Steps to the Photonic Antenna

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Photonic Systems

Analog Optical Signal Processing (AOSP) Study Group 6

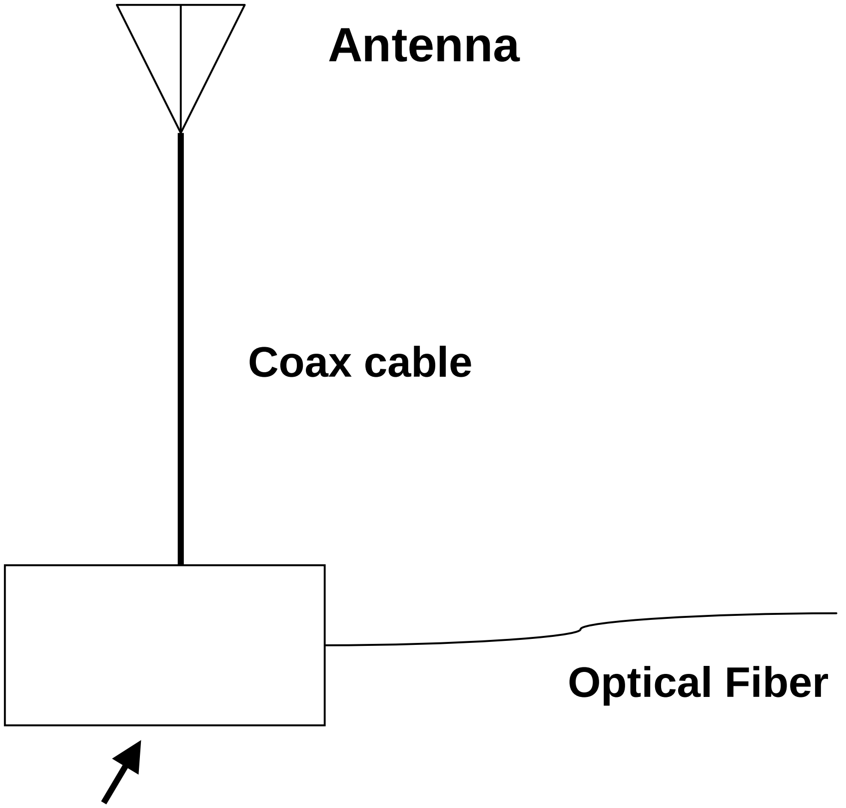
December 2000

Outline

- **Step I: Photonics *separate* from conventional antenna**
  - **Replace coax between antenna and transmitter or receiver with fiber optic link**
  - **Research in the past**
  - **Applications in present and future**
- **Step II: Photonics *integrated* with conventional antenna**
- **Step III: Photonics *assimilated* with antenna**

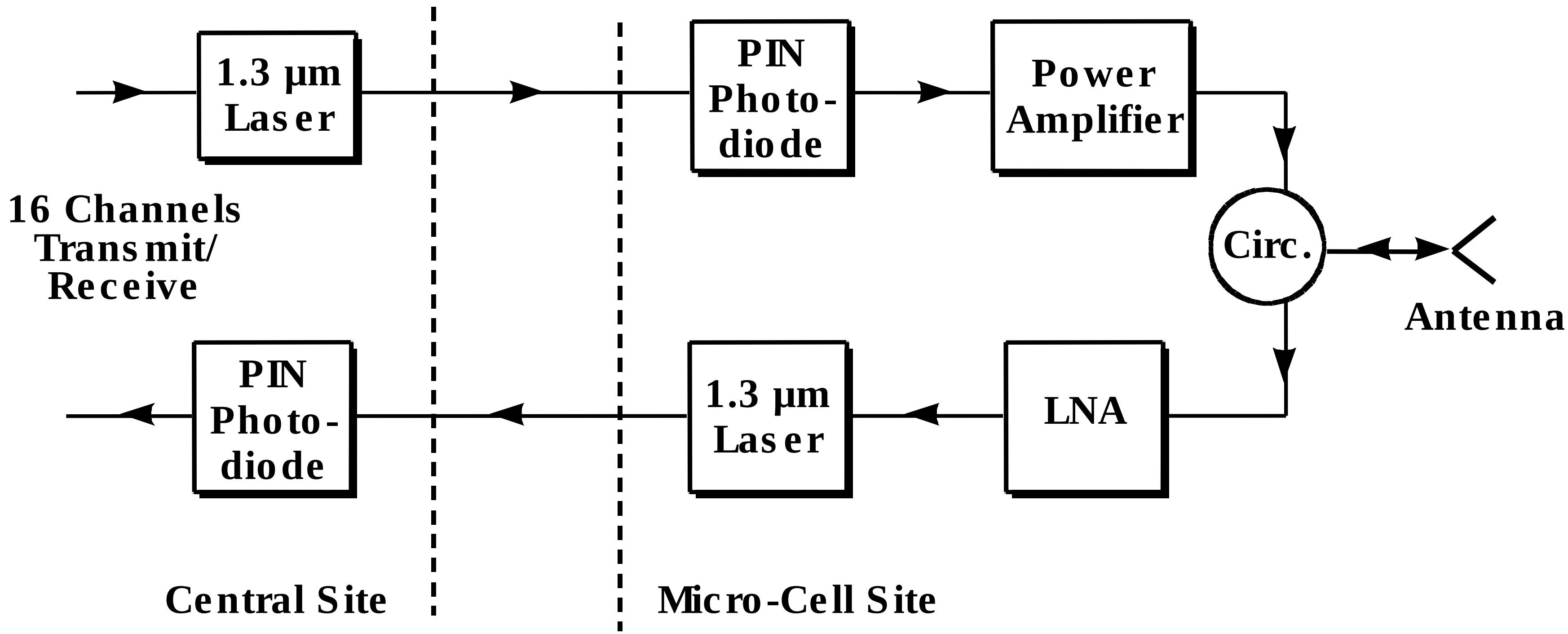
Integration of Photonics with Antennas

Step I: Photonics *separate* from conventional antenna



- Electro-optic modulator for receive applications
- Photodetector for transmit applications

Example: Photonic Remoting of Antenna for Cellular System



Adapted From: Allen Telecom Group

16-Channel, 900 MHz Fiber-Fed Microcellular Base Station

Reference: A. Seeds, University College London

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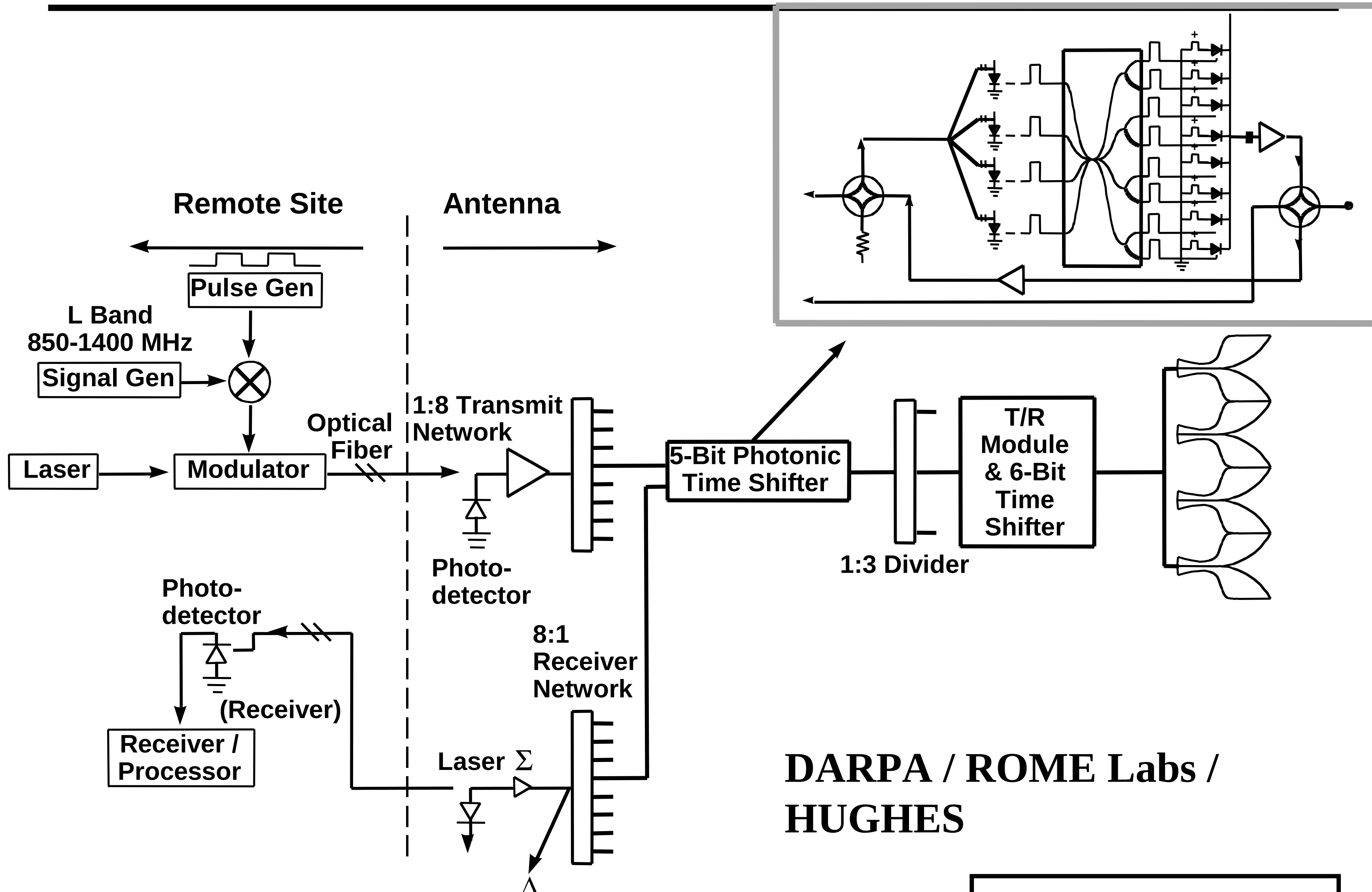
Example: Photonic Remoting and Time Delay for Phased Array Radar



DARPA / ROME Labs / HUGHES

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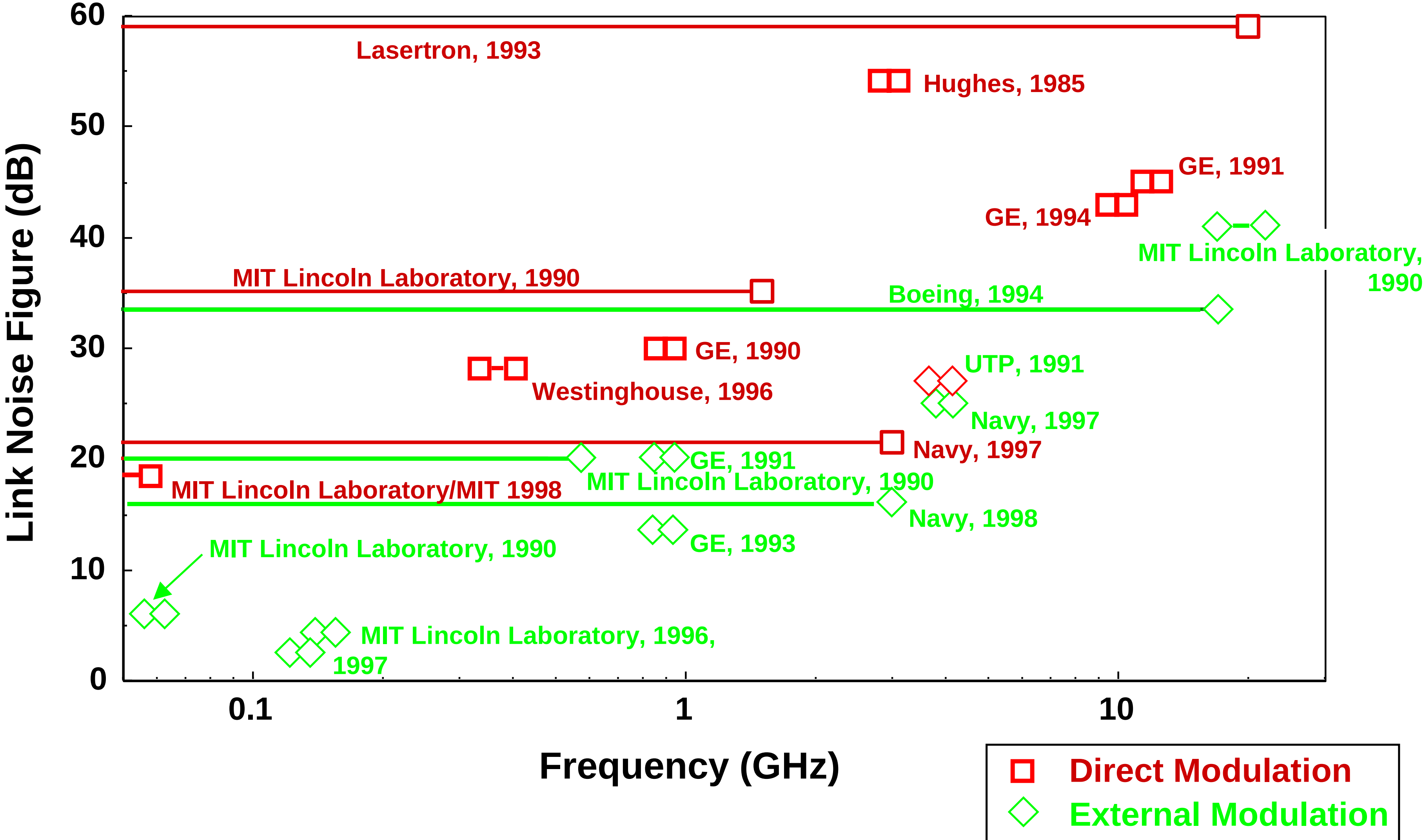
Array Structure

Recent IM / DD Link Noise Figures



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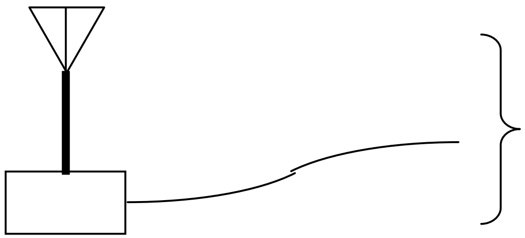
Impact of RFLICS on Photonic Antenna Development Steps

- **Step I: Photonics *separate* from conventional antenna**



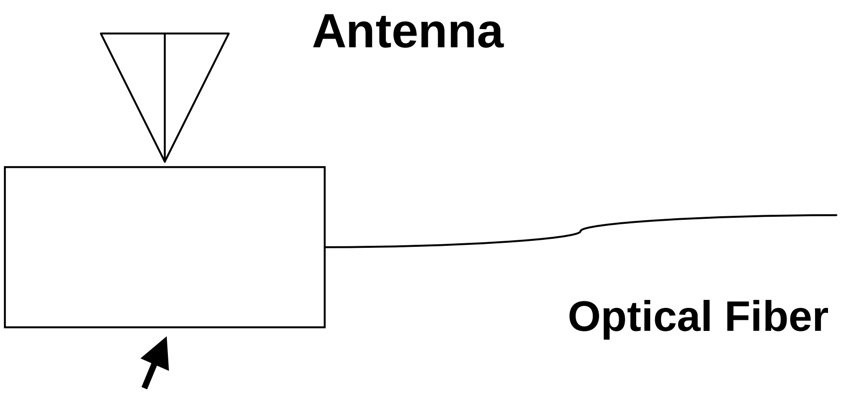
RFLICS modulator development success *beneficial*: would require less pre-amplification, yielding better dynamic range

Outline

- **Step I: Photonics *separate* from conventional antenna**
- **Step II: Photonics *integrated* with conventional antenna**
  - **Integrate antenna with optical photodetector or modulator**
  - **Research in the present**
  - **Applications in the future**
- **Step III: Photonics *assimilated* with antenna**

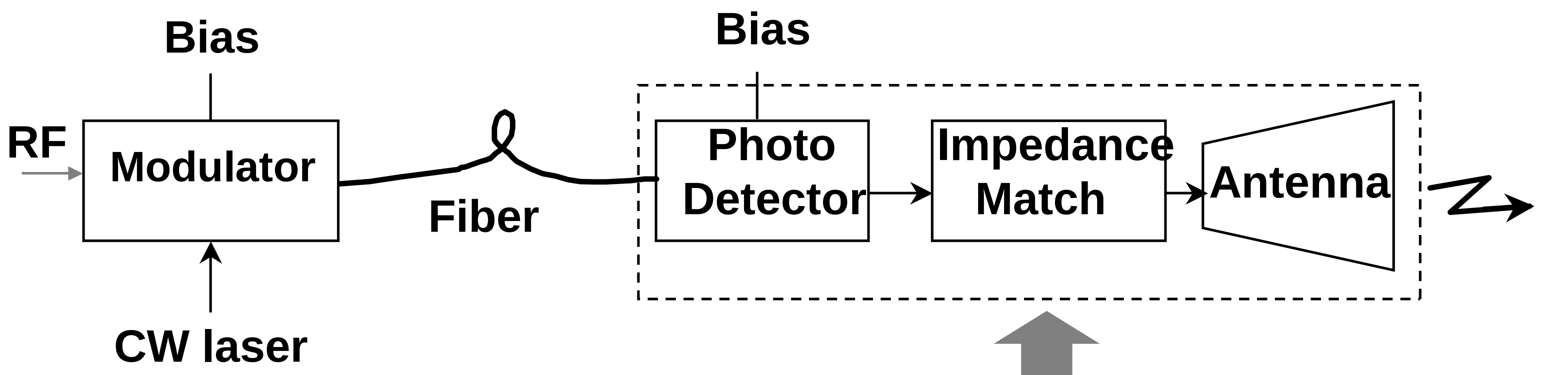
Integration of Photonics with Antennas

Step II: Photonics *integrated* with conventional antenna

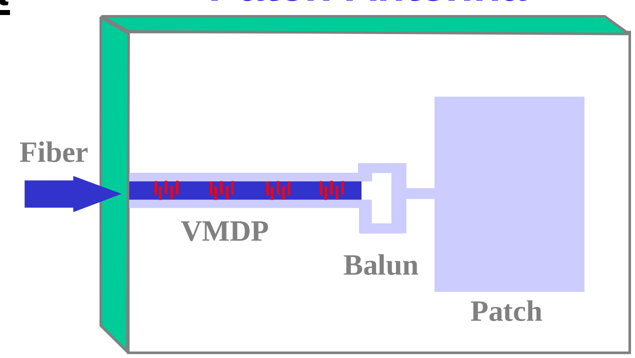


- Electro-optic modulator for receive applications
- Photodetector for transmit applications

Transmit Antennas Integrated with Analog Fiber Optic Links



Integrated Photodetector/ Patch Antenna

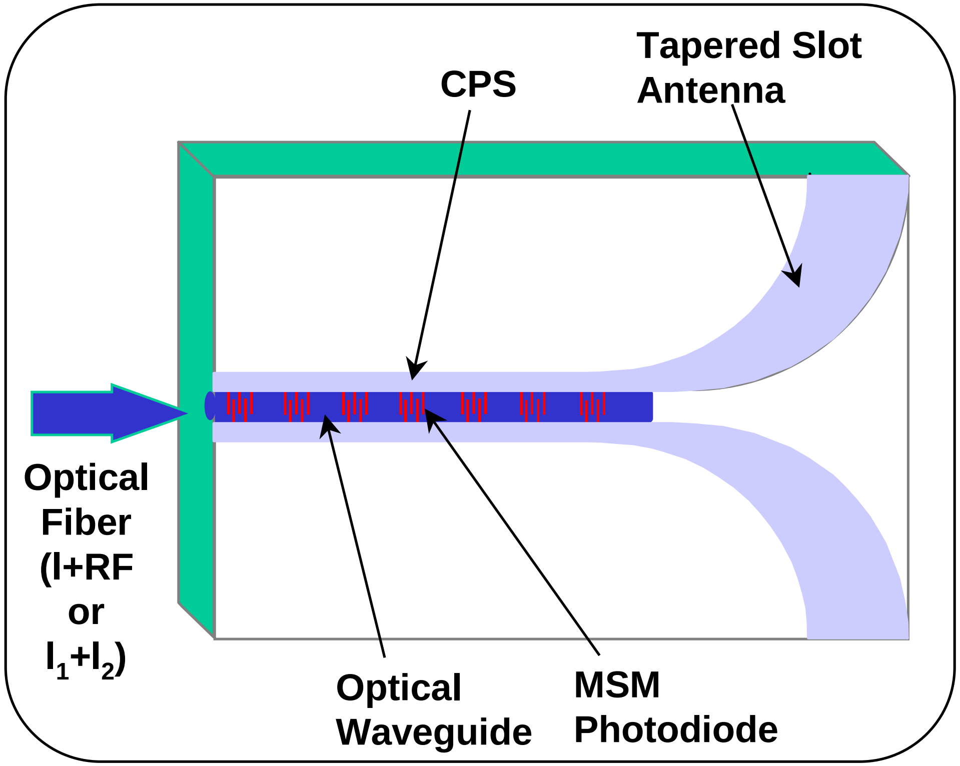


Advantages of Integrated Antenna

- **Compact Front-End**
- **Reduced Insertion Loss**
- **MIC at Microwaves**
- **MMIC at MM-Waves**

Reference: T. Itoh and Y. Qian, UCLA

Integrated VMPD/Tapered Slot Antenna



Features:

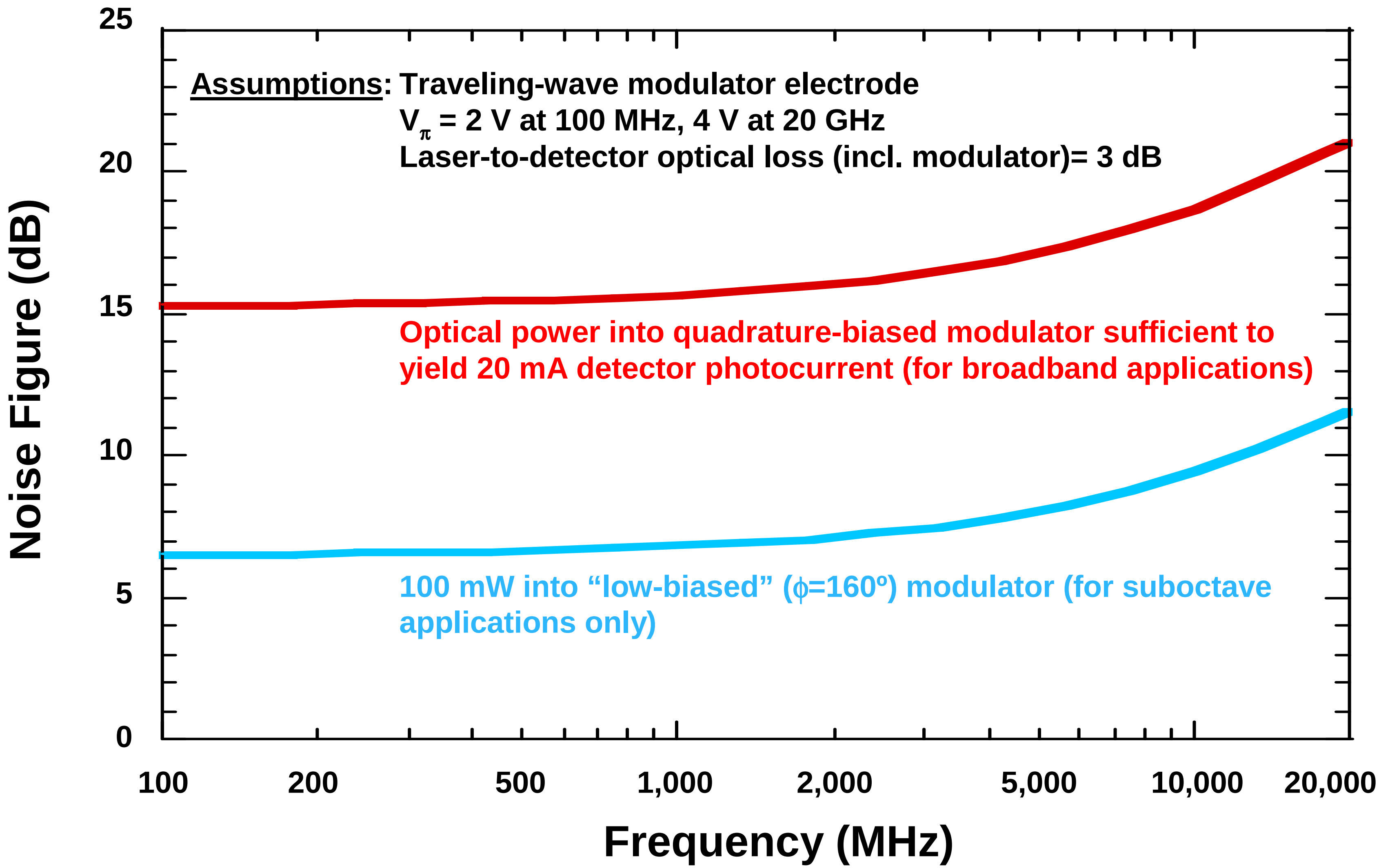
- **Broadband Traveling-Wave Antenna**
- **Easy Transition from CPS to Tapered Slot Lines**
- **Easy Insertion into E-Plane of Waveguide or Horn Antenna**
- **Easy Configuration of 2D Phased Arrays**

Reference: T. Itoh and Y. Qian, UCLA

Concept for Active Modulator

Reference: E Penard, K Matsui and H Ogawa, "Intensity Modulation of $LiNbO_3$ Electro-optic Modulator by Free Space Radiation Coupling," *Optoelectronic Signal Processing for Phased-Array Antennas IV*, Brian Hendrickson, ed., SPIE vol. 2155, 1994.

Integrated Receive Antenna/Modulator Performance Estimate (no amplifiers)



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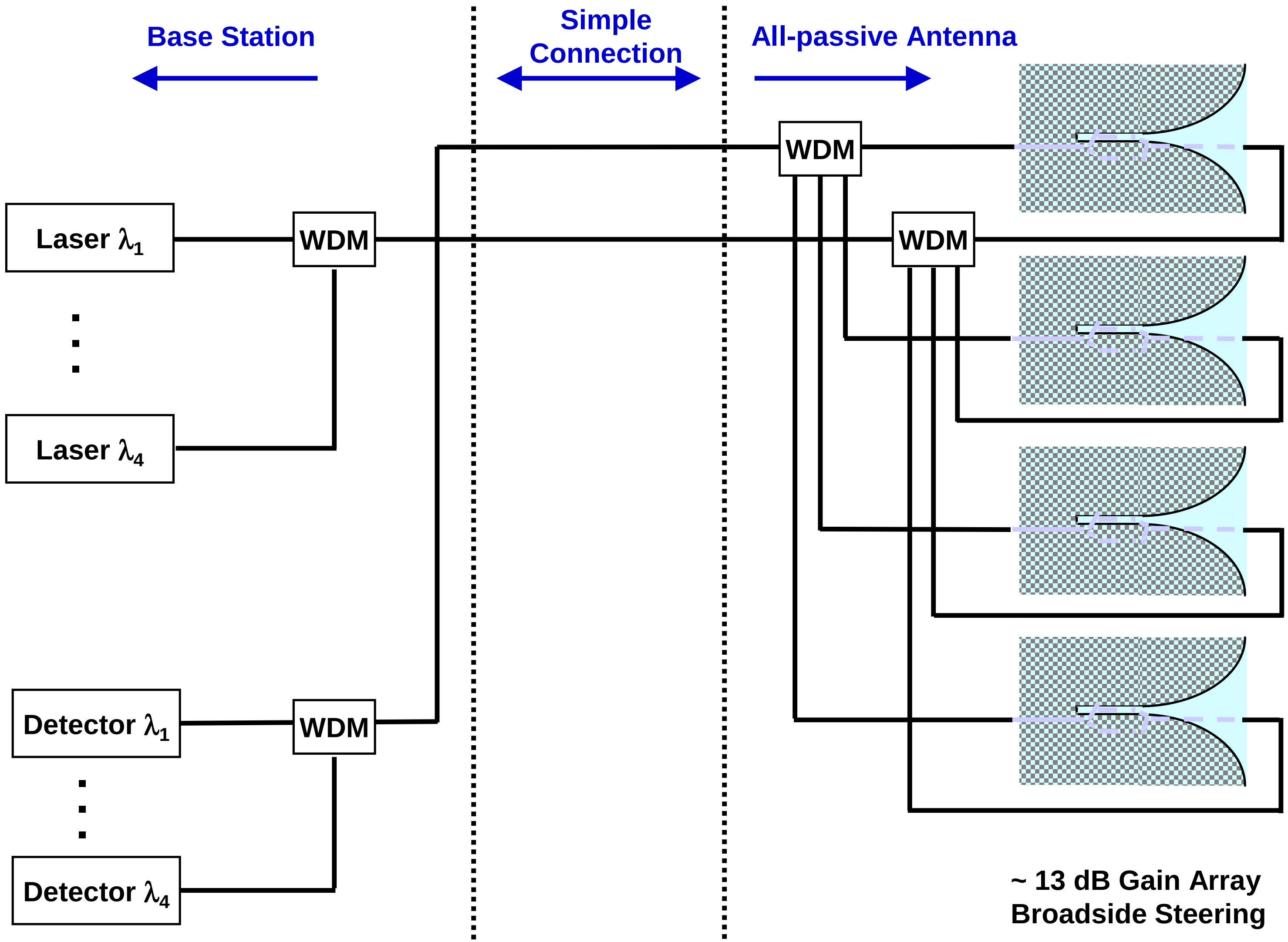
Integrated Receive Array Concept



~ 13 dB Gain Array
Broadside Steering

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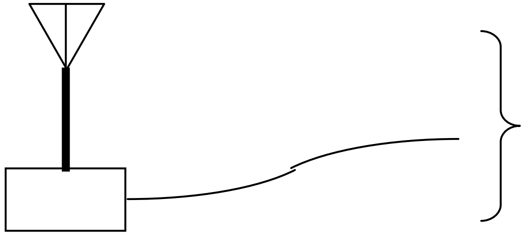
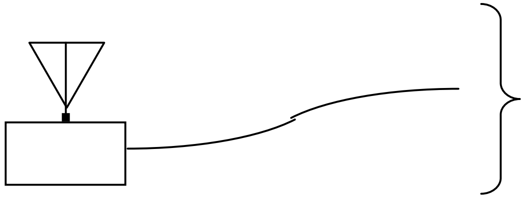


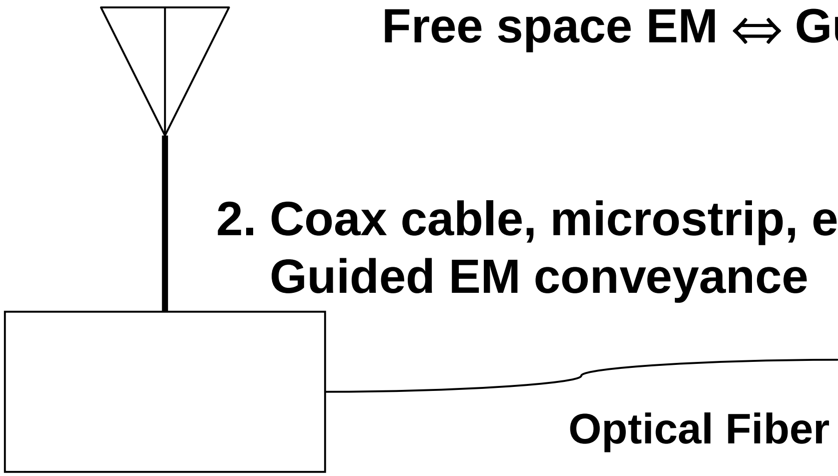
RFLICS modulator development success *beneficial*: would require less pre-amplification, yielding better dynamic range

- **Step II: Photonics *integrated* with conventional antenna**



RFLICS modulator development success *necessary* in some cases: dc power limitations at antenna site may preclude using pre-amp

Another Look at the Problem



1. Antenna:
Free space EM ⇔ Guided Wave EM Transducer

2. Coax cable, microstrip, etc.
Guided EM conveyance

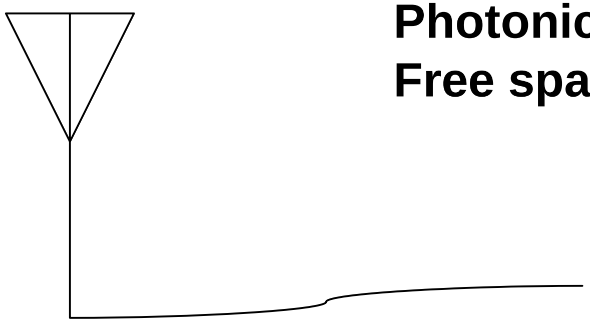
3. Electro-optic modulator:
Guided Wave EM ⇔ Guided Wave Optic Transducer

Outline

- **Step I: Photonics *separate* from conventional antenna**
- **Step II: Photonics *integrated* with conventional antenna**
- **Step III: Photonics *assimilated* with antenna**
  - **Fabricate new device that combines antenna and photodetector or modulator functions**
  - **Research and applications in the future**

Integration of Photonics with Antennas

Step III: Photonics *assimilated* with antenna



Photonic Antenna:
Free space EM ⇔ Guided Wave Optic Transducer

Optical Fiber

Small Element Electric Field Sensor
Layout

Reference: K Tajima, H. Kuwabara and R. Kobayashi, "Evaluation of an Electric Field Sensor with Very Small Elements Using a Mach-Zehnder Interferometer", *Electronics and Communications in Japan* Part I, vol. 80, no. 12, 1997, pp. 69 - 78.

Small Element Electric Field Sensor
Measured Performance

Reference: K Tajima, H. Kuwabara and R. Kobayashi, “Evaluation of an Electric Field Sensor with Very Small Elements Using a Mach-Zehnder Interferometer”, *Electronics and Communications in Japan* Part I, vol. 80, no. 12, 1997, pp. 69 - 78.

Ψ Antenna Coupled Modulator -- Concept

Reference: William B. Bridges, "Antenna-coupled Millimeter-wave Electro-optical Modulators", *RF Photonic Technology and Optical Fiber Links*, W. C. Chang, ed., in preparation.

Experimental Setup
60 GHz Phase Modulator

Reference: Finbar Sheehy PhD Thesis; see William B. Bridges, "Antenna-coupled Millimeter-wave Electro-optical Modulators", ***RF Photonic Technology and Optical Fiber Links*****, W. C. Chang, ed., in preparation.**

Experimental Response
94 GHz Phase Modulator

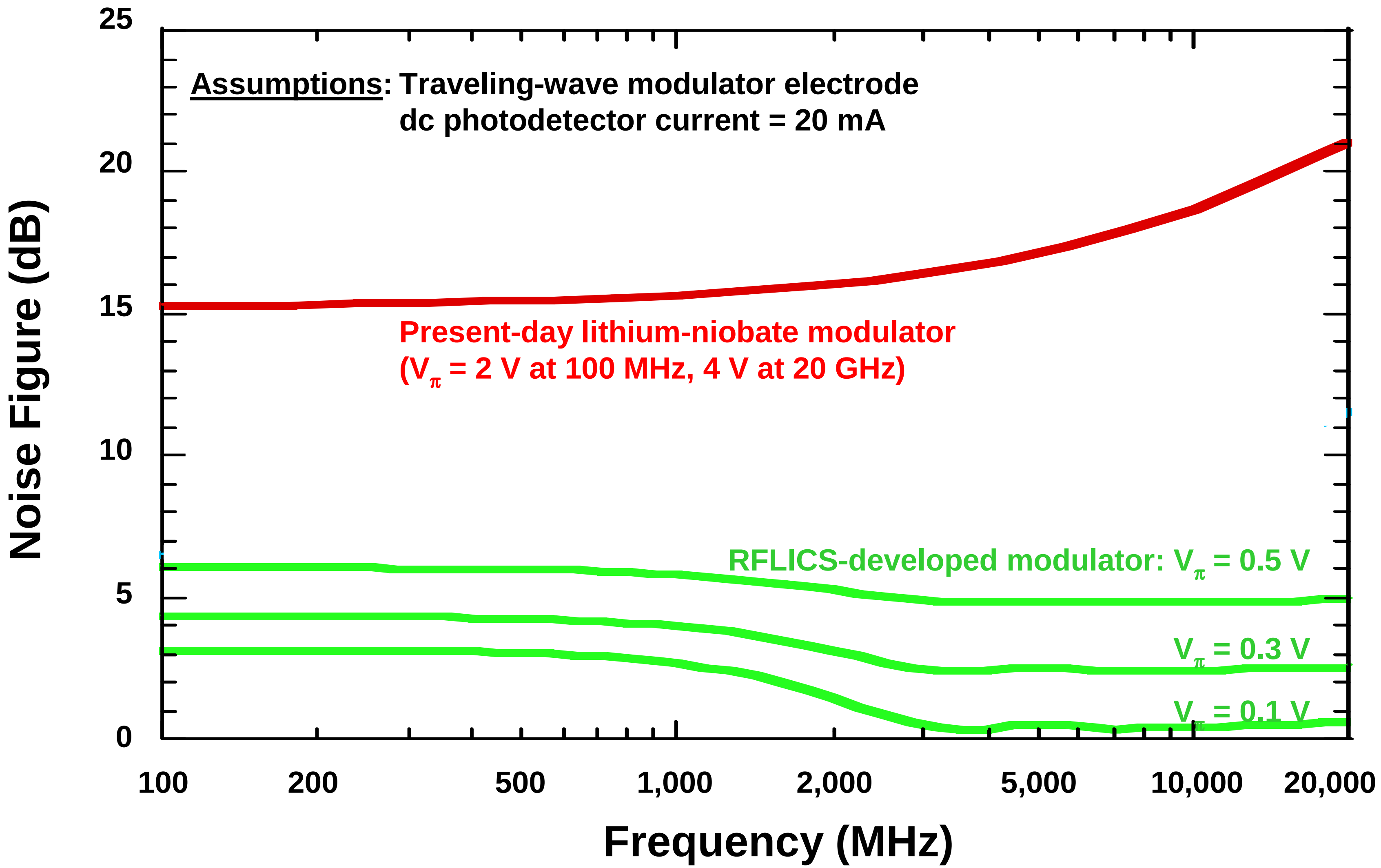
Reference: Finbar Sheehy PhD Thesis; see William B. Bridges, "Antenna-coupled Millimeter-wave Electro-optical Modulators", *RF Photonic Technology and Optical Fiber Links*, W. C. Chang, ed., in preparation.

Integration of Photonics with Antennas

Step III: Photonics enables *novel* antenna

- **Step III Photonic Antenna integration enables**
  - Novel antenna designs that are impossible with conventional coax feeds
  - New antenna forms and locations that are infeasible with present antennas
- **Potential applications include**
  - Wavefront sensing
  - Conformal phased arrays
- **Issues**
  - Noise figure - no electronic low noise preamp
  - Bandwidth - rejection of out-of-band signal?
  - Antennas on low dielectric substrate; modulators on high dielectric substrate
  - Appears well matched to receive applications, transmit is longer term

Impact of RFLICS on Photonic Antenna



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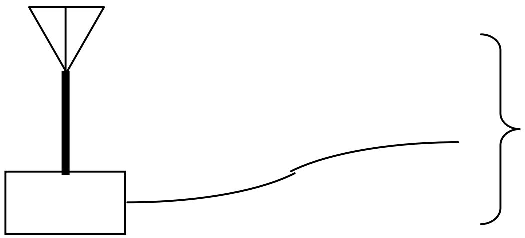

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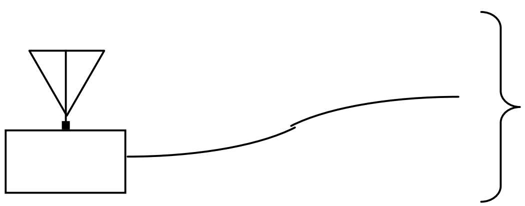
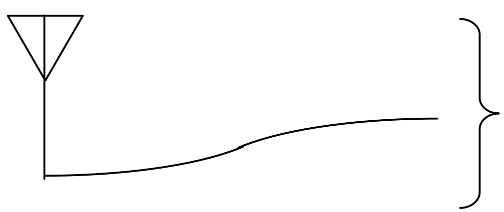
- **Step II: Photonics *integrated* with conventional antenna**



RFLICS modulator development success *necessary* in some cases: dc power limitations at antenna site may preclude using pre-amp

- **Step III: Photonics *assimilated* with antenna**



RFLICS modulator development success *critical:* no pre-amplification possible

Ψ

Summary

- Microwave photonics are presently used to interconnect antennas and electronics.
  - With the antenna and photonics separate devices, it is possible to augment the performance with additional components, such as amplifiers.
- Future applications will require the integration, and eventually the assimilation, of antennas and photonics.
  - As the antenna and photonics merge, it becomes difficult at best, and impossible at worst, to augment performance with additional components.
  - Thus the advanced components anticipated to come out of RFLICS are essential to the eventual realization of the ultimate goal: the photonic antenna.