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Incoherent Light Sources-Based Low Probability of Detection and Covert Radars over Atmospheric Turbulence Channels

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***Abstract*—In this paper we are concerned with the low probability of detection (LPD) and covert radars employing optical incoherent sources. Key idea of our proposed LPD/covert radar concept is to hide the radar signal in solar radiation by employing the broadband (>30 nm) Erbium-doped fiber amplifier source, modulating such source output beam with a constant amplitude modulation format at high-speed, and detect the presence of the target by the cross-correlation method. To demonstrate the proposed concept we developed an outdoor free-space optical (FSO) testbed at the University of Arizona campus. To improve the tolerance to atmospheric turbulence effects the adaptive optics is used. We demonstrate that the LPD/covert radar concept over strong turbulent FSO channel is feasible in a desert environment.**

***Keywords*—Incoherent sources, Radars, Free-space optical (FSO) channels, Low probability of detection radars, atmospheric turbulence effects.**

I. Introduction

The low probability of intercept (LPI) radars are of high relevance for both commercial and defense applications. The LPI radar is defined as a specially designed radar whose emission waveform is difficult to detect and intercept by a non-cooperative intercept receiver [1]. Development of various intercept strategies appears to be an active research area even today [1]-[3], including various machine learning approaches [4],[5].

The quantum radars can be used as an alternative to the LPI radars to improve the target detection probability in a low signal-to-noise ratio regime and beat the quantum limit [6]-[9]. However, the complexity of implementation is too high.

In this paper we propose the low probability of detection (LPD) and covert radar technique employing the incoherent, broadband light sources. The main idea is to hide the radar signal in solar radiation while employing the constant amplitude modulation schemes, such as phase-shift keying (PSK), to modulate the broadband source. To detect the radar return signal the cross-correlation method is used.

To demonstrate the proposed concept, we developed the free-space optical (FSO) testbed at the University of Arizona (UA), between the Department of Electrical and Computer Engineering (ECE) and Meinel (College of Optical Sciences) buildings. Our experimental studies over the outdoor FSO testbed indicate that broadband, incoherent light sources can be used to operate the LDP and covert radars in strong turbulence regime, in a desert environment. To improve the detection probabilities in the presence of atmospheric turbulence adaptive optics (AO) is used.

The paper is organized as follows. In Section II, the proposed LPD/covert radar concept is introduced, and corresponding outdoor FSO radar testbed is described. Experimental results are presented in Section III. Some relevant concluding remarks are provided in Section IV.

II. Proposed Incoherent Source-based LPD Radar and Description of Experimental Testbed

The proposed LPD and covert radars concept is illustrated in Fig. 1. The key idea behind the LPD radar is to hide the radar signal in solar radiation and use constant amplitude modulation, such as M-ary PSK, to make it extremely difficult to distinguish the signal from background radiation. The incoherent source beam is phase modulated, amplified, and with the help of expanding telescope transmitted over noisy, lossy, and atmospheric turbulent channel towards the target. The reflected beam (radar return beam) is collected by the compressing telescope and detected by the radar's receiver based on balanced heterodyne detector, which interacts the LO laser at 1550 nm with the received broadband signal. Given that the transmitted signal is hidden in the solar background radiation and given the distribution of the transmitted signal is the same as the solar radiation, it will be very difficult for *Willie's detector* to either detect or intercept the radar signal.

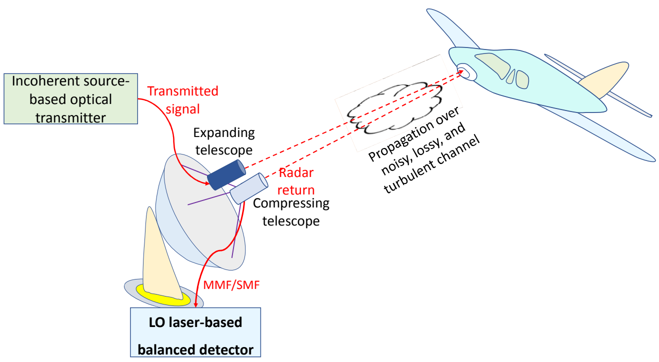

Fig. 1. The proposed broadband, incoherent light source based LPD and covert radars concept.

To study the incoherent sources-based sensing, radar, and communication over turbulent FSO channels on the UA campus, we developed the FSO testbed shown in Fig. 2. Most

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equipment is located in the Quantum Communication Lab (ECE Room 549). The *target* corner-cube retroreflector is on the rooftop of the Meinel building and is 750 m away from the window of ECE Rm 549. This experimental testbed divides into the: incoherent source and modulation stage; optical transceiver; FSO link with the target; AO stage; and heterodyne detection stage.

In our experiment, >30 nm bandwidth Erbium-Doped Fiber Amplifier (EDFA) was an incoherent source, and we used a Binary PSK (BPSK) signal with a corresponding transmitted sequence known to the receiver. The data is organized in packets and the receiver employs the cross-correlation method to determine the presence of radar return signal. A high-power EDFA amplifies the output beam from the phase modulator to a signal level of 100 mW before launching into free space by a beam expender and a periscope. This periscope's beam output propagates toward the Meinel building and is received back by the same periscope after reflection from the target retroreflector on the Meinel building rooftop. At ECE Room 549, this returning beam first propagates through the AO subsystem on an optical bench. Afterward, the beam couples into an optical fiber and is amplified by a low-noise, high-gain amplifier. Finally, the received optical signal is converted into electrical domain with the help of a balanced detector (from OptiLab, 23 GHz) by beating it against a 1550 nm local oscillator (LO) laser signal. The balanced detector's RF output then feeds to a real-time oscilloscope to screen-capture and analyze the waveform for the presence of the target.

AO improves performance in the presence of atmospheric turbulence effects, comprising a wavefront sensor (WFS) and a deformable mirror (DM) operating in a servo loop. The WFS looks for wavefront distortions. A powerful personal computer (PC) calculates the corresponding correction signals for the DM, which in turn deforms the mirror to compensate for the wavefront distortions. To reduce system cost, 8% of constant amplitude radar return serves as a beacon signal to operate the AO subsystem.

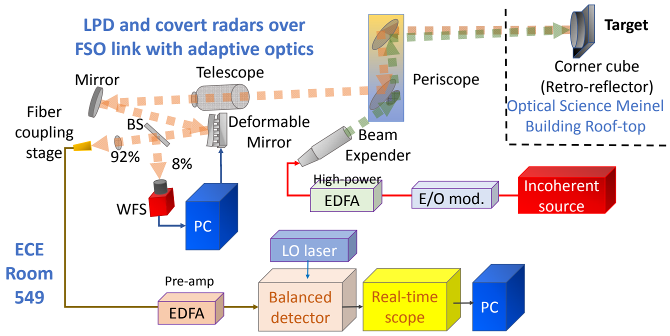

Fig. 2. The UA FSO experimental incoherent source-based radar testbed with adaptive optics. EDFA: Erbium-Doped Fiber Amplifier, WFS: wavefront sensor, BS: beam splitter, PC: personal computer.

III. Experimental Results

Figure 3 summarizes the target detection probabilities corresponding to the LPD radar for our experiments on April 20, 2023, in a strong turbulence regime for different realizations of turbulence. The corresponding histogram of received power, shown in Fig. 4, follows Rayleigh distribution indicating that the turbulence was strong [10],[11].

We compared incoherent source-based detection probability results employing the BPSK at 10 Gb/s and 20 Gb/s, with and without AO. Moren that 30 nm bandwidth transmit signal power was 100 mW, and background solar radiation measured in the 76-mm diameter aperture of the compressing telescope was 41.36 mW. The AO is designed to operate in a weak turbulence regime for astronomic applications. Nevertheless, it provided relevant improvements in target detection probabilities in strong turbulence for the proposed incoherent source-based radar technique. The 10 Gb/s case provided better detection probabilities compared to the 20 Gb/s case (see Fig. 3).

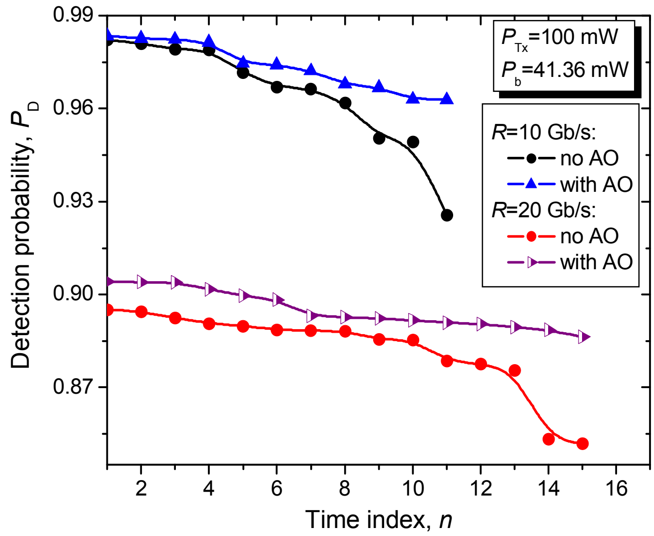

Fig. 3. The target detection probability for different atmospheric turbulence realizations. Experiments were performed on April 20, 2023. The false alarm probability is set to 10^{-6}. AO: Adaptive Optics.

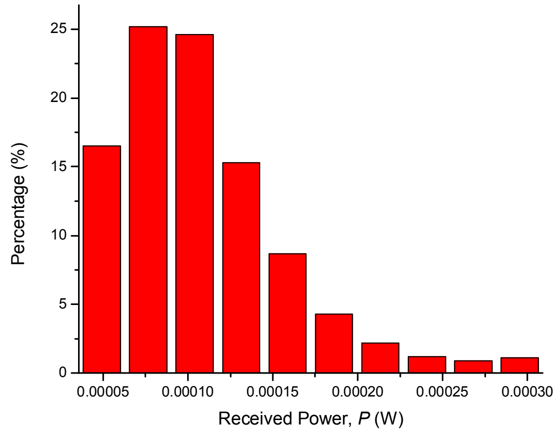

Fig. 4. The histogram of received power measured on April 20, 2023.

We also performed experiments on April 26, 2023, in strong turbulence regime for different channel realizations, and in Fig. 5 we compare the target detection probability results for 10 Gb/s and 5 Gb/s signaling rates. The transmit power was 100 mW, while solar radiation measured in the 76-mm diameter aperture of compressing telescope was 37.08 mW. The adaptive optics feature was turned off. The

5 Gb/s case exhibits much better tolerance to the turbulence effects compared to the 10 Gb/s case.

Additional results will be provided during the conference presentation.

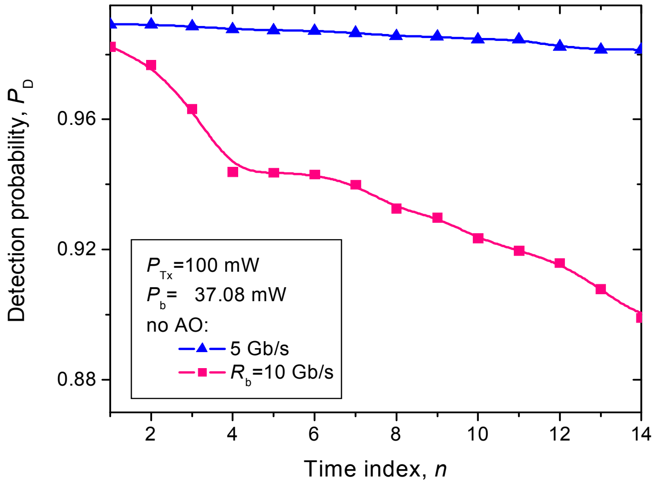

Fig. 5 The target detection probability for different atmospheric turbulence realizations. Experiments were performed on April 26, 2023. The false alarm probability is set to 10^{-6}.

IV. Concluding Remarks

In this paper we have proposed the LPD and covert radar technique employing the broadband, incoherent light sources. The main motivation has been to hide the radar signal in solar radiation while employing the constant amplitude modulation schemes, such as BPSK, to modulate the broadband source. To detect the radar return signal the cross-correlation method has been used.

To demonstrate the proposed concept, we have developed the FSO testbed at the University of Arizona campus. We have experimentally demonstrated that the broadband, incoherent light sources can be indeed used to operate the LDP and covert radars in strong turbulence regime, in a desert environment. To improve the detection probabilities in the presence of atmospheric turbulence adaptive optics has been used. Even though the AO has been designed for astronomic applications and typically operated in weak turbulence regime, the AO has been able to improve the tolerance to turbulence effects even in strong turbulence regime. The proposed AO system does not require the use of the beacon (reference) signal to operate the system. The 8% of phase modulated radar return signal has been used to operate the AO system.

The proposed LPD radar technique has been evaluated in a telecommunication window centered at 1550 nm. Other FSO-compatible transmission wavelength windows include [12] 2.2 μm, 3.5–4.1 μm, and 10 μm, which will be evaluated in the future.

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