RADIO FREQUENCY (RF) SIGNAL DETECTION IN AIR AND ON GROUND USING FIBER-OPTIC CABLES

US Patent Application: 63/841,547, Filed: July 10, 2025

EXCERPTS:

Abstract

The present invention is an all-optical, passive radio frequency (RF) detection system capable of operating in the most contested electromagnetic (EM) environments. It uses Brillouin scattering and advanced fiber-optic modulation techniques to detect, characterize and isolate specific RF signals which would otherwise not be detectable in such an environment. The system does this without emitting any RF energy, making it undetectable and immune to electronic attack. With modular deployment options (UAV, ground, vehicle), it offers real-time situational awareness for defense operations and infrastructure protection. Lightweight, EM-resilient, and compatible with NATO ISR systems, the solution is ready to scale across both military and civilian markets.

Overview (Brief)

The system of the present invention addresses the core challenge of operating in contested and congested electromagnetic (EM) environments by providing an innovative Radio Frequency (RF) sensor that is capable of detecting, isolating and amplifying specific RF signals that would otherwise not be detectable in these environments. Traditional Radio Frequency (RF) sensors and RF-to-fiber systems are vulnerable to jamming, detection, or malfunction under EM interference. The solution is a lightweight, all-optical passive RF sensing system which uses Brillouin scattering in optical fibers to detect, analyze and amplify RF signals of specific frequencies without emitting any RF energy.

This system is immune to EM interference, making it ideal for environments saturated with RF noise or active EW (Electronic Warfare). It does not rely on power at the sensing site and is therefore stealth-capable. The novelty lies in its combination of Brillouin-enhanced signal detection with RF-to-optical communication means, all integrated into a fiber-optic infrastructure. This configuration enables unmatched stealth, sensitivity, and resilience, and allows the sensor to isolate specific RF frequencies within a congested EM environment.

The solution directly supports defense and security needs for passive RF awareness, CUAS (Counter-Uncrewed Aerial Systems) operations, electronic warfare resilience, and ISR (Intelligence, Surveillance, and Reconnaissance).

Technical Solution (Brief)

The system uses Brillouin scattering in single-mode optical fibers to detect and characterize GHz-band Radio Frequency (RF) signals. A passive RF antenna collects (or captures) the RF signals from the environment, which in turn modulates a laser signal in an optical fiber via a lithium niobate electro-optic modulator. The presence of an RF signal alters the light spectrum in the fiber through sideband generation. This signal is then optically amplified by a stimulated Brillouin scattering process and interpreted the receiving end. The benefit of using the system over standard RF-to-fiber solutions is its ability to isolate and detect weak RF signals that would not otherwise be detectable in a congested EM environment. In other words, Brillouin scattering is used to optically amplify a specific RF signal through an optical fiber, thereby effectively detecting, isolating and communicating the specific RF signal in a secure manner. The detectable frequency (Brillouin frequency) is dictated by the type of optical fiber used, and by the wavelength of the laser. The prototype has already demonstrated detection of RF signals at 2.4 GHz, 5.8 GHz, 7.1 GHz, and ~11 GHz. Next-phase testing will expand to the X-band (8–14 GHz) and beyond.

Another benefit of the system is that all components within the detection range are passive (do not emit RF energy), rendering the system undetectable in a contested EM environment. The components of the system are lightweight and passive, ideal for UAV integration via a fiber-optic tether – they are also modular and can be installed in ground, vehicular, or fixed settings.

Dual Applications (Brief)

Civilian Use Case: In urban telecom infrastructure, the sensor can be patched into existing fiber-optic lines to detect radio frequency (RF) anomalies, unauthorized transmissions, or drone activity (e.g., at 2.4/5.8 GHz Wi-Fi bands).

Defense Use Case: In contested electromagnetic (EM) environments, the sensor can detect Counter-Uncrewed Aerial Systems (CUAS) threats, electronic warfare (EW) emitters, or hostile RF surveillance tools without emitting signals or risking interception.

Market Potential: Civil: Airports, utilities, telecom, infrastructure protection, stadiums, and conservation zones.

Military: CUAS, passive ISR, EW detection, drone-mounted surveillance.

DETAILED DESCRIPTION OF THE INVENTION

The solution is a novel Radio Frequency (RF) sensor that can operate in congested electromagnetic (EM) environments, in other words: environments which are high in EM radiation. The solution is an optics-based solution, using an optical fiber as a means of detecting RF signals emitted by enemy or friendly sources, and translating the RF signals into measurable light signals inside of the optical fiber. Because optics is inherently immune to EM radiation, the sensor is therefore inherently immune to EM interference such as EM jamming by hostile actors, or EM attack during electronic warfare (EW).

In addition, the solution does not emit any RF signals in the sensing area, and is therefore a passive device which is not detectable by enemy RF detection means. The optical fiber in the solution which acts as the sensing mechanism, doubles as a communication tool to communicate the detected RF data securely and effectively. The communication function of this sensor is also immune to EM radiation and therefore can withstand EM jamming and EW attack.

This technology is equally applicable in civilian and military environments. Any civil application which requires RF sensing can benefit from the solution.

In addition, the solution can be ground-based, either mounted on a stationary structure, or be mounted on a moving vehicle (fiber-optic car). The solution can also be air-based, mounted on an air-based vehicle (fiber-optic drone). The parts of the solution which are fitted on a unmanned aerial vehicles (UAV), for example, are very lightweight and are capable of being carried by the UAV.

In other words, the solution can be installed in such a way that part of the solution can be fitted onto a unmanned aerial vehicle (UAV) (this part is lightweight and EM resistant), and can connect to the UAV's existing fiber-optic tether to employ it as the sensing mechanism for RF detection and communication. This setup ensures that secure RF detection and communications between the UAV and the operator are maintained, ensuring operational robustness and resilience in electromagnetic contested and congested environments. The sensor is capable of detecting RF signals and communicating them to the operator, where an AI analyzes and characterizes the received signal in real time. This scenario is equally applicable to the ground-based applications, as well as for civilian monitoring of RF signals in areas of electromagnetic interference.

Technical Solution (Detailed)

The proposed solution is a novel fiber-optic method for detecting Radio Frequency (RF) signals emitted by both friendly and hostile sources in the GHz range. It translates RF energy into measurable optical signals using the phenomenon of Brillouin scattering within optical fibers. When an external RF signal is present, it activates Brillouin scattering in the fiber, causing a shift in the optical spectrum of the light transmitted through it. By measuring the resulting change in the output light spectrum, the system enables users to detect the presence and frequency of external RF signals. In the absence of RF input, the optical output remains unchanged, providing a highly reliable signal-to-noise detection method.

Unlike standard RF-to-fiber technologies, the system leverages Brillouin scattering, which is activated only within a narrow "linewidth" (approximately 0.1 GHz), centered at the Brillouin frequency. This specificity allows for the isolation of weak RF signals even in densely saturated electromagnetic environments, and, as a result, the system offers high precision and selectivity. The Brillouin frequency is tunable based on the type of optical fiber and the wavelength of the laser used. With typical single-mode fibers and Distributed Feedback (DFB) lasers, this enables coverage of the 8 to 14 GHz (X-band) range, with ongoing R&D exploring techniques to expand this further.

The system uses a passive RF antenna to collect ambient RF energy. The antenna is never powered and cannot transmit, making it fully undetectable in the RF domain. It is connected to an electro-optic modulator (EOM) containing a lithium niobate crystal. A 1550nm laser source is passed through the EOM via optical fiber. When the RF signal induces an electric field, the lithium niobate crystal alters its refractive index through the Pockels effect, generating two optical sidebands. Each sideband represents an upshifted and downshifted version of the RF frequency.

Brillouin scattering is initiated throughout the optical fiber, which optically amplifies one of these sidebands. This optical amplification process allows for the detection of even extremely weak RF signals and can be enhanced further by increasing the fiber length. Because the EOM and RF antenna are lightweight (under 150 grams) and fully passive, they are ideal for drone-based deployment. This design provides the added advantage of stealth and resistance to jamming, detection, or other forms of electronic warfare.

One of the distinguishing advantages of the system is that it enables separation of the sensing and processing components. The passive antenna and EOM can be mounted on UAVs and tethered via optical fiber to heavier ground-based elements such as the laser source and visualization interface. This allows the system to detect RF signals remotely while ensuring that sensitive components remain far from the detection field. The same optical fiber that detects RF signals can also serve as a robust and interference-free communication line to transmit collected data up to 50 to 100 kilometers away, using standard telecom infrastructure and 1550nm wavelengths.

The solution has already undergone successful testing in multiple environments, demonstrating its technical reliability and environmental adaptability. Field tests were conducted using commercial DJI drones and ground-based RF simulation equipment to replicate both commercial and electronic warfare signal scenarios. These tests were performed across diverse terrain types, including forested areas and dense urban settings in and around Ottawa, Canada. The prototype consistently and accurately detected RF emissions at approximately 2.4 GHz and 5.8 GHz from DJI drones, as well as simulated electronic warfare signals at around 11 GHz. These varied test conditions confirmed the system's robustness in identifying and isolating RF signals within congested and complex electromagnetic environments.
The next phase of development includes expanding the frequency detection range within the X-band (8 to 14 GHz and beyond) and launching additional test campaigns to validate the system's performance against multiple classes of drones and electronic warfare devices. These campaigns will include detecting a wider variety of RF signal sources within the 8 to 18 GHz range.

Because the entire front-end (antenna and EOM) remains passive and lightweight, the solution is suitable for both fixed ground installations and UAV platforms. It is inherently immune to electromagnetic interference, radiation, and jamming. This makes it ideal for deployment in both high-risk military environments and densely packed civilian RF environments. In summary, the system offers a secure, scalable, and interference-resistant method to detect and classify RF activity through a compact, passive, fiber-optic-based solution.

Dual-use Applications (Detailed)

In an urban environment, the solution can be installed in areas with a pre-existing fiber-optic infrastructure, and “patched" into the existing optical fibers for RF sensing and communication applications. The solution uses SMF fibers with communication light signal at 1550nm, which is directly compatible with the existing telecom networks in urban environments. RF signals for civil applications can be detected and communicated, such as Wifi signals (for example, at 2.4 GHz or 5.8 GHz). In the defence context, military drones use RF to communicate with the operator, typically at frequencies of 2.4 GHz and 5.8 GHz. Therefore, the solution can be used to detect the presence of military drones which emit RF signals at these frequencies.

Drawings

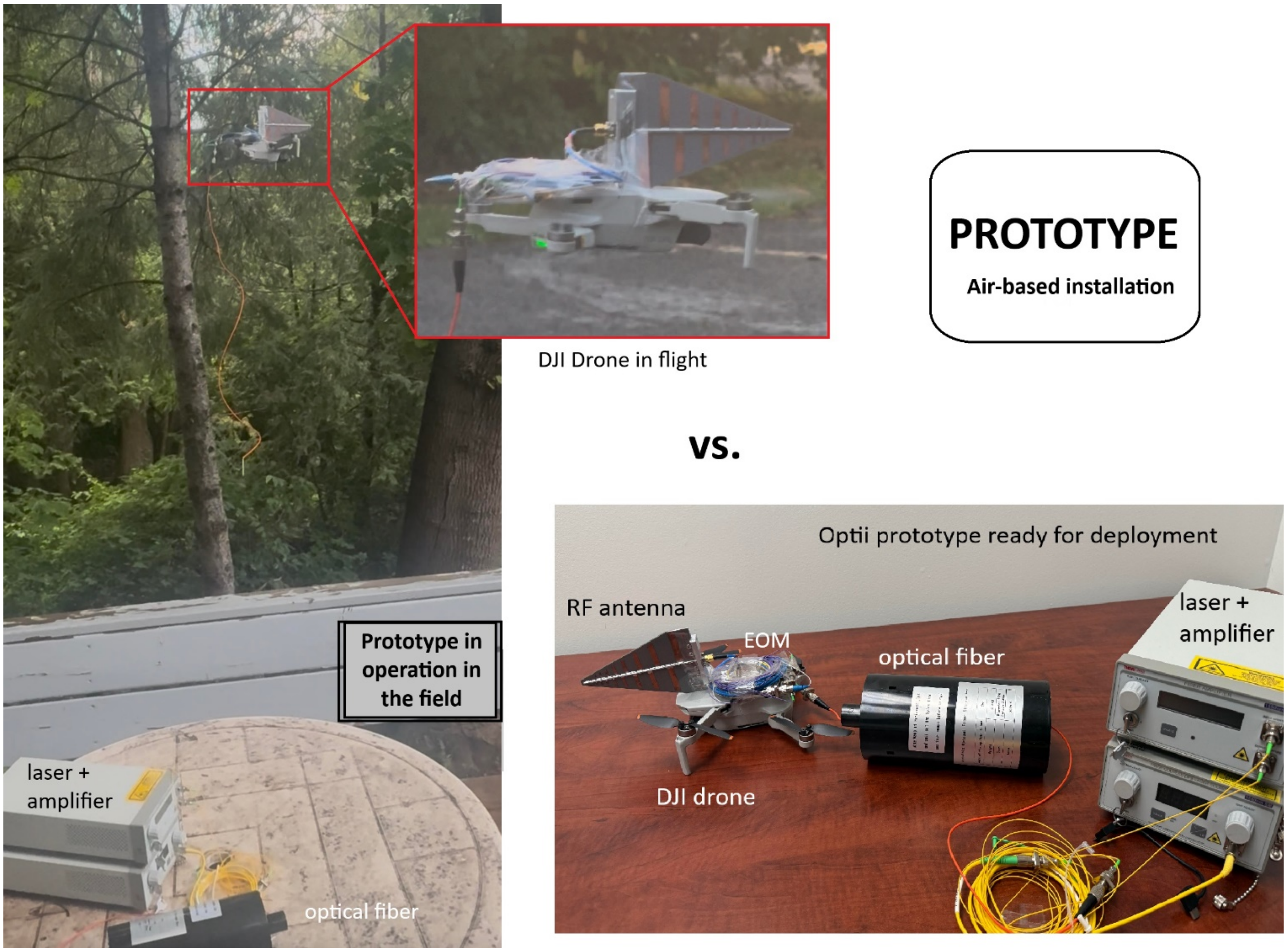


FIGURE 1

PROTOTYPE

In the laboratory

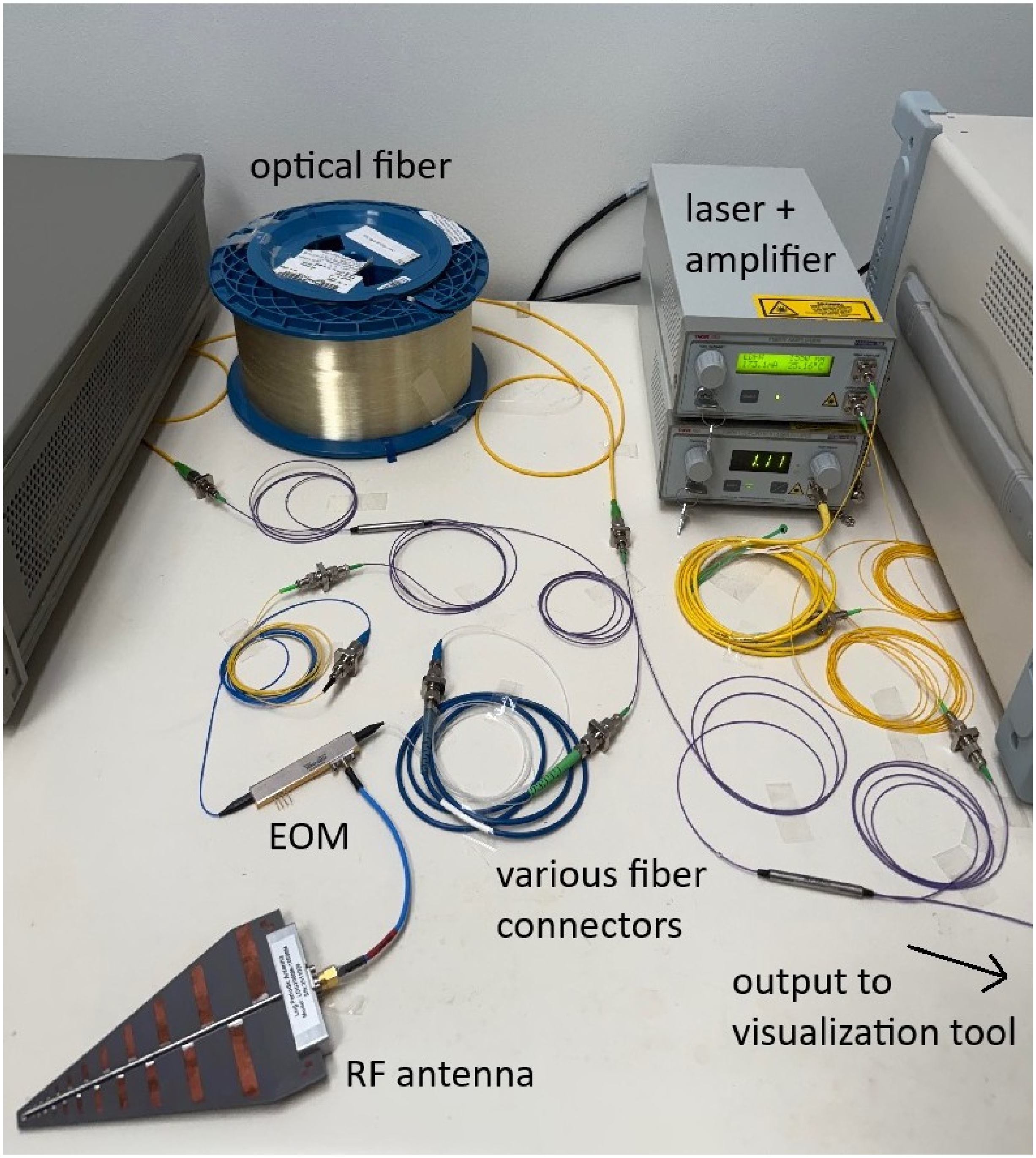
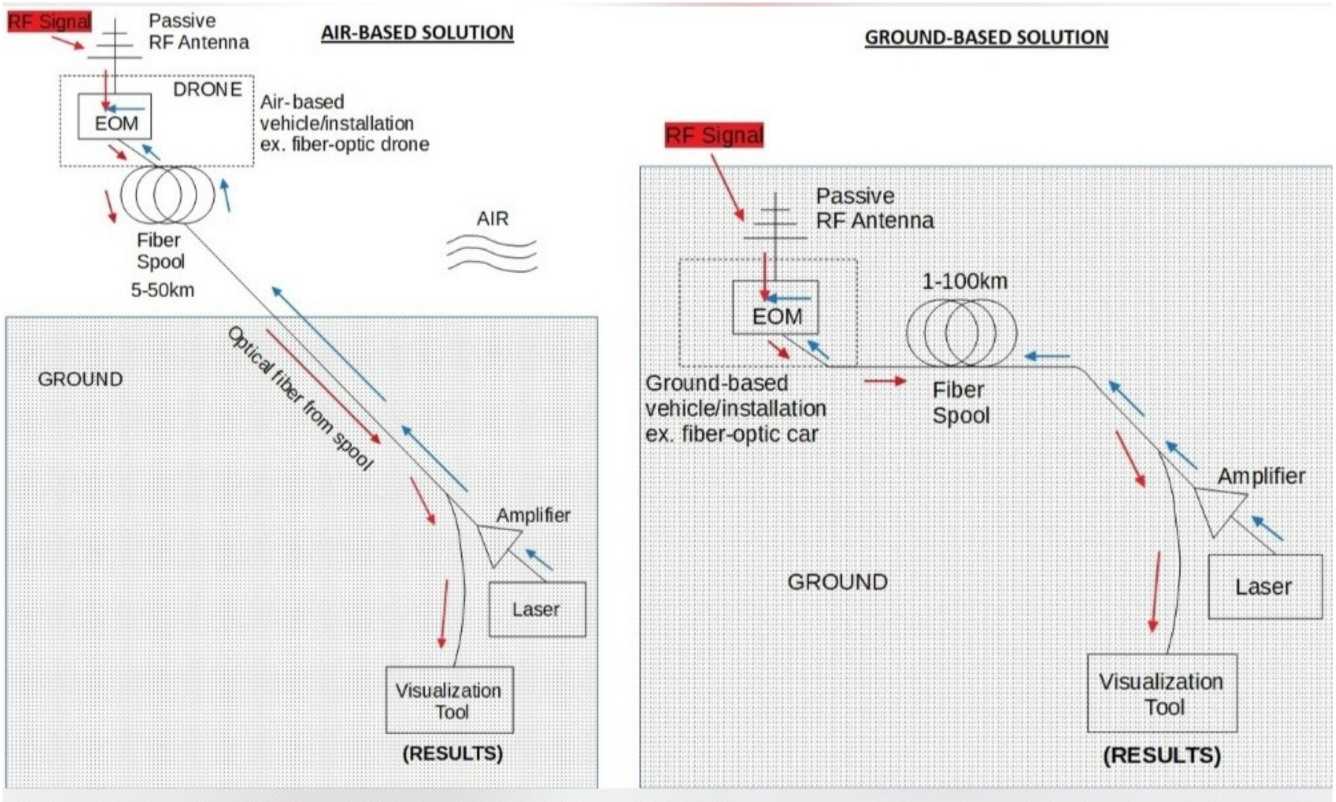


FIGURE 2



(a) (b)

FIGURE 3

Schematic diagrams of the prototype.