FIBER OPTIC DUAL DELAY LINE FOR A MULTI-MODE RADAR TEST TARGET SIMULATOR

*Arthur Paolella, *Steven Malone, *Thomas Higgins, +Barry Scheiner and +Eric Adler

*Army Research Laboratory, EPSD, Ft. Monmouth NJ
+Army Research Laboratory, Sensors, S^3I D, Adelphi, MD

Abstract

A fiber optic delay line has been designed for a multi-mode radar test target simulator. This delay line, operating between 3.0 to 3.6 GHz, has a fixed delay of 30 µsec. Low transmission loss has been achieved using reactive matching techniques and a GRIN lens for optical coupling of the laser to the fiber. The transmission gain of a link consisting of the transmitter and receiver, connected with a short length of single-mode fiber, is -17 dB at 3.3 GHz with 1 dB variation across the band.

Introduction

It is advantageous to test and characterize a radar system using a test target simulator (TTS) in the laboratory rather than incur the inconvenience and expense of performing field testing. The function of a TTS is to accept the radar's transmit waveform as an input and reintroduce into the receiver a replica of this waveform that has been delayed by a time greater than the pulse width to simulate a target at a given range.

Conventional delay techniques that use coaxial cable or microstrip have delays that are frequency dependent, suffer from high losses and are susceptible to electromagnetic radiation. Acoustic techniques, which can provide significant delay time, have losses of 30 dB for each 1 µsec of delay [1]. Single mode fiber optic links can provide the required RF delays at microwave frequencies [2] with advantages of wide bandwidth, low loss, small size and weight, and immunity to EMI. A dual optical delay line has been designed for incorporation into the TTS for a multi-mode radar which can simulate synthetic aperture radar and Doppler radar signals. This fiber optic dual delay line operates over a 3.0 to 3.6 GHz bandwidth with a low transmission loss

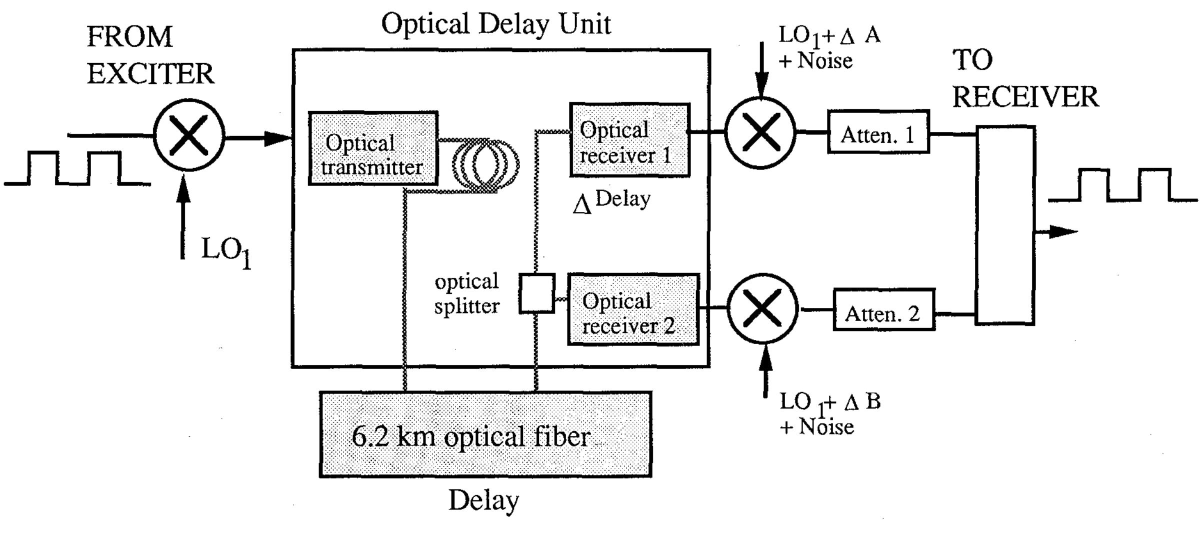

Figure 1. Block diagram of Test Target Simulator

providing a fixed delay of 30 μsec and an additional incremental delay of 2, 6, 60, 100 and 200 nsec.

Test Target Simulator Configuration

The characteristics of the target(s) that are generated by the TTS are a function of the type of radar being tested. A synthetic aperture radar (SAR) requires only a target of some radar cross section (RCS), while a pulse Doppler radar require control of RCS, Doppler frequency, and clutter. In addition, it is useful to determine the ability of the radar to resolve multiple targets in range. The bandwidth of the transmit signal in the SAR mode will be at least 600 MHz centered at upper Ku band, with a maximum pulse width of 25 microseconds and spurious free dynamic range of at least 45 dB. A block diagram of the TTS is shown in Fig. 1. A Ku-band transmit waveform is down converted to the 3 - 3.6 GHz band, converted to the optical domain and delayed 30 μs by a 6.2 km length of single mode fiber. The optical signal is divided into two channels, incrementally delayed by an additional length of fiber in one channel to simulate a second target for SAR processing, and reconverted to the electrical domain at the photo-receivers.

Fiber Optic Link Design Considerations

Fiber optic delay lines are commercially available, however they are designed for general purpose applications and suffer from excessive transmission losses of close to 40 dB [3] and high noise figure. Therefore, an important design aspect is the optimization of the insertion loss and return loss of the fiber optic link by reactive impedance matching [4 ,5] of the laser and photodetector. The gain of the fiber optic link is given as [6]

$$G = \frac{P_{out}}{P_{in}} = \frac{1}{4}(\eta_L K_L L K_D \eta_D)^2 \times$$

$$\frac{(1-|S_{11}|^2)(1-|S_{22}|^2)}{\mathrm{Re}\, Z_L \times \mathrm{Re}\, Z_D} \times$$

$$|H_L(I_b, f)|^2 \; |H_D(V_r, f)|^2$$

where h_L and h_D are responsivities of the laser and the detector, K_L and K_D are the coupling of the laser-to-fiber and the fiber-to-detector, L is the loss of the fiber, H_L and H_D are the frequency responses, and Z_L and Z_D are the impedances of the laser and detector. In addition to improving the transmission loss, reactive matching improves the noise figure of the link [7].

The crucial design aspect of the fiber optic delay line was the development of the optical transmitter and photoreceiver modules. Each module contains the active device, matching circuitry, DC bias port and associated electronics, RF connections and optical fiber connections. The s-parameters of the laser and PIN photodetector were obtained and matching circuits were designed based upon this data. To eliminate package parasitics, the laser and PIN photodetector were in chip form. For the transmitter, the laser selected was an InGaAsP/InP distributed feedback (DFB) laser diode (Fujitsu FLD130F2RH) with a bandwidth of 7 GHz. For the photoreceiver, the photodetector selected was an InGaAs PIN (EG&G C30636ECER) with a bandwidth of approximately 4 GHz and responsivity of 0.86 mA/mW at 1.3 μm. After obtaining the measured s-parameters, the resulting data from each device was transferred into Touchstone for analysis and synthesis of the matching circuits. The matching networks were synthesized using distributed microstrip transmission line elements and lumped elements. Integral to the matching network are low pass filters for DC biasing of the laser and photodetector. The resultant circuits were fabricated on Duroid substrates.

Another important consideration in delay line design is dispersion. Since multimode distortion severely limits the bandwidth of long fiber optic links, single mode fiber is required. The single mode fiber selected (Siecor 1R41-31131) has a dispersion constant of 2.8 ps/(nm•km). The spectral line width of the DFB laser is 0.18 nm, so the dispersion through 6.2 km of fiber is calculated to be approximately 3.1 ps. This translates to about 4 degrees of phase in the 3-3.6 GHz band, indicating that degradation of the RF signal due to dispersion will be minimal.

Experimental Results

The laser impedance matching network consisted of a quarter-wave series impedance transformer and balanced open-circuited shunt stubs. The computer simulation and measured return loss for the transmitter are compared in Fig. 2. The measured results are in good agreement with the simulated data, and demonstrate a measured return loss of 14 dB at 3.3 GHz. For the

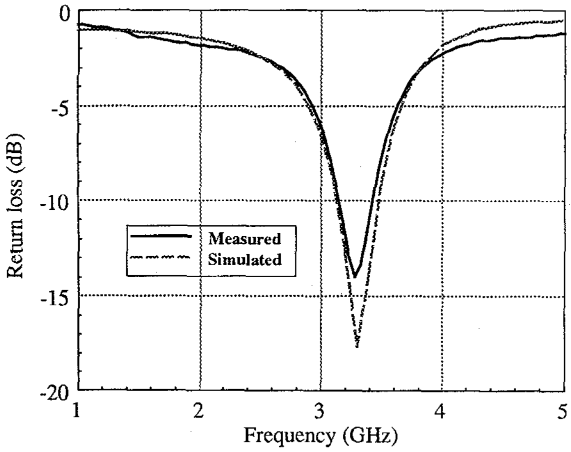

Figure 2. Measured and simulated results of laser transmitter

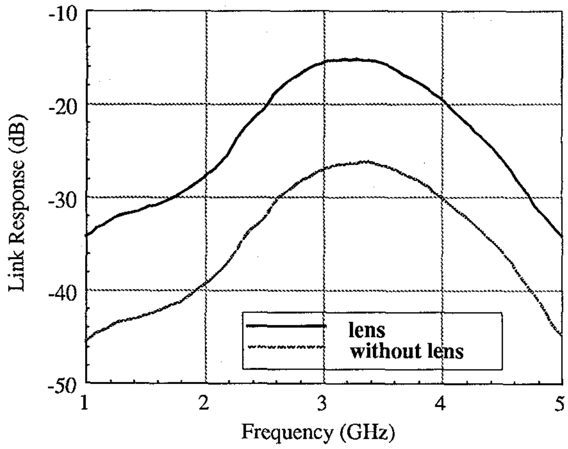

Figure 3. Transmission response of fiber optic link with and without the use of a GRIN lens

photoreceiver, the PIN photodetector was matched using a series impedance transformer and balanced short-circuited shunt stubs. A minimum return loss of 8 dB was achieved over the band of interest.

The transmission gain (loss) (S_{21}) of the laser transmitter and the photoreceiver was measured. The laser transmitter and the photoreceiver were coupled together by a short section of single mode fiber so that a measurement of the gain could be performed on a network analyzer. The coupling of the optical power from the laser to a straight cleaved fiber is limited to approximately 10%. Therefore, to improve the optical coupling between the laser and the single mode fiber, the design includes a plano-convex GRIN rod lens with antireflection coating. The results, indicated in Figure 3, show the gain of the link with a cleaved fiber only was -28.2 dB over the required frequency band with less than 1 dB variation. An improvement of 11.2 dB was obtained with the addition of the GRIN lens. In addition to these improvements, low loss fiber connections were made using Super FC/PC connectors.

The test facility used to measure the time delay is shown in Fig. 4. In this set-up, a microwave signal from a synthesizer is modulated by a pulse generator, delayed by the fiber optic line and displayed along with a reference pulse on a digitizing oscilloscope. The reference and the delayed signals are shown in Fig. 5., indicating 30 μ sec of delay. As expected, variations in the input RF frequency did not affect the time delay. The noise level seen on the trace for the delayed signal is due to a limitation of the measuring system.

Conclusions

The design of a fiber optic delay line with 30 μ sec of delay has been presented. Extremely low transmission loss was achieved using reactive matching techniques and a GRIN lens for optical coupling of the laser to the fiber. Transmission loss of a link consisting of the transmitter and receiver connected with a short length of single-mode fiber was -17 dB at 3.3 GHz with 1 dB variation across the band. It is estimated that the gain of the delay line will be -20 dB due to the additional loss of 3 dB from the 6.2 km of optical fiber. These results show a significant improvement in transmission gain, and can improve the noise figure and dynamic range characteristics over commercially available wideband delay lines. The fiber optic delay line is an alternative to metallic transmission line for delaying microwave signals in radar test target simulators that require frequency independent time delay.

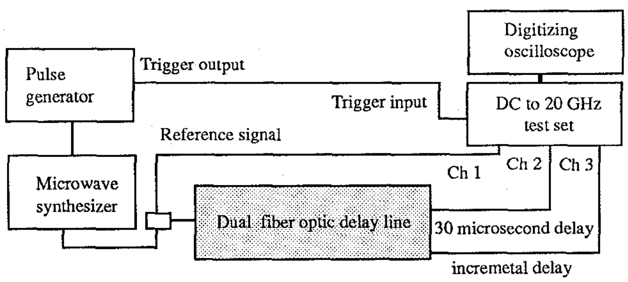

Figure 4. Block diagram of pulse response test facility

References

1. Jackson, K., *et al*, "Optical Fiber Delay Line Signal Processing," *IEEE Transactios on Microwave Theory and Techniques,* Vol.33, No. 3, March 1988.

2. Newberg, I.L., Gee, C., Thurmond, G., Yen, H., " Long Microwave Delay Fiber Optic Link for Radar Testing," *IEEE Transactions on Microwave Theory and Techniques,* Vol.38, No. 5, May 1990.

3. Grimes, G., " Microwave Fiber Optic Delay Lines: Coming of Age in 1992," Microwave Journal, August 1992.

4. Daryoush, A., Ackerman, E., Saedi, R., Kunath, R., Shalkhauser, K., " High Speed Fiber Optic Links for Distribution of Satellite Traffic," *IEEE Transactions on Microwave Theory and Techniques,* Vol.38, No. 5, May 1990.

5. Ackerman, E. Wanuga, S., Komiak, J., Kasemset, D., Scotti, R., MacDonald, Gate, J., "A 3-6 GHz Lightwave/Microwave Transceiver Modules for Microwave Fiber Optic Communications," *1991 IEEE MTT International Symposium Digest,* June 10-14, 1991, Boston, MA.

6. Daryoush, A., Ackerman, E., Saedi, R., Kunath, R., Shalkhauser, K., " High Speed Fiber Optic Links for Distribution of Satellite Traffic," *IEEE Transaction of Microwave Theory and Techniques,* Vol.38, No. 5, May 1990.

7. Daryoush, A., Ackerman, E., Saedi, R., Kunath, R., Shalkhauser, K., " High Speed Fiber Optic Links for Distribution of Satellite Traffic," *IEEE Transaction of Microwave Theory and Techniques,* Vol.38, No. 5, May 1990.

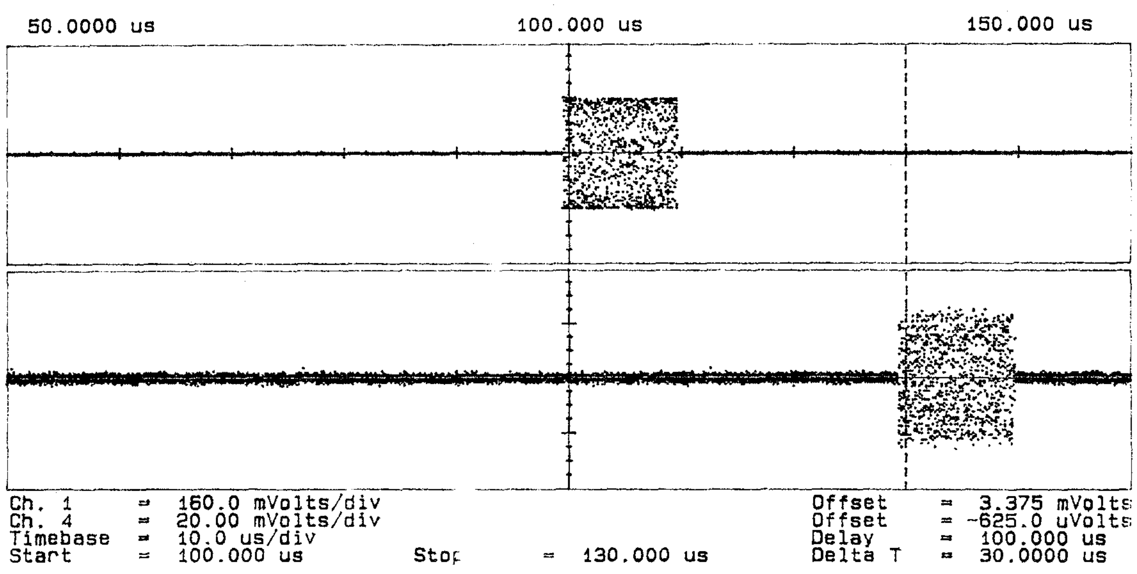

Figure 5. Reference and delayed pulse from digitizing oscillosope