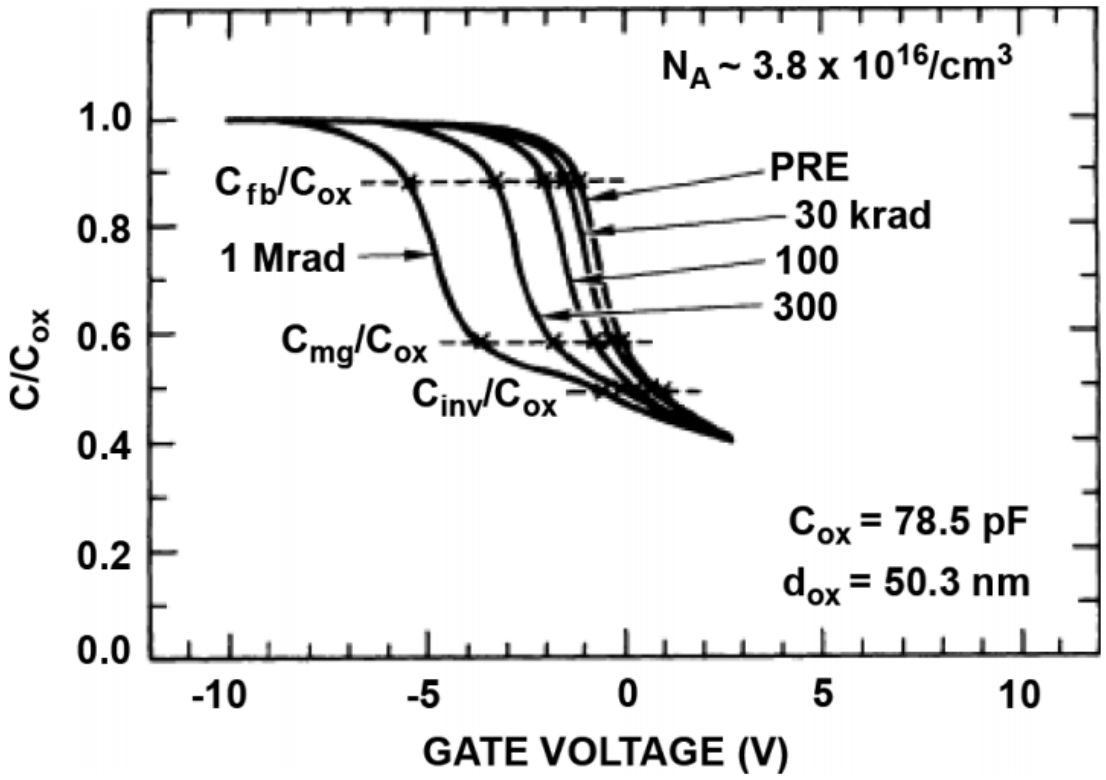


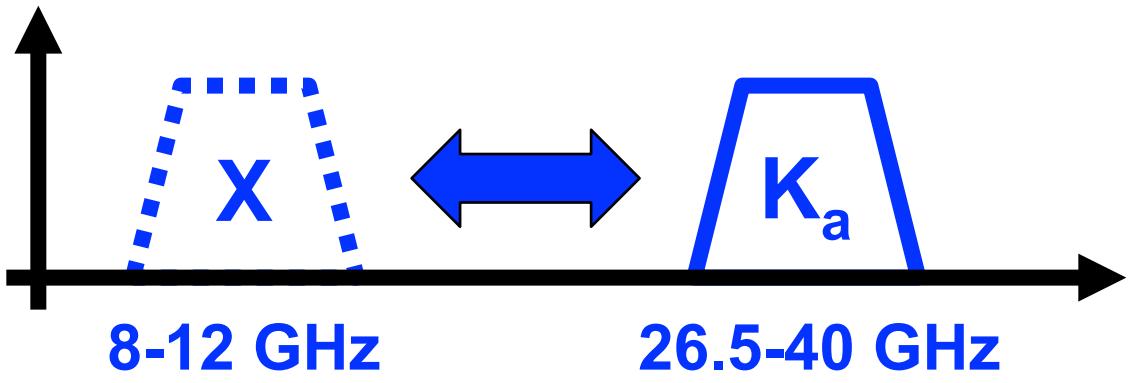
Single Front-End Amplifier

Reduction in Size, Weight, and Power with Minimal Performance Degradation

Implementing Reconfigurability

- **CMOS Transistors Are Excellent <u>Reconfigurable</u> Components**
  - they can act as variable capacitors and resistors by changing gate voltage





Satellite Communications Frequency

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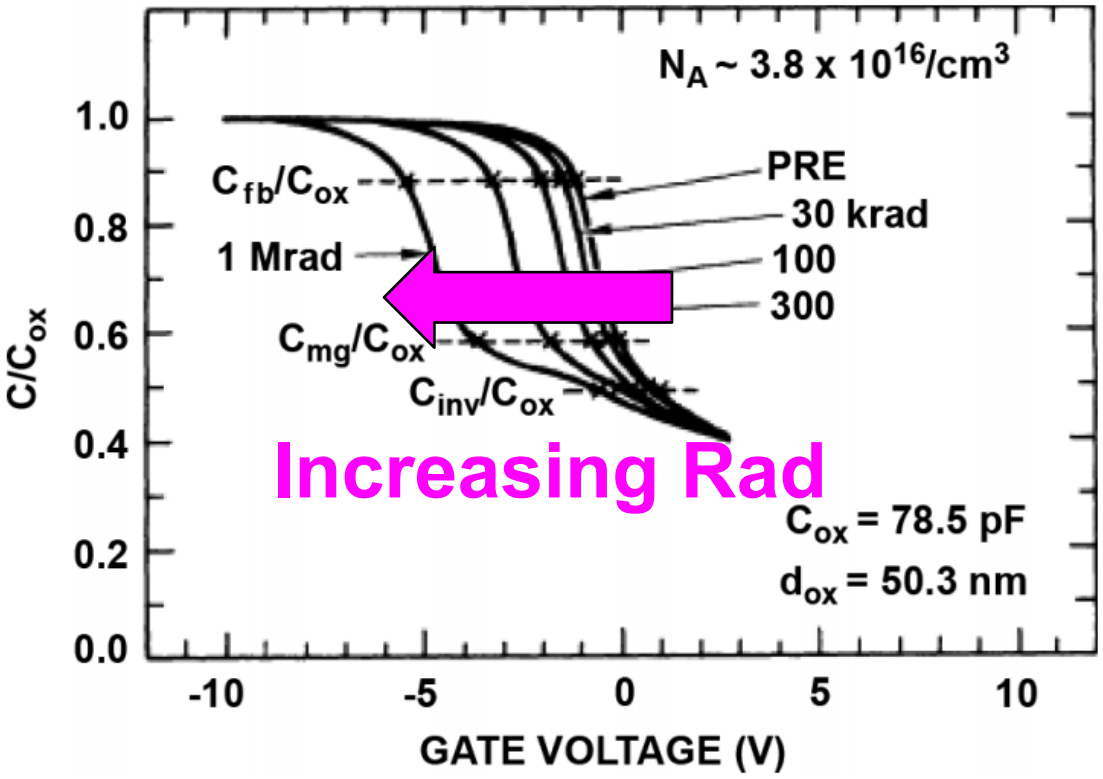

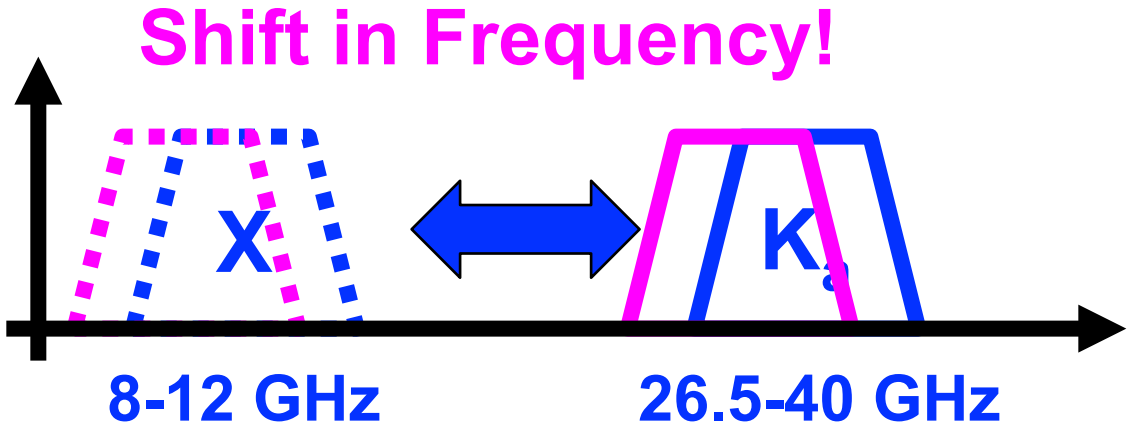

Satellite Communications Frequency

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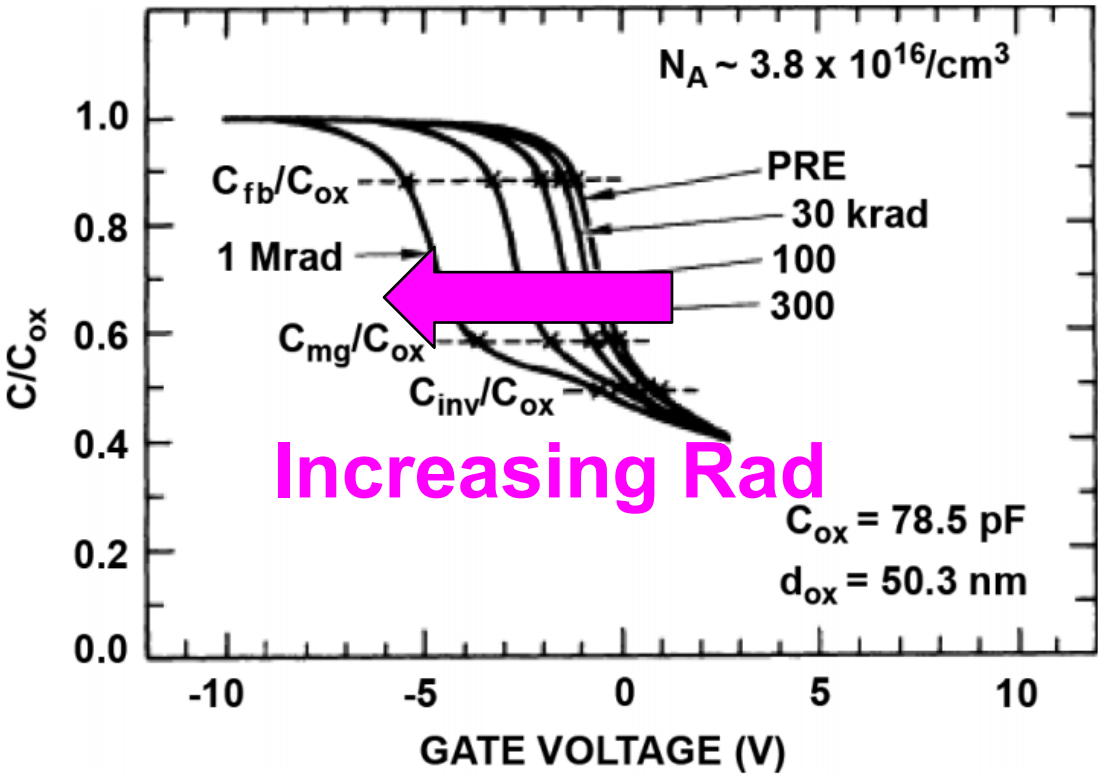
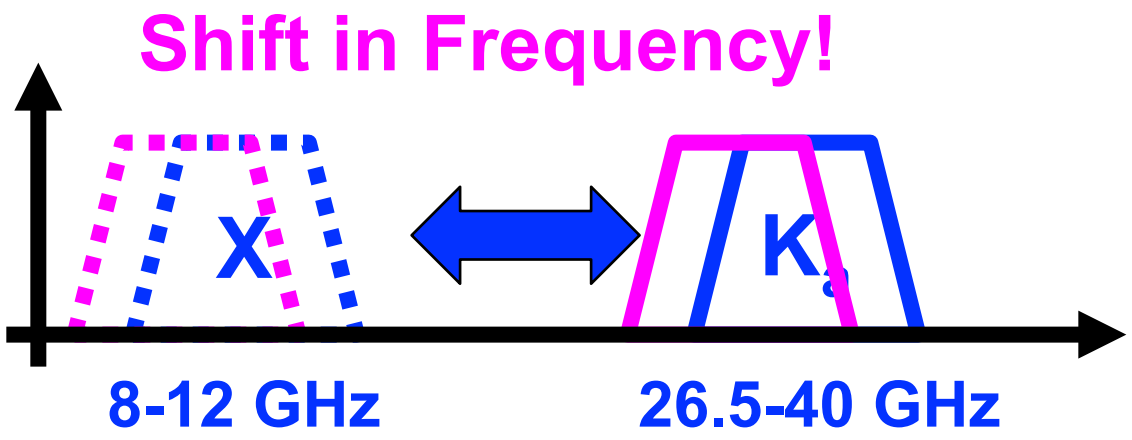


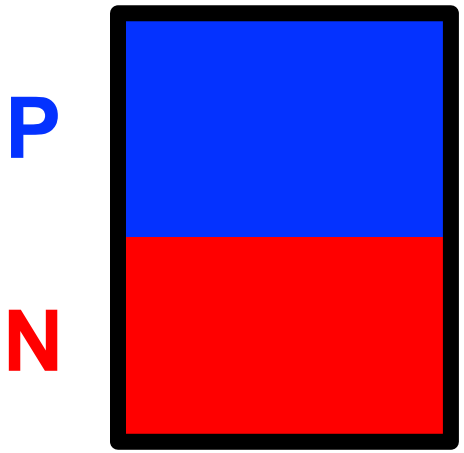


Satellite Communications Frequency

Need a Radiation-tolerant Reconfigurable Component

Candidate: Microwave PIN Diodes

- **Modern SiGe BiCMOS Technologies Feature *pin* Diodes**
  - adds a carefully engineered intrinsic layer between *p* and *n* regions



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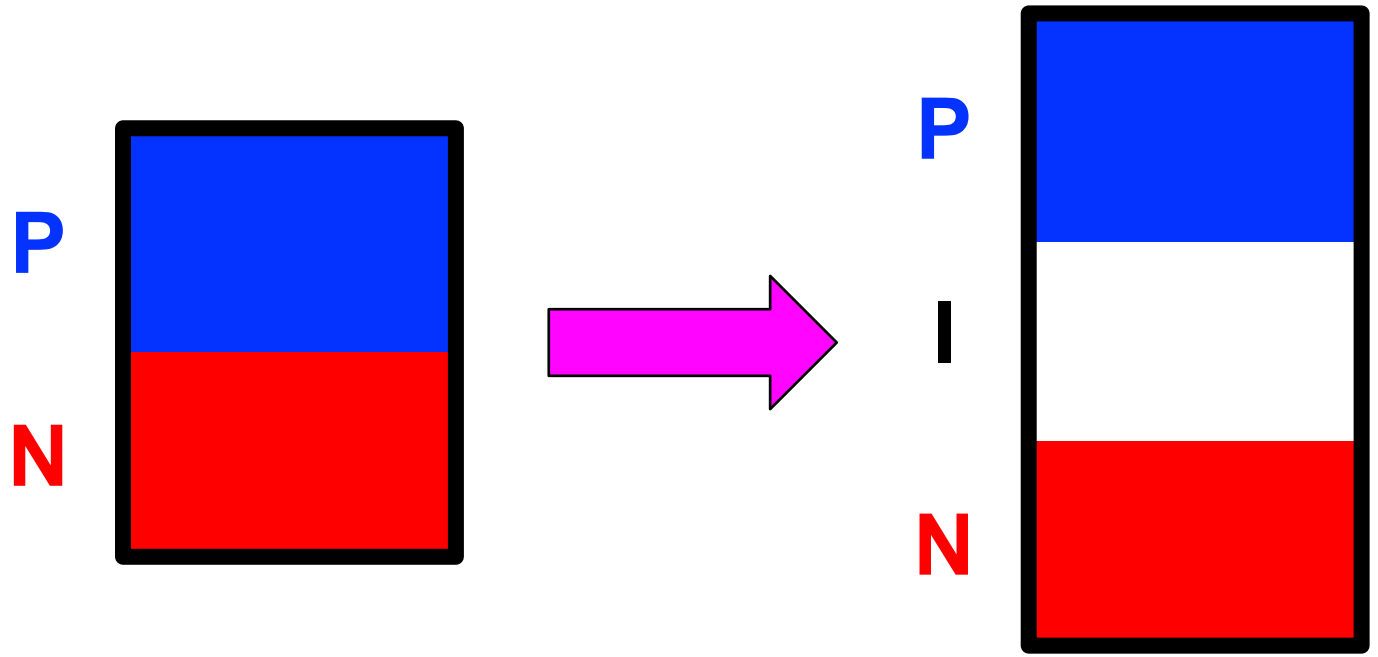
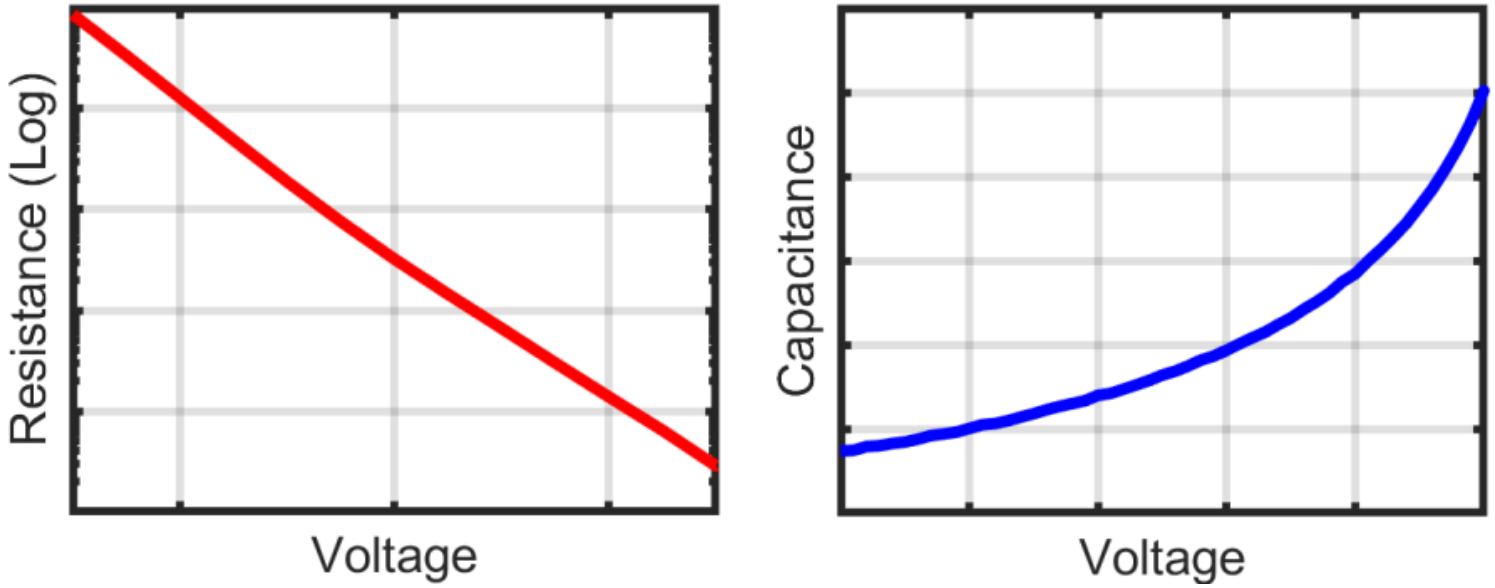


Offers Unique High-Frequency Characteristics

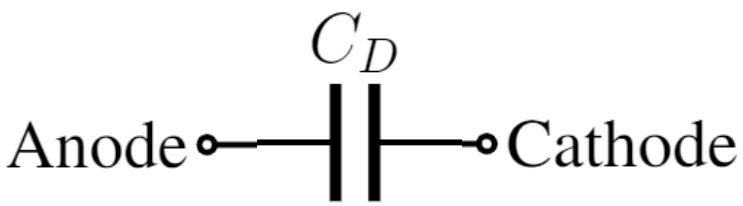
Candidate: Microwave PIN Diodes

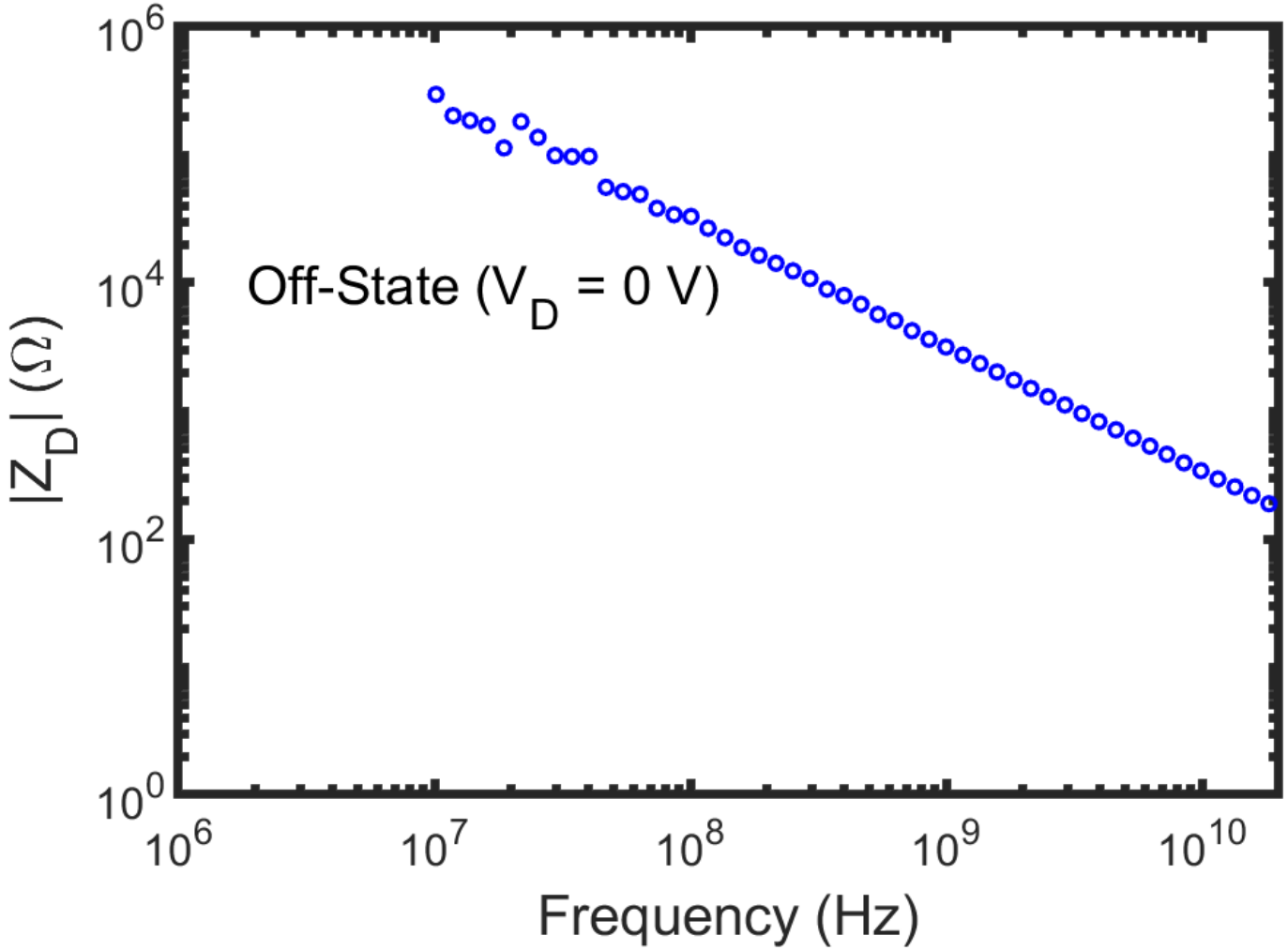
- **Modern SiGe BiCMOS Technologies Feature *pin* Diodes**
  - adds a carefully engineered intrinsic layer between *p* and *n* regions
  - easy to integrate with digital control functions, other RF blocks
  - functions well as a variable resistor (varistor) or a variable capacitor (varactor)



AC Response: Off State

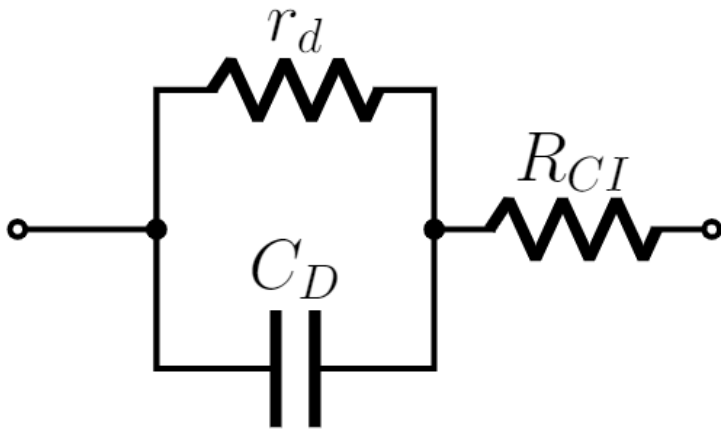
Off State

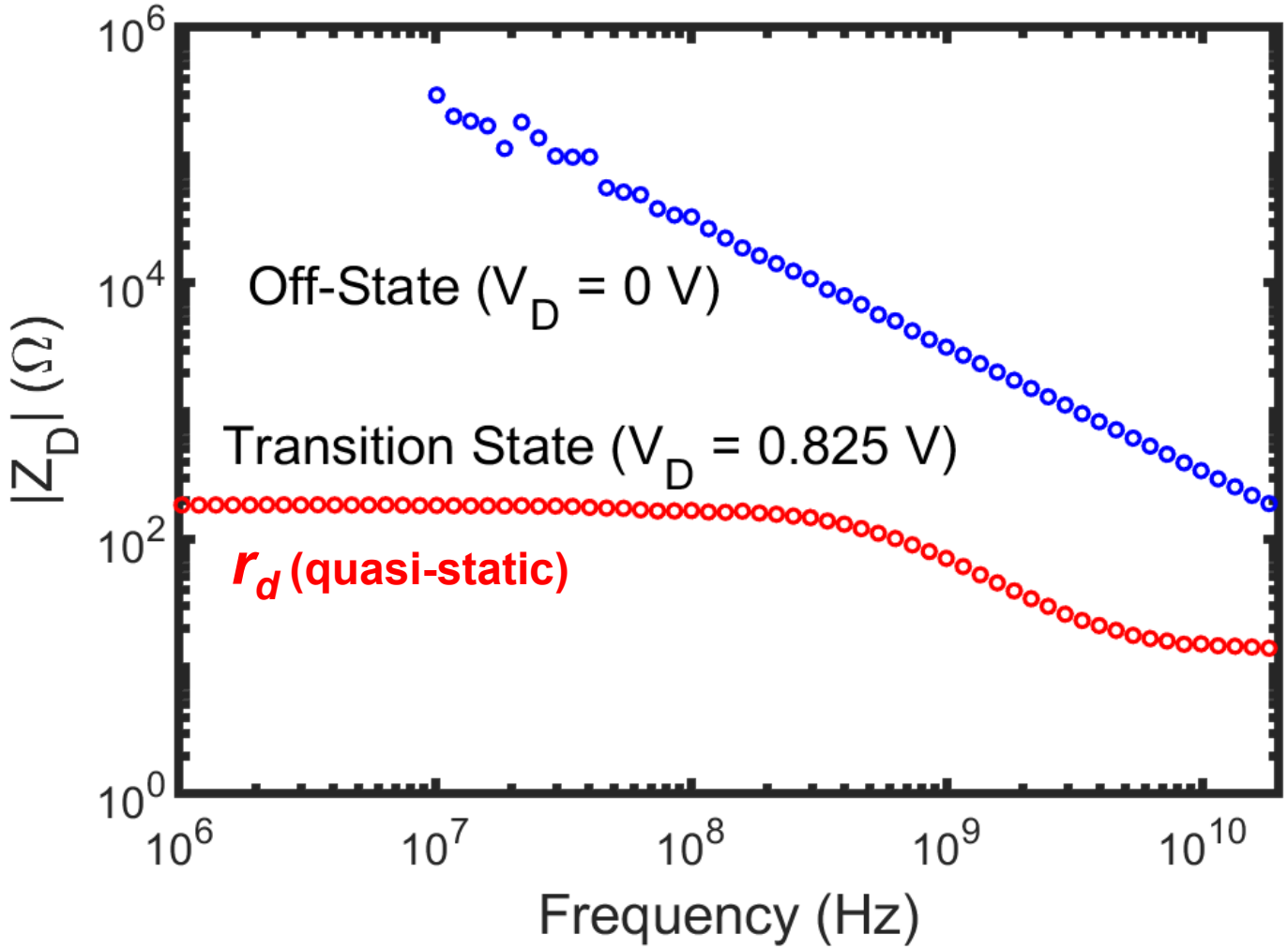




AC Response: Transition State

Transition State





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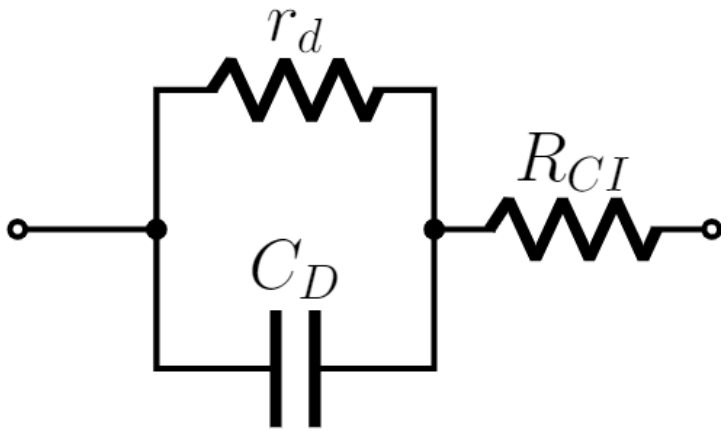

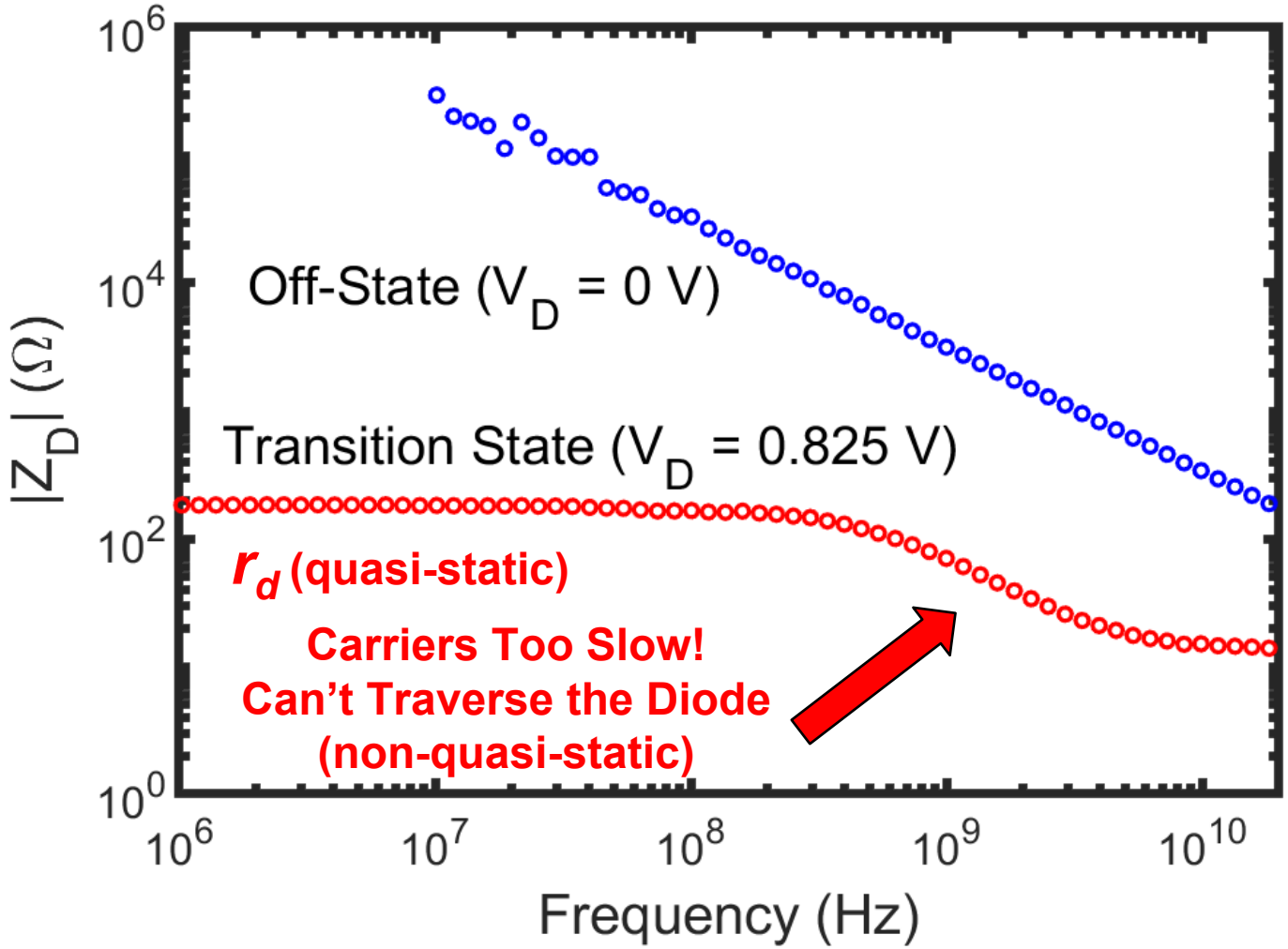

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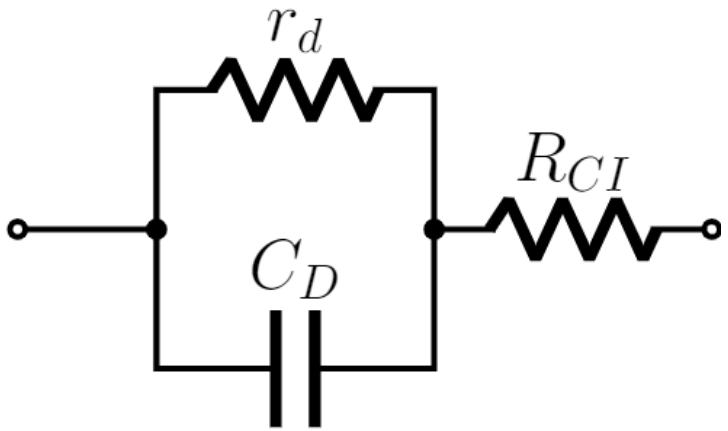
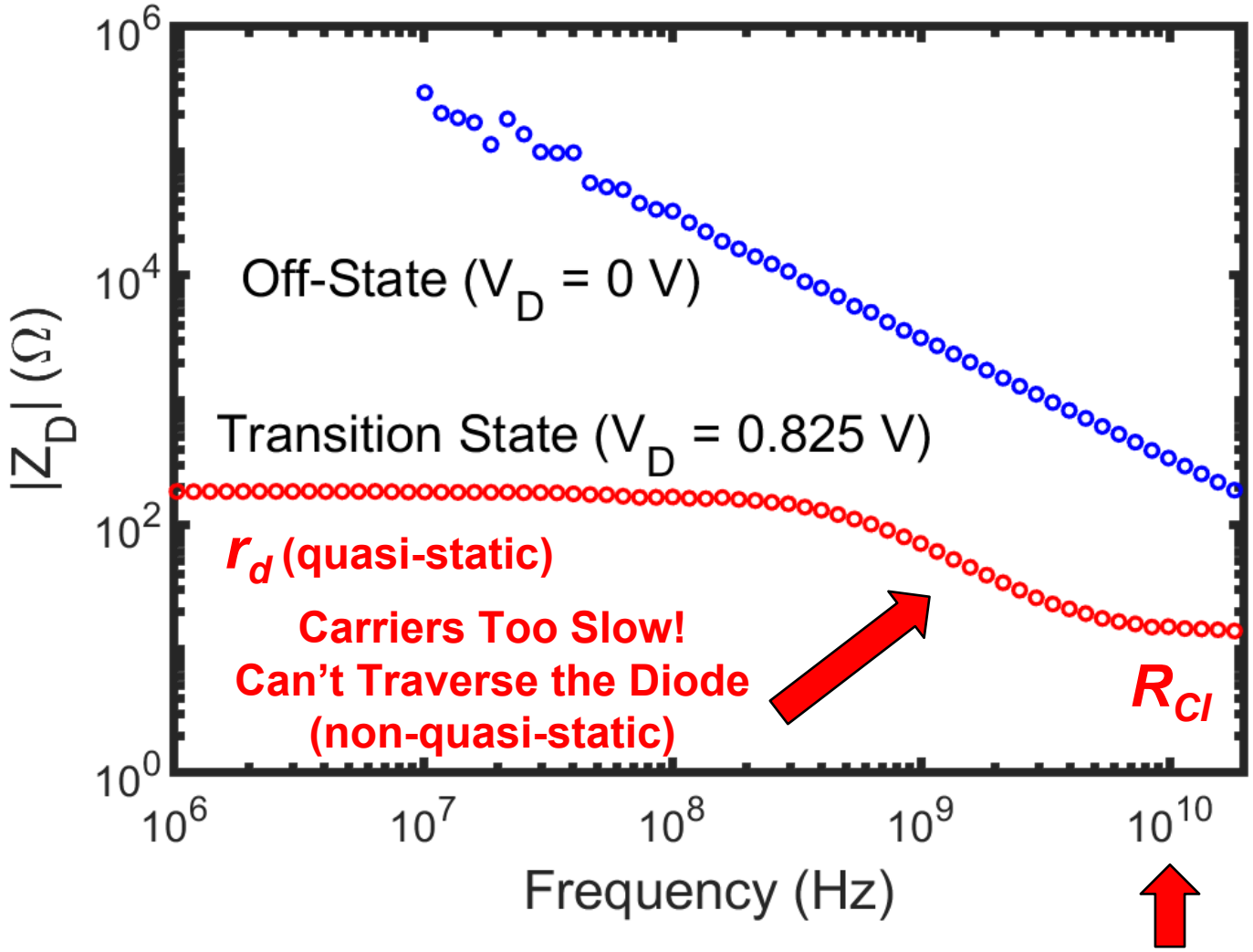
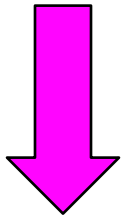




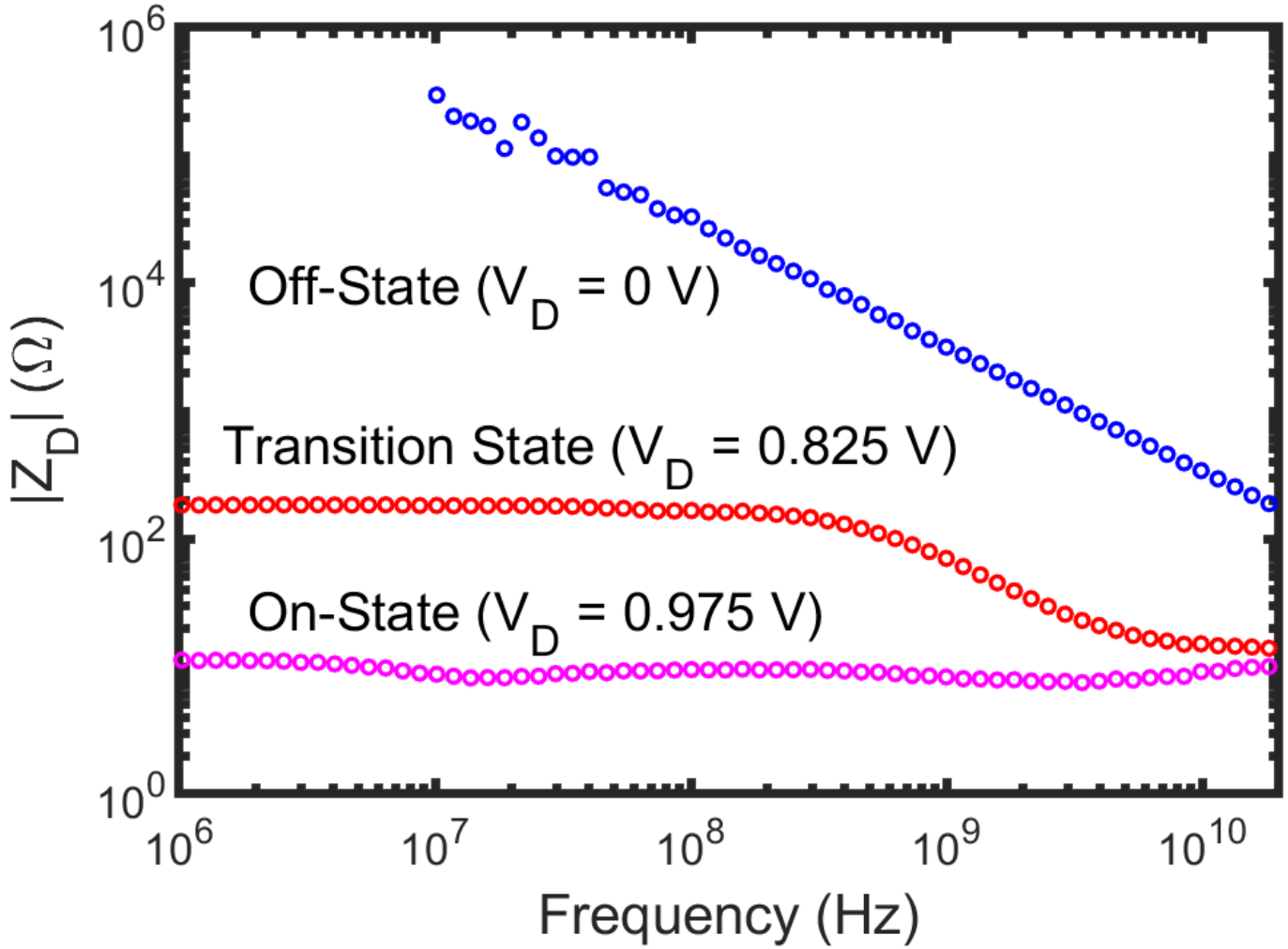
X-band

AC Response: On State

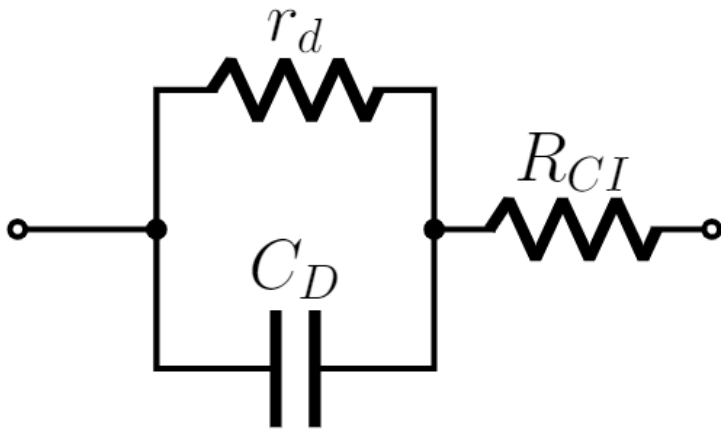


On State

Not Limited by Quasi-static Resistance

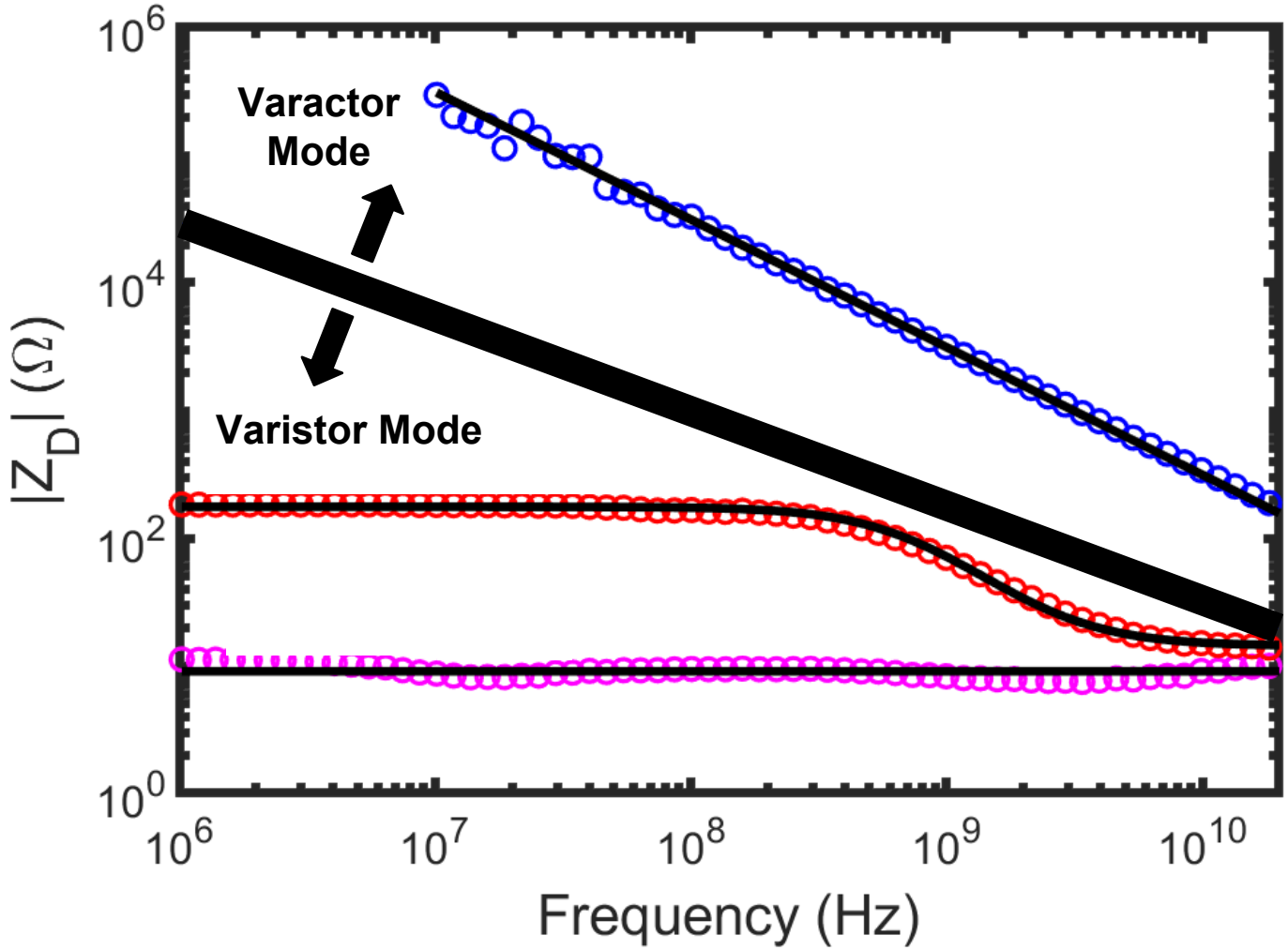


AC Response: Extraction



Fit Function:

$$Z_D = g(f, r_d, C_D, R_{CI})$$



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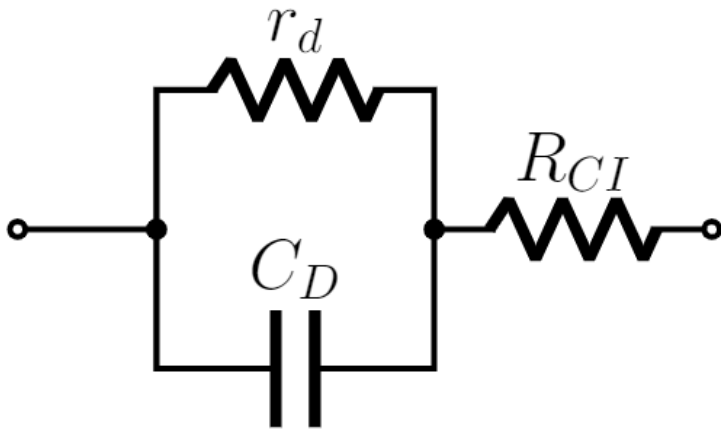

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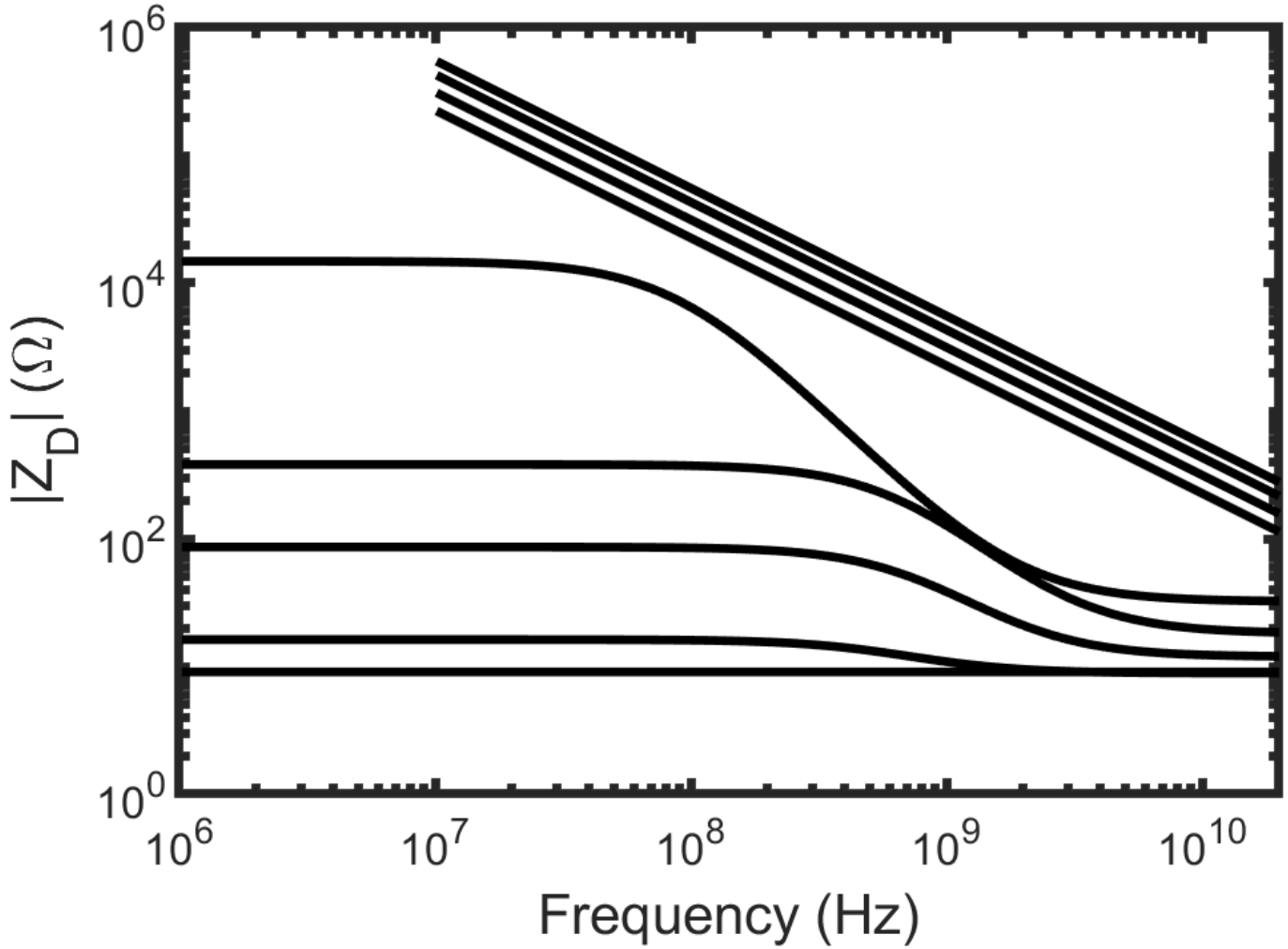

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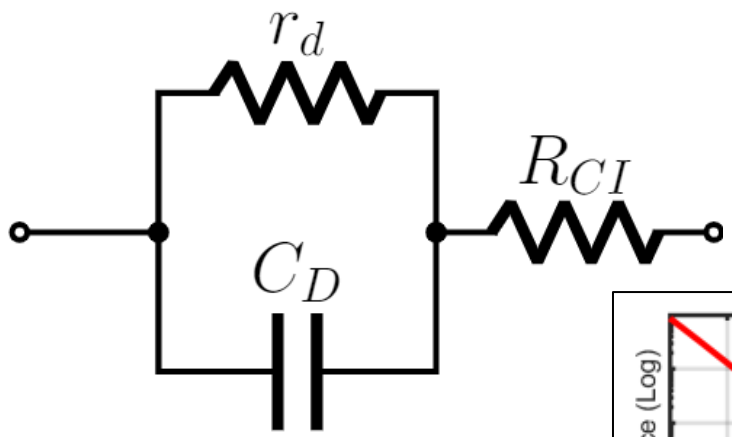

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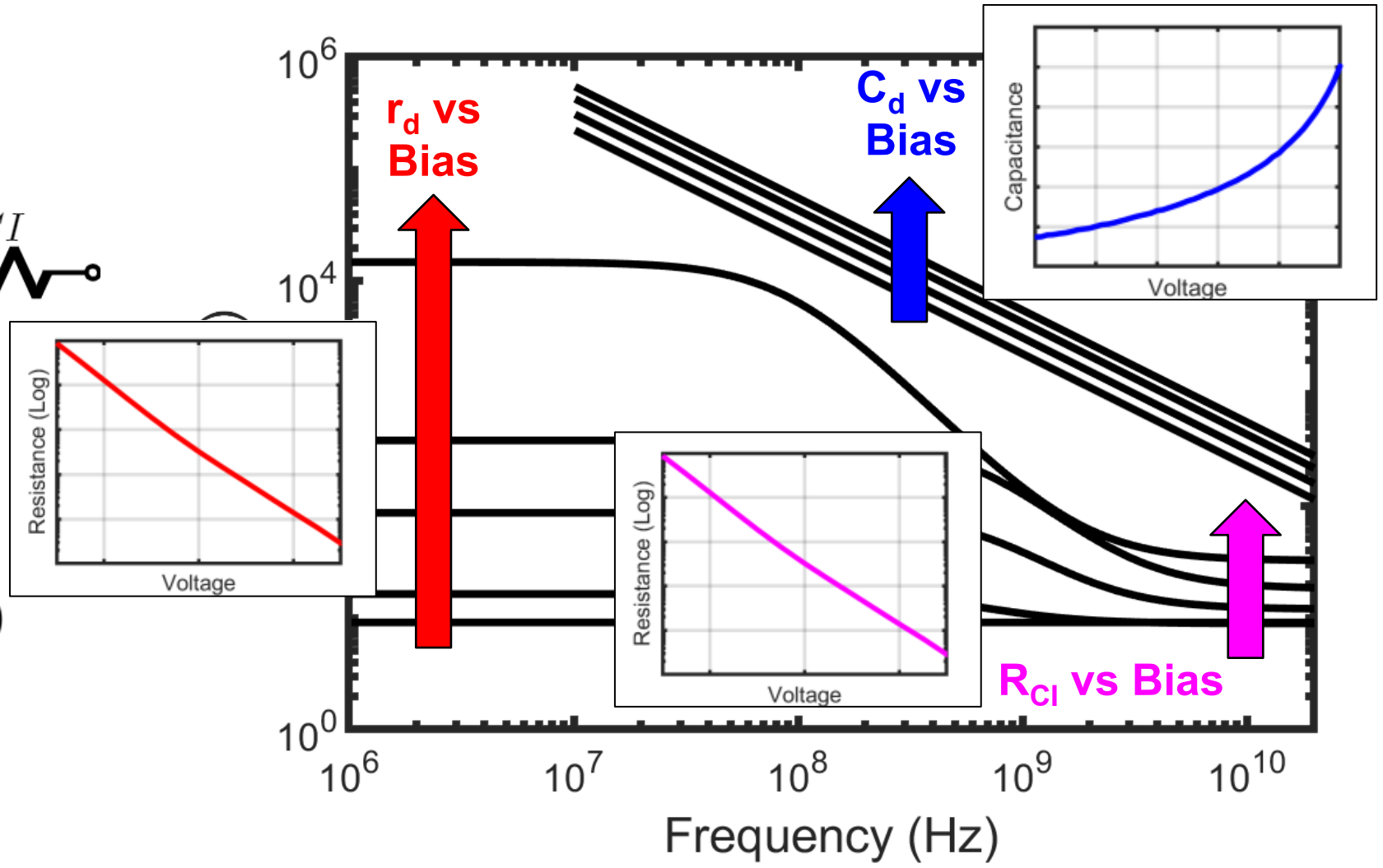


Experimental Conditions

- **X-ray: ARACOR Model 4100 Semiconductor Irradiation System**
  - dose rate = 30 krad(SiO_2)/min
  - maximum dose = 2 Mrad(SiO_2)
  - 0 V irradiation

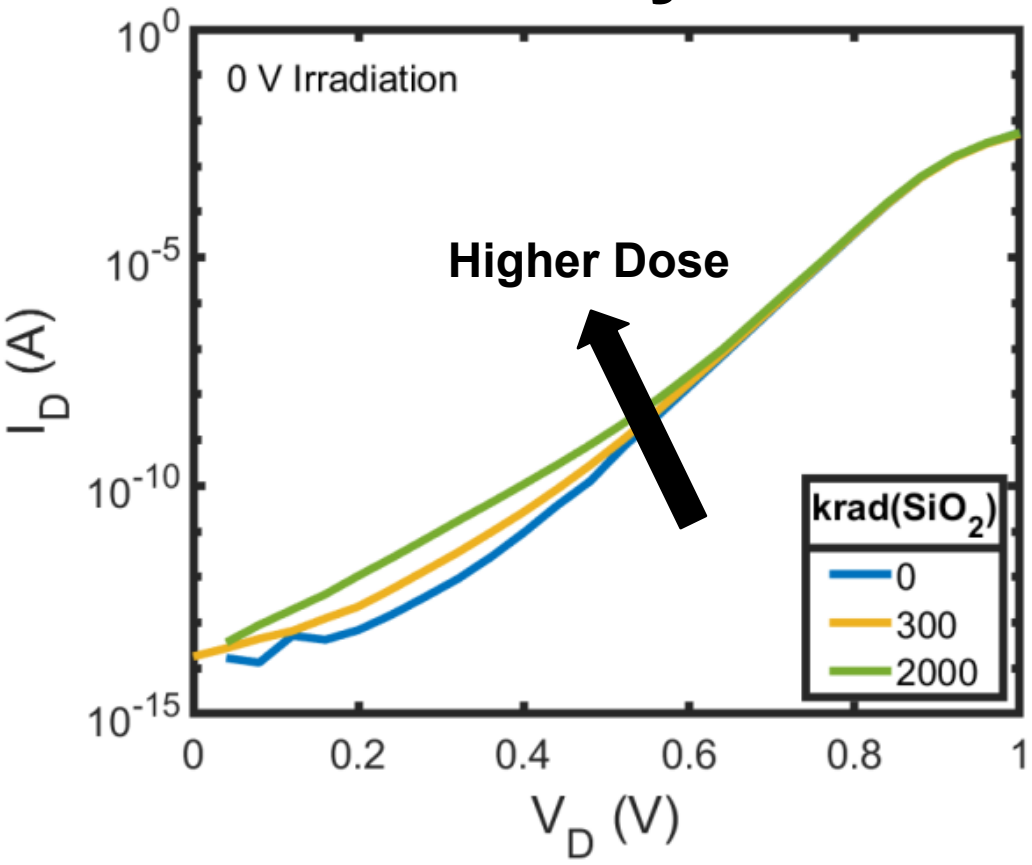
- **14-MeV Fast Neutrons: Sandia's Ion Beam Laboratory**
  - passive exposure with all terminals floating
  - maximum fluence = 2.2 x 10^{13} n/cm^2

- **Samples**
  - Tower Semiconductor's SBC18H5 4th-generation SiGe BiCMOS technology
  - anode area = 4x4 μm^2
  - on-die probed measurements: AC + DC characterization

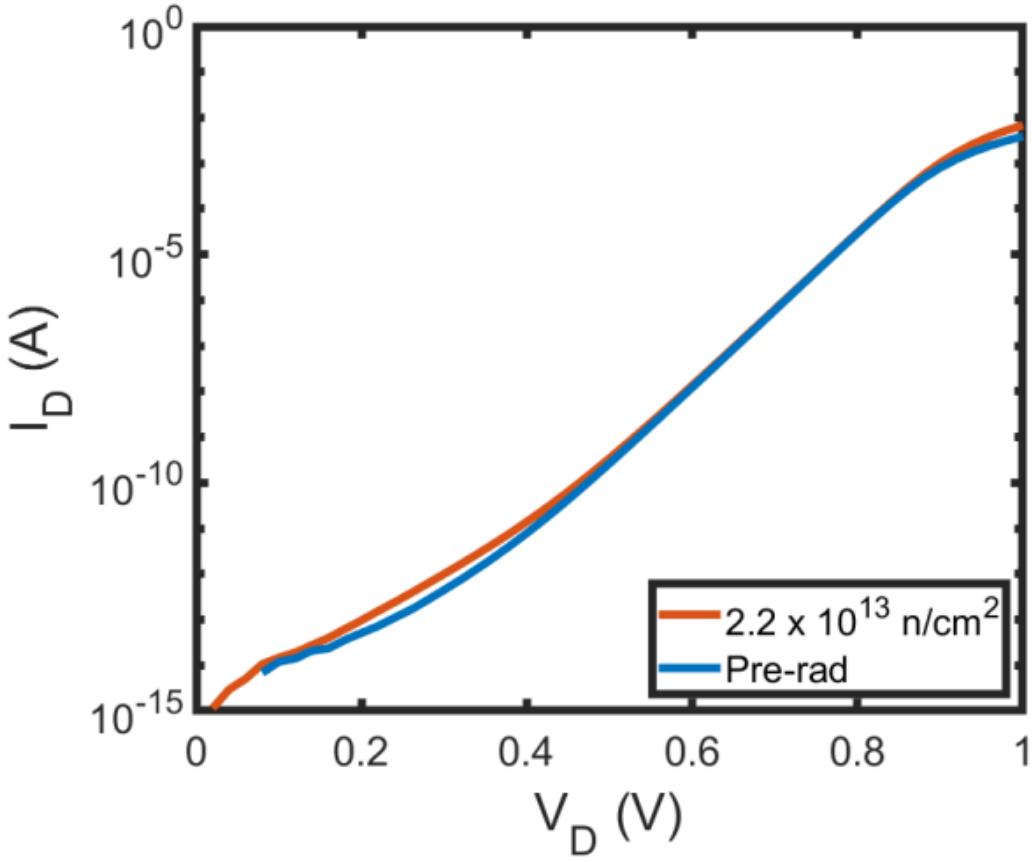
Results: DC

- **Increase in Leakage Currents Expected, But Not Significant for Intended RF Applications**

X-ray

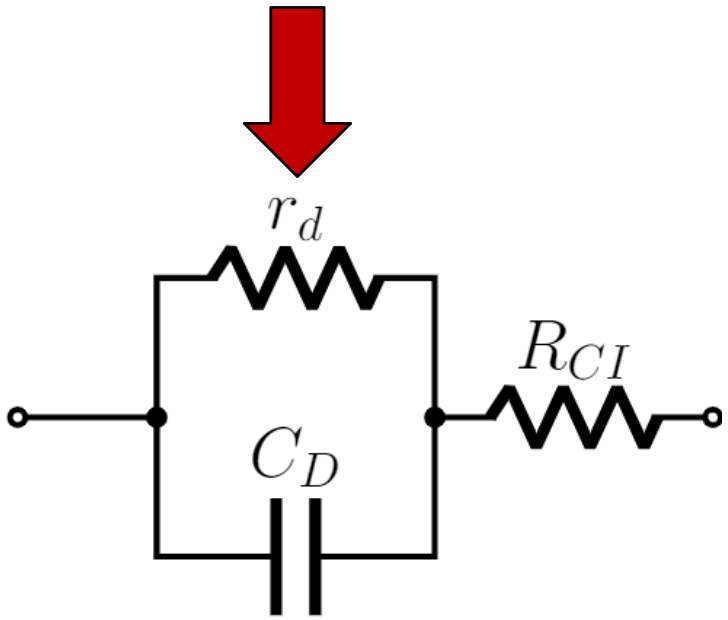


Neutron

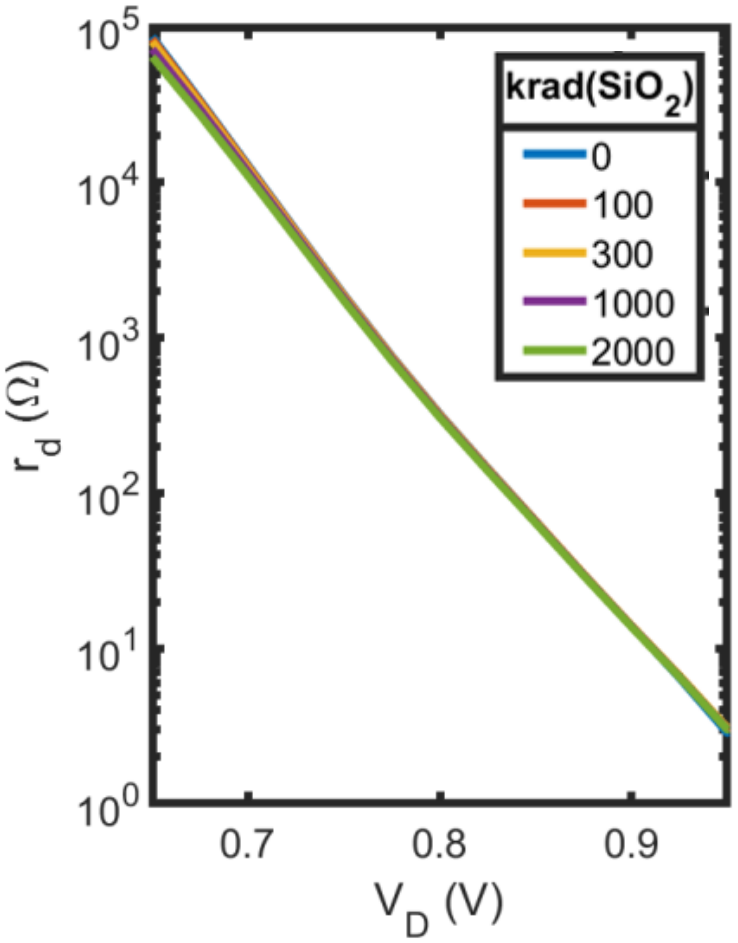


X-ray Results: Varistor Performance

- **Diode Resistance vs. Bias Voltage Extracted from S-parameters**



Quasi-static



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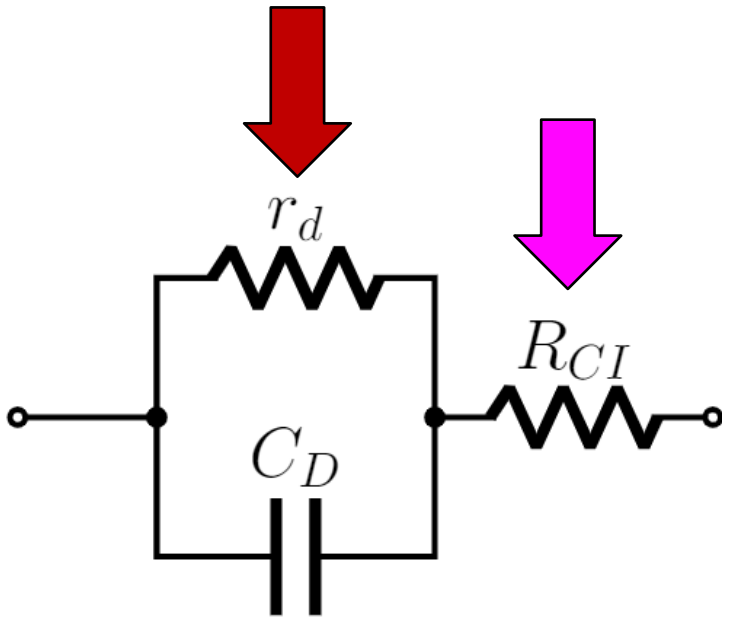

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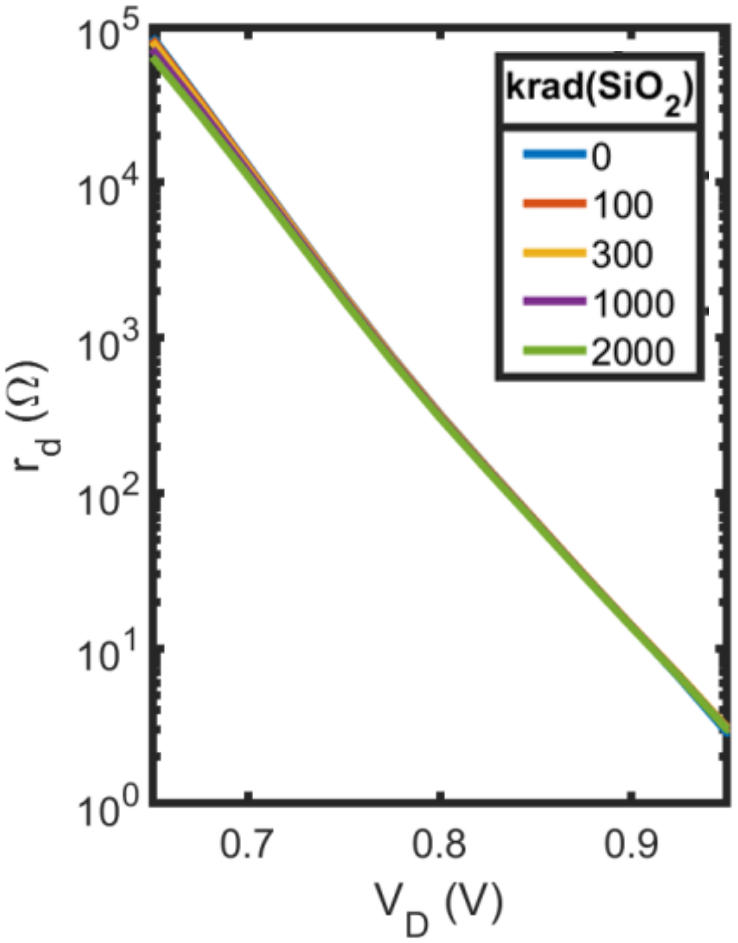
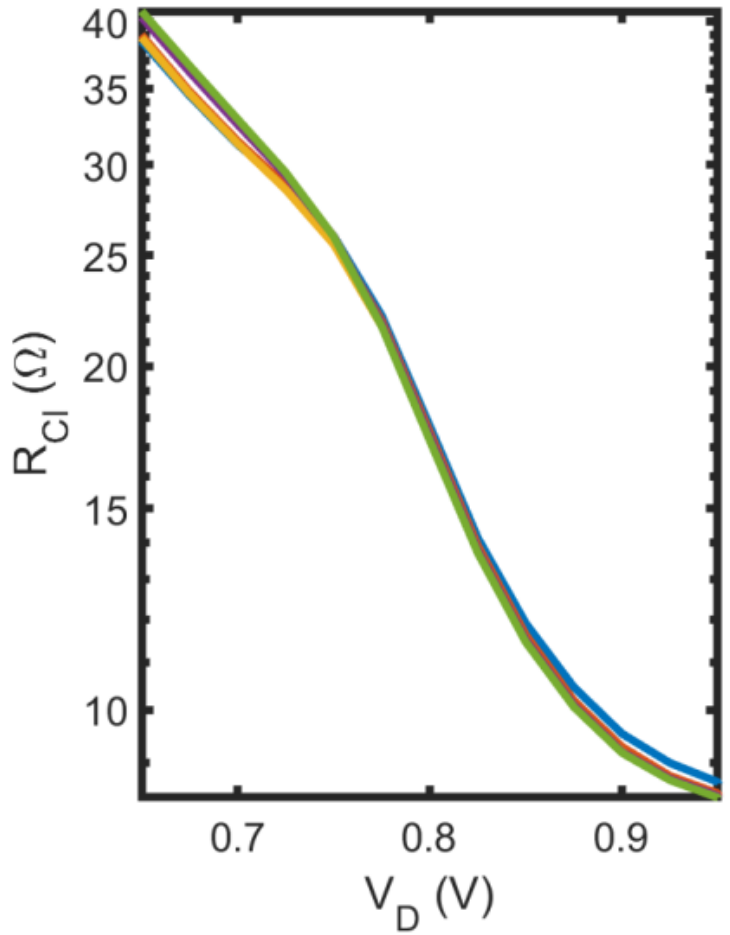


Non-quasi-static



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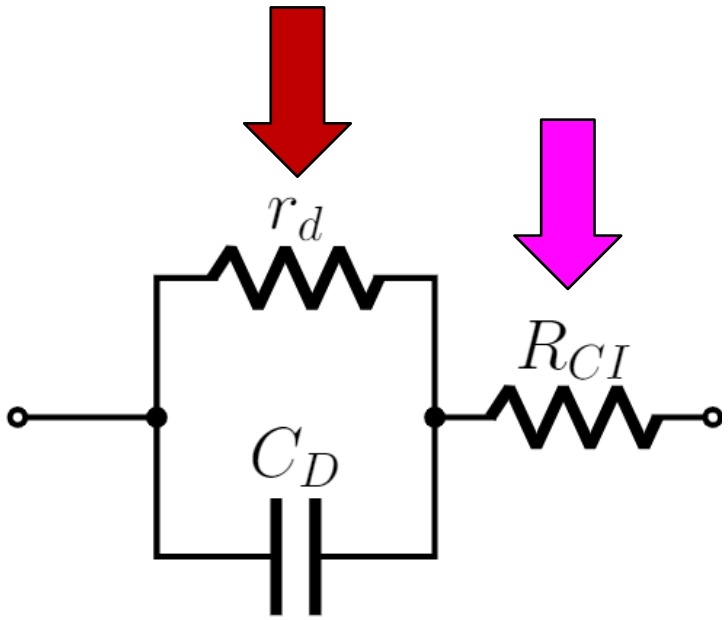
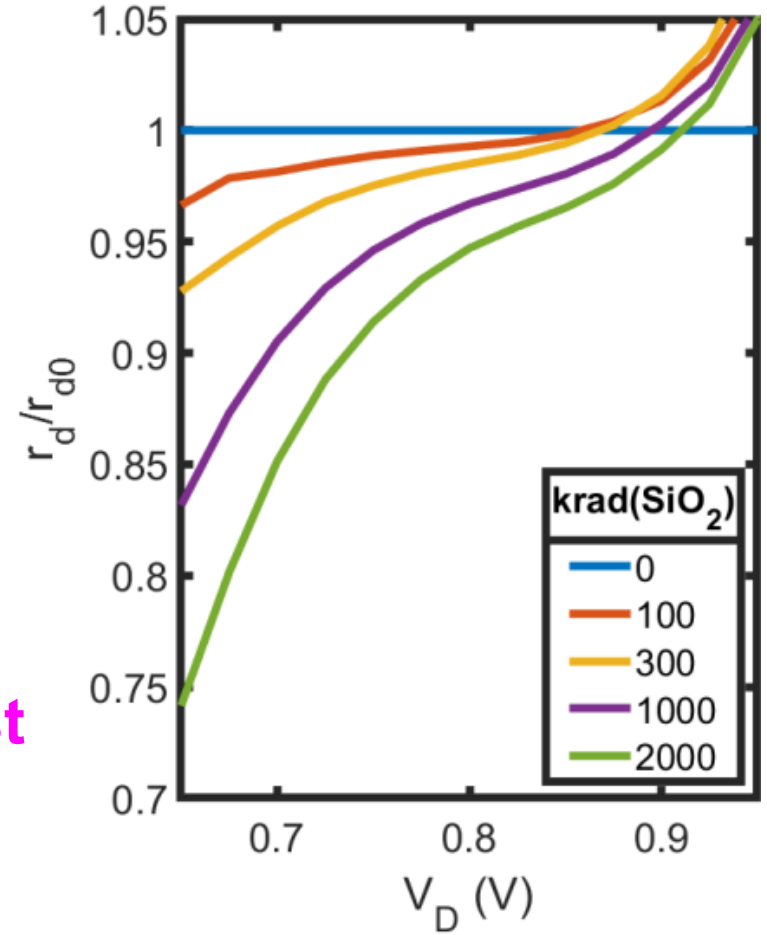


Much Less Effect at Frequencies of Interest

Quasi-static



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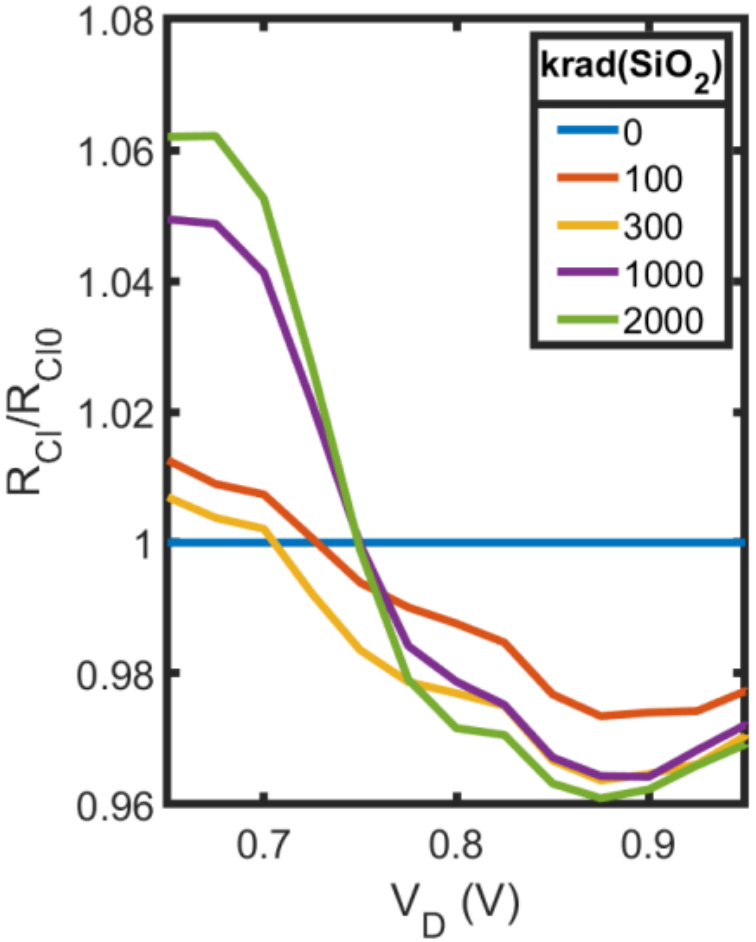
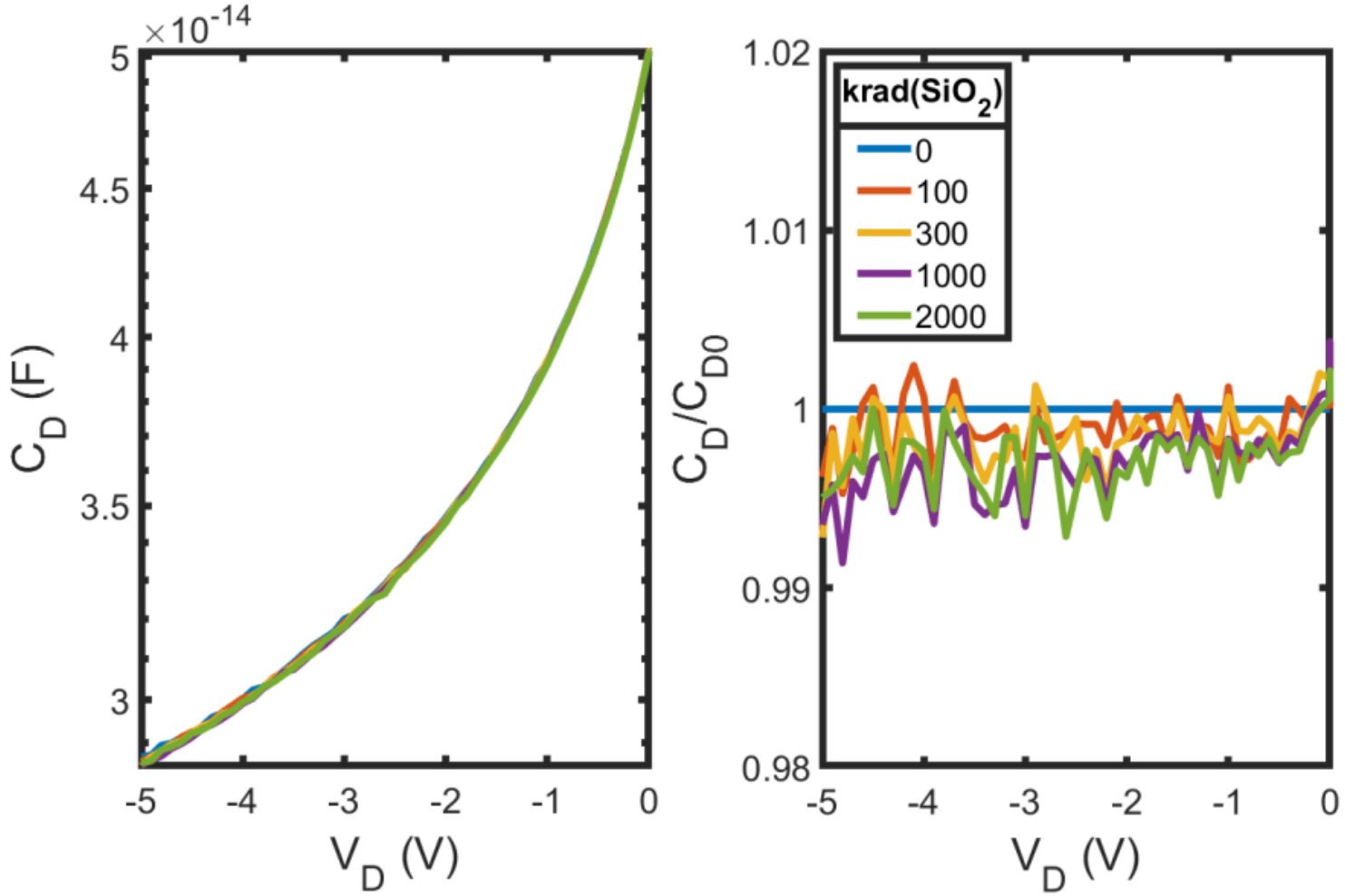


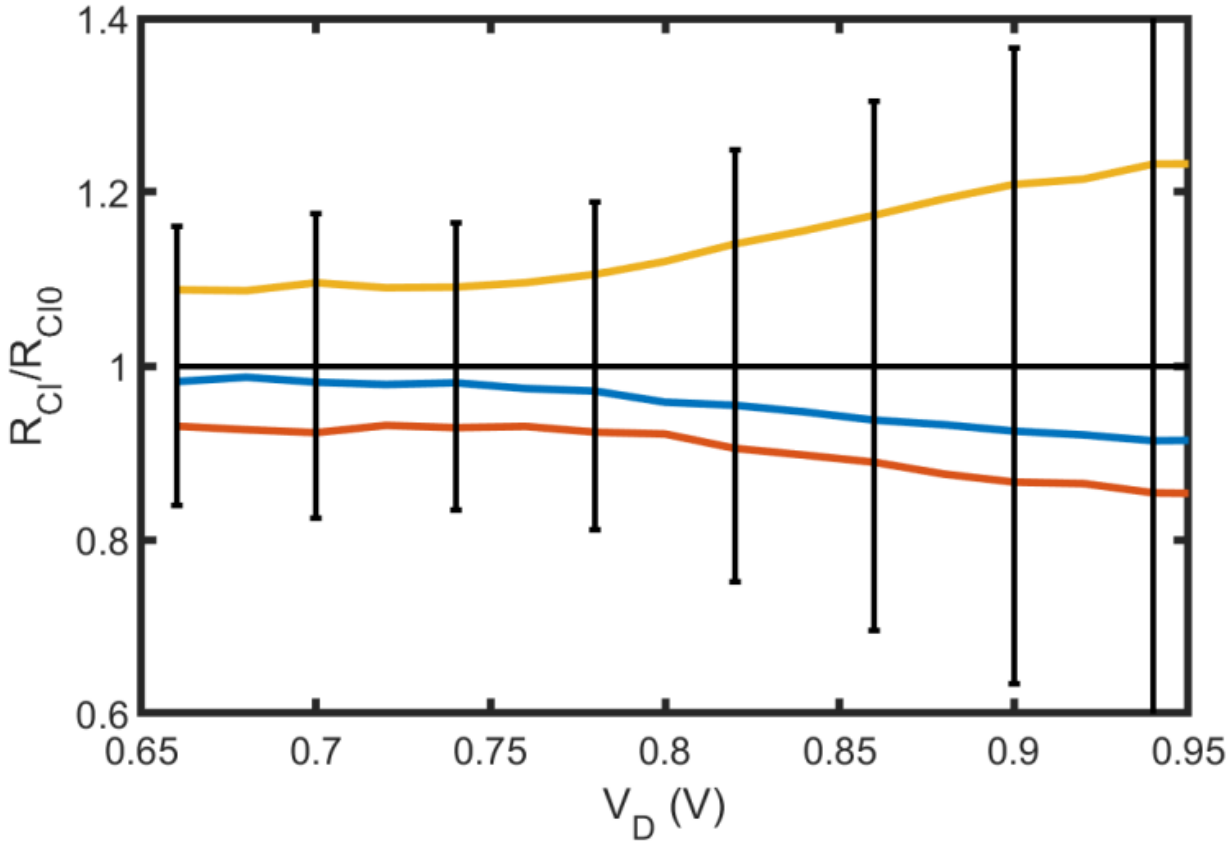
X-ray Results: Varactor Performance



Negligible Change in Varactor Performance

Neutron Results: Varistor Performance

- **Three Chips Compared for Statistical Variations**
  - normalized to reference unirradiated diode
  - fluence of 2.2 x 10^{13} n/cm^2
- **No Statistically Significant Change in Resistance**
  - sensitivity to probing contact



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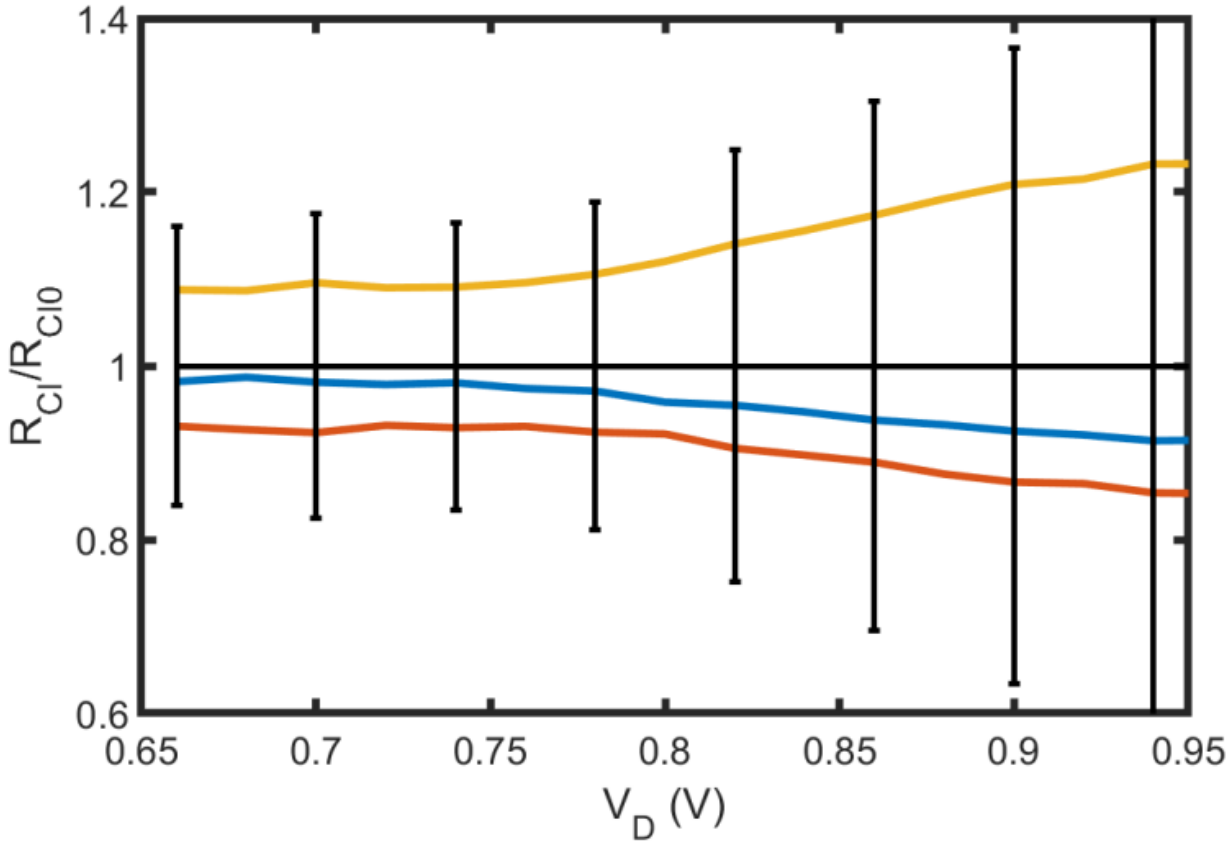
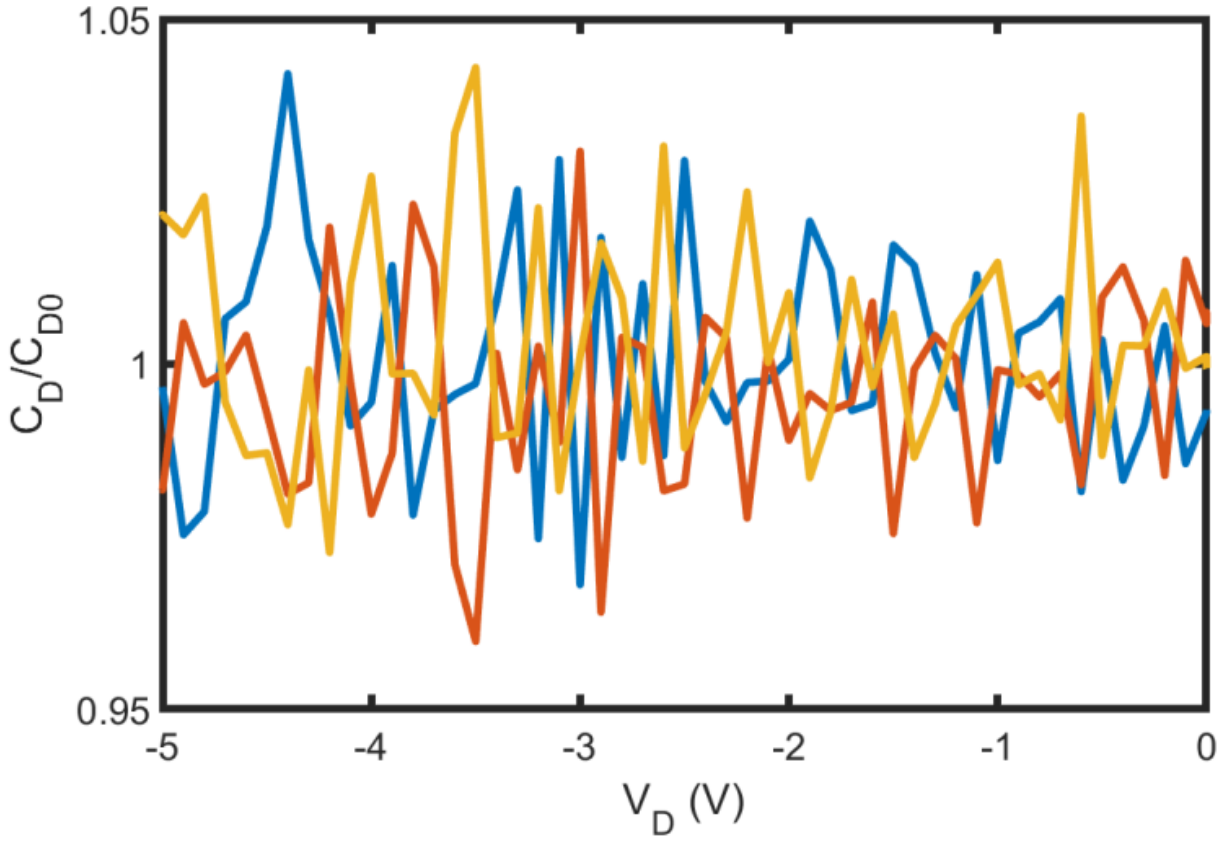
- **Even 20% Change is Tolerable if Considered During Design**



Neutron Results: Varactor Performance

- **Three Chips Compared for Statistical Variations**
  - normalized to reference unirradiated diode
  - fluence of 2.2 x 10^{13} n/cm^2
- **Negligible Change in Capacitance**
  - variations within the measurement noise



Summary

- **Microwave *pin* Diodes Are Excellent Reconfigurable Components**
  - easy to integrate with standard BiCMOS
  - operates as varistor, varactor, or switch
  - low loss, high isolation, high linearity

- **First Radiation Data on Integrated Microwave *pin* Diodes**
  - *pin* diodes contained in a SiGe BiCMOS platform
  - increased DC leakage current is not significant for RF designs
  - variation in varistor performance is suppressed by non-quasi-static effects
  - no detectable change in varactor performance

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Integrated Microwave *pin* Diodes Are Radiation-tolerant Alternatives to CMOS in Reconfigurable Systems for Space Applications