Advanced Integrated Circuits and Systems Laboratory

Dr. Valencia Joyner
Assistant Professor
vjoyner@ece.tufts.edu

McMaster University
6 June 2007

Outline

- Tufts ECE Highlights
- Overview of Lab Research Thrusts
- Broadband Optical Wireless Communication
- Flip-Chip Integrated Optical Receivers
- Research Areas of Interest
- Conclusions

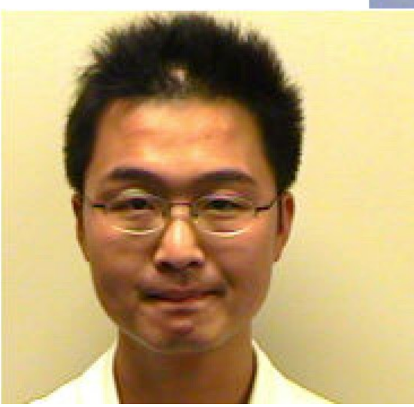
Tufts ECE Department Highlights

- People
  - 11 Faculty, 9 Adjunct Faculty
  - 55 UG, 22 Grads
- Research Areas:
  - Analog/Mixed-Signal VLSI
  - Audio Engineering
  - Control Theory
  - Digital Signal & Image Processing
  - Fault Simulation
  - Information Coding and Theory
  - Microwave Theory & Techniques
  - mm-Wave Measurements
  - Nanoscale Circuits & Systems
  - Optical/RF Comms
  - Plasma Engineering
  - Sensor Electronics

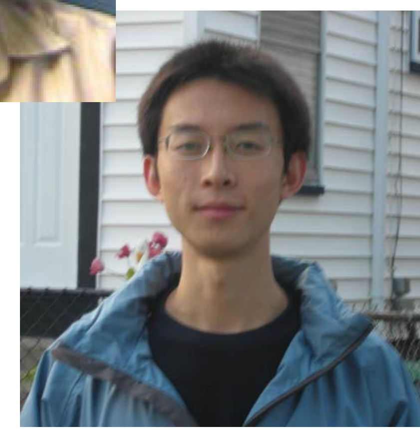
Principal Investigator

- MPhil and PhD, University of Cambridge (UK), 2003
  - Thesis: Integrated Circuit Design for Wireless Network Receivers
  - 1999 Marshall Scholar
  - NSF Graduate Research Fellow
  - 1999-2003 St. John's, Cambridge Scholar
- Assistant Professor, Tufts University, 2005-present
- VLSI Research Engineer, Information Sciences Institute, April 2004 – Sept. 2005
  - DARPA Radiation-Hardening-By-Design (RHBD) Program
  - Developed process monitor chips to track the radiation tolerance of commercial silicon processes (TF 130nm CMOS)
  - Novel RHBD techniques for implementation in silicon technologies

Current Students and Affiliates







- 2 MS, 2 PhD
- Visiting Research Scholar, Beijing Microelectronics Institute

Integrated Circuit Design Curriculum

EE103 – Introduction to VLSI Design

EE147 – Analog and Mixed Signal MOS IC Design

EE194 – Devices and Circuits for Optical Communications

EE148 – Silicon Radio Frequency IC Design

EE294 – Advanced Analog Integrated Circuits

EE117 – Introduction to Microwave Devices

EE118 – Microwave Semi Devices and Circuits

Tufts

Course Structure

- Extensive laboratory work using industry standard design tools (Example: Cadence tools, Agilent ADS, Ansoft HFSS)
- Final projects address real world design problems:
  - System to Silicon implementation
  - Chips fabricated by MOSIS in AMI 0.5u CMOS process
  - PCB design and testing part of the curriculum

Tufts Advanced Technologies Lab

- Shared Interdisciplinary Facility
  - ✓ Sensors and Instrumentation Lab
  - ✓ Micro/Nano Fab
  - ✓ Biomimetic Devices Lab
  - ✓ Soft Materials
  - ✓ Tissue Engineering
  - ✓ Soft-Bodied Robots
  - ✓ Nanoscale Circuits Lab
  - ✓ Advanced Integrated Circuits and Systems Lab

Test and Measurement Facilities

DC and High Frequency Environment

- Agilent 8510C Network Analyzer
- Anritsu MP1800A 12.5Gb/s Signal Quality Analyzer
- Agilent E4408B Spectrum Analyzer
- RF Cascade Probe station for die level testing
- Agilent and Instek Precision power supplies
- Agilent Precision digital multimeters
- Agilent High Bandwidth Mixed-Signal Oscilloscopes 54855A DSO
- Agilent High Speed Logic Analyzers 16702B
- Agilent Arbitrary Function Generators 8648B
- Weller Soldering Workstation
- ESD protected work-area

Optical Workbench for Testing and Characterization

- 10Gb/s, 1550nm Electro-optic Absorption Modulator
- Fiber Coupled Laser Source 1550nm, 1.5mW and Collimator
- Fabry-Perot Laser Diode and TEC Controller (200mA, 16W)
- Si and InGaAs photodetectors
- Optical breadboard, posts, mounting bases, and lens mounts
- Thorlabs Power Meter System with Ge Sensor
- Thorlabs XYZ Translation Stage
- Polarized HeNe Laser System

Tufts

Lab Research Thrusts

Broadband Optical Wireless Links

- Multi-Gb/s, Low-power optical transceivers for secure, high-speed data/sensor communication

Biomedical Imaging

- Imaging Receivers for frequency-domain optical mammography
- Integrated microarrays for fluorescence detection

Optoelectronic Integrated Circuits

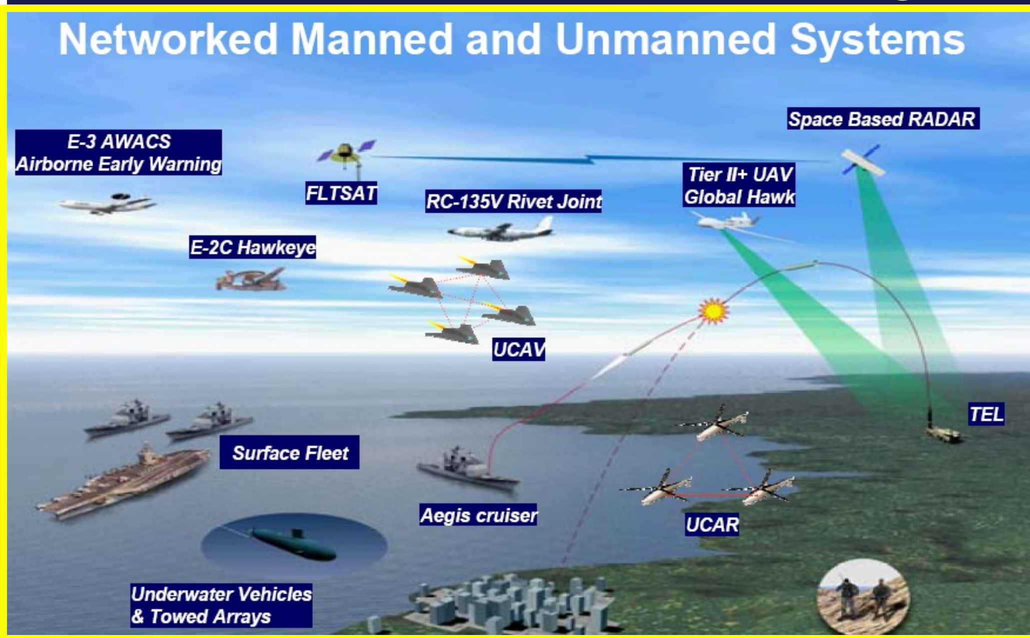
RF and Optical Networks

- High Performance ICs for integration of microwave wireless with the optical fiber backbone

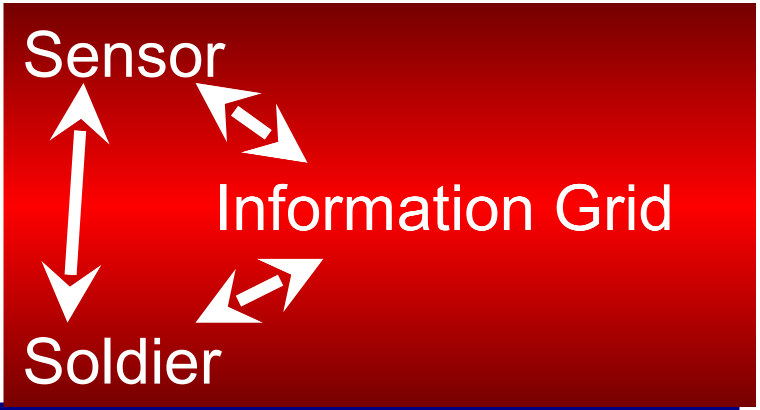
Tufts

Future Generation Communication Systems

21st Century Military/Commercial Communications will require network solutions combining wired and wireless systems



See *anything*…
From *anywhere*….
At *anytime*…



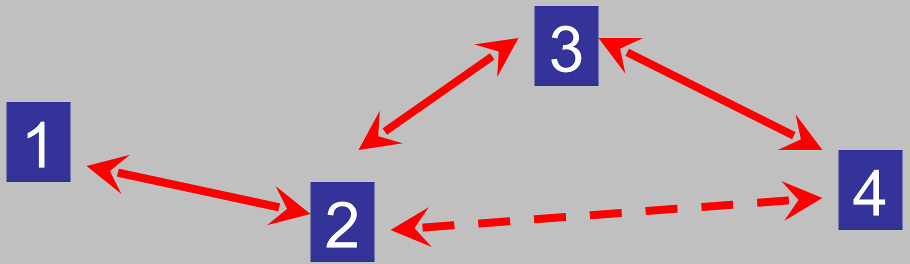
Free-Space Optical Communications brings added security and capacity

* *Dr. Steve Pappert, DARPA-MTO, "Electrons & Photons: You need both", March 2007*

Why Optical Wireless?

RF	Optical
▪ Highly Regulated Spectrum → Low data rates (10s of Mb/s) ▪ High User Mobility, Long Range ▪ High Rx Sensitivity ▪ No obstruction	▪ Unregulated THz channels ▪ No EMI → Secure Channels ▪ WDM → Higher Aggregate Capacity ▪ Baseband Processing → Low-Power Compatibility ▪ LOS channels prone to blocking

Realistic optical wireless deployments that will deliver on the promise of the technology will require reconfigurable, ad-hoc mesh networks with multi-point/hybrid transceivers

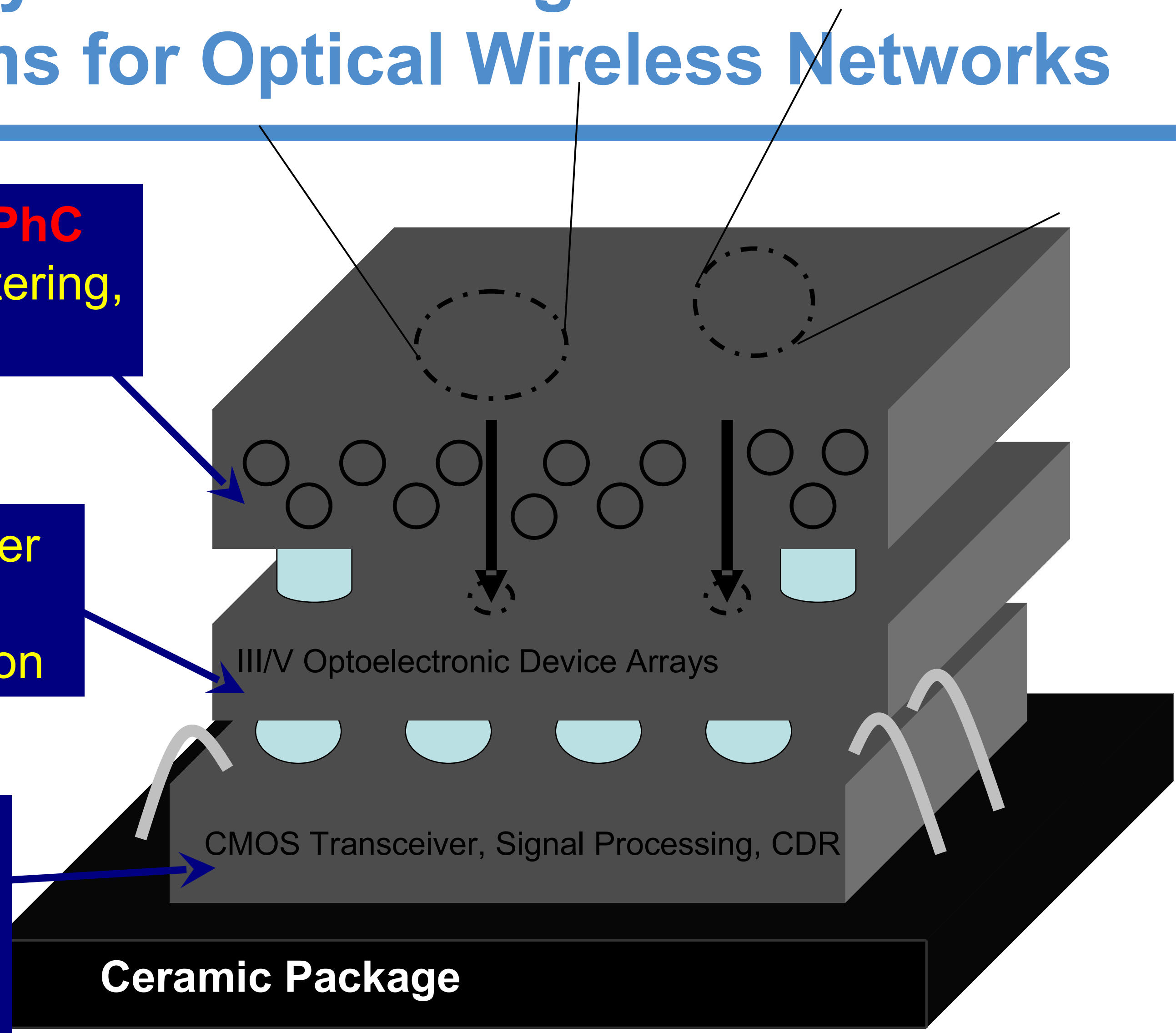


Integrated System-in-Package Microsystems for Optical Wireless Networks

Metamaterials and PhC for beam steering, filtering, waveguiding

III/V devices allow higher transmit powers and hybrid flip-chip integration

CMOS: Sensitive analog circuits integrated with low-power back-end digital processing circuits

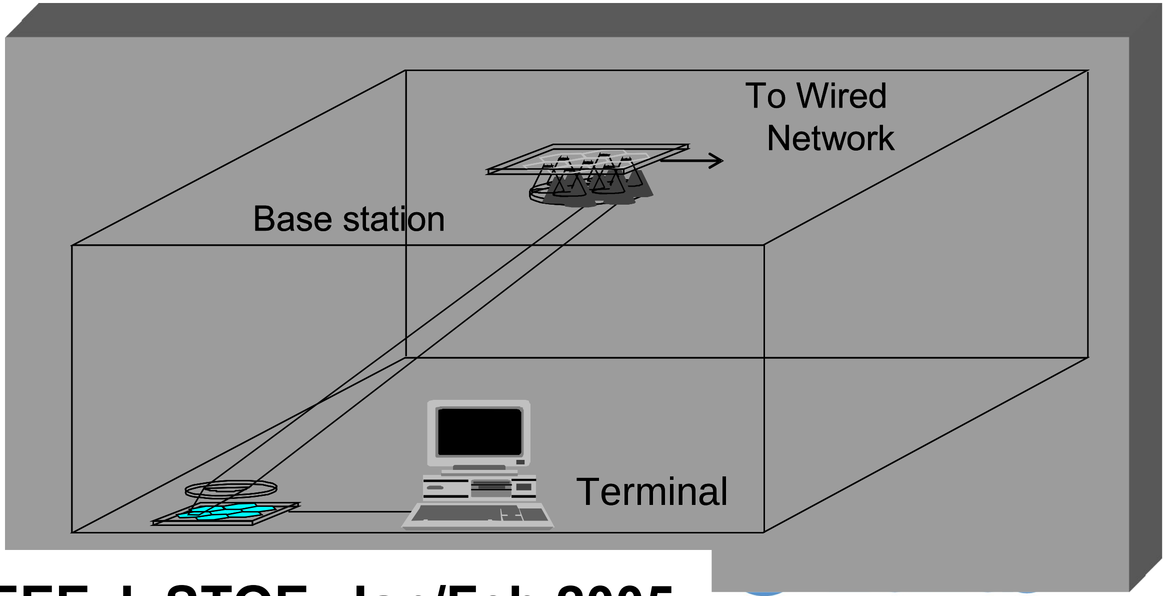


Tufts

Cellular Optical LAN Approach

4-yr Research Partnership with promising results

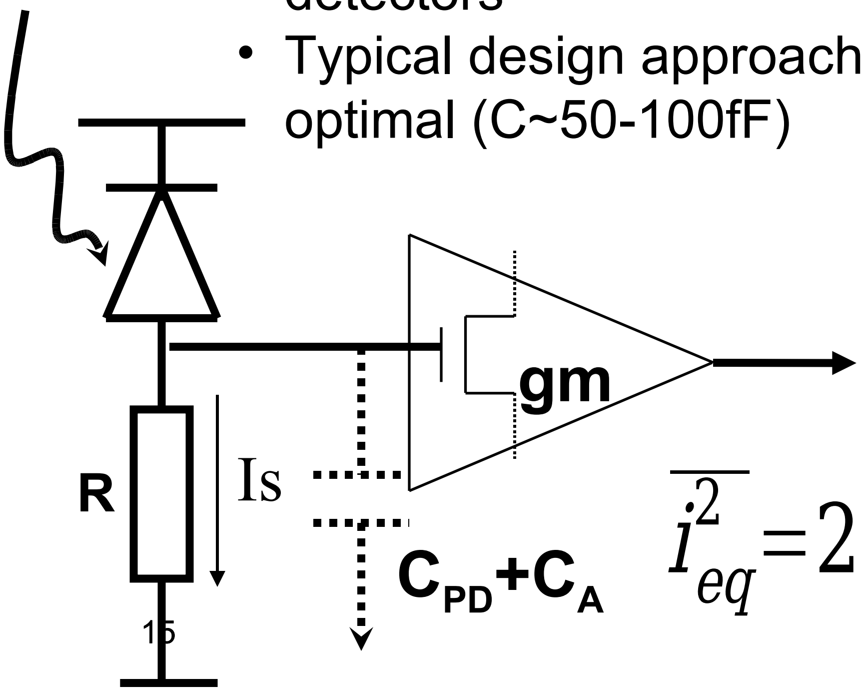
- **Integrated transceiver components**
- **Imaging optics to implement tracking**
- **Eye safe 1.3 - 1.5μm optical transmission**



***O'Brien, et al., IEEE J. STQE, Jan/Feb 2005.**

Receiver Design Challenges

- Overall System Performance limited by Rx Bandwidth and Noise:
  - Allowed Tx power level at 1550nm is 20x greater than at 880nm for Class 1 eye safety BUT
    - Long λ detectors have high C (typically 40-50pF/mm2)
    - Difficult to focus incoming radiation to allow small high bandwidth detectors
    - Typical design approaches for fiber-based receivers may not be optimal (C~50-100fF)

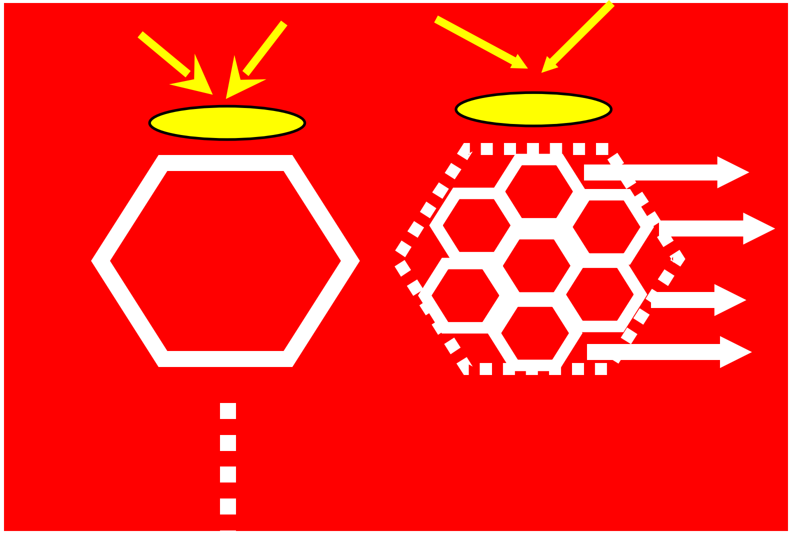


$$BW = \frac{1}{RC_{in}}$$

$$\overline{i_{eq}^2} = 2qI + \frac{4kT}{R} + \frac{4kT\gamma}{g_m}\left(\frac{1}{R^2} + \omega^2 C_{in}^2\right)$$

Receiver Design Challenges

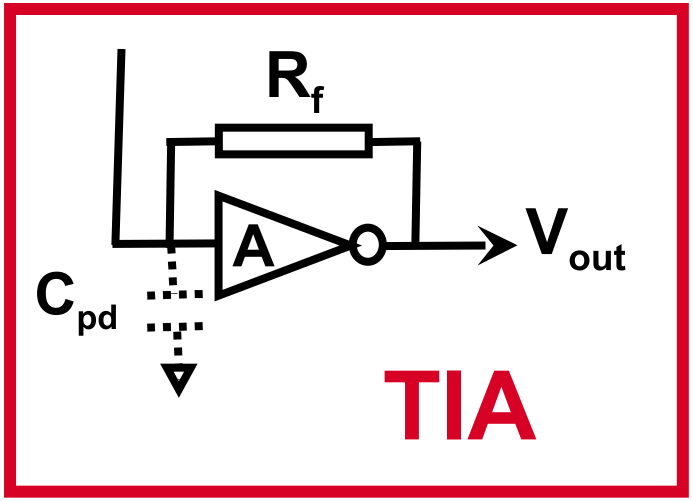
- Single element detector
  → Large area for coverage
  - Poor bandwidth
  - Ambient noise
  - Noise performance degradation



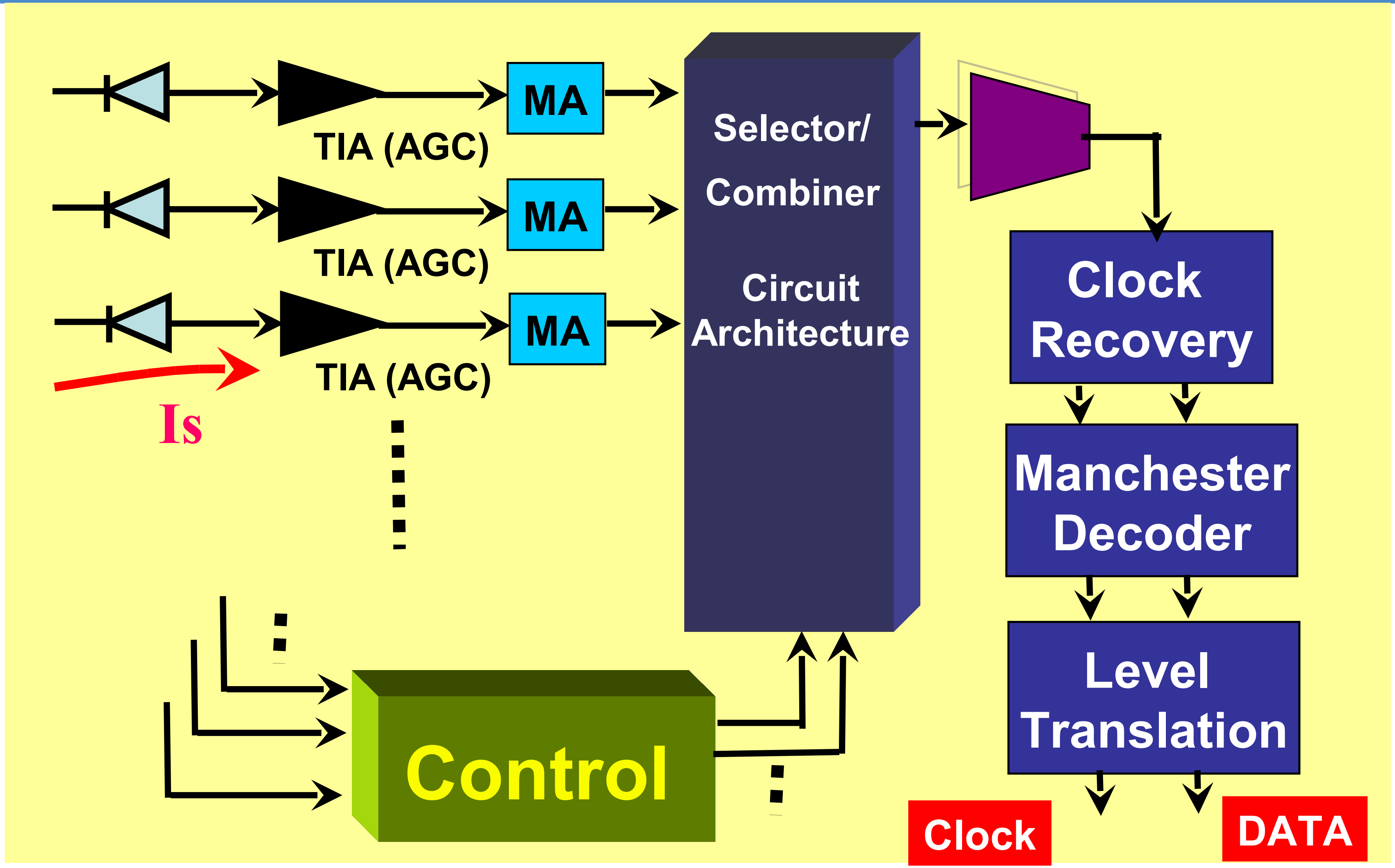
Transimpedance Amplifier:

➢ For a given BW and Cin, achieves higher gain and better noise performance

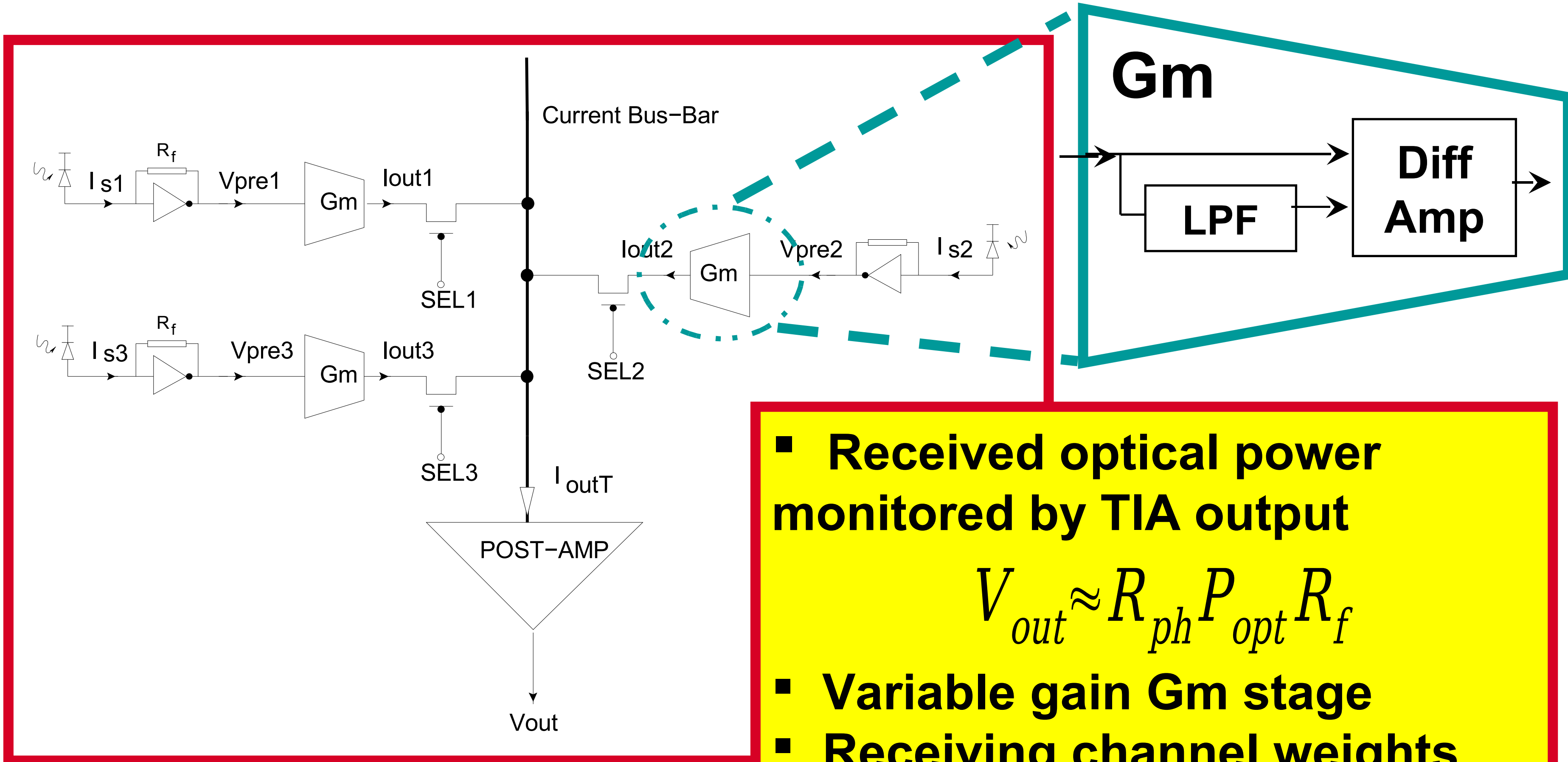
$$f_{BW} \approx \frac{1+A}{2\pi \cdot R_f C_{pd}}$$



Receiver Subsystem



Selector/Combiner Circuit



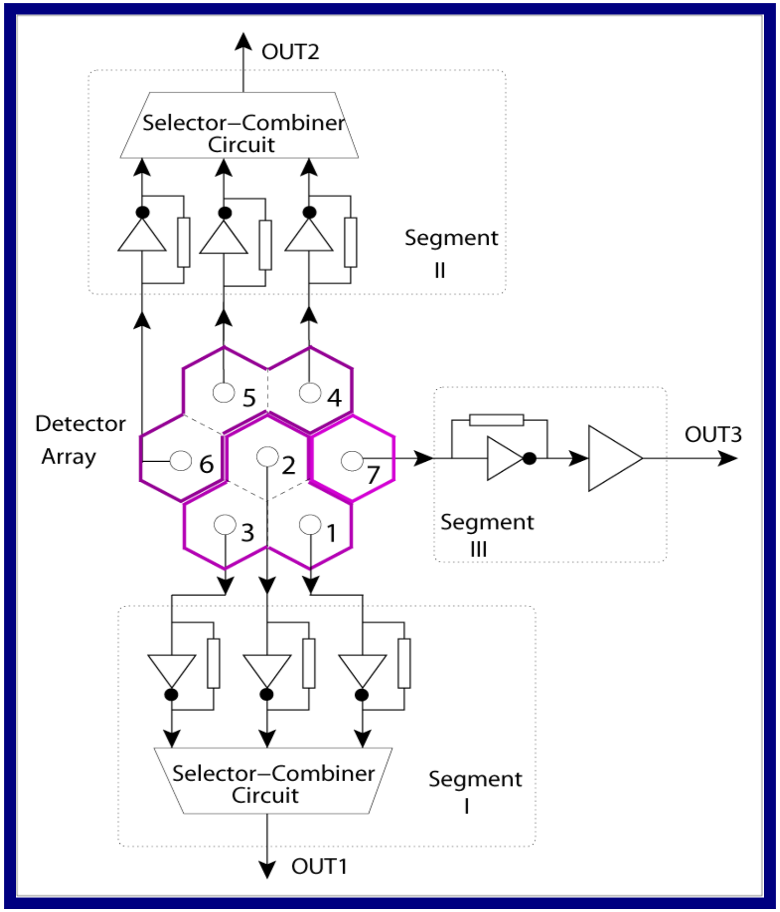
- **Received optical power monitored by TIA output**

$$V_{out} \approx R_{ph} P_{opt} R_f$$

- **Variable gain Gm stage**
- **Receiving channel weights set by control switch**
- **"Current Bus-Bar" implements channel combining**

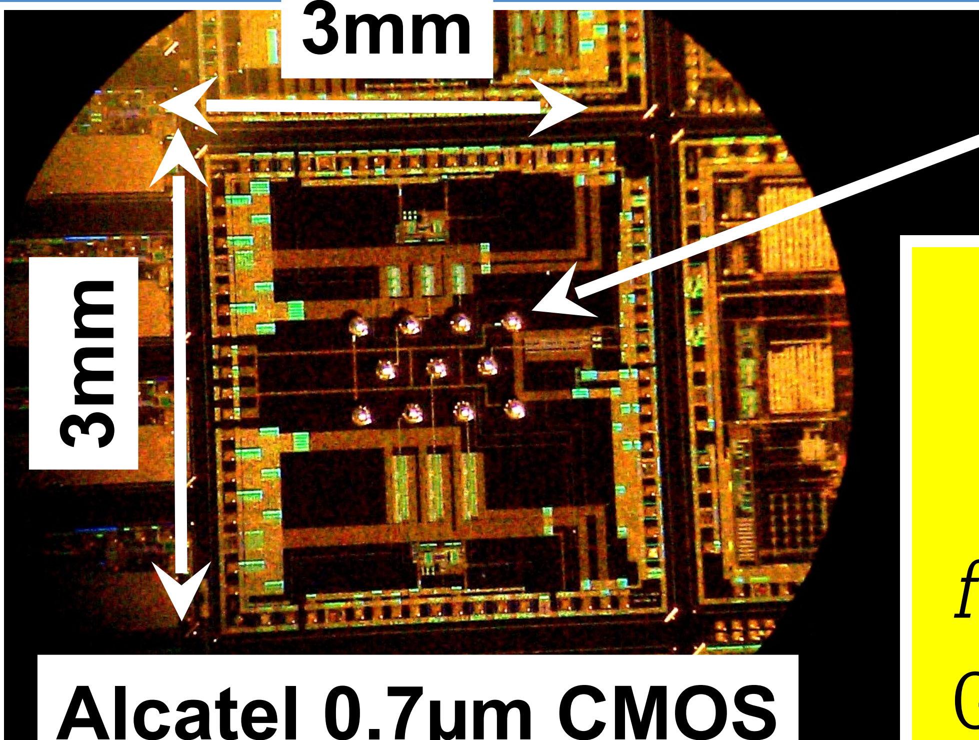
CMOS Imaging Diversity Receiver

- **Selector/Combiner Circuit**
  - **Analog Signal Processing Circuits**
  - **Enables diversity combining increasing output SNR**
- **Flip-Chip:**
  - **III-V devices with low cost, low-power CMOS**
  - **Scalability**



Segmented receiver chip to account for variable device yield

CMOS Receiver Chip



100µm Sn-Pb bumps

Post-processing & bump placement by PacTech

TIA Preamplifier Electrical Characterization

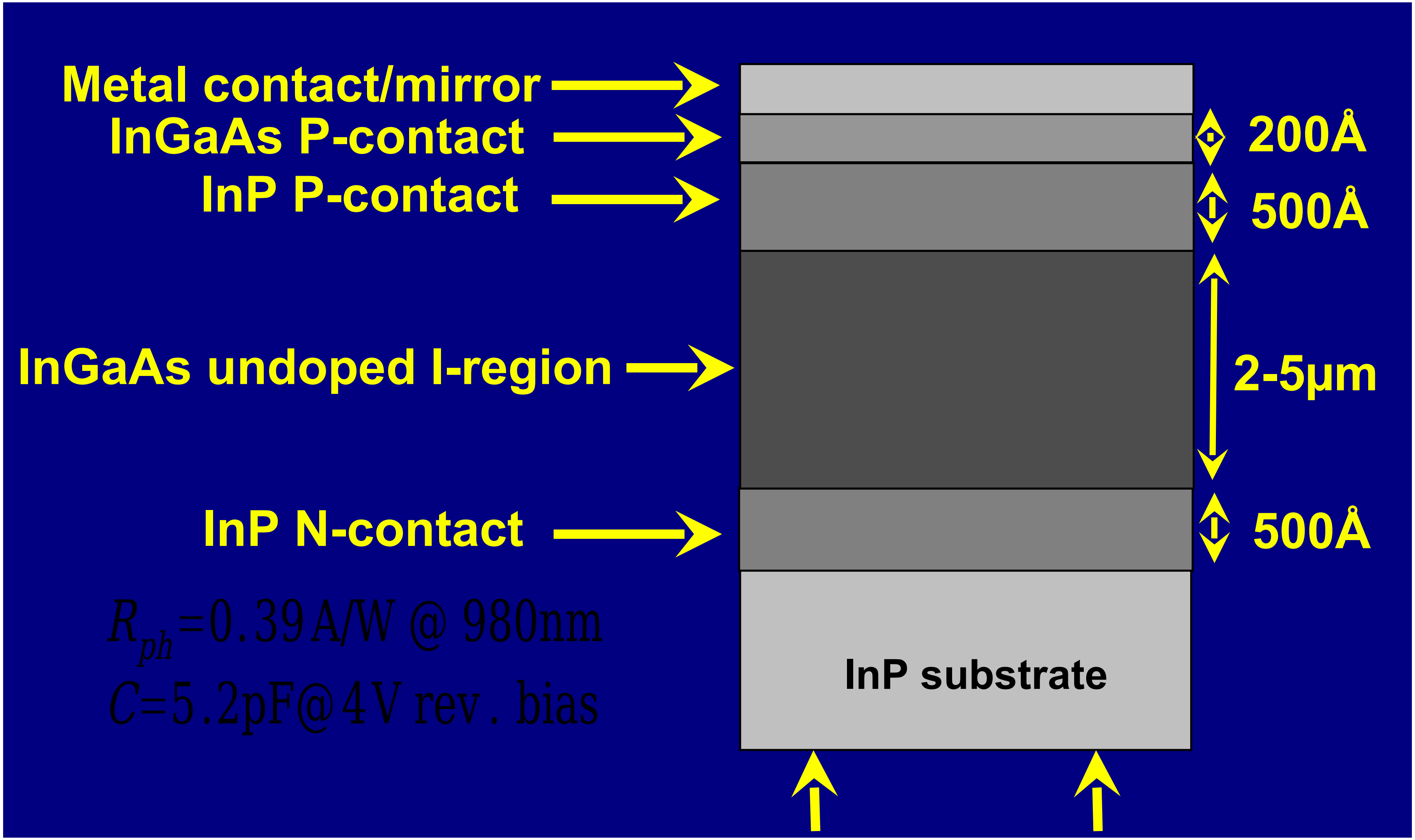
$f_{-3\,db} = 155$ MHz

Gain = 72.2 dBΩ

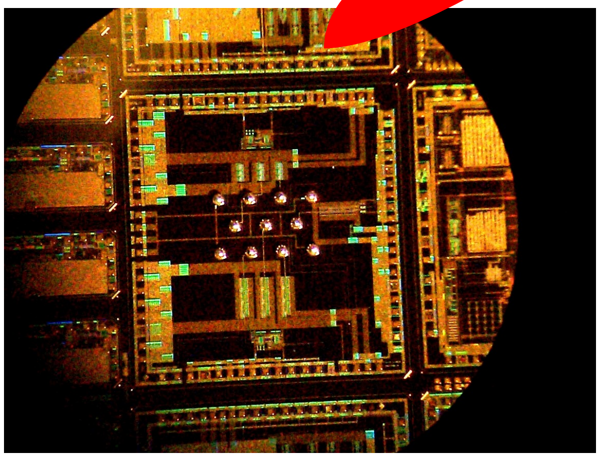
Sens = -30 dBm @ BER = 10^{-9}

$(C_{pd} = 6 - 10\text{pF})$

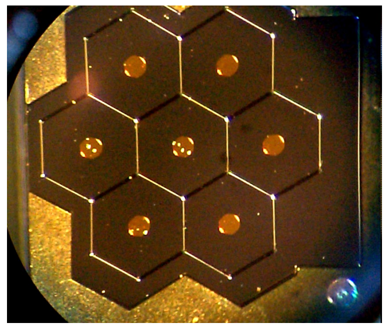
Photodetector Device



Flip-Chip Integration

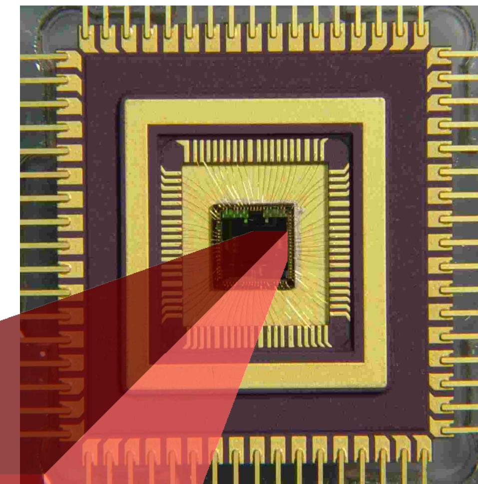


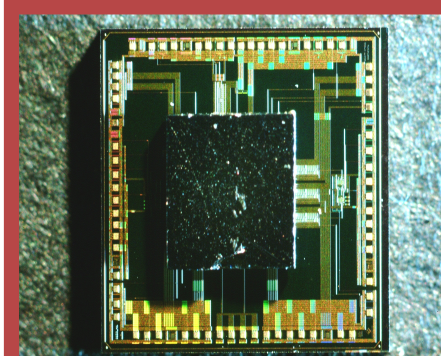
CMOS Receiver Chip



Detector Array

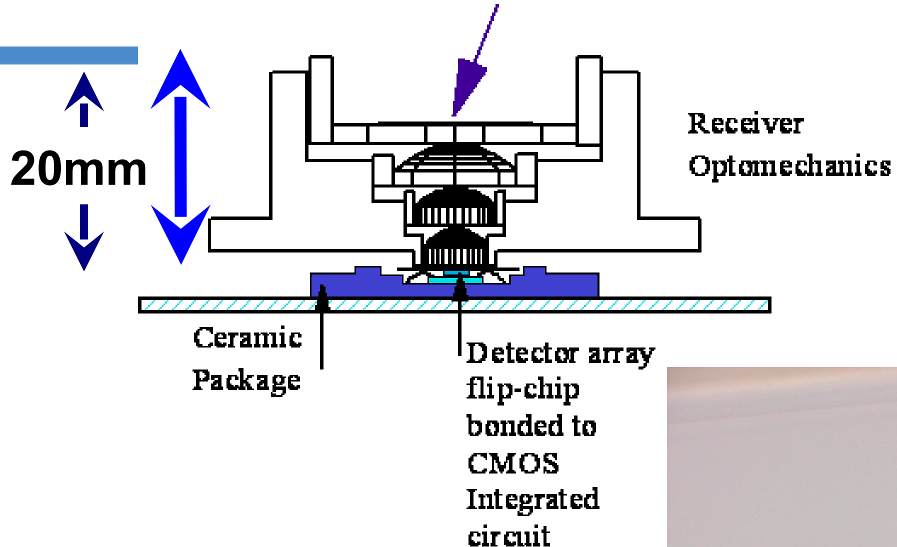
Flip-Chip Bonding



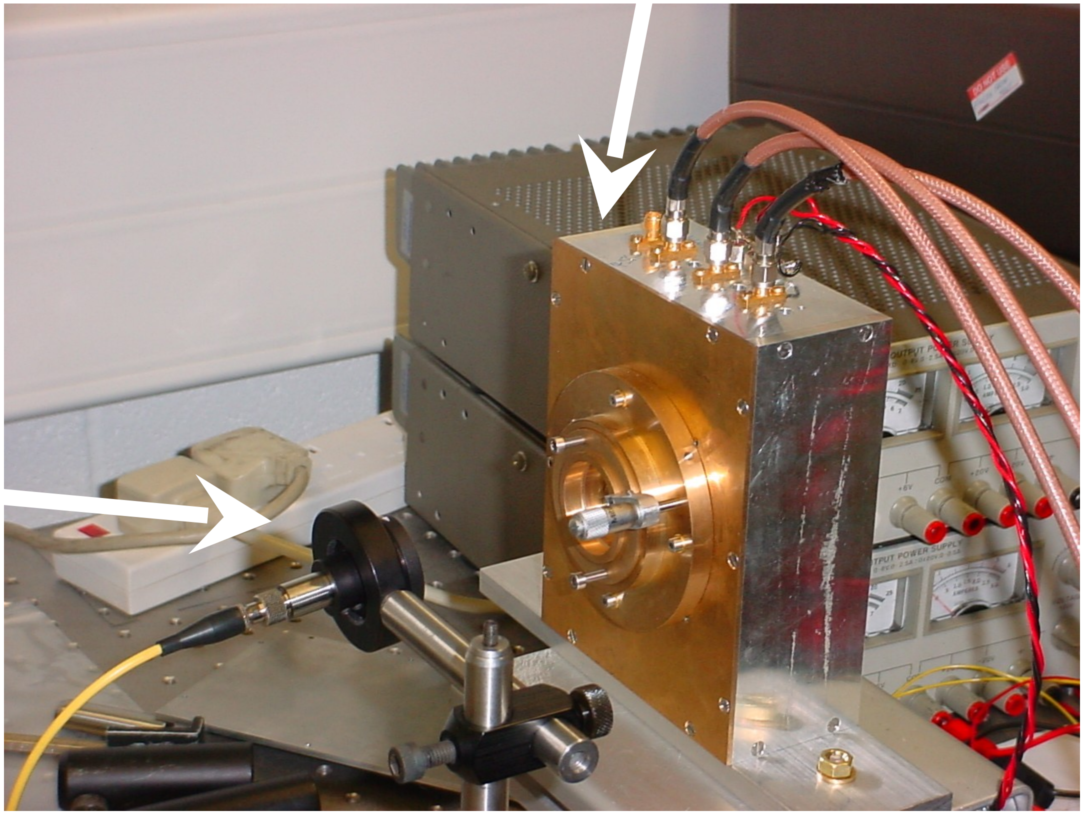


Improved through AFRL collaboration

Opto-Mechanics Integration

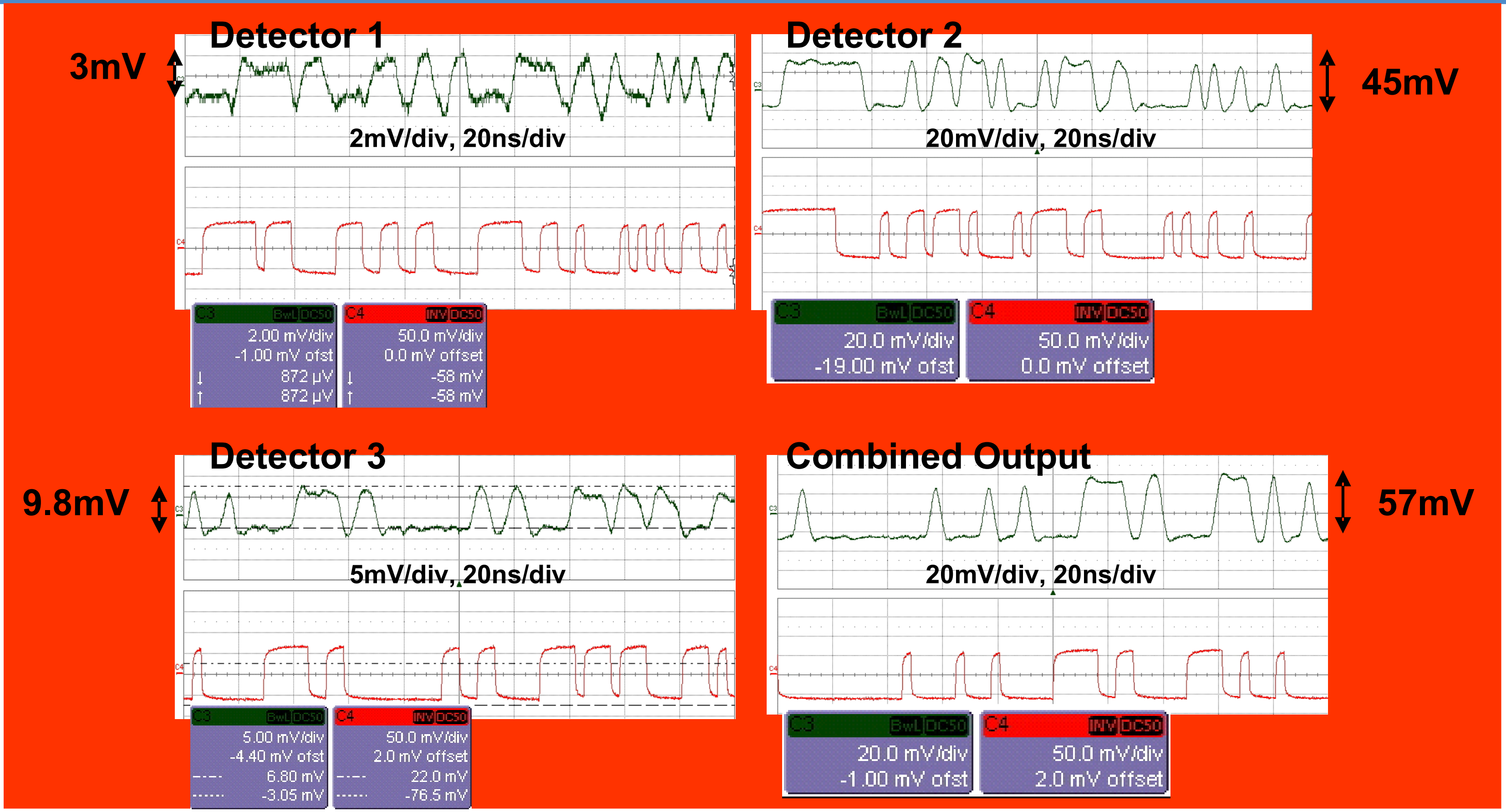


PCB-mounted integrated receiver



Fiber-coupled, externally modulated source

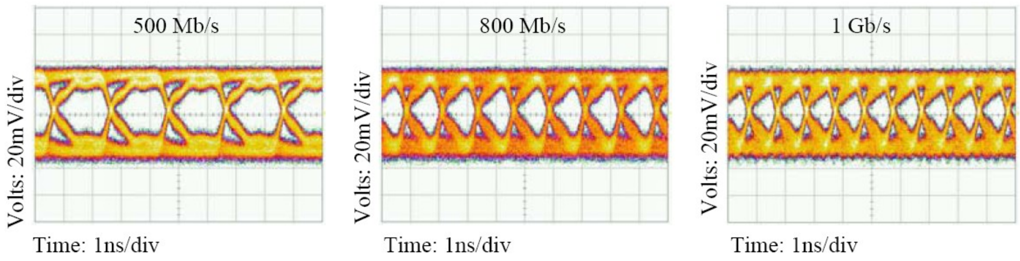
Selector-Combiner Results

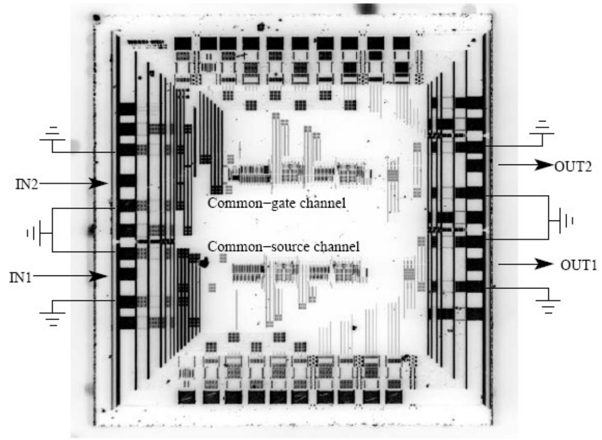


Channel Weighting over 10dB range

Unable to measure power at each channel

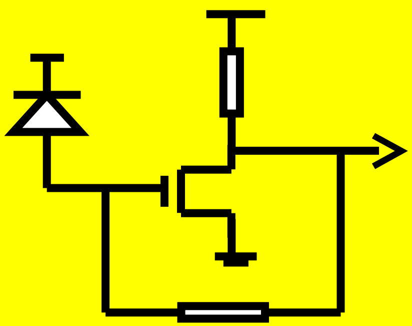
>1 Gb/s Operation in CMOS



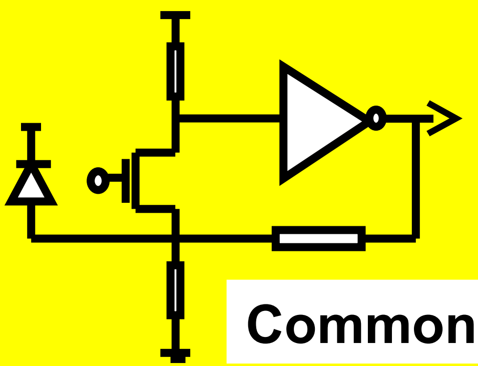


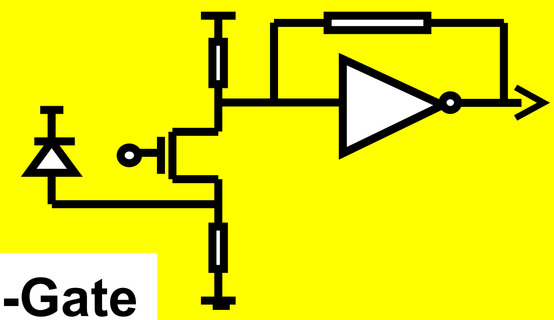
Input Noise=14pA/rtHz @ 500MHz

What is the optimal gain stage A for Stability and Power dissipation in CMOS?



Common-Source





Common-Gate

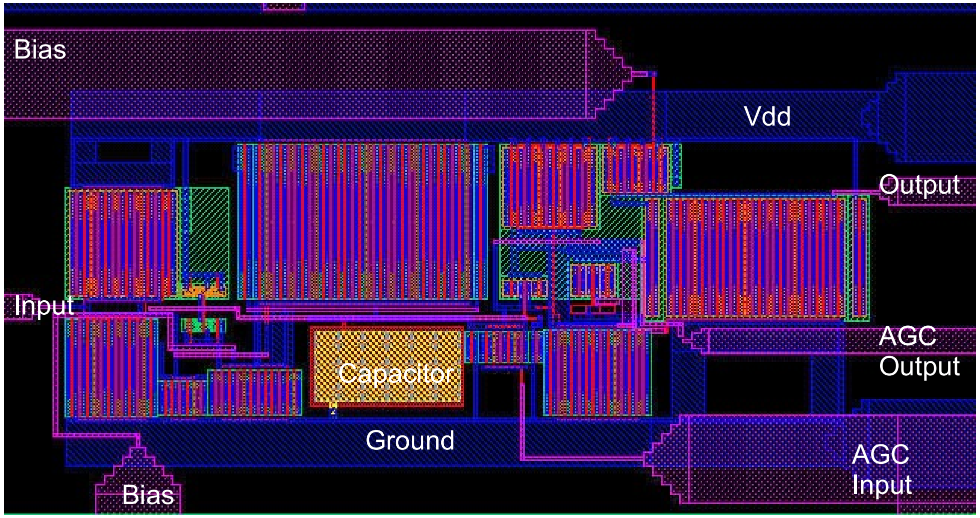
Self-Biased AGC Front-End Amplifier

OW "mesh" require high dynamic range Rx

✓Multipoint reception

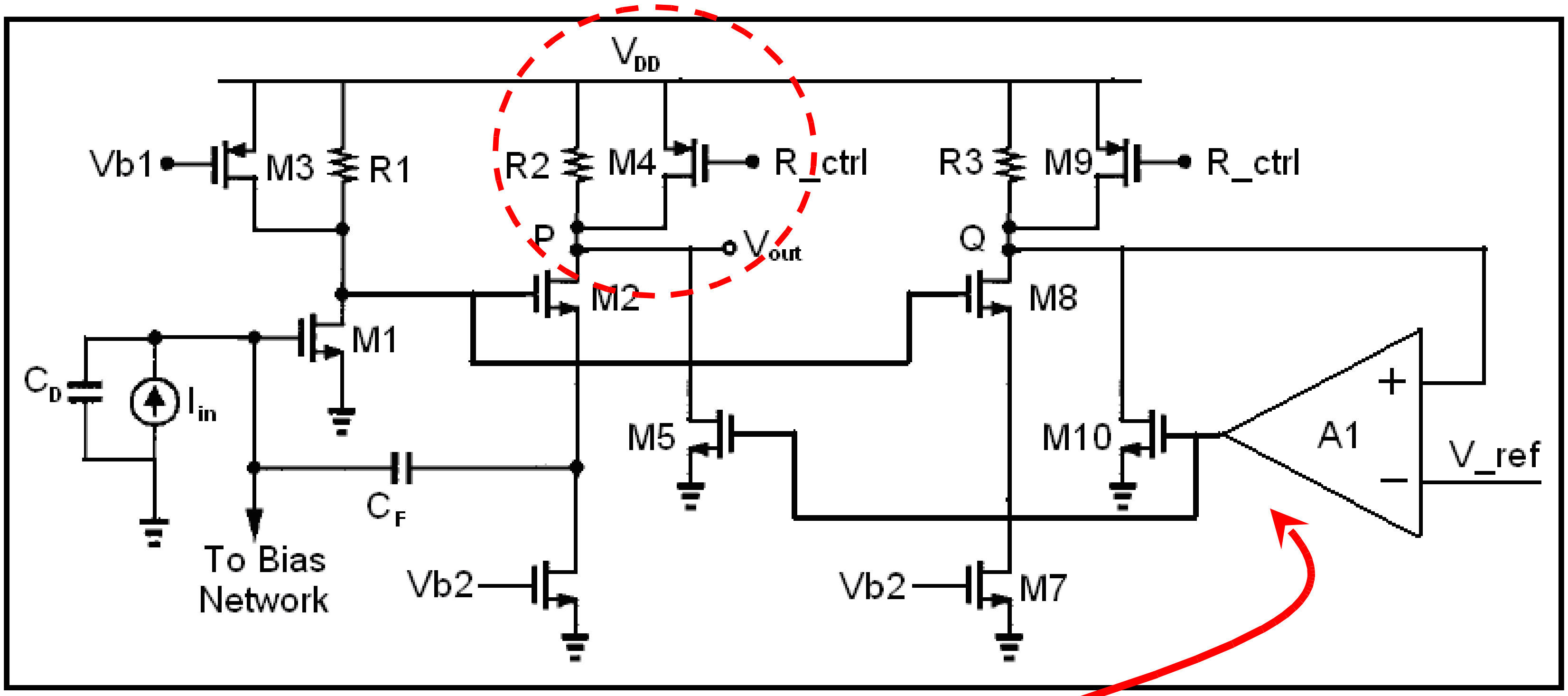
✓Accommodate variable link distance, signal amplitude, modulation formats

Technology	0.5μm AMI CMOS
DC Gain	50dBΩ – 38dB
-3-dB Bandwidth	345MHz
Power Dissipation	106mW
Input Capacitance	6pF
Chip Area	270μm x 125μm
Input Referred Noise	12.5pA/√Hz



1-Gb/s Automatic Gain Control TIA with Common-mode Feedback

- Gain Control achieved by tuning the resistance at the output
- Control determined by on-chip peak detection circuit

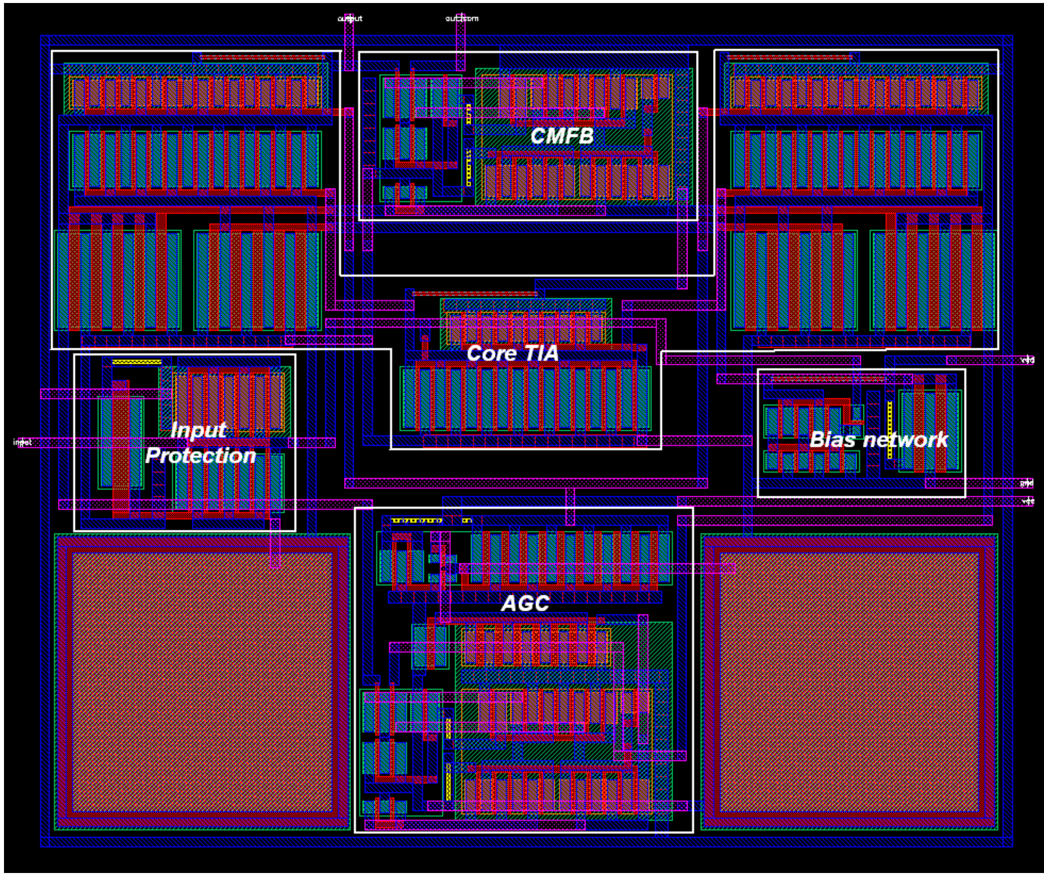


DC level adjustment

By: Yiling Zhang, MS candidate

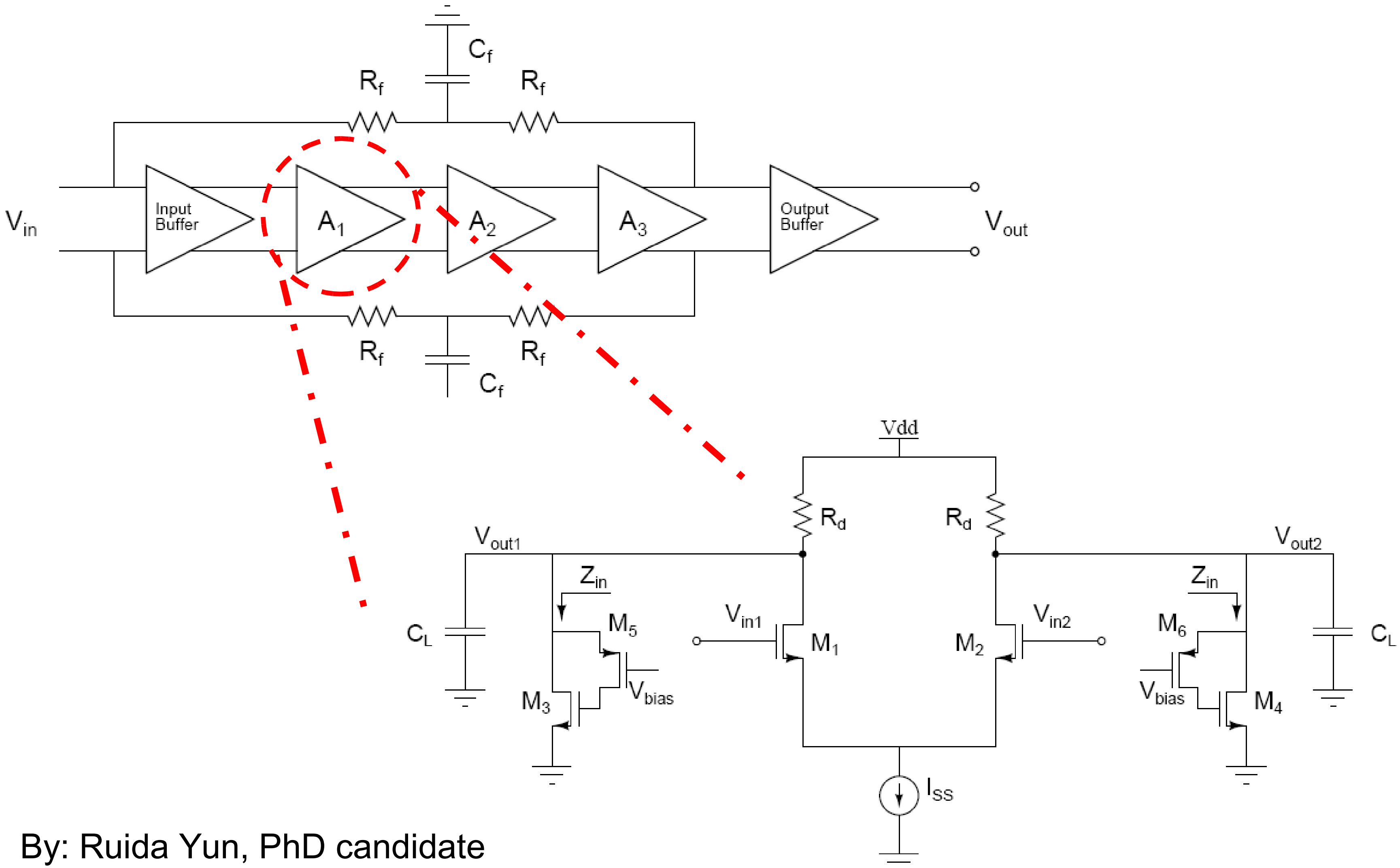
AGC TIA Summary

Technology	**0.5µm AMI CMOS**
DC Gain	**53dBΩ – 38dB**
-3-dB Bandwidth	**436.2MHz @ 5pF 548.8MHz @ 0.5pF**
Power Dissipation	**41.3mW**
Chip Area	**190µm x 160µm**
Input Referred Noise	**27.3pA/√Hz @ 5pF 14.2pA/√Hz @ 0.5pF**



By: Yiling Zhang, MS candidate

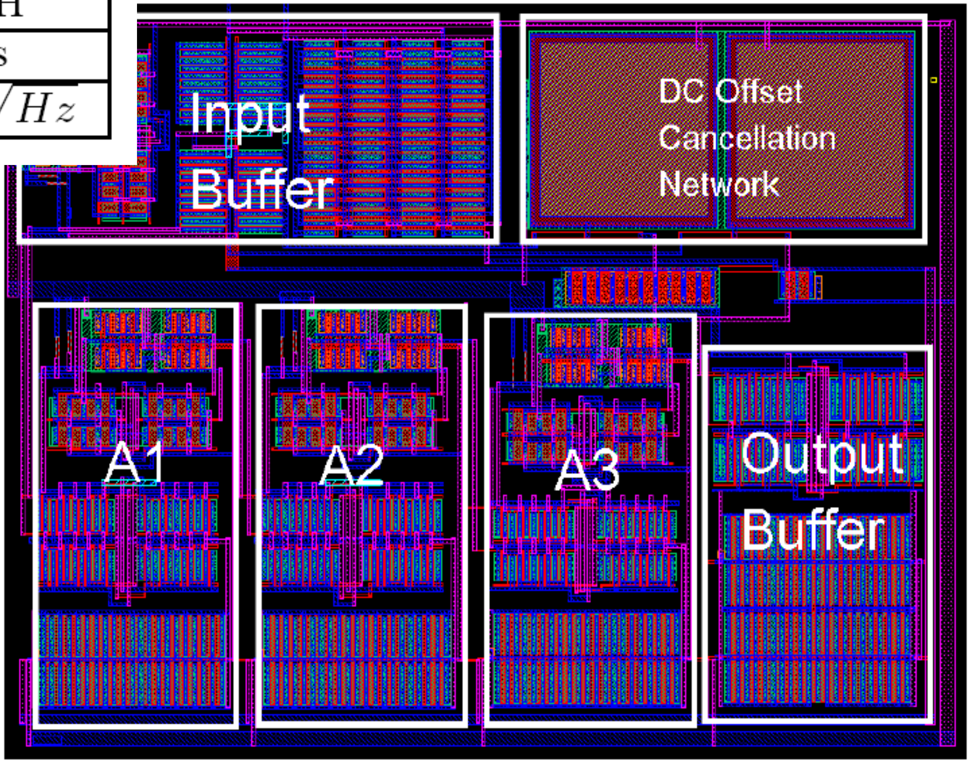
1-Gb/s 30dB Limiting Amplifier with Active Inductor



By: Ruida Yun, PhD candidate

Limiting Amplifier Summary

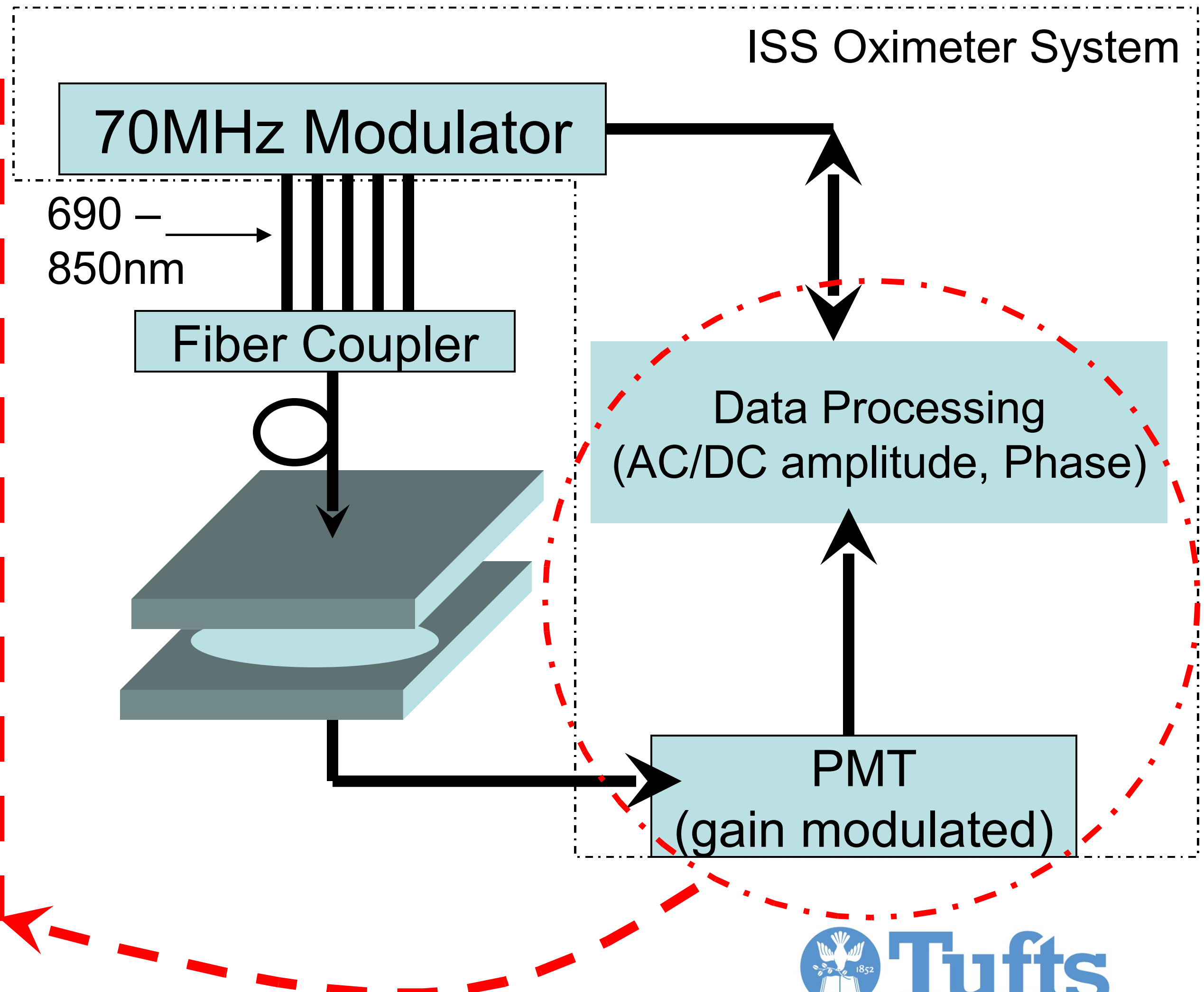
Technology	AMI $0.5\mu m$	
Supply Voltage	3.3V	
Power Dissipation	130mW	
Chip Area	$232 * 320\mu m^2$	
DC gain	30dB	
	Schematic	Post Layout
Bandwidth(-3dB)	940MHz	695MH
Data Bits	1.34Gb/s	1Gb/s
Input Noise	-	$766pv/\sqrt{Hz}$



By: Ruida Yun, PhD candidate

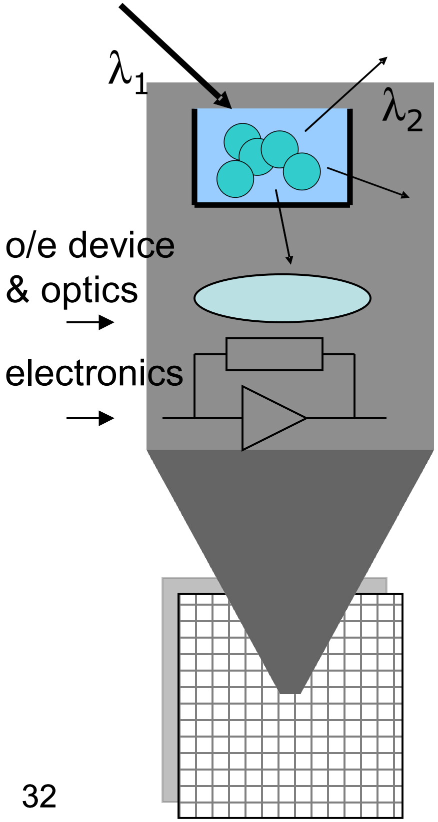
Biomedical Imaging

CMOS Imaging Rx Chip
- **CMOS photodetectors**
- **Low-noise front-end for high sensitivity (nW)**
- **On-chip phase detection (<1 deg)**
- **AGC receiver to avoid optical overload**



Integrated Micro-arrays for Fluorescence Detection

- Silicon-based micro-arrays for high-throughput diagnostics and screening.



Silicon microchip

- How can circuit techniques for optical comms. enhance the detection process and increase sensitivity and selectivity?
- What types of photonic materials are best for integration with CMOS and for contact with living cells?

Tufts

Related Projects

- Flip-chip Integrated Imaging Diversity Receivers
  - In collaboration with AFRL which provides expertise in custom InGaAs detector arrays with minimum pixel size of 15um x 15um.
  - Developing architecture for 24 x 24 CMOS imaging diversity Rx
- Multipoint CMOS Receiver Architectures for Optical Wireless Mesh Network Topologies
- Current-mode signal processing approaches to optical diversity combining

Conclusions

- Review of key design aspects of free-space optical links for broadband wireless communication.
- Presented the design and experimental results for a flip-chip integrated, imaging diversity receiver for use in a free-space optical link operating at 310 Mb/s.
- Demonstrated channel selection and equal gain combining.
- Presented design of a TIA accommodating 6pF detectors and implemented in 0.35um CMOS with good eye diagrams up to 1Gb/s.
- Presented design of a self-biased AGC TIA for use highly varying free-space optical channels.

THANK YOU