Title

Radio Frequency ID Tags to Enhance Safety

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Abstract

This project was originally conceived and executed to deliver a proof-of-concept of a near-term "cooperative vehicle-highway system" using a Radio Frequency Identification (RFID) tagging system to significantly improve the reliability of rear-end truck-based forward collision warning (FCW) systems. A hardware apparatus was developed but proved difficult and relatively costly to design and prototype; however, one set of RFID apparatus was delivered by our Raytheon subcontractor to PATH, then it was tested at PATH. Because of range limitations it did not perform to the extent that it could conceivably enhance FCW systems.

At the time this work was being conducted, the emergent TO 5217 dealing with Vehicle-Infrastructure Integration (VII) was beginning, and an idea – curve overspeed warning – was inspired by the generalization of "look-ahead" within this project. The work under this project, therefore, was transformed into conceiving and the start of implementing such a system of dynamic road-curve assistance and, to complement TO 5217, to investigate some of the test results. In the end, this system was deemed to be practicable and was in fact further investigated in TO 5217 and TO 6217.

Keywords

Forward Collision Warning (FCW), Advanced Driver Assist System (ADAS), Radio Frequency Identification (RFID), Vehicle-Infrastructure Integration (VII), Curve Over-Speed Warning Systems (COWS)

Executive Summary

This project was originally conceived and executed to deliver a proof-of-concept of a near-term "cooperative vehicle-highway system" using a Radio Frequency Identification (RFID) tagging system to significantly improve the reliability of rear-end truck-based forward collision warning (FCW) systems. In concept, the RFID-based cooperative system would consist of three main elements: (a) a passive RFID tag, mounted on roadway objects or forward vehicles (b) the vehicle radar source of signal, and (c) a RFID receiver mounted on the vehicle that receives the tag response. The subject vehicle would sense the RFID tag, and its signal would enhance either the forward vehicle's signal in an "I am the target" mode and/or the infrastructure in an "I'm not the target" mode. The concept would greatly enhance operational reliability of FCW systems, as is would overcome inherent limitations with target signal-to- background clutter. Provision of this additional information that would in a reliable way allow FCW systems to work under difficult conditions underpins this project.

A hardware apparatus proved difficult and relatively costly to design and prototype; however, one set of RFID apparatus was delivered by our Raytheon subcontractor to PATH, then it was tested at PATH. Because of range limitations it did not perform to the extent that it could conceivably enhance FCW systems.

At the time this work was being conducted, the emergent TO 5217 dealing with Vehicle-Infrastructure Integration (VII) was beginning, and an idea – curve over-speed warning – was inspired by the generalization of "look-ahead" within this project. Specifically, the idea of dynamically extracting incoming road attributes with more detail than "I am not the target" or "I'm the target", was considered in an upcoming curve. Consider a Curve Overspeed Warning System (COSW), where a system with a much more rich set of look-ahead data was provided. The work under this project, therefore, was transformed into conceiving and the start of implementing such a system and, to complement TO 5217, to investigate some of the test results. In the end, this system was deemed to be practicable and was in fact further investigated in TO 5217 and TO 6217.

1.0 Radio Frequency Identification (RFID) System Development and Results

This project was originally conceived and executed to deliver a proof-of-concept of a near-term Radio Frequency Identification (RFID) tagging system to significantly improve the reliability of rear-end truck-based forward collision warning (FCW) systems. In concept, the RFID-based cooperative system would consist of three main elements: (a) a passive RFID tag, mounted on roadway objects or forward vehicles (b) the vehicle radar source of signal, and (c) a RFID receiver mounted on the vehicle that receives the tag response. The subject vehicle would sense the RFID tag, and its signal would enhance either the forward vehicle's signal in an "I am the target" mode and/or the infrastructure in an "I'm not the target" mode. The basic operation is illustrated in Figure 1.

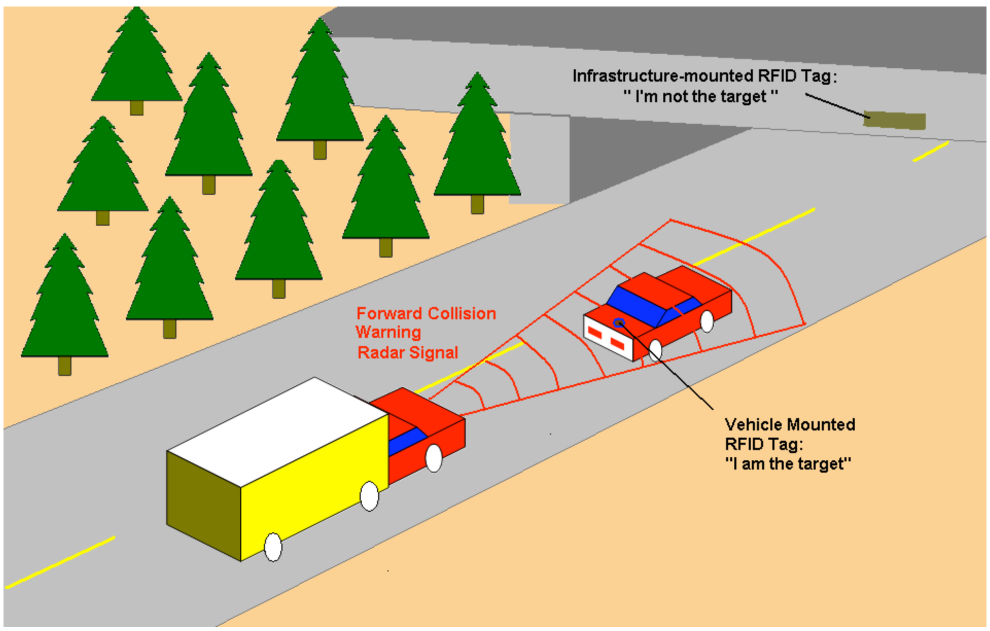

Figure 1. Illustration of RFID-based Cooperative System Operational Concept

The basic question – why RFID? – is addressed by the simple fact that operational reliability of FCW systems is constrained by signal-to-clutter. A cluttered background, and especially where there are 'internal corners' (or dihedrals) where the FCW radar wave reflects causes potential noises, often confounds FCW systems. RFID tags on vehicles increase the target signal – "I am the target" – and/or RFID tags on complicated (to radar) road and roadside geometries such as bridge overpasses or overhead signs allow the system to throw away the background signal – "I'm not the target". Provision of this additional information in a reliable way to make FCW systems work under difficult conditions underpins this project.

At the communication link level, the original concept leverages K-Band (24 GHz) RFID tag technology to respond to a query from commercially-available automotive radar, such as the Eaton-Vorad EVT-300 or the Raytheon 24 GHz forward-looking radar already used by many truck fleets.

On the RFID tag end the concept would be passive and cheap. “Passive and cheap” are relative and subjective terms, but the initial definition for this project is that if the RFID tag could be powered by the incident FCW radar energy, coupled with the assumption that given large-scale production the integrated circuit components would be affordable.

1.1 Prototype Development

The RFID tag prototype was based on existing passive 915 MHz (not 24 GHz) tag technology, with existing and standard encoding scheme. The idea was to provide upon this RFID tag an active K-band appliqué to interface with the commercial truck radar band (e.g., EVT-300’s band). The appliqué would be comprised of a simple up-down converter, with gain applied to support the desired range. We illustrate the concept and schematic in Figure 2.

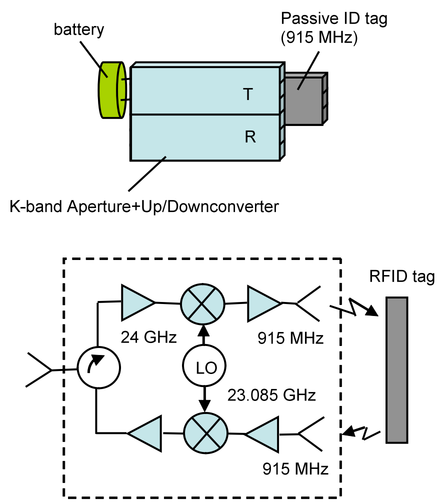

Figure 2. RFID Tag Concept and Schematic

During the design and laboratory testing phases, however, it was discovered that the power density required at the front end or aperture of the passive RFID tag to generate enough power to bias a code-generating integrated circuit. Subsequently, a tradeoff study was conducted to understand whether high energy density lithium batteries or solar cell-rechargeable batteries could supplement the inadequate RF energy coupling into the tag. Either would work; the lithium battery alternative seemed technically feasible, although long term cost projections were not conducted.

Work on the experimental prototype proceeded on this basis, with the design schematic shown in Figure 2 instantiated in Figure 3 below. The prototype tag enclosures are 6"(H) x 6"(W) x 3.5" (D). These were relatively large because we believe that the highway environment required a robust enclosure. Another driver to the enclosure dimension was the need for six D-size batteries such that at least provide two years of service life was provided.

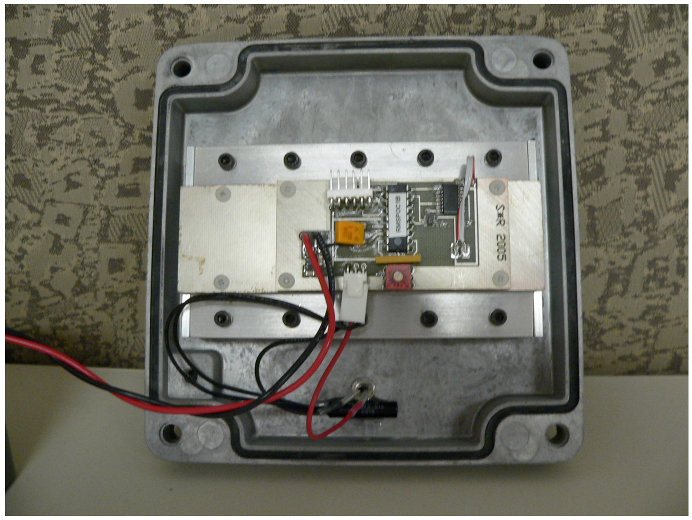

Figure 3a. RFID Tag: Interior View

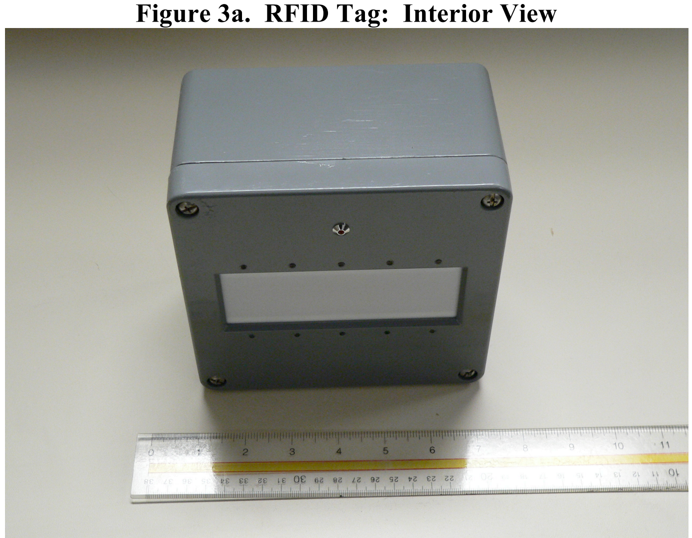

Figure 3b. RFID Tag: Front View

Figure 3. Experimental RFID Tag

1.2 Prototype Testing

Laboratory testing was initiated at the Raytheon subcontractor's facility. However, shortly after this juncture, the Raytheon subcontractor's funds expired (due to high prototype development costs), and the equipment was transferred to PATH. PATH researchers developed a test apparatus shown in Figure 4 and also a test plan. (Note additional implementation details, e.g., the K-band receiver is relatively close to the EVT-300 to minimize path losses.)

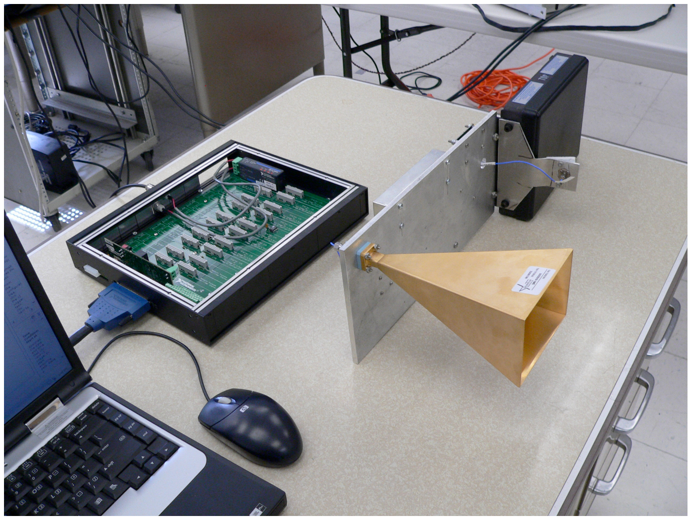

Figure 4a. RFID Test Apparatus with Signal Horn

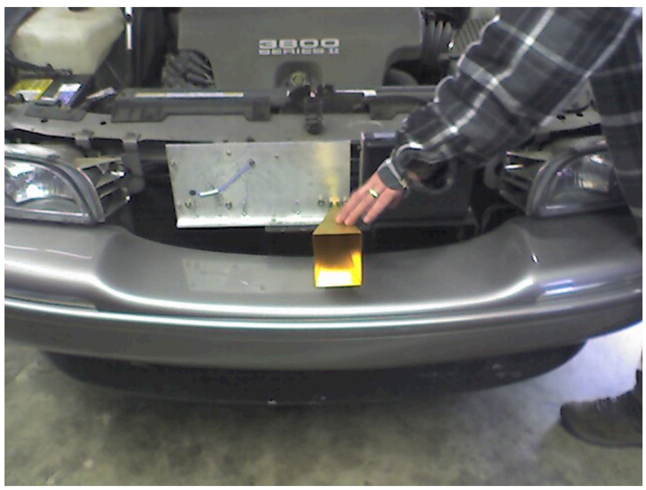

Figure 4b. RFID Test Apparatus with Signal Horn

Figure 4. RFID Test Apparatus

The test plan objectives were two-fold:

1. Basic RFID transceiver functionality
2. Lane resolution of approaching vehicle

During this test, we planned on using an instrumented test vehicle to record its own speed and position at all times as a measure of ground truth. In each run, the instrumented vehicle would start from a predetermined position and travel in the same direction at the predetermined speeds. We planned on testing the performance of the RFID transceiver, and at the same time we would measure its latency.

In combination with the prototype apparatus, the tag reader was placed on the side of the road where nothing is obstructing its view, illustrated in Figure 5.

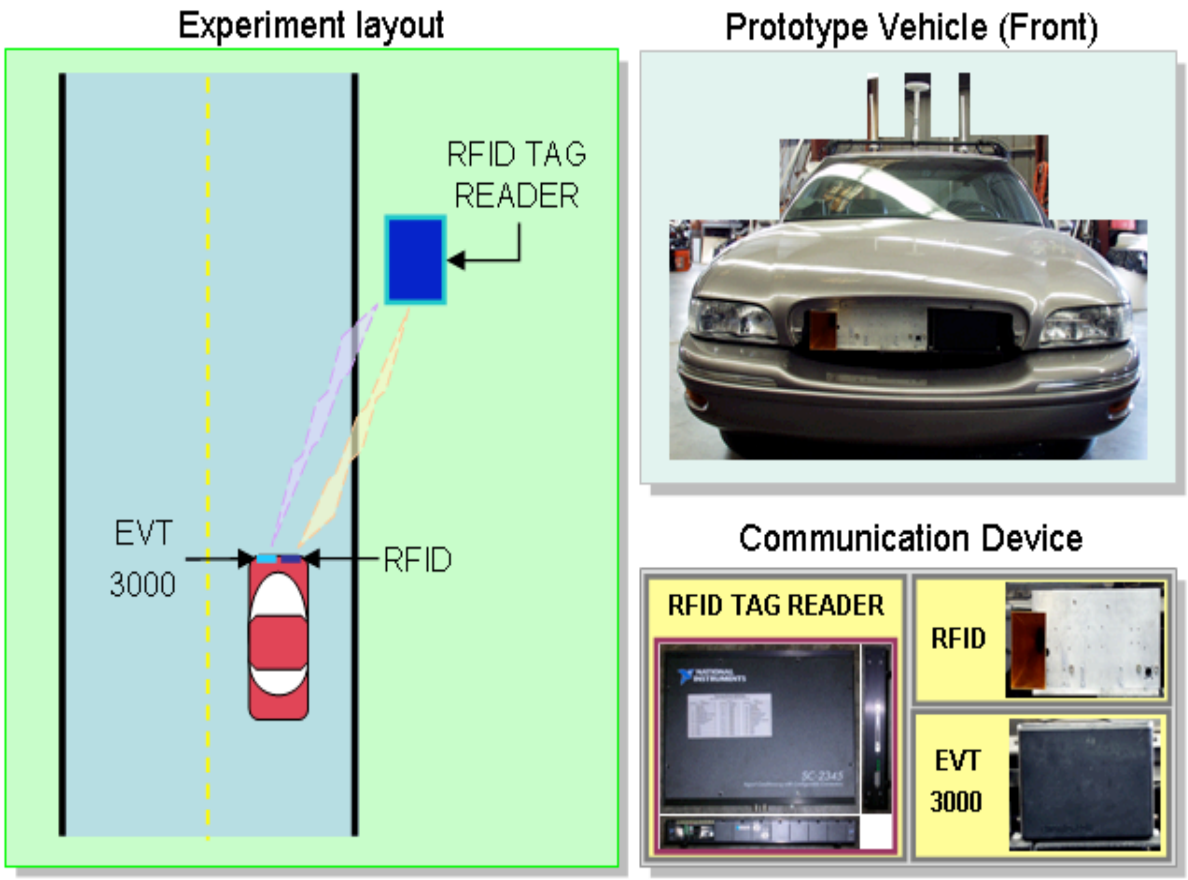

Figure 5. Experimental Configuration

The best we could do in our pilot tests outdoor laboratory tests was to show that the necessary 12-18dB signal-to-noise ratio could be obtained at 30 m range, but the falloff beyond that range was below the threshold for detection. The issue, therefore, is in operation of the RFID: freeway operations may be nominally at 30 m/sec, so the range obtained corresponds to 1 or fewer seconds of time gap – not enough to effect a change in a FCW, as it is on the same order of magnitude of nominal drivers' perception-reaction time.

Based on these emergent and disappointing results, the RFID investigation was curtailed.

2.0 Dynamic Road Curve Assist System Development and Selected Results

The research was reconsidered, and a slightly different problem was posed: the fundamental concept the RFID tagging system is to supplement and provide look-ahead information to Advanced Driver Assist Systems (ADAS) systems such as FCW. At the same time, the emergent TO 5217 dealing with Vehicle-Infrastructure Integration (VII) was beginning, and an idea – curve over-speed warning – was inspired by the aforementioned generalization of "look-ahead". Specifically, the idea of dynamically extracting incoming road attributes with more detail than "I am not the target" or "I'm the target" of Figure 1, was considered in an upcoming curve.

2.1 Concept Development

Consider a Curve Overspeed Warning System (COSW), where a system with a much more rich set of look-ahead data was provided. The work under this project, therefore, was transformed into conceiving and the start of implementing such a system, shown in the block diagram in Figure 6. This system integrates (D)GPS, vehicular sensors, wireless communication (e.g. Dedicated Short Range Communication or DSRC), and a digital application map to perform safety-related applications such as curve overspeed warning, stop sign warning and junction/intersection speed warning.

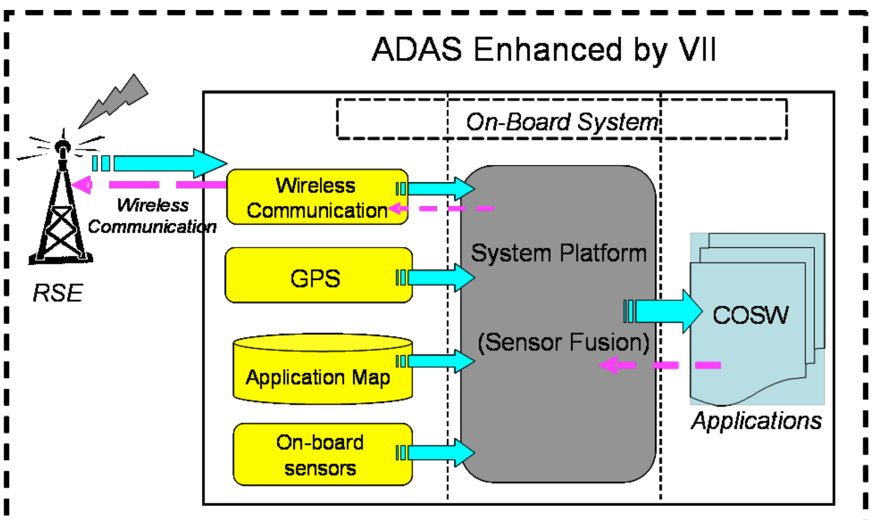

Figure 6. Concept of ADAS Enhanced by VII

The system can not only operate in a stand-alone fashion using on-board sensors and digital map, but it can also operate in a cooperative enhancement manner through VII. When there is a Road Side Equipment (RSE) nearby, the equipped vehicle can exchange data with RSE via vehicle-to-infrastructure wireless communication, e.g. DSRC and Wi-Fi. Detailed or dynamic road attributes such as super-elevation, grade, friction, traffic signal at ramp end (metering) etc., as well as event-based messages such as traffic accident, lane closures, detour, or construction zone, can be transmitted from the RSE to the vehicle. In addition, it is possible to provide GPS correction signal and map update service to the on-board system through VII [2]. On the other hand, the equipped vehicle can transmit detected or computed data such as speed advisory, air bag activation and ABS activation, to the RSE, so that RSE can inform other nearby drivers of an incident ahead.

Specifically, this system uses “look ahead” and Digital Short Range Communication (DSRC)-transmitted digital map data in the following functional units: Map-Matching, Attribute Provider, Position Enhancement, and Safety Application modules. This is illustrated in Figure 7.

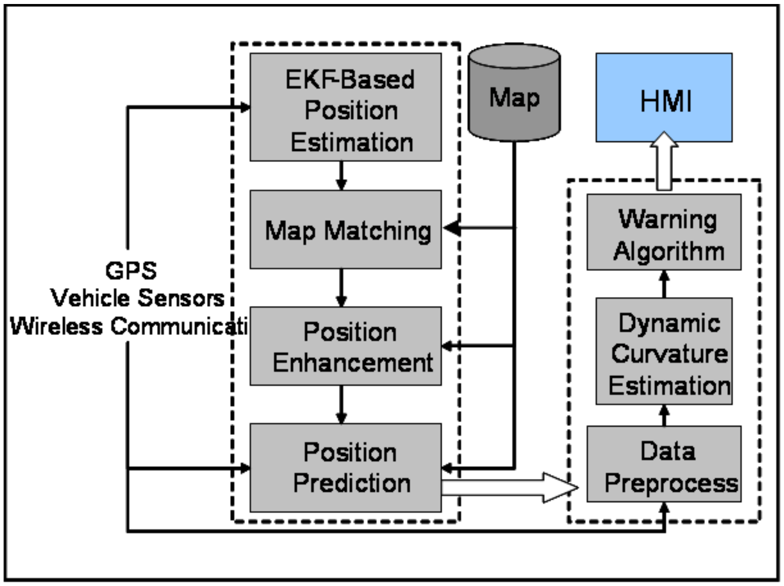

Figure 7. Functional Components of a COSW System

The on-board system platform consists of the following functional modules: Extended-Kalman-Filter (EKF)-based GPS/INS positioning unit, Map-Matching processor, Attribute Provider, Position Enhancement unit, Safety Application module, and the Wireless Communication unit. (The functional modules given in the sentence above do not match those explicitly identified or highlighted in Figure 7?) The advantages of this system design are described as follows.

2.2 Initial Experiment

Under TO 5217, a dynamic curvature estimation algorithm was implemented in the experimental system. Under this RTA, it was tested in real-time at the Richmond Field Station test track. Figure 8 shows one test result on a curve in one of the test track where GPS satellites are not available due to the surrounding tall trees. The safe speed for negotiating this curve is 9.3 m/s as computed by the COSW algorithm in real-time. The experiment showed that the COSW system did provide appropriate warnings when it detected the vehicle speed was unsafe for an upcoming curve based on both the positioning system and the map information. Figure 9 shows the corresponding vehicle speeds, number of satellites used in position computation, and the horizontal dilution of precision (HDOP) of GPS. When approaching this curve, GPS speed was constant due to satellite signal outage. The wheel speed was higher than the safety speed between 163~ 165.3 seconds, and the speed warning was activated. After the vehicle was slowed down, the warning was automatically turned off by the system.

Figure 8 does show that the enhanced EKF-based positions have the potential to achieve the desired "lane-level" positioning requirement.

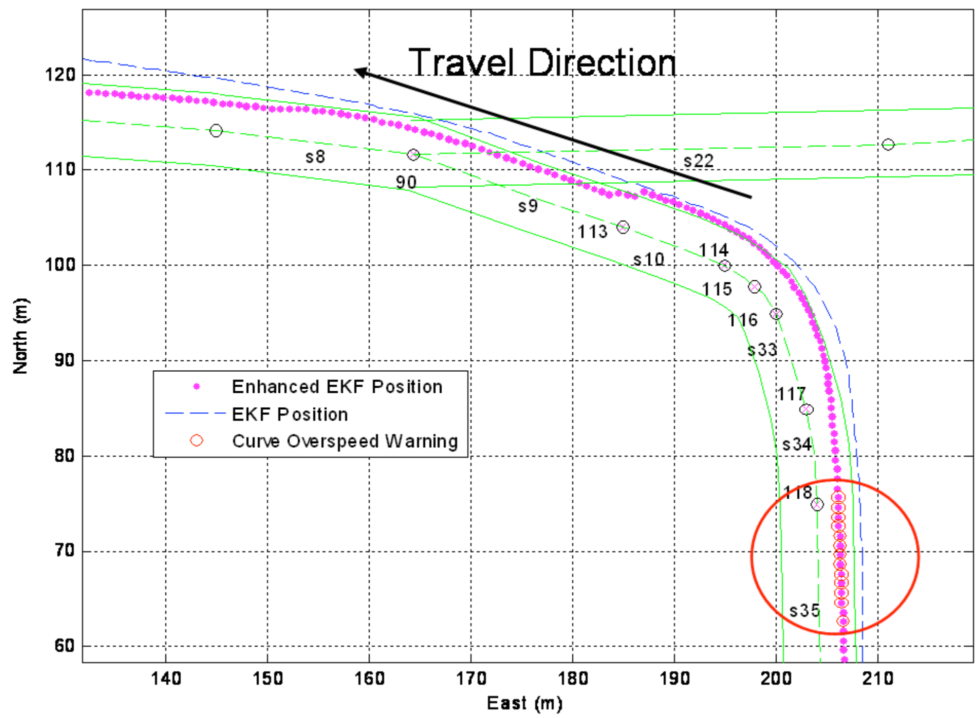

Figure 8. Example of COSW field test at the RFS test track

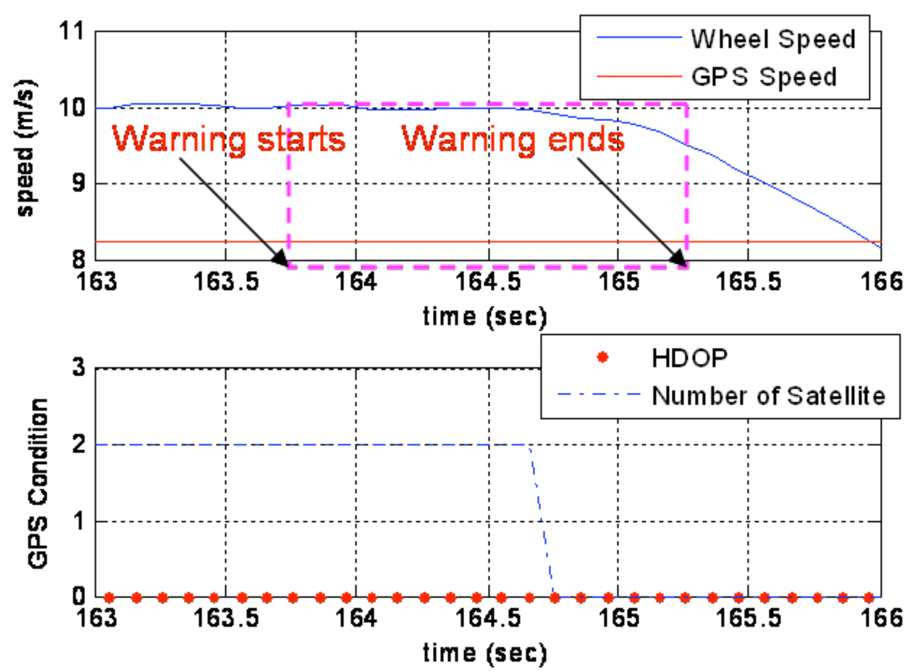

Figure 9. Vehicle Speed and GPS Output when Approaching the Curve

3.0 Conclusions

While a RFID tag to enhance FCW systems could be meritorious, to develop a low-power, long-lasting and well-performing RFID system that works with 24 GHz FCW radar proved difficult, given that there was one prototype opportunity. With the one prototype, the issue is that freeway operations may be nominally at 30 m/sec, and the range experimentally obtained corresponds to 1 or fewer seconds of time gap – not enough to effect a change in a FCW, as it is on the same order of magnitude of nominal drivers' perception-reaction time. Hence, the RFID investigation was curtailed. Certainly, given time and resources, it could be re-investigated with the lessons learned from this effort and iterated to the point it may be meritorious.

However, as this effort was being investigated a sea change in 'cooperative systems' was occurring: VII. The DSRC transceiver on the roadside could be multi-functional and provided a richer source of roadside advisory to RFID. In recognition of this, a COSW system was conceived under this project, and a proof-of-principle experiment was conducted. It shows that a COSW system could provide appropriate warnings when it detected the vehicle speed was unsafe for an upcoming curve based on both the positioning system and the map information. Hence, this 'look-ahead' type of information would be very useful; as such, it is a natural evolution from and if implemented for a myriad of other reasons, a much more robust, more significant deployment target for ADAS functionality than the limited RFID concept.

4.0 References

[1] CAMP, *Enhanced Digital Mapping Project Final Report*, United States Department of Transportation, Washington, DC, 2004.
[2] CAMP Vehicle Safety Communications Consortium, *Vehicle Safety Communications Project Task 3 Final Report - Identify Intelligent Vehicle Safety Applications Enabled by DSRC*, U.S. Department of Transportation, National Highway Traffic Safety Administration, 2005.