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# High-Performance Analog Optical Links

**Photonic Systems, Inc.**

**MIT**

**Sarnoff Corporation**

**Columbia University**

**August 16, 2000**

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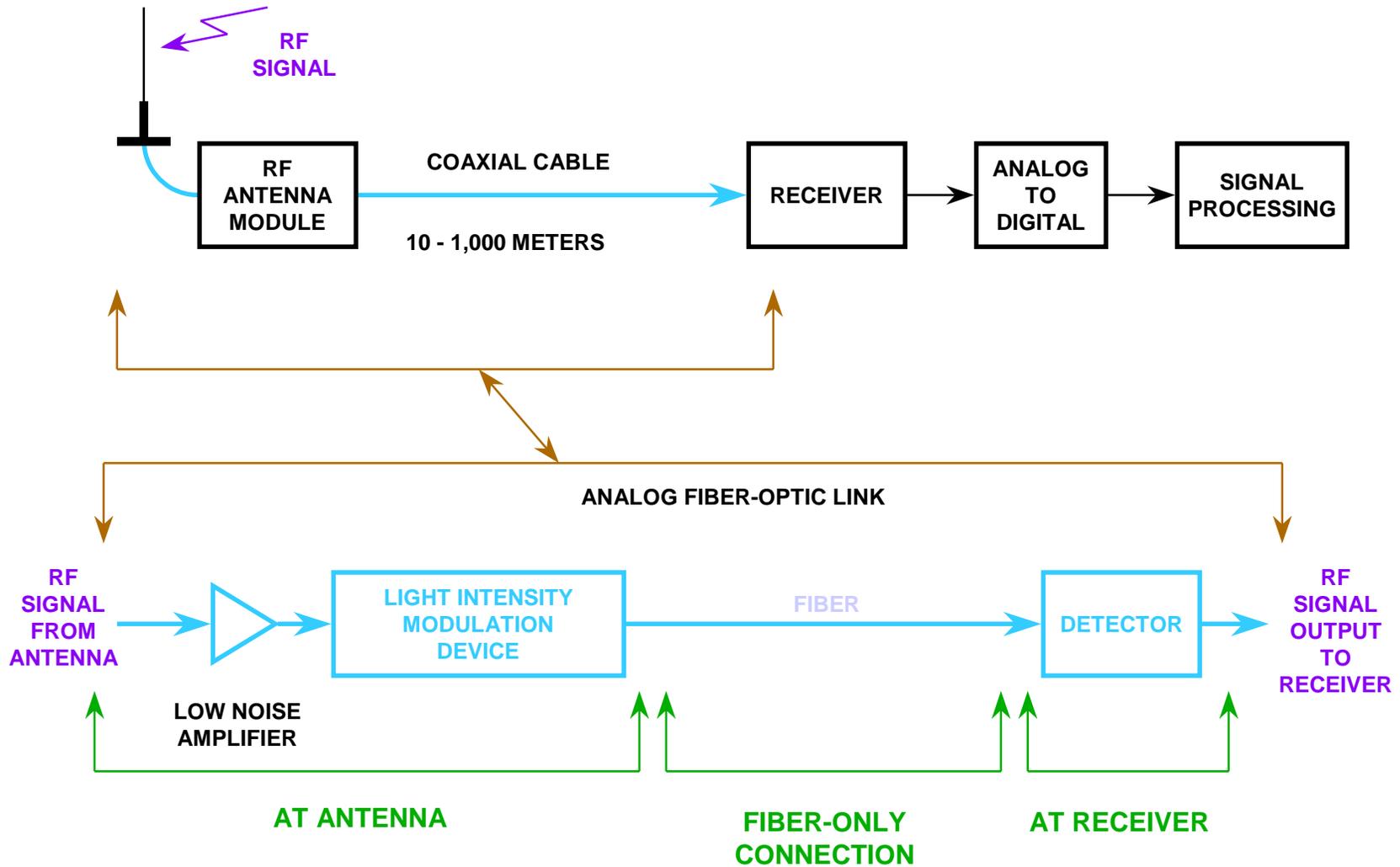
# Outline

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- **Introduction**
  - Survey of present performance
  - Need for higher slope efficiency
- **Cascade Laser Development**
  - Laser options
  - Development plans
- **Summary**



# Antenna Remoting Concept

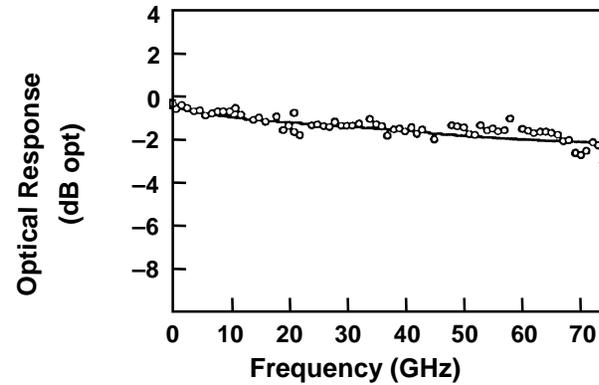


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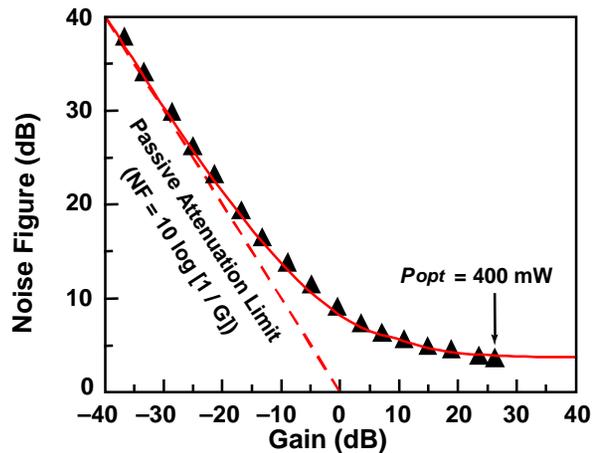


# Record Performance of Analog Links External Modulation

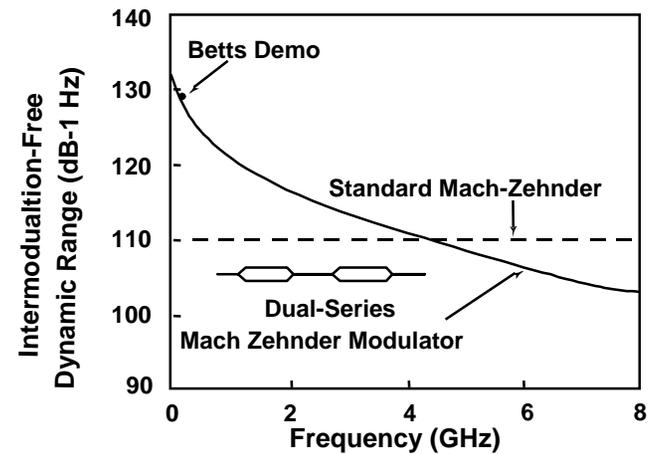
**Record Bandwidth: 75 GHz**  
Noguchi et. al, NTT Opto-Electronic Laboratories  
Noise Figure: 25 dB    Dynamic Range: 110 dB Hz



**Record Noise Figure: 2.5 dB**  
Ackerman & Cox, MIT Lincoln Laboratory  
Bandwidth: 20 MHz    Dynamic Range: 110 dB Hz



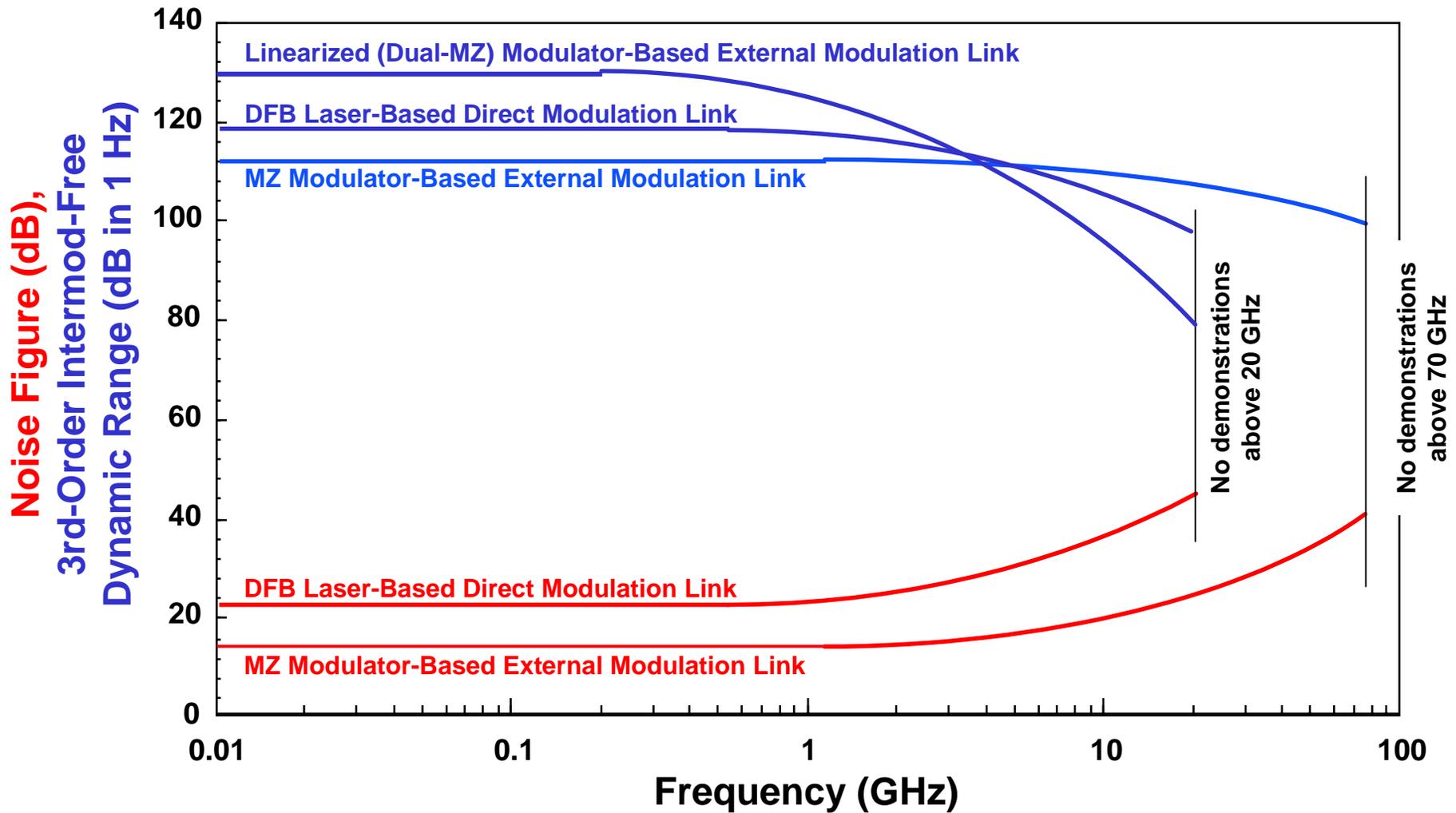
**Record Dynamic Range: 130 dB**  
Betts, MIT Lincoln Laboratory  
Bandwidth: 200 MHz    Noise Figure: 6 dB



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# Experimental Link Performance Trends: Noise Figure and Dynamic Range

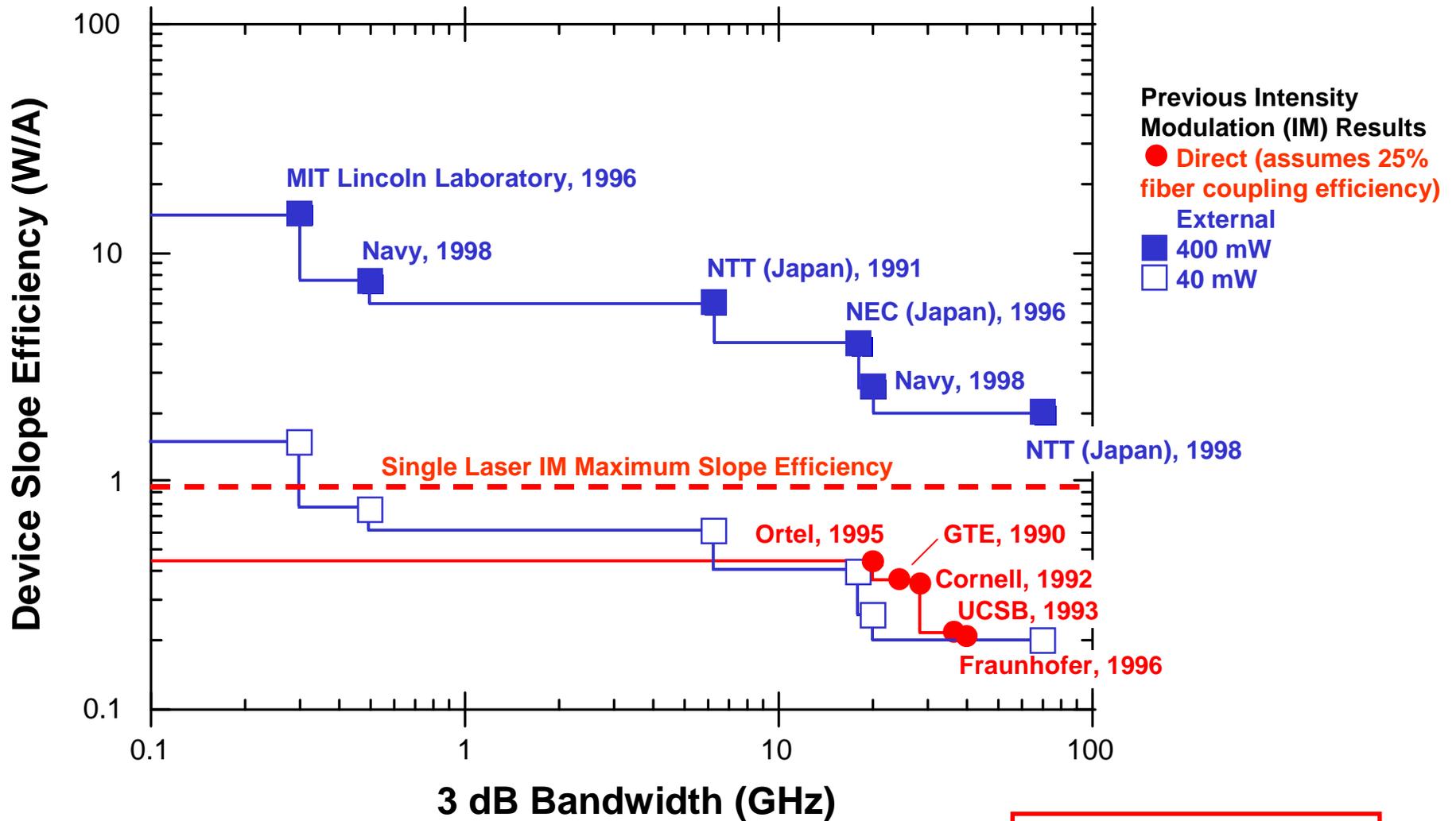


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# Slope Efficiency vs Frequency

Estimates at 1.3  $\mu\text{m}$  Based on Reported Device Parameters



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# Approaches to increased slope efficiency

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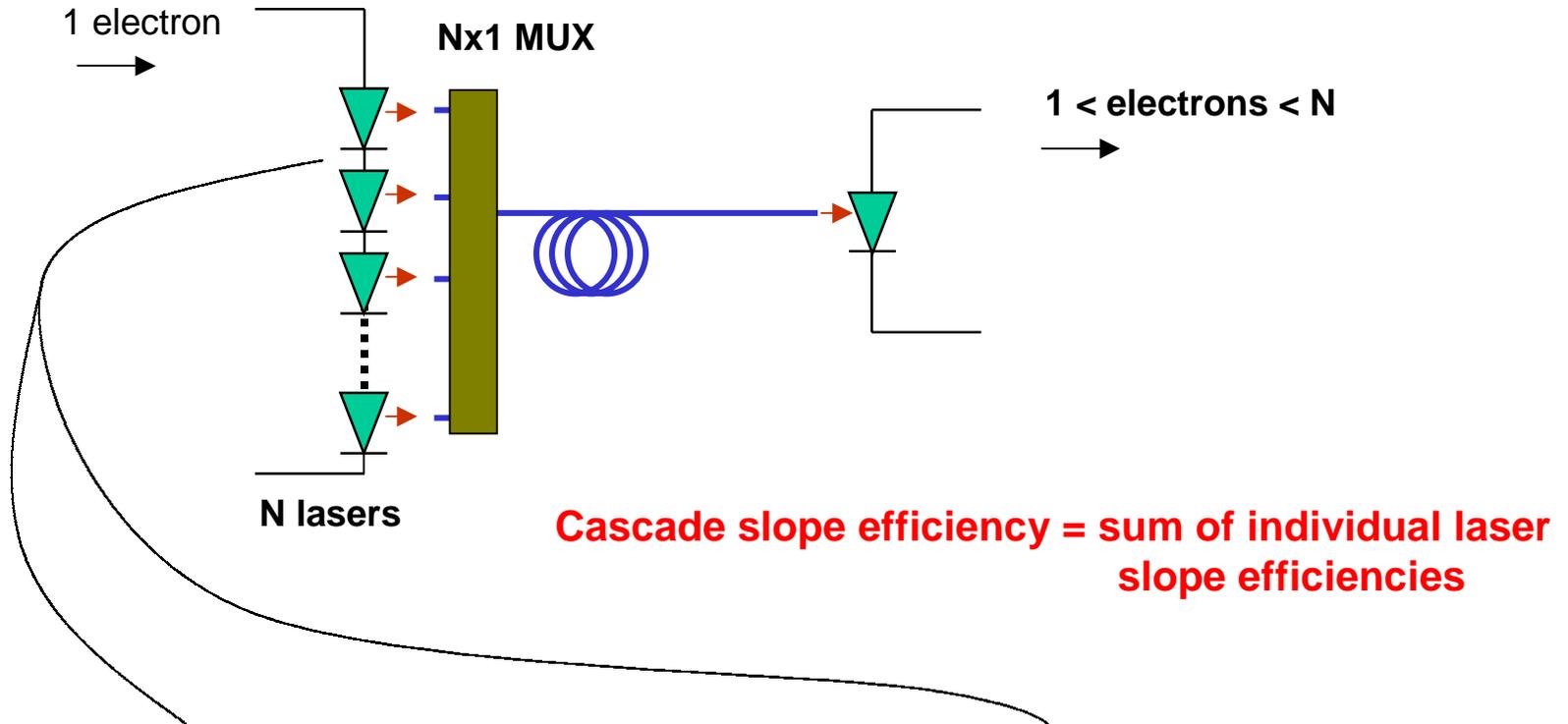
- **Direct modulation**
  - Electrical means: pre-amp, transformers
  - Gain lever laser
  - Optical FM
  - ➔ – Cascade laser - **PSI R-FLICS team**
  - ???
- **External modulation**
  - Increase average optical power
  - Micro-resonant modulator
  - Electro-absorption modulator
  - ???

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# Cascade Laser Options



## Ohmic Connection

- Discrete Cascade
  - Cox et al. 1st demo
- Interconnect Coupled Cascade
  - PSI SBIR Phase II

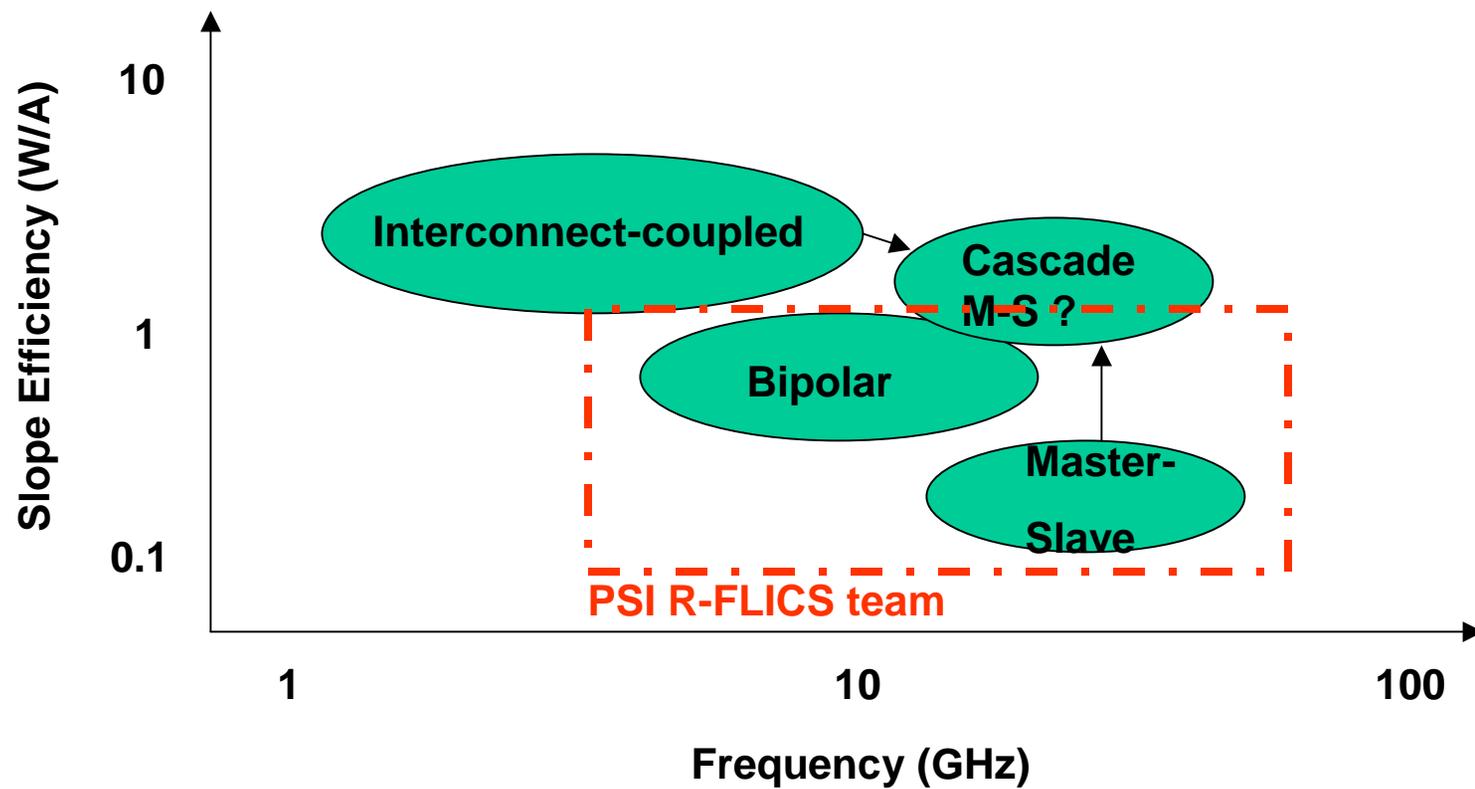
## Tunnel-junction Connection

- Bipolar Cascade
  - PSI R-FLICS team

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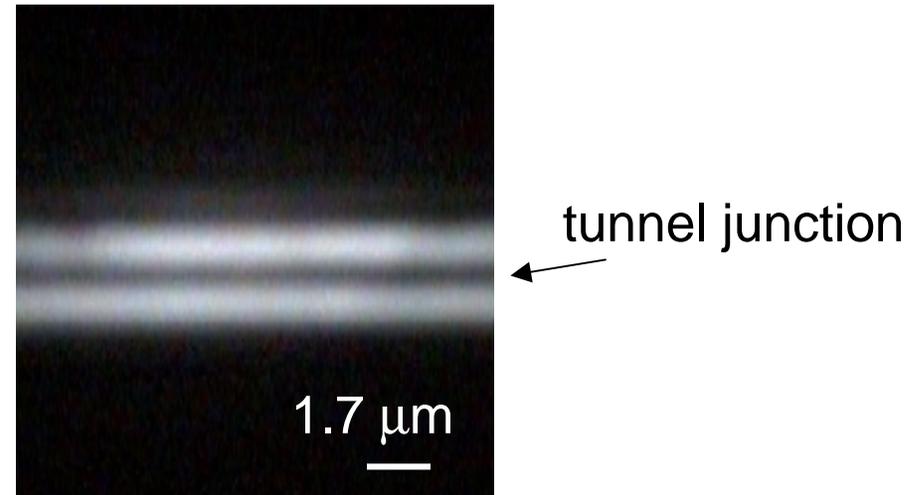
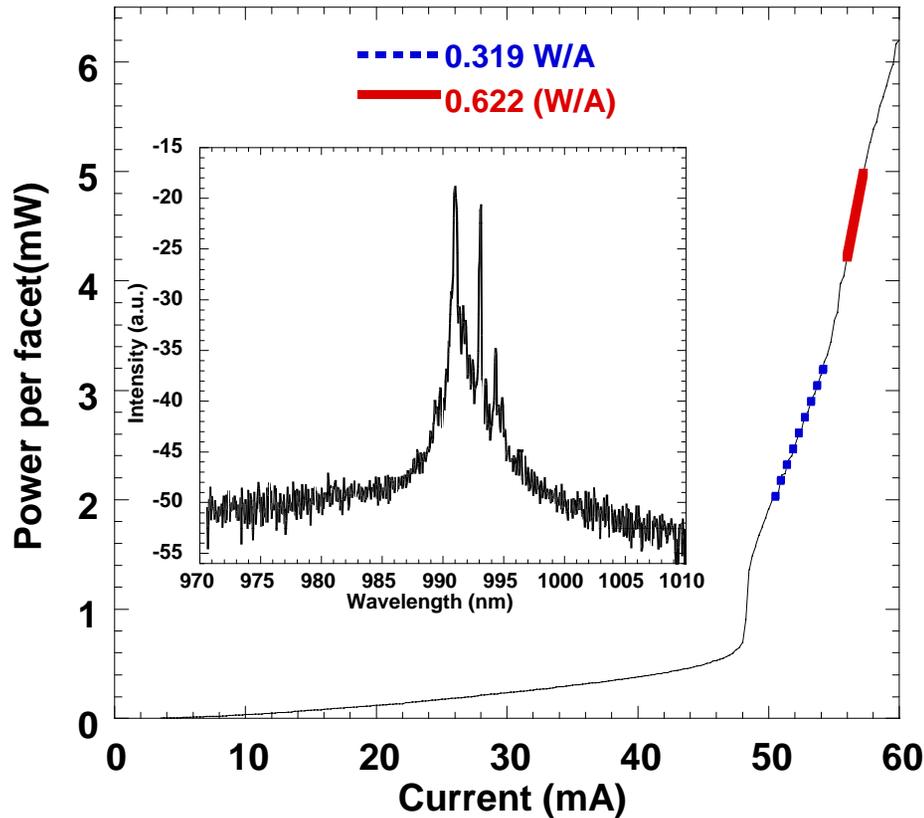


# Comparative Performance of Cascade Lasers



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# First Continuous Wave(300K) Bipolar Cascade Laser



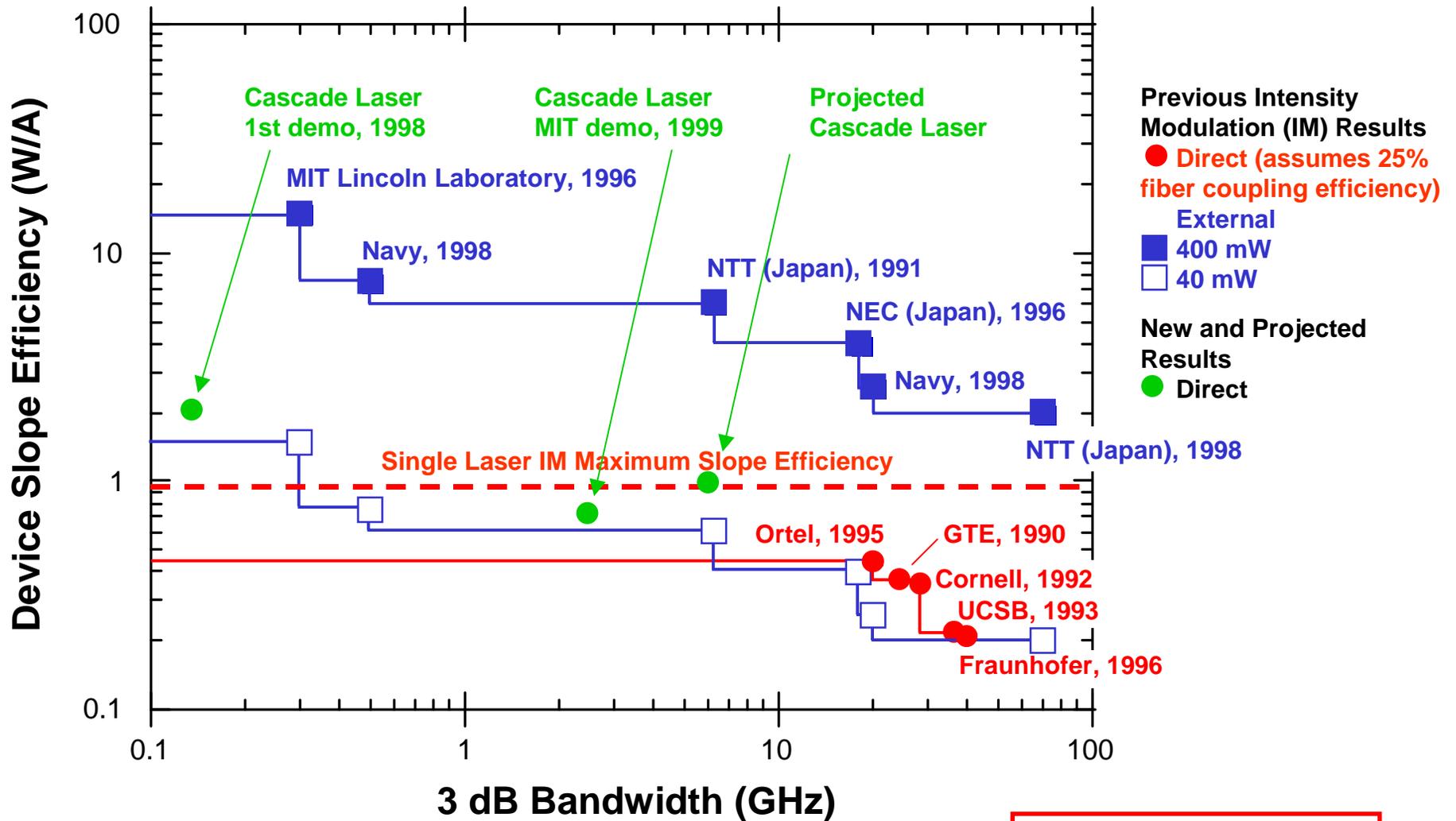
- Abrupt switch from slope of 0.313 W/A (per facet) to 0.622 W/A (per facet)
- Differential quantum efficiency of 99.3% at  $\lambda = 990$  nm

\* S. G. Patterson, G. S. Petrich, R. J. Ram, L. A. Kolodziejski, "Continuous-wave room temperature operation of bipolar cascade laser", Elec. Lett. 35, 5, 395-397 (1999).



# Slope Efficiency vs Frequency

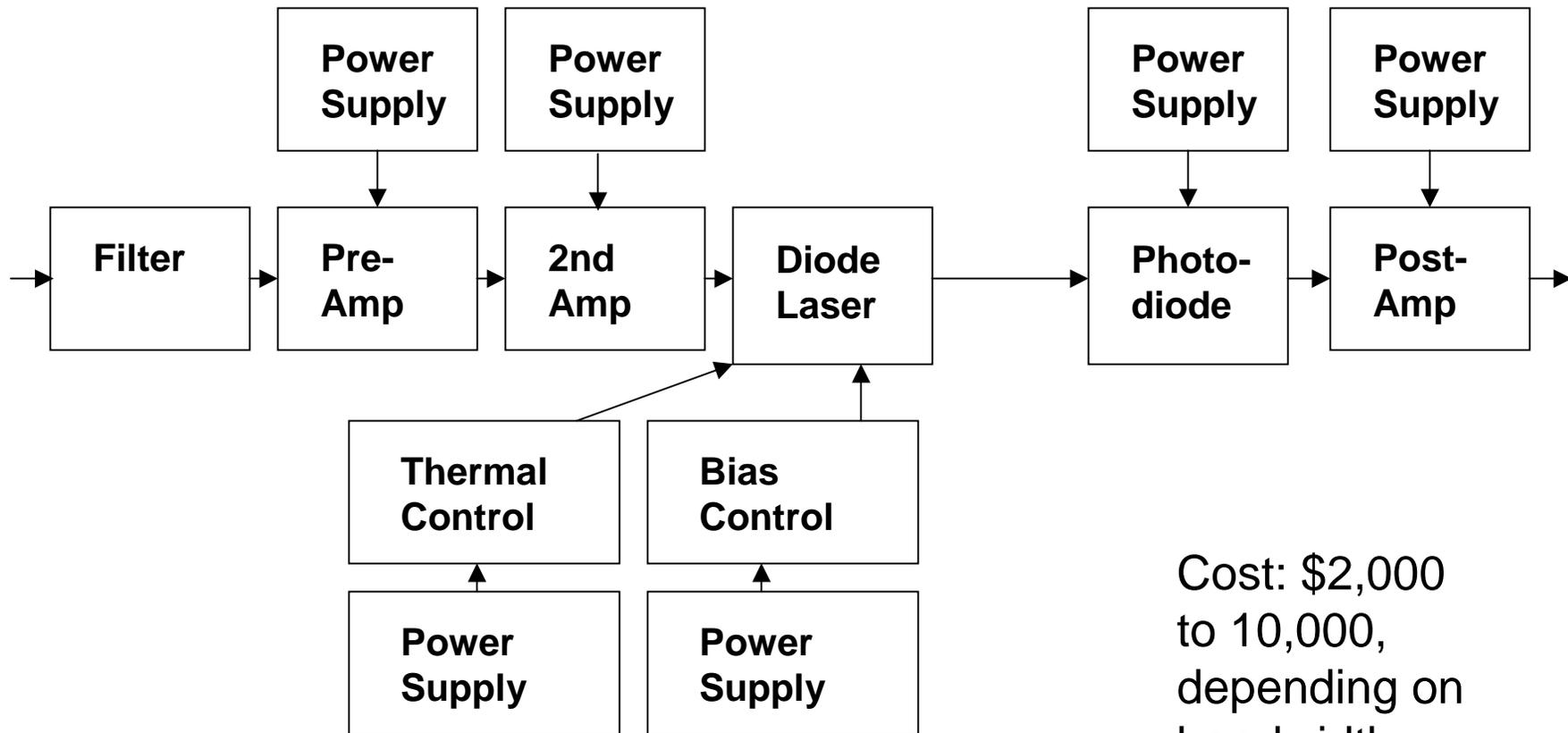
Estimates at 1.3  $\mu\text{m}$  Based on Reported Device Parameters



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# State-of-the-Art Link Direct Modulation - 1999



Cost: \$2,000  
to 10,000,  
depending on  
bandwidth

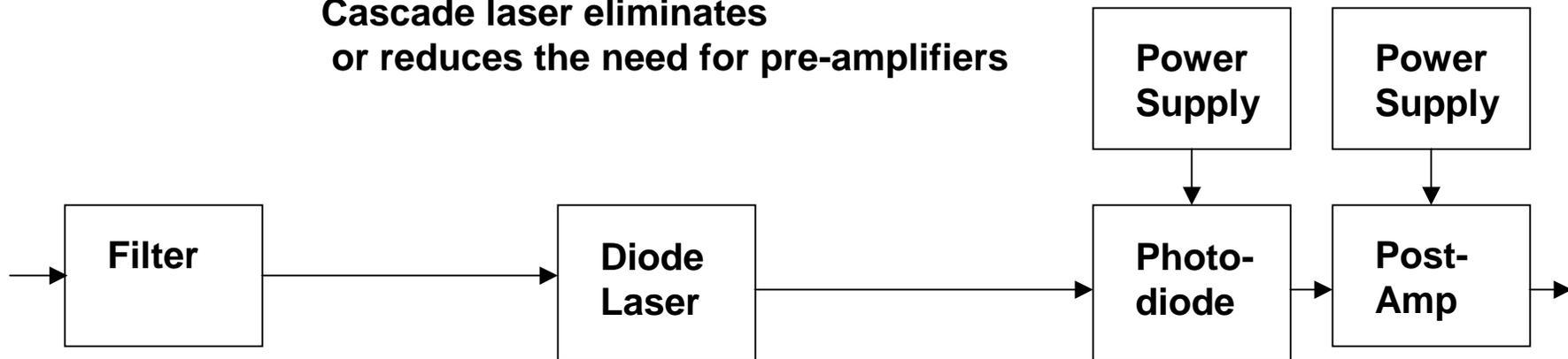
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# State of the art Link Direct Modulation - 2003

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Cascade laser eliminates  
or reduces the need for pre-amplifiers



Master-slave laser  
permits bandwidths to 40 GHz

## Costs

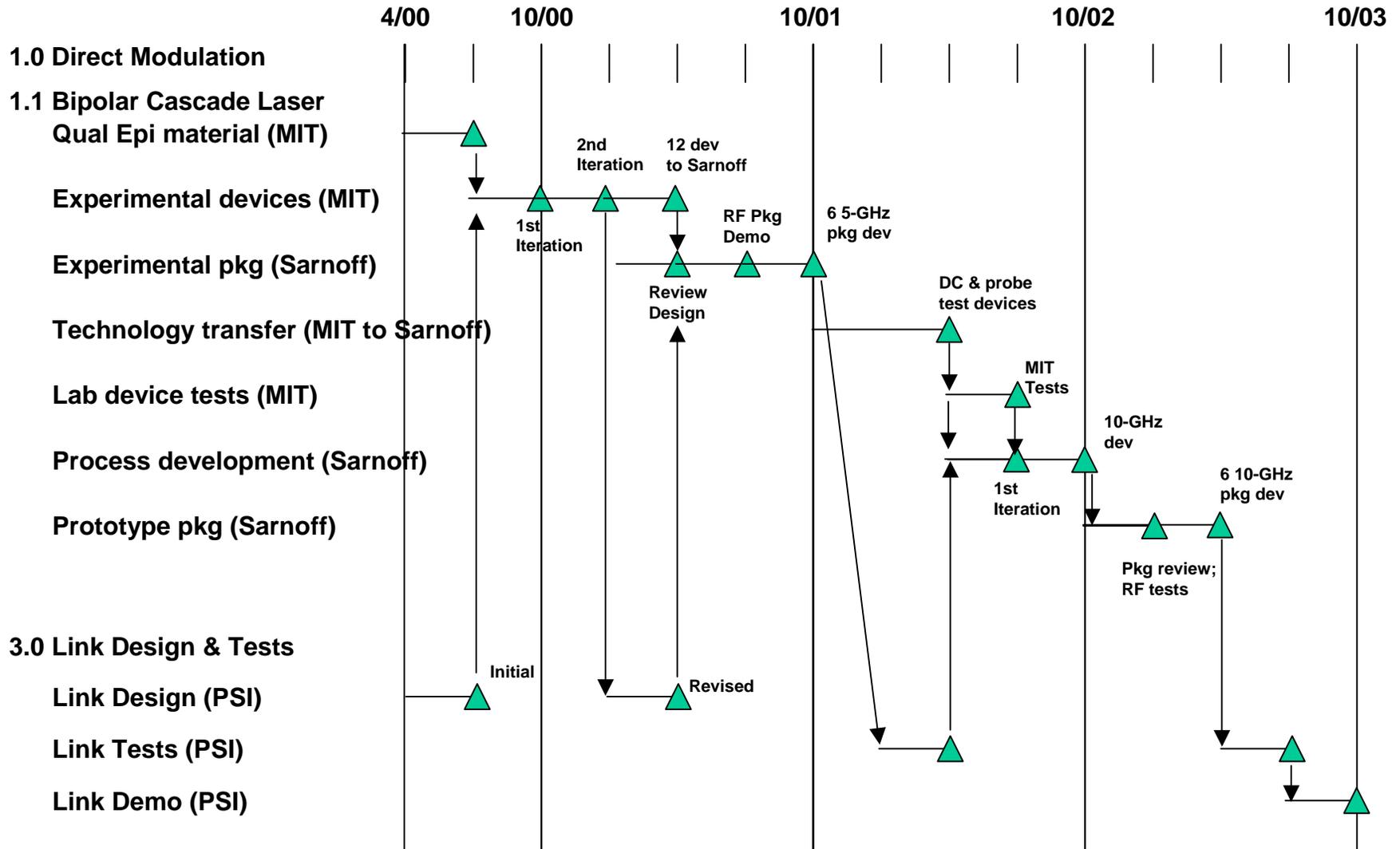
High performance: \$5,000  
Low cost:: \$200

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# Revised R-FLICs Plan Cascade Laser



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Proprietary Information - Photonic Systems, Inc.

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# Summary

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- **Record performance of external modulation links is sufficient for advanced system applications -- but only at frequencies below ~ 1GHz**
- **Key to improved performance is higher slope efficiency of the modulation device**
  - Diode laser
  - External modulator
- **Cost of microwave photonics has limited the market to technology-driven applications**
  - Lower cost components would enable microwave photonics to enter the much larger competition-driven markets
- **The R-FLICS program in general, and Photonic Systems' team in particular, are focused on demonstrating innovative solutions to these cost and performance issues**