INSTITUTE FOR RESEARCH IN ELECTRONICS & APPLIED PHYSICS

Schottky Diode and MOSFET RF-Detector and Focused Ion Beam Post-Processing

MURI Annual Review

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Original Project Objectives:

- Direct analog microwave level measurement on a chip (goal: up to 100GHz) using
  - a) Schottky diodes
  - b) Thermal detectors
- Incorporation of RF detectors on chips, including FIB diode fabrication on existing chips
- Focused ion beam diagnosis circuit restructuring and device diagnosis by burned out element sectioning

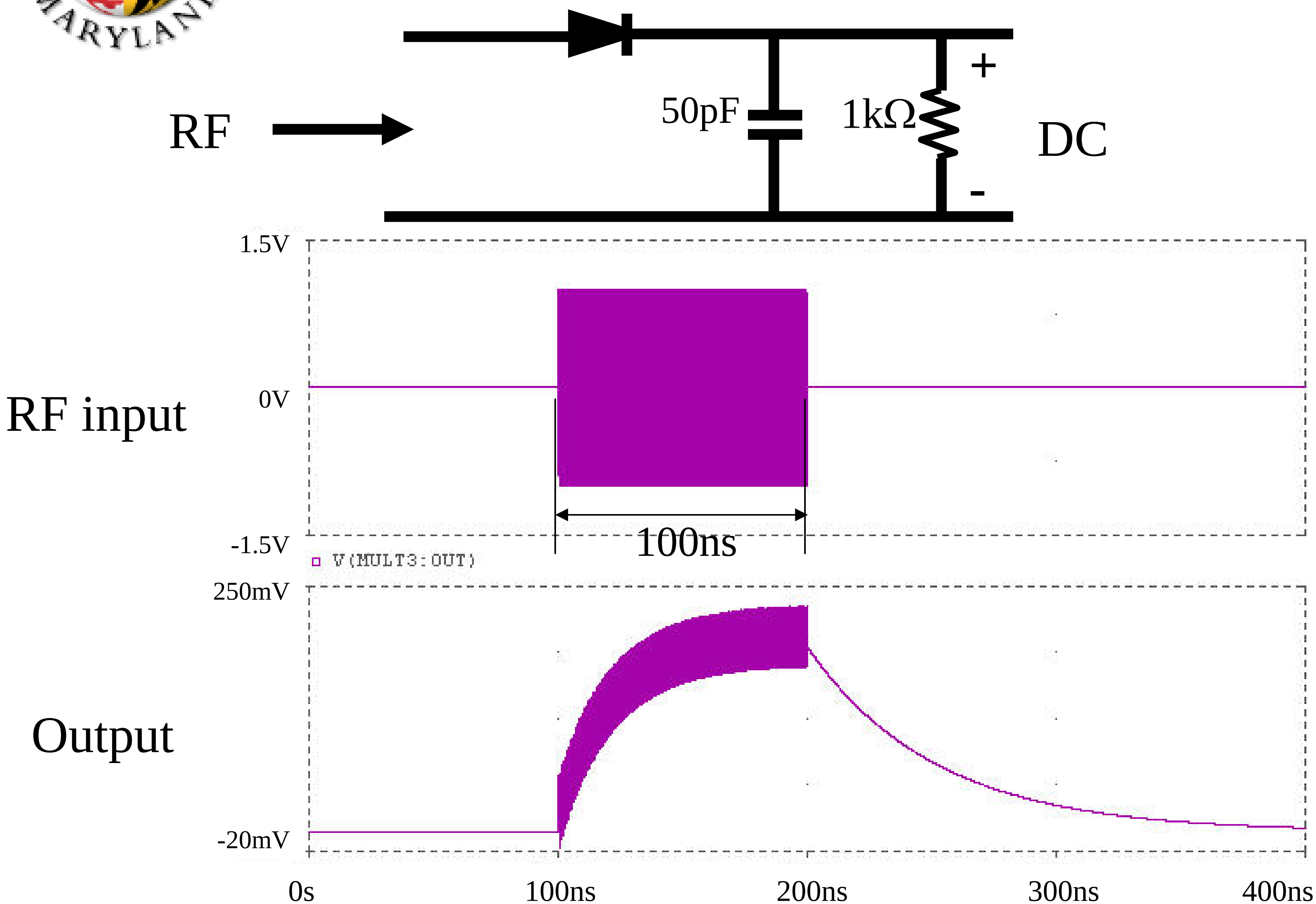
Changes to Objectives:

- Thermal detectors not pursued
- Concentrate on lower frequency <10GHz
- MOSFET power detectors included

Outline

- Operation of Schottky power detector
- Fabricated Schottky diodes by CMOS process
- Fabricated Schottky diodes by FIB as a post CMOS process
- MOSFET power detector
- Effect on adding power detector to a logic circuit
- Conclusion and future work

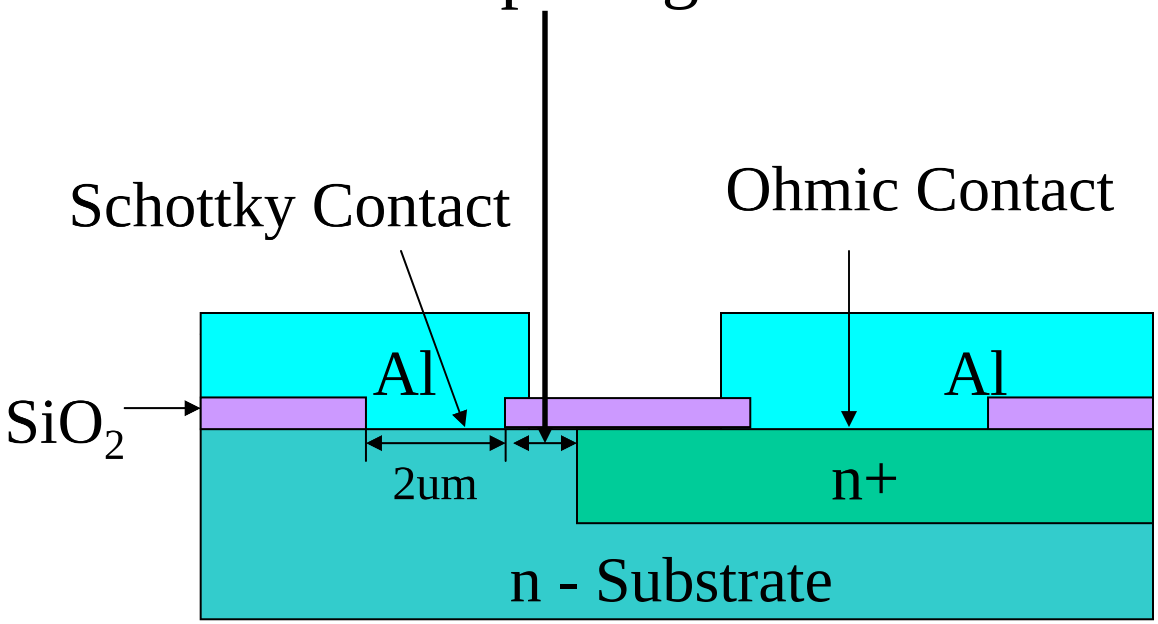
Operation of RF Power Detector



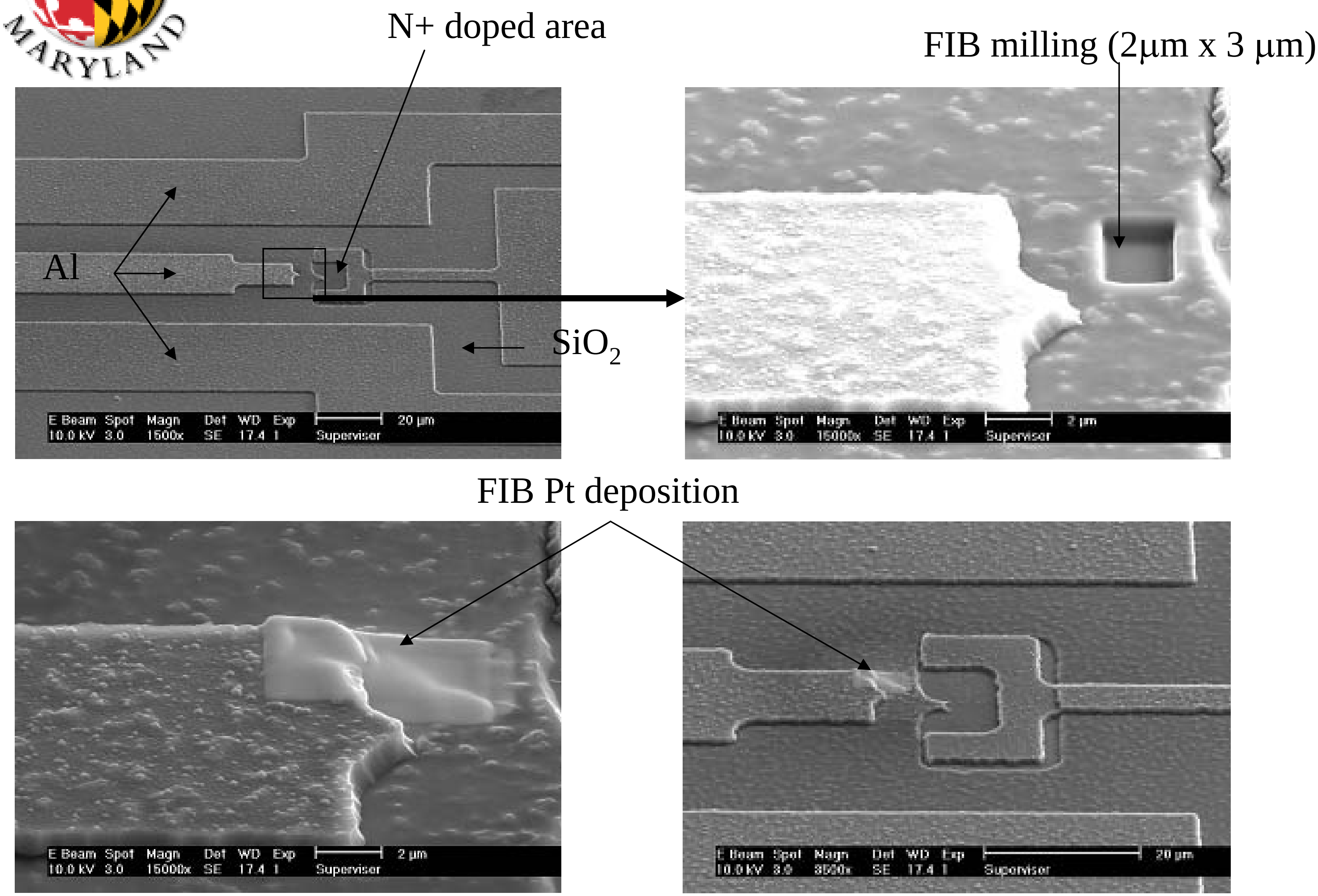
Schottky diode Design for CMOS process

➔ Design a diode structure to minimize series resistance of n layer without using Silicon Molecular Beam Epitaxy(Si-MBE)

➔ Minimize contact spacing



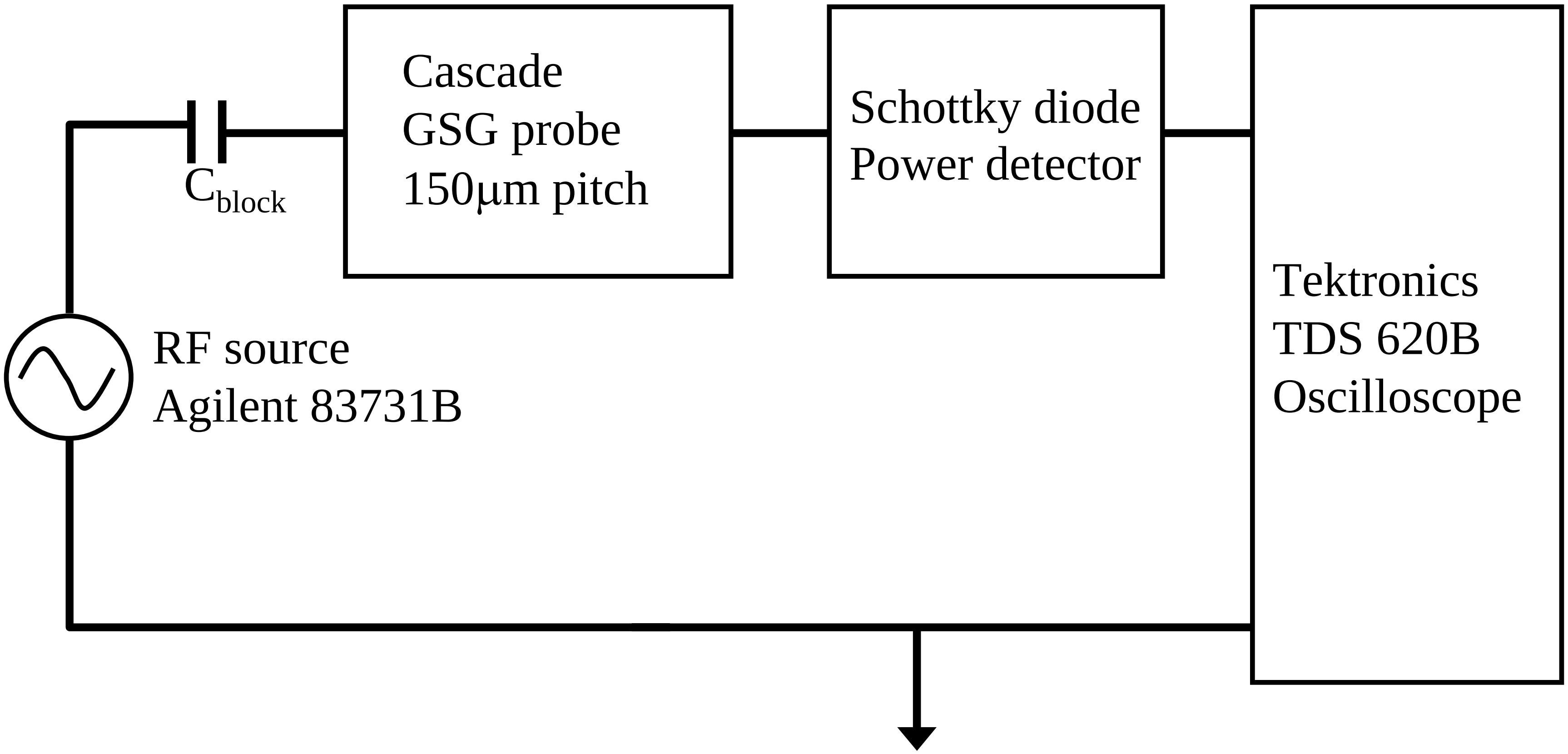
Fabrication of Schottky diode by FIB



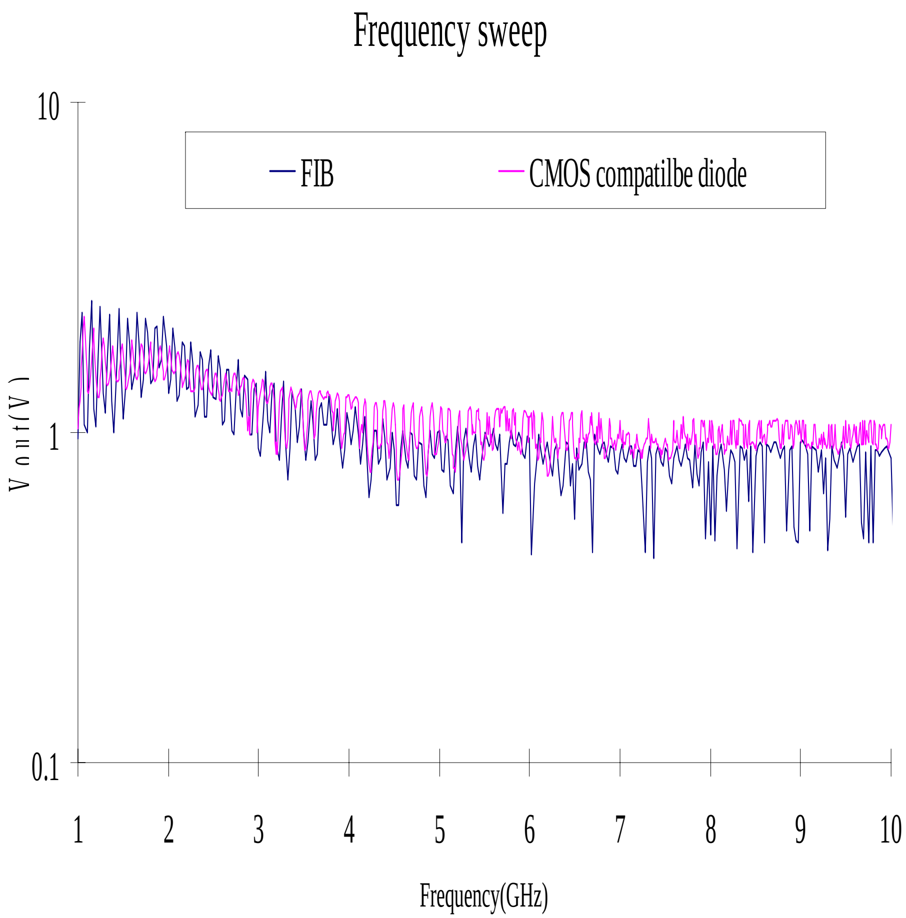
2µm scale

20µm scale

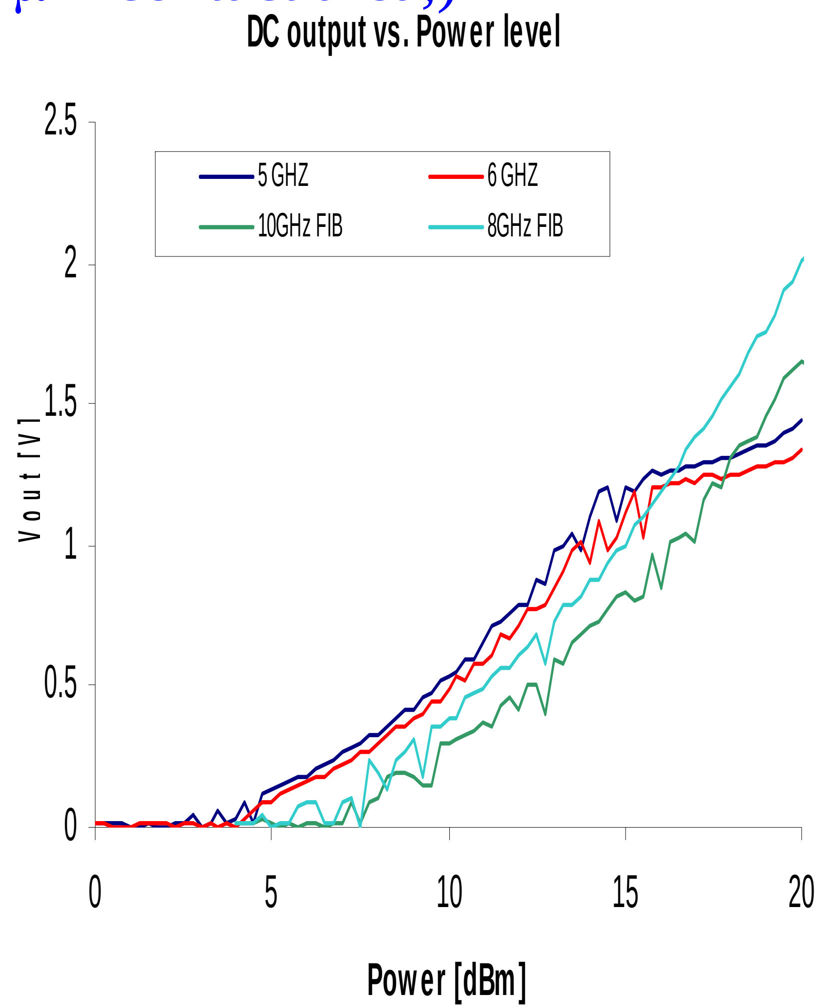
RF direct injection test measurement setup



RF direct injection test of evaporated contact diode and FIB diode made at UMd (2µm x 3 µm contact area,)

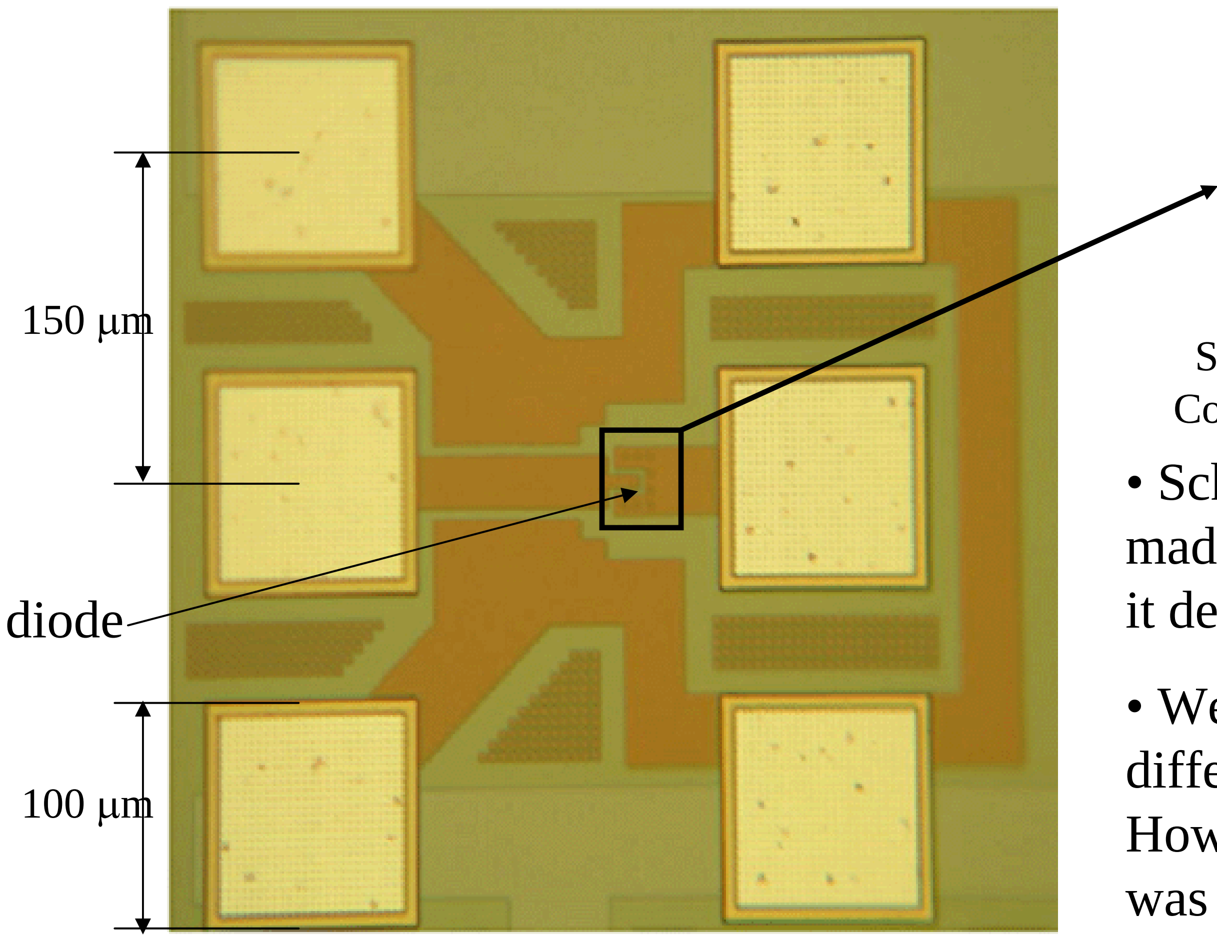


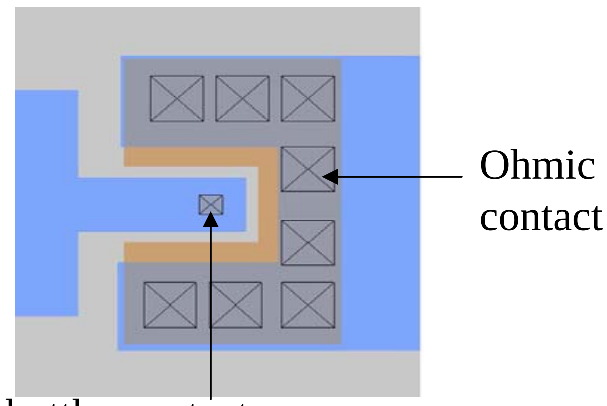
Vout vs. Frequency sweep



Vout vs. RF power sweep

Photo of diode structure with test pads for Cascade probe made by MOSIS CMOS process



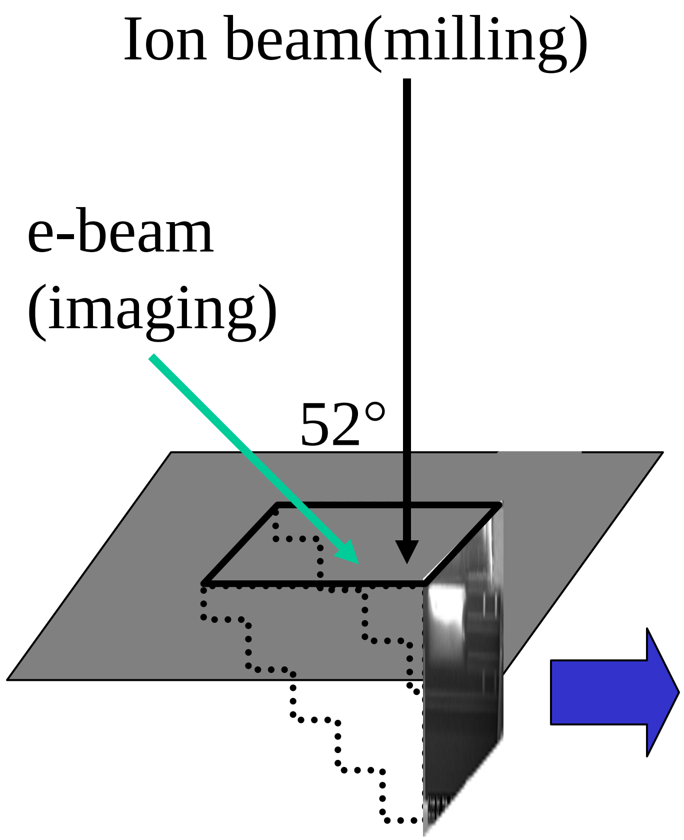


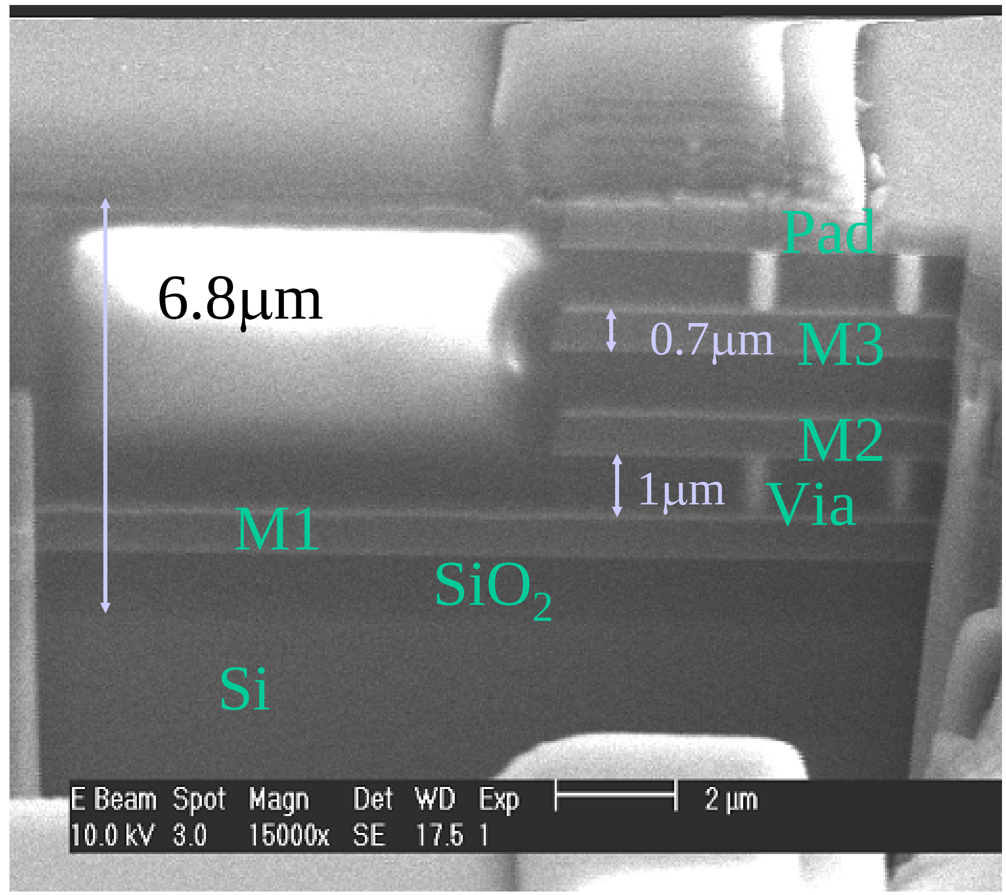
Contact area: 2x2 μm^2 - 40x 40 μm^2

- Schottky contact could not be made on CMOS process, though it depends on CMOS run itself.
- We have tried 4 times with different CMOS process. However, no Schottky contact was made.

➔ Post CMOS process required

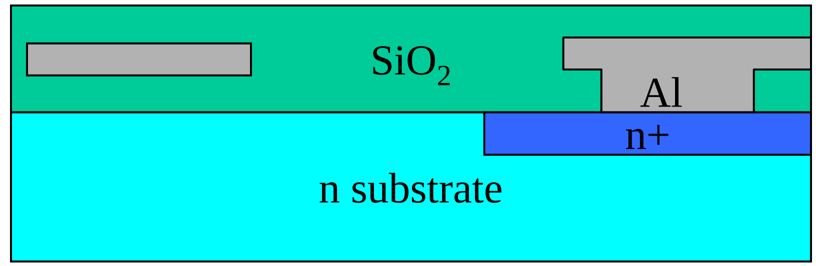
Cross section a CMOS chip



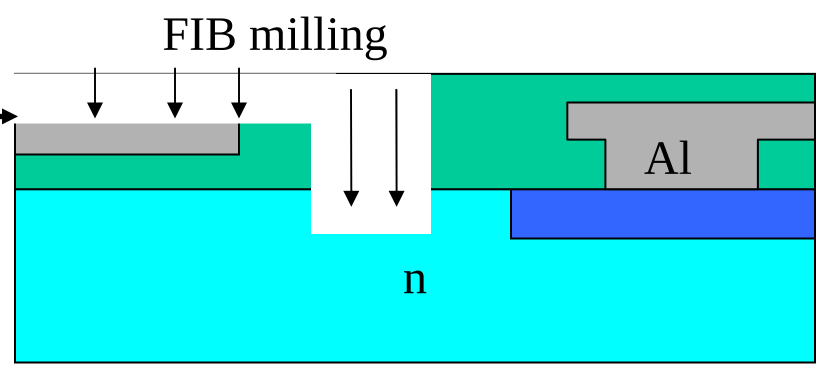


Fabricating Schottky diodes on CMOS chip by FIB

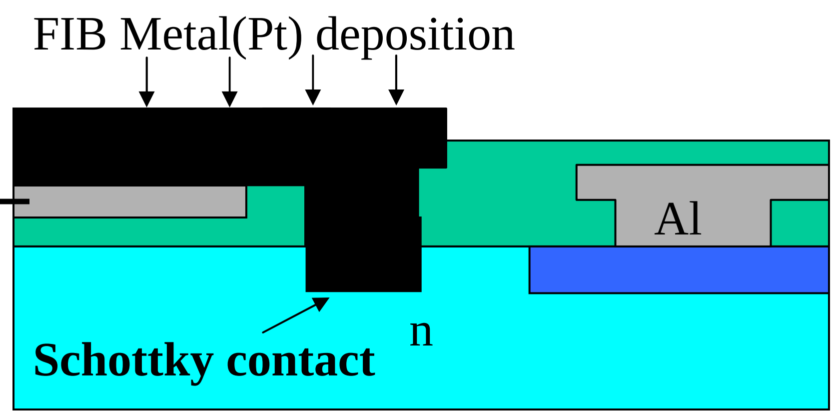
Start with a CMOS chip



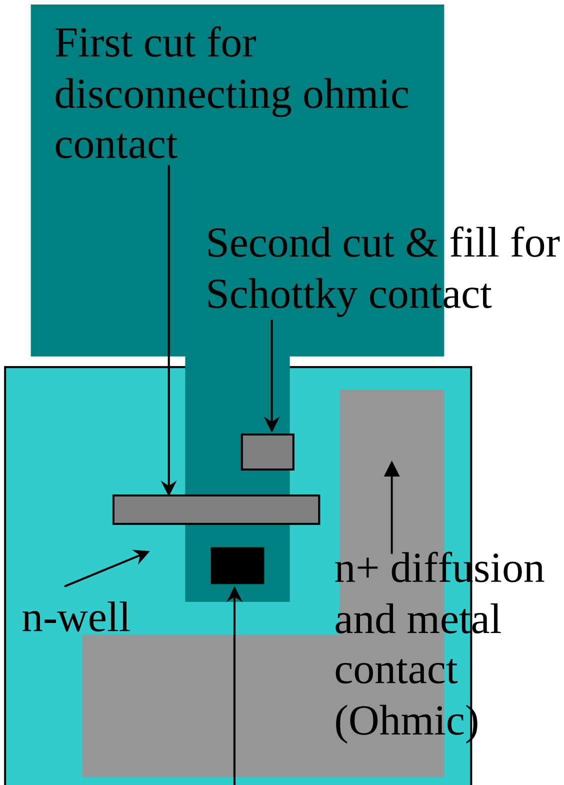
Mill SiO2 to expose metal layer for contacting to pad



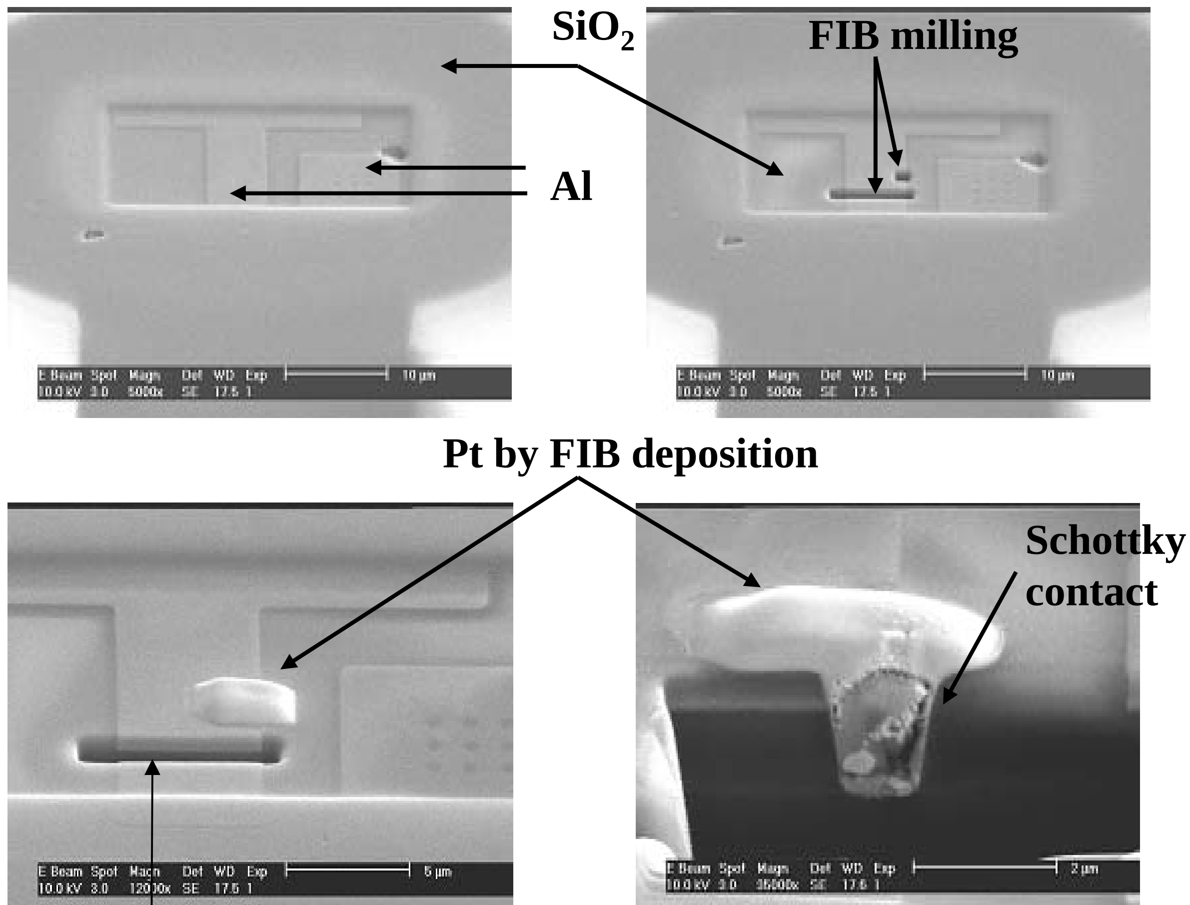
To pad for directly injecting RF signal



Fabrication of Schottky diode by FIB on a CMOS chip



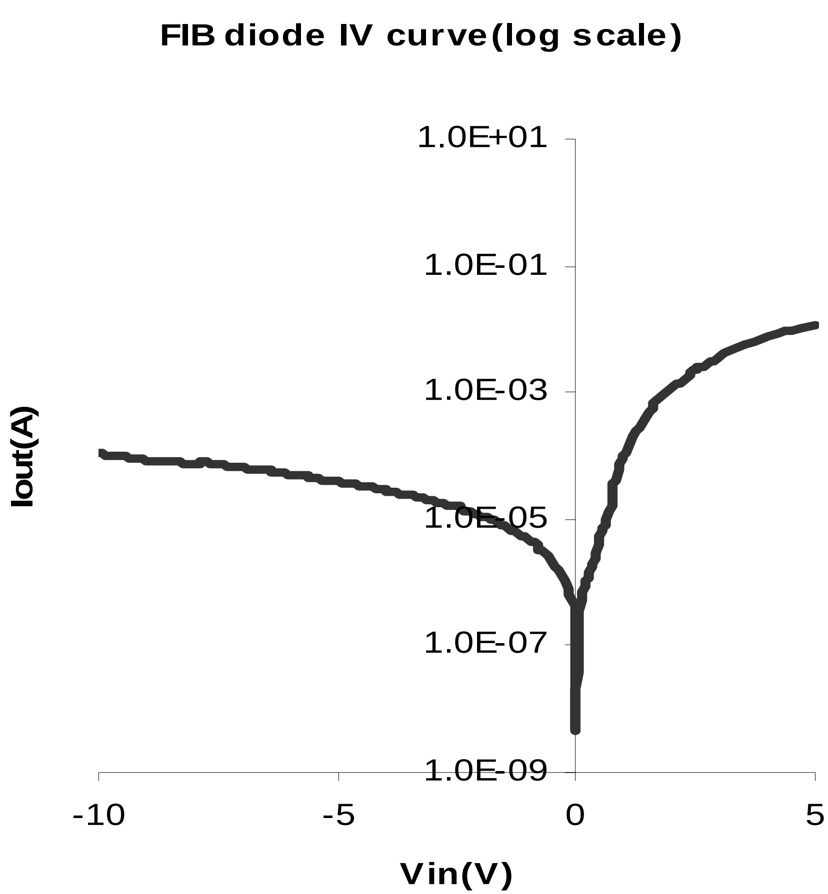
p-substrate contact - Ohmic
(Supposed to be Schottky contact)

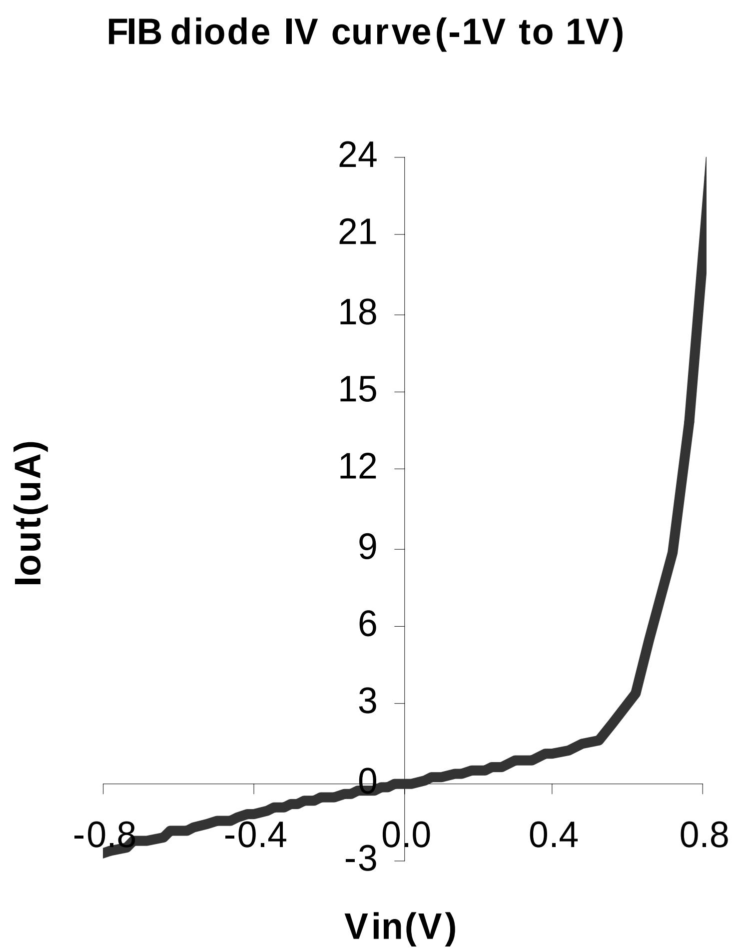


• cut to disconnect MOSIS diode

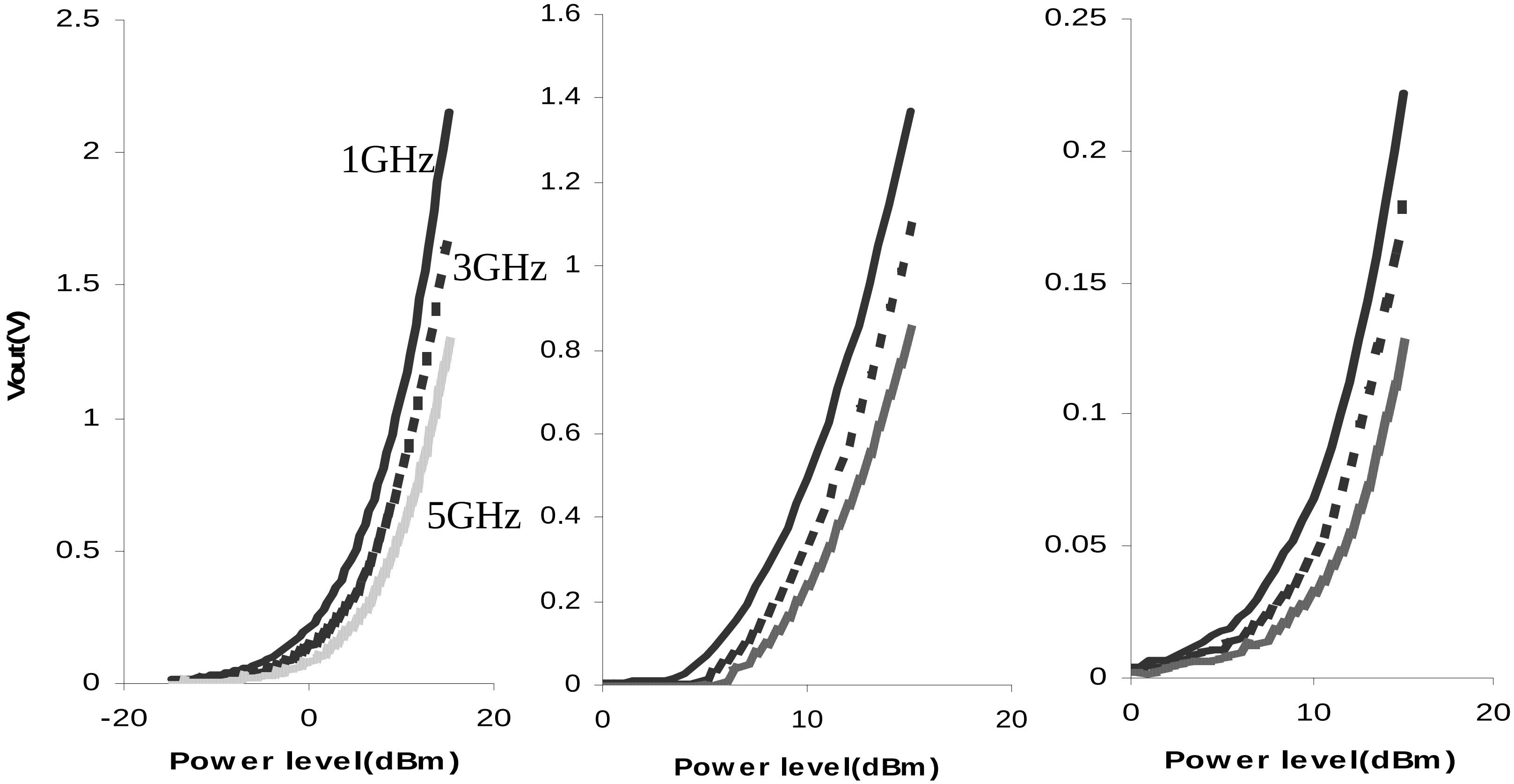
• Cross section of burned out device after applying 8V of forward bias voltage

Measured result(DC)



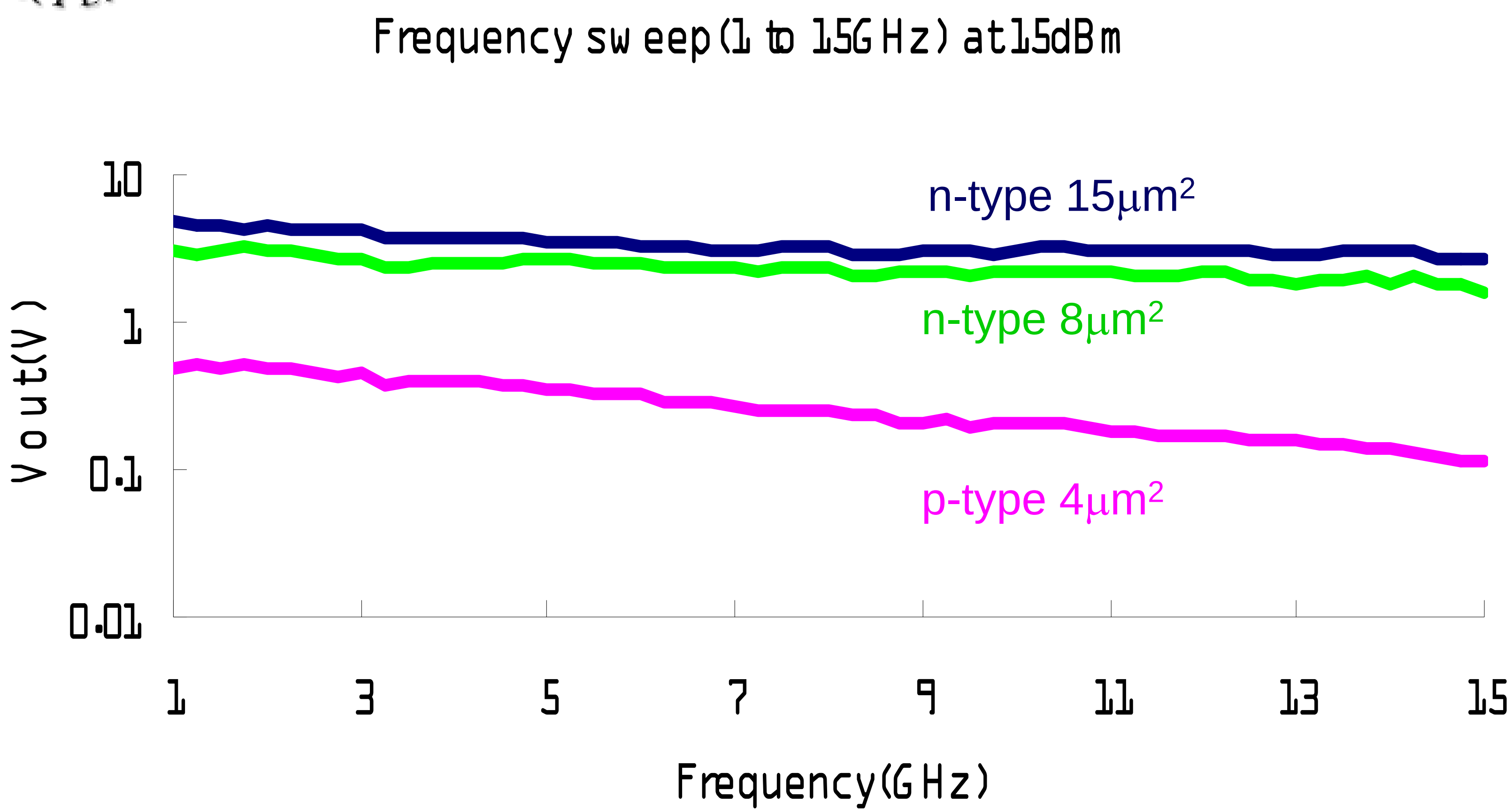


Measured result (Power sweep)



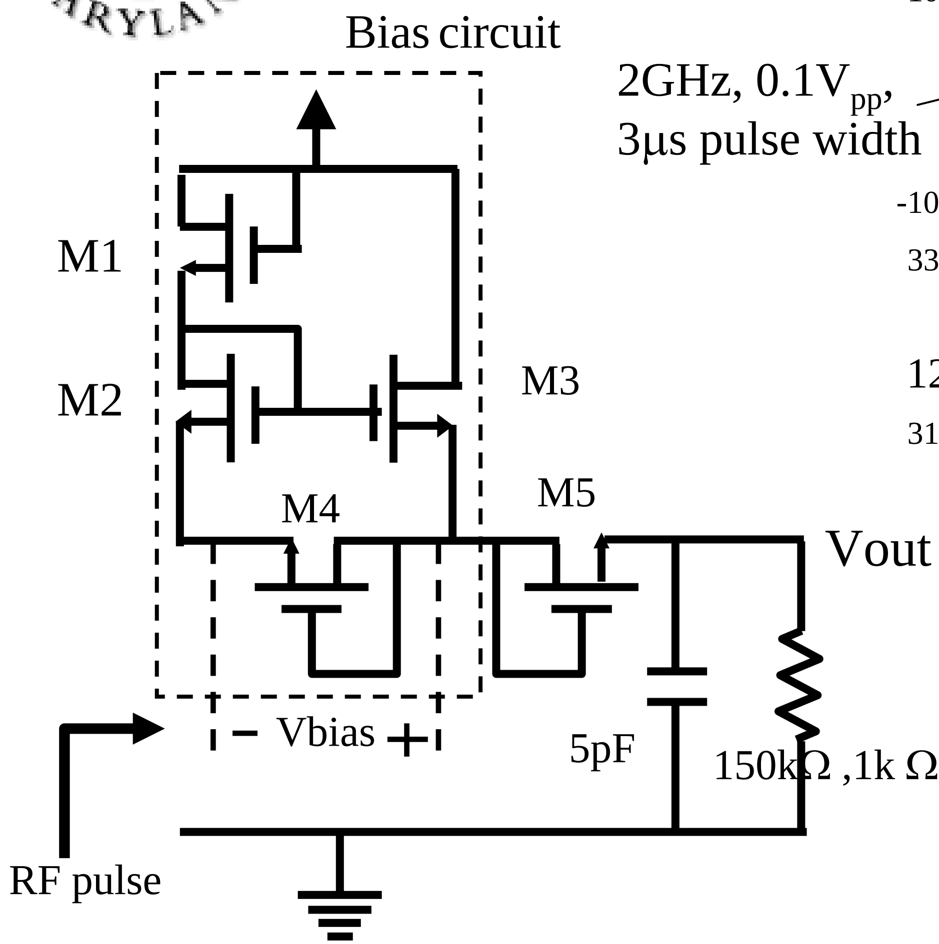
Power sweep at 1GHz, 3GHz, and 5GHz for three diodes: n-type 15μm^2 diode, 6μm^2 diode, and p-type 4μm^2 Schottky diode, respectively

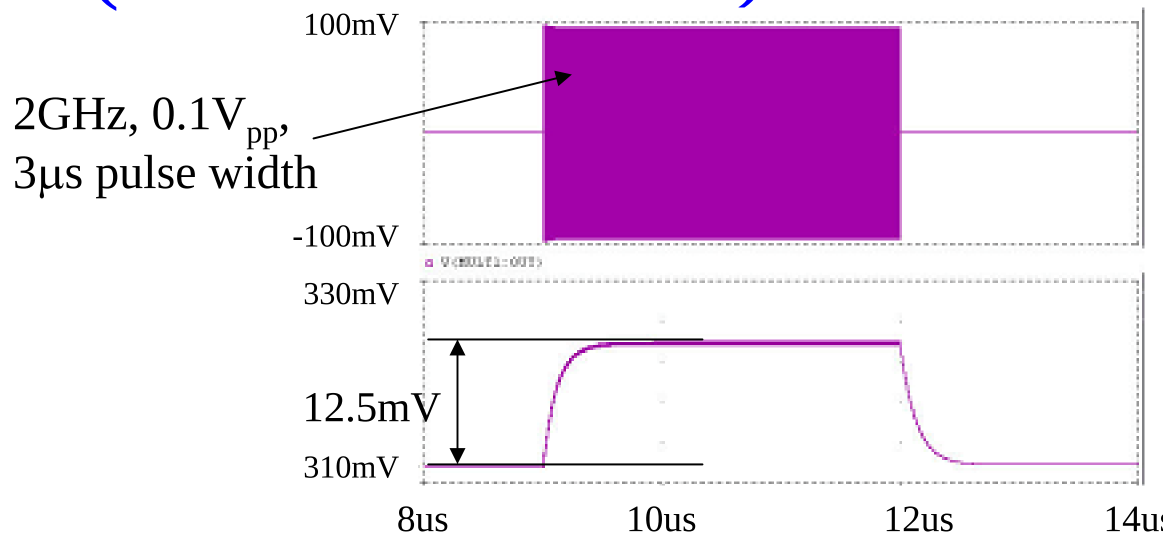
Measured result (Frequency sweep)

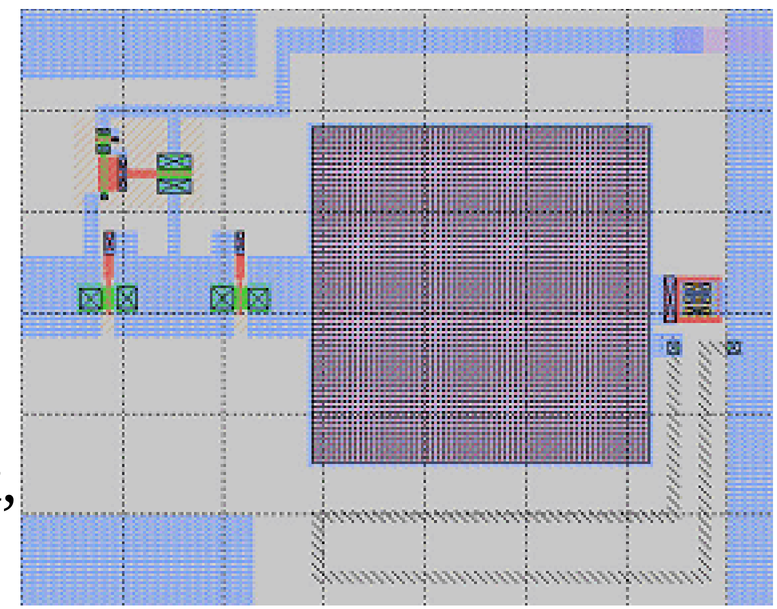


Frequency sweep from 1GHz to 15GHz at 15dBm

Alternative CMOS design (MOSFET diode)

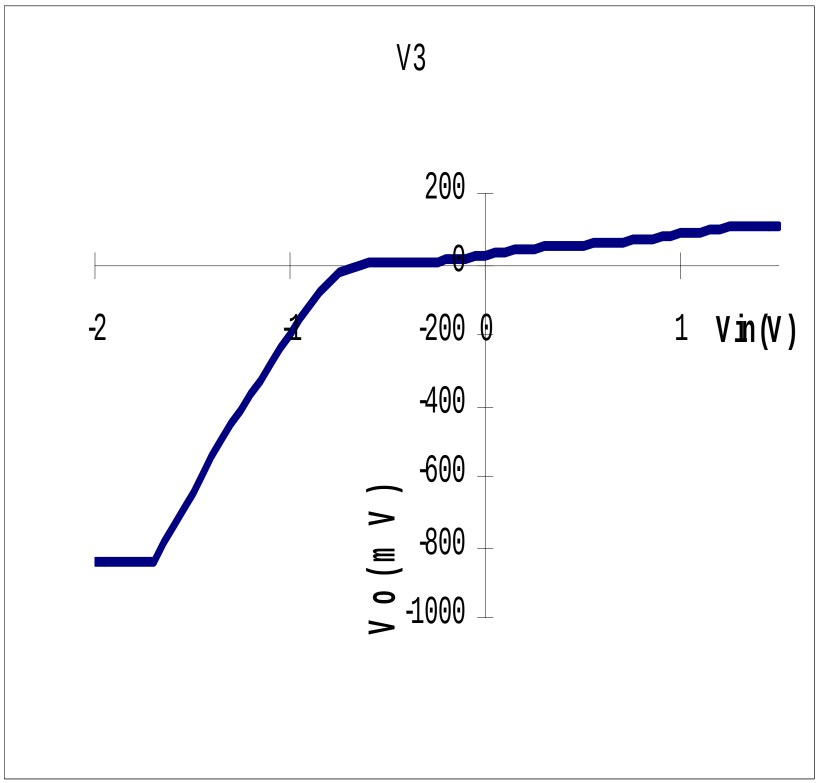


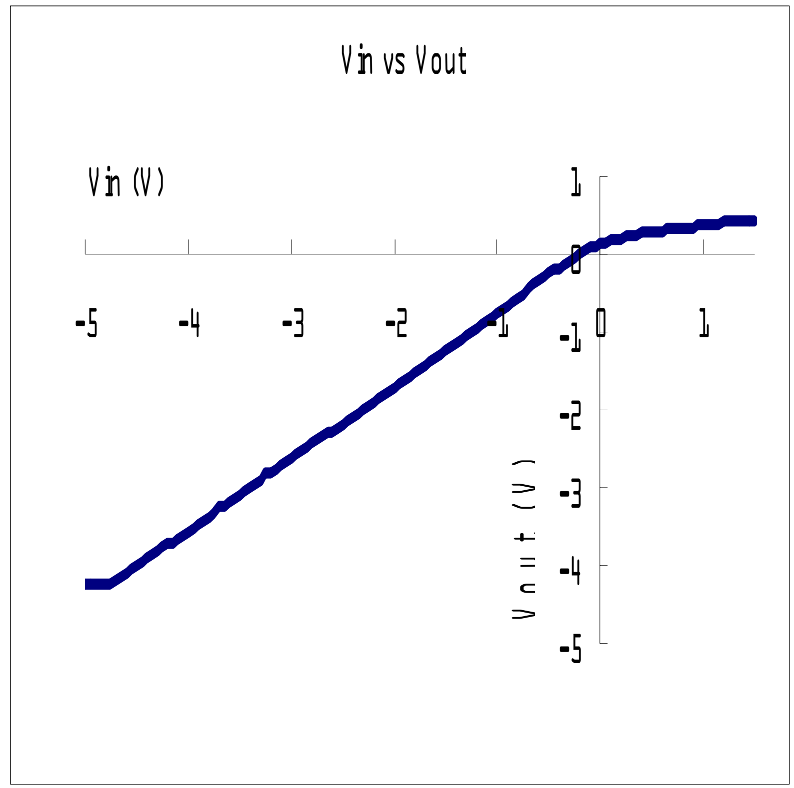




MOSFET diode power detector circuit, Pspice simulation result, and layout

MOSFET diode measured result
(Vin vs Vo curve)



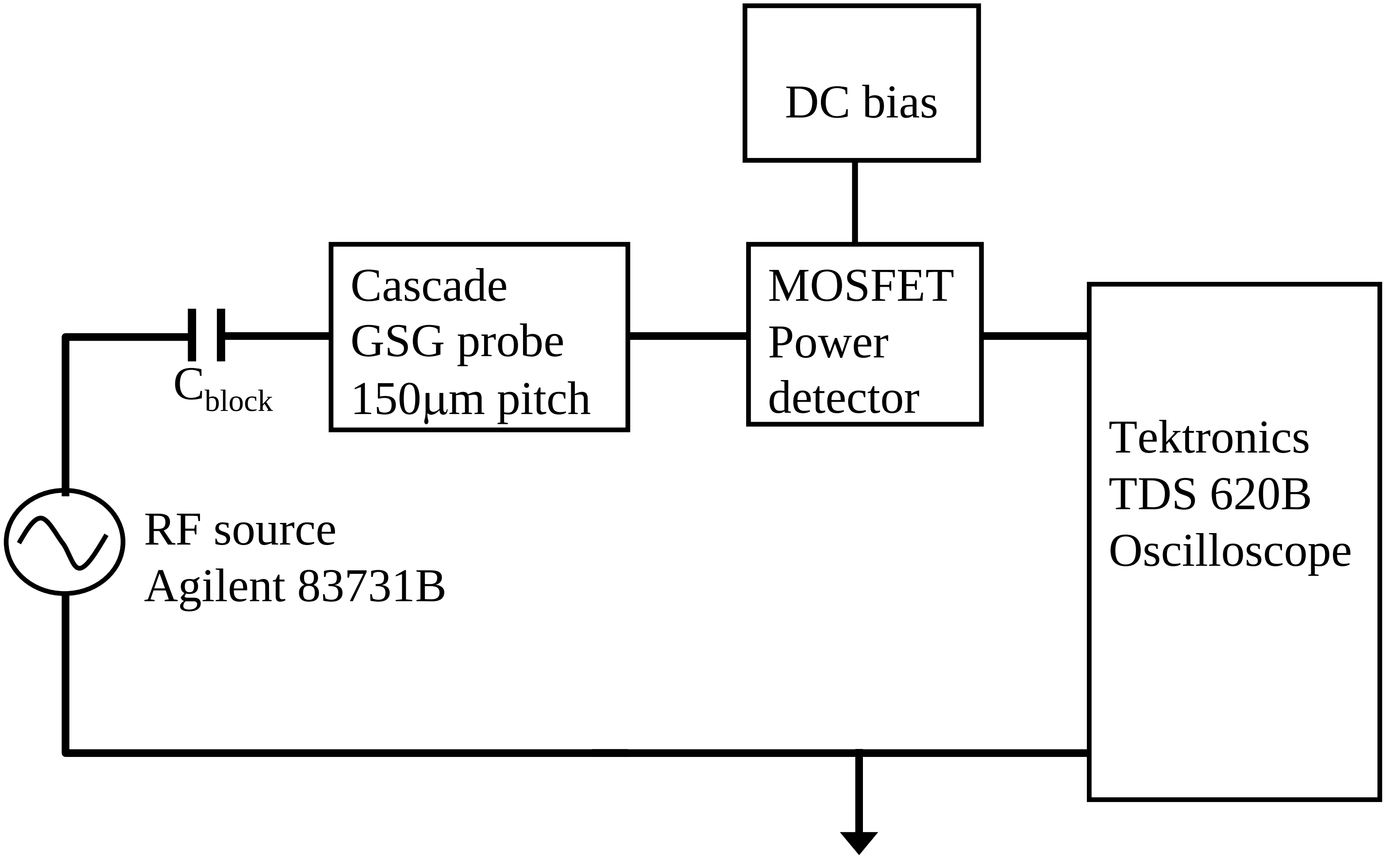


- Detector with 1kΩ load

➔ Negative detectors.

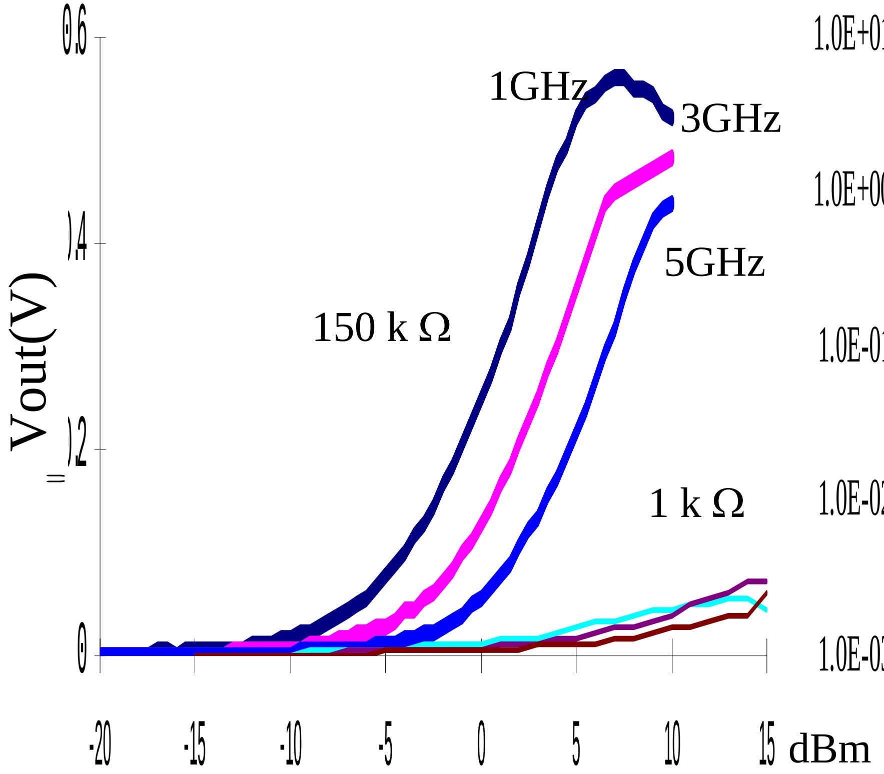
- Detector with 150kΩload

RF direct injection test measurement setup

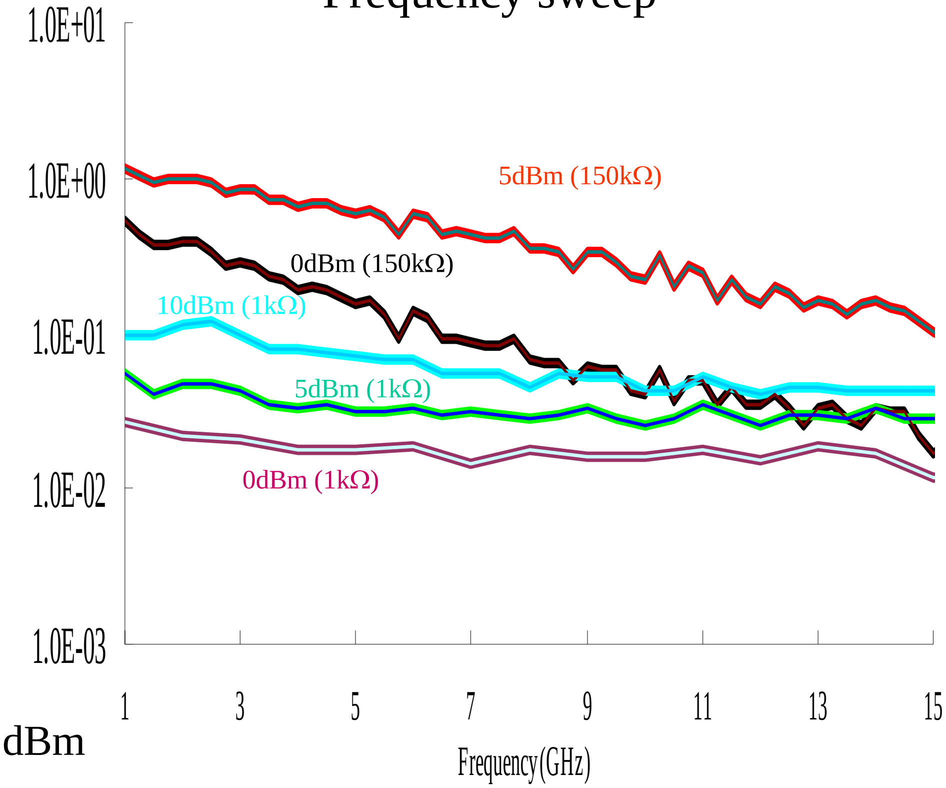


MOSFET detector measured result
(RF direct injection with 1kΩ & 150kΩ load)

Power sweep

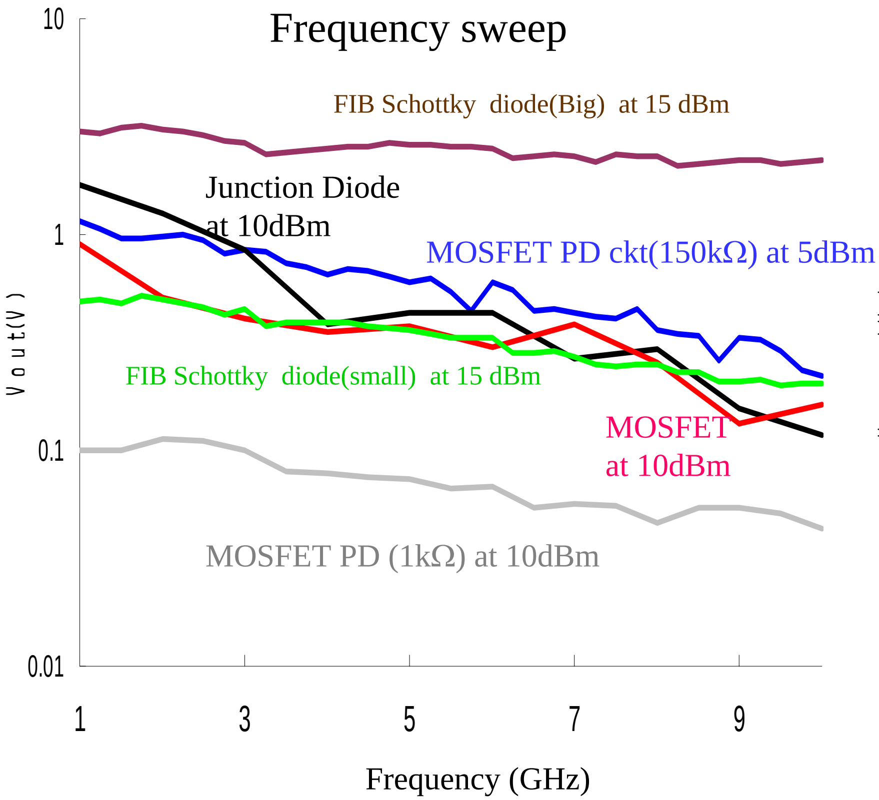


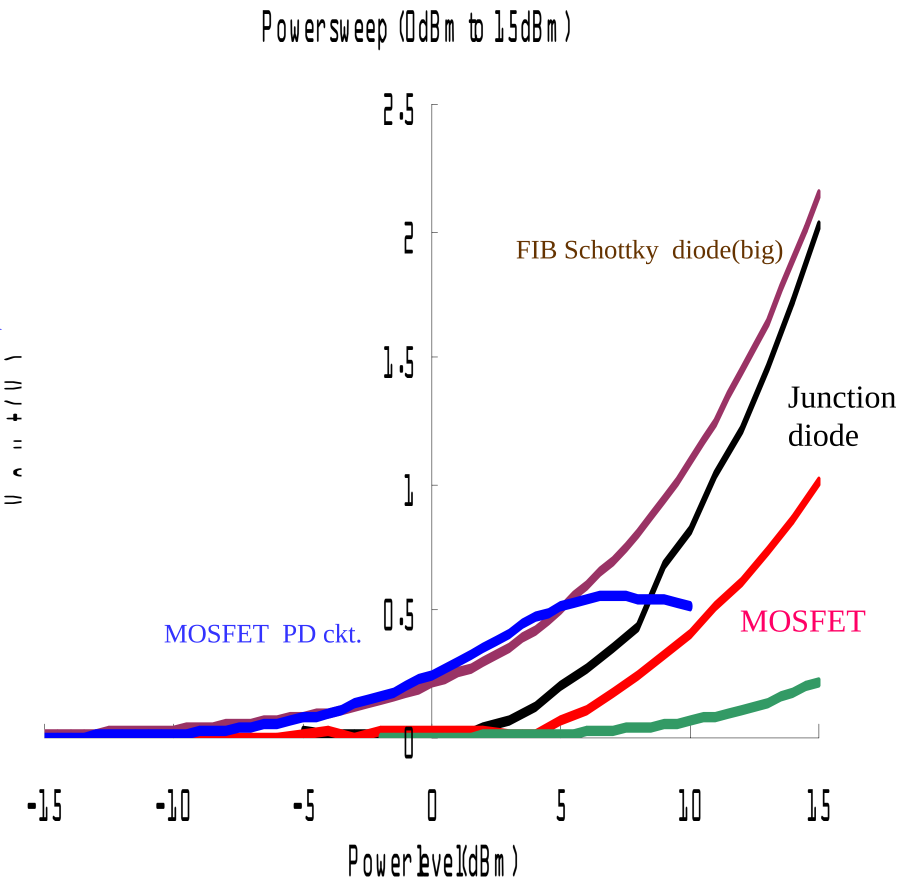
Frequency sweep



- Power sweep from –20dBm to 15dBm at 1GHz, 3GHz, and 5GHz
- Frequency sweep from 1GHz to 15GHz
- Pulse response time was 56 to 104nsec (1kΩ load) and 200 to 700nsec (150kΩ load) to –5 to 5dBm at 1 to 5GHz pulse

Comparison of FIB diodes, pn junction diode & MOSFET detector with & without bias





➔RF direct injection test for pn Junction diode(black line) and diode connected MOSFET(red line)

*Green line: FIB Schottky diode power detector

*Blue line: MOSFET power detector circuit for comparison

➔ Better frequency response and sensitivity

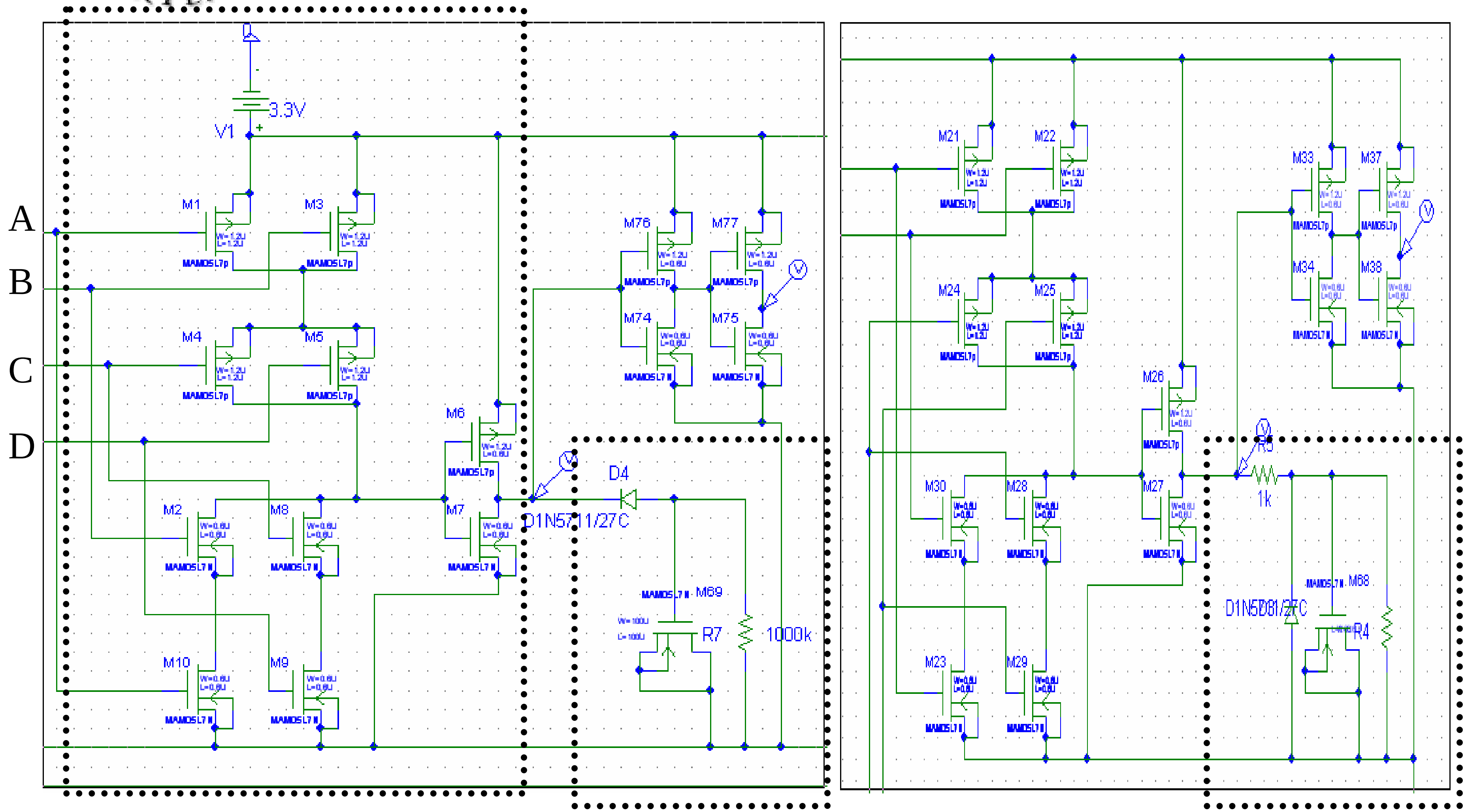
Comparison table

	FIB diode			MOSFET detector		MOSFET	Junction diode
	N-type 15μm²	N-type 6μm²	P-type 4μm²	150kΩ Load	1kΩ Load		
Pulse response time	6μsec	2.56μsec	192nsec	200nsec	56nsec	1.2μsec	16μsec
Frequency response (Vout at 1GHz / Vout at 10GHz)	1.52	1.34	2.40	5.23	2.28	5.50	14.4
Dynamic range	> 25 dBm	> 15dBm	> 15dBm	15dBm	25dBm	> 10dBm	> 10dBm
Sensitivity (smallest possible detection)	-10 dBm	5dBm	0dBm	-12dBm	-12dBm	4dBm	7dBm

➔ Short pulse (< 1 μs) detection: MOSFET detector or small p-type FIB diode detector due to its fast pulse response time

➔ Long pulse (>10 μs) detection: big n-type FIB diode is the best choice due to its flat frequency response, wide dynamic range, and good sensitivity

Effect on adding diode power detectors to a logic circuit



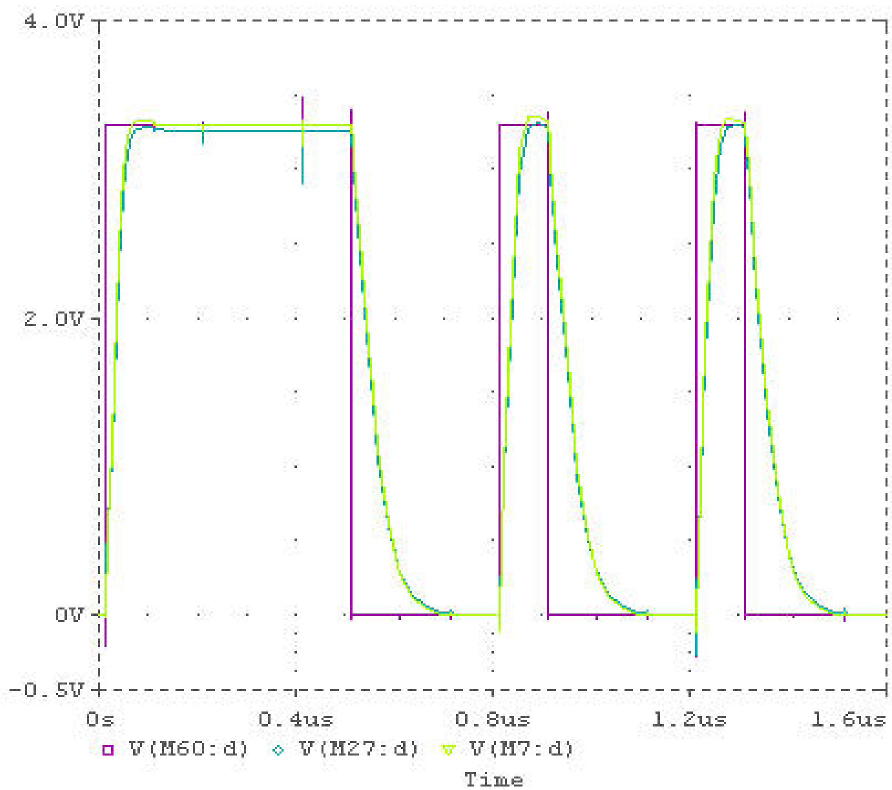
AB + CD logic circuit

Series diode detector

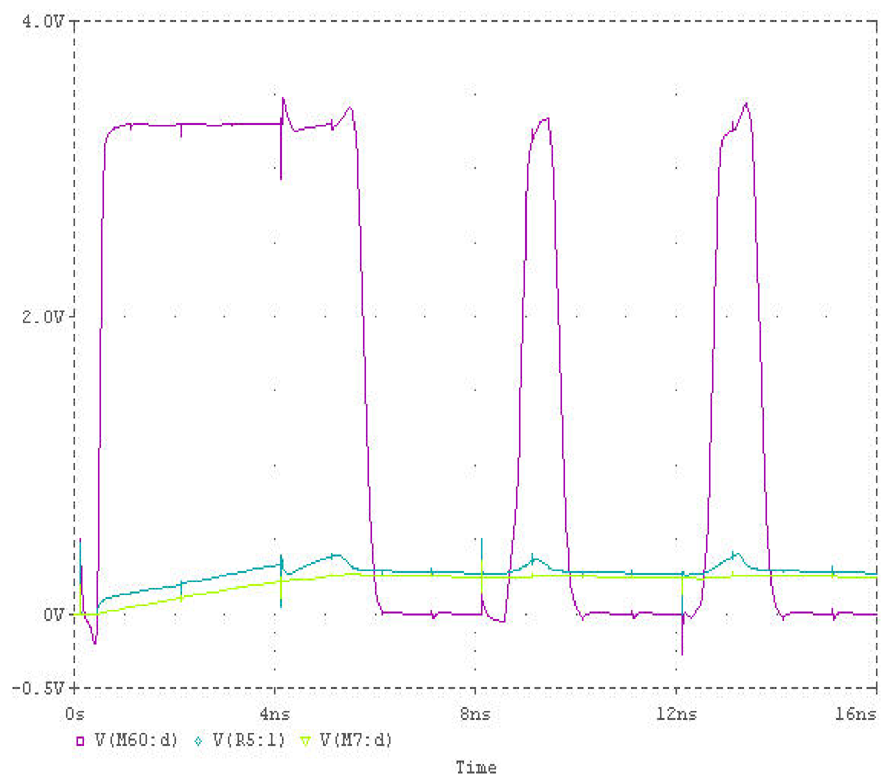
Parallel diode detector

Effect on adding diode power detectors to a logic circuit

With series diode ⸺ With parallel diode ⸺ Without detector ⸺



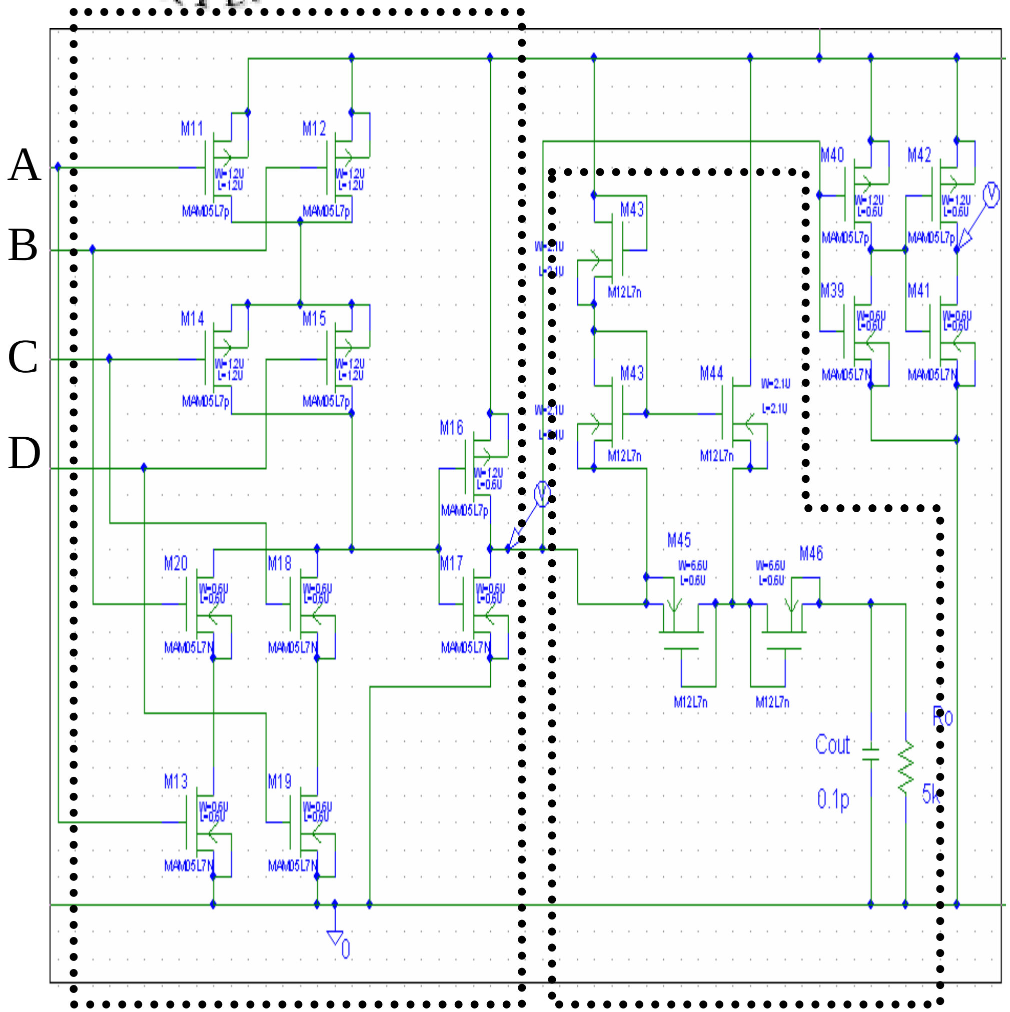
Low clock frequency (10MHz)



High clock frequency (1GHz)

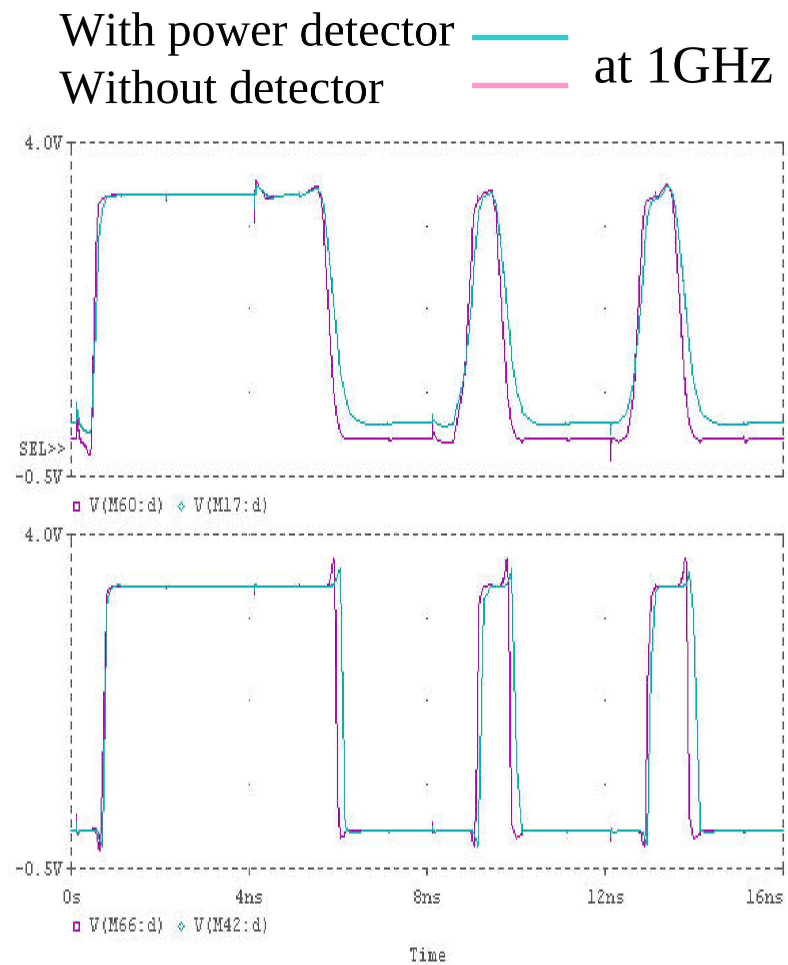
➔ Change output value when clock frequency becomes higher

Effect on adding MOSFET power detectors to a logic circuit



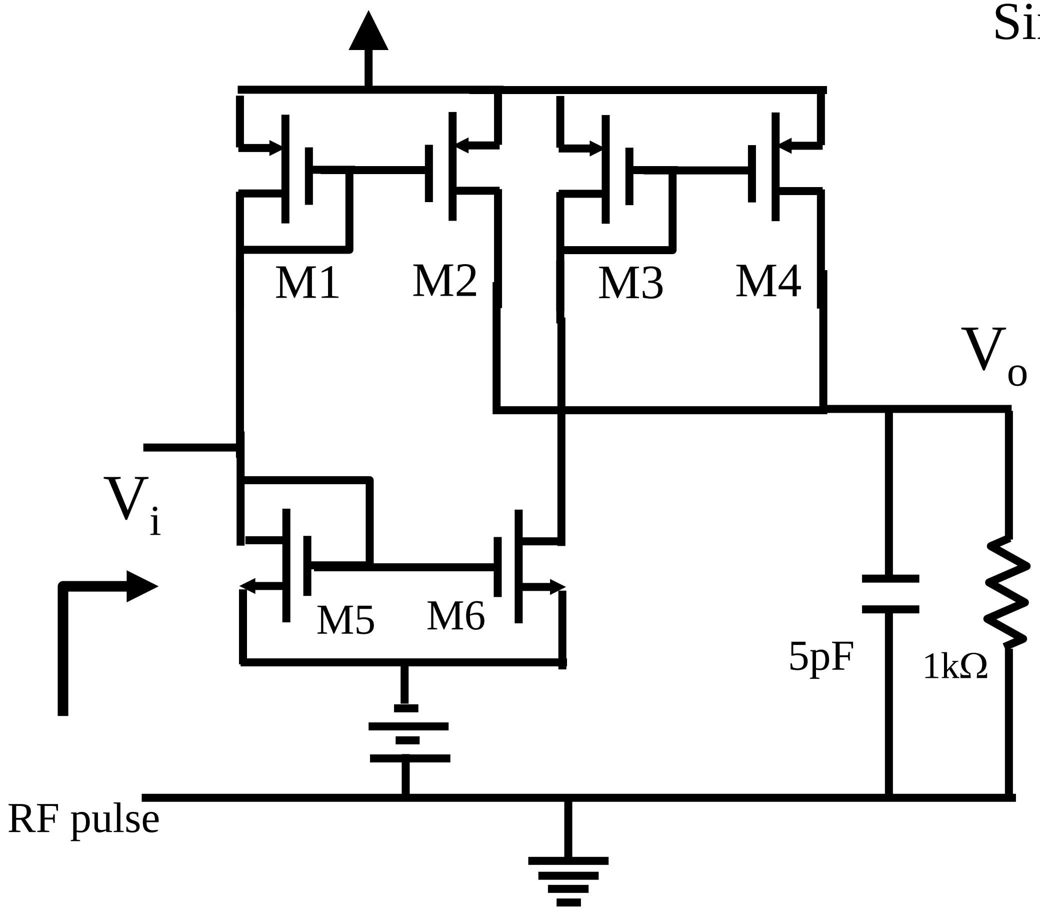
AB + CD logic circuit

Power detector

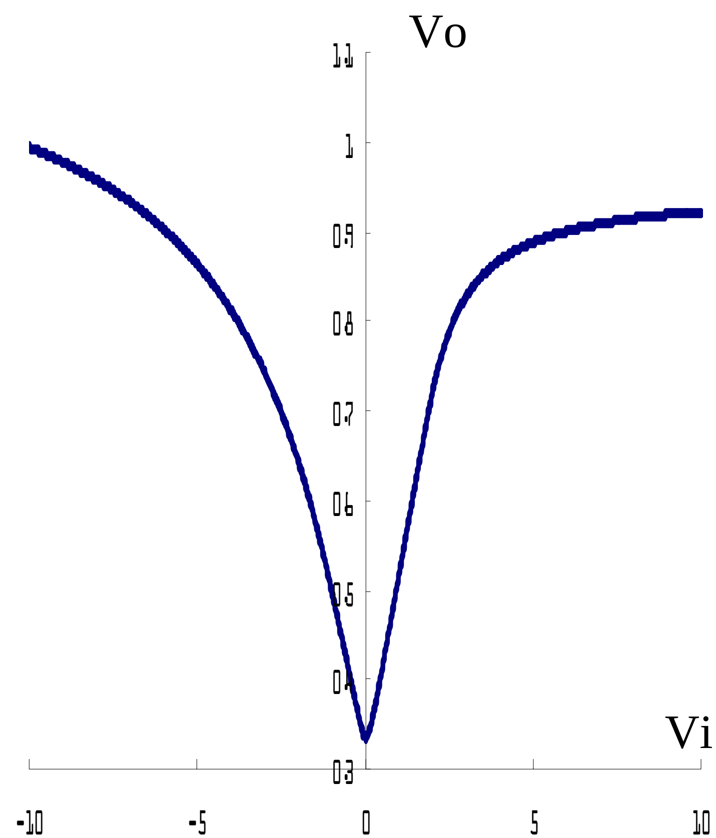


Showed a small delay, almost the same

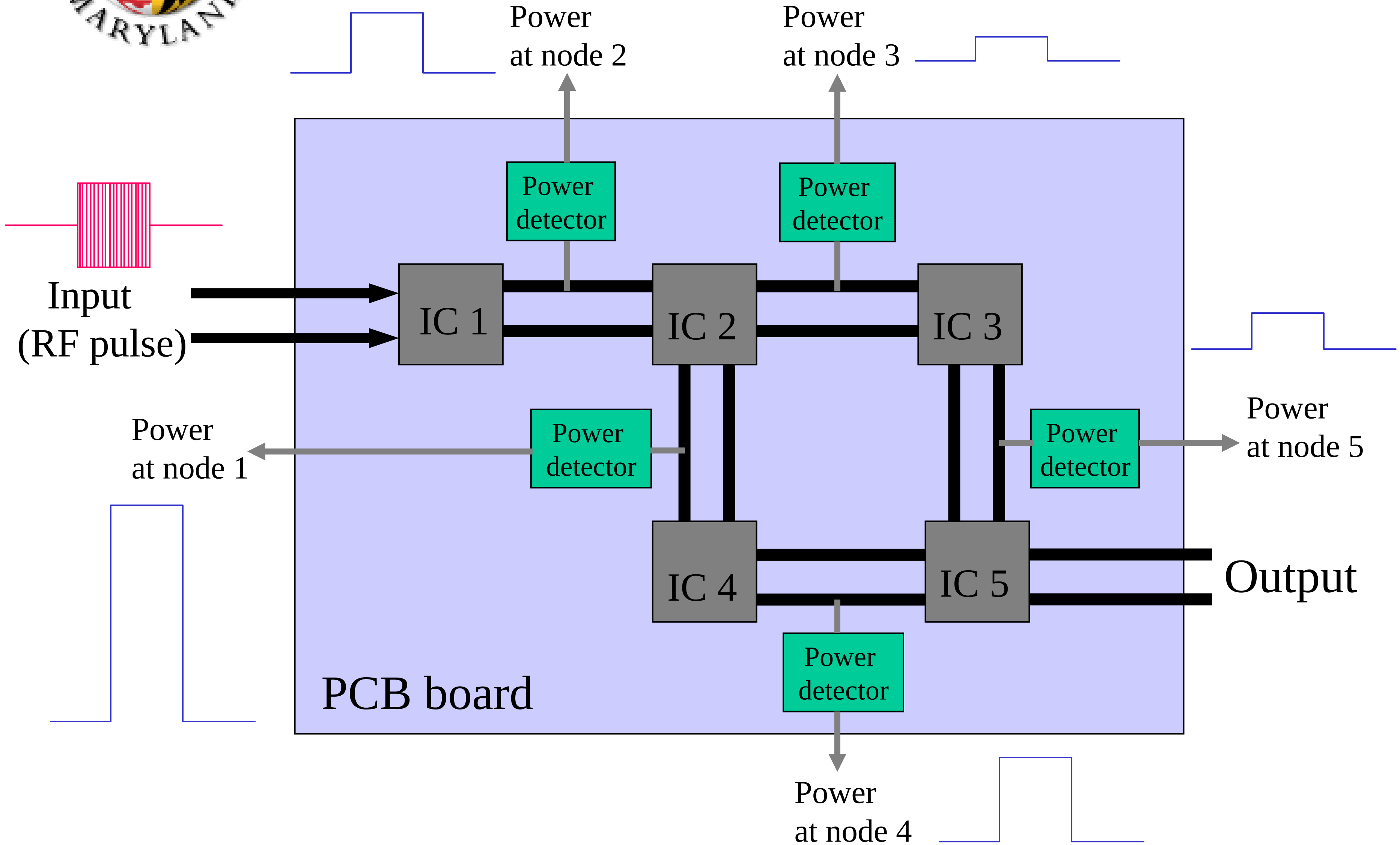
MOSFET detector circuit (Future work)
Full-wave rectifier circuit



Simulation result (Vi vs Vo, DC)



Detecting RF level on a PCB board



Summary

- Schottky diodes were attempted by AMI 1.5μ, 0.5μ, and 0.35μ CMOS process through the MOSIS
- Schottky diodes were fabricated by FIB techniques on a CMOS chip and tested up to 15 GHz
- As an alternative CMOS design, MOSFET power detector circuit designed and tested
- pn junction diode and diode connected MOSFET detector tested and compared
- Schottky diode RF detector loading of logic circuit simulated

Publications:

Woochul Jeon, Todd M. Firestone John C. Rodgers, and John Melngailis,
“Design and fabrication os Schottky diode, on-chip RF detectors”
Solid State Electronics **48**, 2089 (2004)

Woochul Jeon, Todd M. Firestone John C. Rodgers, and John Melngailis,
“On-chip RF power detector using focused ion beam as a post-CMOS fabrication process” to be published Electromagnetics Journal

Future work

- design (and implement) RF pulse detectors for system board,
- design (and implement) RF pulse detectors inside chips,
- build full wave rectifier circuits
- alter circuits with FIB
- test sensitivity of RFID tags to deprogramming with RF bursts (seeking industry funding)