LONG MICROWAVE DELAY FIBER OPTIC LINK FOR RADAR TESTING

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ABSTRACT

A unique application of a long fiber optic delay line as a radar repeater to improve radar testing capabilities is described. Using a 31.6 kilometer long experimental externally modulated fiber optic link with a DFB laser, we demonstrated the first known generation of 152 microsecond delayed ideal target at X-band (10 GHz) frequencies having the phase stability and signal-to-noise ratio (SNR) needed for testing modern high resolution Doppler radars.

INTRODUCTION

Fiber optic (FO) links are potentially important for many applications in current and future radar and avionic systems. Fiber optics offer many advantages for microwave and high-speed digital signal transmission including wide bandwidth, low loss in fiber, light weight, small size and EMI resistance. Furthermore, fiber optics can provide RF delays much longer than practical with coaxial cable or waveguide at X-band (10 GHz) frequencies. In this paper, we present a new and unique application of a fiber optic link in a radar test set. Using a 31.6 km length of fiber to obtain a 152 μs delay line in a radar repeater test set, we generated an ideal target for testing radars with very long RF transmitter pulses. The experimental fiber optic link included an external modulator operated with a distributed-feedback (DFB) laser and specially selected low loss single mode fiber matched to the laser wavelength to obtain very low dispersion for achieving large bandwidth-length performance. Present radar systems that use an external test target repeater must operate with a long distance separation between the test target repeater and the radar, and with the competing external environmental interference. This is the first known implementation of X-band modulated fiber optic links with radar systems which utilize transmitted waveforms with very long RF pulses needed for long range, high performance operation. The successful tests, in which pulse compression peak sidelobe measurements were used to confirm the link RF phase linearity and SNR performance, demonstrates that these fiber optic links can meet the stringent SNR, and phase linearity and stability requirements for Doppler radar systems that use pulse compression waveforms to obtain long range operation with high resolution.

TEST SET APPLICATION

The application of high-speed fiber optic links in a radar repeater test set is shown in Figure 1 where the fiber optic repeater test set is colocated with a radar system. The radar system includes an exciter unit which generates a low noise coherent CW RF signal with a pulse compression waveform that is amplified in the transmitter and pulsed at a pulse repetition frequency (PRF). The duplexer directs the transmitted energy out of the antenna and the received energy into the receiver while providing isolation between the two of them. The received signal is processed in the radar signal and data processor. During the transmit pulse, the receiver is blanked to prevent damage to the receiver by the transmitter pulse output. Pulse compression waveforms are used to obtain good radar range resolution while achieving high average power output to obtain long range target detections. The waveform is encoded with phase or frequency coding which allows the return radar signal to be specially processed to "compress" (autocorrelate) it to obtain a very narrow pulse from the long coded pulse (thus the name of pulse compression).

Current repeater test targets are typically located several miles from the radar to achieve sufficient delay for the radar to receive its transmitted pulse. The delay in this case is obtained by the time required for the radar transmitted pulse to reach the repeater and be retransmitted as a target return to the radar. The fiber optic repeater provides the long delay required for the radar to receive and process its own transmitter pulse with the repeater test set colocated with the radar.

LINK CONFIGURATION

The long delay and high frequency specification for this application required a specially designed fiber optic link. The FO link, illustrated in Figure 2 and shown pictorially in Figure 3 consists of a 1.3 μm (light wavelength of 1.3 micrometers, μm) CW DFB laser transmitter, GRIN lens for focusing the light, an optical isolator to minimize reflected light into the laser, a traveling-wave $LiNbO_3$ electro-optic

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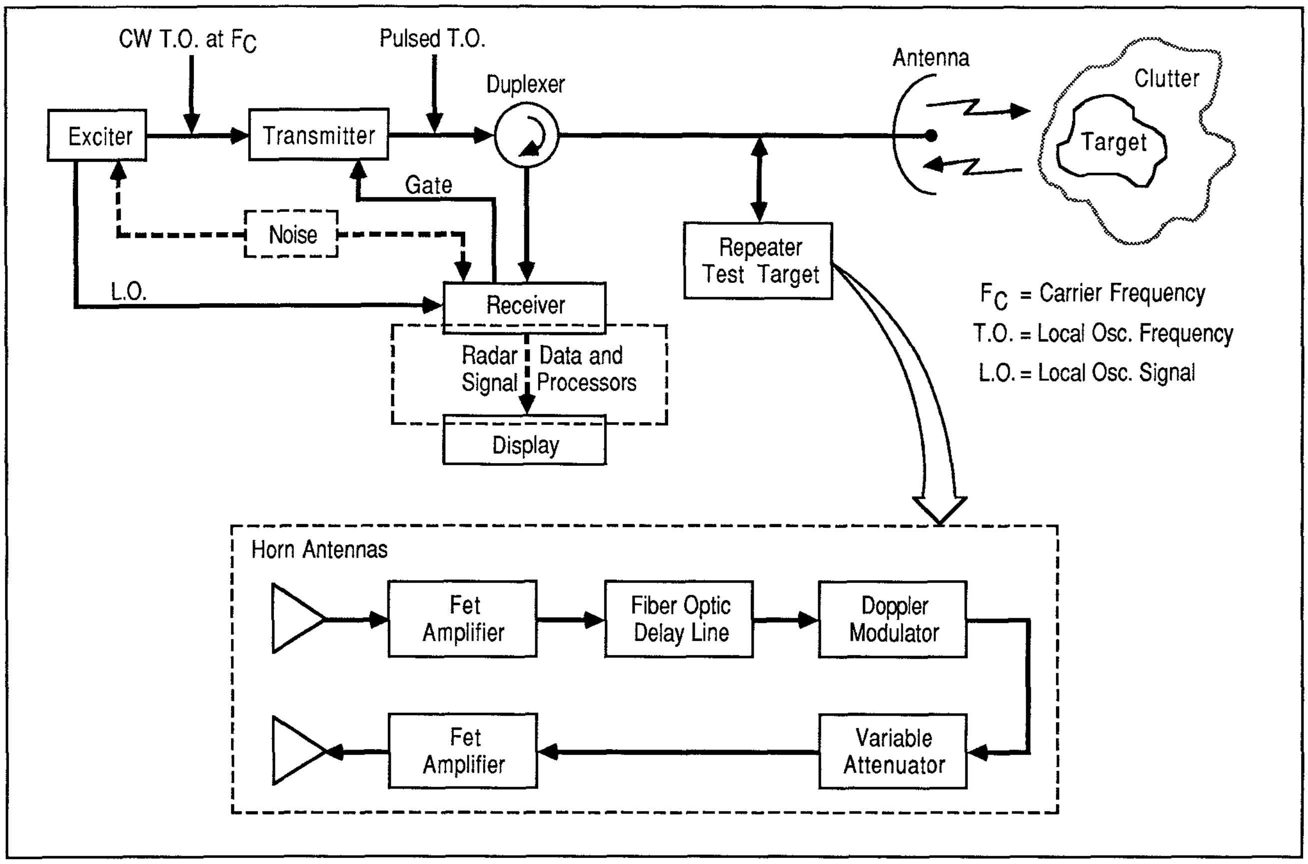

Figure 1. A radar system with a colocated repeater test set to provide the delay that is generally achieved with a test target located many miles from the radar. A fiber optic delay line is incorporated in the repeater.

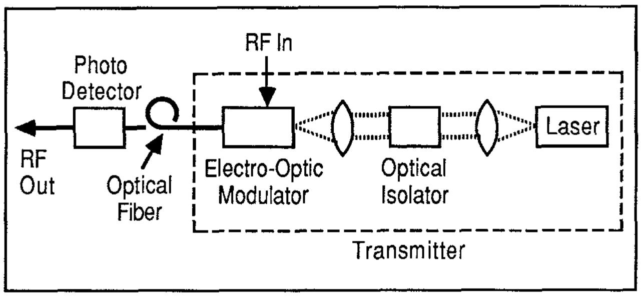

Figure 2. External modulation fiber optic link

modulator[1], a long (31.6 km) single mode fiber, and a high-speed photodiode detector receiver. The major advantages of the external modulation technique over the more typically used direct laser modulation technique for this application is the high microwave frequency operation (currently up to 18 GHz with potential for much higher) of the external modulator, and the ability to separately select a DFB laser transmitter with a very narrow light spectrum line width for low dispersion performance over the long fiber length. The fiber used had its zero dispersion wavelength specially matched to the wavelength of the DFB laser. Since the fiber has a zero dispersion slope of about 0.092 ps/(nm^2•km), the dispersion of the link was calculated to have a light dispersion through the 31.6 kilometers of fiber of approximately one picosecond (ps). This means that after the 152 μs fiber delay, a 10 GHz RF signal amplitude modulated on the light would arrive with less than 5 degrees of phase difference caused by dispersion in the fiber. By comparison, a typical 1.3 μm multimode Fabry-Perot semiconductor laser will have a line spectrum of about 3 nm (nanometer) width that will cause at least 50 ps dispersion over 31.6 km of fiber. Since 50 ps represents 180 degrees of phase at 10 GHz, this RF spread in delay would cause partial cancellation of the desired signal. We also placed the long length of fiber in an insulated container to isolate it from ambient temperature variations. Since the fiber has a coefficient of linear thermal expansion of about 5.6×10^{-7} cm/cm/^{o}C, a one-degree-centigrade change in temperature will cause the 31.6 km of fiber to change length by about 1.5 cm. This is equivalent to 180 degrees of phase change at 10 GHz.

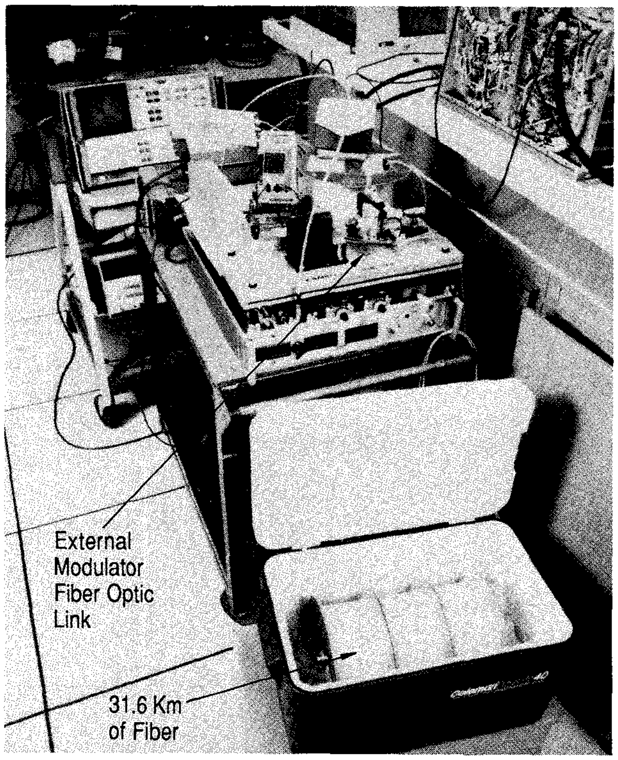

Figure 3. Fiber optic link test target with 152 μs delay

LINK TESTING

The output SNR of the link with the 31.6 km of single mode fiber was about 113 dBc/Hz (dB below the carrier in a one-hertz noise bandwidth). Figure 4 shows a signal-to-noise ratio curve taken using a spectrum analyzer over a 1 GHz frequency range using a low noise of 9.6 GHz CW signal source as input to link. RF FET amplifiers were used to establish usable RF levels at the link input and output. The 31.6 km long fiber had an equivalent electrical loss of about 22 dB (11 dB optical) and the DFB laser and external modulator fiber optic link connected without the fiber cable had an "electrical" insertion loss (RF in to RF out) of about 60 dB. The SNR of 113 dBc/Hz is more than adequate and extrapolation of the link SNR to obtain an estimate of potential maximum length of fiber cable that could be put in the fiber optic link indicates that a 100 km length of fiber could be used to obtain a usable narrow bandwidth SNR. A length of 100 km would provide about a 500 μs delay.

The link performance was tested by installing it in a laboratory area with a radar system requiring the long delay and small phase distortion in its long pulse compressed waveforms. The results of these tests demonstrated the link performance. By measuring radar peak sidelobes on the radar processed pulse compressed waveform with and without the fiber optic link in the radar system, we determined that the fiber optics did not degrade the radar performance, and the addition of the fiber optic link's long delay allowed the radar to evaluate its own performance within the laboratory for the first time.

Radar systems that use long transmitter pulses to obtain high average power for long range operation and use pulse compression to obtain good range resolution (for separating closely spaced targets) require good phase linearity and SNR up to several seconds during the processing time of the long radar pulses. Thus, the minimum dispersion achieved with the fiber optic link is required for modern pulse Doppler radars. The radar itself is the best test set for evaluation of its own overall end-to-end performance, and the fiber optic delay line repeater test set provides for the first time an "ideal" target return for the radar to process and evaluate.

CONCLUSIONS

We have demonstrated that fiber optics can improve the capability of radar test set systems. With the use of a 1.3 μm wavelength DFB laser and an external modulator connected to a long fiber cable to provide long (152 μs) delays with minimum dispersion at X-band (10 GHz) frequencies, performance measurements can be made on modern Doppler radars utilizing long transmitter pulses. The results show that fiber optic links will meet the stringent phase and noise requirements of modern radars at high microwave frequencies. Thus, fiber optics provides a unique and needed capability for testing many radars that has not been possible before and in the future delays of up to 500 μs may be obtained.

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REFERENCE

[1] C. M. Gee, G. D. Thurmond and H. W. Yen "17-GHz Bandwidth Electro-Optic Modulator," Appl. Phys. Lett., Vol 43, pp 998-1000, Dec. 1983

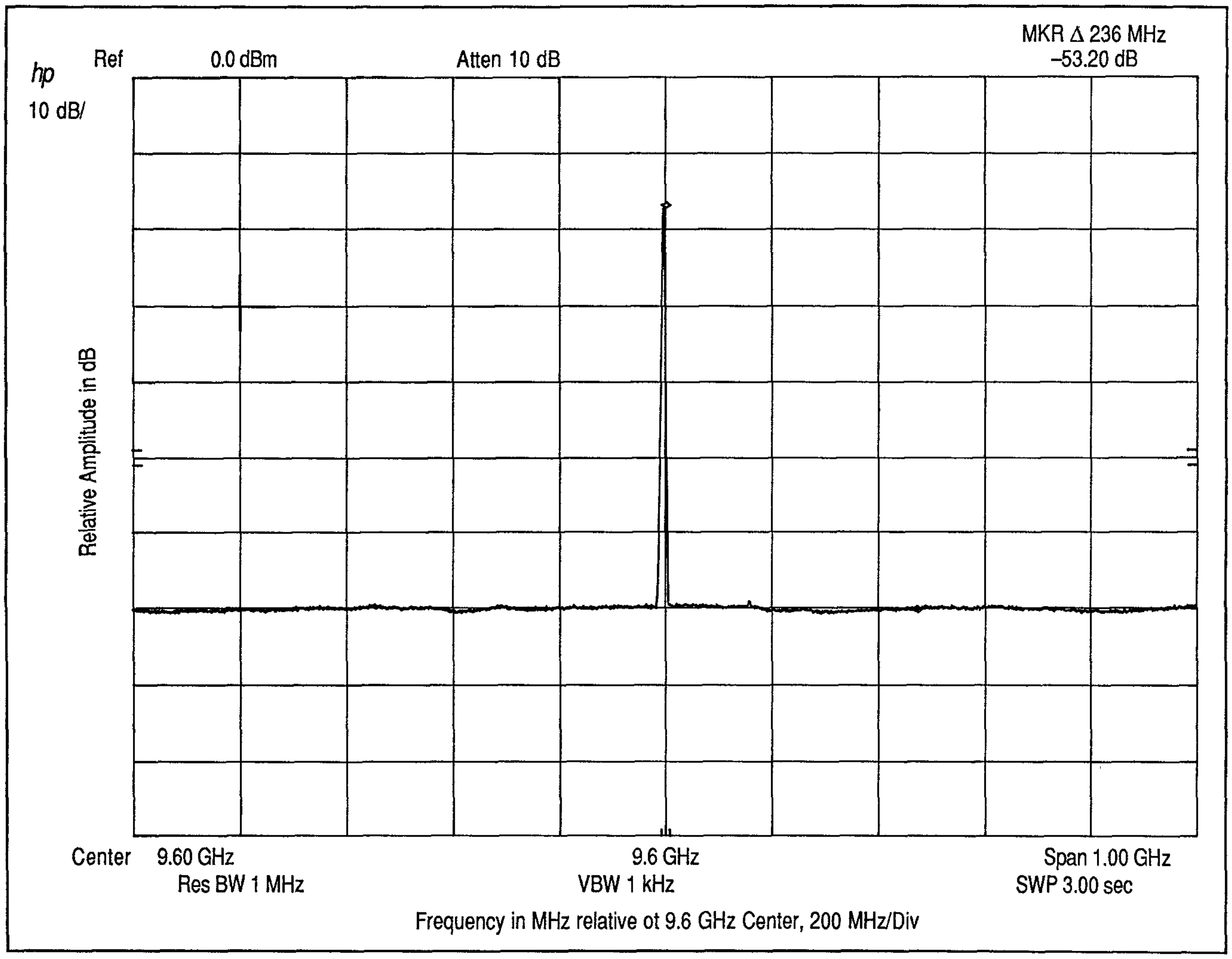

Figure 4. 113 dBc/Hz (53 dBc/MHz) signal-to-noise ratio curve of fiber optic link with 31.6 km fiber cable