Train Detection in Non-Track Circuited Areas of Railroad Crossings Utilizing Overhead Microwave Radar

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ABSTRACT
Insulating joints at crossings and junctions can suffer electrical failure due to metal shavings and other conductive contaminants that accumulate in the insulator gaps. Increasing joint distance from the diamond frog junction can reduce build-up of grease and other debris, but creates dead zones in which train cars and locomotives cannot be detected using traditional track circuits. Tie-mounted PD loops can be used to detect trains in these dead sections, but are highly vulnerable to damage and failure.

The paper describes the design, testing, and implementation of a radar-based train detection system at a BNSF full flange bearing diamond frog junction with dead sections greater than 30 feet (FRA requirement is 35 feet or shortest wheel base of a locomotive, which is 30 feet at BNSF). Detection performance was evaluated at a test site over a five-month period, and contrasted with that of a surface-mounted presence detection loop system. Revenue service implementation at future sites includes vitally circuiting redundant radar sensors to provide equivalent protection for these dead sections.

CROSSINGS AND THE NEED TO DETECT TRAINS IN TRACK CIRCUIT DEAD SECTIONS
A railroad crossing is defined as a location where two railroads cross at grade (as illustrated in Figure 1, below). These complex structures permit trains to pass over intersecting tracks without the need for switches. Crossing improvements have sought to maximize train speed and ride quality, while minimizing wear and vibration - objectives that are often mutually exclusive.

Figure 1 – Railroad Crossing

Because of the need to provide rigid support to the crossing, the typical railroad crossing is constructed of steel and manganese inserts (see Figure 2). The manganese inserts are interchangeable to allow for replacement when worn. This “all metal” design presents a
challenge for detection of trains because track circuits at the point of intersection are disrupted. Typical track circuits require both rails to be insulated from each other to utilize the wheel and axle to shunt the track circuit. Because the rails on a diamond are all connected, the rails are therefore not insulated from each other. This undetectable section of track is known as a “dead section”. Depending on the shortest wheel base on the railroad traversing its portion of the crossing, the dead section cannot exceed 35 feet (or the shortest wheel base for the operating railroad) without a special circuit to prevent a car that is completely within the insulated, dead section area of the crossing from disappearing from the signalling circuits. If the dead section is 35 feet or less, shorter than a car length, there is no FRA requirement for presence detectors or special circuits. Where the dead section exceeds 35 feet, a special circuit must be utilized, which may include a presence detector, a trap circuit, or other techniques that may mitigate the risk associated with a track circuit dead section that is longer than a car length.

![Figure 2 – Typical Crossing Design](image)

Presence detection in dead sections has historically been accomplished with inductive loops, which respond to the high metallic content of trains or cars positioned or passing overhead. Called Presence Detector (PD) loops, these cables are mounted to the tops of ties surrounding the dead sections, a location where they may be subjected to environmental and mechanical damage. This can create false activations of the loop detection system as well as heightened maintenance challenges. Other options include trap-circuit wheel counting systems that determine whether the number of wheels entering an interlocking matches the number of wheels exiting. If the count-in / count-out number does not match, the assumption is made that there is a car in the crossing and the signals are placed in their most restrictive state. This non-deterministic system requires a special circuit to count the wheels and in some cases utilizes wheel pick-up transducers to accomplish this detection. Like other detection technologies that are located at ground level or clamped to ties themselves, transducers can become loose from the vibration in the interlocking and also pose a maintenance challenge.

Radar systems that have recently been implemented at highway-rail grade crossings have shown promise as an alternative to presence detector loops in crossing applications. Because the radar system is entirely isolated from track components and mounted above the crossing, it is not affected by the extreme vibrations that are present in a crossing. Also, the physical components are not in a position where they may suffer mechanical damage due to track maintenance and other work crew activity in and around the crossing.

OWLS Diamonds – One Way Low Speed (OWLS) diamonds (see Figure 3) have been recently introduced into the industry to eliminate the vibration that is typical for a railroad crossing. The OWLS diamonds utilize flange bearing technology, but until recently have only permitted operation at low speeds. There is interest in progressing this technology to a higher speed application, but this requires the slopes that provide the rise in the wheel to be extended. This increases the length of the dead sections around the diamond, and increases the need to utilize deterministic detection technologies for those enlarged dead sections.
DEVELOPMENT OF A RADAR-BASED DETECTION SOLUTION FOR RAILROAD APPLICATIONS

In 2010, several states and railroad organizations expressed renewed interest in the possibility of utilizing radar for vehicle and train detection applications in the railroad industry. Citing vulnerabilities inherent in presence detector loops installations, their typically short lifetime, and the safety and train delay consequences associated with installation and replacement, interest in a viable non-embedded detection technology was unequivocal and widespread. In practice, certain presence detector (PD) loop installations did not completely cover the detection areas of interest due to the inability to place them in close proximity to tracks or to other loop segments. It was thought that a radar-based solution might improve coverage and possibly offer a degree of redundancy through the overlapping of detection zones.

Numerous traffic detection radars are commercially available for the growing ITS (Intelligent Transportation System) industry sector. A survey of available ITS radars revealed one that was uniquely designed for radar-based detection as an alternative for buried inductive loops. Designed and manufactured for vehicle detection at signalized intersections, the device featured a detection footprint that was large enough to cover an entire crossing.

Implemented utilizing a solid state array of 16 distinct radar sensors, the overall detection area measures 90 degrees by 140 feet - nearly 16,000 ft² (see Figure 4). The radar allows up to 10 lanes of traffic and 16 zones to be established within this quarter-circle shaped footprint, large enough to completely span most highway-rail grade crossing islands and railroad crossing structures. This allowed large detection zones to be established, covering the entire area in which vehicle or train occupancy is to be detected, with no gaps or need to isolate contiguous detectors, as is sometimes the case with PD loops. To be detected, vehicles need to present a radar cross-section that reflects emitted 24GHz energy with sufficient magnitude to trigger classification algorithms within the radar. This requires that the detected objects contain reflective characteristics (i.e. metallic) and that they be of sufficient height within the detection area to be adequately differentiated from the baseline, background ‘scene’ accumulated by the radar sensor (e.g. greater than 3 feet in height).

Figure 4 – Sixteen Radar Array Sensor
Because the application for which the radar was designed anticipated multiple radars in close proximity, for example at each of four lanes of approaching a signalized traffic intersection, Wavetronix developers encoded the radar emissions to prevent proximate radar sensors from interfering with one another. This feature became a valuable addition for the radar’s use in railroad applications, because it allows multiple radar sensors to be turned to face into the intersection, collaboratively detecting vehicles in the same detection zones, but from opposite sides of a highway-rail grade crossing island or railroad crossing dead section. Several reliability advantages are realized, including a full redundancy that is not physically possible with PD loop technologies.

Field testing of the Wavetronix radar technology over the course of many months revealed several operational areas where certain modifications were necessary in order to adapt and optimize the radar sensor for railroad applications. In addition, it was necessary to develop a new hardware controller in order to comply with AREMA environmental and electrical isolation specifications, and the failsafe state criteria common to the railroad industry – all of which differ from practices in the traffic control industry.

With preliminary testing complete and necessary hardware and software modifications accomplished, the dual radar system was installed and placed into operation in December 2011 at the Illinois four-quadrant gate demonstration site in Hinsdale, Illinois. Over a four-month period involving more than 120,000 vehicles, the radar-based system reported no missed detections. A small percentage of false radar detection events were noted (27 occurrences or .023%), but at half the false detection rate of the PD loops that were also installed at the test site (68 occurrences or .057%). This complete, preliminary report associated with this FRA-sponsored testing phase is available online from the FRA/DOT website, under report number DOT/FRA/ORD-12/24.

The University of Illinois Center for Transportation and North Carolina State’s Institute for Transportation Research and Education have independently conducted performance verification testing on an ongoing basis for radar-equipped crossings in Illinois and North Carolina, and those results are to be made available by those organizations.

Despite performance that is generally equal to or better than that of PD loops, it should be noted that only recently, and primarily a result of data preliminary produced by these investigations, have the radar systems included the following additions and refinements:

- Elimination of a queue-forming feature used in the traffic industry, but which created a false detection propensity in the railroad applications.
- Inclusion of a heavy weather optimization feature and more dynamic processing of background radar data, both of which minimize unnecessary detection threshold elevation during ground level snow ‘rutting’ conditions.

Performance improvements anticipated by these upgrades are expected to be quantified by University of Illinois and North Carolina State University studies, currently underway and scheduled for publication by the end of 2014.

**RADAR-BASED TRAIN DETECTION AT CROSSINGS, INITIAL TESTS**

Based on the positive performance experienced in vehicle detection applications in railroad crossing settings, BNSF and ByStep, LLC (aka. Island Radar Company LLC, or Island Radar) installed a dual radar test site at a crossing near Lamar, Missouri. The purpose was to test the ability of the radar detection system to detect trains occupying the dead sections of a full flange bearing lift frog crossing with distances in excess of the FRAs 35-foot criteria.
At this junction of the BNSF and the Missouri & Northern Arkansas (MNA) Railroads, two radar sensors were installed (see Figure 5), permitting the entire dead section area of the railroad crossing to be ‘viewed’, by redundant radar sensors, each from opposite paradigms. Masts were installed at convenient, but not optimal locations along the BNSF north-south main line on opposite sides of the ends of the east-west MNA line.

Following installation, configuration, and a period of initial testing, comprehensive detection performance data was collected from both the radar system and a PD Loop system on a north-south BNSF track section. During this formal test period, which ran from mid-February to mid-April 2013, 835 BNSF trains were detected by the radar detection system with a 100% correlation to detection events registered by the PD Loop system. A total of 128 trains were detected on the east-west MNA track at the site. However, it was not possible to record collaborative PD Loop state information from the MNA track due to problems with the PD Loop system’s auxiliary output circuitry or its configuration.

During the formal data collection period there were a number of snowfall and rain events, typical for the months February through April. But the radar system showed no adverse effects due to weather or any suspected disruption of operation due to the proximate overhead power transmission lines.
Visual data obtained from the radar systems configuration application illustrated and affirmed the radar’s return emission signal power levels (signal to noise ratios) to be substantial and continuous when a train occupied the track segment and virtually zero when the track segment was clear.

Figure 7 - Radar Cross Section of a Train Relative to Background

Based on the performance data provided by the Lamar Missouri test site, a second site has been selected for installation, but with the radar system vitally circuited in a trap release configuration.

**RADAR-BASED DETECTION IN A VITALLY-CIRCUITED IMPLEMENTATION**

The location selected is at the Bridge Junction Interlocker located in West Memphis, AR. This location is a double crossing, with two Union Pacific (UP) tracks crossing one BNSF track. The dead sections in which train occupancy is to be detected are shown in the image below as colored rectangles overlayed on each of the three tracks.
Strategic locating of the two radars is important so that each radar has a clear ‘view’ of each of the detection zones. As shown in the image below, each radar was placed between the UP and BNSF tracks, close enough to the crossing that the radars’ 140 foot, quarter-circle shaped detection footprint covered the far extents of the detection zones. The radar sensors were mounted atop 20-foot wooden poles and the communication cable from each radar sensor was contained in underground conduit leading to the equipment cabinet adjacent to the crossing.
As the radar system itself is not a vital system, the design uses outputs of the two radars, each of which is monitoring the same detection zones (the highlighted rectangular zones in Figure 9), but from opposite viewpoints. A detection by one radar must correspond with a detection by the other within three seconds of any change. In this manner, the internal logic within the vital microprocessor provides a vital system allowing this to be used as a special circuit to detect the presence of trains within the dead section. The detection states signalled by each radar must agree or the signal system will be set to its most restrictive aspect.

Because the radar sensors are able to operate redundantly, this design and implementation is expected to achieve a level of vitality and reliability that is greater than that available from other special circuits or PD loop detectors that do not offer redundant presence information for comparative analysis by a vital processor.

\[ \text{Figure 10 – Radar Placement in Crossing Schematic} \]

The two sensors are mounted on 20 foot masts and positioned in opposite quadrants surrounding the diamond at the center (highlighted in yellow in Figure 10). The purpose of having these sensors located in differing quadrants is to ensure that if one pole is struck, the timing and co-incident detection events provided by the sensors will be altered. If the sensors were attached to the same pole, this would not be possible. The north sensor is named 1RDR1 (Main 1, Radar Sensor 1) and the south sensor 1RDR2 (Main 1, Radar Sensor 2). The sensors are appropriately cabled to the controller contained in the signal house. This controller’s role is to pick and drop two relays, the 1RDR1R and the 1RDR2R. These relays then gate the voltage applied to inputs 6 and 8 of the Slot 7 VIO-86S card contained in a GE ElectroLogIXS Vital Logic Controller.

\textbf{Internal Logic}

The software for the ElectroLogIXS contains vital locking functionality specific to radar detection systems. This logic will ensure that a single point of failure does not exist in the presence detection circuit. The code and variables referenced in this section follow this document. For the purposes of discussion this document makes use of the following naming conventions:

\begin{itemize}
  \item 1DSOCC ↑ = Dead Section Sensing Occupied
  \item 1DSOCC ↓ = Dead Section Sensing Not Occupied
  \item 1DSCLR ↑ = Dead Section Sensing Clear
  \item 1DSCLR ↓ = Dead Section Sensing Not Clear
  \item 1DS ↑ = Dead Section Clear For Traffic and System Operational
  \item 1DS ↓ = Dead Section Occupied or System Failed
\end{itemize}
The operation of this system uses logic that is designed to work as follows (the ladder logic is shown on the right side of the following operational sequence):

<table>
<thead>
<tr>
<th>Normal Operation</th>
<th>Action: Train enters sensing area in diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• 1RDR1_IN and 1RDR2_IN drop</td>
</tr>
<tr>
<td></td>
<td>• 1DSOCC picks/sticks and 1DSCLR drops</td>
</tr>
<tr>
<td></td>
<td>• 1DS drops, indicating dead section is occupied</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation With 1RDR1 Failed Up</th>
<th>Action: Train enters sensing area in diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• 1RDR1_IN remains up, 1RDR2 drops</td>
</tr>
<tr>
<td></td>
<td>• 1DSCLR_TE starts running 3 second timer</td>
</tr>
<tr>
<td></td>
<td>• 1DSCLR_TE completes 3 second time and picks, drops 1DSCLR</td>
</tr>
<tr>
<td></td>
<td>• 1DSOCC does NOT pick, remains down</td>
</tr>
<tr>
<td></td>
<td>• 1DS drops indicating dead section is occupied</td>
</tr>
<tr>
<td></td>
<td>• 1DSOCC and 1DSCLR are both down simultaneously, indicative of a failed state</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation With 1RDR1 Failed Up</th>
<th>Action: Train departs sensing area in diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• 1RDR1_IN still up, 1RDR2 picks</td>
</tr>
<tr>
<td></td>
<td>• 1DSCLR remains down</td>
</tr>
<tr>
<td></td>
<td>• 1DS remains down</td>
</tr>
<tr>
<td></td>
<td>• Locking logic will prevent a signal from clearing with the 1DS down</td>
</tr>
<tr>
<td></td>
<td>• System requires repair and reset</td>
</tr>
</tbody>
</table>

**Figure 11 - Vital Circuit Equations and Logic**

**INSTALLATION AND TESTING**

Installation of the dual radar detection system is scheduled for late July 2014. Sensitivity and timing settings for the radar subsystem will reflect those configuration parameters utilized and proven during the Lamar, Missouri pilot studies. An event recorder is to be utilized to log detection data and to verify that there are no instances of false or missed detections. The authors intend to provide updates regarding overall system performance by September 2014, after the installation is cut over and initial performance data becomes available.