RF AND MICROWAVE FIBER OPTIC DELAY LINE TECHNIQUES

Historical Delay Line Applications and Construction.

Delay lines are used for developing, qualifying, and calibrating RADAR systems, Radio Altimeters, Radios, feed-forward amplifiers, telemetry and other systems. Traditional RF and Microwave delay line technology requires long, bulky, electrical transmission lines to delay electrical signals for a precise period of time. Flexible, coaxial cables are commonly used to produce the desired delay.

EO Programmable microwave delay line

Other delay line techniques include energy transfer methods such as crystal or glass substrates that generate acoustic waves. Here, electrical energy is converted to mechanical energy using a transducer. The energy moves through a medium at a speed related to properties of the material used to construct the delay line. Specific geometries of crystal or glass result in longer delays due to internal reflections and the propagation velocity of the medium. At the output of the crystal/glass, the mechanical energy is converted back to electrical energy using a second transducer. Crystal based delay lines require precisely polished surfaces in order to avoid signal distortion from unwanted reflections which may occur during the delay process. Temperature stability of crystal and glass based delay lines is essential to assure consistent delay times. Crystal delay lines are very susceptible to vibrations, making them unusable in harsh environments common to aircraft and vehicular applications. Further, crystal delay lines are expensive to produce and require long lead-time tooling for new applications, and produce high losses.

RF Delay lines built using long lengths of coaxial cable require significant storage volume for the cable spools. Long cable runs will have high losses that typically require support circuitry to restore the signal to the desired amplitude. For example, using a low loss cable such as RG-141 (semi-rigid) for a 1 km delay (4.7 us) will produce more than 100 db of loss (@ 4.3 GHz), weigh 95 pounds, and require a 10 inch diameter coil, 6 inches tall. Long lengths of electrical cable are heavy and susceptible to interference from other electrical sources. Interference may result in compromising the signal if the equipment is not properly shielded or if shielding integrity is lowered because of age or maintenance.

Recent advancements in delay line technology include approaches where the signal is converted to digital data using an analog-to-digital converter (A/D), stored in deep memory, and reconverted to an analog signal in a digital-to-analog converter (D/A). The A/D to D/A approach offers some advantages over traditional approaches, but is susceptible to interference and distortion. Distortion from digitization (quantization error) can result in performance degradation under certain operating conditions. Analog-to-digital conversion requires power hungry integrated circuits that limit frequency to a few GHz and provide a small instantaneous bandwidth.

The EO Delay Line.

An alternative RF and Microwave delay line technology developed by EO uses optical signals offering superior performance over competing techniques (See Fig.1). Electrical signals up to 40 GHz are used to modulate a light source which is then connected to a specially wound optical fiber coil. The coil length is selected to produce a specific time delay. The output of the fiber terminates into an optical receiver which then demodulates the signal and faithfully reproduces the original electrical waveform.

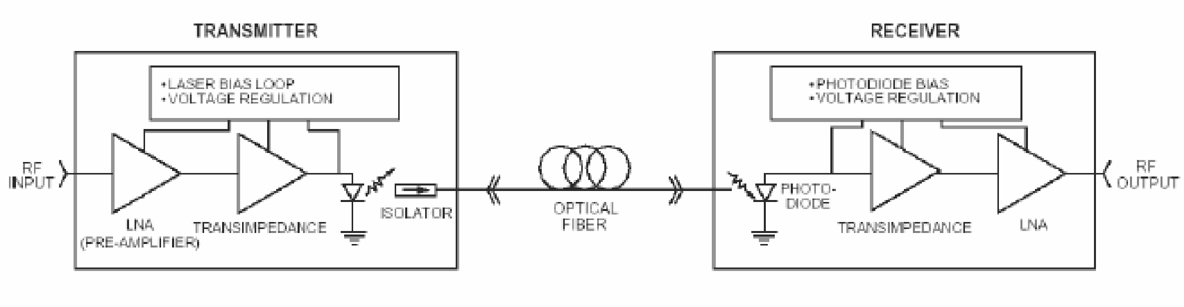
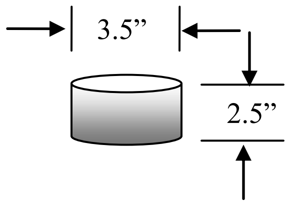
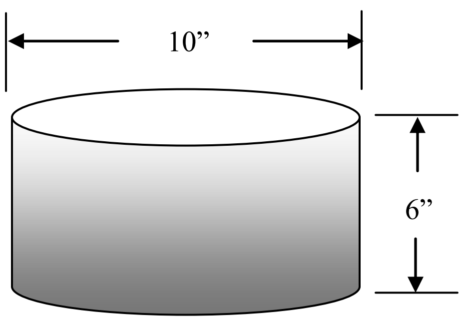


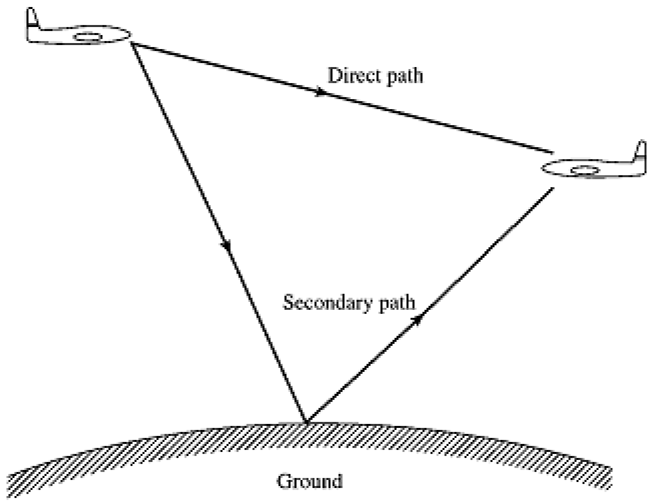
Figure 1. Block diagram of standard fiber optic link.

Fiber based delay lines offer greatly reduced insertion loss and dramatically improved signal quality. Fiber based delay lines have a constant delay versus frequency, are immune to vibration, and are largely resistant to electromagnetic interference. Furthermore, fiber delays do not radiate energy which may interfere with the operation of other electrical devices or allow unauthorized detection. Unlike crystal delay systems the fiber optic approach does not require complex thermal control. Finally, the EO fiber optic system is smaller, lighter, and lower loss than the electrical transmission line approach (See Table 1). For example, a 1 km fiber optic delay (5 us) will produce less than 0.04 db of loss, weigh less than 0.45 pounds, and require a spool that is less than 3.5 inches in diameter and under 2.5 inches tall.

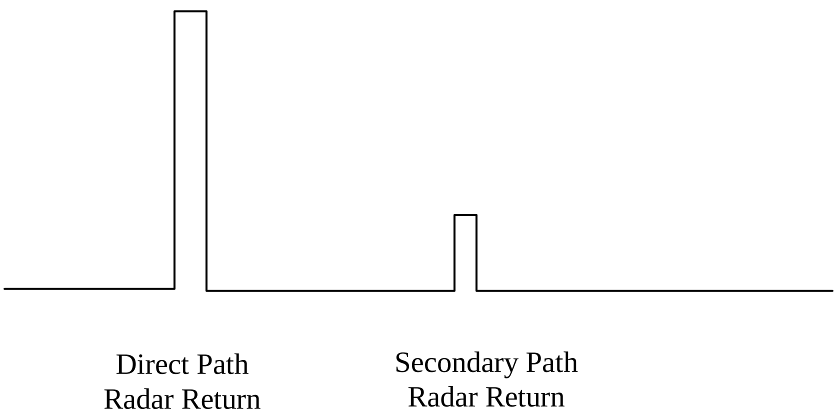
Table 1. EO vs Conventional Delay Lines (1 km).	Size	Weight (lbs/km)	Loss (dB/km @ 4.3 GHz))
EO Delay		0.45	0.04
Electrical Transmission Line Delay (RG-141)		95	100

The modulated optical signal may be divided into multiple paths and coupled into multiple fiber spools, each with a different time delay. Practical uses in RADAR and communication systems include simulation of variable target ranging and multipath production. Combining this coupled solution with a Wavelength Division Multiplexing (WDM) approach results in a single fiber that offers a wide range of delay times for many different signals. Space savings gained from this hybrid solution enable considerable redundancy opportunities for future delay line systems.

The same approach is used to replicate communication channels for complex testing of radio transmissions. Using signal separation techniques and WDM a single optical delay can be used to carry signals in both directions between two or more radio transceivers. This multi-direction channel replication allows radios to be operated in full duplex mode and will faithfully reproduce all possible propagation paths. Multipath or fading problems can be added to test the radio network in a real-world environment directly on the laboratory test bench.



Typical Multipath Application



Using optical switches multiple delay lines may be configured in parallel or serial groupings. These configurations provide either low loss fixed delays or a binary summation of multiple delays which allow the user change the total delay in small step sizes. Figures 2 and 3 below show block diagrams of the two approaches. A hybrid of both configurations is also possible.

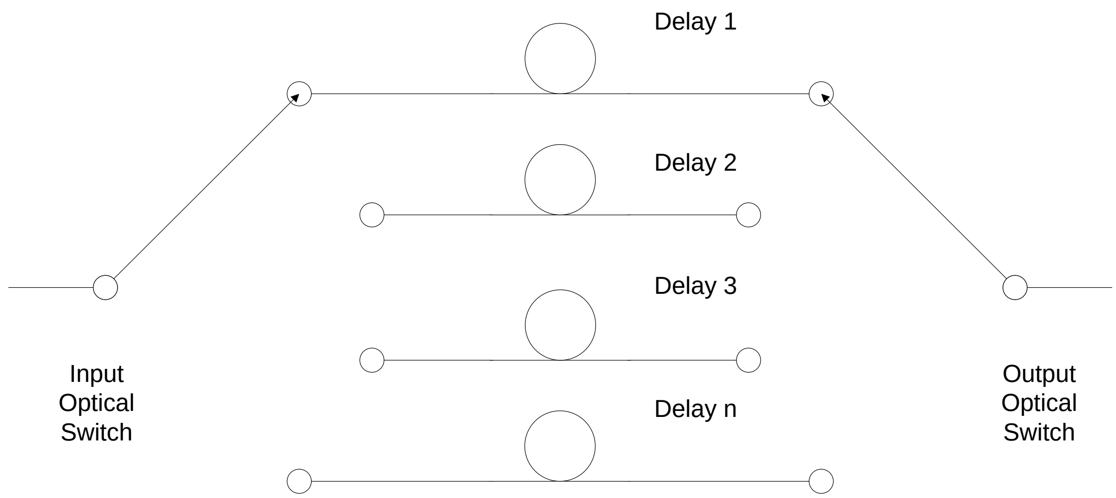


Figure 2. Parallel Configuration

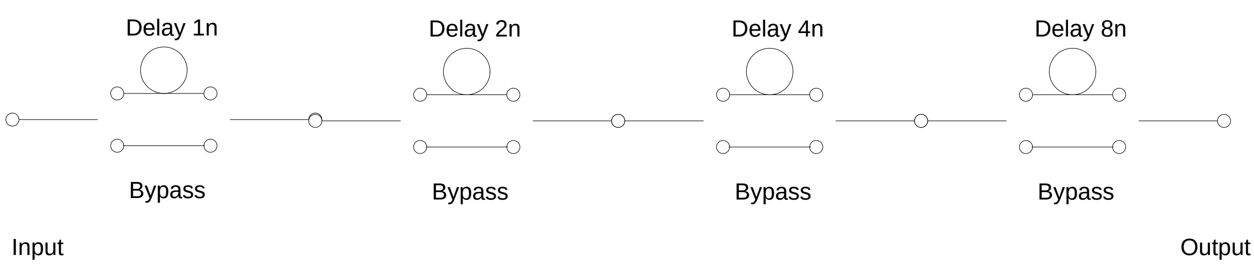


Figure 3. Binary Configuration (4-Bit)

Fiber based delay lines can deliver superior performance, higher reliability, reduced manufacturing costs, reduced size, reduced power consumption, EMI/EMC/Vibration immunity and longer life cycles. Fiber based delay lines are a much needed component for RADAR systems of the future and for refurbishment of our existing aging systems. Additional features such as Doppler Generation for moving targets, external optical delays, receding and proceeding target generation, and free-space propagation loss simulation are standard options.

Eastern OptX, Inc.A Veteran Owned Small Business
710 E. Main Street • Moorestown, NJ 08057 • 800-861-7445 • 856-231-9022 (fax)
www.eastern-optx.com

EASTERN OPTX TYPICAL SPECIFICATIONS

Parameter	Value	Unit	*Notes*
Total time delay	64	µsec	**600 µs total time delay available**
Minimum Time delay step size	.01	µsec	**Larger and smaller step sizes available. Delays may be configured in switched digital step and parallel discrete arrays.**
Number of delay steps	1 - 14		**Additional step sizes available**
Delay accuracy	1	%	
Low frequency	100	MHz	**3 dB bandwidth**
High frequency	40	GHz	**Select upper frequency when ordering**
System RF gain	10	dB	**All switches in pass mode Higher system gain available**
VSWR	2:1		**Maximum**
Spurious free dynamic range	100	$dB/Hz^{2/3}$	**1 Hz bandwidth**
1 dB input compression point	-15	dBm	**+ 30 available**
Noise figure	12	dB	**Typical**
Input / output impedance	50	ohms	
Switching speed	10	msec	**Micro-second switching speed available**
System control	**Manual toggle switch, optional touch panel LCD display, or Remote control via Ethernet SCPI Commands or supplied User GUI**		
Power supply	120- 220	VAC	**50- 60 Hz**
Dimensions	**5.25” (3-U) height, 18 “ depth, 19” rack mounted**		
RF connector	**Available with SMA, K, and N-type connectors**		