Portable Reconfigurable Line Sensor (PRLS) and Technology Transfer*

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Abstract

The Portable Reconfigurable Line Sensor (PRLS) is a bistatic, pulsed-Doppler, microwave intrusion detection system developed at Sandia National Laboratories for the U. S. Air Force. The PRLS is rapidly and easily deployed, and can detect intruders ranging from a slow creeping intruder to a high speed vehicle. The system has a sharply defined detection zone and will not falsely alarm on nearby traffic. Unlike most microwave sensors, the PRLS requires no alignment or calibration. The PRLS's unique ellipsoidal detection zone eliminates the need for an offset distance to achieve total detection coverage. The sensors themselves are inside their own detection zone and are therefore self-protecting. Other unique features of the PRLS are its limited terrain-following capability and its ability to minimize the effects of rippling water and blowing grass. Its portability, battery operation, ease of setup, and RF alarm reporting capability make it an excellent choice for perimeter, portal, and gap-filler applications in the important new field of rapidly-deployable sensor systems.

In October 1992, the U. S. Air Force and Racon, Inc., entered into a Cooperative Research and Development Agreement (CRADA) to commercialize the PRLS, jointly sharing government and industry resources. The Air Force brings the user's perspective and requirements to the cooperative effort. Sandia, serving as the technical arm of the Air Force, adds the actual PRLS technology to the joint effort, and provides security systems and radar development expertise. Racon puts the Air Force requirements and Sandia technology together into a commercial product, making the system meet important

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commercial manufacturing constraints. The result is a true "win-win" situation, with reduced government investment during the commercial development of the PRLS, and industry access to technology not otherwise available.

The joint USAF/Racon CRADA to commercially develop the PRLS has culminated in a successful working relationship between the Air Force, Racon, and Sandia. The expected result: an affordable, commercial version of a military-developed, portable security system that will be available to, and usable by, the commercial sector and all government agencies.

Introduction

The demand for, and desirability of rapidly deployable security systems has been steadily increasing in the government and commercial sectors. Providing such a system, while at the same time enhancing the competitiveness of U. S. small business, is an advantageous combination. This paper discusses a portable intrusion detection system—the Portable Reconfigurable Line Sensor (PRLS)—and the transfer of this PRLS technology to the private sector. The PRLS was originally developed for the U. S. Air Force at Sandia National Laboratories. The first three sections of this paper describe the PRLS—its sensor concept and unique features, its technical overview, and its applications. The last section discusses how the PRLS technology is being transferred to a privately-held small business, Racon, Inc., through a Cooperative Research and Development Agreement (CRADA), and how government and industry benefit from this cooperative arrangement.

Sensor Concept and Description[1,2,3]

The PRLS is a unique, rapidly-deployable, bistatic pulsed-Doppler radar sensor originally developed for the U. S. Air Force by Sandia National Laboratories (Figure 1).

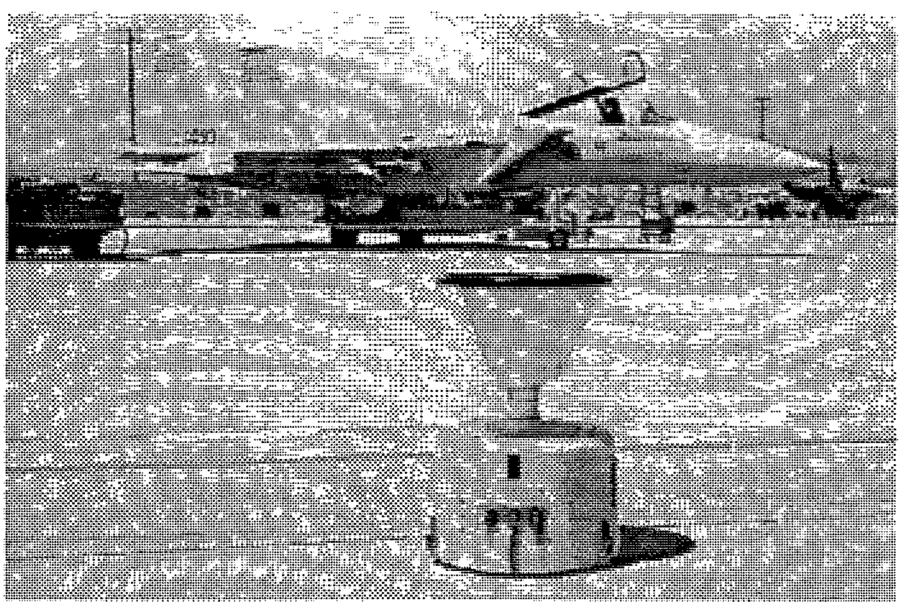

Figure 1. PRLS

The PRLS is rapidly and easily deployed by unskilled personnel and can detect intruders ranging from a slow, creeping person (1 inch/second) to a high-speed vehicle (70 mph). The PRLS units, which are self-protecting, can be used in temporary, semi-permanent or permanent applications. A simple perimeter (e.g., around an aircraft) consisting of four PRLS units can be set up in about five minutes—essentially the time it takes to drive the perimeter, placing and powering-on the sensors. The PRLS can operate on batteries or from a solar panel as well as from ac power. The PRLS includes an RF alarm link used to communicate intrusion alarms to a portable, hand-held annunciator or to a conventional security console. Zone-identifying codes are selected by the user for the RF alarm link in each sensor. A hardwire alarm link is also available.

A major attraction of the PRLS is the speed and ease of the setup process. One sensor is placed at each end of the desired detection zone (orientation is not critical), and the sensors are powered on. Alignment and cables are not required, and it is not necessary to tell the sensors their spacing. The detection zone is ellipsoidal, with the transmitter and receiver located at the foci. Thus, the units are inside the detection zone as shown in Figure 2.

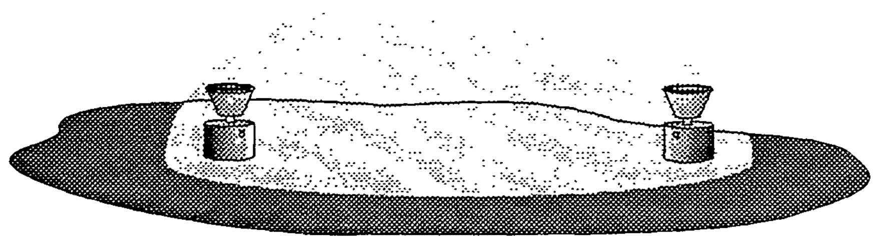

Figure 2. PRLS Detection Zone.

The PRLS differs in this respect from traditional microwave sensors, which are outside the protected zone (Figure 3).

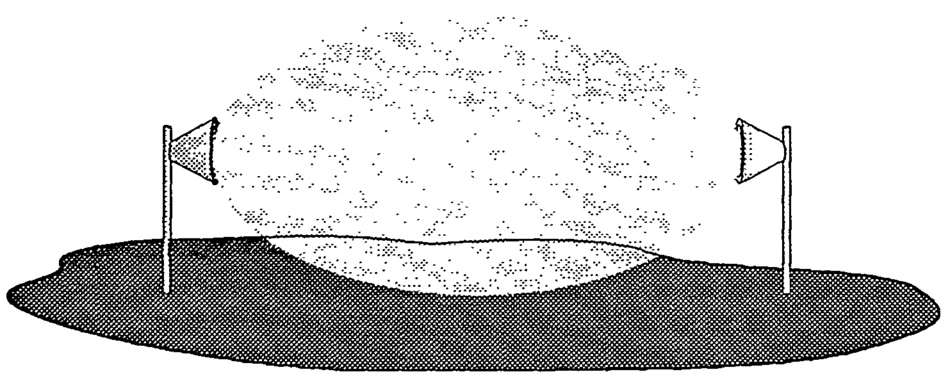

Figure 3. Traditional Bistatic Microwave Detection Zone.

The maximum detection zone width (and height) occurs midway between the transmitter and receiver and depends on the separation distance of the pair. For a separation of 70 meters, the maximum width is about 16 meters, the maximum height about 8 meters.

Moving or adjusting the location of the PRLS detection zone is simple — just pick up one or both of the associated sensors and move them to the end points of the new detection zone. Multiple sensors can operate together to form a continuous line of detection. Figure 4 shows how multiple sensors could be configured to secure a building and demonstrates the continuous-line-of-detection concept.

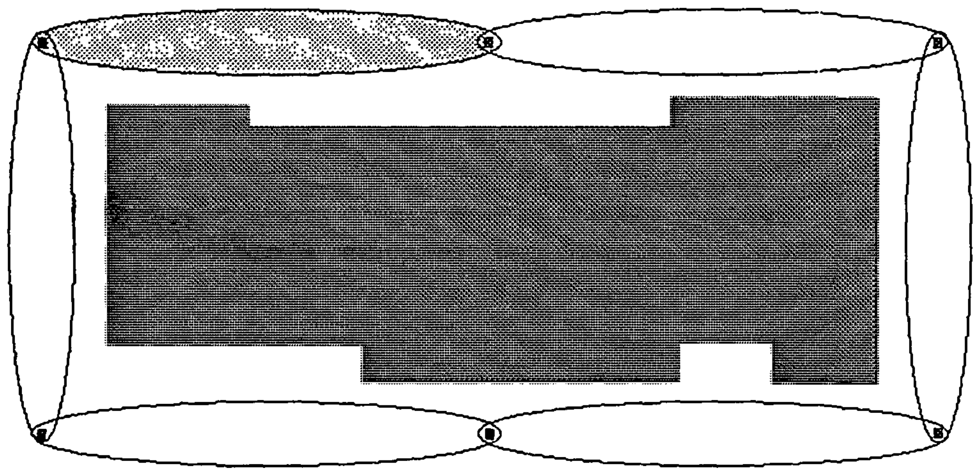

Figure 4. Securing a Building with PRLS.

The existing PRLS units were originally built in 1982 for securing parked aircraft. Since that time, Sandia has made several modifications to enhance use of the PRLS as a rapidly-deployable security sensor. The existing PRLSs operate at a single frequency of 5.8 GHz and each contains both a microwave transmitter and receiver. Although all transmitters operate on the same frequency and transmit a 6 nanosecond pulse, each receiver distinguishes its associated bistatic transmitter by a unique pulse repetition frequency (PRF). When the transmitter of one sensor is set to the same PRF as the receiver of another sensor, a detection zone is formed between the two sensors. By using a variety of PRFs, up to 30 sensors can operate in close proximity without causing mutual interference.

The PRLS has several unique capabilities not available in commercial microwave sensors. Because the PRLS is equipped with an omnidirectional radar antenna, the transmitter and receiver need no alignment or calibration. The unique ellipsoidal detection zone eliminates the need for an offset distance to achieve total detection coverage. The sensors themselves are inside their own detection zone and are therefore protected from tampering. The sensors can be separated by 15 to 70 meters without user input.

The new commercialized PRLS will operate at separation distances up to 100 meters, and will support up to 50 sensors operating in close proximity. Thus, a 5000-meter perimeter could be set up without mutual interference problems. In fact, longer perimeters could be established if PRFs are used over again. The requirement for re-using a PRF is that the two sensor pairs (i.e., two transmittter/receiver pairs) with the same PRF be separated by enough distance to preclude their unwanted synchronization.

During testing, probabilities of intruder detection have consistently approached 100 percent. The PRLS has a sharply defined, sensitive detection zone and will not falsely alarm on nearby vehicular traffic or other nearby motion outside the desired detection zone. The PRLS has been designed to minimize nuisance alarms. Unlike most existing commercial microwave sensor systems, the PRLS is not subject to nuisance alarms caused by rippling water and relatively high grass (approximately 7 inches). Nor does severe weather cause the PRLS to alarm, unless rain exceeds 3 inches per hour and is accompanied by high winds (greater than 15 mph). These capabilities combine to make the PRLS very promising for use in rapid-deployment, high-security operations.

The characteristics of the PRLS are summarized below.

1. Easy setup
   -- Portable
   -- No alignment required (omnidirectional antenna)
   -- No calibration required
   -- Setup and detection zones established in minutes

2. Self Protection (Tamper Resistance)
   -- Sensors within detection zone
   -- No offset distance

3. Minimal Site Preparation
   -- Some terrain following capability
   -- Rippling water rejection
   -- Blowing grass rejection

4. "Sharp" Detection Zone Edges
   -- Well defined detection boundaries (via range-gating)
   -- Variable zone lengths and widths

5. RF Communications and Battery Operations

Technical Description[4]

This section describes the system operation and the basic functional blocks of the PRLS. A description of the functional operation of specific PRLS electronic circuits is contained in the report *Aircraft Security Radar Development Report*, SAND87-0310, February 1989, by Bruce C. Walker.

System Operation

The PRLS is a bistatic, pulse-Doppler intruder detection system. A detection line is formed between two battery-powered radar sensors. When an intruder enters the sensitive volume, the PRLS detects this intrusion and, by means of a relay closure, sends an alarm to the monitoring station. There are two main factors that determine the detection capability of the system: 1) Doppler frequency shift, and 2) detection edge sharpness.

Doppler Frequency Shift: The PRLS detects intruders using the Doppler principle. Motion within the sensitive volume causes the frequency of the reflected signal to shift. The Doppler shift, f_d, for a moving object in the bistatic sensitive volume is approximately given by:

$$f_d = (2 \times \text{radial velocity}) / \text{wavelength}$$

where the wavelength is 5.17 cm. If this frequency shift is within the detectable range, the moving object (intruder) is detected and an alarm is generated from the PRLS. Stationary objects within the sensitive volume are not detected and no alarm is generated.

Detection Edge Sharpness: The other factor used by the PRLS in detecting intruders and rejecting out-of-range movement is the range gate or the sharpness of the edges of the detection volume. If the detection volume edge is sharp (as it is for the PRLS), vehicles and other movement outside of the detection volume will not be detected and will not cause nuisance alarms. This detection edge sharpness is a function of the rapid rise time of the transmitted microwave pulse.

Basic Functional Blocks

Transmitter Module: The transmitter module transmits a high frequency pulse with a duration of a few nanoseconds. This pulse is transmitted at a user-specified pulse repetition frequency (PRF). The PRF is the means used to synchronize a receiver to its associated transmitter. Each PRLS unit includes a receiver and a transmitter, which enables a single PRLS to transmit one PRF to a sensor and receive a different PRF from another sensor. The transmitter module monitors PRLS status and controls system communication. Status inputs include bistatic intruder alarm lines, a synchronization flag, a battery voltage indicator, and a control panel access indicator. These signals are processed and the proper alarms generated.

Receiver Module: A pulse of transmitted energy (called the direct pulse) is received by the microwave receiver circuitry and amplified to a detectable level. The receiver is synchronized to the direct pulse using a binary phase-locked loop. If a moving object is inside the sensitive volume, an echo pulse is mixed with the direct pulse to form a Doppler frequency shift. The processor in the receiver uses this information to determine whether the frequency shift occurred in one of the selected Doppler bands and, if so, initiates an alarm signal.

Antenna: The PRLS uses a biconical antenna that has an omnidirectional pattern in the horizontal (azimuth) plane. This enables the user to deploy the PRLS without regard to orientation of the sensors. No alignment of the transmitter PRLS or the receiver PRLS is required. The antenna is horizontally polarized and uses an inverted-conical radome to minimize nuisance alarms due to the effects of rain. The antenna is broadband (400 MHz bandwidth) to minimize the effects of ring-down and to minimize distortion of the narrow microwave pulses.

Battery Pack: The PRLS battery pack consists of two 12 V rechargeable lead acid batteries and a built-in recharger. These batteries have a sealed electrolyte, making them safe for air transportation. The operation time between charging has been tested for 72 hours at –40°C. The battery pack will operate over a temperature range of –40° to +58°C. A built-in battery charger is capable of recharging the batteries in about 8-10 hours.

Applications[3]

Sensors and security systems that can be rapidly deployed are being sought by military, government and commercial organizations. The PRLS fits this rapid deployment requirement very well. The securing of a four-sector closed perimeter in approximately five minutes has demonstrated its ease of setup and its portability. The combination of rapid deployment and other features (e.g., no alignment required, no offset distance, self-protection) make the PRLS a very attractive security system solution.

Applications of interest to the military include high-value asset protection (e.g., aircraft), flight-line perimeter security, dispersed weapons security, and vehicle portal security. In addition, military uses of PRLS could include temporary sector monitoring (gap filler) and the securing of taxiway gaps.

Arms control presents several other potential applications for PRLS. These include portal and perimeter monitoring of inspection sites and entrance monitoring of storage sites. The PRLS might also be used for temporary sector monitoring (gap filler) and to monitor the movement of material and personnel through chokepoints (e.g., a road bounded by steep terrain).

Use of the PRLS to secure commercial airplanes from acts of sabotage or tampering is being studied by the Federal Aviation Administration. The PRLS could be used for airport ramp-area security and for securing taxiway gaps. Other applications for PRLS include perimeter security of controlled areas and buildings, and border monitoring.

The PRLS has been successfully demonstrated in many of these scenarios, including aircraft, perimeter, portal, airport ramp-area, and taxiway gap security applications.

Technology Transfer[5]

Although the Sandia engineering PRLS prototypes have demonstrated many unique and desirable features, important issues remained with regard to readying the PRLS for production. These issues were concerned with manufacturing and economic constraints. For example, critical portions of the RF circuitry in the PRLS prototypes were constructed using custom-modified, manually-optimized components, since no acceptable commercial components were available at the time. Use of these labor-intensive components had to be eliminated in the production design. Commercial components are now available that meet the RF requirements of the system. Thus, for manufacturing and cost reasons, additional pre-production engineering was required to get the PRLS into production.

The normal procurement process would have required the funding agency, the U. S. Air Force, to pay for these pre-production engineering costs. As an alternative, the Air Force decided to transfer the PRLS technology to a commercial firm willing to bear these up-front costs. This arrangement was fulfilled in October 1992 with the approval of a Cooperative Research and Development Agreement (CRADA) between the Air Force Electronic Systems Center (ESC), Electronic Security and Communication Center of Excellence (ESCCE; Hanscom AFB, MA)*, and Racon, Inc. (Seattle, WA).

Cooperative Research and Development Agreements (CRADAs)

In general, a CRADA places the government and a commercial firm in direct partnership to exploit existing technology and to develop new technology or a product. The CRADA is not a contract and is therefore exempt from the normal competitive requirements of the Federal Acquisition Regulations. It is also not a grant—the government may not provide funds to the commercial partner. It is a partnership in which each of the parties is expected to bring something to the agreement. The exact terms of the CRADA and the roles of each party are negotiable.

Under the CRADA, the government may provide:

- Information
- Personnel
- Laboratory access
- Facilities
- Equipment

This list is not all inclusive, but gives a good idea of how flexible the arrangements can be.

Likewise, the industry partner may choose to provide access and resources to government laboratory staff. In a typical scenario, government and industry staff work side-by-side at either the government or industry site.

Benefits of this kind of agreement are enjoyed by both the government and industry. In general, federal technology transfer fosters more open communication between government and industry. Additional benefits are:

- Government benefits
  -- Provides a return on otherwise lost government research dollars
  -- Provides commercially-off-the-shelf products for government use
  -- Leverages federal R&D funds (provides a cost effective method to get government developed technology to the market)

* Patent rights to the original PRLS design are held by the U. S. Air Force, the original funding agency.

-- Provides the government access to and appreciation of industry's:
  - manufacturing expertise
  - marketing techniques
  - emphasis on cost control

- Industry benefits
  -- Increases U. S. small business global competitiveness
  -- Stimulates industry to engage in pre-competitive technologies
  -- Reduces R&D costs usually associated with bringing a technological concept to market

The PRLS Agreements

The Air Force and Racon are the official partners to the PRLS CRADA. With regard to PRLS technology transfer, Sandia is directed by, and serves as the technical arm of the Air Force under a "work for other federal agencies" agreement. The day-to-day interactions of transferring the PRLS technology occur between Racon and Sandia.

Each of the partners brings something unique to the relationship:

- Air Force/Electronic Systems Center (ESC)
  -- User's requirements
  -- User's perspective

- Sandia
  -- Actual PRLS technology
  -- Security and microwave systems engineering expertise
  -- Facilities and equipment

- Racon
  -- Manufacturing expertise (producibility and profitability)
  -- Marketing expertise

At the request of ESC, Sandia has been providing engineering expertise (design assistance, consulting, evaluation and testing), equipment and facilities to Racon to assist them in commercializing the PRLS. Sandia and Racon have both benefitted from the CRADA relationship. Racon engineers have received the benefit of Sandia security systems and radar development expertise, while Sandia engineers have gained valuable exposure to important commercial manufacturing constraints and requirements.

PRLS Status

Racon's product will include several modifications to the original design. A significant improvement is the increase of the maximum separation to 100 meters. This is desirable since many perimeter security sectors are based on 100-meter zones. Another change is being made to the pulse repetition frequency (PRF) circuitry to alleviate mutual interference between systems located near each other.

The radar pulse parameters are being changed to allow the PRLS to meet FCC part 15 "no license required" constraints. This will open the market for PRLS to commercial as well as government users.

Finally, Racon is modifying the antenna and mechanical packaging to reduce manufacturing costs. Figure 5 shows the proposed mechanical configuration.

Six Racon advanced engineering prototype PRLSs will be delivered to Sandia in October 1993 for evaluation. Racon production PRLSs are expected to be available in March 1994.

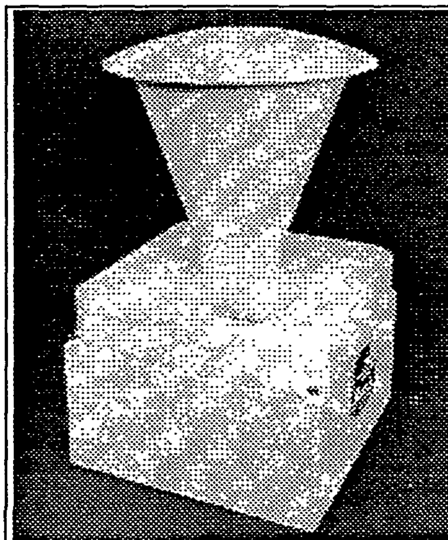

Figure 5. Racon, Inc., PRLS prototype

Summary

The Portable, Reconfigurable Line Sensor (PRLS) is a unique, bistatic, intruder-detection radar sensor. The PRLS's ease-of-setup, detection capabilities, lack of alignment and calibration requirements, self-protection features, battery operation, and RF communication capabilities make the PRLS an excellent choice for many government, military and commercial applications. The transfer of the PRLS technology to industry for commercial production will provide a valuable addition to the suite of sensors currently available for portable, rapid-deployment applications. In addition, this PRLS technology transfer effort will serve as a model for future government-industry cooperative research and development agreements.

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