The Institute of OPTICS

JPL

Tunable True-Time Delay (TTTD) Using Side-Coupled Integrated Spaced Sequence Of Resonators (SCISSOR) Devices

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Agenda

- Background
- Task Plan Requirements
- Results To Date
- Way Ahead

Objective

- Demonstrate Tunable True-Time Delay (TTTD) of an RF modulated optical carrier by using the group velocity delay intrinsic to the Side-Coupled Integrated Spaced Sequence Of Resonators (SCISSOR).

Uniqueness over State-of-the-Art Approaches

These solid state devices can be used to dynamically delay the RF signal distribution while:

- Creating economies of scale through photolithographic definition and fabrication.
- Providing voltage controlled tunable true-time delays which:
  - Means fewer delay devices needed per aperture element.
  - Leads to continuously tunable rather than discrete time delays.
- Allowing ease of integration onto transmit/receive Milli-Meter Integrated Circuit (MMIC) chips.
- Providing a compact, low mass design which is readily amenable to deployment in satellite applications.

Background

- Fiber optic true-time delay is enabling for wideband phased array applications.
- Recent "slow light demonstrations" in the physics community suggest exploitation opportunity for true time delay.
- Slow light effects based on sending photons into a medium with a low group velocity which slows down photons:
  - Bose Einstein Condensates (Hau et. al., Nature 397, 594.)
  - Hot Rubidium gas (M. Fleischhauer and M.D. Lukin, PRL 84 (2000) 5094.)
- We proposed solid state approach using group velocity delay observed when waveguides and resonators are coupled.

Task Plan

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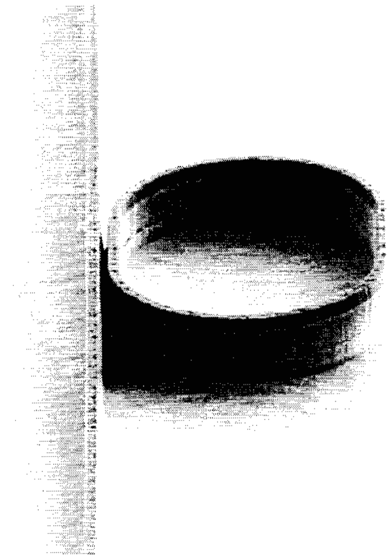
- Task 1: Optically characterize SCISSOR devices (U. or Rochester).
- Task 2: Model anticipated SCISSOR behavior (U. or Rochester)
- Task 3: Model true-time delay systems issues (JPL)
- Task 4: RF breadboard demonstration of true-time delay (JPL)

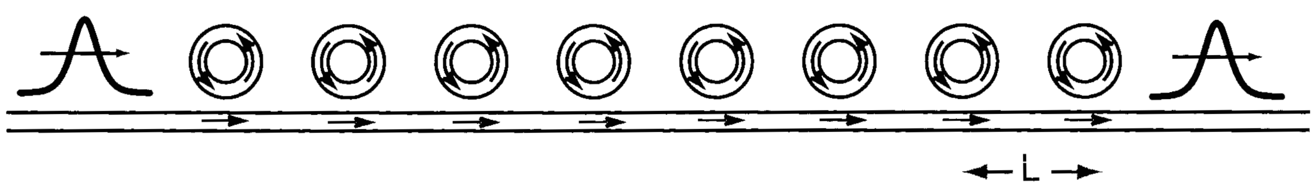
SCISSOR Concept

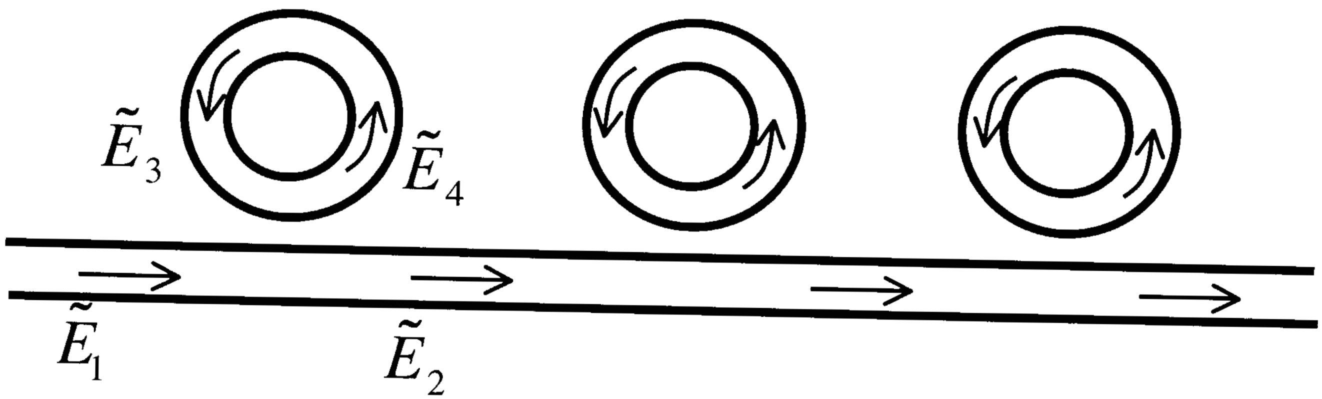
- Waveguide coupled to resonator allows one to engineer group velocity delay by defining waveguide and resonator dimensions.
  - $v_g = c/n_g$; $n_g = n(1+4RF/L)$
  - select bandwidth, $\Delta\nu = \frac{c}{nF2\pi R}$
  - select time delay, $\tau_i = 1/\Delta\nu$

$$\tau_{total} = \Sigma\, \tau_i$$

GaAlAs waveguide/resonator pair



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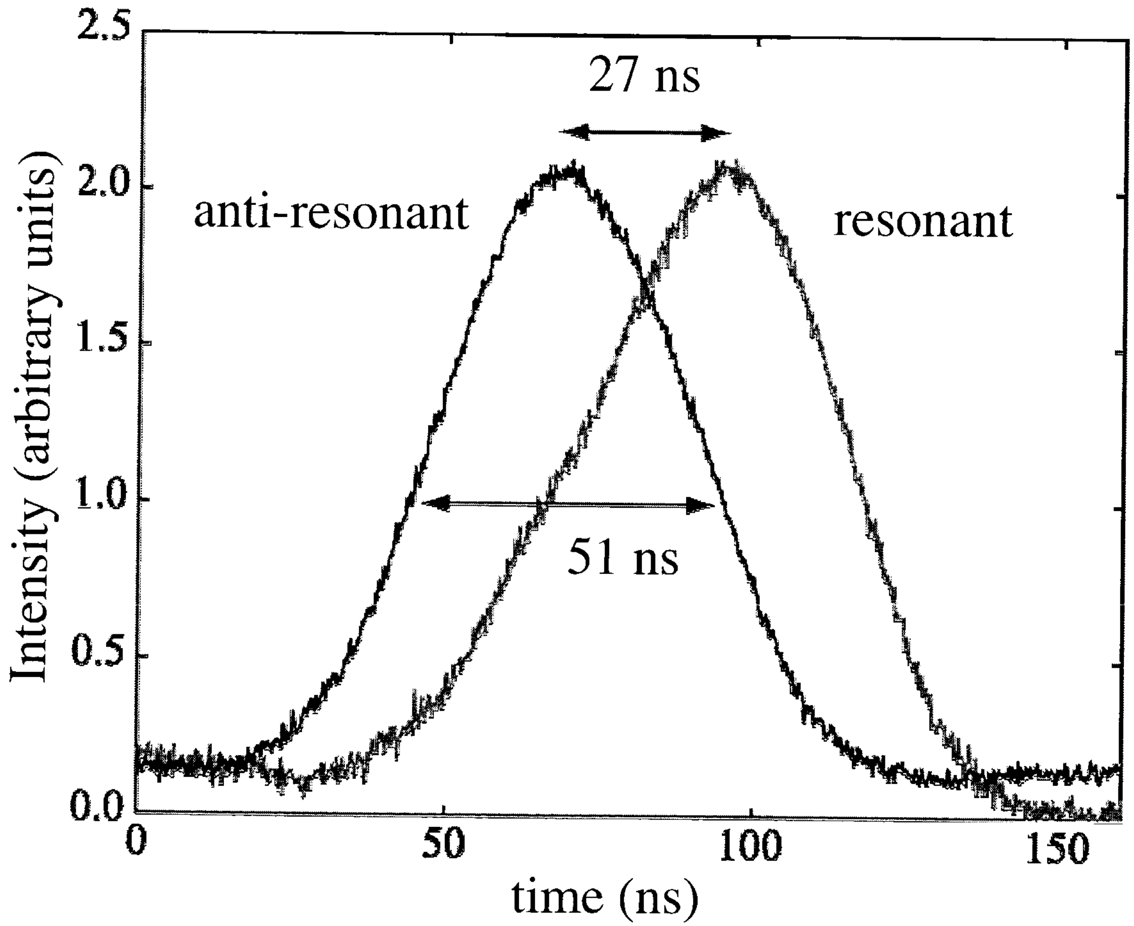
U. Of Rochester Tasks

- Both SCISSOR devices and fiber resonator devices fabricated and characterized*
  - Transmission spectrum
  - Phase spectrum
  - Impulse response (fiber resonator only)
  - Resonant pulses delayed relative to non-resonant transmission (fiber resonator only)
- Data agrees with model's predictions =>
  - Fiber resonators useful for ground based phased arrays
  - SCISSORs useful for satellite phased arrays
- Key design improvement needed for SCISSOR
  - Lower loss due to surface roughness scattering in resonator.
  - Requires re-growth step during waveguide definition process.

* Because SCISSOR devices were lossy, some measurement were easier to do in fiber resonator.

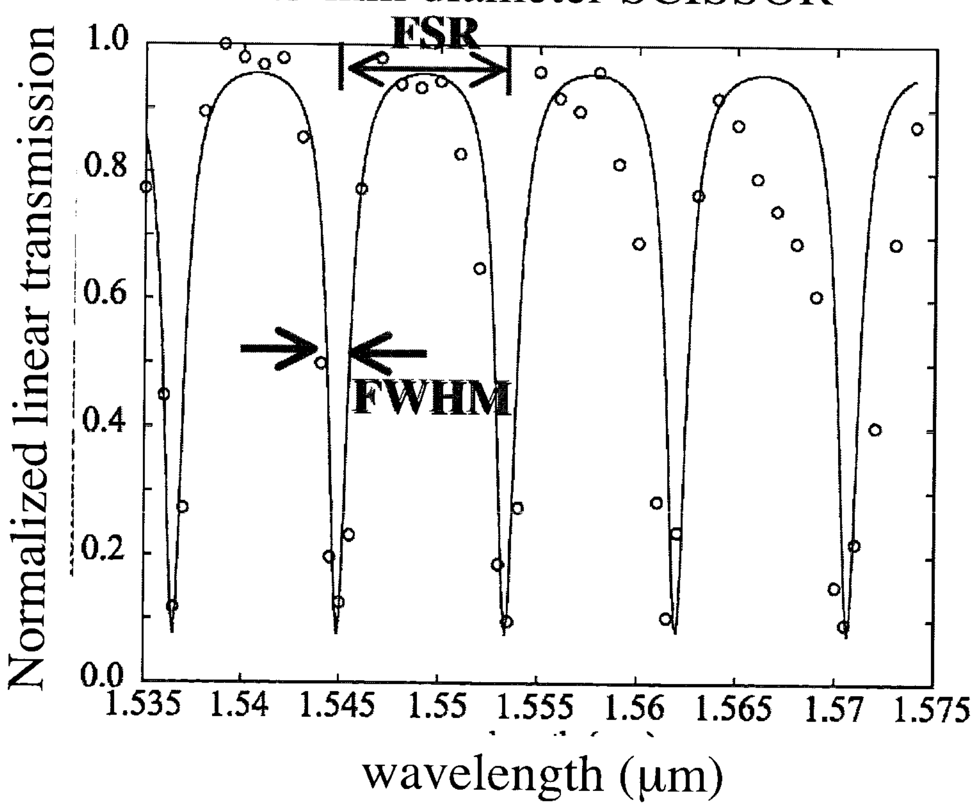
Low-Q, 3-meter Diameter Fiber Resonator Exhibits resonant Time Delay

1/2 fractional pulse delay



Basic task objectives completed

12.5 mm diameter SCISSOR



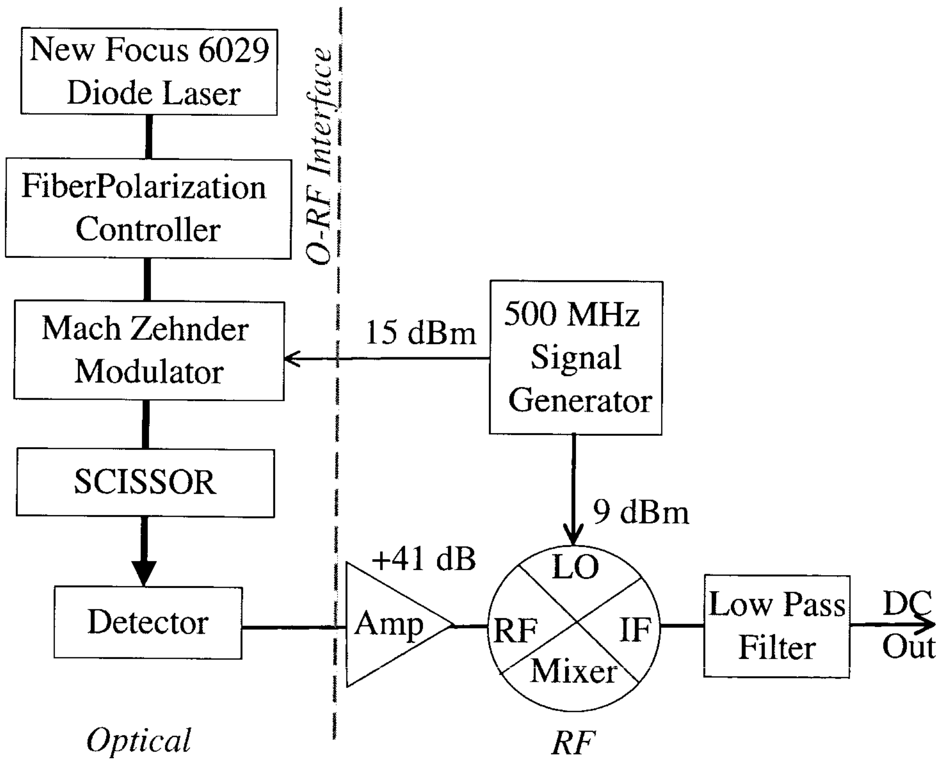
SCISSOR transmission spectra permit one to calculate time delay.

$$\frac{1}{\tau_i} \equiv \frac{c}{nF2\pi R}; \quad F \equiv FSR/FWHM$$

$$\tau_{total} = \Sigma\, \tau_i$$

- Transmission spectra data permit one to predict time delay and device bandwidth for
  - SCISSOR
  - Fiber resonator
- Optical pulsed measurement on fiber resonator confirm time delay predictions are correct.

JPL Task: RF Testbed



- RF-Optical Testbed completed.
- Currently testing fiber resonator to measure on-resonance RF phase shift relative to non-resonant phase.
- Will wrap up testbed task by 06/30/03.

JPL Task: RF system characterization

- Calculated the modulations bandwidths (BW) for
  - Amplitude modulation
  - Phase modulation
  - Frequency modulation
- Concluded that SCISSORs bandwidth, $\Delta\nu \gg$ BW
- Modeling of other parameters to be completed after testbed measurements finished.

Summary

- From the optical demonstration of true time delay, we have shown:
  - SCISSOR devices and fiber resonator devices are both capable of supplying true time delay function.
    - Fiber resonators provide longer delays (multi-ns)
    - SCISSORs provide fine incremental delays (10's or ps)
  - SCISSOR scattering losses lowers the Q and limits the number of delay devices that can be coupled in series.
  - Correcting SCISSOR scattering losses requires re-growth step during fabrication which is beyond scope of task funding.
- With the remaining funds
  - RF demonstration of time delay will be completed using fiber resonator.
  - SCISSOR with a finesse, F=10, will be delivered to JPL.
  - Systems issues that can be evaluated with the data taken thus far will be addressed.