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Multi-Functional True-Time-Delay Optical Beam Steering System

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Steered Agile Beams (STAB)
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Multi-Functional TTD STAB System: Outline

- Background and Approach
- Motivation
- Potential Applications
- Strawman TTD System
- Program Plan
- Conclusion

Background and Approach

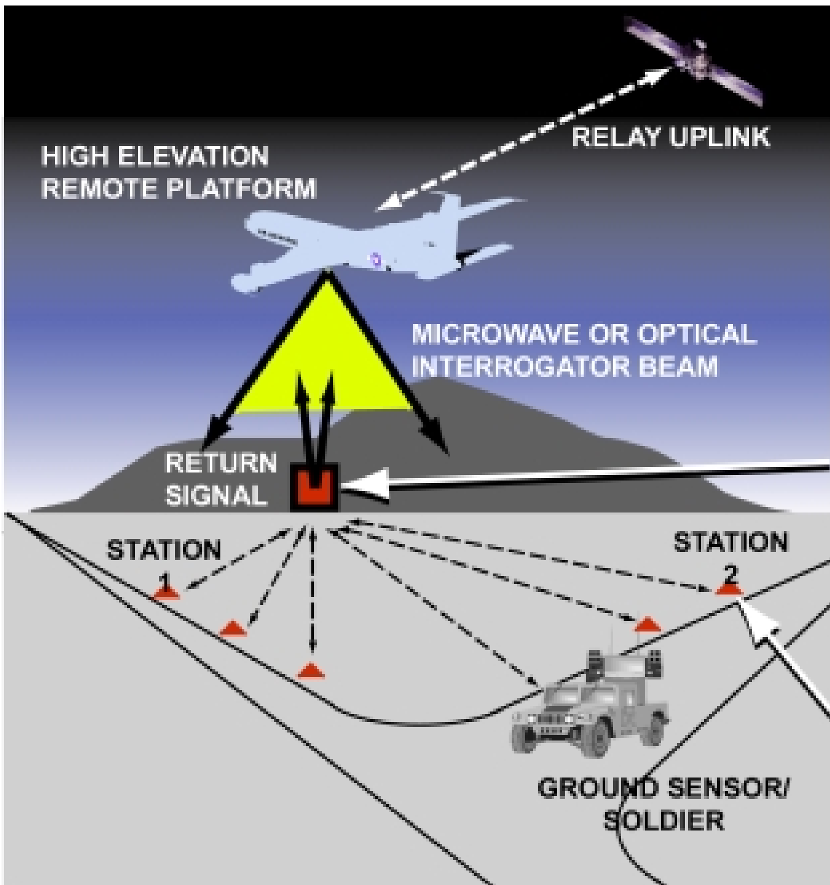
- Customer is seeking non-mechanical, compact beam steering systems to replace/augment existing mechanical gimbal devices
  - Rapid beam steering capability (≈ 1 msec) over wide FOV (≈ 45°)
  - High-bandwidth (> Gb/s), eyesafe operation ($\lambda \approx 1.5\ \mu m$)
  - Potential for multiple steered beams for networking, etc.

- ***Multi-functional*** applications envisioned include high-bandwidth laser communication, IRCM, target designation, IFF, LADAR, and others

- Our approach involves the use of true-time delay (TTD) of multiple beamlets across an aperture: *An outgrowth of HRL's RF Photonics efforts*
  - All beamlets emerge from the aperture at the same time, for all angles
    - High-bandwidth links possible
  - All the beamlets can be made to be phase-coherent
    - Enhanced link performance, suitable for next-generation laser comm.

- Our TTD system is modular, so that a variety of beam steering subsystems (O-MEMS, LC OPAs, etc.) can be integrated into a STAB system

STAB Communication Scenarios



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- Multi-Platform Implementation
- Single and Multi-Node Links
- Vertical and Horizontal Paths

THIS PROPOSAL:
HIGH-BW SECURE
STAB COMMUNICATOR

THIS PROPOSAL:
MAN-PORTABLE PULSE-
BURST STAB COMMUNICATOR

True-Time Delay STAB Systems: Motivation

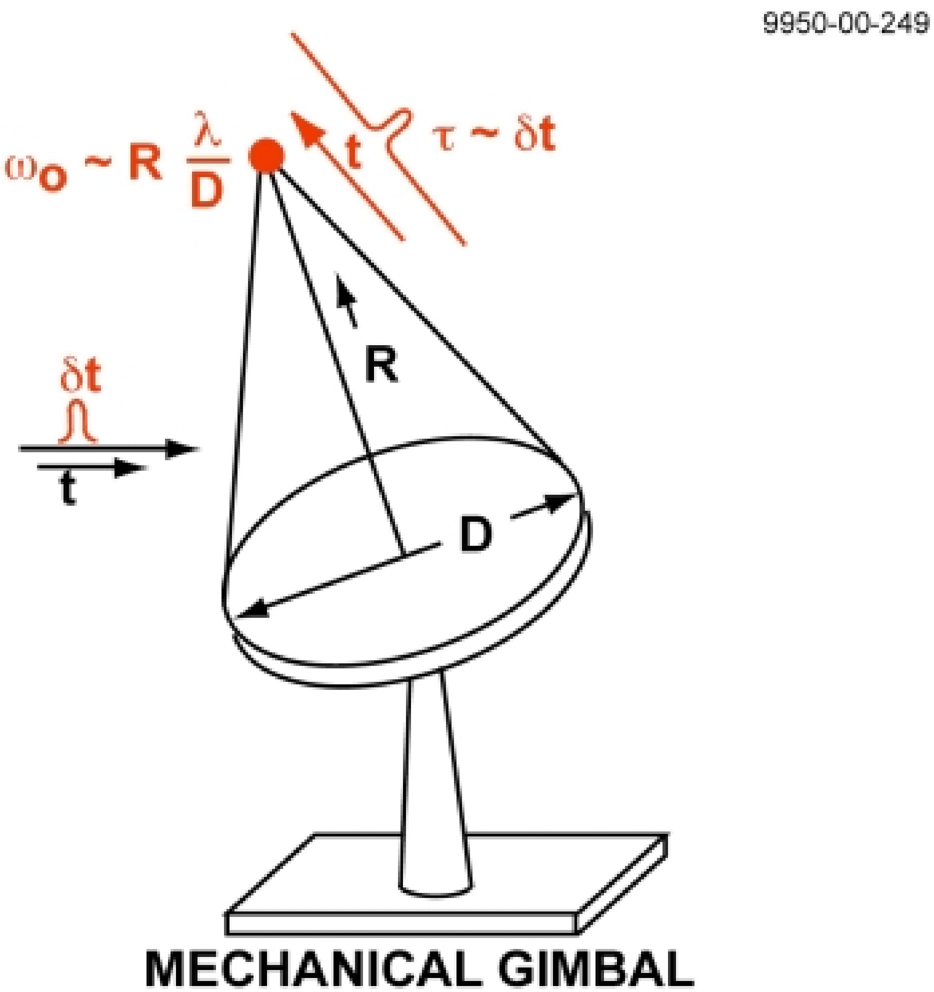
- For a single, flat mirror (neglecting dispersion), the incident (δt) and reflected output (τ) pulse shapes are preserved: $\tau = \delta t$

- However, for a co-planar multi-element beam director (a planar MEMS array, OPA, etc.), the redirected pulselets (reflected or transmitted) from the subaperture ensemble will result in a broadened "composite" pulse: $\tau > \delta t$
  - Broadening of the output pulse will vary as a function of the input/output angle
  - A look-up table provides pulselet synchronization info for all resolvable angles

- The temporal broadening becomes important when…
  - The pulse width becomes comparable or less than the transit time across the output aperture
  - A modulation format is used whose resolution time becomes comparable or less than the transit time across the output aperture

Example: A 1 GHz link degrades as the aperture size, d, > 30 cm

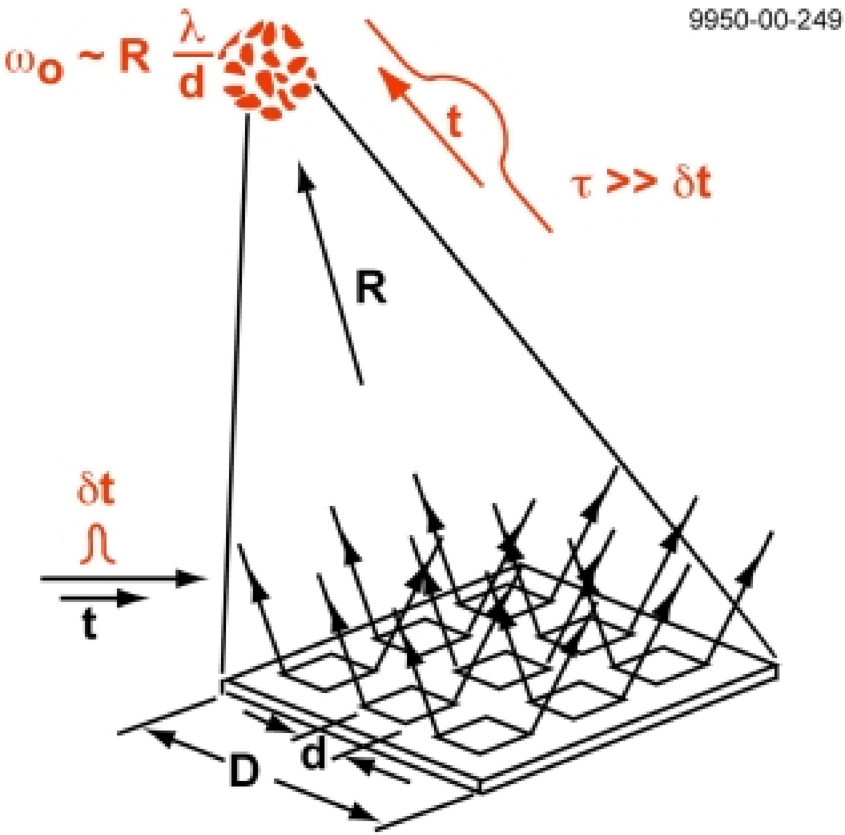
(A 10 GHz link degrades as d > 3 cm)



(+)
- Diffraction-Limited Beam
- Time Coincident Output Pulse

(-)
- Bulky
- Mechanical
- Single Output Beam

STAB Comparisons (1): Single Mechanical Gimbal



"CONVENTIONAL" OPTICAL MEMS OR LIQUID CRYSTAL ARRAY

(+)
- Compact, Chip-Scale
- Rugged
- Single or Multiple Output Beams

(-)
- Spatially Incoherent (Speckle)
- Diffraction-Limit of Sub-Element, d
- Temporarily Dispersed Output Pulse

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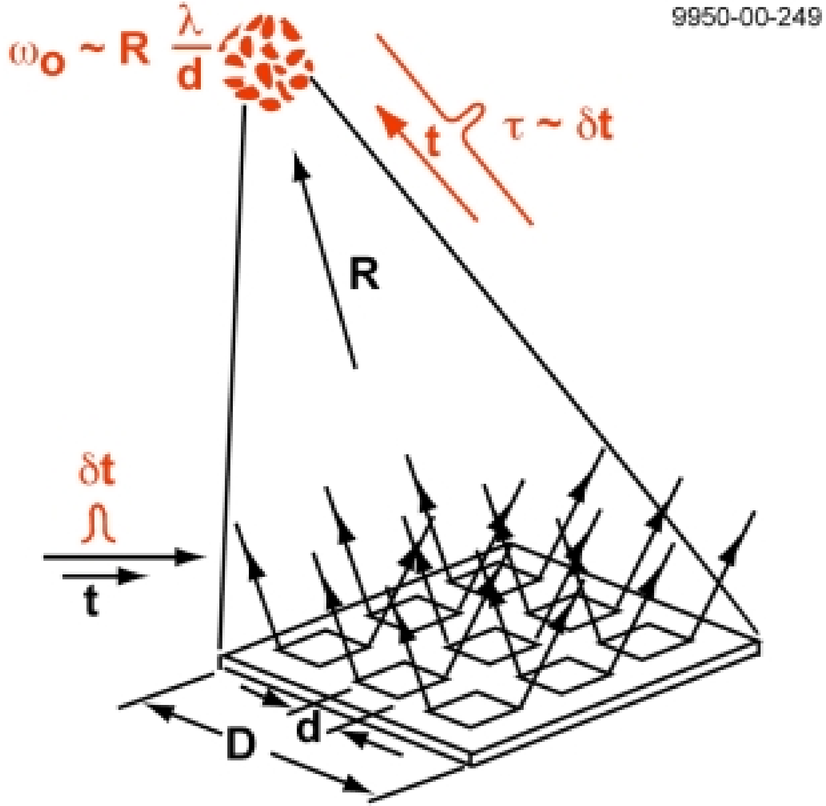
STAB Comparisons (2): STAB Array

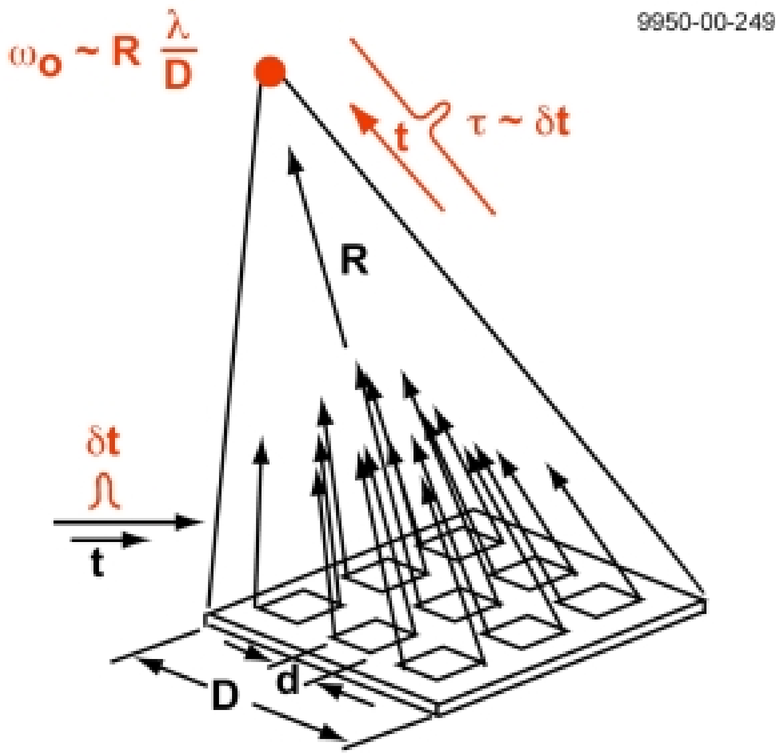


TRUE-TIME-DELAY STAB

STAB Comparisons (3): True-Time Delay STAB Array

(+)
- Time Coincident Output Pulse
- Compact, Chip-Scale
- Rugged
- Single or Multiple Output Beams

(-)
- Spatially Incoherent (Speckle)
- Diffraction-Limit of Sub-Element, d



TRUE-TIME-DELAY STAB
WITH SPATIAL COHERENCE

(+)

- Time Coincident Output Pulse
- Diffraction-Limited Beam of Overall Aperture, D
- Compact, Chip-Scale
- Rugged
- Single or Multiple Beams

(-)

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STAB Comparisons (4): True-Time Delay STAB Array with Spatial (Wavefront) Coherence

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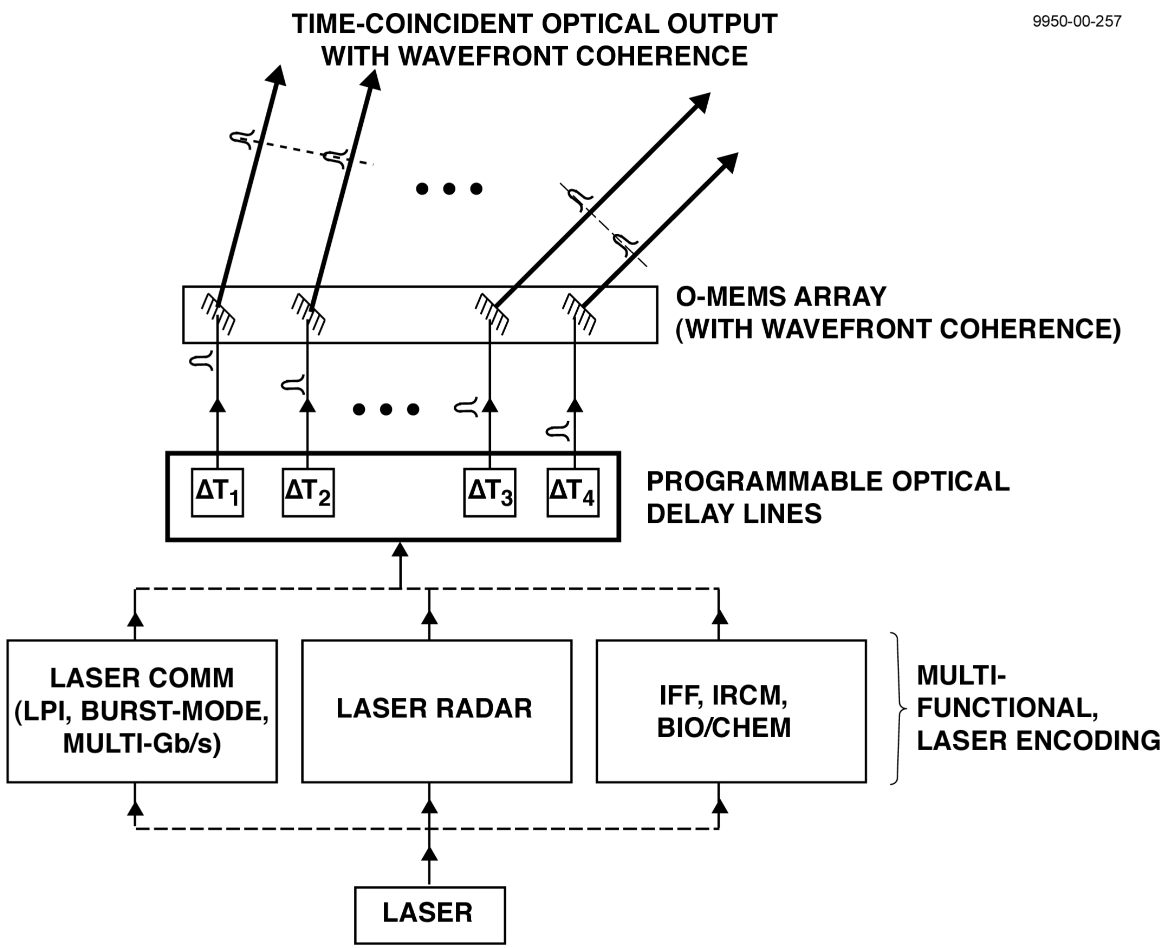
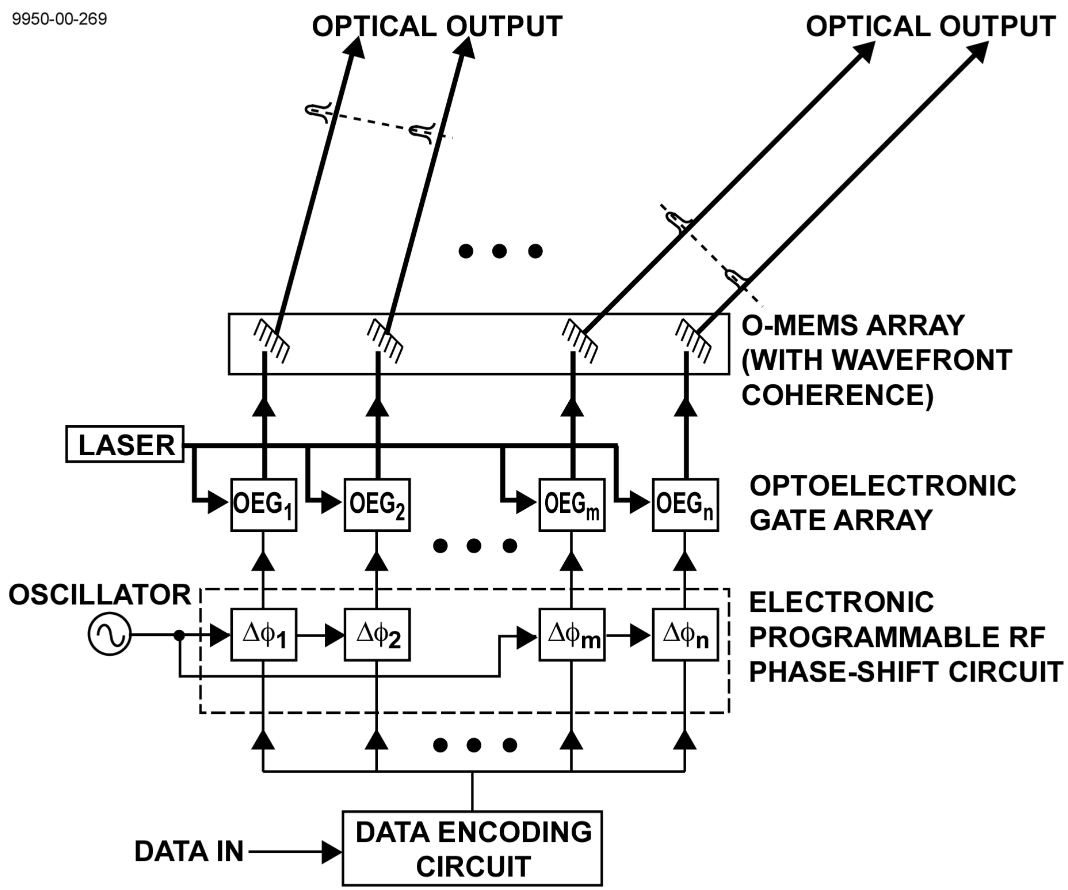
Multi-Functional "All-Optical" TTD STAB System (Patent Pending)

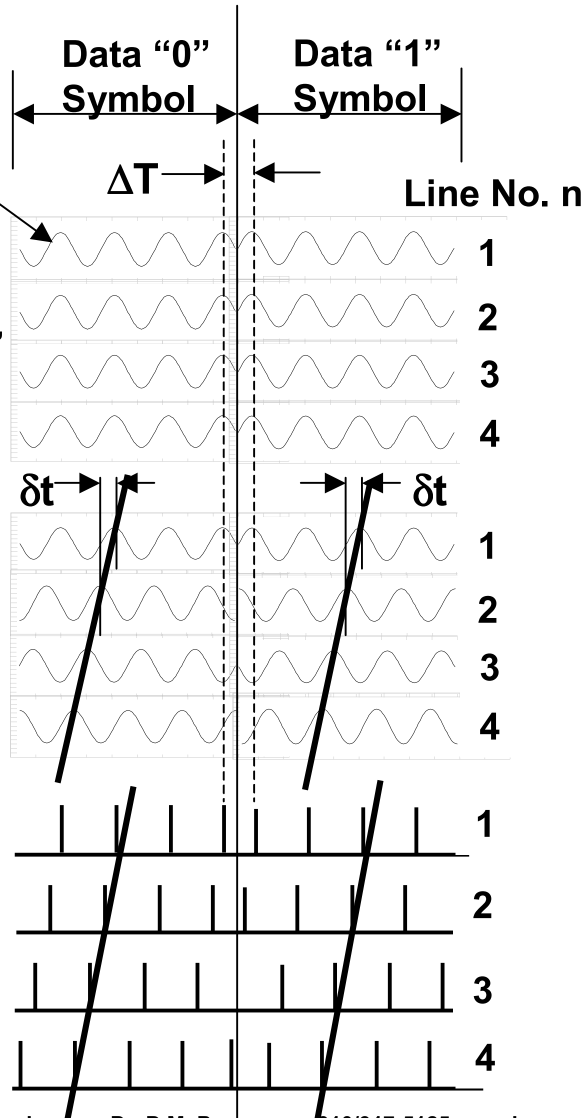


An Opto-Electronic TTD STAB System
(Patent Pending)



Example of a Pulse-Position Encoding Scheme:
BPSK System with 4 Pulses Per Symbol

Sine Wave
At Frequency f_P



A

- BPSK Modulator Phase Shifts f_P Data “1” by π Relative to Data “0”
- Equivalent to a Constant Delay ΔT

B

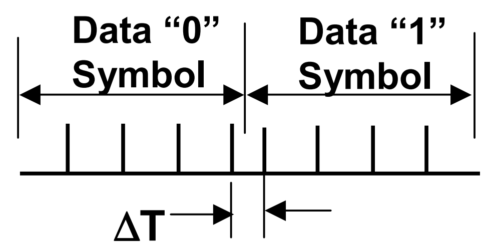
- Antenna Scan Phase Shifters Place $\delta\phi_{Sn}$ on Each Line
- Equivalent to Progressive Delay $n\delta t$ Among Lines

C

- Pulse Formers Generate Short Pulse at Each Sine Wave Crest
- Pulses Delayed By $\Delta T + n\delta t$

D

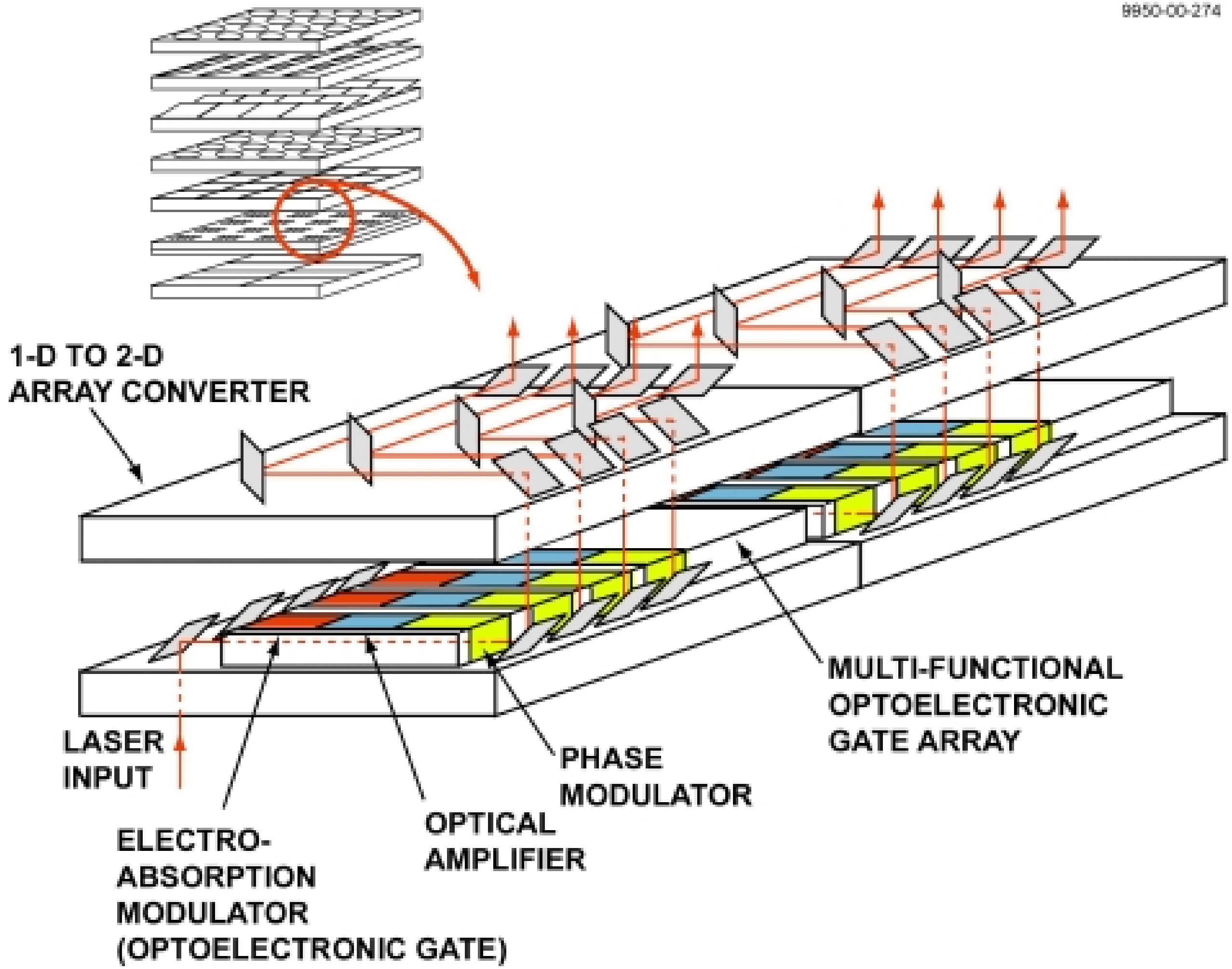
- At Receiver, Progressive Delays $n\delta t$ Removed by Propagation to Far Field at Angle θ_o
- Antenna Element Signals Coincide and Thus Add in Phase to Give Vector Sum and Reproduce Intersymbol Delay ΔT.
- Because of Exact Coincidence There is No Beam Squint



E

- Data Read by Pulse Position Demodulation
- Encoded Symbols Can Be Produced by Nulling Selected Pulses within Symbol by Reducing Sine Wave Amplitude Below Non-Linear Threshold

Opto-Electronic TTD STAB Assembly



Program Plan

- Device and system considerations
- Design and demonstrate a linear TTD module
- Investigation of 2-d TTD arrays and spatial coherence modules
- Establish pathway for system implementation and productization
  - Multi-functionality and modularity
  - Integration with other STAB subsystems

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Conclusion

- **Program goal: Develop *multi-functional* STAB system capability**
    - Laser comm, IRCM, target designation, IFF, LADAR, bio/chem, ...
- **Our approach is based on TTD with optional wavefront coherence**
  - **STAB TTD systems are robust and can enhance performance**
    - Higher bandwidth operation with general encoding formats
    - Greater system link efficiency
    - Programmable for multi-point network distribution (electronic partitioning)
    - Multi-wavelength operation
  - **Can be augmented with an adaptive wavefront compensator**
    - Coherent communications with diffraction-limited performance (LPD, LPI)
    - Potential for TTD STAB subsystems at both ends of a link
    - Path correction: Compensated imaging and narrow-FOV beacons (IFF)
  - **Consistent with DARPA/MTO vision**
    - Modular, chip-scale integration of Photonics, MEMS, and Microelectronics
    - Compatible with myriad STAB modules: OPAs, O-MEMS, ...

We welcome collaboration with STAB participants to leverage novel applications and systems integration for technology transfer