RADAR APPLICATIONS OF X-BAND FIBER OPTIC LINKS

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ABSTRACT

High-speed fiber optic delay lines for unique application in radar phase noise and repeater test sets are described. FM and AM signal-to-noise performance measurements of the X-band-modulated fiber optic links for these applications are presented.

INTRODUCTION

Fiber optic links are potentially important for future radar and avionic systems. In this paper, we present performance data of radar phase noise and repeater test sets that utilize analog fiber optic links as delay lines. Specifically, using long delay lines, we achieved improved measurement capability and flexibility with smaller components. This is the first known implementation of fiber optics in a radar system at X-band (10 GHz) frequencies. The test set application demonstrates that fiber optics can meet the stringent signal-to-noise ratio (SNR) requirements of radar systems.

PHASE NOISE TEST SET

Figure 1 illustrates a phase noise test set that incorporates a fiber optic delay line. The absolute phase noise of an rf exciter (rf signal generator) in a Doppler radar is measured with a phase noise test set. One such test set type incorporates a delay line to form a discriminator that decorrelates phase noise of an rf signal source and converts the noise to a baseband signal amplitude that can be measured on a spectrum analyzer. With a fiber optic link as a long delay line, the test set becomes sensitive enough to measure noise closer than 100 Hz to the rf carrier. This is a significant capability for Doppler radar applications.

A delay line type of phase noise test set works as follows.(1) Frequency fluctuations are first converted into phase fluctuations in the delay line (shown in Figure 1 as a fiber optic delay line). The nominal frequency arrives at the double-balanced mixer at a particular phase. As the frequency varies slightly, the phase shift incurred in the fixed delay time changes proportionally. The delay line

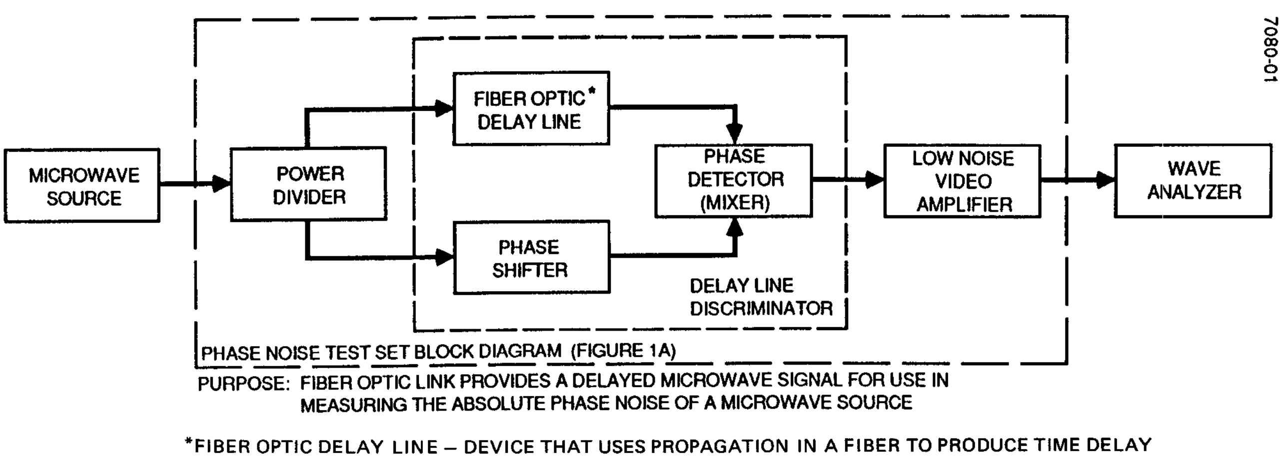
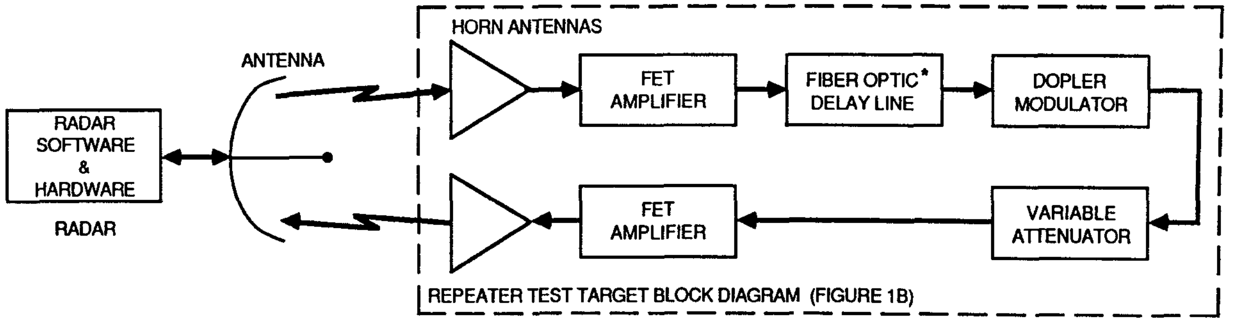


Figure 1. Radar Phase Noise Test Set Utilizing Fiber Optic Link to Provide RF Delay.



PURPOSE: FIBER OPTIC LINK PROVIDES A DELAYED REPLICA OF A TRANSMITTED RADAR SIGNAL FOR TESTING AND EVALUATION RADAR SYSTEM PERFORMANCE

*FIBER OPTIC DELAY LINE – DEVICE THAT USES PROPAGATION IN A FIBER TO PRODUCE TIME DELAY

Figure 2. Radar Repeater Test Set Utilizing Fiber Optic Link to Provide RF Delay.

converts the frequency change at the line input to a phase change at the line output, when the delay line output is compared with the undelayed signal arriving at the mixer. The double-balanced mixer, acting as a phase detector, transforms the instantaneous phase fluctuations into voltage fluctuations. When we set the phase shifter so the two input signals are 90 degrees out of phase (phase quadrature), the mixer becomes a phase detector and the output voltage is proportional to the input phase fluctuations. The voltage fluctuations can then be measured with a baseband spectrum analyzer and converted to phase-noise units of decibels relative to the signal carrier in a given bandwidth. A known level and frequency of FM sideband energy can be added to the test set signal input to calibrate the test set output displayed on the spectrum analyzer.

The sensitivity of the noise test set improves directly with longer delay lines, allowing noise measurements close to the radar carrier frequency. Waveguide delay lines presently used in these test sets are limited to $\simeq 0.25$ μs because of their size, weight, and loss at X-band frequencies. On the other hand, we have demonstrated a test set using 11 μs delay achieved with 2.25 km of fiber. Hence, by selection of the proper delay, noise closer than 100 Hz to the carrier can be measured.

RADAR REPEATER TEST SET

Another application of high-speed fiber optic links is in a radar repeater test set (shown in Figure 2). The basic function of a radar repeater is to amplify the radar transmitted signals and retransmit them to the radar with a sufficiently long delay. Current repeater test sets 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. Because it is transmitted through the air, the return radar pulse must compete with the outside environmental noise and clutter.

A long fiber optic delay line utilized in a test set colocated with a radar provides a delayed coherent replica of the input signal, allowing a radar to receive and process (analyze) its own transmitted pulsed rf signal as if it were an actual target return. The long fiber optic delay provides a method to perform complete end-to-end radar system evaluation within a single test facility by providing an "ideal" test target signal, without environmental effects, to the radar input. This permits determination of radar performance parameters under the influence of added noise and spurious signals caused by the radar exciter, transmitter, waveform modulation and signal processing. Using the radar to analyze its own performance by supplying it an "ideal" test target signal is an excellent way to determine performance.

FIBER OPTIC LINK CHARACTERIZATION

For these applications, we have characterized close-in AM and FM noise for both externally and directly modulated fiber optic links. These links are illustrated in Figure 3. The external modulation link transmitter includes a 1.3 μm CW InGaAsP laser, a GRIN lens, a series of two optical isolators, and a traveling-wave $LiNbO_3$ electro-optic modulator.(2) Incoming rf signals modulate the external electro-optic device. The direct modulation link transmitter is an rf modulated high-speed semiconductor laser. The receiver, a high-speed InGaAs photodetector, is linked to the transmitter by single-mode optical fiber, which also provides the signal delay. The direct modulation link is simple and more compact, but the external modulation technique offers better broadband performance. For both methods, an incoming rf signal to the link amplitude

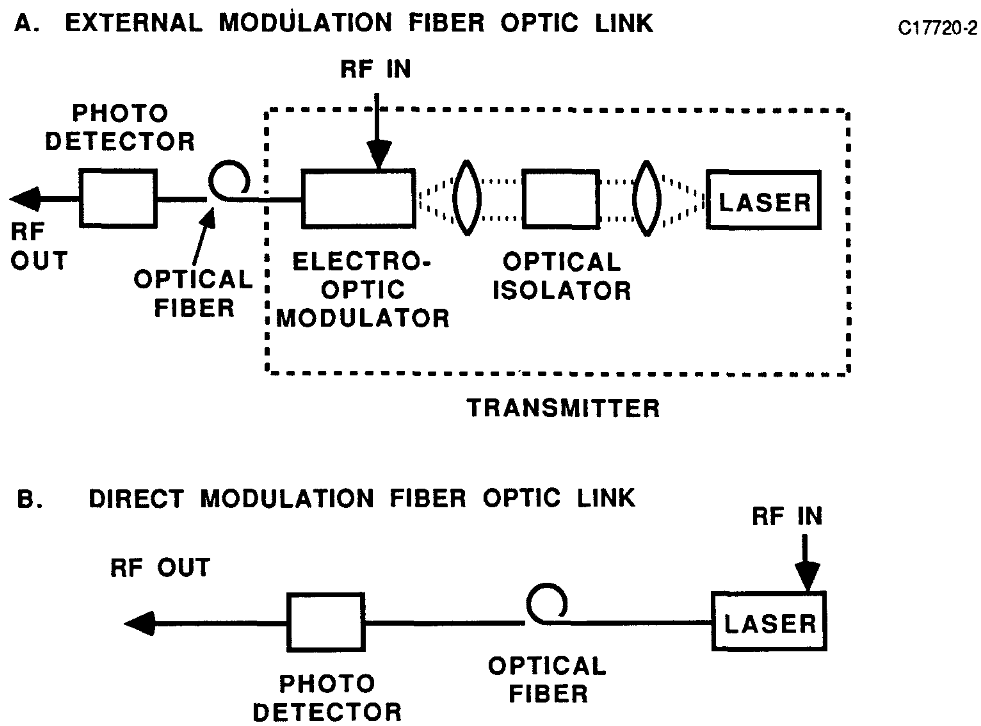


Figure 3. Illustration of Fiber Optic Links.

modulates the optical carrier emitted by the laser. The modulated light travels along the fiber and is detected at the other end with a high-speed photodetector. The photodetector demodulates the optical signal to produce a microwave output that coherently replicates the rf input to the link. The high-speed device detects the AM in a manner similar to a microwave diode detector in that it responds to the amplitude only and not to the phase of the light.

The relative SNR corruption added to the input rf carrier by the fiber optic link determines whether or not fiber optics would degrade the radar test set performance. The AM and FM relative SNR of the link were measured, and Table 1 summarizes the performance.

The best SNR at 10 kHz offset frequency from a 9.6 GHz carrier was -138 dBc/Hz (dBc/Hz is dB relative to the rf carrier in a 1-Hz bandwidth), achieved with the external modulation link. In that case, the link output noise level was about equal to the link photodetector and output first stage rf amplifier noise. The direct modulation link noise level was higher, with a

Table 1. FM and AM Noise Levels at at 10 KHz Offset Frequency Relative to the 9.6 GHz Carrier Signal

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SIGNAL CARRIER	FM NOISE	AM NOISE
TYPICAL RADAR SIGNAL SOURCE	-125 dBc/Hz	-145 dBc/Hz
4 m EXTERNAL MOD FO LINK	-138 dBc/Hz	-138 dBc/Hz
100 m EXTERNAL MOD FO LINK	-135 dBc/Hz	-135 dBc/Hz
2.25 m EXTERNAL MOD FO LINK	-130 dBc/Hz	-133 dBc/Hz
100 m DIRECT MOD FO LINK	-130 dBc/Hz	-129 dBc/Hz

SNR of -130 dBc/Hz. This SNR is poorer because the frequency response of the laser is lower than that of the external modulator, and the noise level of the laser is higher under direct laser modulation. It was readily apparent that reflections back to the laser increased the noise level and caused instability. The SNR of the 2.25 km fiber optic link was lower and less stable. Degraded performance could be due to increased fiber loss, reflections from Rayleigh scattering in the fiber, increased noise level because of fiber dispersion, or perturbations over the long fiber length. When reflections are low, the link is stable and the SRN for the fiber optic links meets the -130 dBc/Hz desired for radar test sets.

CONCLUSIONS

We have demonstrated that fiber optics can increase the capability of radar test set systems. Fiber otpics provide delays longer than is practical with coaxial cables or waveguides; this will allow performance measurements on Doppler radars. The results show that fiber optic links will meet the SNR requirements of modern radars and have the potential for many radar and electronic warfare applications in the near future.

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