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Interim Report

IVHS Countermeasures for Rear-End Collisions

Task 3-Test Results

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ABSTRACT FOR THE TASK 3 REPORT

The attached report is from the NHTSA sponsored program, "IVHS Countermeasures for Rear-End Collisions," contract #DTNH22-93-C-07326. This program's primary objective is the development of practical performance guidelines or specifications for rear-end collision avoidance systems. The program consists of three Phases: Phase one: "Laying the Foundation" (Tasks l-4), Phase two: "Understanding the state-of-the-art" (Tasks 5 & 6), and Phase three: "Testing and Reporting" (Tasks 7-9). This work focuses on light vehicles only and emphasizes autonomous in-vehicle-based equipment [as opposed to cooperative infrastructure-based equipment.)

The results and conclusion presented in this interim report are preliminary in nature. The Task 3 report "Test Results" presents the results of the tests carried out on existing collision-avoidance systems. These systems were tested to determine limits, boundaries, and capabilities of the systems, to help in formulating performance requirements relative to IVHS safety needs, and to eliminate technologies that are not appropriate as potential rear-end collision countermeasures. Covered in the report is the plan for testing, contacts made with suppliers, an overview of the instrumentation, results, and summary. The existing systems selected for testing were to be complete systems consisting of all components and subsystems needed for sensing, data processing and interfacing with the driver and/or vehicle. System tests were performed in the laboratory and in the field. Human factors testing was performed at the University of Iowa, Center for Computer Aided Research, Iowa Driving Simulator.

The results presented in this report are based on a limited mount of work carried out with limited interaction with the academic, research, and industry communities. Any conclusions drawn from the results presented must bear this in mind.

Phase two goals include a detailed state-of-the-art review of technologies related to rear-end collision avoidance systems and the design of a test bed system(s). Phase two will finish in mid June 1996.

Phase three goals include the building and use of the test bed system, the generation of the final performance guidelines or specifications, and the final reporting on all aspects of the project. Phase three will finish in early 1998.

Work continues through Phase two and three to add to, and to refine, the preliminary performance guidelines or specifications presented in the Task **4** report.

Arthur Carter, COTR

EXECUTIVE SUMMARY / ABSTRACT

Task 3

The overall purpose of this project is to develop practicable performance specifications or guidelines for rear-end collision avoidance systems.

Phase one of this contract, Laying the Foundation, consisted of four Tasks: Task 1: a detailed analysis of the rear-end crash problem, Task 2: development of system-level functional goals, Task 3: hardware testing of existing technologies, and Task 4: development of preliminary performance specifications or guidelines.

The goals of the first three tasks were to develop the background needed to write the preliminary performance guidelines.

In Task 3 collision avoidance systems (existing hardware) were obtained and tested. Results of the tests carried out on existing collision-avoidance systems are presented. The systems were tested to determine limits, boundaries, and capabilities of the systems, to help in formulating performance requirements concerning IVHS safety needs, and to eliminate technologies. that are not appropriate as potential rear-end collision countermeasures. Covered is the plan for testing, contacts made with suppliers, an overview of the instrumentation, results, and summary. Existing systems selected for testing were to be complete systems consisting of all components and subsystems needed for sensing, data processing and interfacing with the driver and/or vehicle. System tests were performed in the laboratory and in the field. Human factors testing was performed at the University of Iowa, Center for Computer Aided Research, Iowa Driving Simulator.

For many reasons, not the least of which was manufacturers' sensitivity to proprietary issues, only one system was available for testing during the desired Task 3 schedule.

In summary:

1. Four manufacturers responded to our request for systems to test and only one participated in our testing.
2. The system available for testing was at best a prototype. The processor / display(an early prototype) of the system was limited.
3. The tests revealed many outstanding issues regarding the usefulness of the system but it was felt all these issues are correctable from a technical perspective.

This report (all volumes) forms the foundation for the work in the later stages of the contract.

Key words: Collision Avoidance Systems, Rear-end Collision, Crash Analysis, Performance Specifications, Causal Factors, Dynamic Situations, Human Factors.

TASK 3 INTERIM REPORT

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1 INTRODUCTION

This document is the Task 3 Interim Report, deliverable item 11, for IVHS Countermeasures for Rear-End Collisions, Contract DTNH22-93-C-07326. The primary objective of this program, as stated in the contract statement of work, is to develop practical performance specifications for rear-end collision avoidance systems. In Task 3, existing systems were tested to obtain basic operational performance and functional data.The purpose of the testing is to determine liits, boundaries, and capabilities of the systems, to assist in formulating performance requirements relative to IVHS safety needs, and to eliminate technologies that are not appropriate as potential rear-end countermeasures. Section 2 outlines the plan for testing of existing systems. Section 3 has an overview of the contacts made with existing system suppliers. Section **4** has an overview of the instrumentation and simulation effort required to perform the testing. Section 5 covers the test results of this task. Section 6 summarizes the Task 3 effort. Two additional documents are included, one outlining the Test Instrumentation effort, and the other the Vendor Packet that was sent to potential suppliers of existing systems.

1.1 SCOPE

According to data from the General Estimates (GES) and Fatal Accident Reporting System (FARS) databases, rear-end collisions are the second largest single category of collisions. They represented almost 23% of all collisions in 1991. Studies have shown that upwards of 90% of rear-end collisions driver inattention/distraction and/or following too closely were contributing factors. This information leads to the conclusion that a rear-end collision avoidance system might be very beneficial in reducing the total number of vehicular accidents and that a system that aids the driver's capabilities, by giving a warning of an impending collision situation or maintaining a headway for example, could provide this service.

Systems that provide this service will assist the driver by: (1) sensing potential and/or impending collisions or dangers to the front of the vehicle; (2) eliciting proper collision avoidance actions from the driver; and/or (3) providing temporary automatic control of the vehicle to assist in avoiding the potential collision situation. Collision avoidance systems will typically contain subsystems performing three separate functions; perception, processing and presentation. These subsystems are for sensing critical information about an impending collision, processing the information into a form which is usable by the driver or an automatic controller, and presenting this information to the driver (or directly to the vehicle) in a manner which elicits appropriate collision avoidance action. In systems where automatic action is taken by a controller, it is necessary to ensure that the actions are compatible with vehicle and driver capabilities and limitations. It is also important that the system be self-diagnosing in order to limit the negative impact of system failures.

Rear-end collision warning and control is defined as a subservice of longitudinal collision avoidance in the National Program Plan for IVHS. A longitudinal collision is a vehicular collision in which vehicles are moving in essentially parallel paths prior to the collision, or one in which the struck vehicle is stationary. This category is further divided into rear-end, backing and head-on collisions, as well as struck pedestrians. Systems providing this service augment driver capabilities to avoid or decrease the severity of collisions.

1.1.1 Rear-End Collision Warning and Control

Rear-End Collision Warning and Control systems would, through driver notification and vehicle control, help avoid collisions with the rear-end of either a stationary or moving vehicle. These collisions are often associated with driver inattention or too short of a headway from the vehicle in front. The driver maintains full control of the vehicle until a dangerous condition, such as a stationary vehicle on the roadway ahead, is detected. Then the driver is warned. If there is no response, or an improper response is perceived, appropriate vehicle control actions to avoid the danger could be taken automatically.

There are three general categories of systems:

1. Those that present information to the driver about other vehicles and situations in the vicinity of the vehicle. (Headway Maintenance Systems)
2. Those that direct the driver to take evasive action to avoid a collision. (Driver Warning Systems)
3. Those that take control of the vehicle away from the driver and automatically take evasive action. (Automatic Control Systems)

1.1.1.1 Headway Maintenance Systems

A headway maintenance system presents information about other vehicles and situations in the forward path of the vehicle. The headway maintenance system includes two subgroups:

- A manual operations system.
- An Intelligent Cruise Control (ICC) system.

1.1.1.l. 1 Manual Operations Systems

Manual Operations systems present information to the driver such that the driver can maintain adequate headway from the vehicle in front. The driver maintains full control of the vehicle.

1.1.1.1.2 Intelligent Cruise Control Systems

Intelligent Cruise Control systems would allow the driver to select a cruise control feature that tracks the vehicle in front and maintains safe headway. An extension of ICC is a system in which leading vehicles include a rearward-looking transponder or other means of transmitting information of vehicle dynamics to a following vehicle. Two or more properly-equipped vehicles can cooperatively "platoon" on the highway using basic ICC sensing plus inter-vehicle communication and on-board computer processing. ICC concepts may also include receiving information from the infrastructure about roadway speed limits in order to maintain a lawful vehicle speed.

1.1.1.2 Driver Warning Systems

Driver Warning systems would, through driver notification, help avoid collisions with the rear end of either a stationary or moving vehicle. A driver response, or action, would be elicited upon detection of a dangerous situation or impending collision. The driver maintains full control of the vehicle. One type of system would merely notify the drivers of a dangerous situation, while another type would tell the drivers what actions to take.

I. 1. I .3 Automatic Control Systems

Automatic Control systems are an extension of driver warning systems. Automatic control systems would take temporary control of the vehicle to avoid a dangerous situation or impending collision when no response, or an improper response, from the driver is detected. The control of the vehicle could include braking and, in severe cases, steering the vehicle out of the path of the collision. Automatic vehicle actions must be compatible with vehicle and driver capabilities and limitations.

2 PLAN FOR TESTING

As part of the testing of existing systems, an Acquisition and Test Plan was developed, deliverable item 9. This plan describes acquiring and testing existing rear-end collision avoidance systems in conjunction with this contract.

The existing systems selected for testing were to be complete systems consisting of all components and subsystems needed for sensing, data processing and interfacing with the driver and/or vehicle. System tests were to be performed in the laboratory and in the field. Laboratory tests were to be primarily those required to get ready for field testing. The field testing was to be performed at the Vehicle Research & Test Center (VRTC) in East Liberty, Ohio. Human factors testing was to be performed at the University of Iowa, Center for Computer Aided Research, Iowa Driving Simulator.

The Acquisition and Test Plan outlines the three categories of systems: Headway Maintenance Systems, Driver Warning Systems, and Automatic Control Systems. For each system type, what is expected from testing (questions to be answered) was presented. A test matrix was presented that outlines the eighty-three tests to be performed. Public road testing for qualitative information was also reviewed. The test instrumentation was then covered. Finally the human factors usability tests and evaluation of driver interfaces was presented.

For additional information regarding the plan for testing, please refer to the Acquisition and Test Plan (revised), deliverable item 9, February 4, 1994.

3 **EXISTING SUPPLIER CONTACTS**

3.1 INTRODUCTION

Over eighty companies have been contacted, in the United States and abroad, to assess their role regarding rear-end collision avoidance technology and determine the availability of systems to test in conjunction with this contract. There are several purposes to contacting potential rear-end collision avoidance system suppliers. First and foremost is to identify existing countermeasures systems to test. Second, a determination can be made, based on the number of companies involved in rear-end collision avoidance, regarding the commitment of the private sector in rear-end collision avoidance technology. Third, the status or time frame of the rear-end collision avoidance technology can be assessed based on the availability of systems to test. Fourth, renewed interest in rear-end collision avoidance technology can be generated by making private sector companies aware of the NHTSA efforts in this area. And finally, new interest can be generated in companies looking to invest their resources in a growth technology area.

3.2 ACQUISITION METHODOLOGY

The first step taken in the process was the placing of an advertisement in the Commerce Business Daily (CBD) by NHTSA. A copy of the advertisement is included as part of the Vendor Packet. This was followed closely by the preparation of a Memorandum of Agreement (MOA) whose intent was to describe the test participant's roles and to protect the system manufacturer's proprietary information. A copy of the MOA is also included in the Vendor Packet.

A list of potential system manufacturers was prepared to pursue sources that might not have seen the CBD advertisement or chose not to respond. The list eventually included nearly eighty names of companies, individuals and organizations. Initial contact was performed by phone. If parties interested in rear-end collision avoidance were found, then a packet of information was prepared and sent to the respective parties. This packet is contained in Vendor Packet.

3.3 RESULTS

This section presents the results of the process described in Section 3.2. It is broken into subsections as follows:

- Respondents to the CBD advertisement
- Those parties that are considered as potential system suppliers
- Those parties that are not considered potential system suppliers.

3.3.1 CBD Advertisement Respondents

There were four respondents to the CBD advertisement as follows:

- HE Microwave, a subsidiary of GM Hughes Electronics
- Leica
- GEC-Marconi Avionics
- O'Conner Engineering

Some discussion on these respondents is contained in the following paragraphs.

3.3.1.1 HE Microwave

HE Microwave is a subsidary of General Motors and, as such, develops equipment for use in GM automobiles. A letter was received by NHTSA from HE Microwave. In general, the letter stated HE Microwave's acceptance of NHTSA's invitation to participate in the test program and described their system to some extent. Further discussions revealed that the system offered was not really ready for testing and wouldn't be until probably sometime in 1995.

3.3.1.2 Leica

A number of discussions took place with representatives of Leica. Leica manufactures a laser/infrared based sensor only. The sensor has been integrated into an ICC application on a SAAB automobile. This vehicle is in high demand and is presently being used on a NHTSA contract with the University of Michigan Transportation Research Institute. As a result of this contract, and numerous other demands on the vehicle, there is little interest from Leica in participating in the testing on this contract.

3.3.1.3 GEC-Marconi Avionics

Three separate letters were received from GEC-Marconi. This looked very promising at first, but now they aren't sure if they want to participate. There has been no definitive rejection from GEC-Marconi. Recently, a revised MOA has been received from GEC-Marconi. Changes to the MOA were performed by Frontier and the revised copy returned to GEC-Marconi. Additional comments have not been received. Contact with GEC-Marconi is ongoing.

3.3.1.4 O'Conner Engineering

The O'Conner system consists of a ranging and doppler velocity radar. This system is not "off-the-shelf" and is not for loan.

3.3.2 Potential Suppliers

A list of suppliers with whom contact was made is shown in Table 3.3.2-l.

Table 3.3.2-1 List of Potential System Suppliers

COMPANY / ORGANIZATION
Aerojet
Airbag Systems
Allied Signal Automotive
Amerigon, Inc.
American Microwave Corp.
AXYAL, Corp.
Deutsche Aerospace AG
EATON/VORAD
Fujitsu Ten Corp.
GEC Marconi Avionics, Ltd.
General Motors
Honda R&D
IAI-MBT
Jaguar Cars
Laser Atlanta
Mazda
Mercedes
Mitsubishi
Nissan NA
Nissan R&D
Peugeot/Citroen
Phillips Research Laboratories
Renault
Subaru
Technodyne Research International
Toyota
TRW Automotive
Vehicle Radar Safety Systems
Volvo

3.3.3 Other Contacts

Table 3.3.3-l is a list of companies or organizations that have been contacted but do not build systems. In most instances, they build components, but not systems.

Table 3.3.3-1 Other Contacts List

COMPANY / ORGANIZATION
ATA Foundation
Battelle
Brookhaven National Laboratories
Chang Industries, Inc.
Chrysler
Comsis
Dynamic Science, Inc.
Epsilon Lambda
Finkelstein & Associates
Ford
GEC Plessey Semiconductor
General Motors (includes HE Microwave)
Haugen Associates (includes Leica)
Hittite Microwave
Honeywell SRC
IAI-MBT Systems and Space Technologies
IMRA America, Inc.
JPL
Lucas Industries
Martin Marietta Laboratories
Millitech Corp.
Mitre Corp.
Motorola AECG
National Public Services Research
Northrop Corp.
Odeties
Peterbuilt Motors
Polaroid Ranging Systems
Racal Electronics
RCA Laboratories
Red Zone Robotics
Rockwell
SAIC
Smart Car and Truck Technology
SSDD Research Corp.
Systems Technology, Inc.
Texas Instruments
Transportation Research Board
Trend Tec, Inc.
University of Michigan Transportation Research Institute
WESTAT
Westinghouse

3.4 SUMMARY

There were four responses to the CBD advertisement. Two American based companies using radar technology to develop systems, and two European companies using laser technology to develop systems. Only one of these companies, committed to participating. Most companies were pursuing ICC type systems. The reason for this is that the industry views ICC systems as a “convenience” device and not a collision avoidance device. This makes these systems safer from a liability standpoint. Also these systems typically only see moving vehicles, making them simpler technologically.

Sixty potential suppliers have been contacted, and forty-one of these either declined to participate or didn’t have a system to test. There were nineteen suppliers who have been contacted and expressed some initial interest, but have not committed to anything. Five suppliers have not been contacted to date.

Indications are that there are a number of reasons for this poor response.

1. The technology is fairly new, and there aren’t a lot of systems available.
2. Prototype systems that do exist seem to be hard to schedule for this program because of the high demand.
3. There is a great deal of reluctance to be involved due to proprietary issues. Because of the competitive nature of the industry, and the potential for large profits along with large liabilities, most companies with systems have declined to participate. Some have stated that the MOA helped this problem, but not enough

Several of the companies have stated that they would be willing to have their systems tested in conjunction with this contract at a future date. Because of this, it is suggested that testing should continue during the length of the program if deemed necessary or prudent.

4 TEST INSTRUMENTATION

As part of the testing being performed on this contract, a fully instrumented test vehicle and lead vehicle were constructed to perform detailed testing of rear-end collision avoidance systems. A determination was made to design the instrumented vehicle to work cooperatively with a lead vehicle. The focus of the instrumentation effort was then to provide a system of data collection for longitudinal encounters between the test vehicle and the lead vehicle. The test instrumentation effort is described in a separate attached report. Additionally, the test instrumentation will be used to test the testbed system as part of Task 7 and Task 8 under this contract.

Other documents that are pertinent to the test instrumentation effort, are the Acquisition and Test Plan, deliverable item 9, the Data Collection and Control (DCC) computer software, and the Software Specification for the Lead Vehicle Control (LVC) computer software.

5 TEST RESULTS

This section describes the testing that was performed in conjunction with this contract and as part of Task 3.

5.1 BASELINE TESTING

A set of baseline tests was executed. These tests were centered around the driver warning system type. These tests allowed a complete checkout of the test vehicles, as well as the test procedures, in preparation for performing testing on existing systems. There were no problems or issues found with the test vehicle's performance. Several clarifications were added to the Acquisition and Test Plan as a result of these tests. It was determined that in the future, some of the tests could be combined, to cut down on the number of tests, and speed the testing process. Additionally, it was discovered that the most time consuming part of the testing was data reduction, where video data had to be manually transferred to the magnetic media so that it could be compared with measured data. Section 5.2 presents the data taken during testing with the collision avoidance system.

5.2 SYSTEM TESTING

Only one system was available for testing during the desired Task 3 time frame. The manufacturer of the system has been sanitized from the data within this report.

5.2.1 System Description

The system consists of two sensors, one for ranging and one for velocity, as well as two separate processor / display units. The system has a single LED that is labeled target. This LED turns on, and the audible alarm sounds, during an alarm condition when the host vehicle is closing on the lead vehicle at >10 mph and is within 60 meters of the lead vehicle. The LCD display on the system displays the distance to the lead vehicle in meters, and will see stopped vehicle. The relative velocity system has three LED's, one for target indication, one for closing target indication, and one for receding target indication. The target indication is active when a moving target is sensed in front of the host vehicle. The audible alarm (chime) is active when the host vehicle is closing at greater than 10 to 15 mph on a moving vehicle. The LCD display on the system will show the absolute velocity of the host vehicle, when no target is indicated, and will show the absolute velocity of the lead vehicle when a lead vehicle target is indicated.

The system was received and installed on the test vehicle. Initial tests proved disappointing, as the system did not detect targets reliably. The entire system was returned to the manufacturer for further checkout. When the system was again received, it was configured for driver warning / manual headway maintenance. The system was reinstalled on the test vehicle, and the driver warning tests were performed on the system as delineated in the following paragraphs.

5.2.2 System Questions

The following questions were presented in the Acquisition and Test Plan, deliverable item 9. The purpose of the questions is to give the reviewer a better feel for the operation and performance of the system under test.

Qualitative System Performance	
What situations was the system designed for?	The ranging system is designed to work on vehicles within the 50+ meter range. The relative velocity system is designed to work on relative velocities between >0 and 90 mph.
What situations does the system work under?	The ranging system will work on all types of dynamic situations as long as the host vehicle's velocity is > 10 mph (this is user selectable between 10 and 35 mph). The relative veiocity system will only work on moving lead vehicles.
Does the system minimize the occurrence of driver error?	The system exhibits some anomalous readings that would make it difficult to be perceived as reliable.
Does the system provide sufficient information to avoid a rear end collision?	The system provides fairly accurate range and relative velocity information. The alarm times require additional work in order to function at a safe headway.
Does the system enhance driver reaction time?	The alarm times are set in such a way that the system may not enhance driver reaction time. Currently, the driver warning alarm is set at a fixed range instead of being dependent on velocity. This causes the alarm times to be too short at the higher velocities making the system potentially hazardous
Does the system focus the driver's attention on the hazard?	The display is a prototype engineering display, and as a result, the driver's focus is dependent on where the display is mounted.
Is the system perceived by the driver as reliable?	Not without some training. The indications from the relative velocity system are fairly reliable. The range alarm would not necessarily be considered reliable due to the false alarms
Is the system effective for drivers of differing abilities?	Not currently, the systems are prototype modules. A level of expertise is required to use both the systems.
What is the expected per unit production cost?	This is dependent on the final form, fit, and function of the system, and is not currently available for the system. It is believed that a sensor must cost between $200 and $300. and initially the entire system should be under $1 .000.

Quantitative System Performance	
What is the minimum and maximum range capability?	The minimum range would potentially be zero, but in order for the system to function, the host vehicle must have a velocity of >10 mph, which makes testing the minimum range difficult The maximum range is typically around 80 meters for normal vehicles, and greater for large trucks.
What is the range accuracy?	The display resolution is limited to 1 meter. Refer to the graphs for an indication as to range accuracy.
What is the minimum and maximum range rate capability?	The minimum range rate capability is around 12 kph. There was no definable maximum range rate capability.
What is the range rate accuracy?	The display resolution is limited to 1 mph. Refer to the graphs for an indication as to range rate accuracy
Is the system capable of self test?	There is no self test.
What is the power drain of the system?	About 500 ma on the +12 VDC line, and about 50 ma on the -15 VDC line
Are the system parameters adjustable for different driving situations (highway, freeway, city)?	There is an adjustment on the range display for a minimum velocity at which the system stops functioning.
Is the system adjustable for different driver types?	No
Is the system adjustable for different weather conditions?	No
Do warning times adjust for the different dynamic situations?	No

Sensor Performance	
What is the specific type of technology used by the sensor?	Frequency modulation continuous wave (FMCW) ranging radar operating in conjunction with a Doppler relative velocity radar at 24.125 GHz.
Does the sensor transmit a safe power level per applicable standards?	Yes
Is the sensor beam fixed or scanned?	Fixed. single beam
What is the angle discrimination capability both vertical and horizontal?	Ranging 3.5° circular Relative velocity 7.0' circular (these quantities were not measured)

Processor Performance	
Does the system have a low false alarm rate under clutter free conditions?	Under clutter free conditions, both displays seem to have low false alarm rates.
Does the system fail to detect the lead vehicle? How often?	The range system failed to detect the lead vehicle during merging/decelerating conditions due to long integration time.
Do the algorithms take in account the speed and deceleration of the two vehicles?	No. The driver warning alarms at a fixed range independent of velocity. The relative velocity alarms based on the relative velocity between the two vehicles as long as the lead vehicle is moving.
Are the algorithms adequate to avoid a collision?	No

Display Performance	
What type of display is used?	Both displays have a LCD digital readout for the range and relative velocity. LEDs are used to denote system parameters. The relative velocity display has a green backlight, the range display does not. The range system has an audible alarm, the relative velocity has an audible chime, that is difficult to hear over background noise.
What controls are provided to the driver?	An engage control is available on the range display to set a speed at which the unit becomes active.
How well can they be controlled?	The engage control on the range display is a linear adjustment from 10 mph to 35 mph.
Can the system be disabled?	Yes, an on/off switch is provided on both units.
Does the display give accurate information?	The digital readout of the range and relative velocity seemed to be accurate, refer to the graphs for accuracy. Long update times degrade this accuracy significantly
Is the display non-confusing to the driver?	The systems require some amount of expertise in order to interpret the displays.
Is the display of informant salient and understandable?	Again the systems require some amount of expertise in order to interpret the displays.
Does the display of information startle the driver?	No
Is the display effective in all illuminance levels?	The relative velocity LCD is backlit and usable at night. The range display is not. Bright light tends to make both displays difficult to read.
If audio, how well can it be heard?	The driver warning alarm is loud enough to be heard over engine and road noise. The chime on the relative velocity is not.

5.2.3 Test Results

Driver warning tests, as outlined in the Acquisition and Test Plan, were performed on the system. The system had supposedly been configured with a processor and display that could warn the driver. For this reason, driver warning tests were chosen, rather than testing the system as an AICC or CICC. Due to the extensive nature of the tests, and the data presented, they have been contained in Appendix A.

5.2.3.1 Lead Vehicle Stopped Tests

The system was alarming at a fixed (40 meter, approximately) distance from the stopped vehicle, independent of closing velocity. This is unacceptable performance. At a closing velocity of 45 mph or higher, a 40 meter alarm range does not allow enough time to bring a vehicle to a stop. The system relative velocity sensor and system does not recognize stopped lead vehicles.

5.2.3.2 Constant Velocity Tests

The system relative velocity sensor typically detects a moving lead vehicle out above 100 meters. The fixed range alarm is still a problem for high closing velocities on moving vehicles.

5.2.3.3 Lead Vehicle Decelerating Tests

The relative velocity system typically detects a moving lead vehicle out above 100 meters. The relative velocity system typically lost the lead vehicle when the lead vehicle's absolute velocity dropped below about 12 kph. The fixed range alarm is still a problem for high closing velocities on moving vehicles.

5.2.3.4 Lead Vehicle Decelerating and Stopped Tests

The relative velocity system typically detects a moving lead vehicle out above 100 meters. The relative velocity system typically lost the lead vehicle when the lead vehicle's absolute velocity dropped below about 12 kph. The fixed range alarm is still a problem for high closing velocities on moving vehicles.

5.2.3.5 Lead and Host Vehicle Decelerating Tests

The relative velocity system typically detects a moving lead vehicle out above 100 meters. The relative velocity system typically lost the lead vehicle when the lead vehicle's absolute velocity dropped below about 12 kph. The fixed range alarm is still a problem for high closing velocities on moving vehicles.

5.2.3.6 Adjacent Lane Tests

The relative velocity system does not sense stopped vehicles. The range system did detect and alarm on vehicles in adjacent lanes.

5.2.3.7 Curve Road Tests

For a fixed beam sensor, the curve road tests were as expected, a shortened range alarm and target indication.

5.2.3.8 Curved Road Adjacent Lane Tests

The relative velocity system could not distinguish the difference between vehicles in adjacent lanes on curves, as expected.

5.2.3.9 Merging Tests

The range system takes approximately 0.8 seconds to update the display with the range information. Due to this slow update rate, there were times when the lead vehicle could merge in front of the host vehicle and no alarm indication would be given from the system.

5.2.3.10 Hills, Sags, Grade Tests

The performance on Hills, and Sags was as expected for a fixed beam system. The tests conducted were on hills that were more abrupt than normally encountered in typical driving. It is believed that the system should have adequate performance for hills and sags, based on the vertical beam width.

5.2.4 Specific System Issues

The range system had numerous false alarms, mostly on signs, posts, and other vehicles that didn't pose a threat. The alarms were short in duration and could be ignored by the driver but this might cause the driver to be less responsive to the system. The main false alarm with the range system was while driving at a constant velocity behind another vehicle. Every time the relative velocity between the two vehicles went from closing to receding or vice versa, an alarm was received from the system. This is probably a result of bad data being received at the range system from the relative velocity system when the range rate is 0 kph. The most disturbing problem with the range system was the near tied alarm distance independent of velocity. This caused the range system to alarm at too great a headway with slow relative velocity, and too short a headway with higher relative velocities.

The relative velocity system tends to reliably track moving targets in the forward path. At times when the vehicle is stopped, the display on the relative velocity indicator read -14 mph and the alarm chimes for no apparent reason. This may be caused by improperly handling the host vehicle's absolute velocity indication from the ABS system. The relative velocity system also detects vehicles that are approaching in the opposite lane, when the host vehicle is stopped.

The update rate to the range display is on the order of 0.8 seconds. This would need to be reduced to 0.1 seconds so that the driver could be warned in time to avoid the collision. The relative velocity display has an update rate on the order of 0.2 seconds. This would also have to be reduced to 0.1 seconds so that the driver could be warned in time to avoid the collision. Additionally the two system, range and relative velocity, need further integration to allow alarm times that are functions of range and velocity.

5.2.4.1 Repeatability

Figure 5.2.4. l-l shows the distribution of the tests that were performed with the lead vehicle in the same lane, on straight roads. As can be distinguished, the range alarm is typically around 40 meters regardless of velocity.

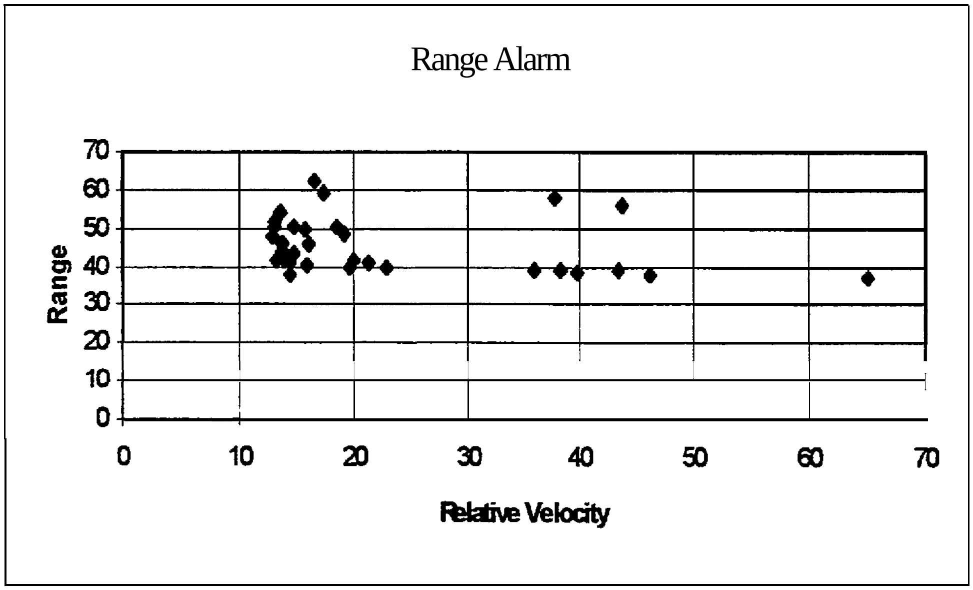

Figure 5.2.4. l-l Range Alarm Repeatability

5.2.5 Summary

The system is at best considered a prototype. The main problem with the system appears to be in the processor / display and not in the sensor. The addition of a processor that had programmable “smarts” would allow the system to be further developed into a workable collision avoidance system. The sensors as packaged tended to be too big and bulky for mounting on a typical passenger vehicle. Integration of the two sensors into one, would be necessary to provide a system that was small enough to be easily mounted, and would most likely reduce system cost. It was determined that additional work was needed by the manufacturer to fix the glaring problems with the system. It is hoped that changes can be made to the processor to allow future testing of specific problems with the system. The displays are not robust enough to provide accurate, timely, and salient information to the driver. Additional display issues are covered in Section 5.3.

5.3 HUMAN FACTORS TESTING

As part of the original statement of work, a series of experiments, using the Iowa Driving Simulator, were planned to test a number of existing collision intervention devices. Unfortunately, only one system was submitted for testing, but it was judged to be too experimental a display to be viable for the display task. Task 3 was originally designed to include a set of simulation experiments which allowed human factors researchers to very accurately measure driver responses to lead vehicle changes using existing collision intervention technologies. This information would then be compared to data which were collected using no collision warning devices. All simulation studies share common experimental design, protocol, and materials. Subjects will drive for 30 minutes on a simulated two-lane rural highway and three-lane freeway. Eight lead vehicle changes will be encountered during this drive that will require driver reaction to avoid a collision. These events mimic a variety of every day lead vehicle changes. In addition, secondary tasks will be used to momentarily bring the subjects attention off of the forward roadway. These secondary tasks are similar to the type of eye-off-the-road situations that typically occur as part of normal driving (e.g., checking the instruments or changing radio stations). A variety of driving performance measures will be taken in order to determine differences between display conditions. Some of these measures include: driver reaction time; braking and/or steering intensity; amount of time the brake pedal is depressed; coupled headways; minimum following distance after braking; and coupled headway after braking. Because no existing systems were available to test, this report will review information obtained to date on existing collision warning and intelligent cruise control systems.

5.3.1 Collision Warning System

One system was available for testing in conjunction with this contract. In review of this system and display, it was determined that it was inadequate to perform the display task as compared to recommendations from the Comsis report, and previous work from the University of Iowa. Included here is a critique of the display that was evaluated as part of the testing of existing systems. A driver warning system, generally referred to as a “collision warning system”, indicates to the driver the actions required to avoid an impending rear-end collision. For example, this system would warn the driver of an unsafe rate of closure and inform the driver to brake to avoid an impending collision. This type of system will not automatically take control of the vehicle to avoid a crash. Only one such system (referred to as “system”) was submitted to Frontier Engineering for testing. The system was not tested, in conjunction with the human factors testing, due to a lack of a usable user interface. The manufacturer has concentrated on the sensor aspects of the system and at the time of this report, had not developed a consumer quality display. The description that follows describes the existing engineering user interface.

There are two displays associated with the system, a range display and a relative velocity display. See Figures 5.3.1-1 and 5.3.1-2. The range display is 2"h x 6"w x 7"d with a ± 3 digit liquid crystal green backlit display 1 inch in height. There are four indicator LED's, an amber LED for power, a clear off / red on for closing targets, a amber LED for target acquisition, and a green LED for receding targets. The relative velocity display is also 2"h x 6"w x 7"d with a ± 3 digit liquid crystal display 1/2 inch in height. There is one amber LED for power and one clear off / red on LED for targets.

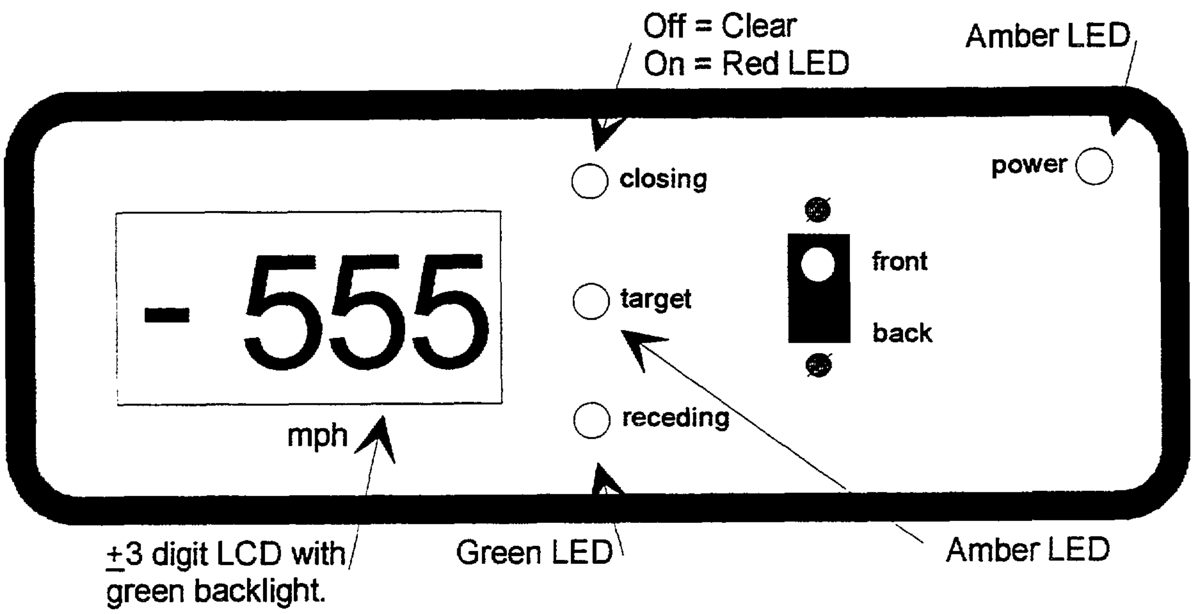

Figure 5.3.1-1 Relative Velocity System Display

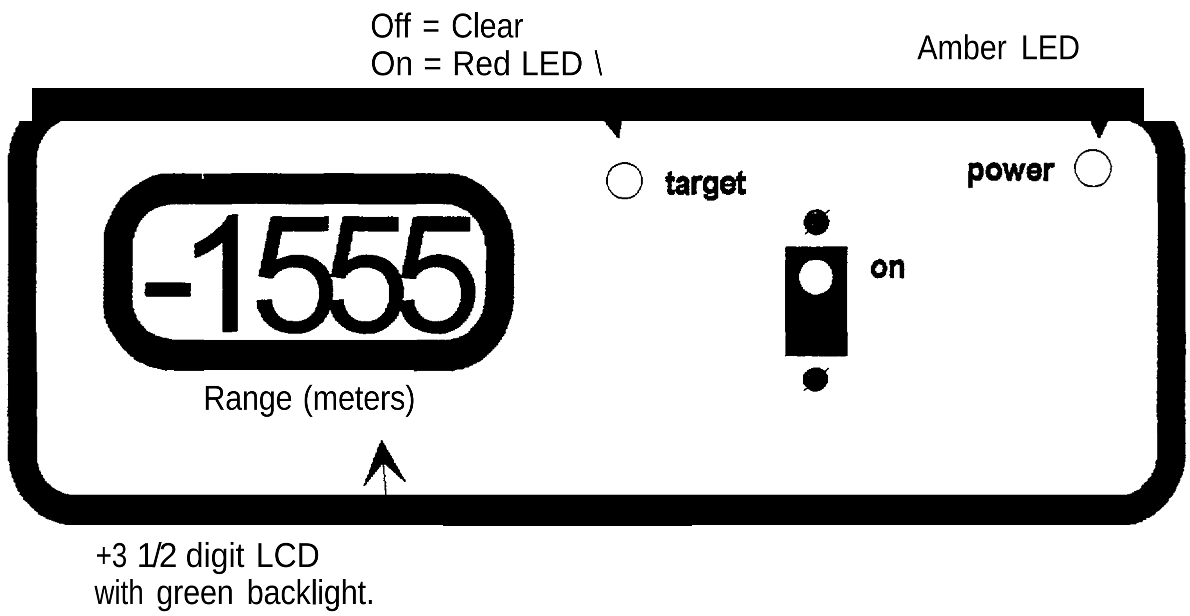

Figure 5.3.1-2 Range System Display

This system uses two displays: one to indicate to the driver the relative velocity of the lead vehicle; and the other the range (distance) to the lead vehicle. The relative velocity display was configured to display the absolute velocity of the host vehicle, in miles per hour, when a target is not being tracked, and the absolute velocity of the vehicle in front, in miles per hour, when a target is present. The relative velocity display also displays when a target is being tracked, as well as whether the target is closing or receding from the host vehicle. A high pitched tone is displayed, and the target LED is illuminated from the range display, when the range is less than 40 meters and the closing velocity is greater than 10 mph. A secondary chime is displayed, from the relative velocity, if the closing velocity to a moving lead vehicle is > 10- 15 mph.

Although the system is considered an engineering prototype display, a basic human factors analysis was performed. The system displays both range and range rate (relative velocity) information via two independent digital (LCD) displays. Since trend information (i-e. the change and rate of change of distance between vehicles) is of critical importance to the driver, a more efficient display method would utilize analog or graphical representation of the range and range rate. It is possible to integrate this information on a single display for an effective and salient presentation. Sanders and McCormick (1993) suggest that a fixed scale, moving pointer display is one of the most effective ways to indicated trend information. Digital numeric outputs of this type of information have little inherent meaning to the driver and will result in long processing times. When information is continually changing (as range and range rate does), the driver will have difficulty recognizing changes in the lead vehicle's distance and velocity.

The nomenclature of the system should be reevaluated such that the words chosen are easy to understand and meaningful. The current display layout uses words paired with single, discrete LED's. Words such as "closing", "target" and "receding" may be difficult to understand. Again by integrating much of the range and range rate information into a graphical form, much of the current nomenclature would be unnecessary.

The current system does not include a failure indicator. If the systems were to malfunction, it is important to inform the driver that the system is not working correctly. This would be an important system attribute if drivers start depending on such systems in daily driving.

The system currently uses two types of auditory alerts-One for range information and the other for range rate. There is a single tone for the range warning and a warbling auditory tone for dangerous range rate. Auditory alerting in general should be reserved for information requiring immediate response and therefore the range tone is probably not optimally displayed. The dangerous rate alert, if at the proper volume and frequency (should be 15 to 16 dB above the ambient noise level), should adjust itself for increasing sound levels at higher speeds (Salvendy, 1987). Sounds having fundamental frequencies between 500 and 3000 Hz are recommended for acoustic crash avoidance warnings (COMSIS, 1994). The sound location of the device is located on the rear of the display and is difficult to hear. Although humans are generally good sound localizers, they have difficulty identifying sounds directly above, in front of, behind them, without some head movement. As a result, front to back perceptual confusions occur frequently (Blauert, 1969, 1970; Makous and Middlebrooks, 1990). However, offsetting such sounds by a few degrees to the right or left eliminates this problem because of the acute human perceptual sensitivity to inter-aural time differences (McFadden and Pasanen, 1976).

According to the Comsis report, visual displays such as collision warning devices should be located within 15 degrees of the drivers expected line of sight in a given crash avoidance situation. Character size of the display should have a minimum of 12 minutes of arc. As recommended earlier, numeric presentations should be avoided due to the lack of trend displayed. Drivers should not have to transpose, compute or interpolate displayed crash avoidance information.

The system relative velocity display currently uses a backlit 3 digit liquid crystal display. This type of numeric display is difficult to read due to the low contrast the display characters have against the background. This becomes more difficult during low light conditions. This particular display uses a green back light which washes out the display further. Digital LED displays can be effective in all types of light if they have automatic brightness control. As mentioned earlier, more effective display techniques would increase the saliency of such a display.

5.3.2 Automatic Target Acquisition Intelligent Cruise Control

The Automatic Target Acquisition Intelligent Cruise Control (ICC) System (being developed by Leica) is able to take an active roll in controlling the vehicle's speed during coupled and uncoupled driving circumstances. This system is able to provide limited deceleration by using transmission downshifting, or engine speed control.

Different levels of system interaction are possible, ranging from informative to automatic. This system works the same as a typical cruise control, with the exception that if a vehicle in front slows down, the ICC matches the lead vehicle's speed within the deceleration limits of the system. When it is possible to resume the original speed set by the driver, the system automatically does so. The determination of the target is automatic (the system locks onto any lead vehicle traveling at highway speeds). In either case, should the vehicle require deceleration greater than that provided by the system, it is the driver's responsibility to provide the deceleration. The system has been designed to ignore stopped objects and vehicles. It will acquire vehicles within the sensor cone that are traveling within 70% of the host vehicle's speed. The minimum operating speed of the system is 20 kph. A slight to moderate engine down-shift also signals the driver of a potential hazard ahead. The system provides average acceleration in ICC mode of 0.1 g, maximum acceleration in ICC mode of 0.15 g, average deceleration in ICC mode of 0.05 g, and maximum deceleration in ICC mode of 0.07 g (Saab 9000 specific data).

The Leica ICC system automatically controls the speed of the car based upon a preset desired speed. The speed is kept constant, much like a conventional cruise control, until the car approaches another vehicle traveling slower. The Leica system then automatically switches to a headway distance control mode. In this mode the car uses an infrared sensor to measure distance and relative velocity between the car and the vehicle ahead. Based upon distance, relative velocity, and the speed of the host vehicle, the system calculates an appropriate headway distance and sets the actuators of the vehicle to maintain a system defined 1.5 second following distance. When the vehicle in front either disappears from the sensor cone or accelerates above the desired speed, the ICC resumes its preset speed.

The Leica display illuminates a red LED in the upper right hand portion of the display when a target is acquired (see Figure 5.3.2-l). An array of colored LED's also show the driver the headway distance, with the green LED indicating greater than 1.5 second headway, the yellow indicating 1.5 second headway, and the red indicating a distance that less than 1.5 seconds. The left side of the display has a digital LED set speed display which the driver can control in five MPH increments. The vehicle will never exceed this setting while the ICC system is engaged. The three LED's above the headway indicator are for diagnostic purposes. The square green LED is illuminated when the system is engaged. The system stays engaged until either the brake pedal is depressed or it is manually disengaged on the turn signal stalk.

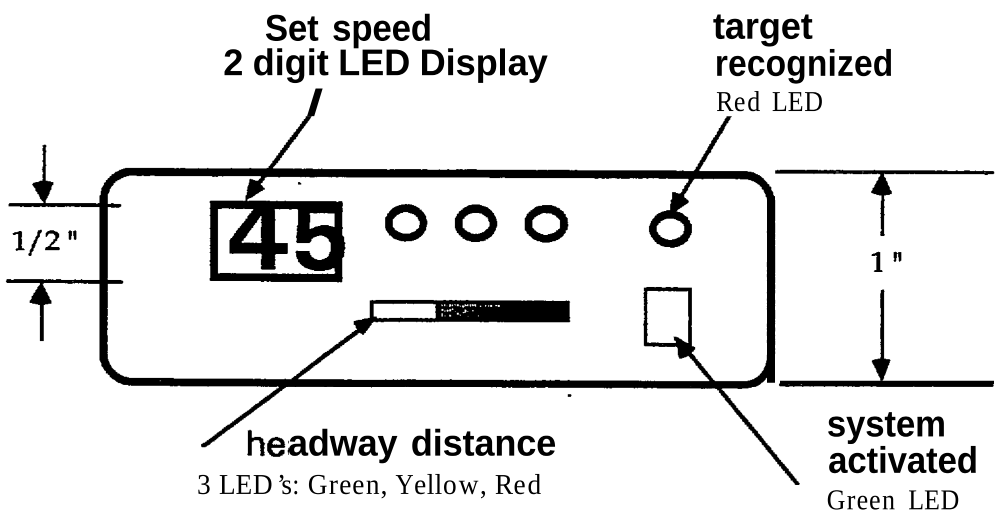

Figure 5.3.2- 1 Prototype Leica Intelligent Cruise Control Display

Controls for the Leica system are typical turn signal stalk mounted cruise control switches consisting of On/Off, Set, and Resume. Setting the desired set speed is accomplished similar to conventional cruise systems. The driver must engage the system, and set the desired speed by depressing the set button.

A driver scenario has been created to describe the Leica systems operation.

- A driver enters the freeway and accelerates to 65 MPH. The driver of the host vehicle sets the ICC speed at 65 MPH.
- If a slower moving vehicle is encountered, the host vehicle adapts its speed to the lead vehicle within the deceleration limits of the system.
- If the lead vehicle increases speed, the host vehicle will increase its speed to 65 MPH and remain at 65 MPH.
- If the lead vehicle brakes, the host vehicle will down-shift to alert the driver to the lead vehicle deceleration. The driver must then apply the brakes.
- If the host vehicle is traveling with no lead vehicle, it remains at the set speed until a lead vehicle is encountered.
- If the lead vehicle is driving below the set speed of the host vehicle and it drives around a narrow radius curve, the host vehicle will accelerate toward the lead vehicle until the vehicle is re-acquired by the system.

Automatic target acquisition ICC requires very little input from the driver while engaged. The Leica system relies on haptic cues to alert the driver of lead vehicle slow downs. There are no visual or aural alerts associated with the Leica system. The headway visual alerts are not salient and provide the driver with minimal information regarding their following distance.

Although the Leica system is also considered a prototype, it too, was evaluated based on the limited information available. This type of system is generally considered or classified as a "convenience" system and an aid to drivers and is not typically referred to as a collision warning device. Little has been written in the human factors literature on the design of such systems, however, basic human factors design principles apply.

The set speed indicator is a l/2 inch LED digital display (red) which displays the status of the speed desired. Based on character height and type of digital presentation (LED), this display conforms to the Comsis as well as other general human factors design recommendations. The placement of the display is slightly occluded by the steering column and the headway display portion of the display is very washed out and hard to read. Since the goal of this ICC system is that of convenience, the headway LED portion of the display could be either redesigned as a more effective headway maintenance display or removed completely. According to the Comsis report, visual displays such as collision warning devices should be located within 15 degrees of the drivers expected line of sight in a given crash avoidance situation. The target acquisition LED is a useful addition to this type of system. This allows the driver to see whether the vehicle ahead has been acquired. The speed set button is located on the conventional cruise control stalk. Although the nomenclature is occluded on the turn signal stalk, the cruise control operates similar to most cruise controls systems. Currently, the system only allows the driver to increase the set speed by 5 mph increments. It may be more convenient to allow a finer adjustment of speed in the 50 mph and higher speed range. Finer adjustment may prevent drivers from easily obtaining high cruising speeds. The current Leica system does not have any auditory alerts. One alert that may aid the driver is that of a warning that indicates that the relative velocity between the host and lead vehicle may be dangerous, or that the system does not have the ability to decelerate at a level to avoid the collision. One scenario to consider is when a leading vehicle is traveling much slower than the host vehicle and the driver may have to initiate braking to avoid a collision. It is recommended that an auditory alert which orients the drivers attention to the hazard be implemented when this condition occurs. Although auditory alerts have been proposed, due to liability issues, inclusion of a auditory alert is still being evaluated for inclusion with the system. Currently, the system will down-shift when a slower moving vehicle is detected. This is a good haptic cue to alert the driver, and some studies have shown that appropriate and timely driver action is elicited. In its current configuration, the Leica system could, under circumstances of rapid lead vehicle deceleration, result in an increased accident risk due to factors of driver habituation/adaptation, and a lack of a salient warning cue. More information is needed to determine if driver habituation/adaptation will result. An additional feature that should be implemented is that of a failure alert. If the system fails, the driver should be alerted. It is possible that if the sensor fails and the intelligent cruise control does not, the driver may drive into the rear of another vehicle. Work is currently being performed to add soft braking to the system control as a means of providing additional deceleration.

5.3.3 Manual Target Acquisition ICC

Manual Target Acquisition (MTA) ICC systems have been proposed. Only general system descriptions were available at the time this report was written. A human factors evaluation of driver interfaces was not done since no manufacturers have presented their driver interfaces. The primary difference between manual target acquisition and automatic target acquisition is that the driver must select a lead vehicle target and “lock” onto it. Once the leading vehicle is manually acquired, the host vehicle maintains the lead vehicle’s speed by automatically accelerating and decelerating. Limited braking is currently under consideration. Although no driver interfaces are currently available, elements of such a device are very similar to conventional cruise control.

A driver scenario has been created to describe the conceptual aspects of MTA ICC.

- A driver enters the freeway and accelerates to 65 MPH. A lead vehicle is present and the driver engages the system. The MTA ICC then “locks” onto the lead vehicle.
- If the lead vehicle accelerates to 70 mph, so does the host vehicle
- If the lead vehicle decelerates to 60 MPH, so does the host vehicle
- If the host vehicle changes lanes, the MTA ICC disengages
- If the lead vehicle leaves the lane ahead, the system disengages
- If the lead vehicle leaves the sensor cone, the system will disengage

When there is no lead vehicle present, the system will not enter into MTA ICC mode. If there is no lead vehicle present, then the driver can operate in conventional cruise control mode. If the driver of the host vehicle comes across a slow moving vehicle and the driver does not apply the brakes, the host vehicle will collide with the lead vehicle without warning (just as conventional cruise control will). These system are also being designed to ignore stopped, or slow moving, objects and vehicles. The MTA ICC concept essentially enables the host vehicle to lock onto the vehicle ahead and be “dragged” along in a non-cooperative platoon.

5.4 PRELIMINARY REAR-END COUNTERMEASURE SIMULATION TEST PLAN

As part of the test plan to test existing systems, a simulation database was developed to evaluate both fundamental driver performance during lead vehicle slow-downs using no collision warning information and while using collision intervention information. This section describes this database and the dependent measures collected during the driving simulation.

The primary objective of the Task 3 studies is to evaluate several collision intervention driver interfaces. The effects of system errors (false alarms and misses), the type and timing of information provided to the driver, and the sensory modality utilized will be tested. Baseline driver performance will also be measured as a control group. Information from these tests will provide information for the final performance specification. This process will lead to a human factors collision intervention specification.

A motion based simulator at The University of Iowa, Center for Computer Aided Design will be used for this study. A 1993 GM Saturn will be driven by all drivers. Four configurable channels of high resolution textured graphics currently provide a 191 degree x 40 degree forward field of view (FOV) and a 60 degree x 40 degree FOV to the rear. Sound is provided by a full 3D audio imaging system. The motion base is a six degree of freedom 60 inch stroke hexapod which has a 360 degree dome enclosing the cab.

In order to meet the objectives of the study, a series of experiments will be conducted (when systems become available) that will compare collision intervention systems that have similar attributes. By using the same scenario data base and events across a series of vehicle configurations, comparisons can be made regarding differences in driver performance. The same protocol will therefore be used across all simulator ‘experiments. The first experiment that will be conducted will be that of a baseline test which utilizes no collision intervention information. This test will allow human factors researchers to examine fundamental driver reaction to simulated lead vehicle changes and rear-end collision events. Subjects will initially undergo pre-screening at the driving simulator facility, to ensure that they are currently licensed drivers, have normal or corrected normal vision, hearing, and are not susceptible to motion sickness. An information summary of the experiment will be explained to the subjects and they will be asked to sign an informed consent form. A general demographic questionnaire will also be completed by the subjects. After subjects are briefed on how the simulator operates and the collision intervention system to be tested, a 5 minute familiarization drive will begin. This ftiliarization drive will take place on an empty 2-lane highway. If subjects are participating in one of the cruise control conditions, they will be asked to practice engaging and disengaging the system. If a collision warning display is being used, it will also be demonstrated while they drive. Subjects will be reminded during the ftiliarization drive that they should pay attention to the visual scenes so they can evaluate the fidelity and the realism. A review of the vehicles features will also be conducted. After the familiarization drive, subjects will begin the experimental drive. Eight different lead vehicle braking changes (events) will occur over the course of the half hour drive. These events will provide a consistent basis from which to measure driver reaction and interaction with the various collision warning and cruise control systems being tested. Each of these critical events are described in detail below. During the experimental drive, subjects will also be asked to perform a variety of secondary tasks. These tasks consist of routine in-vehicle tasks, such as changing the radio station. Approximately 32 secondary tasks will be targeted to take place throughout the drive (tasks to be determined). Just prior to most events (time TBD), a secondary task will take place such that it distracts the driver’s attention away from the forward roadway and the event about to occur. Secondary tasks will also occur between events such that the driver does not associate secondary tasks with lead vehicle driver changes. Some events (e.g., event 5) may have no secondary task due to naturally occurring increased attention. At the end of the last critical event, drivers will exit from the simulator and fill out a post-drive questionnaire concerning preference and acceptance of the different displays and modalities. They will also be asked for any comments they may have about the information presentation, the functionality of the systems, and the conceptual designs. During the drive, the in-vehicle experimenter will take notes to describe subject responses during the drive with regard to the system of interest (collision warning or cruise control). Following the drive, the experimenter will review the video tape with their notes and increase the detail of their subjective comments. Once researchers are able to drive the entire database, final inputs will be made to the protocols, scripts and questionnaires.

Scenarios during the experimental drive consist of 8 pre-scripted events spread across an approximate 25 mile long course (18 miles on a two-lane highway and 7 miles on 4-lane freeway). The driving scenario and events are described below.

The subject vehicle starts at a single starting point on the side of a two-lane rural highway. The subject vehicle will merge onto the road after two vehicles driving 55 mph, five seconds apart drive by. No other traffic will follow these vehicles. Oncoming generic traffic on the two-lane highway will be spaced at approximately 6 vehicles per mile. Refer to Figure 5.4- 1.

- Event 1 occurs approximately 3 miles into the drive on a 5% hill. The subject vehicle comes in contact with a slow moving semi-tractor trailer driving 40 miles per hour up a hill. This scenario will measure driver reaction time and response to a lead vehicle moving scenario. The truck will accelerate to 55 mph after the crest of the hill. After the crest of the hill, the truck will pull off the highway and let the subject vehicle pass.
- Event 2 occurs at the first intersection which is approximately 4 miles from the last event. The subject vehicle comes across a stopped vehicle waiting to make a left turn. This condition will allow the measurement of subject reaction to a lead vehicle stationary condition. The subject vehicle will have to brake to a full stop before the lead vehicle finds a gap and turns left. The brake lights and left turn signal will be on while the lead vehicle is waiting to turn. After the lead vehicle turns left at the first intersection, the subject vehicle then continues to drive straight on the two-lane highway. The subject will drive with no lead vehicle until the next event occurs.
- Event 3 occurs at 4 miles later when the subject vehicle comes in contact with a vehicle (car) driving at 35 mph. Once the two vehicles become coupled (the

relative velocity is near zero) at 35 mph for 2 seconds, the lead vehicle will speed up to 55 mph at + 0.1 g. Lead vehicle continues on to next event. This event evaluates the subject drivers reaction in a lead vehicle moving circumstance on a flat roadway.

- Event 4 occurs at the second intersection 3 miles later. The lead vehicle decelerates moderately with brake lights and turns left at the second intersection. The left turn signal should turn on 100 feet before the intersection. The subject vehicle then continues to drive straight along the highway. The subject vehicle encounters no lead vehicle until the next event.

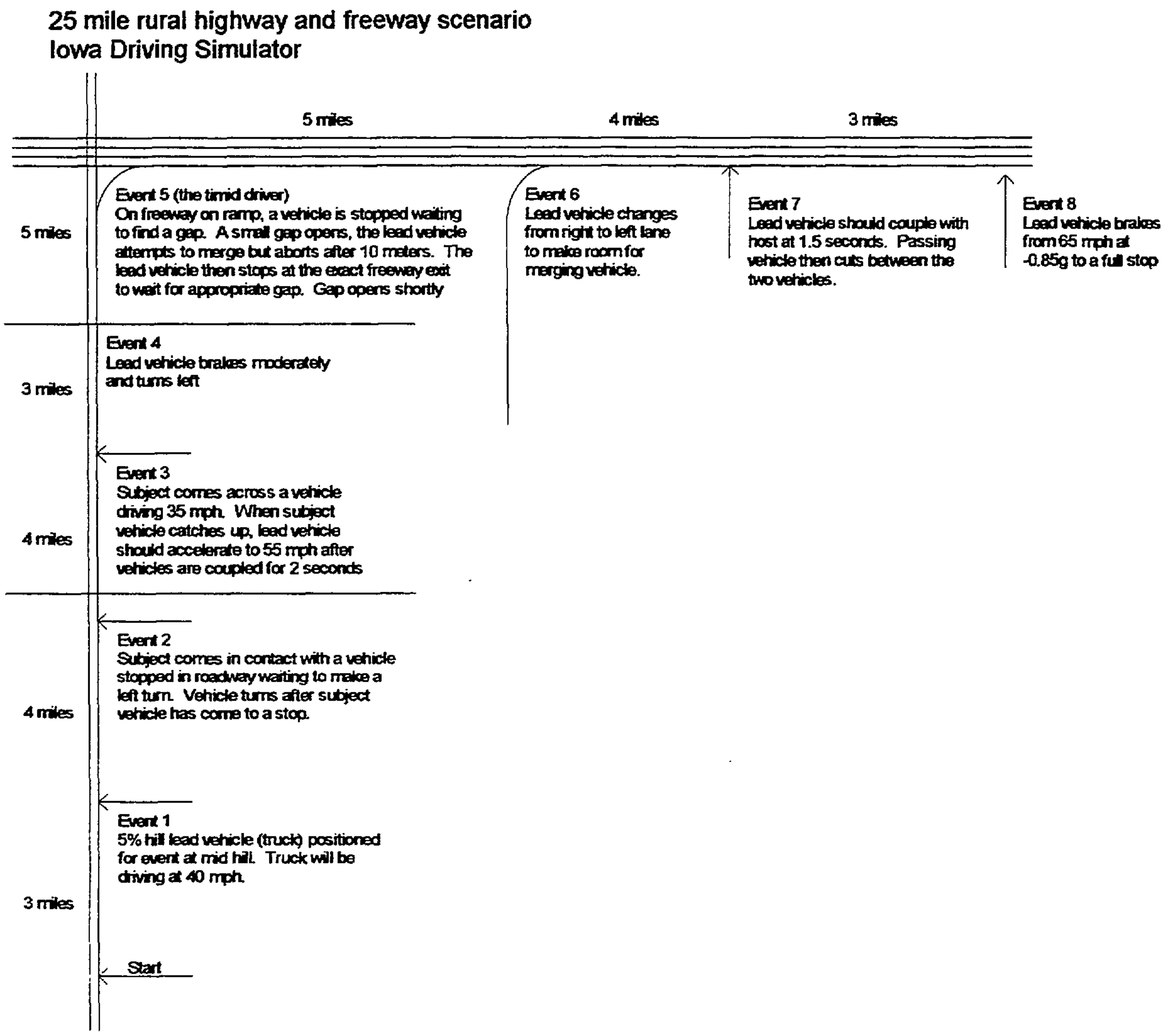

Figure 5.4-1 Map of Frontier Database

- Event 5 occurs at the freeway entrance 5 miles later. As the subject vehicle drives the entrance trumpet onto the freeway, a lead vehicle will be stopped at zero speed 15 meters before the entrance to the freeway waiting for a gap (generic traffic on the 4 lane freeway will be driving with headways of approximately 0.5 seconds). Once the subject vehicle stops completely behind the lead vehicle and they are stopped for 5 seconds, a 3 second headway gap opens up on the freeway. The lead vehicle will then attempt to enter this 3 second gap by accelerating. After recognizing that the gap is too small, the lead vehicle will then stop abruptly after driving 10 meters. A second gap of 10 seconds will open after 3 cars have driven by. The lead vehicle will then accelerate to 65 mph (from 0 to 65 in 10 seconds) into the right lane of the freeway. The subject vehicle should theoretically have enough time to enter as well. If the subject vehicle misses the gap the lead vehicle drives into, a second 10 second gap will open after two vehicles pass. If the subject vehicle misses the second gap, three vehicles will drive by and a 20 second gap will open. Once the subject vehicle merges onto the freeway, the next vehicle it catches up to will become the new lead vehicle.
- Event 6 occurs 5 miles later at the merge point of an entrance ramp. Freeway drivers will be coupled and driving at 55 mph. The lead vehicle changes from the right lane to the left lane to allow the merging vehicle onto the freeway. There will also be a vehicle directly to the left of the subject vehicle so the subject vehicle will not be allowed to change into the left lane. The merging vehicle driving 5.5 mph will then merge onto the freeway in front of the subject vehicle. This event is designed to measure the response of ICC systems and driver warning systems to merging vehicles. If the subjects car maintains its velocity and lane position, it will collide with the merging vehicle. Once the merging vehicle couples with the subject vehicle for 3 seconds it will accelerate to 65 mph in 3 seconds. Once the vehicle that merged attains a speed of 65 mph, it will maintain 65 mph and become the scenario's new lead vehicle. If the vehicle that merged ends up behind the subject vehicle, the merging vehicle decelerates so it disappears. If this occurs, a new lead vehicle driving 65 mph will be available a mile later.
- Event 7 occurs approximately 4 miles after event 6. The subject will be coupled with the lead vehicle at 65 mph with a 1.5 second headway. The lead vehicle should maintain this coupling irrespective of the subject vehicles speed. Two passing vehicles in the left lane driving 70 mph will come along side of the subject vehicle and slow to 65 mph and will not allow the subject vehicle to pass the lead

vehicle. At a designated trigger point, the lead passing vehicle will cut in between the subject vehicle and its lead vehicle without decreasing its velocity (65 mph). The new lead vehicle will then drive 65 mph until the next event. The second passing vehicle will pass and then accelerate to the point of disappearing. This event will evaluate subject vehicle response to "'cut ins". Use of collision warning and ICC systems will compare driver response to baseline driving. Data reduction starts at 110,580 feet and ends at 116,160 feet.

- Event 8 occurs 3 miles later where the subject vehicle will couple with the lead vehicle at 1.5 seconds. The lead vehicle should maintain this coupling irrespective of the subject vehicles speed. After they have become coupled for 5 seconds, the lead vehicle will brake at -0.85 g to a full stop. If the subject vehicle hits the braking vehicle the simulation ends. If the subject successfully avoids a collision, then the simulation will end ten seconds after the braking vehicle has come to a complete stop. This event will evaluate driver reaction time and behavior in an extreme lead vehicle braking condition.

The eight event scenarios will be presented in the same order for all subjects and will be a within subject factor. Age will be a between subject design where three male and three female drivers age 30-45 and three male and three female drivers over 65 years of age will be used for each display configuration experiment. Display type and modality will also be a between subject factor.

Dependent variables will vary according to the event that is taking place. Primary dependent variables in each experiment include:

- Event 1 Driver reaction time to slow truck (accelerator pedal release, time between accelerator release-and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration, brake pedal pressure and negative acceleration also included), amount of time the brake pedal is depressed, accelerator pedal release, minimum following distance after braking, coupled headway at 40 mph (time and distance).
- Event2 Driver reaction time to slowing lead vehicle (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration, brake pedal pressure and negative acceleration also included), amount

of time the brake pedal is depressed, minimum following distance after braking, coupled headway before lead vehicle braking is initiated.

- Event 3 Driver reaction time to slow vehicle (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration, brake pedal pressure and negative acceleration also included), amount of time the brake pedal is depressed, minimum following distance after braking, coupled headway after braking.
- Event 4 Driver reaction time to brake lights (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration), amount of time the brake pedal is depressed (brake pedal pressure and negative acceleration also included), minimum following distance after braking, coupled headway at 40 mph (time and distance).
- Event 5 Driver reaction time to stopped vehicle ((accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration), amount of time the brake pedal is depressed (brake pedal pressure and negative acceleration also included), minimum following distance after braking.
- Event 6 Driver reaction time to merging vehicle (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration), amount of time the brake pedal is depressed, minimum following distance after braking, coupled headway after braking.
- Event 7 Driver reaction time to vehicle cutting in (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration, brake pedal pressure and negative acceleration also included), amount of time the brake pedal is depressed, minimum following distance after braking, coupled headway after event.
- Event 8 Driver reaction time to stopped vehicle (accelerator pedal release, time between accelerator release and brake pedal depression, number of feet in to the drive the brake pedal is depressed), braking and/or steering intensity (lateral acceleration), amount of time the brake pedal is depressed (brake pedal pressure and negative acceleration also included), minimum following distance after braking, coupled headway at 40 mph (time and distance).

Only licensed drivers who meet the age requirements will be used in this study. Drivers will be recruited from advertisements placed in local newspapers. They will be paid at a rate of $15 per hour. Subjects will be given a questionnaire to access likelihood of simulator induced motion sickness. Subjects with a high score will not participate in the study. The age grouping of the subjects for these studies will be between the ages of 30 and 45 and over age 65. Twelve subjects will be recruited for each display format/modality experiment for a total of 84 subjects across all the study formats.

Statistics that will be applied to the data will consist of ANOVAs to discover where statistical differences lie. If differences are found between the baseline and an experimental group, then means will be plotted to locate the differences. For variables with more than two levels, post-hoc tests will be conducted to discover which levels are significantly different. Questionnaire data will be reduced and analyzed using appropriate inferential tests to establish differences among conditions.

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5.5 SUMMARY

Information on collision intervention and intelligent cruise control systems is continuing to be made public. It is anticipated that systems will be evaluated by field testing and on the Iowa Driving Simulator as they come available. Manufacturers have been sensitive about providing systems to this project since they are still in prototype form.

6 SUMMARY

There were four responses to the CBD advertisement, and only one of these has participated in the testing to date. Sixty potential suppliers have been contacted, and forty-one of these either declined to participate or didn't have a system to test. There are nineteen suppliers who have been contacted and expressed some initial interest, but have not committed to anything. Five suppliers have not been contacted to date.

Indications are that them are a number of reasons for this poor response.

1. The technology is fairly new, and there aren't a lot of systems available.
2. Prototype systems that do exist seem to be hard to schedule for this program because of the high demand.
3. There is a great deal of reluctance to be involved due to proprietary issues. Because of the competitive nature of the industry, and the potential for large profits along with large liabilities, most companies with systems have declined to participate. Some have stated that the MOA helped this problem, but not enough

Tests on the one system tested received mixed results. Although numerous outstanding issues exist regarding the system, it is felt that with all these issues are correctable from a technical perspective. Display issues discussed here are not necessarily appropriate, because the display is in the early prototype area, primarily designed to support the processor and sensor, and not to interface with the average driver.

Information on collision intervention and intelligent cruise control systems and display types is continuing to be gathered. Most of the research and development costs being spent by companies in this area is on the sensor and processor, and not on the human interface. It is expected that most of the issues relating to human factors will need to be inferred from the literature, and by collaboration with industry and academic experts.

Several of the companies contacted have stated that they would be willing to have their systems tested in conjunction with this contract at a future date. Because of this, it is suggested that the contract be modified to allow testing at anytime during this program as appropriate.

APPENDIX A SYSTEM SPECIFIC TEST DATA

The following presents the results found during testing of the system. Test numbers correspond to the driver warning test numbers in the Acquisition and Test Plan.

Test Number 1: Lead Vehicle Stopped, Host Vehicle 10 kph

The actual range, the measured range from the system is shown in Figure l-l. The range error is shown in Figure 1-2. The absolute velocity of the two vehicles is shown in Figure 1-3. There was no range alarm from the system The relative velocity sensor does not sense stopped vehicles.

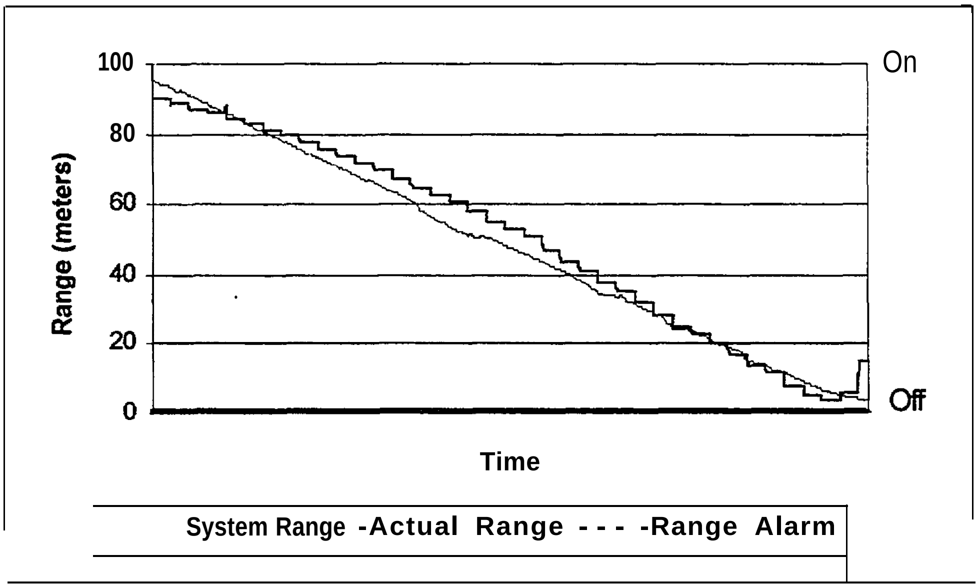

Figure l-l Test 1, Range Measurement

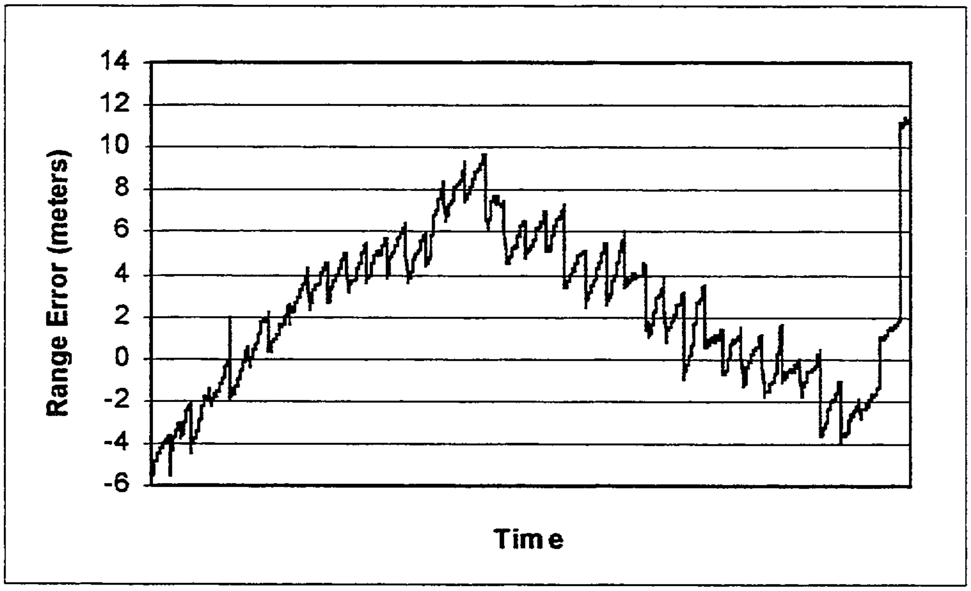

Figure 1-2 Test 1, Range Error Measurement

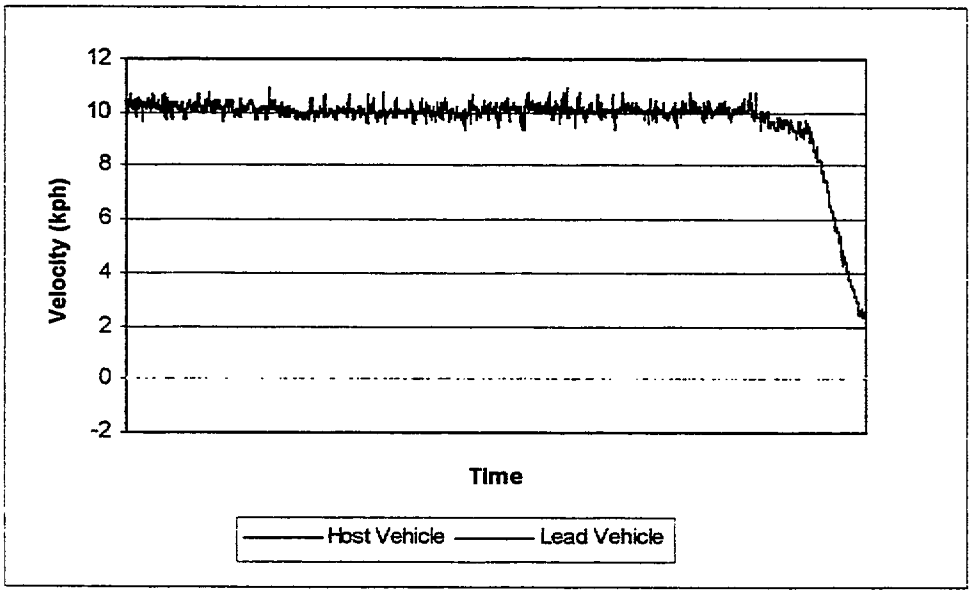

Figure 1-3 Test 1, Absolute Velocity Measurement

Test Number 2: Lead Vehicle Stopped. Host Vehicle 25 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 2-1. The range error is shown in Figure 2-2. The absolute velocity of the two vehicles is shown in Figure 2-3. The range alarm from the system was detected at 40 meters, 23 kph from the lead vehicle. The relative velocity sensor does not sense stopped vehicles.

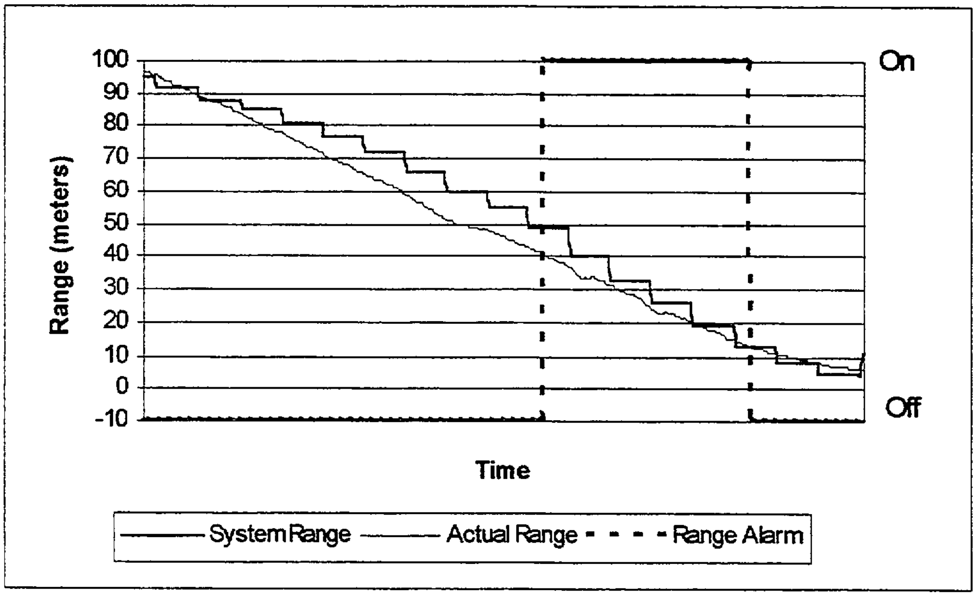

Figure 2-1 Test 2, Range Measurement

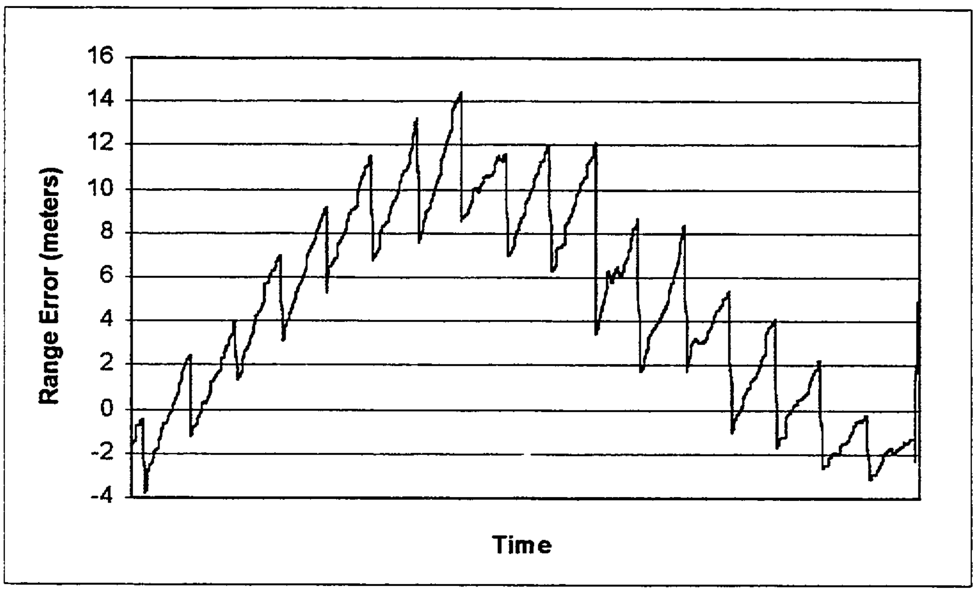

Figure 2-2 Test 2, Range Error Measurement

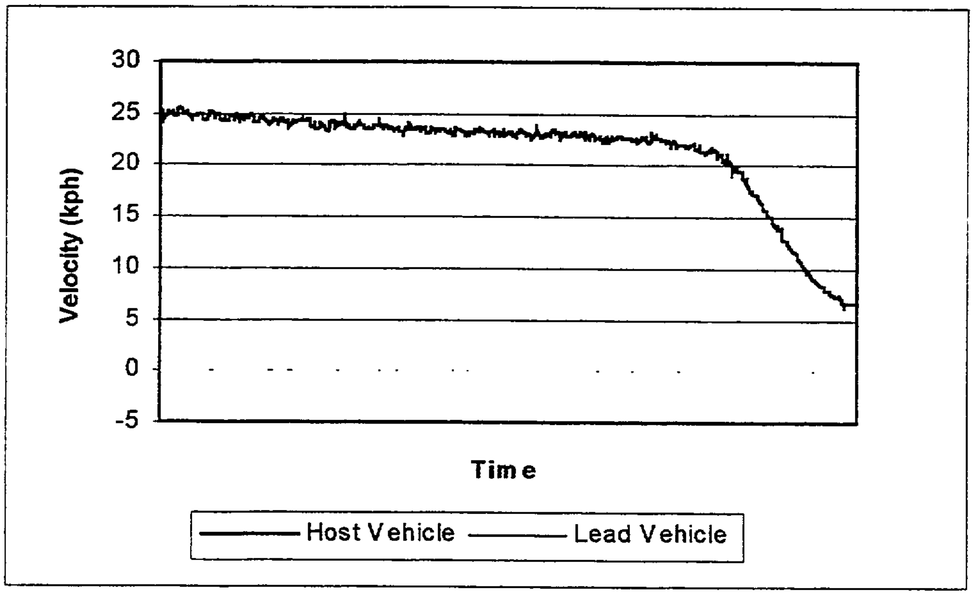

Figure 2-3 Test 2, Absolute Velocity Measurement

Test Number 3: Lead Vehicle Stopped, Host Vehicle 50 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 3-1. The range error is shown in Figure 3-2. The absolute velocity of the two vehicles is shown in Figure 3-3. The range alarm from the system was detected at 46 meters, 16 kph from the lead vehicle. The relative velocity sensor does not sense stopped vehicles.

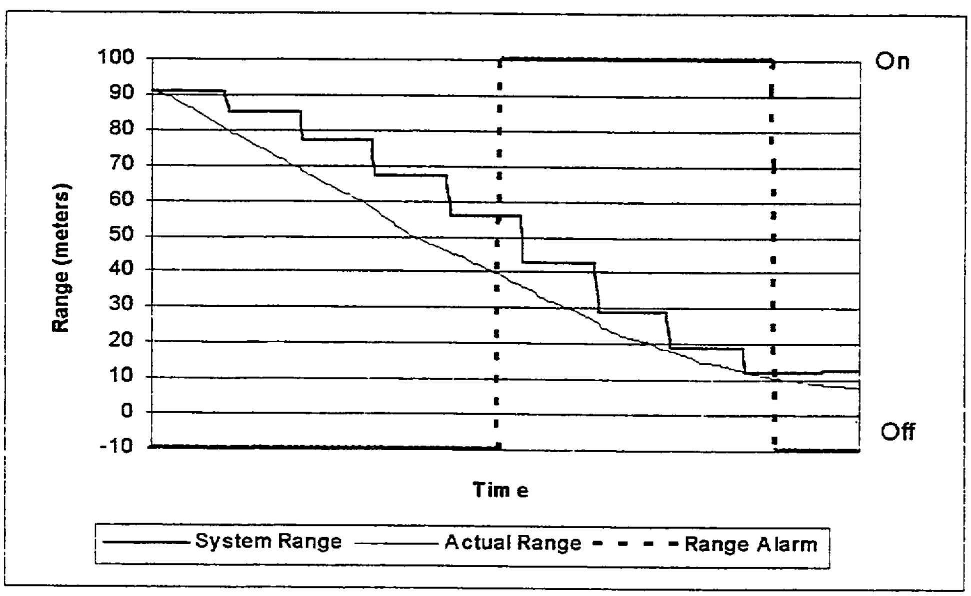

Figure 3-1 Test 3, Range Measurement

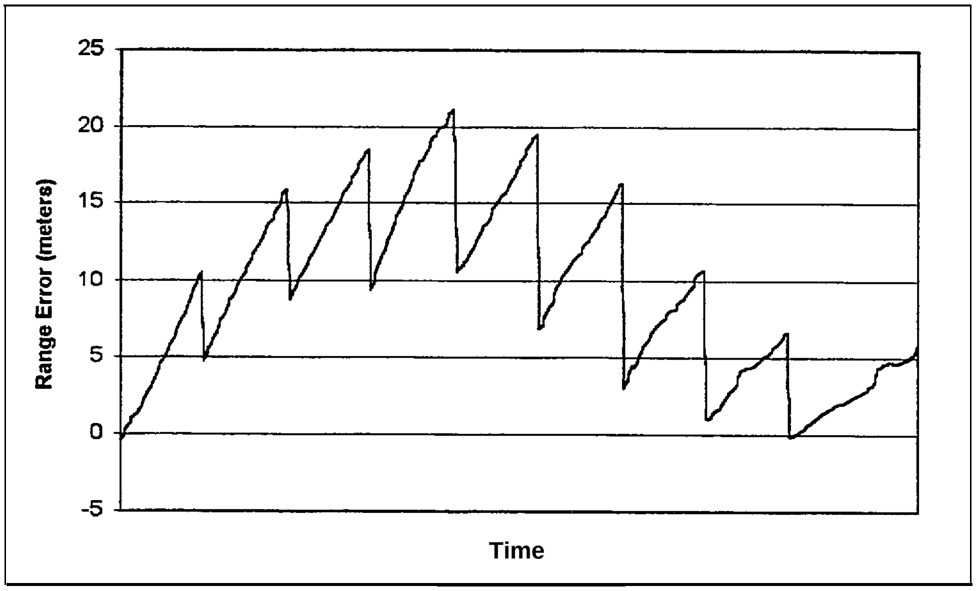

Figure 3-2 Test 3, Range Error Measurement

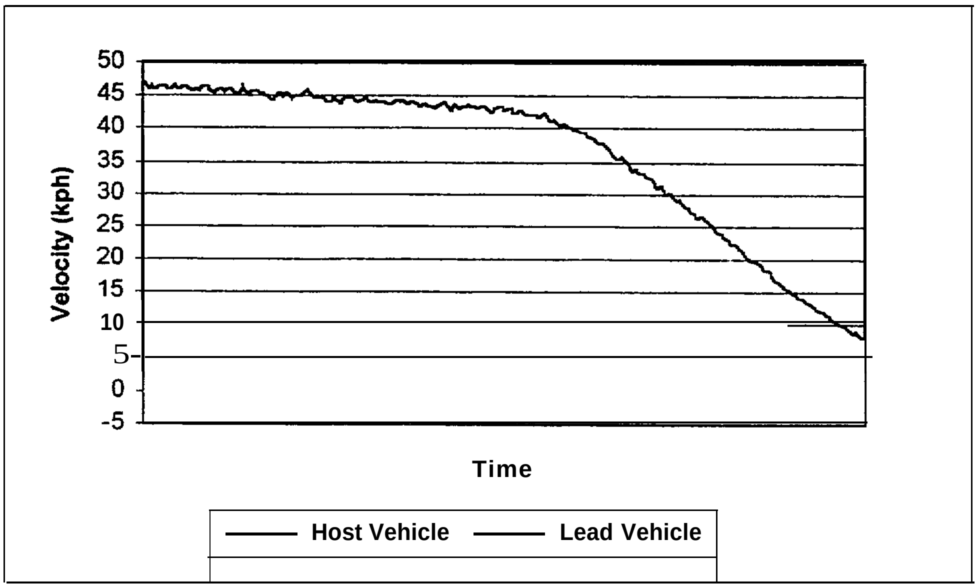

Figure 3-3 Test 3, Absolute Velocity Measurement

Test Number 4: Lead Vehicle Stopped. Host Vehicle 75 kph

This test was attempted, however, it was aborted due to the high closing velocity with a stopped lead vehicle, and the fixed range alarm of the system.

Test Number 5: Lead Vehicle Stopped, Host Vehicle 100 kph

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other lead vehicle stopped tests.

Test Number 6: Lead Vehicle 30 kph, Host Vehicle 50 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 6-l_ The range error is shown in Figure 6-2. The absolute velocity of the two vehicles is shown in Figure 6-3. The actual relative velocity as well as the measured relative velocity from the system is shown in Figure 6-4. The relative velocity error is shown in Figure 6-5. The range alarm from the system was detected at 62 meters, 17 kph from the lead vehicle.

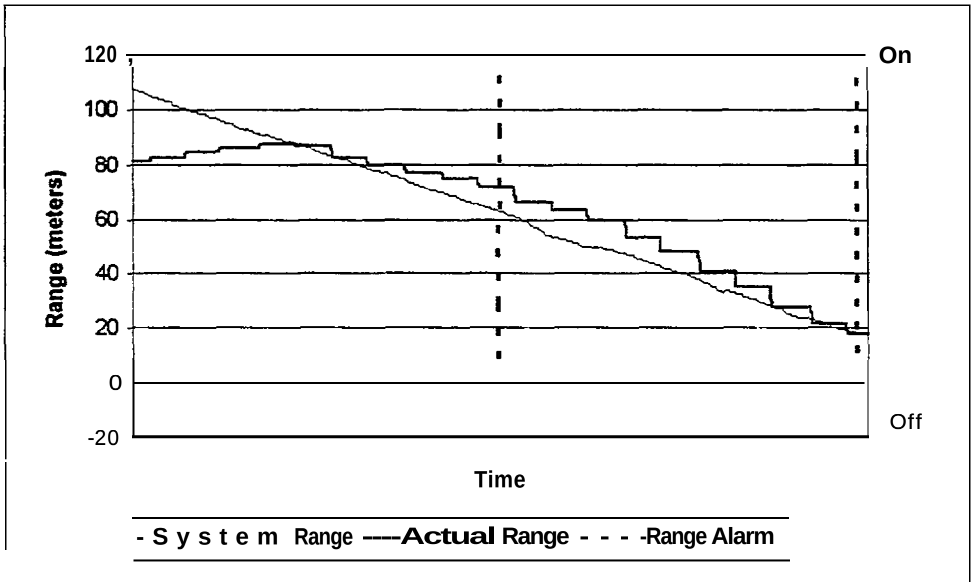

Figure 6-l Test 6, Range Measurement

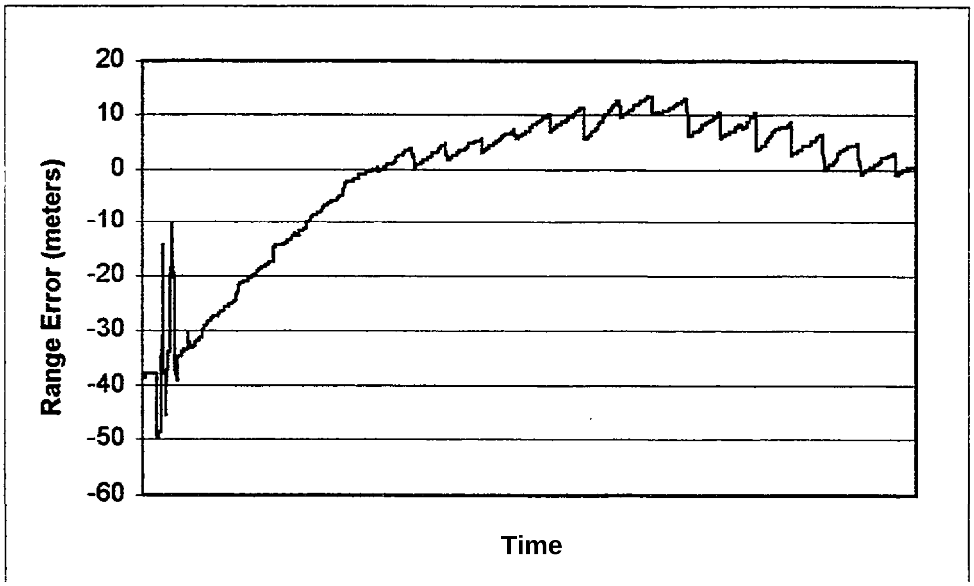

Figure 6-2 Test 6, Range Error Measurement

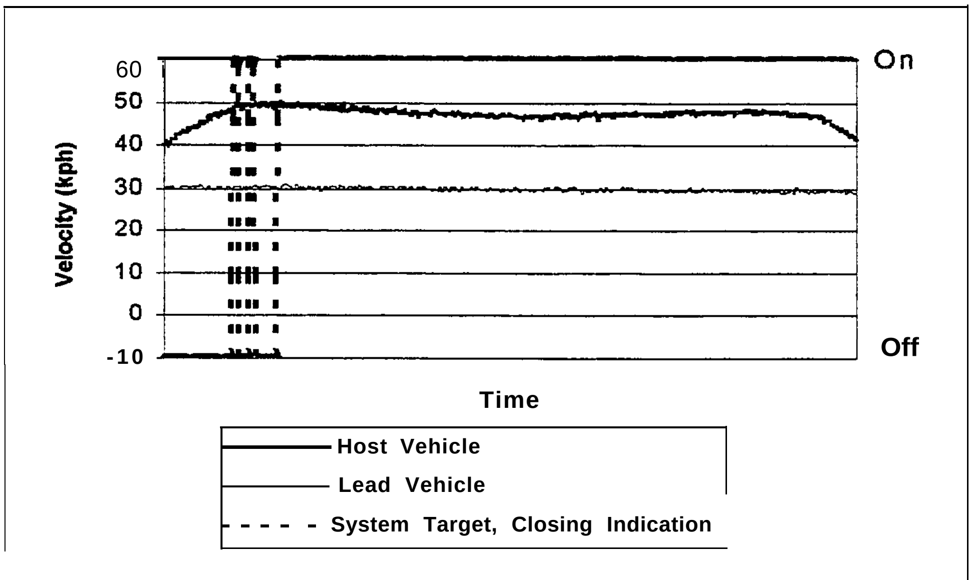

Figure 6-3 Test 6, Absolute Velocity Measurement

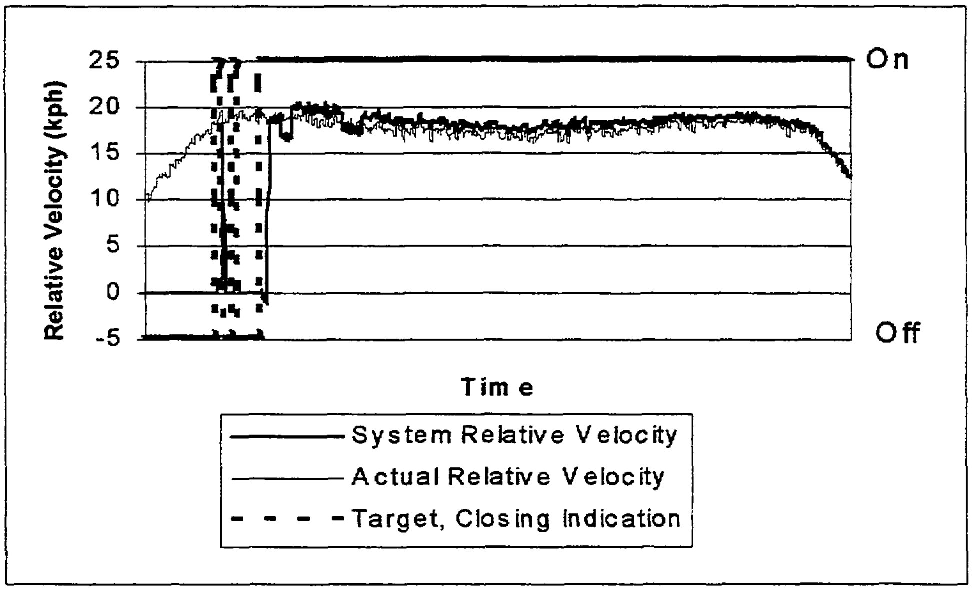

Figure 6-4 Test 6, Relative Velocity Measurement

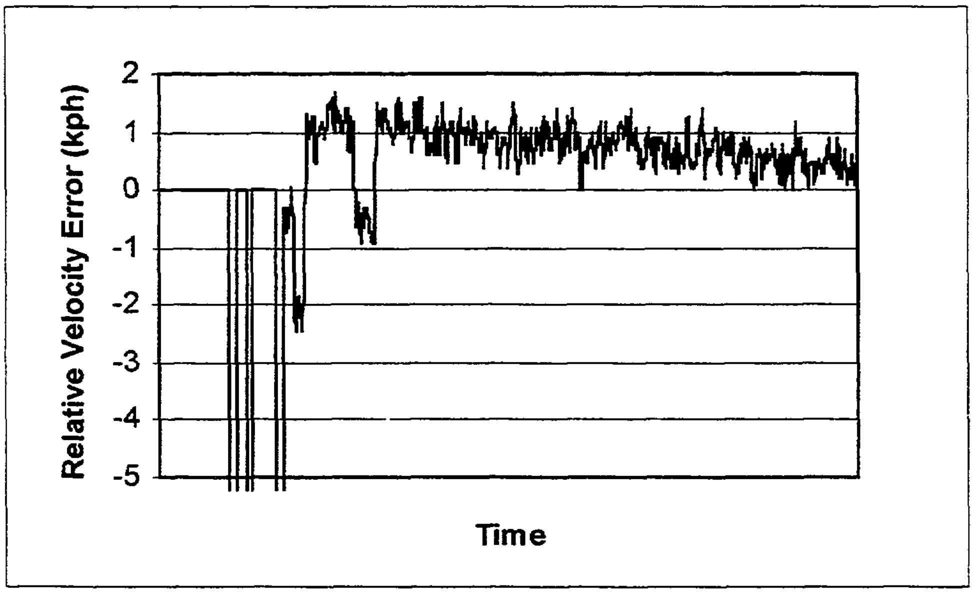

Figure 6-5 Test 6, Relative Velocity Error Measurement

Test Number 7: Lead Vehicle 30 kph, Host Vehicle 75 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 7-1. The range error is shown in Figure 7-2. The absolute velocity of the two vehicles is shown in Figure 7-3. The actual relative velocity as well as the system relative velocity is shown in Figure 7-4. The relative velocity error is shown in Figure 7-5. The range alarm from the system was detected at 56 meters, 43 kph from the lead vehicle.

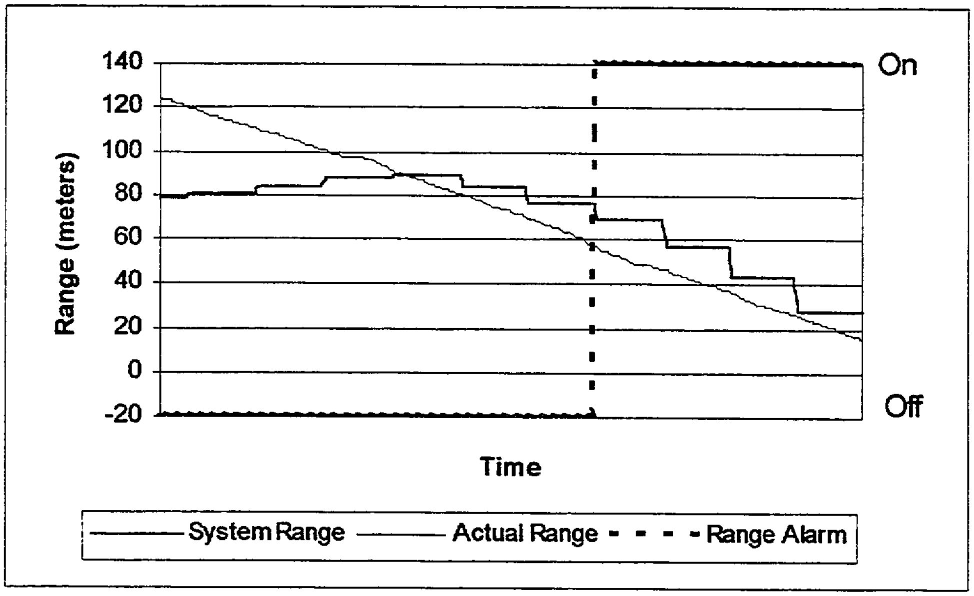

Figure 7-1 Test 7, Range Measurement

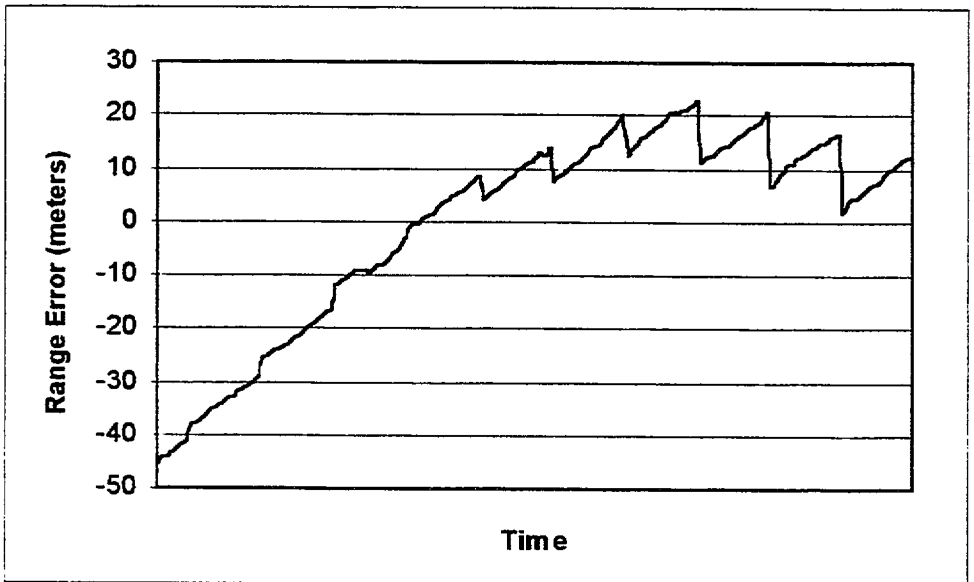

Figure 7-2 Test 7, Range Error Measurement

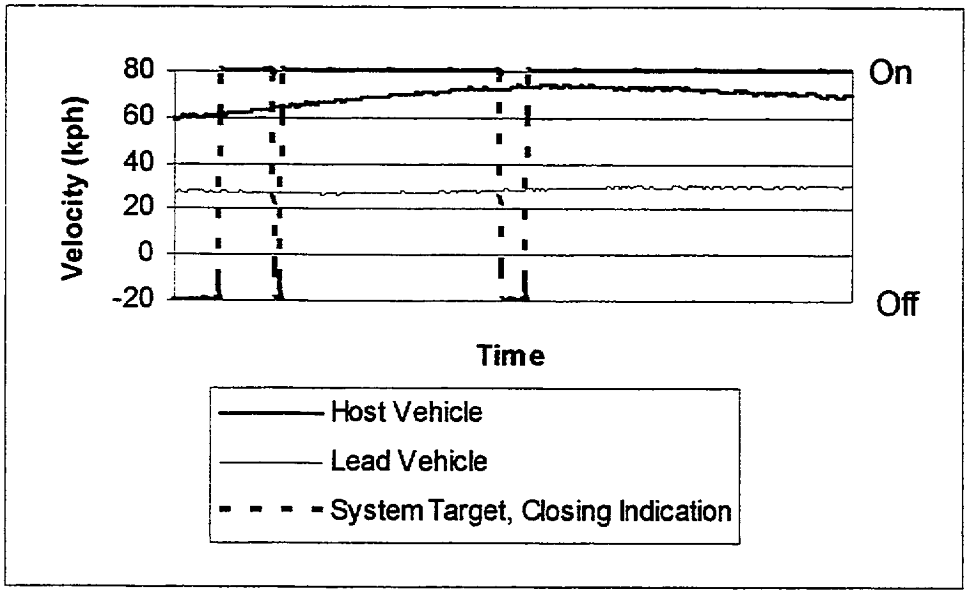

Figure 7-3 Test 7, Absolute Velocity Measurement

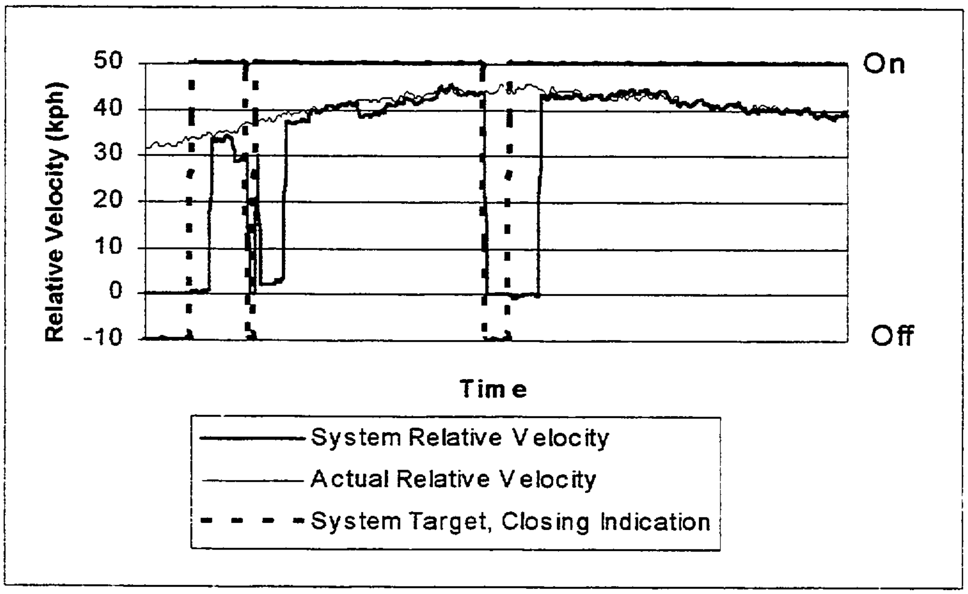

Figure 7-4 Test 7, Relative Velocity Measurement

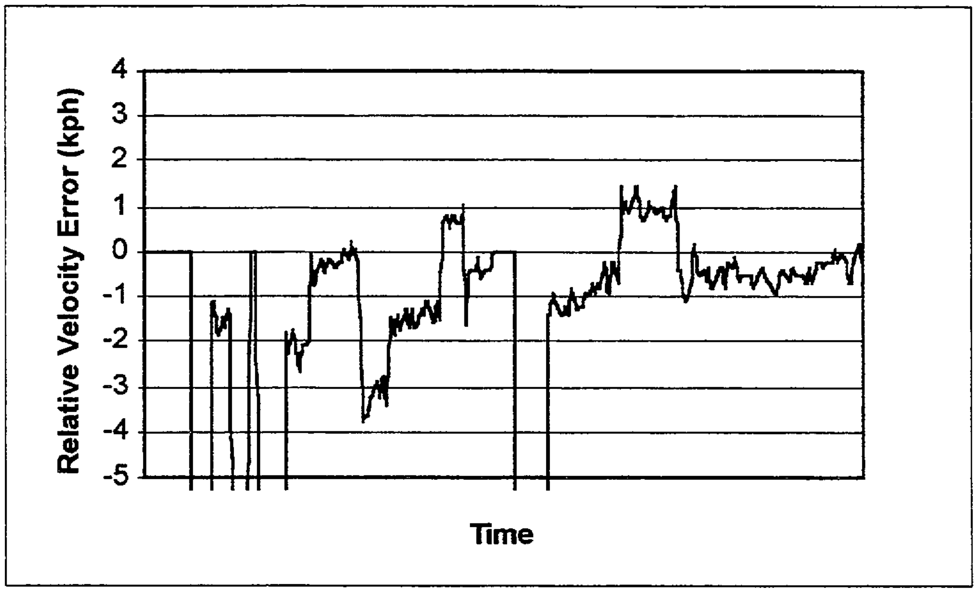

Figure 7-5 Test 7, Relative Velocity Error Measurement

Test Number 8: Lead Vehicle 30 kph, Host Vehicle 100 kph

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other lead vehicle stopped tests.

Test Number 9: Lead Vehicle 60 kph, Host Vehicle 75 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 9-1. The range error is shown in Figure 9-2. The absolute velocity of the two vehicles is shown in Figure 9-3. The measured relative velocity as well as the system relative velocity is shown in Figure 9-4. The relative velocity error is shown in Figure 9-5. The range alarm from the system was detected at 48 meters, 13 kph from the lead vehicle.

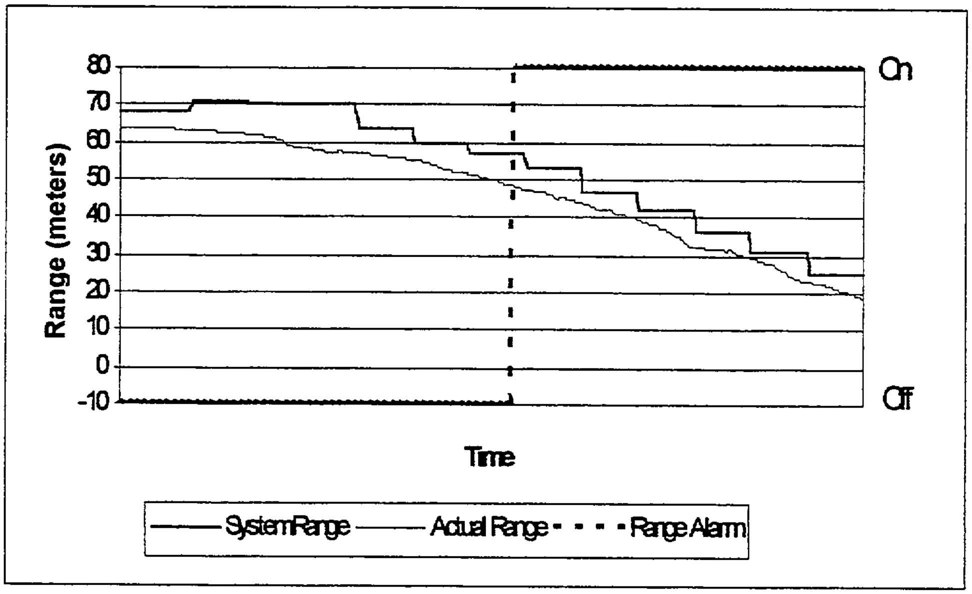

Figure 9-1 Test 9, Range Measurement

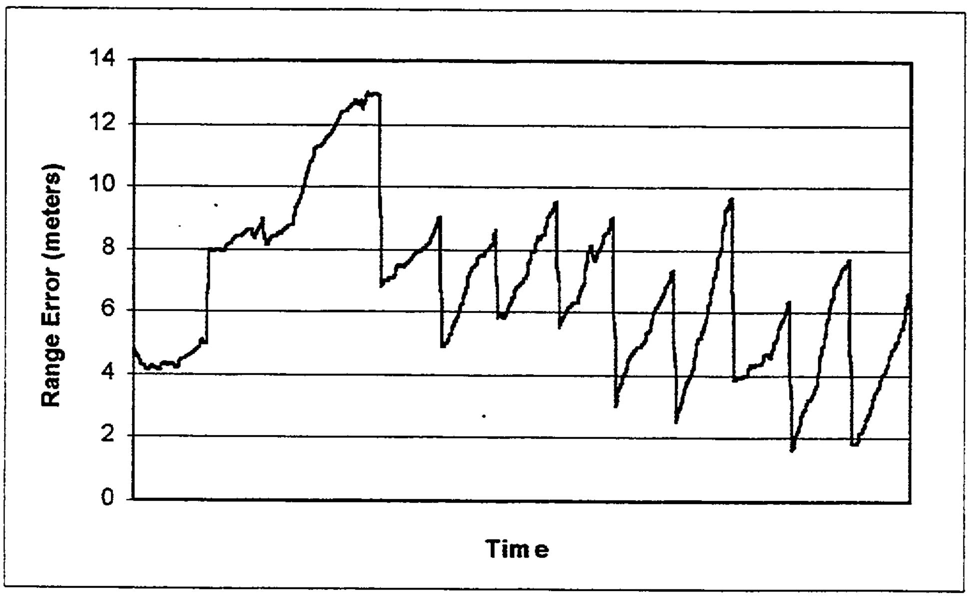

Figure 9-2 Test 9, Range Error Measurement

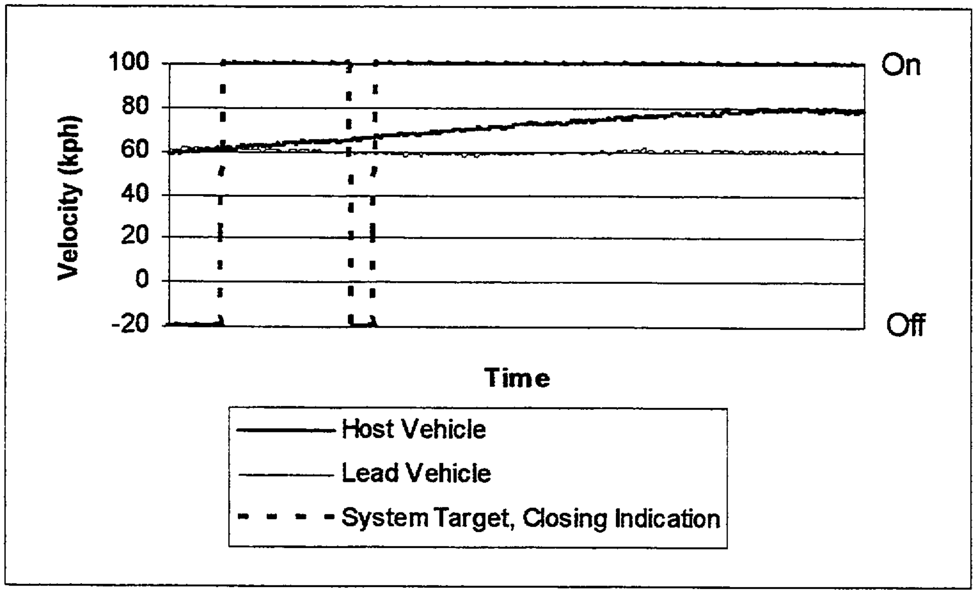

Figure 9-3 Test 9, Absolute Velocity Measurement

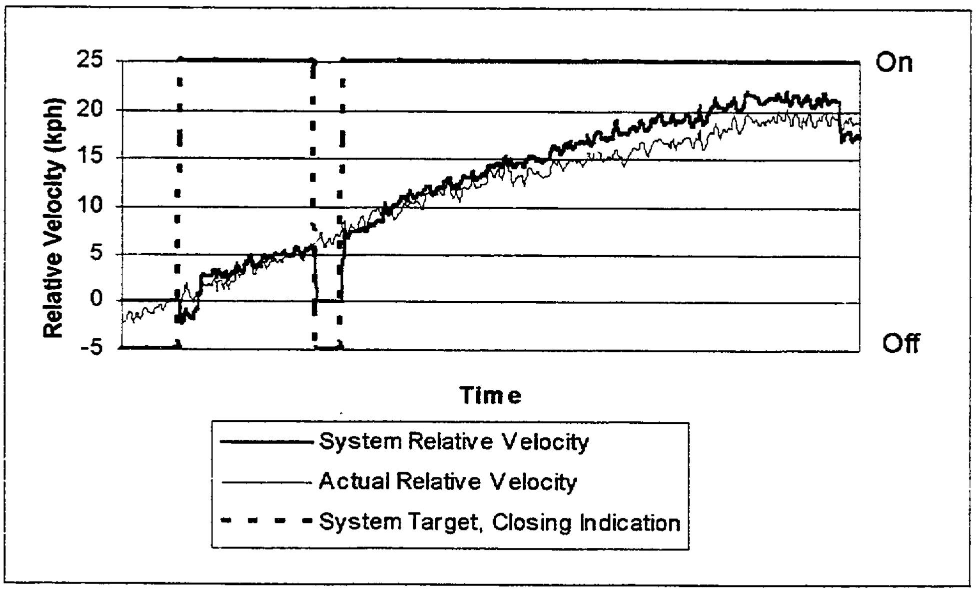

Figure 9-4 Test 9, Relative Velocity Measurement

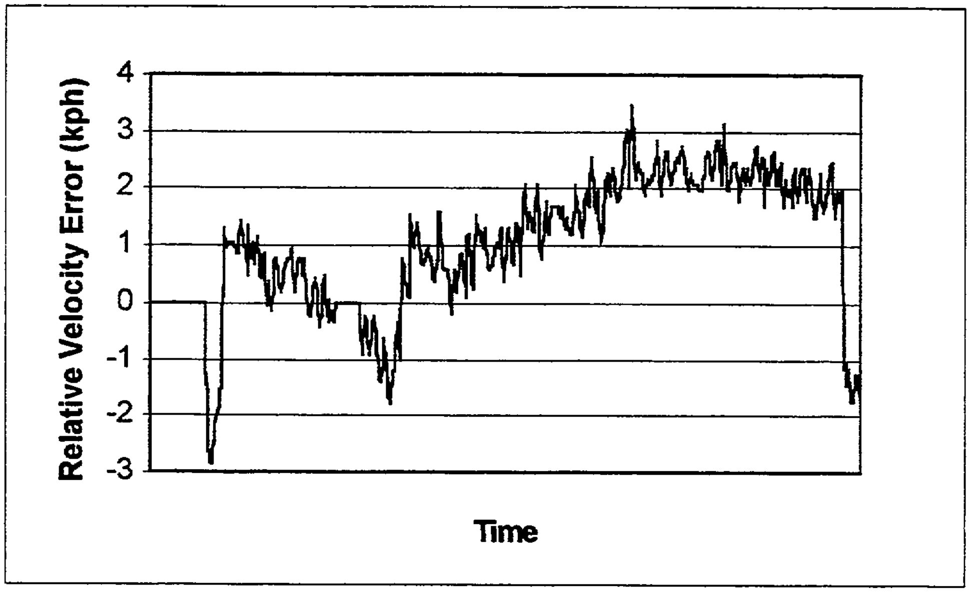

Figure 9-5 Test 9, Relative Velocity Error Measurement

Test Number 10: Lead Vehicle 60 kph, Host Vehicle 100 kph

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other lead vehicle stopped tests.

Test Number 11: Lead Vehicle 40 kph, 0.25g deceleration, Host Vehicle 40 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 11-1. The range error is shown in Figure 11-2. The absolute velocity of the two vehicles is shown in Figure 11-3. The measured relative velocity as well as the system relative velocity is shown in Figure 11-4. The relative velocity error is shown in Figure 11-5. The measured longitudinal acceleration is shown in Figure 11-6. The range alarm from the system was detected at 46 meters, 16 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 12 kph.

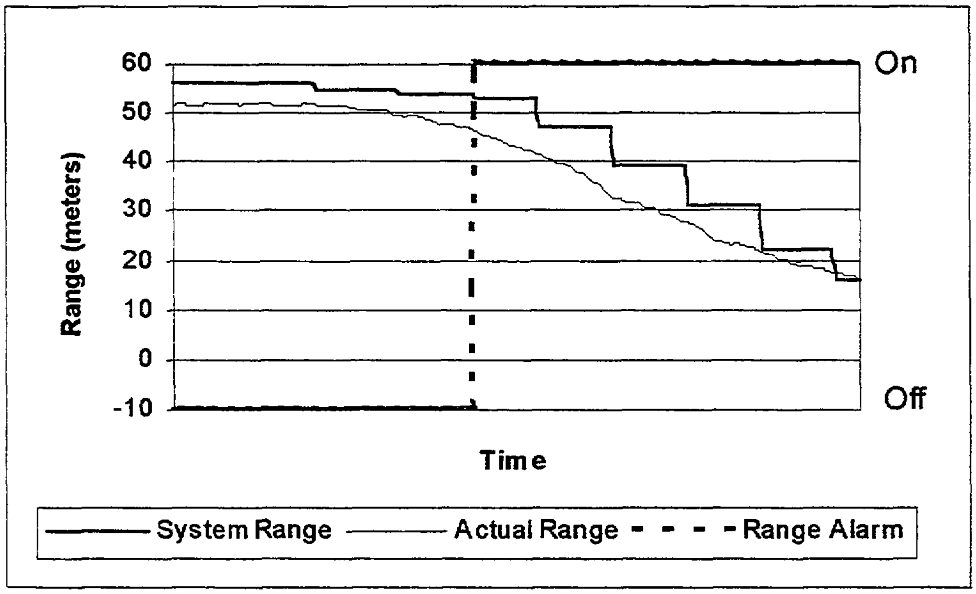

Figure 11-1 Test 11, Range Measurement

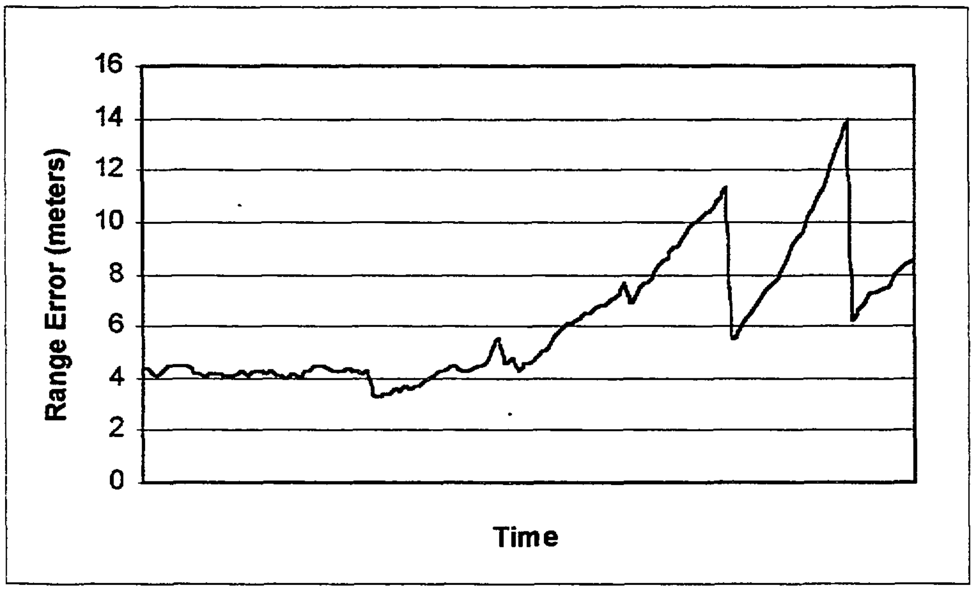

Figure 11-2 Test 11, Range Error Measurement

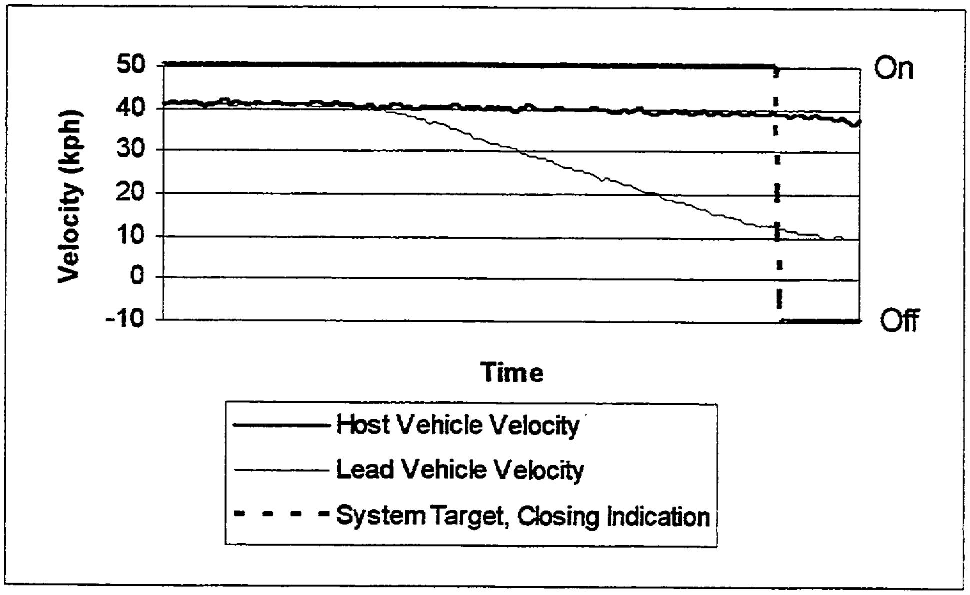

Figure 11-3 Test 11, Absolute Velocity Measurement

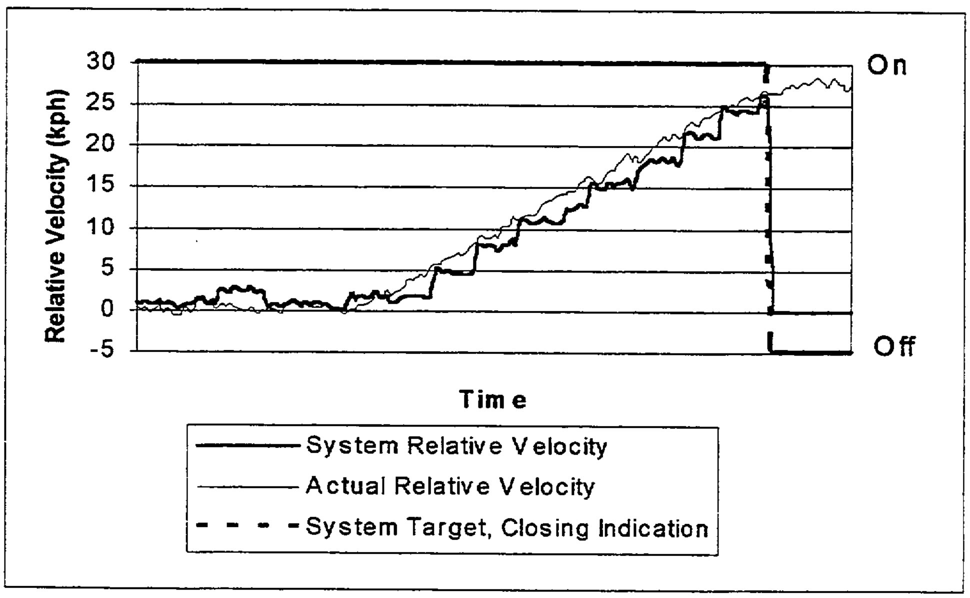

Figure 11-4 Test 11, Relative Velocity Measurement

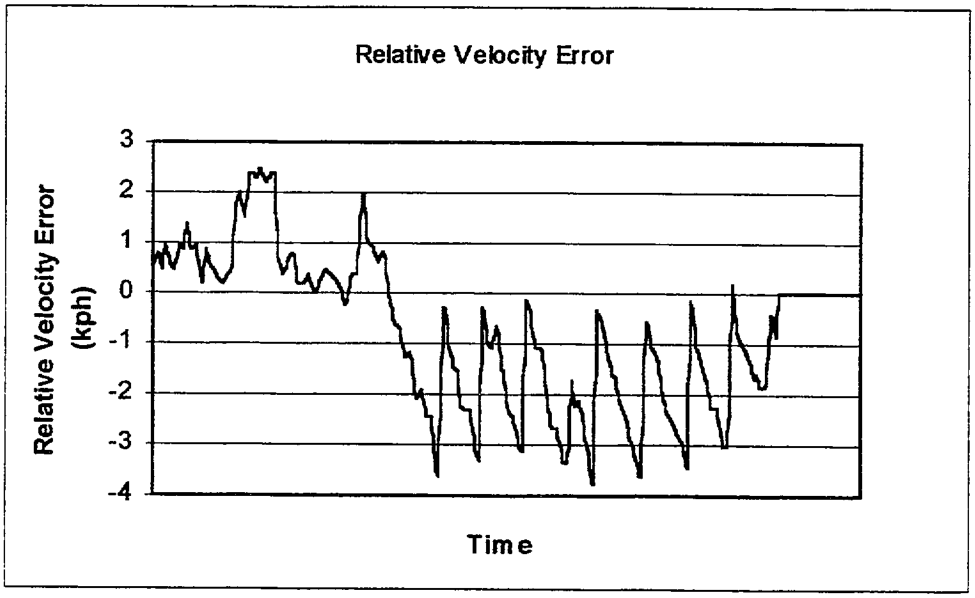

Figure 11-5 Test 11, Relative Velocity Error Measurement

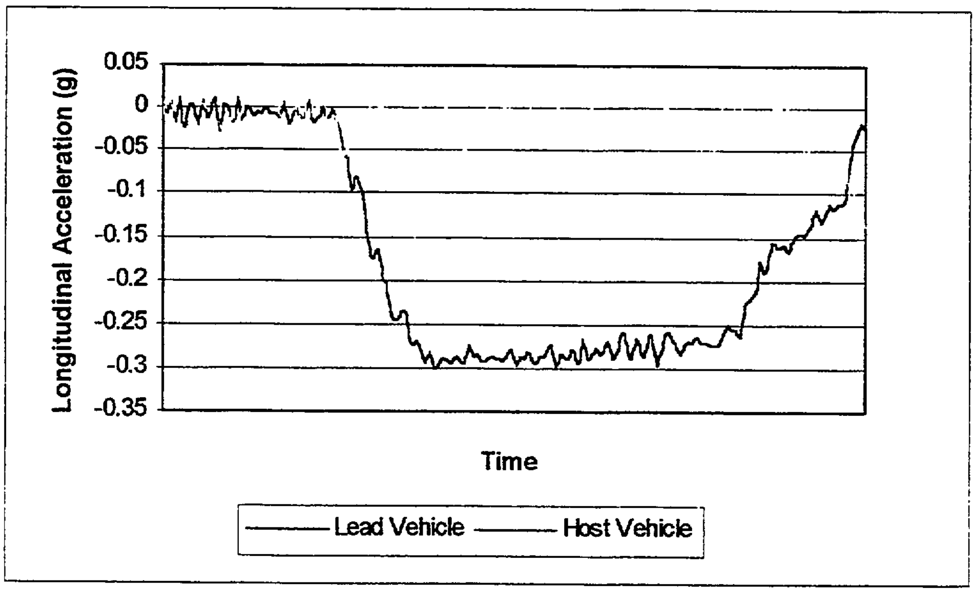

Figure 11-6 Test 11, Longitudinal Acceleration Measurement

Test Number 12: Lead Vehicle 40 kph, 0.5g deceleration, Host Vehicle 40 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 12-l. The range error is shown in Figure 12-2. The absolute velocity of the two vehicles is shown in Figure 12-3. The actual relative velocity as well as the system relative velocity is shown in Figure 12-4. The relative velocity error is shown in Figure 12-5. The measured longitudinal acceleration is shown in Figure 12-6. The range alarm from the system was detected at 40 meters, 16 kph relative velocity from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 12 kph.

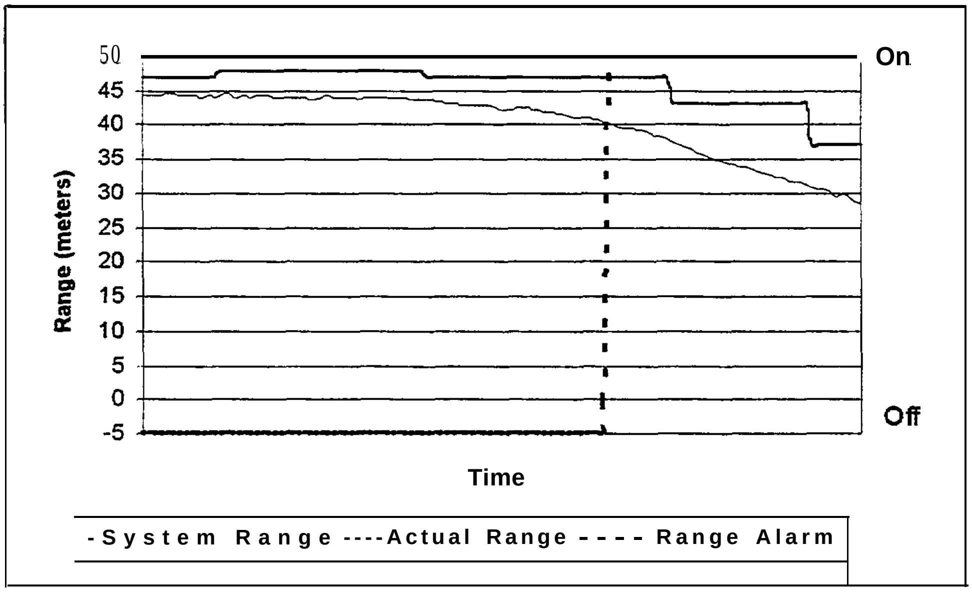

Figure 12- 1 Test 12, Range Measurement

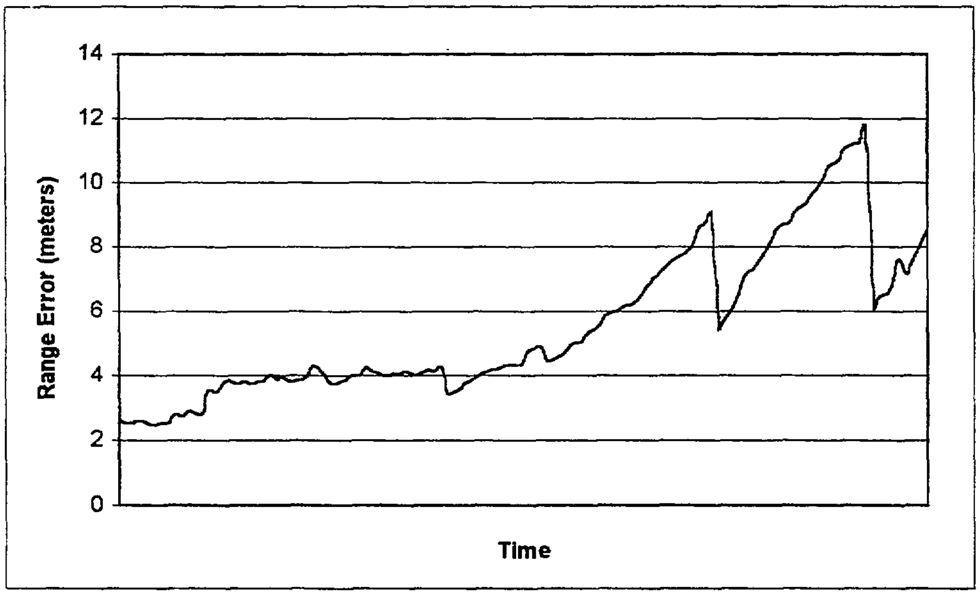

Figure 12-2 Test 12, Range Error Measurement

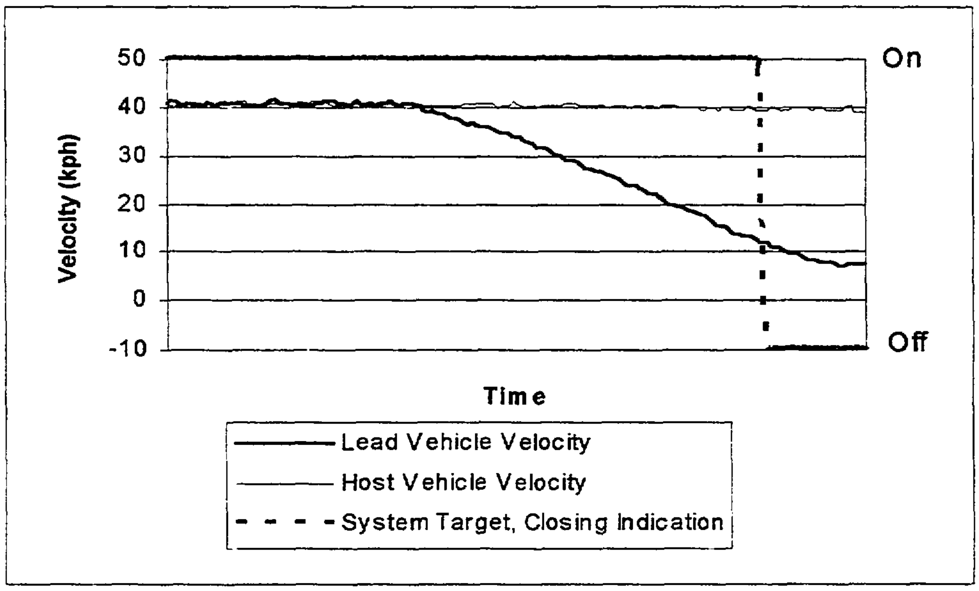

Figure 12-3 Test 12, Absolute Velocity Measurement

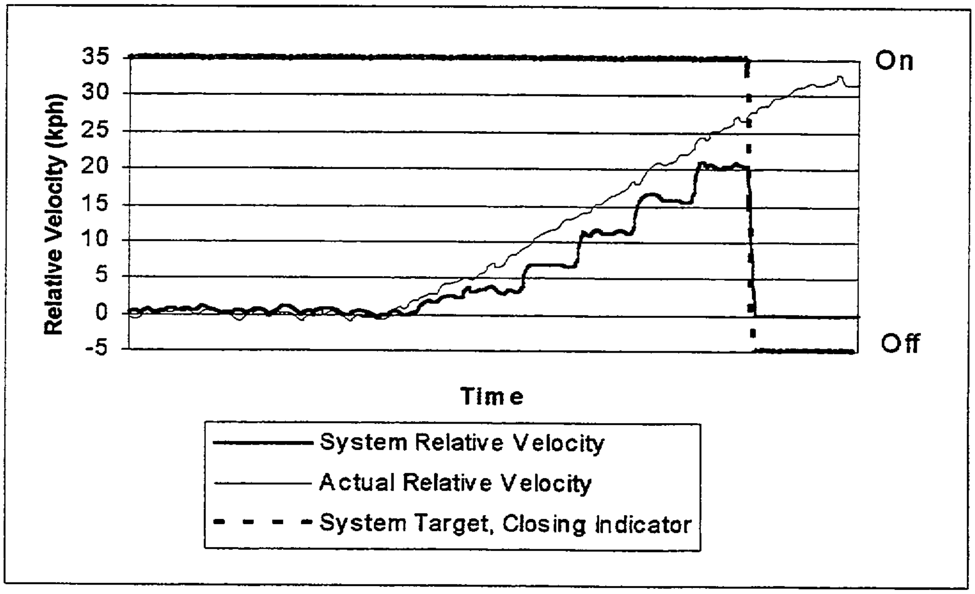

Figure 12-4 Test 12, Relative Velocity Measurement

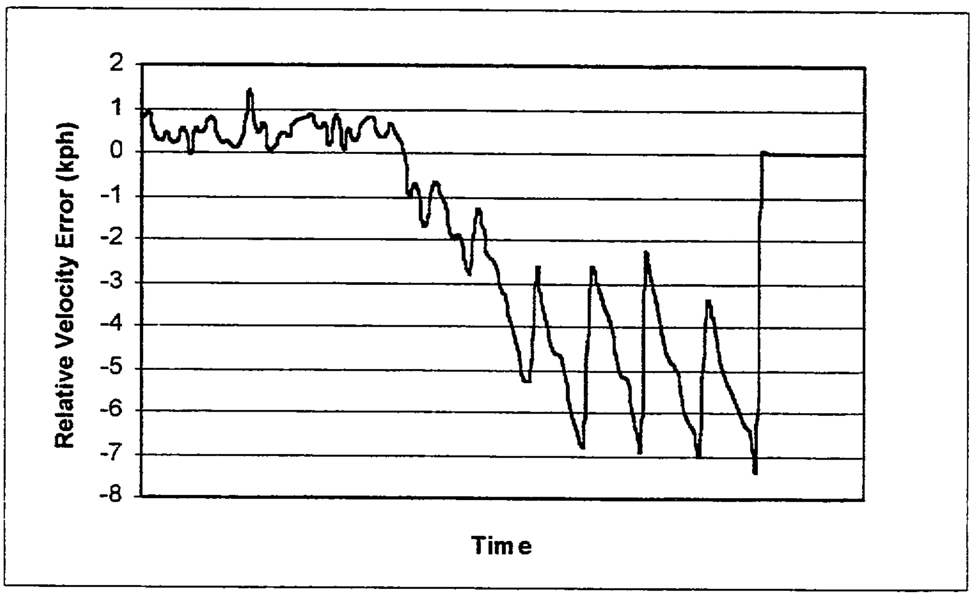

Figure 12-5 Test 12, Relative Velocity Error Measurement

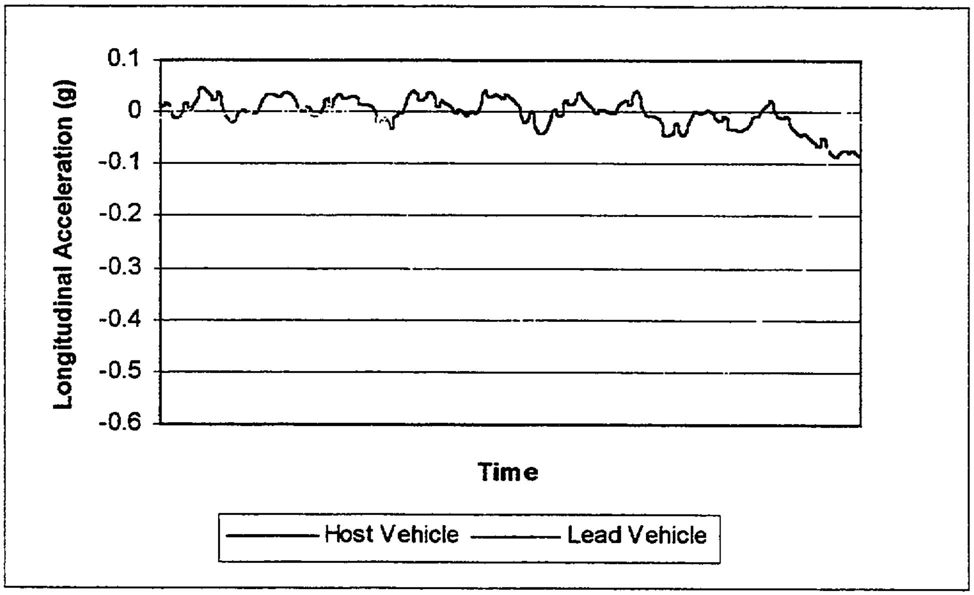

Figure 12-6 Test 12, Longitudinal Acceleration Measurement

Test Number 13: Lead Vehicle 40 kph, 0.75g deceleration, Host Vehicle 40 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 13-1. The range error is shown in Figure 13-2. The absolute velocity of the two vehicles is shown in Figure 13-3. The measured relative velocity as well as the system relative velocity is shown in Figure 13-4. The relative velocity error is shown in Figure 13-5. The measured longitudinal acceleration is shown in Figure 13-6. The range alarm from the system was detected at 50 meters, 16 kph from the lead vehicle. The relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 12 kph.

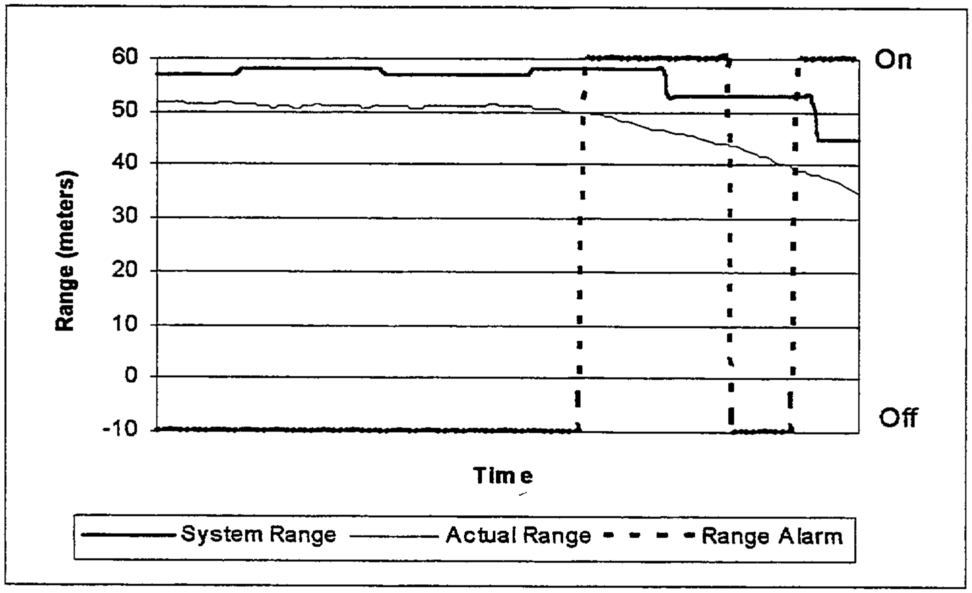

Figure 13-1 Test 13, Range Measurement

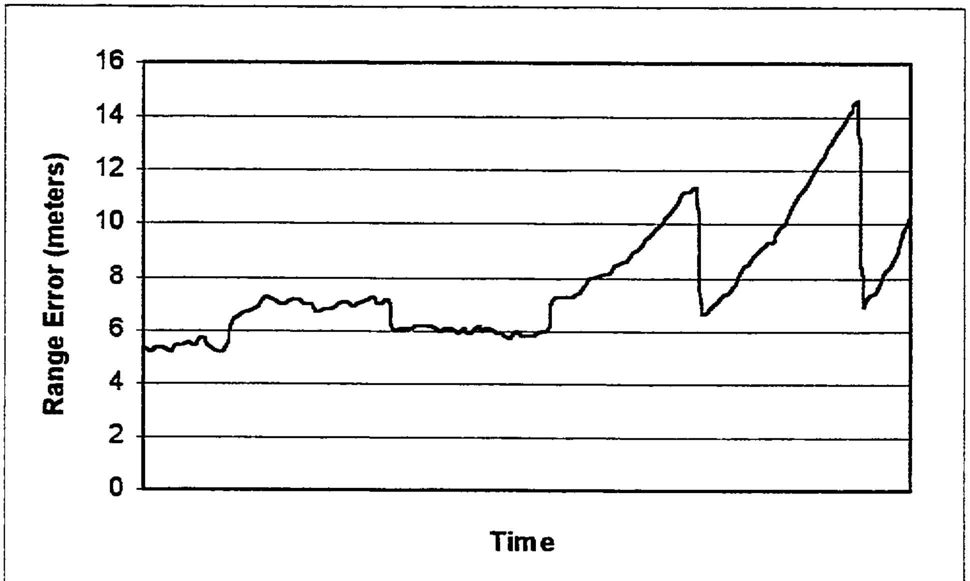

Figure 13-2 Test 13, Range Error Measurement

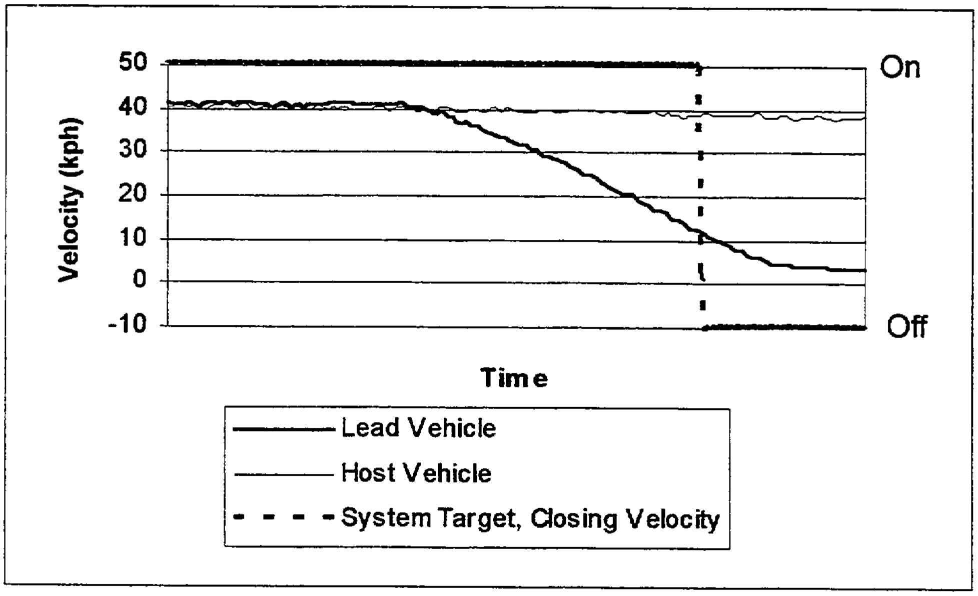

Figure 13-3 Test 13, Absolute Velocity Measurement

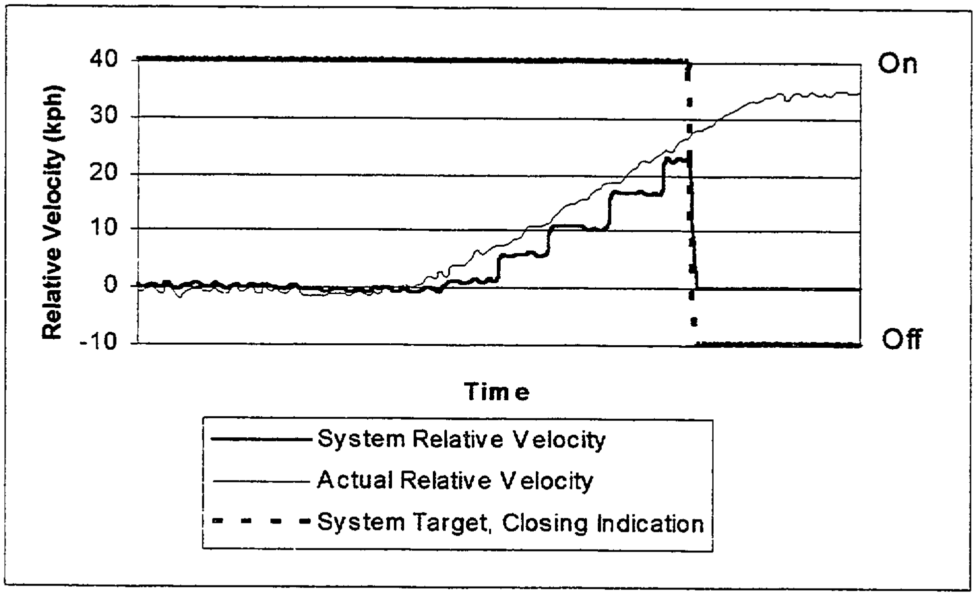

Figure 13-4 Test 13, Relative Velocity Measurement

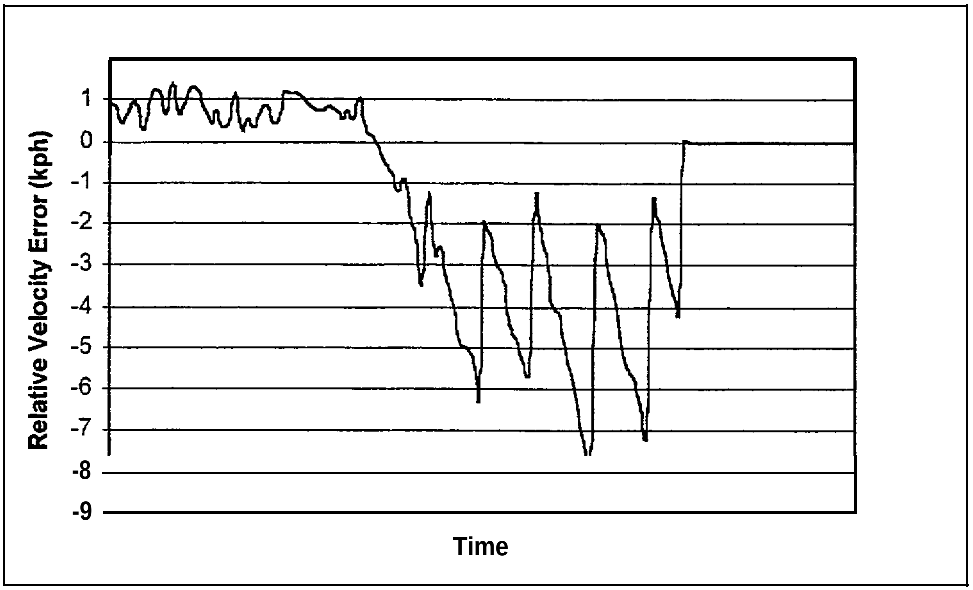

Figure 13-5 Test 13, Relative Velocity Error Measurement

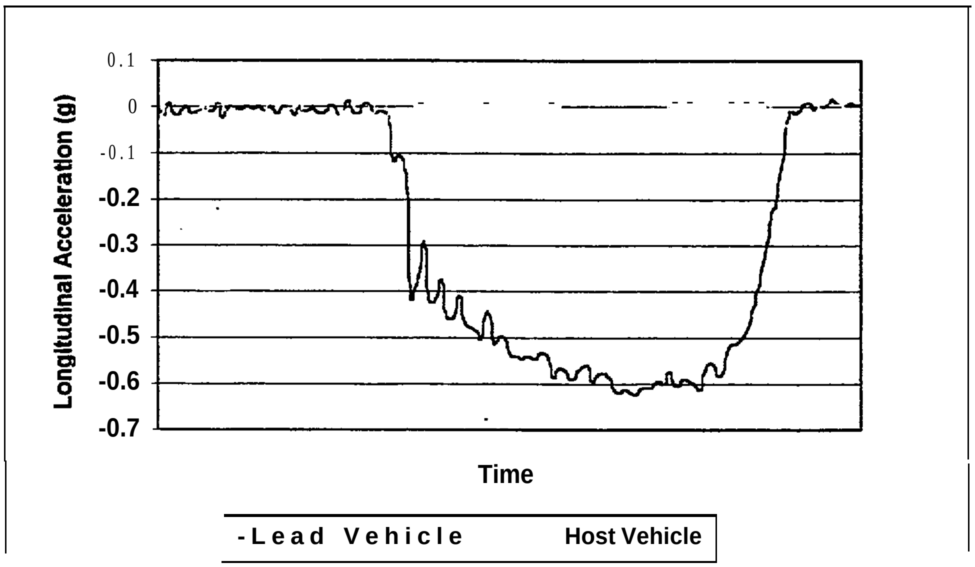

Figure 13-6 Test 13, Longitudinal Acceleration Measurement

Test Number 14: Lead Vehicle 60 kph, 0.25g deceleration, Host Vehicle 60 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 14-1. The range error is shown in Figure 14-2. The absolute velocity of the two vehicles is shown in Figure 14-3. The measured relative velocity as well as the system relative velocity is shown in Figure 14-4. The relative velocity error is shown in Figure 14-5. The measured longitudinal acceleration is shown in Figure 14-6. The range alarm from the system was detected at 52 meters, 13 kph from the lead vehicle.

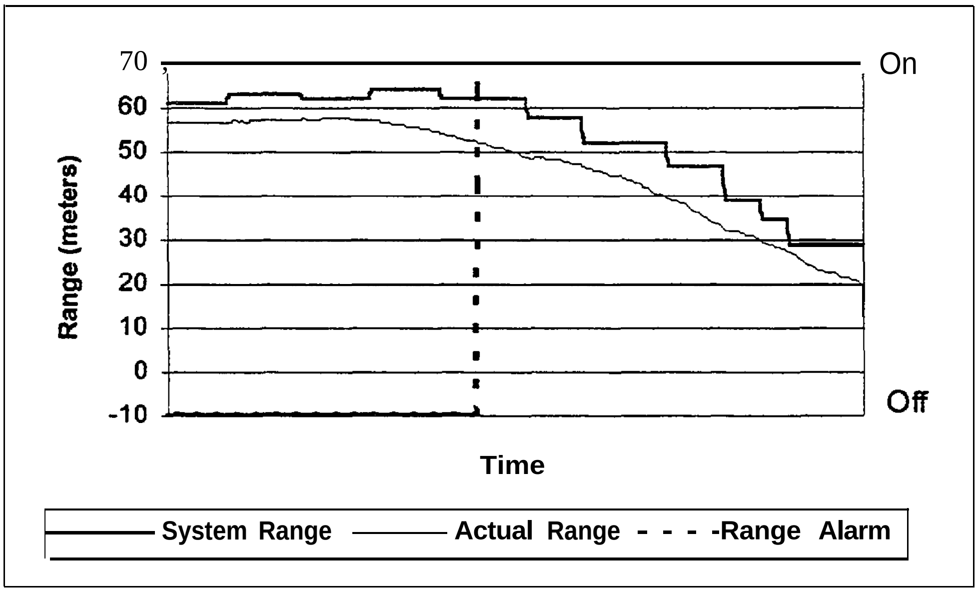

Figure 14-1 Test 14, Range Measurement

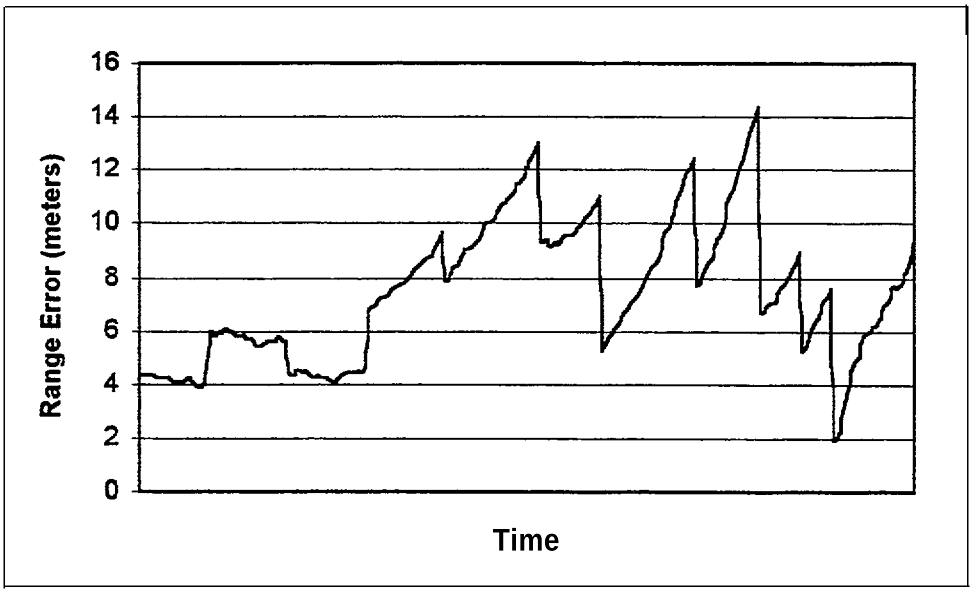

Figure 14-2 Test 14, Range Error Measurement

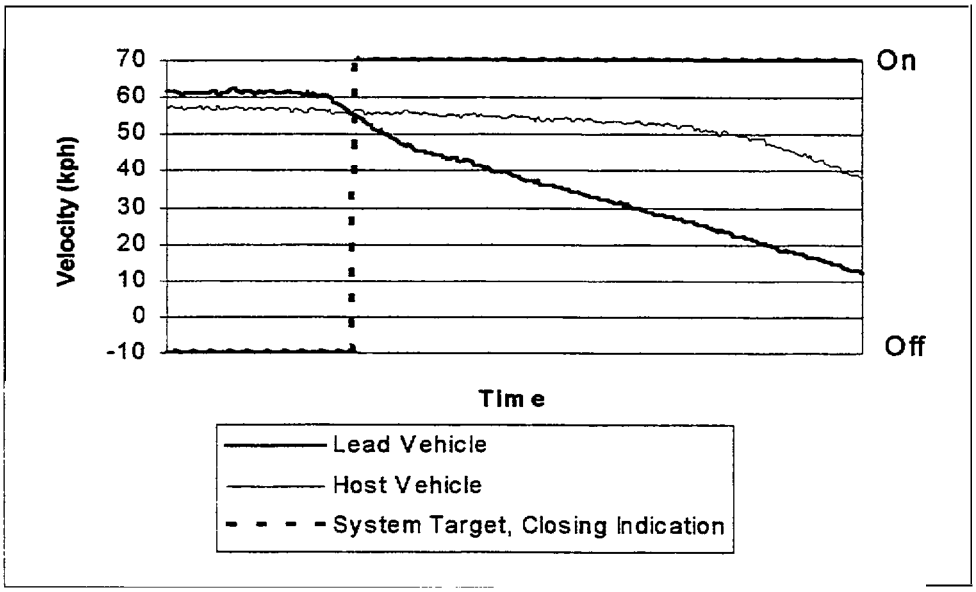

Figure 14-3 Test 14, Absolute Velocity Measurement

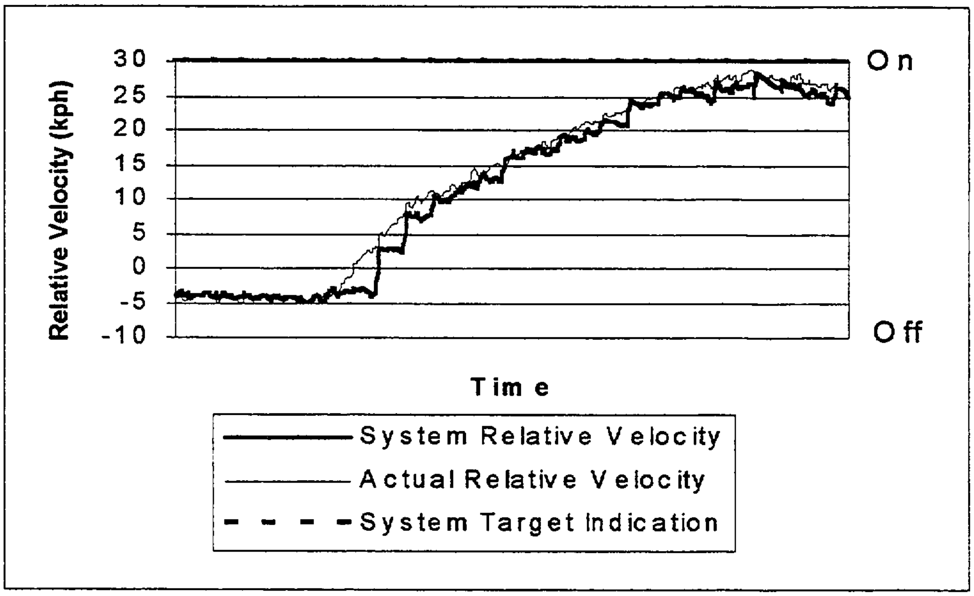

Figure 14-4 Test 14, Relative Velocity Measurement

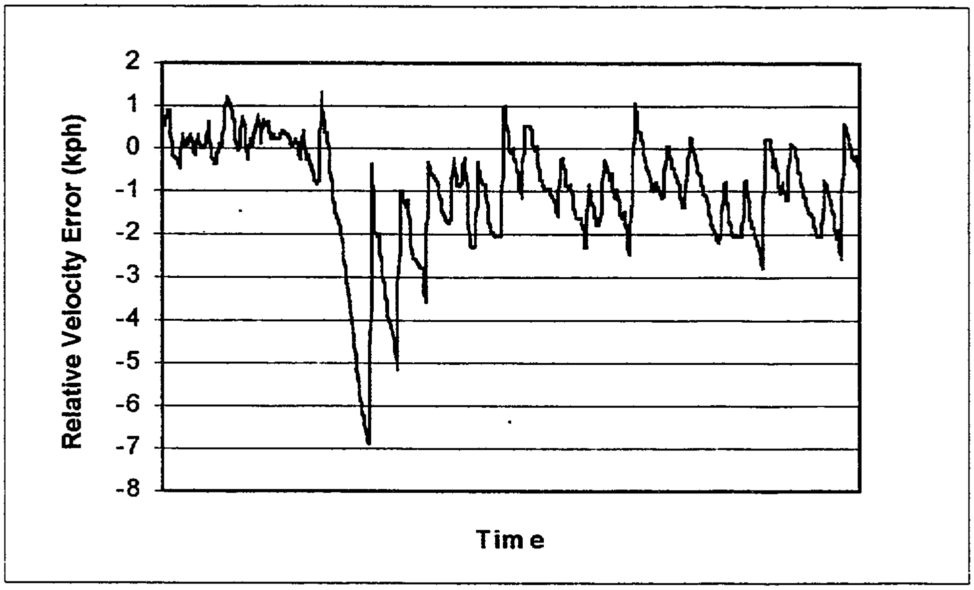

Figure 14-5 Test 14, Relative Velocity Error Measurement

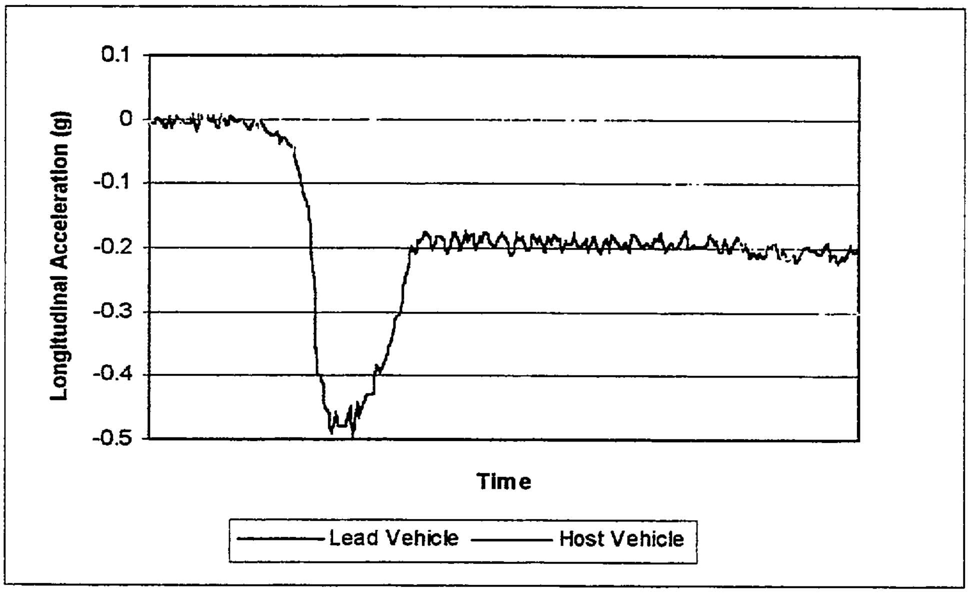

Figure 14-6 Test 14, Longitudinal Acceleration Measurement

Test Number 15: Lead Vehicle 60 kph, 0.5g deceleration, Host Vehicle 60 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 15-1. The range error is shown in Figure 15-2. The absolute velocity of the two vehicles is shown in Figure 15-3. The measured relative velocity as well as the system relative velocity is shown in Figure 15-4. The relative velocity error is shown in Figure 15-5. The range alarm from the system was detected at 54 meters, 14 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 17 kph.

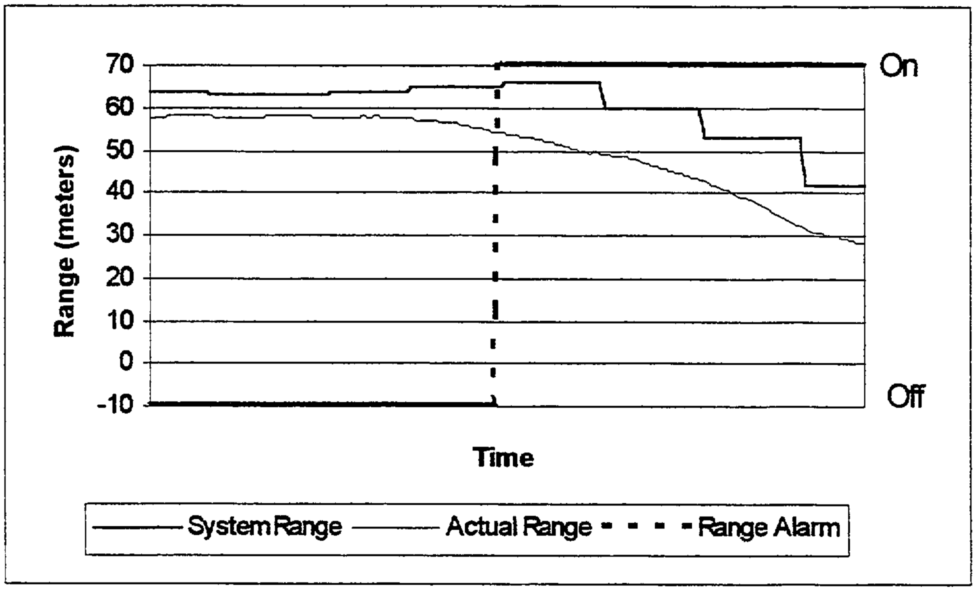

Figure 15-1 Test 15, Range Measurement

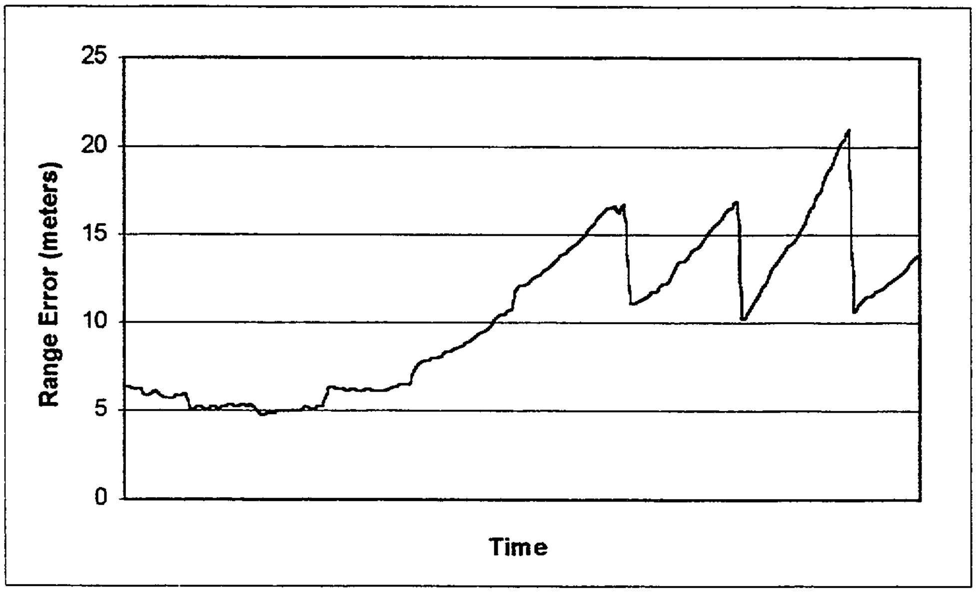

Figure 15-2 Test 15, Range Error Measurement

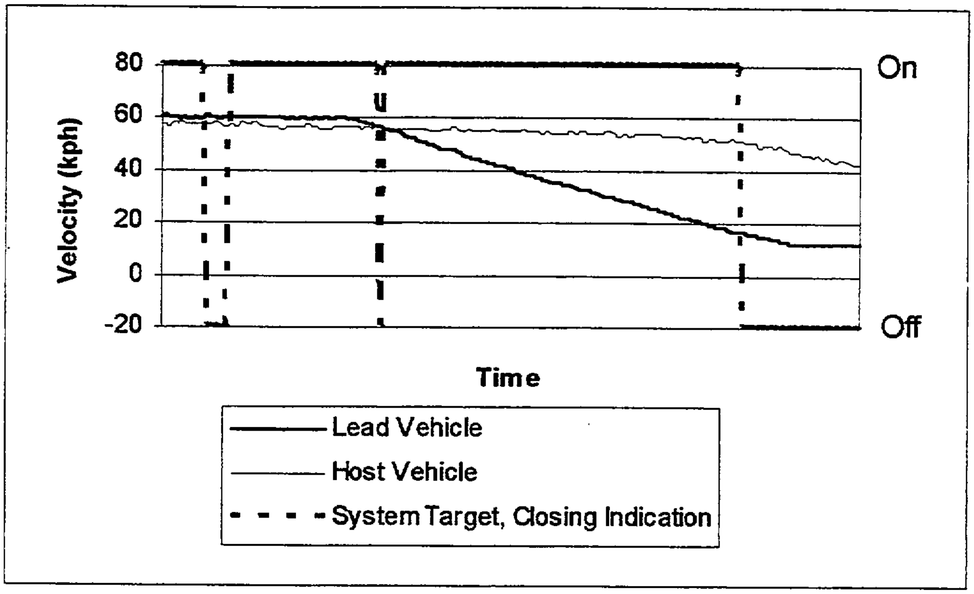

Figure 15-3 Test 15, Absolute Velocity Measurement

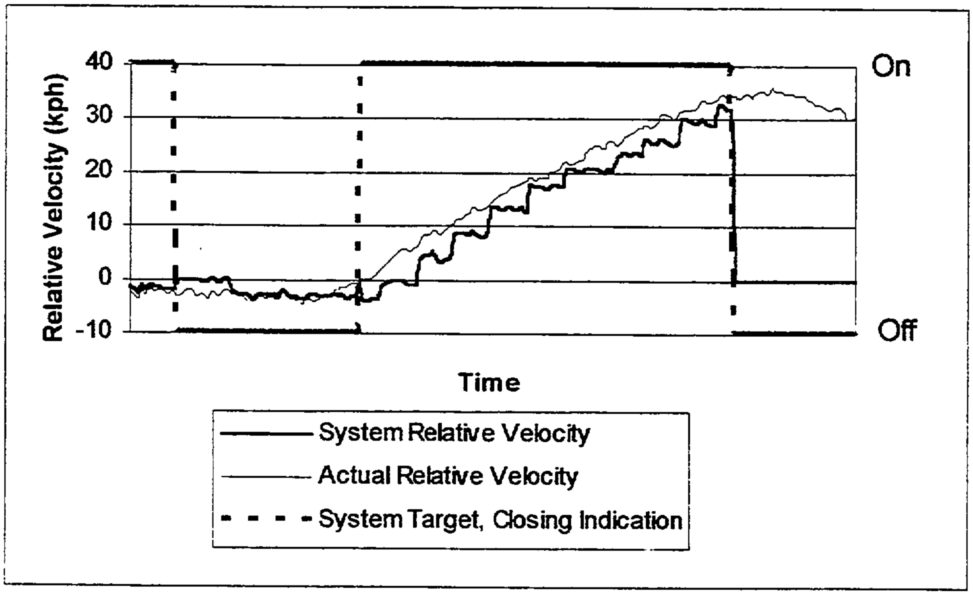

Figure 15-4 Test 15, Relative Velocity Measurement

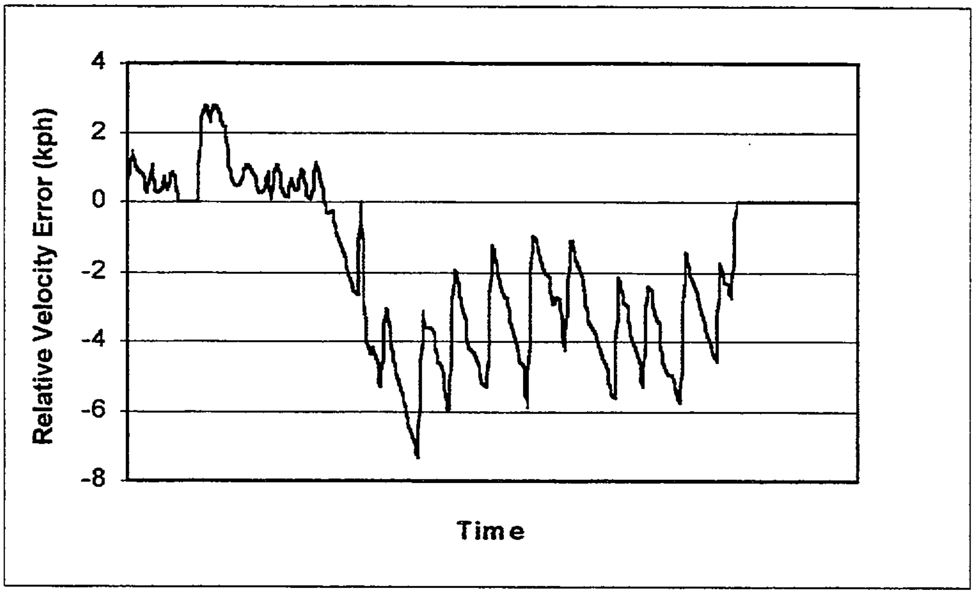

Figure 15-5 Test 15, Relative Velocity Error Measurement

Test Number 16: Lead Vehicle 60 kph, 0.75g deceleration, Host Vehicle 60 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 16-1. The range error is shown in Figure 16-2. The absolute velocity of the two vehicles is shown in Figure 16-3. The measured relative velocity as well as the system relative velocity is shown in Figure 16-4. The relative velocity error is shown in Figure 16-5. The range alarm from the system was detected at 50 meters, 15 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 17 kph.

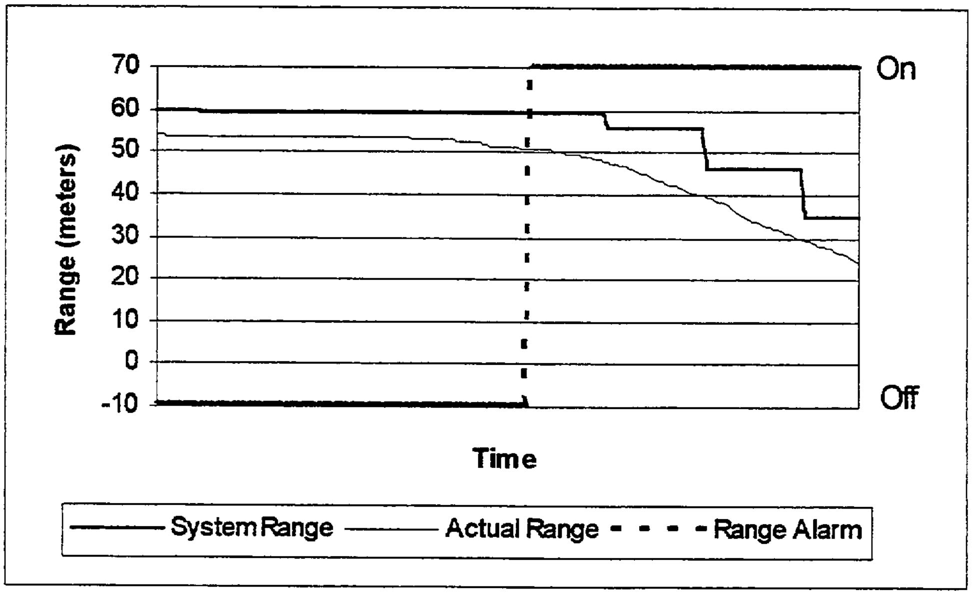

Figure 16-1 Test 16, Range Measurement

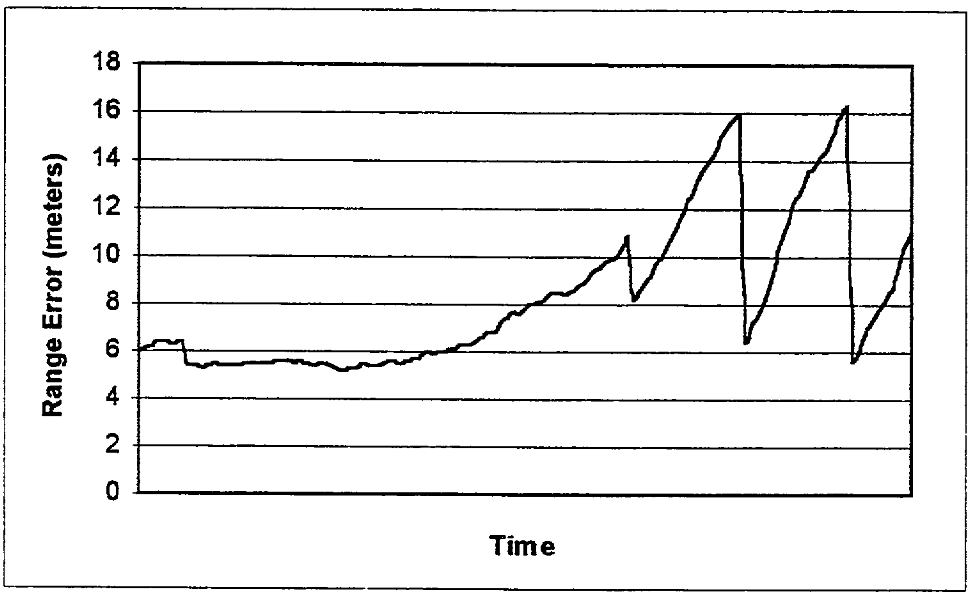

Figure 16-2 Test 16, Range Error Measurement

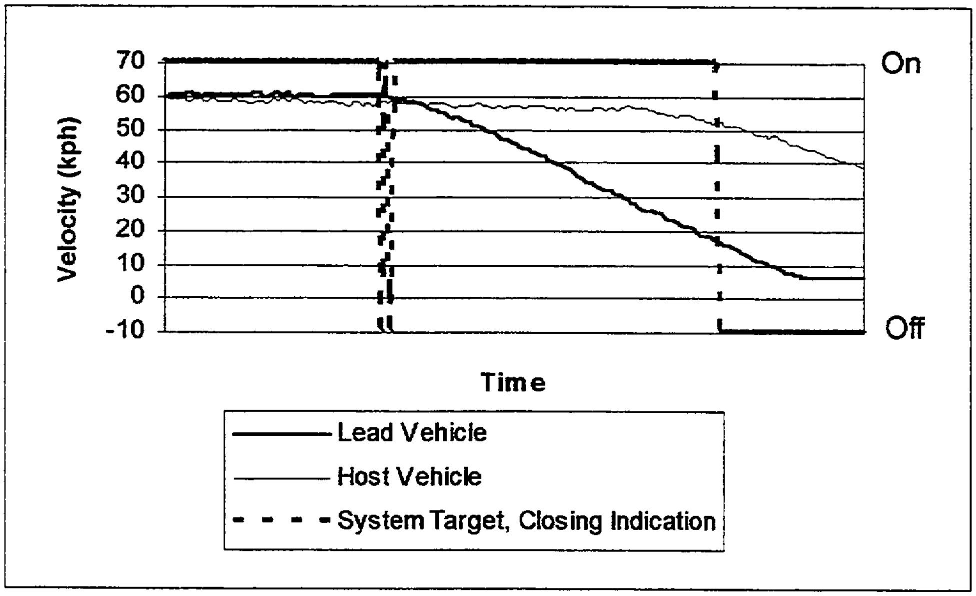

Figure 16-3 Test 16, Absolute Velocity Measurement

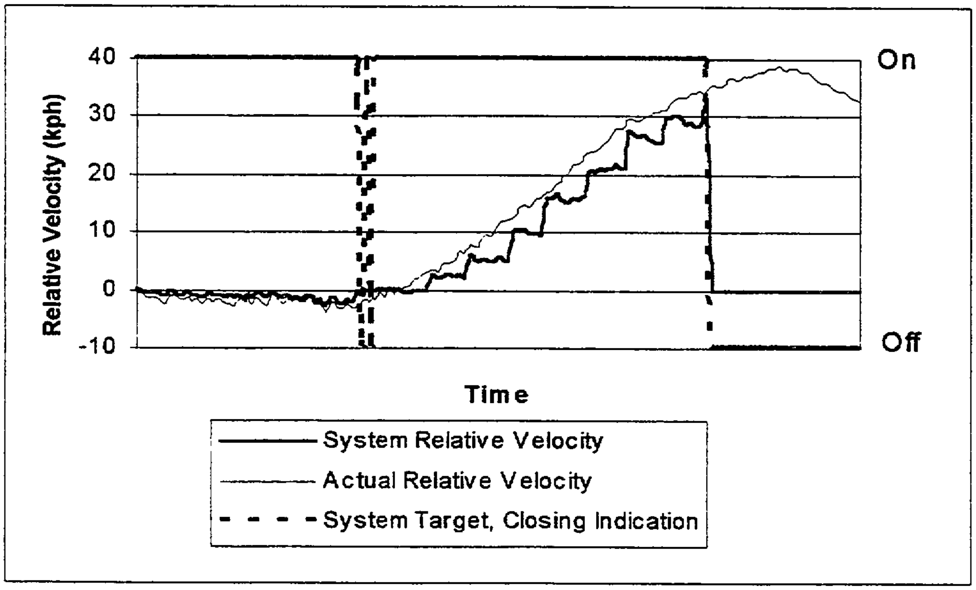

Figure 16-4 Test 16, Relative Velocity Measurement

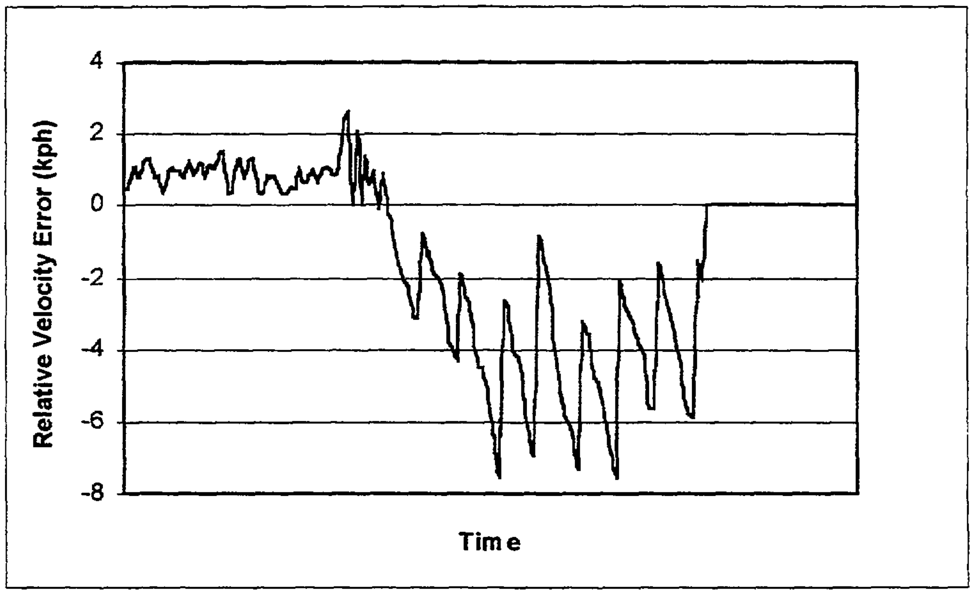

Figure 16-5 Test 16, Relative Velocity Error Measurement

Test Number 17: Lead Vehicle 40 kph, 0.25g deceleration and stopped, Host Vehicle 40 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 17-1. The range error is shown in Figure 17-2. The absolute velocity of the two vehicles is shown in Figure 17-3. The measured relative velocity as well as the system relative velocity is shown in Figure 17-4. The relative velocity error is shown in Figure 17-5. The range alarm from the system was detected at 46 meters, 14 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 12 kph.

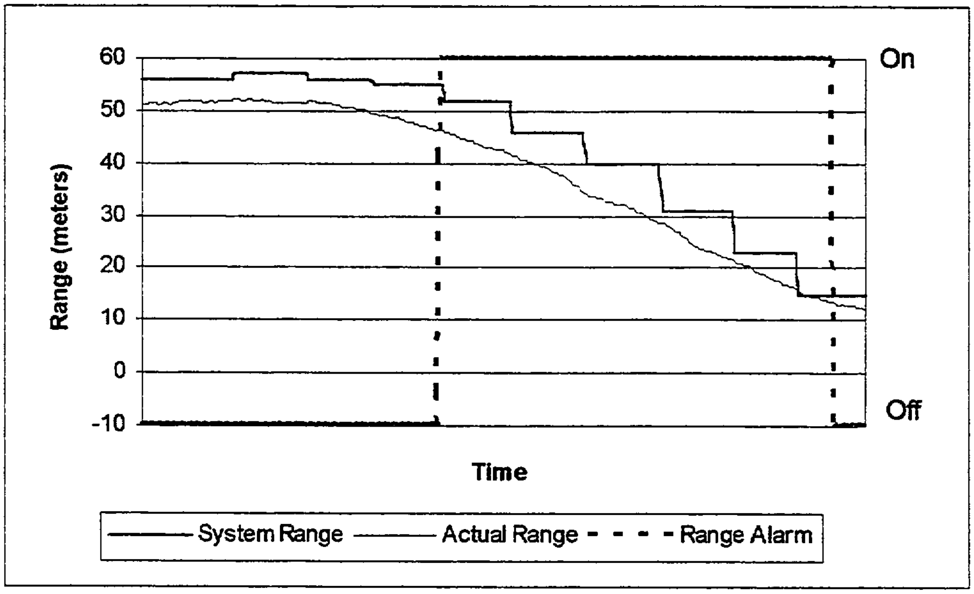

Figure 17-1 Test 17, Range Measurement

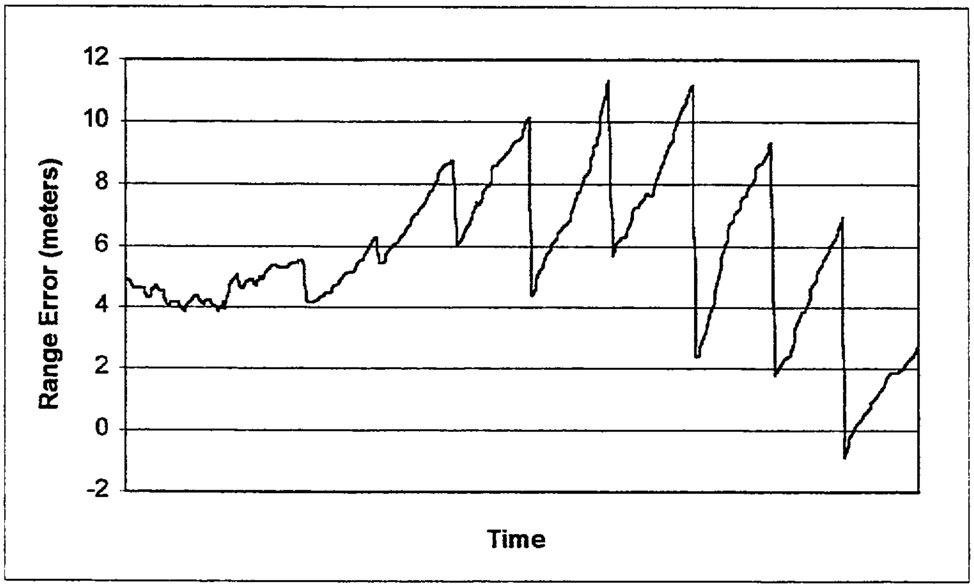

Figure 17-2 Test 17, Range Error Measurement

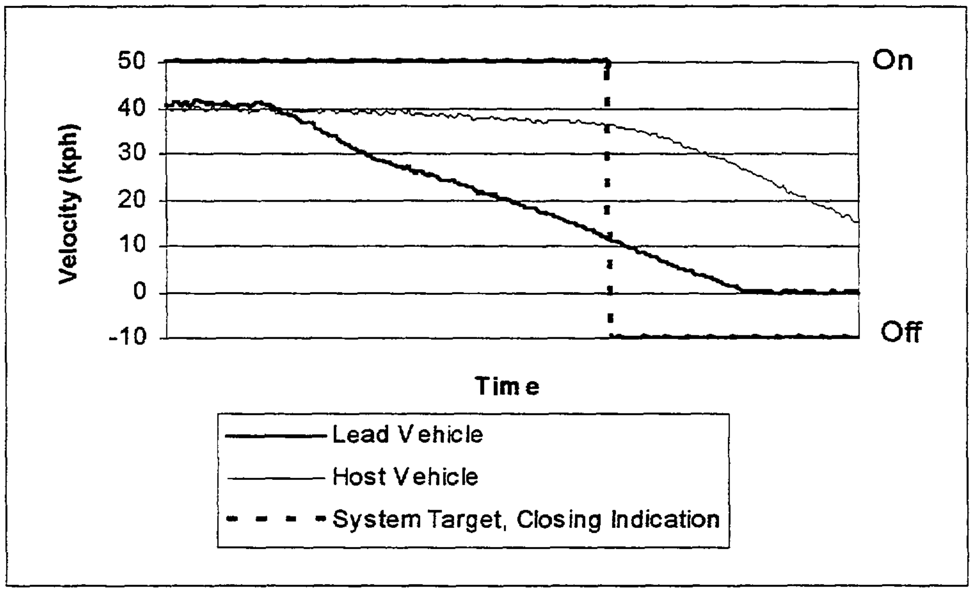

Figure 17-3 Test 17, Absolute Velocity Measurement

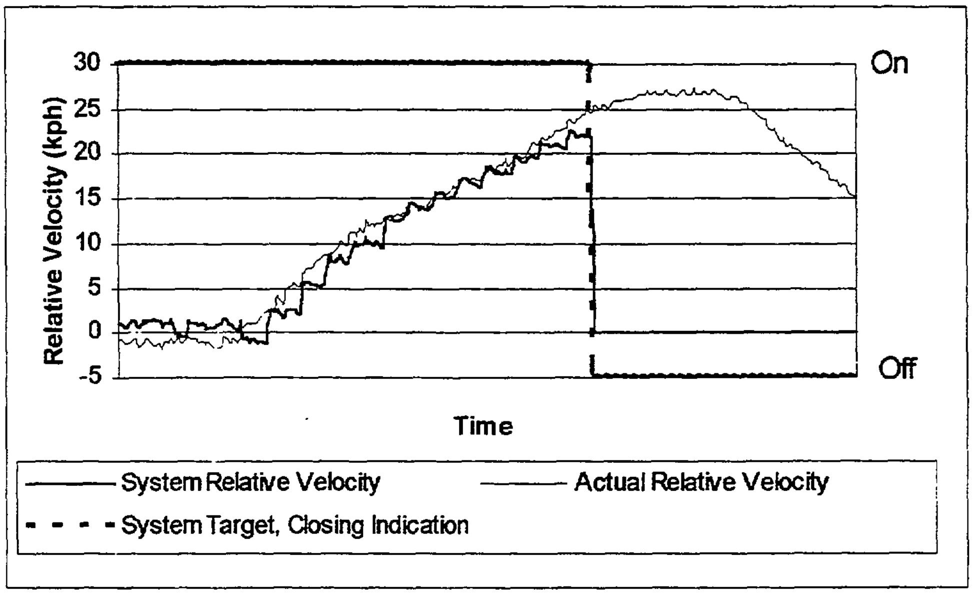

Figure 17-4 Test 17, Relative Velocity Measurement

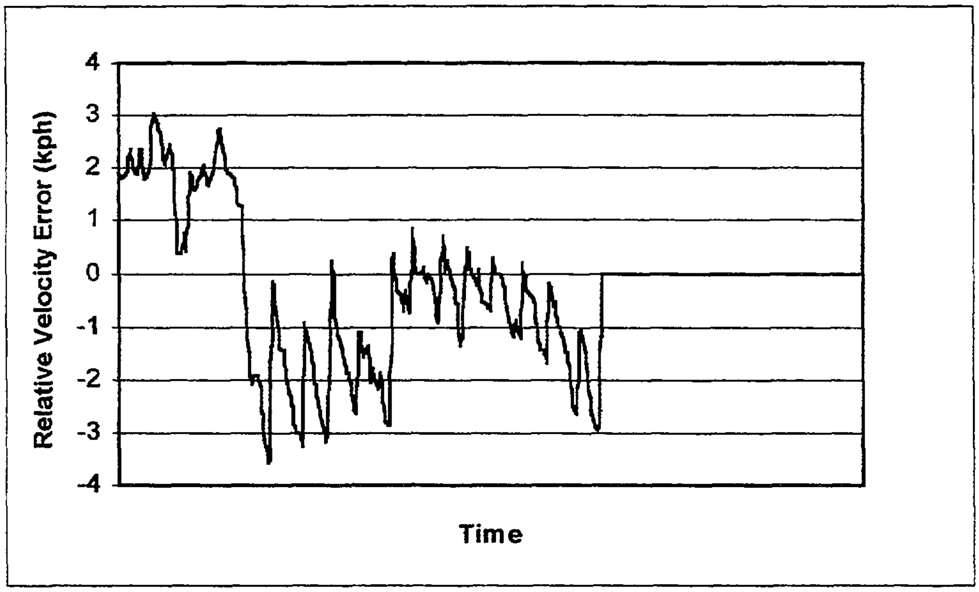

Figure 17-5 Test 17, Relative Velocity Error Measurement

Test Number 18: Lead Vehicle 40 kph, 0.5g deceleration and stopped, Host Vehicle 40 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 18-1. The range error is shown in Figure 18-2. The absolute velocity of the two vehicles is shown in Figure 18-3. The measured relative velocity as well as the system relative velocity is shown in Figure 18-4. The relative velocity error is shown in Figure 18-5. The range alarm from the system was detected at 50 meters, 19 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 12 kph.

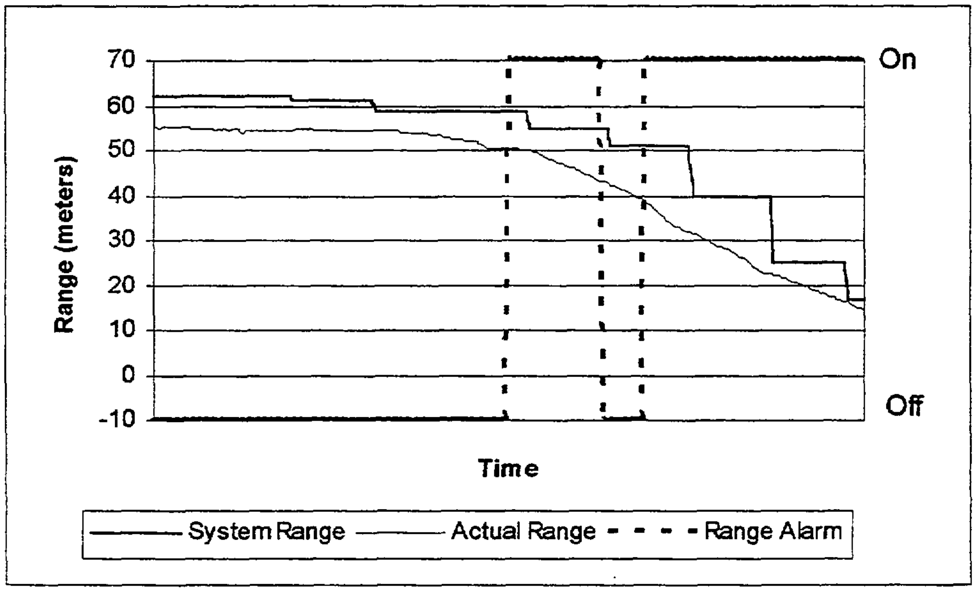

Figure 18-1 Test 18, Range Measurement

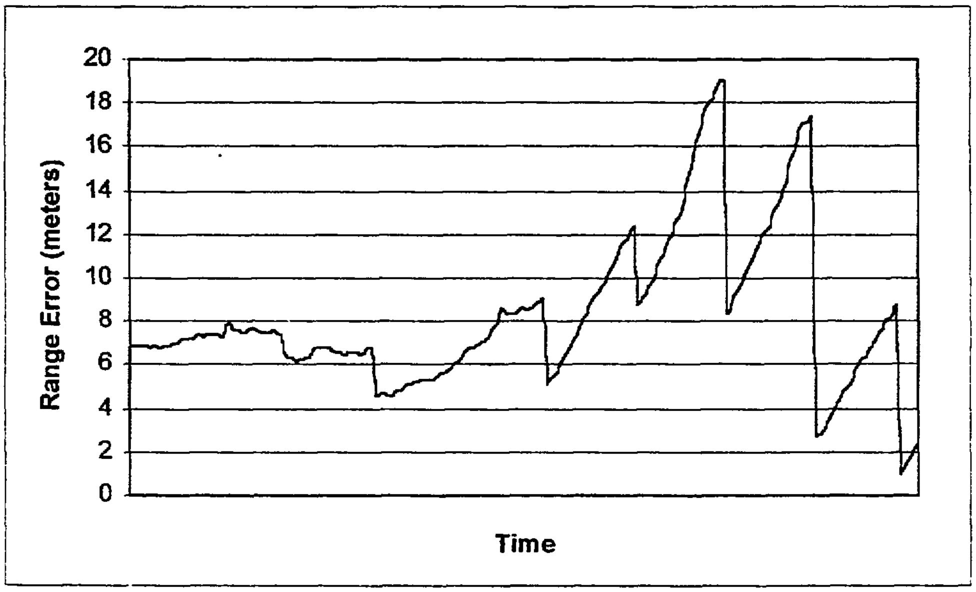

Figure 18-2 Test 18, Range Error Measurement

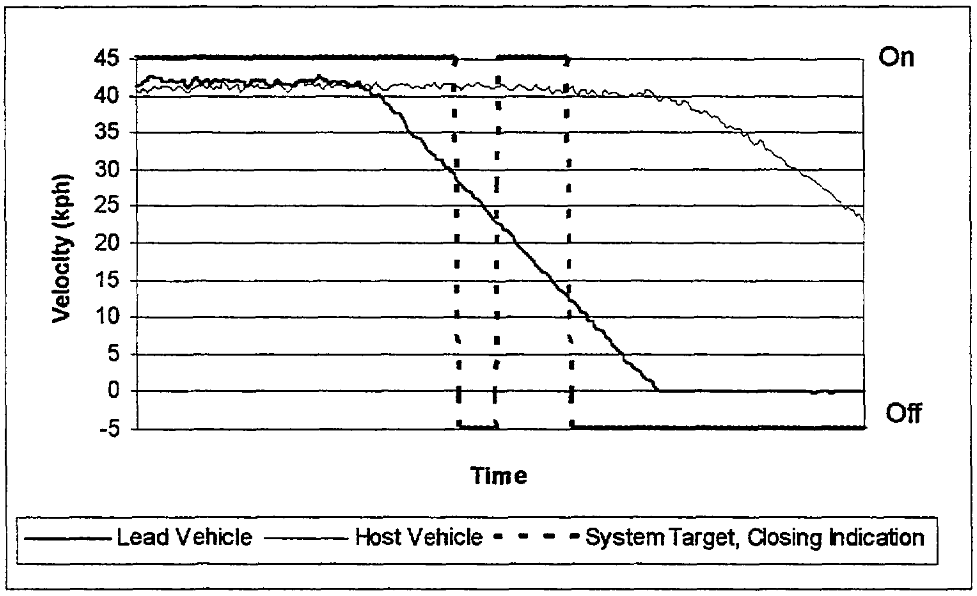

Figure 18-3 Test 18, Absolute Velocity Measurement

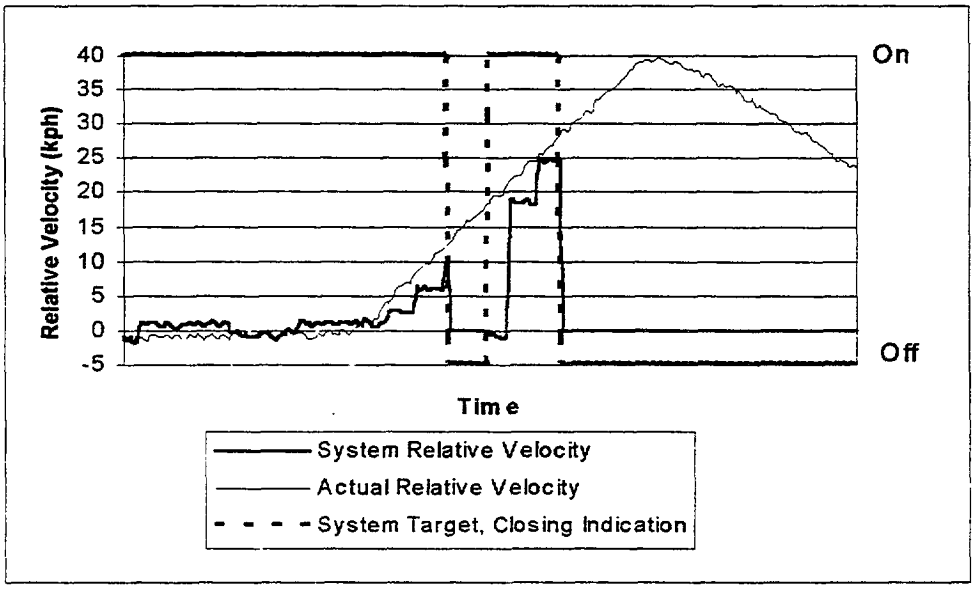

Figure 18-4 Test 18, Relative Velocity Measurement

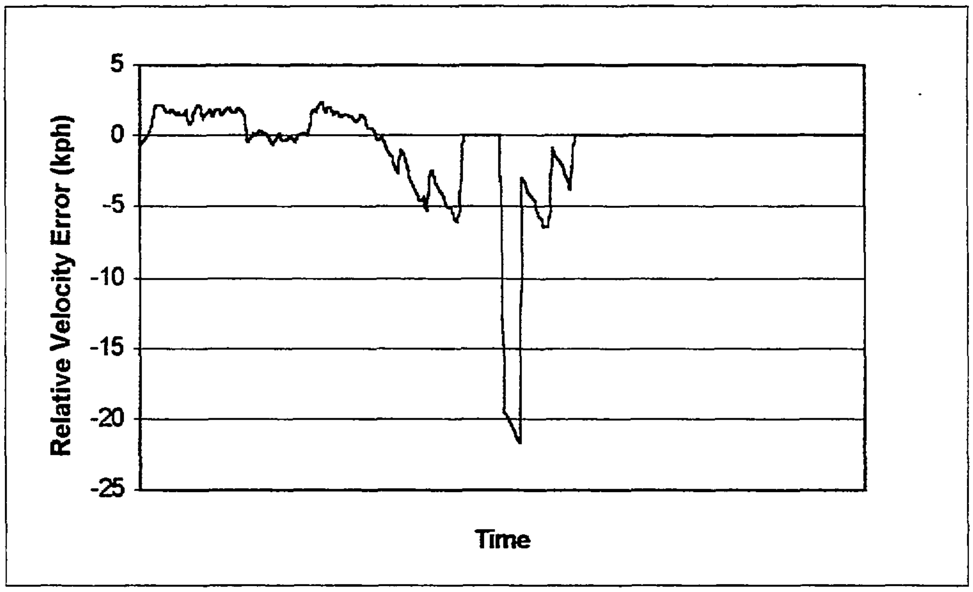

Figure 18-5 Test 18, Relative Velocity Error Measurement

Test Number 19: Lead Vehicle 40 kph, 0.75g deceleration and stopped. Host Vehicle 40 kph

The datafile for this test was inadvertently lost. The data presented has been taken from the video tape record of the test. The alarm from the system was detected at 42 meters, 16 kph from the lead vehicle.

Test Number 20: Lead Vehicle Stopped. Host Vehicle 20 kph. 0.25g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 20-1. The range error is shown in Figure 20-2. The absolute velocity of the two vehicles is shown in Figure 20-3. The range alarm from the system was detected at 41 meters, 21 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

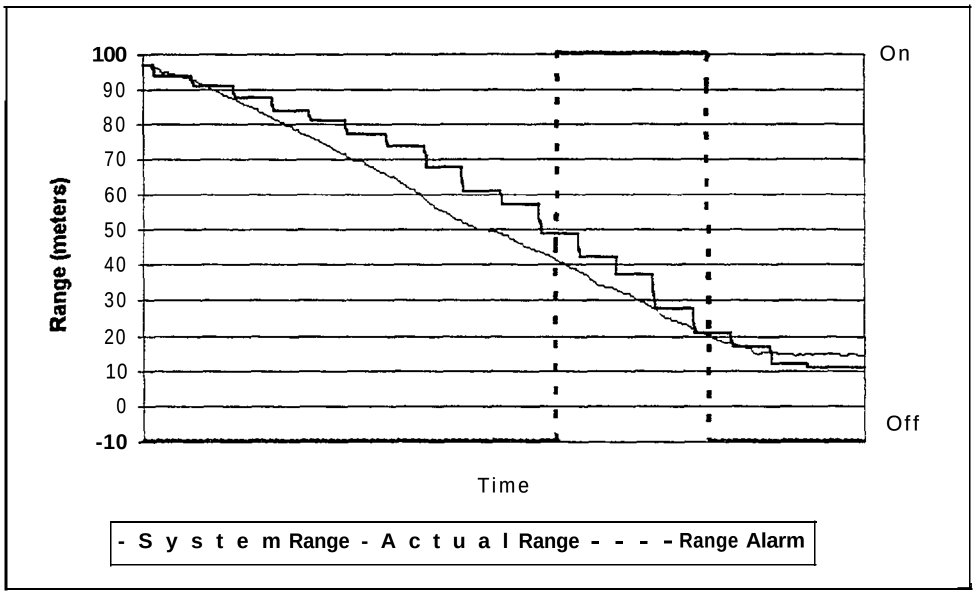

Figure 20-l Test 20, Range Measurement

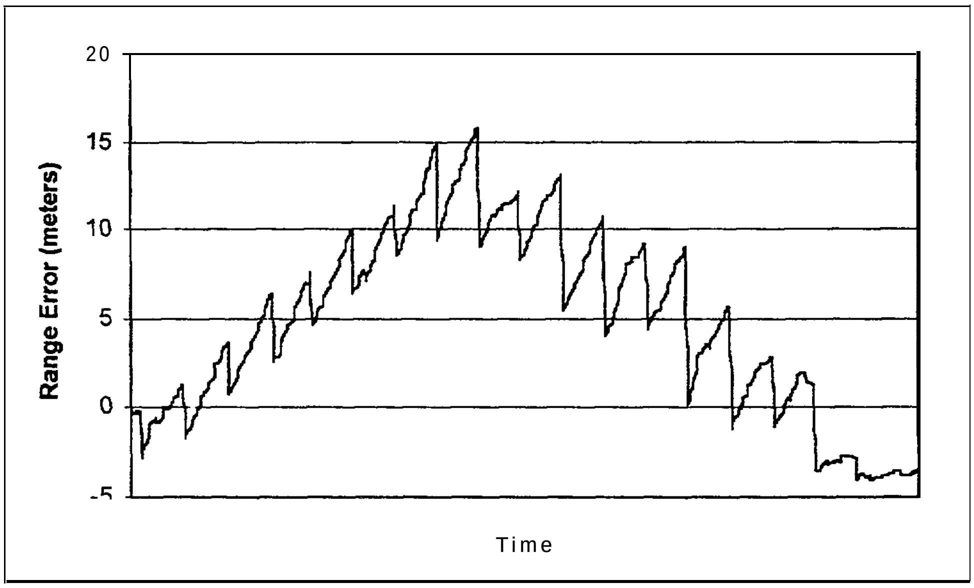

Figure 20-2 Test 20, Range Error Measurement

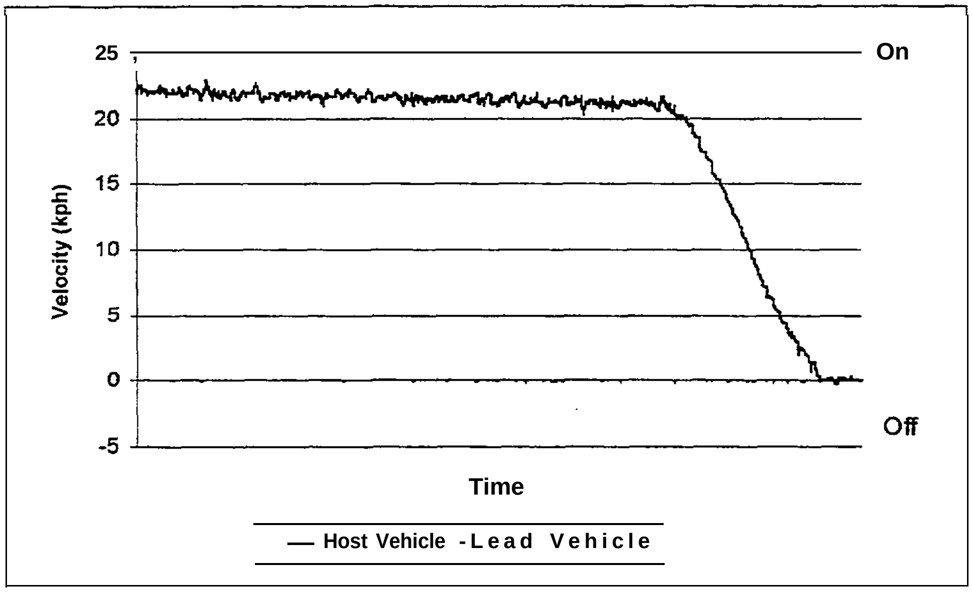

Figure 20-3 Test 20, Absolute Velocity Measurement

Test Number 21: Lead Vehicle Stopped Host Vehicle 20 kph, 0.5g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 2 l- 1. The range error is shown in Figure 21-2. The absolute velocity of the two vehicles is shown in Figure 2 I-3. The range alarm from the system was detected at 40 meters, 20 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles

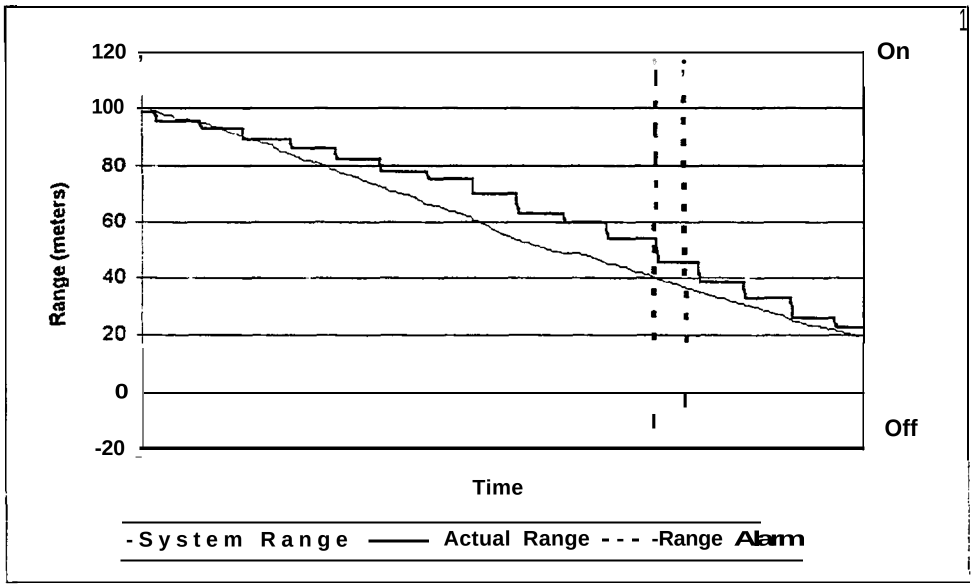

Figure 2 1 - 1 Test 2 I, Range Measurement

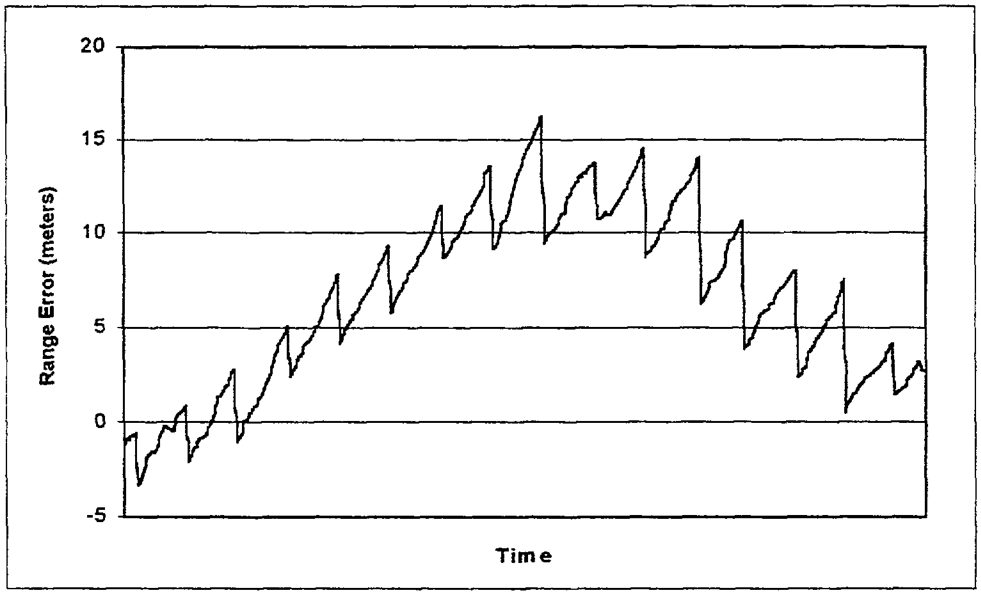

Figure 21-2 Test 21, Range Error Measurement

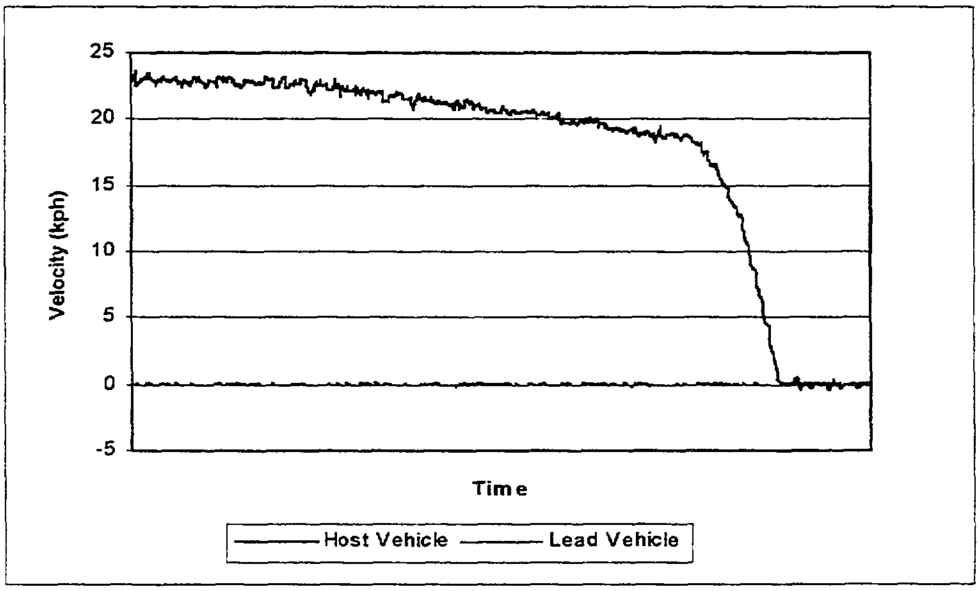

Figure 21-3 Test 21, Absolute Velocity Measurement

Test Number 22: Lead Vehicle Stopped, Host Vehicle 40 kph, 0.25g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 22-1. The range error is shown in Figure 22-2. The absolute velocity of the two vehicles is shown in Figure 22-3. The range alarm from the system was detected at 39 meters, 38 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

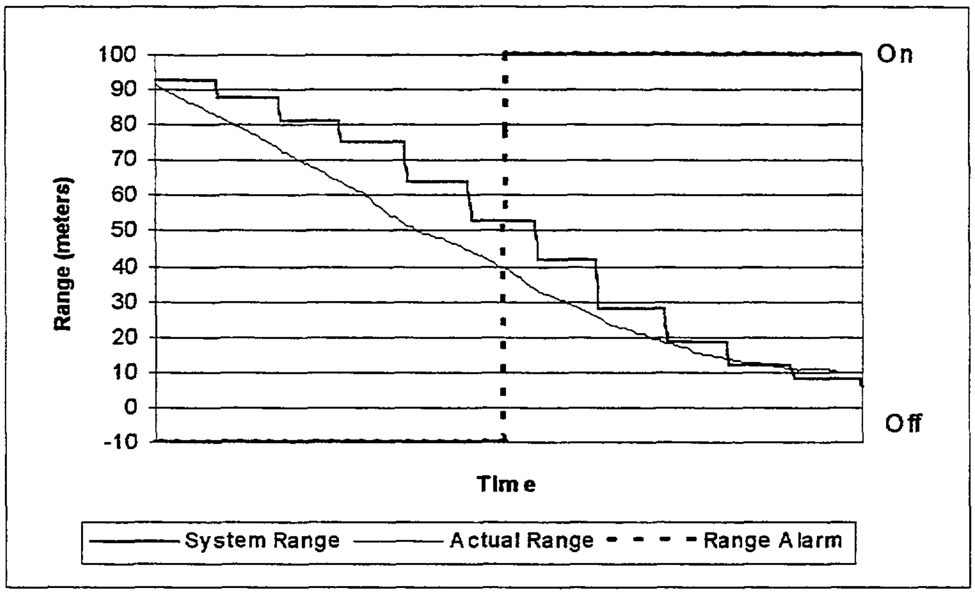

Figure 22-1 Test 22, Range Measurement

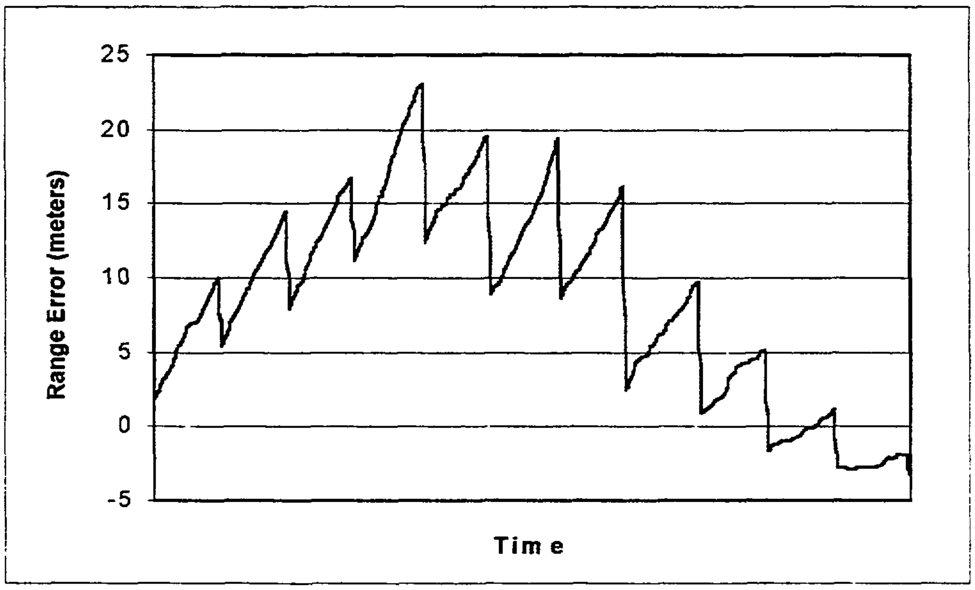

Figure 22-2 Test 22, Range Error Measurement

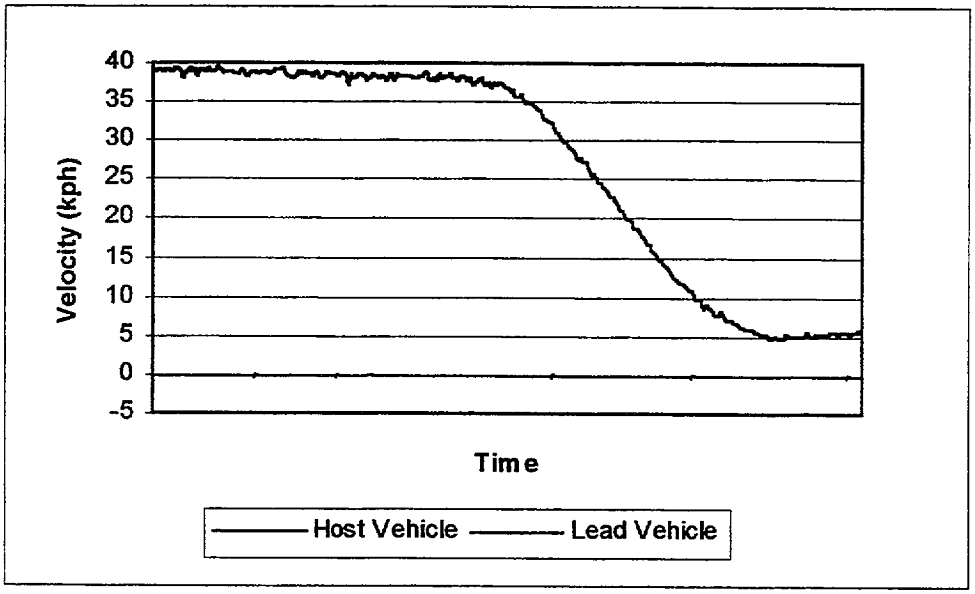

Figure 22-3 Test 22, Absolute Velocity Measurement

Test Number 23: Lead Vehicle Stopped, Host Vehicle 40 kph, 0.5g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 23-1. The range error is shown in Figure 23-2. The absolute velocity of the two vehicles is shown in Figure 23-3. The range alarm from the system was detected at 39 meters, 36 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

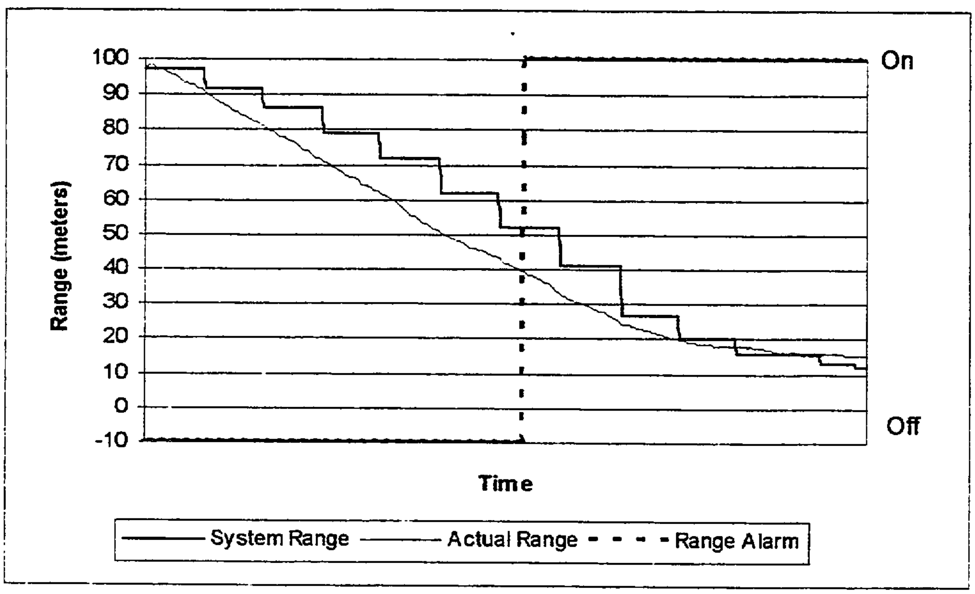

Figure 23-1 Test 23, Range Measurement

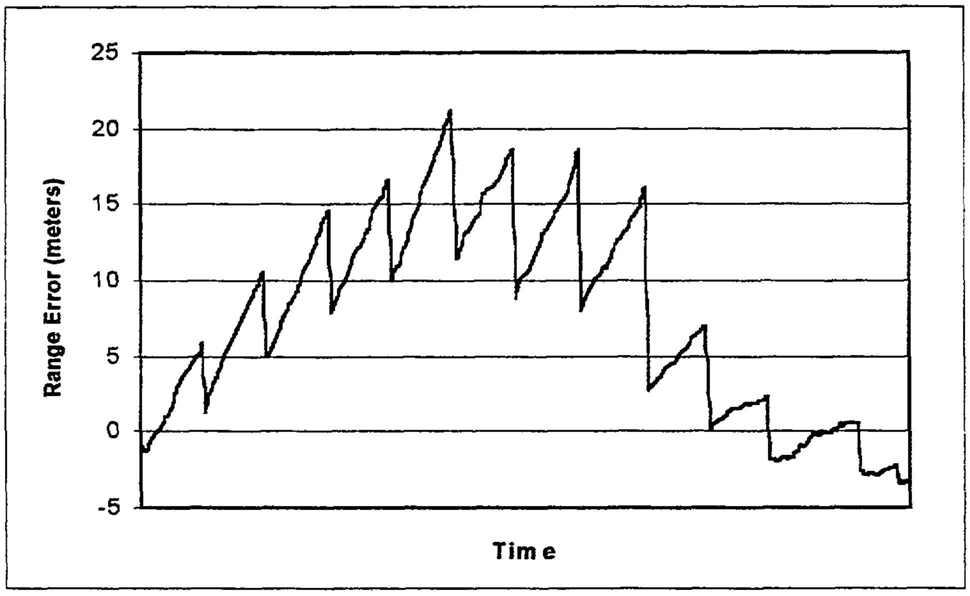

Figure 23-2 Test 23, Range Error Measurement

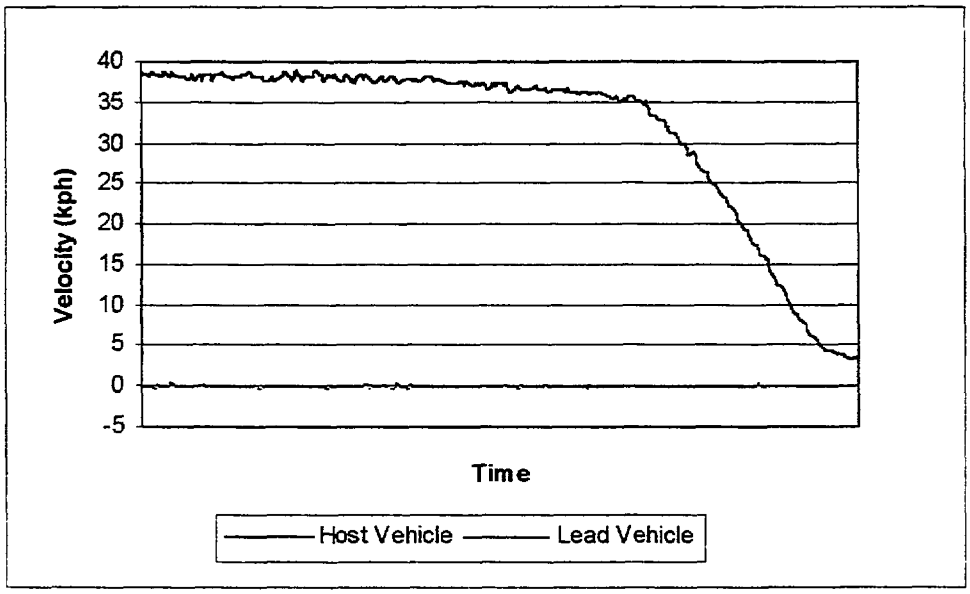

Figure 23-3 Test 23, Absolute Velocity Measurement

Test Number 24: Lead Vehicle Stopped, Host Vehicle 60 kph, 0.25g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 24-1. The range error is shown in Figure 24-2. The absolute velocity of the two vehicles is shown in Figure 24-3. The range alarm from the system was detected at 38 meters, 40 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

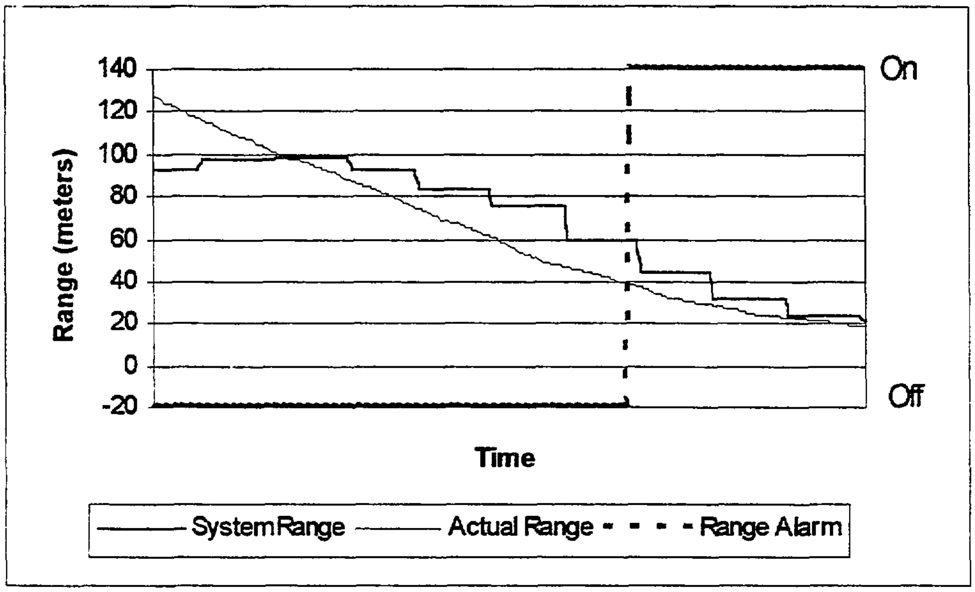

Figure 24-1 Test 24, Range Measurement

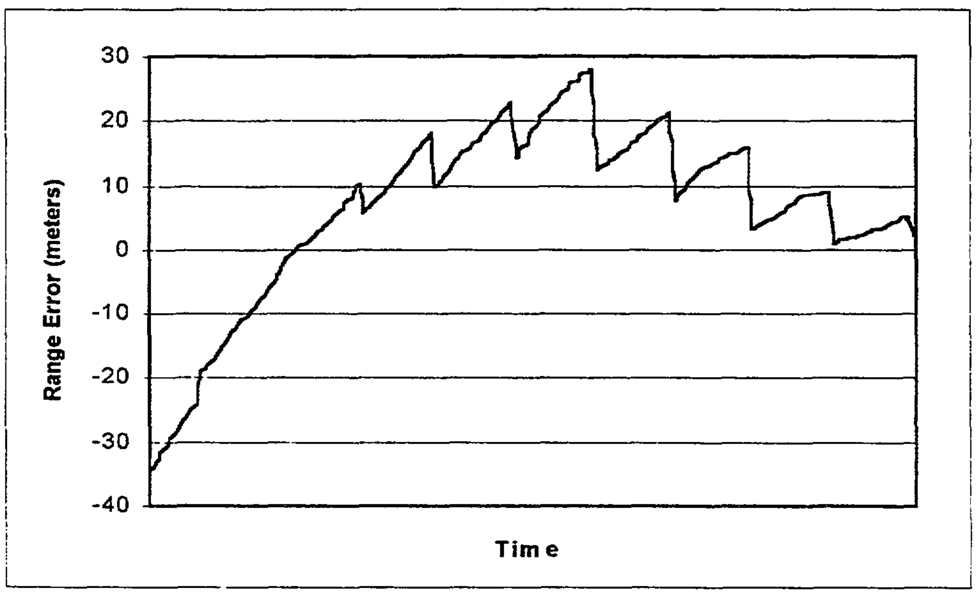

Figure 24-2 Test 24, Range Error Measurement

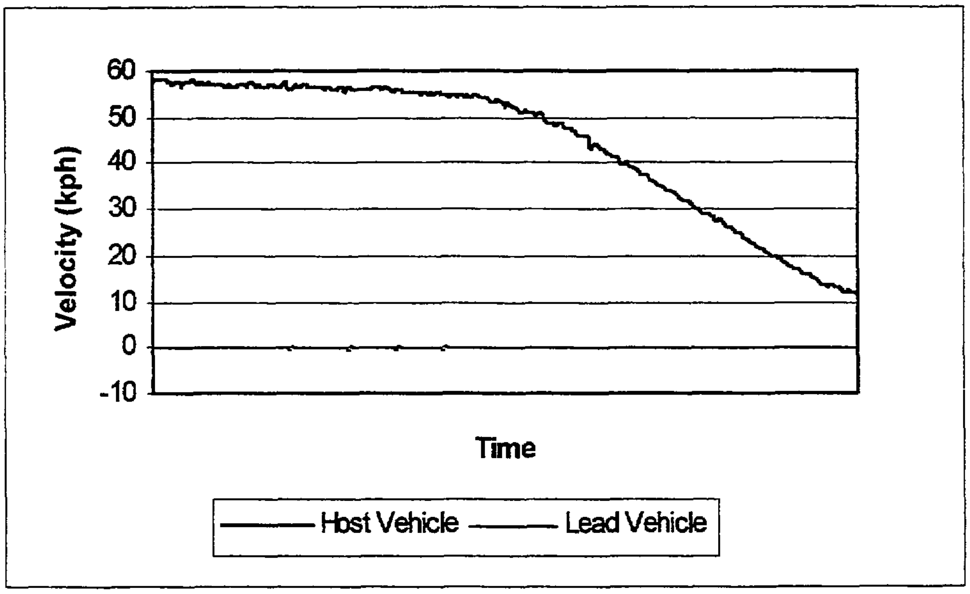

Figure 24-3 Test 24, Absolute Velocity Measurement

Test Number 25: Lead Vehicle Stopped, Host Vehicle 60 kph, 0.5g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 25-1. The range error is shown in Figure 25-2. The absolute velocity of the two vehicles is shown in Figure 25-3. The range alarm from the system was detected at 38 meters, 46 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

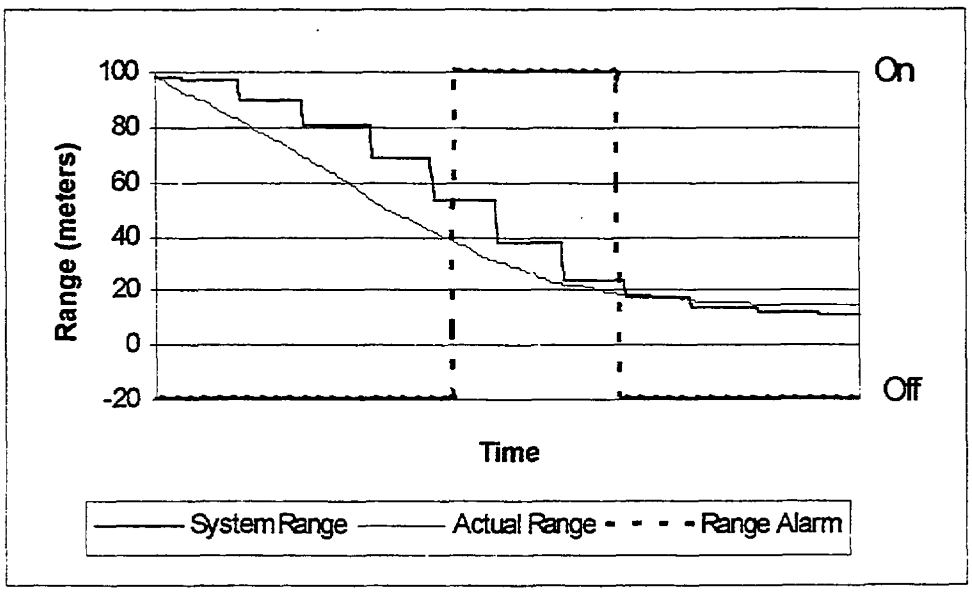

Figure 25-1 Test 25, Range Measurement

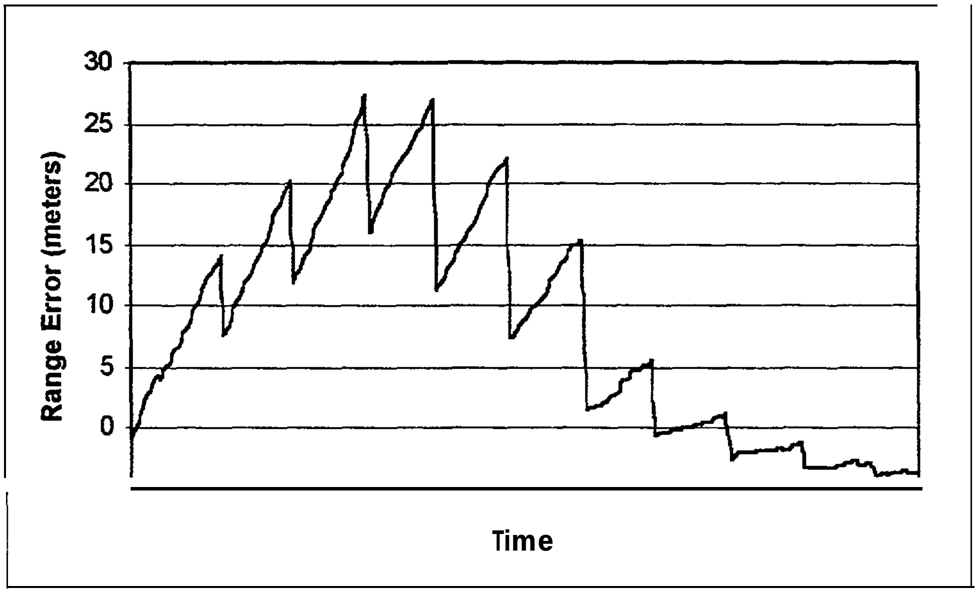

Figure 25-2 Test 25, Range Error Measurement

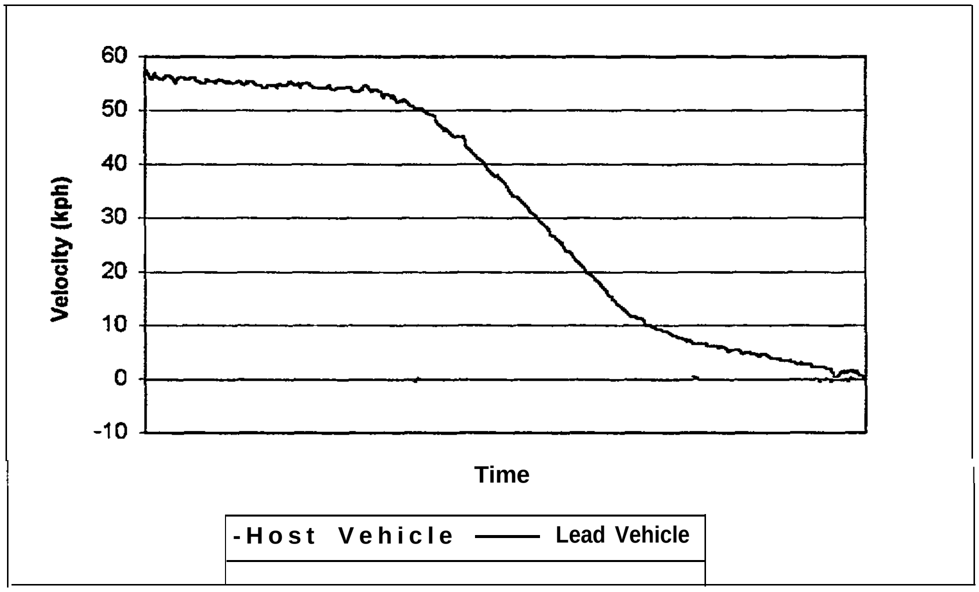

Figure 25-3 Test 25, Absolute Velocity Measurement

Test Number 26: Lead Vehicle 40 kph, Host Vehicle 60 kph, 0.25g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 26-l. The range error is shown in Figure 26-2. The absolute velocity of the two vehicles is shown in Figure 26-3. The actual relative velocity as well as the system relative velocity is shown in Figure 26-4. The relative velocity error is shown in Figure 26-5. The range alarm from the system *was* detected at 59 m.eters, 17 kph from the lead vehicle.

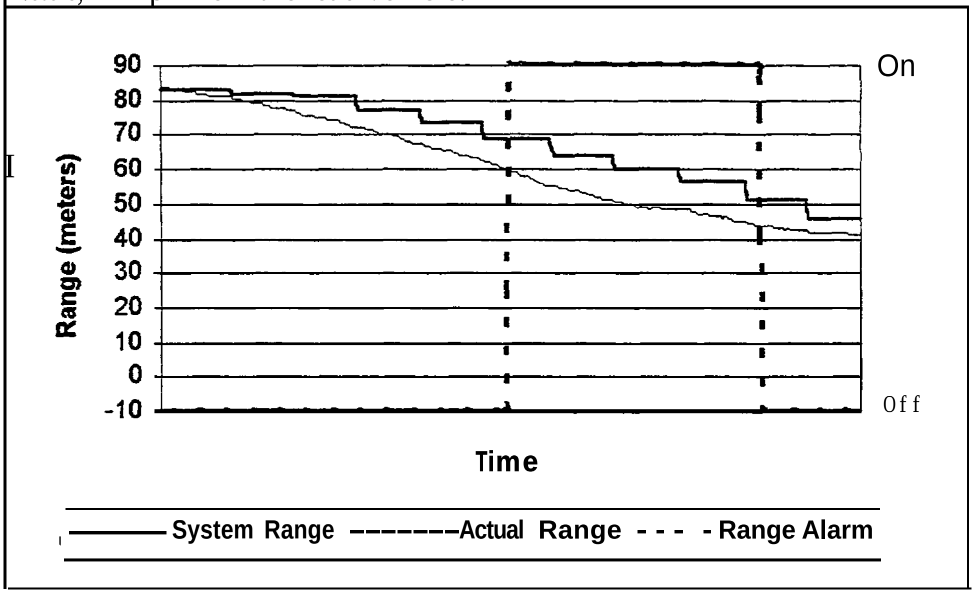

Figure 26- 1 Test 26, Range Measurement

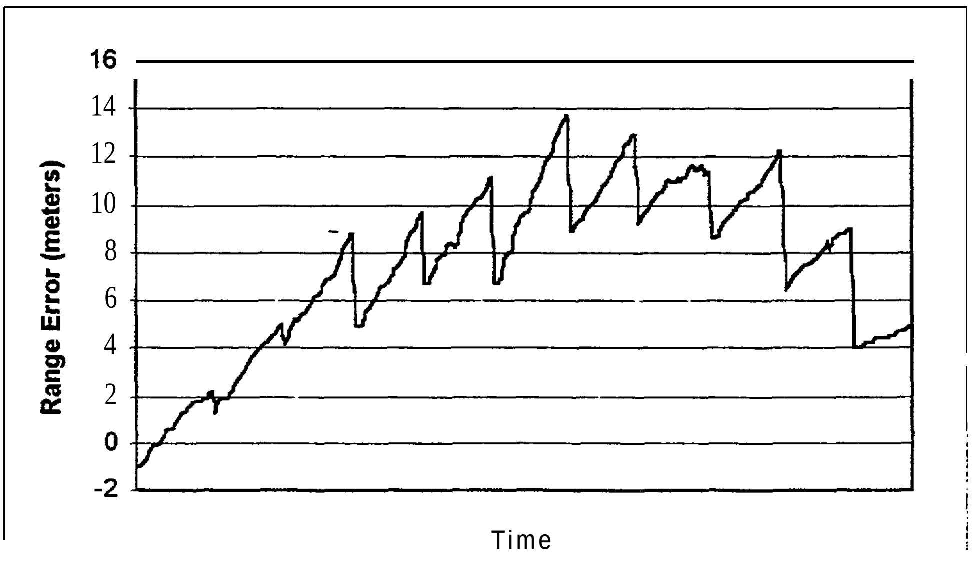

Figure 26-2 Test 26, Range Error Measurement

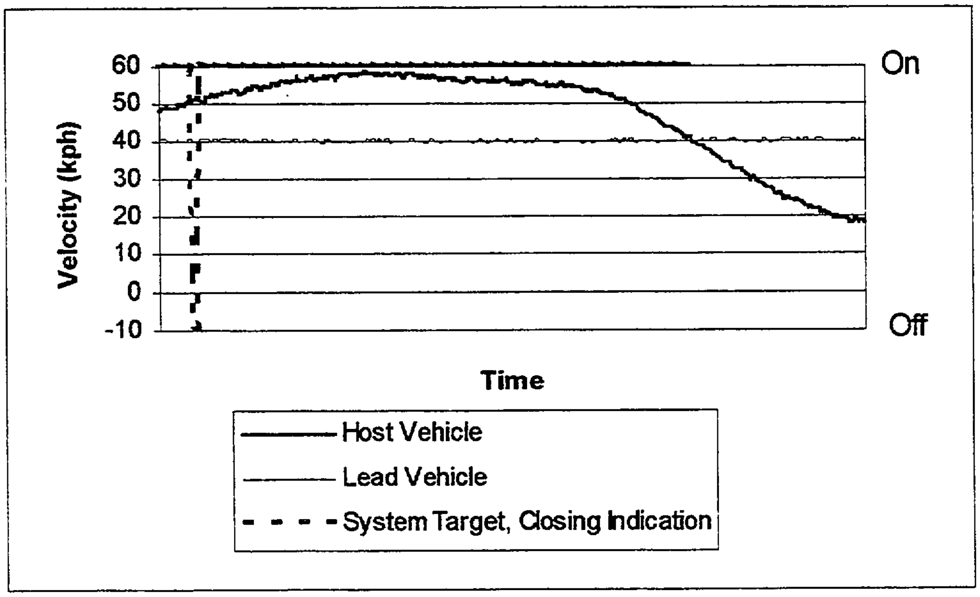

Figure 26-3 Test 26, Absolute Velocity Measurement

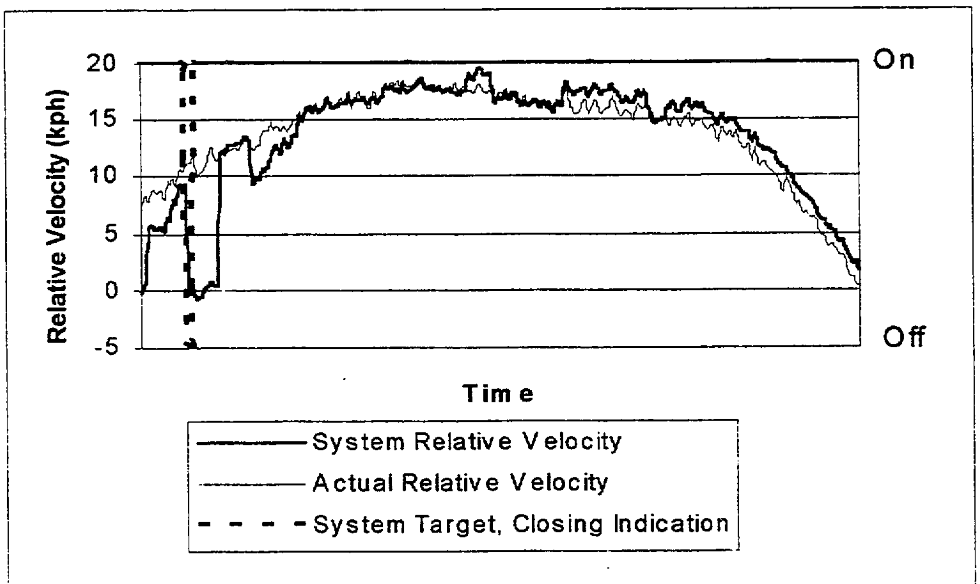

Figure 26-4 Test 26, Relative Velocity Measurement

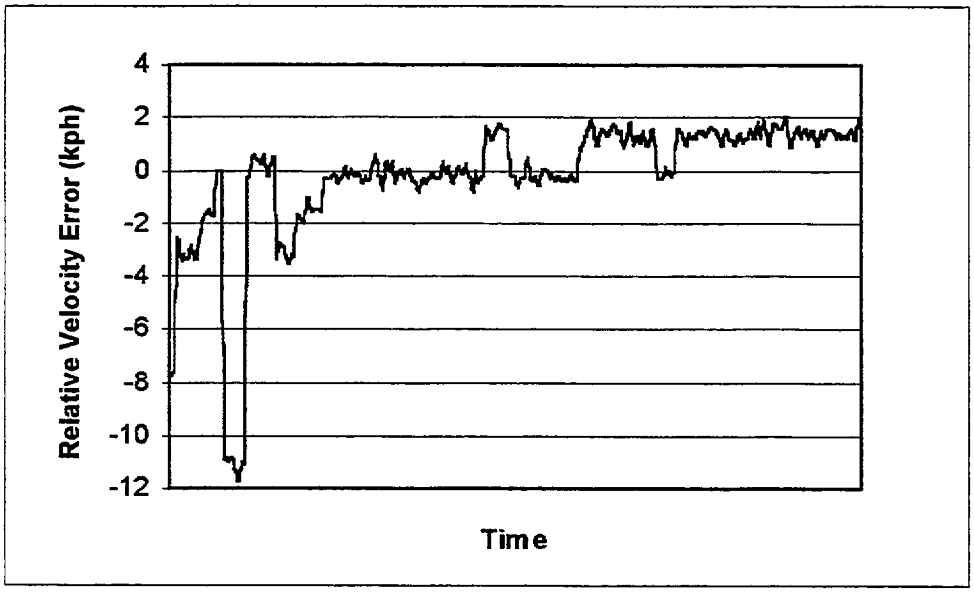

Figure 26-5 Test 26, Relative Velocity Error Measurement

Test Number 27: Lead Vehicle 20 kph, Host Vehicle 60 kph, 0.5g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 27-1. The range error is shown in Figure 27-2. The absolute velocity of the two vehicles is shown in Figure 27-3. The actual relative velocity as well as the system relative velocity is shown in Figure 27-4. The relative velocity error is shown in Figure 27-5. The alarm from the system was detected at 58 meters, 39 kph from the lead vehicle.

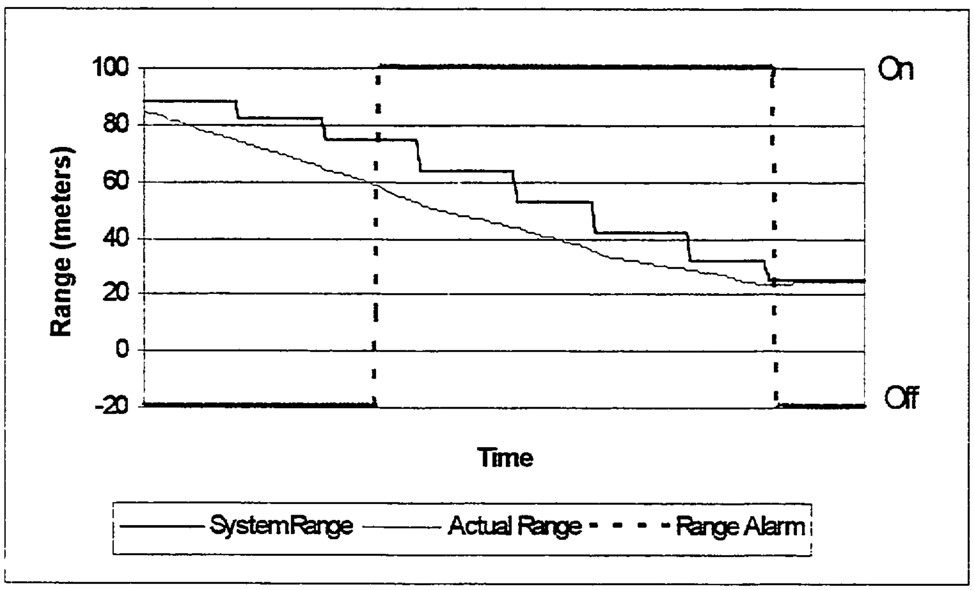

Figure 27-1 Test 27, Range Measurement

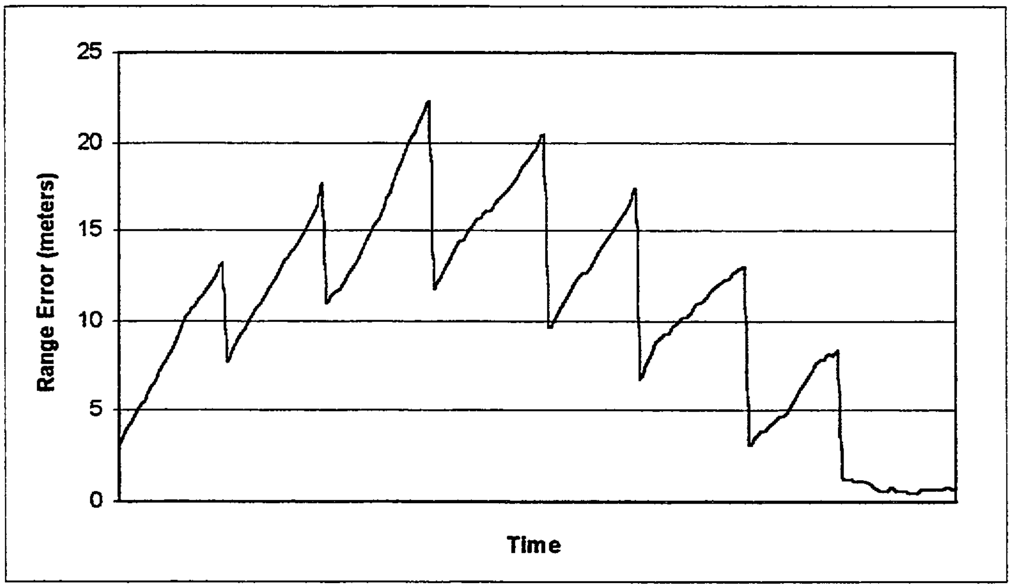

Figure 27-2 Test 27, Range Error Measurement

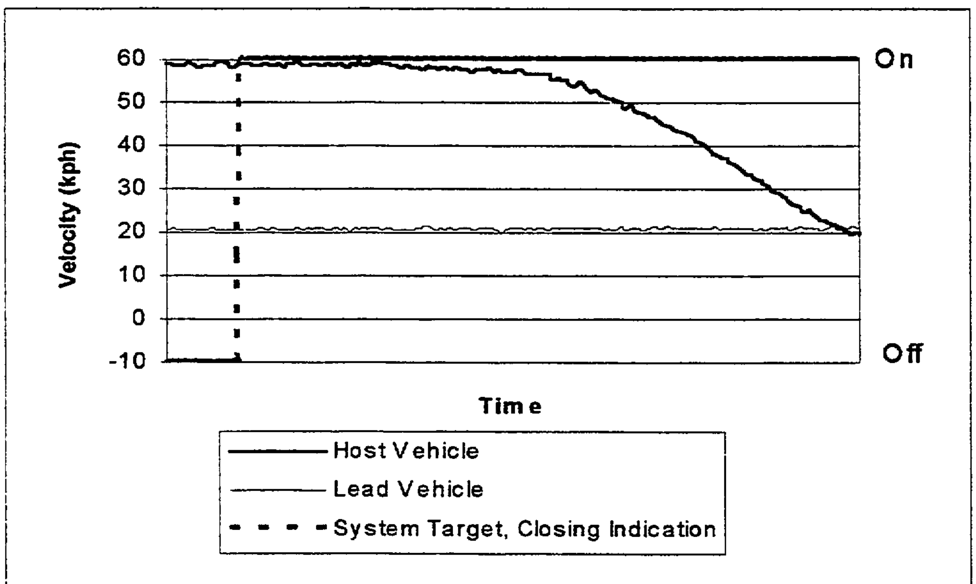

Figure 27-3 Test 27, Absolute Velocity Measurement

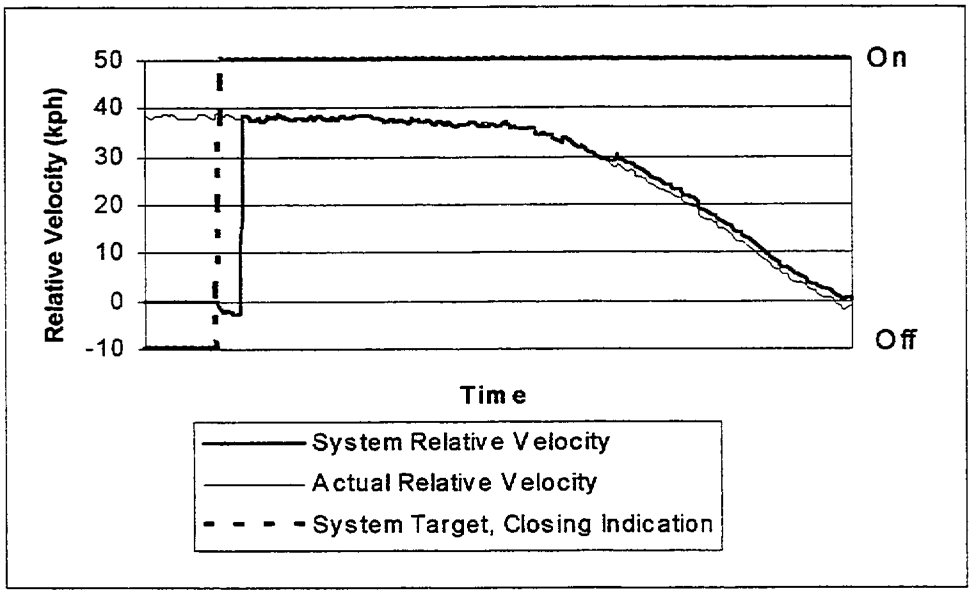

Figure 27-4 Test 27, Relative Velocity Measurement

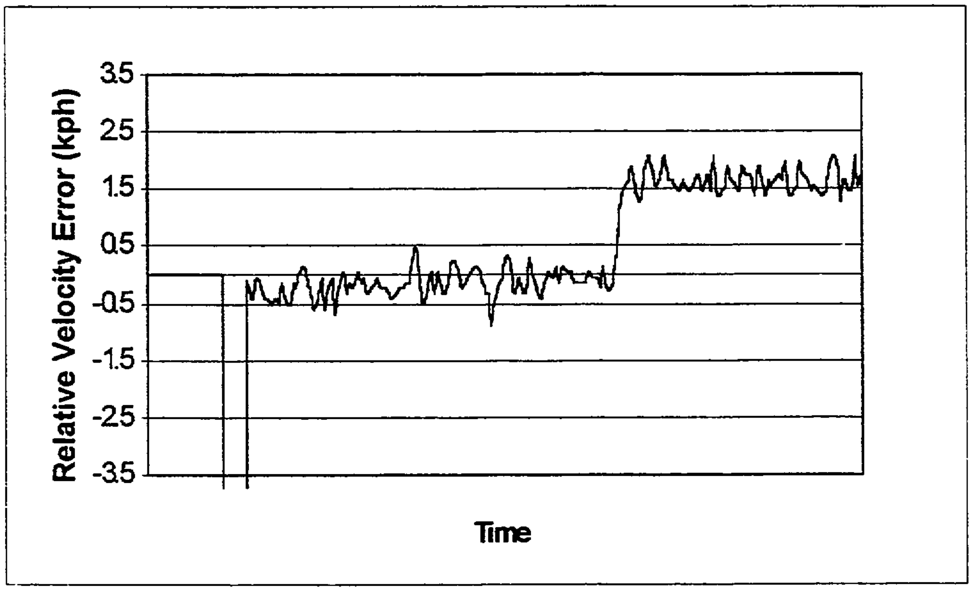

Figure 27-5 Test 27, Relative Velocity Error Measurement

Test Number 28: Lead Vehicle 40 kph, 0.5g deceleration, Host Vehicle 40 kph, 0.25 g deceleration

The actual range, the measured range from the system is shown in Figure 28-1. The range error is shown in Figure 28-2. The absolute velocity of the two vehicles is shown in Figure 28-3. The measured relative velocity as well as the system relative velocity is shown in Figure 28-4. The relative velocity error is shown in Figure 28-5. There was no range alarm from the system.

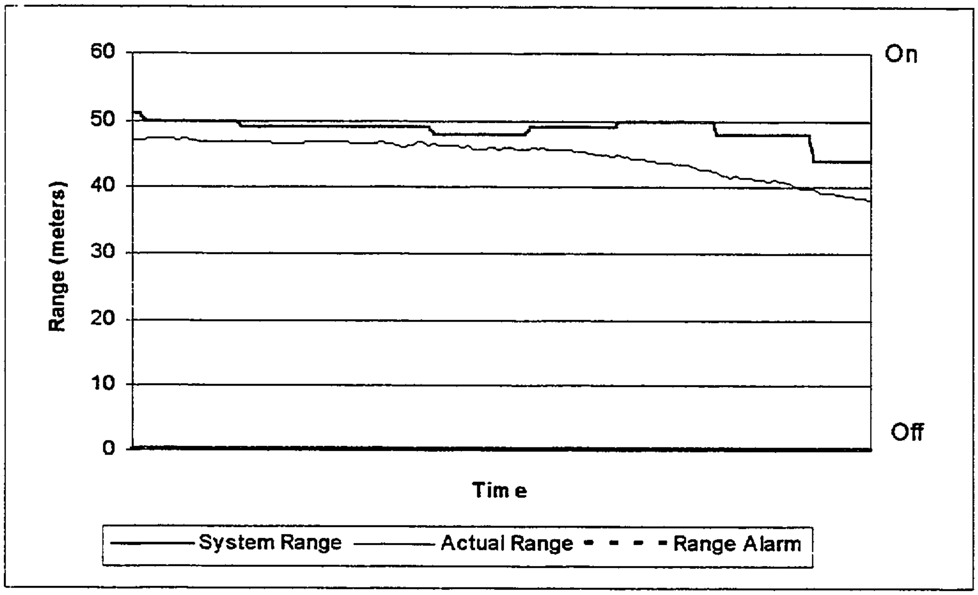

Figure 28-1 Test 28, Range Measurement

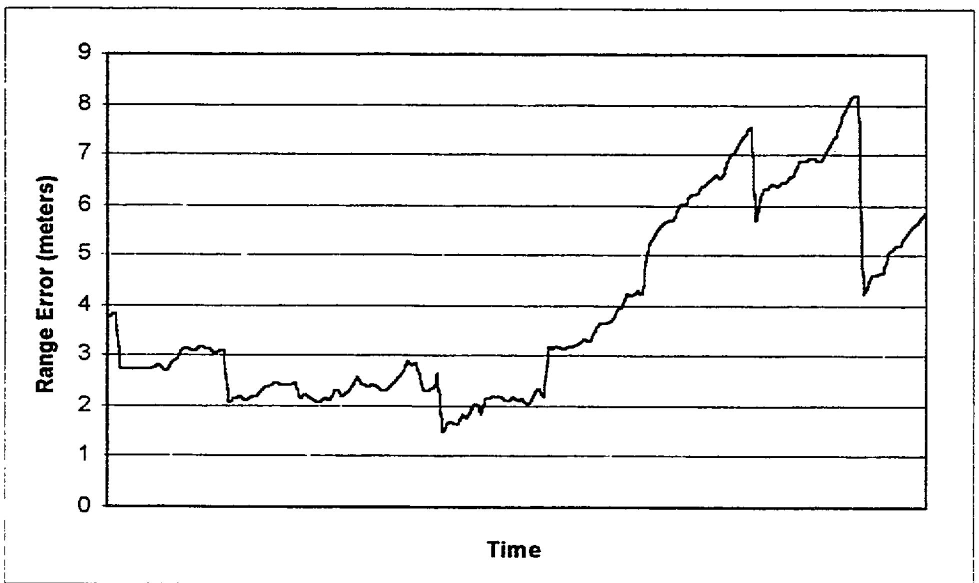

Figure 28-2 Test 28, Range Error Measurement

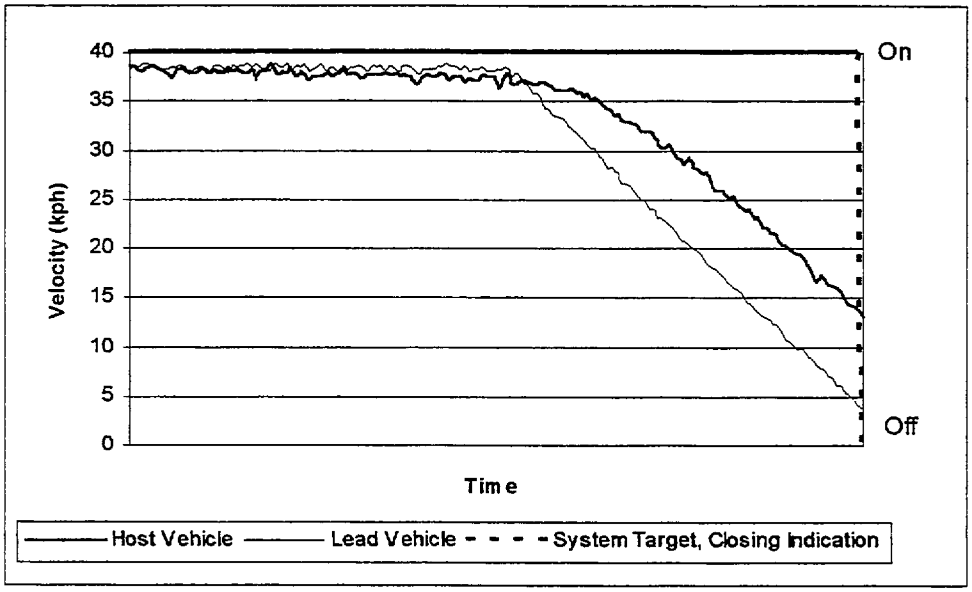

Figure 28-3 Test 28, Absolute Velocity Measurement

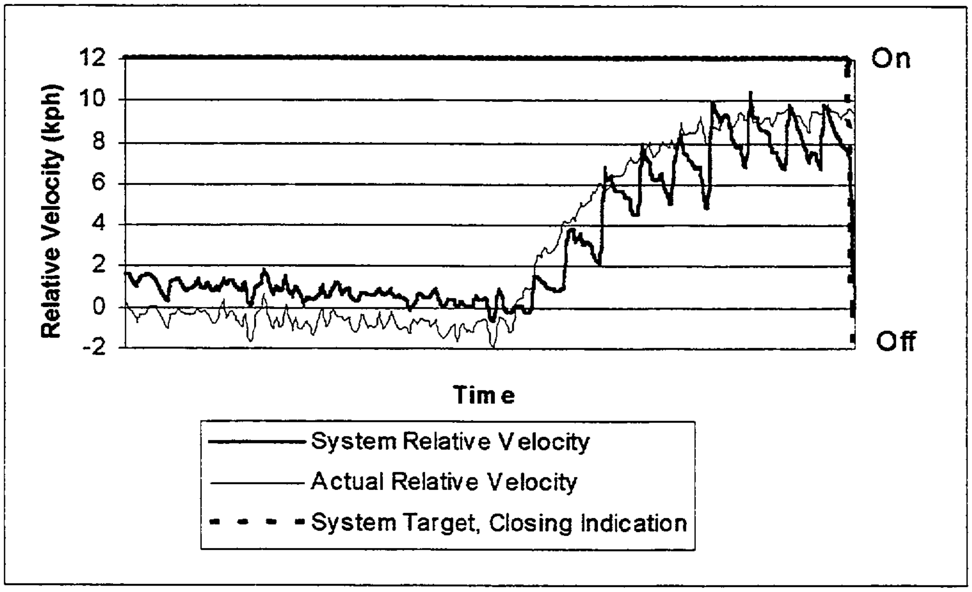

Figure 28-4 Test 28, Relative Velocity Measurement

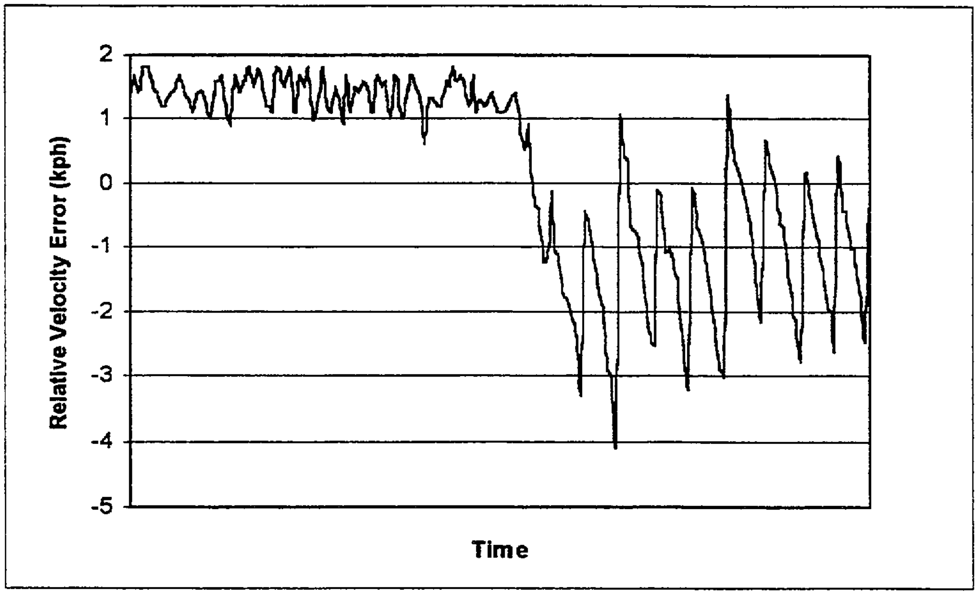

Figure 28-5 Test 28, Relative Velocity Error Measurement

Test Number 29: Lead Vehicle 40 kph, 0.75g deceleration, Host Vehicle 40 kph, 0.5 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 29-1. The range error is shown in Figure 29-2. The absolute velocity of the two vehicles is shown in Figure 29-3. The actual relative velocity as well as the system relative velocity is shown in Figure 29-4. The relative velocity error is shown in Figure 29-5. The range alarm from the system was detected at 43 meters, 15 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 11 kph.

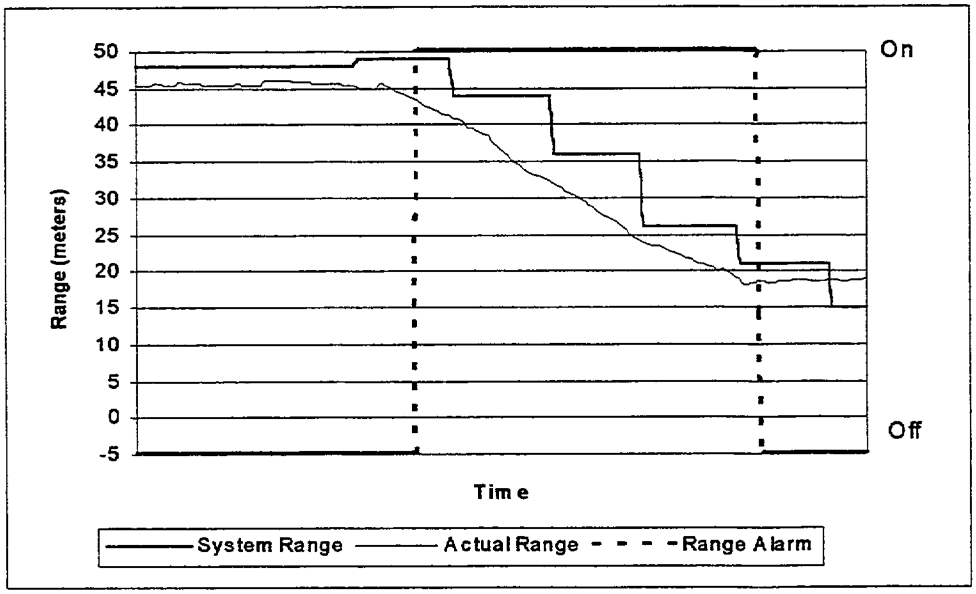

Figure 29-1 Test 29, Range Measurement

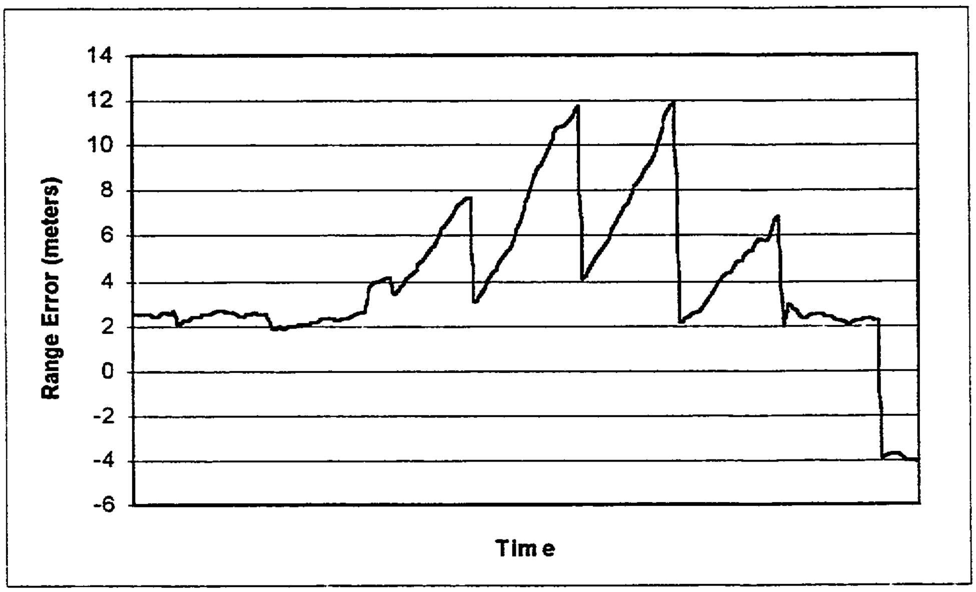

Figure 29-2 Test 29, Range Error Measurement

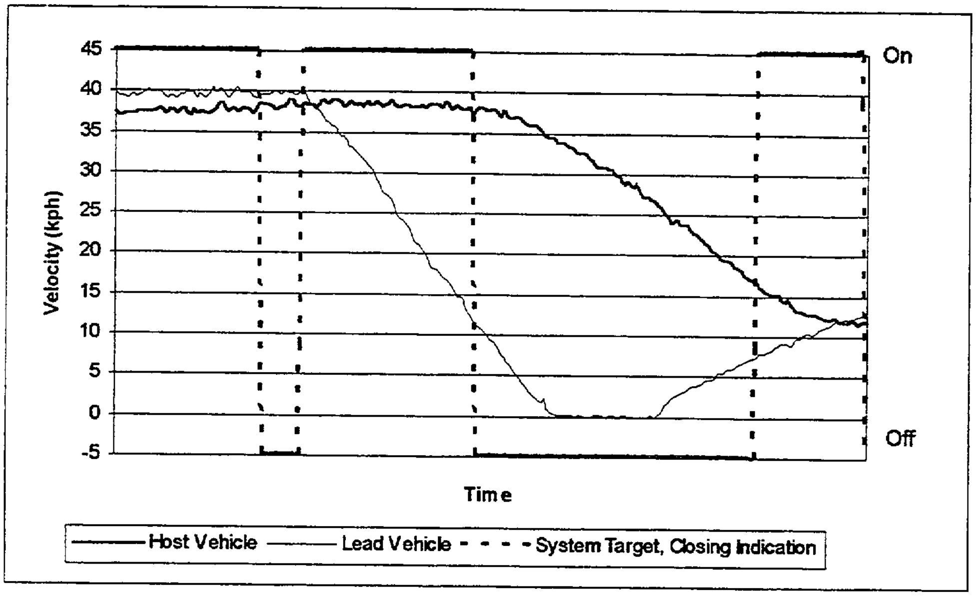

Figure 29-3 Test 29, Absolute Velocity Measurement

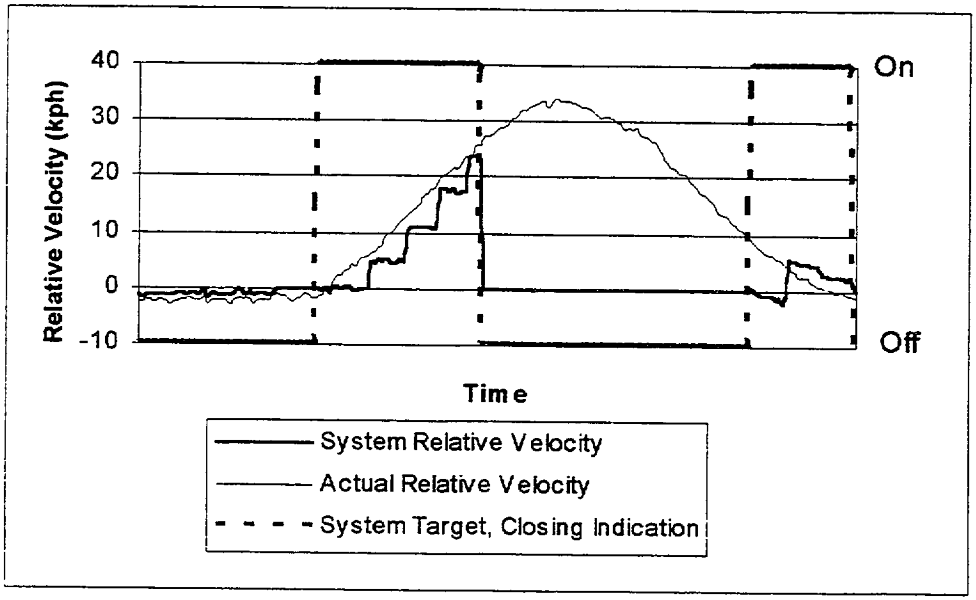

Figure 29-4 Test 29, Relative Velocity Measurement

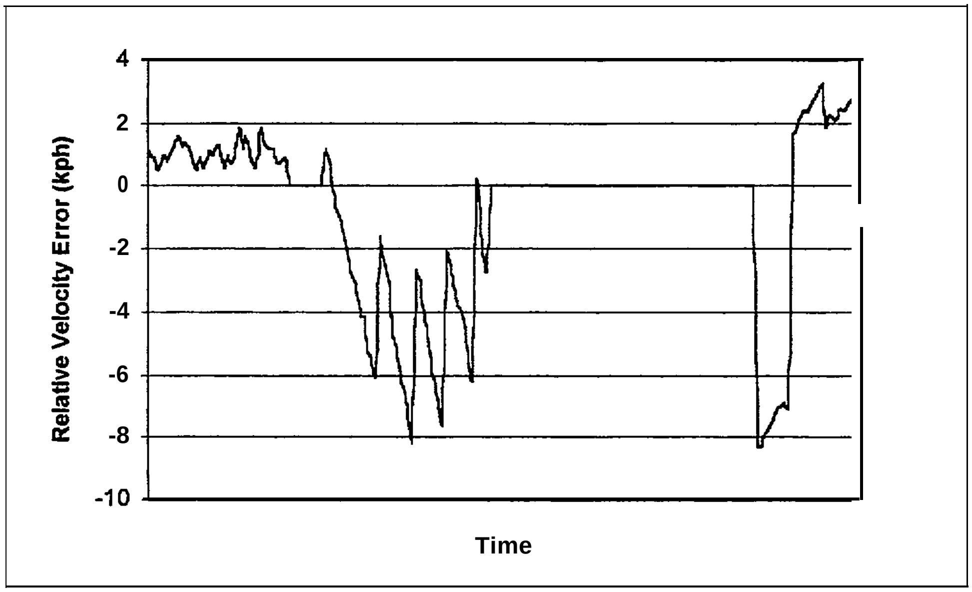

Figure 29-5 Test 29, Relative Velocity Error Measurement

Test Number 30: Lead Vehicle 40 kph, 0.5g deceleration, Host Vehicle 40 kph, 0.25 g deceleration

Test bypassed due to redundancy of test.

Test Number 31: Lead Vehicle 40 kph 0.75g deceleration, Host Vehicle 40 kph, 0.5 g deceleration

Test bypassed due to redundancy of test.

Test Number 32: Lead Vehicle 40 kph, 0.5g deceleration, Host Vehicle 40 kph 0.25 g deceleration

Test bypassed due to redundancy of test.

Test Number 33: Lead Vehicle 40 kph 0.75g deceleration, Host Vehicle 40 kph, 0.5 g deceleration

Test bypassed due to redundancy of test.

Test Number 34: Lead Vehicle 40 kph 0.5g deceleration, Host Vehicle 40 kph 0.25 g deceleration

Test bypassed due to redundancy of test.

Test Number 35: Lead Vehicle 40 kph, 0.75g deceleration, Host Vehicle 40 kph, 0.5 g deceleration

Test bypassed due to redundancy of test.

Test Number 36: Lead Vehicle 40 kph, .5g decel & stopped, Host Vehicle 40 kph, 0.25 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 36-1. The range error is shown in Figure 36-2. The absolute velocity of the two vehicles is shown in Figure 36-3. The actual relative velocity as well as the system relative velocity is shown in Figure 36-4. The relative velocity error is shown in Figure 36-5. The range alarm from the system was detected at 38 meters, 14 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 9 kph.

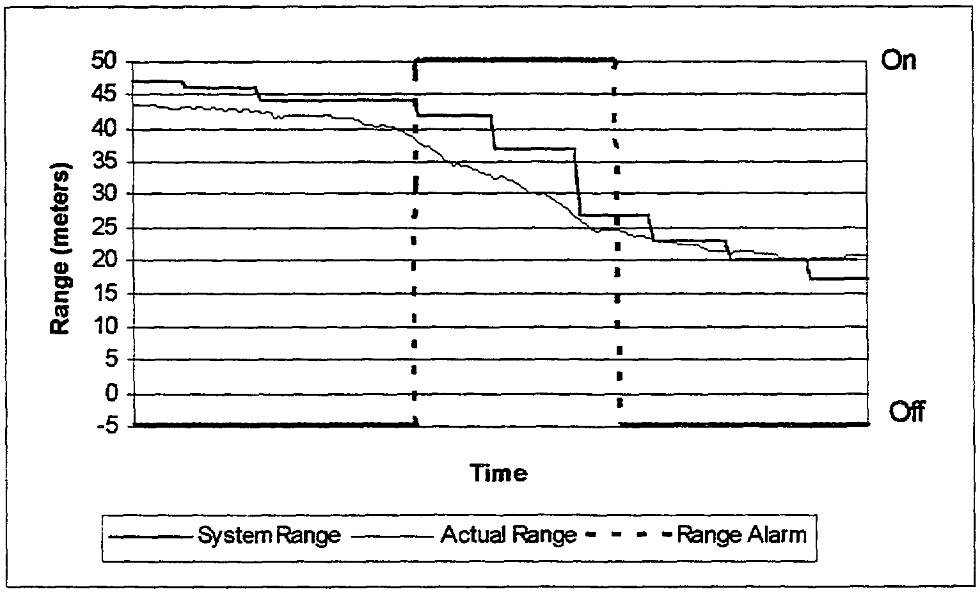

Figure 36-1 Test 36, Range Measurement

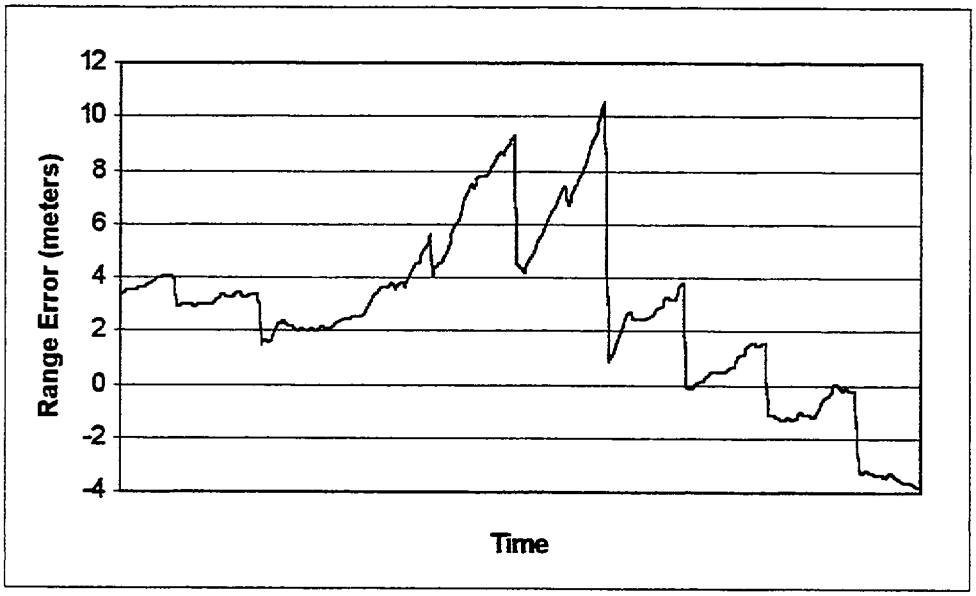

Figure 36-2 Test 36, Range Error Measurement

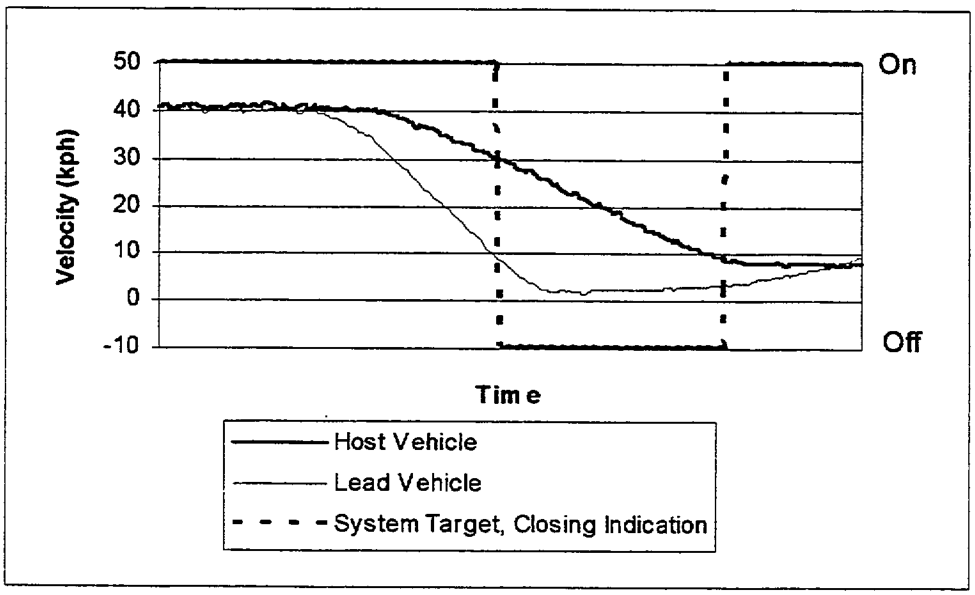

Figure 36-3 Test 36, Absolute Velocity Measurement

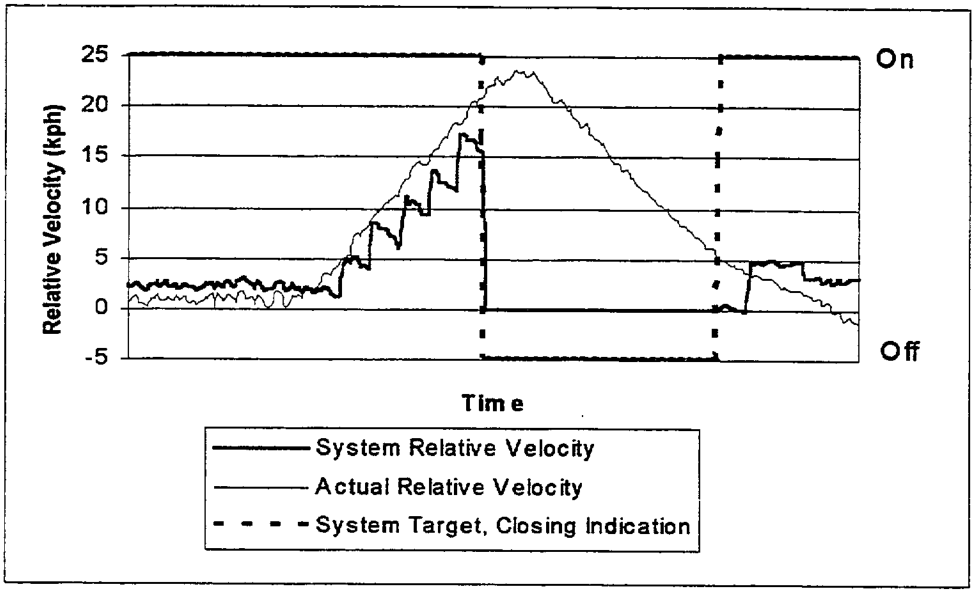

Figure 36-4 Test 36, Relative Velocity Measurement

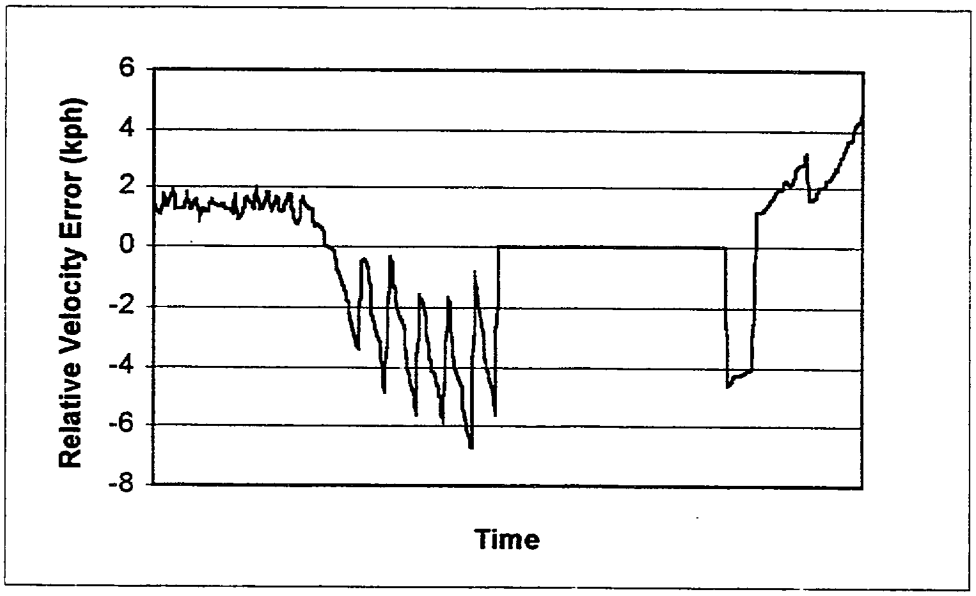

Figure 36-5 Test 36, Relative Velocity Error Measurement

Test Number 37: Lead Vehicle 40 kph, .75g decel & stopped, Host Vehicle 40 kph, .25 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 37-1. The range error is shown in Figure 37-2. The absolute velocity of the two vehicles is shown in Figure 37-3. The actual relative velocity as well as the system relative velocity is shown in Figure 37-4. The relative velocity error is shown in Figure 37-5. The range alarm from the system was detected at 44 meters, 14 kph from the lead vehicle.

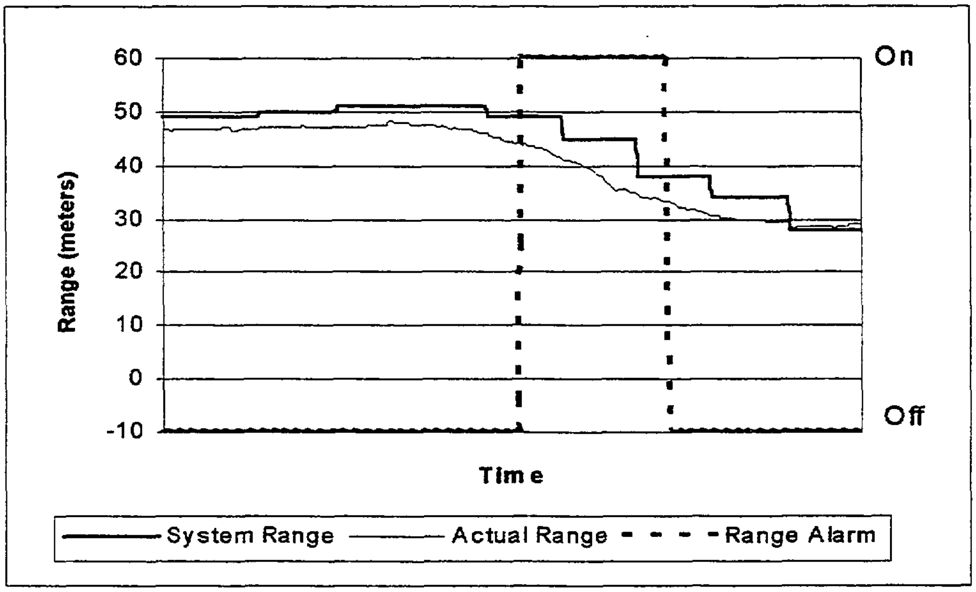

Figure 37-1 Test 37, Range Measurement

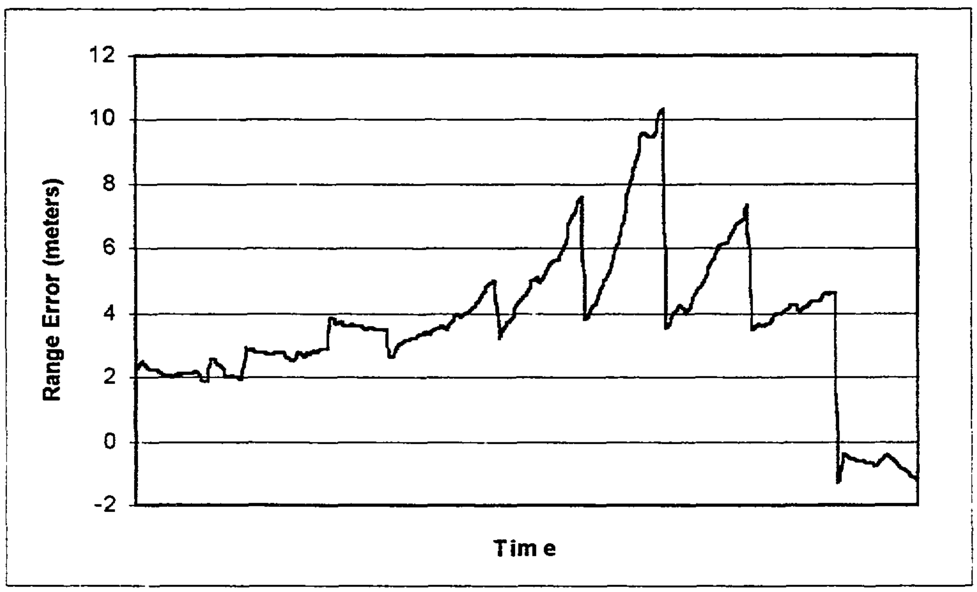

Figure 37-2 Test 37, Range Error Measurement

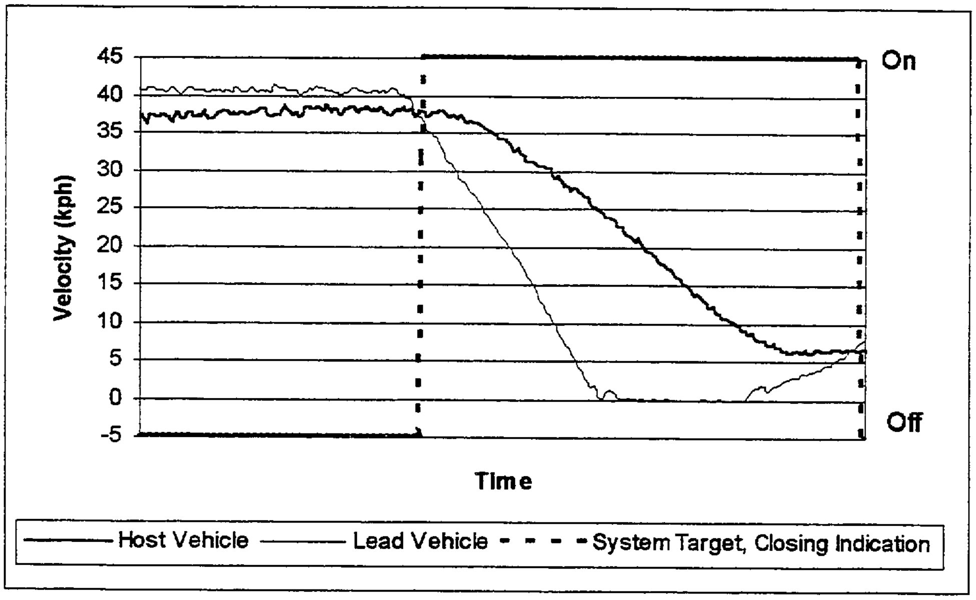

Figure 37-3 Test 37, Absolute Velocity Measurement

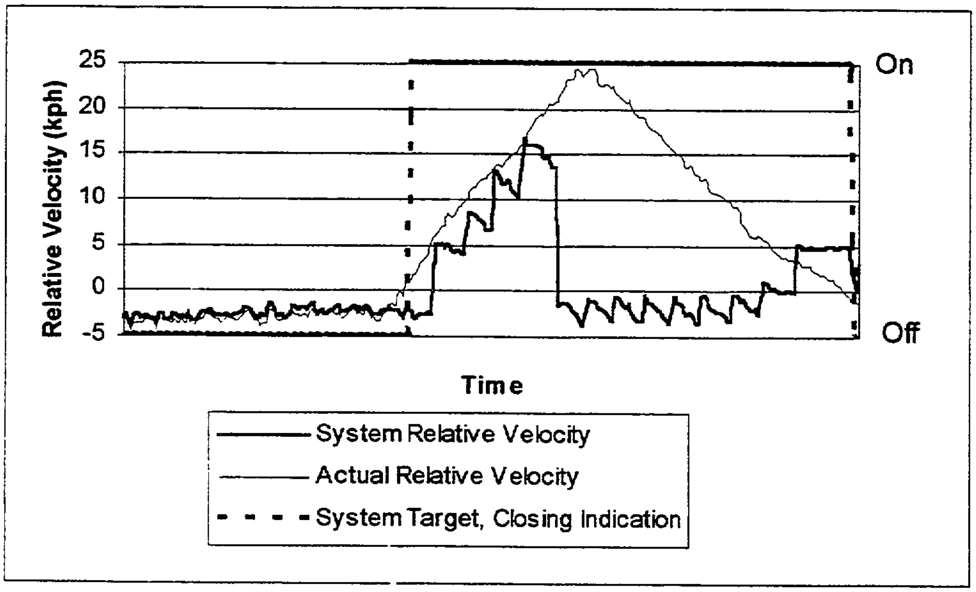

Figure 37-4 Test 37, Relative Velocity Measurement

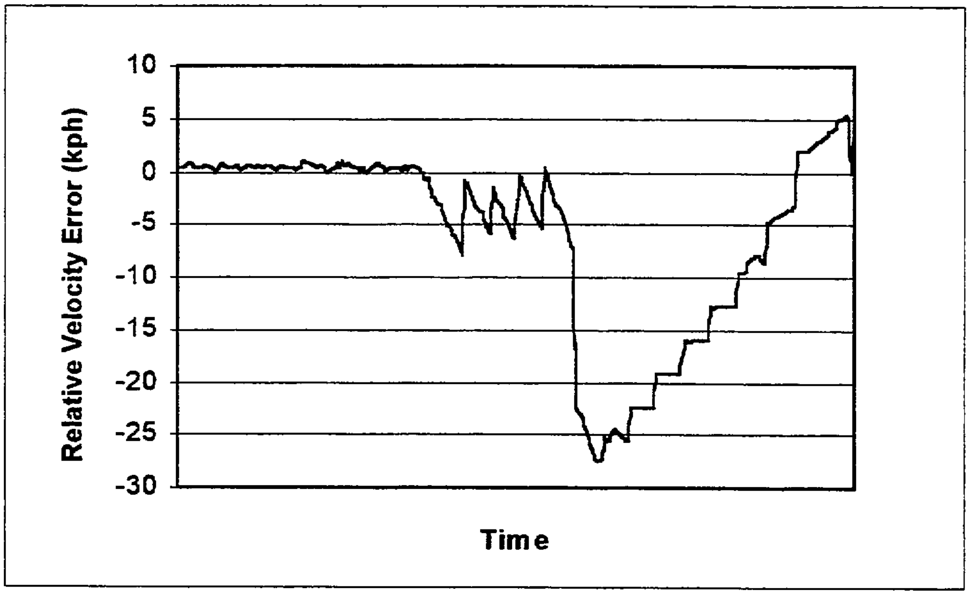

Figure 37-5 Test 37, Relative Velocity Error Measurement

Test Number 38: Lead Vehicle 40 kph, .75g decel & stopped, Host Vehicle 40 kph, .5 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 38-1. The range error is shown in Figure 38-2. The absolute velocity of the two vehicles is shown in Figure 38-3. The actual relative velocity as well as the system relative velocity is shown in Figure 38-4. The relative velocity error is shown in Figure 38-5. The range alarm from the system was detected at 42 meters, 14 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 6 kph.

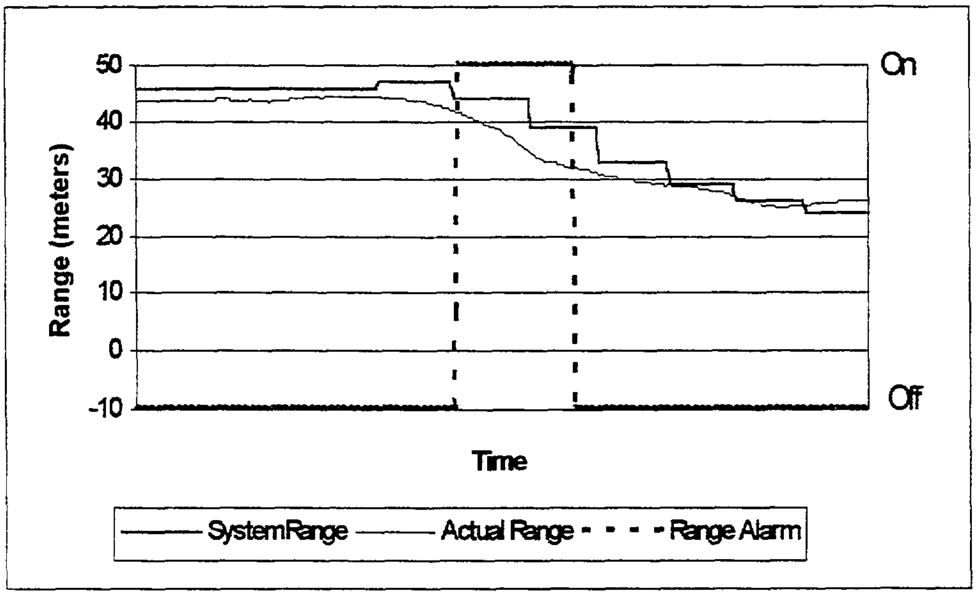

Figure 38-1 Test 38, Range Measurement

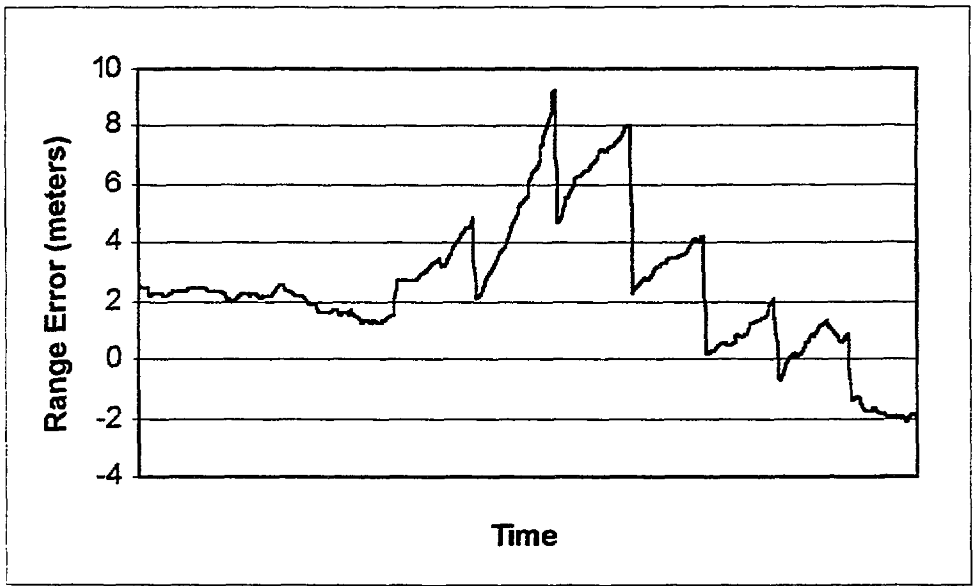

Figure 38-2 Test 38, Range Error Measurement

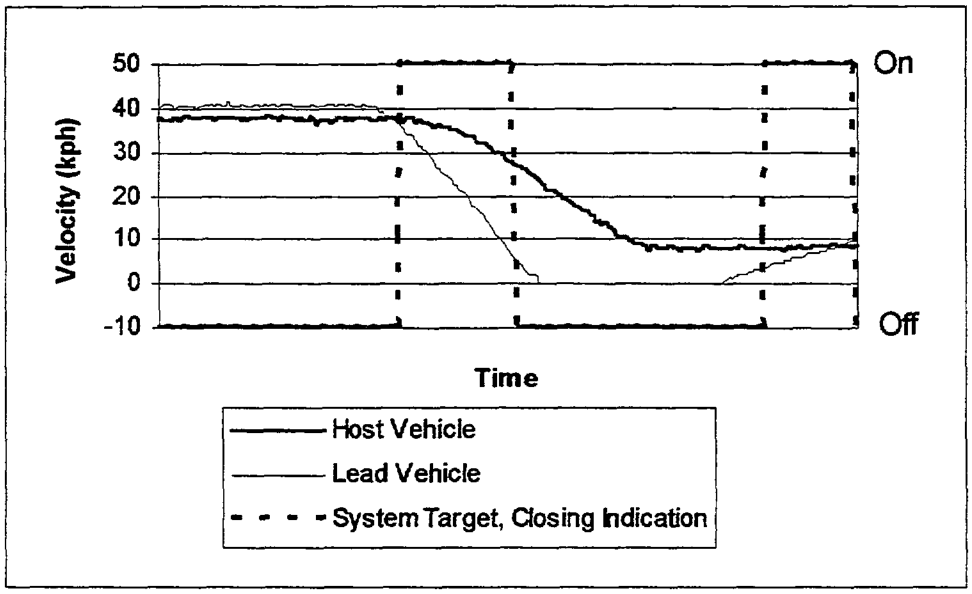

Figure 38-3 Test 38, Absolute Velocity Measurement

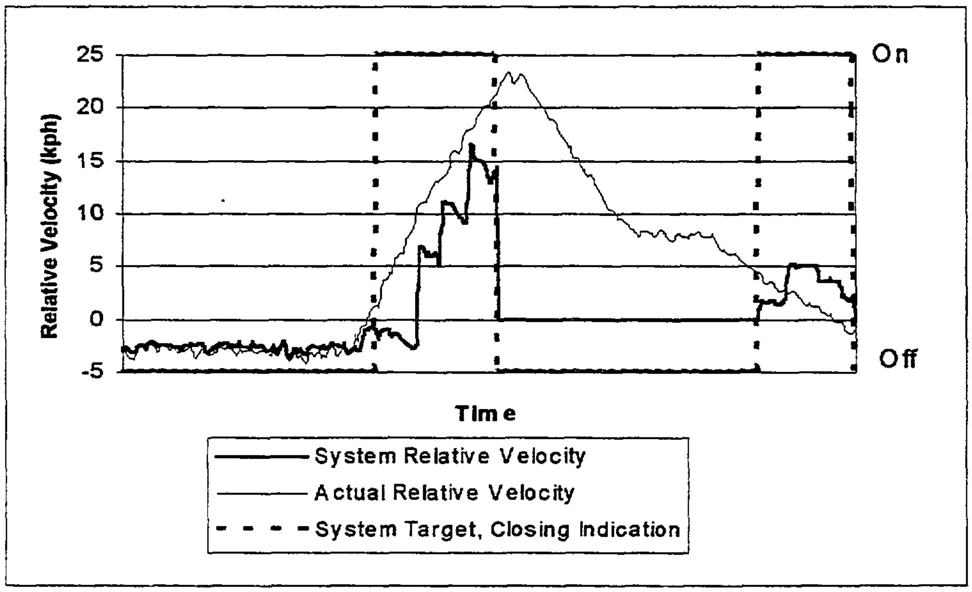

Figure 38-4 Test 38, Relative Velocity Measurement

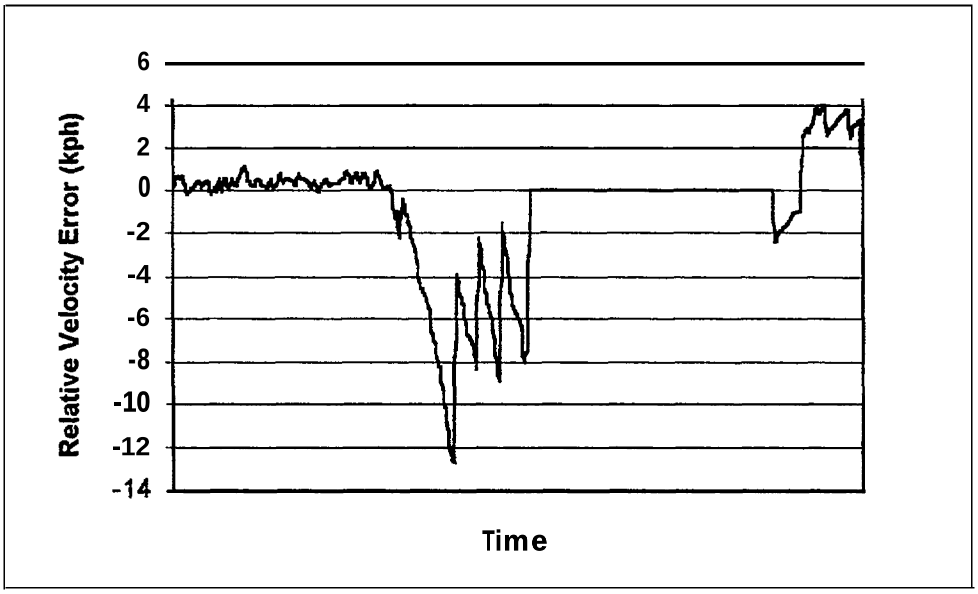

Figure 38-5 Test 38, Relative Velocity Error Measurement

Test Number 39: Lead Vehicle 60 kph, .5g decel & stopped, Host Vehicle 60 kph, .25 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 39-l. The range error is shown in Figure 39-2. The absolute velocity of the two vehicles is shown in Figure 39-3. The actual relative velocity as well as the system relative velocity is shown in Figure 39-4. The relative velocity error is shown in Figure 39-5. The range alarm from the system was detected at 41 meters, 14 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 7 kph.

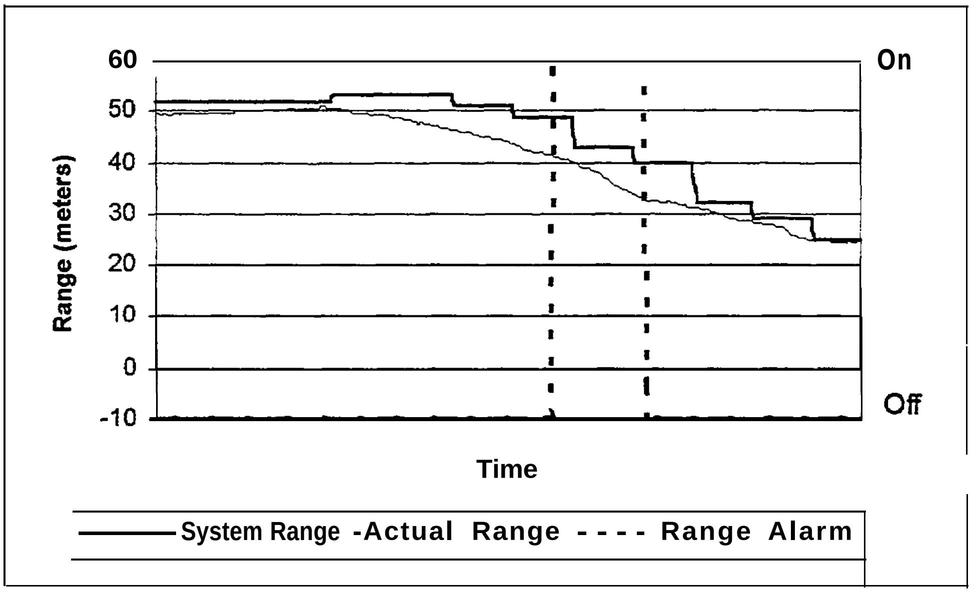

Figure 39-l Test 39, Range Measurement

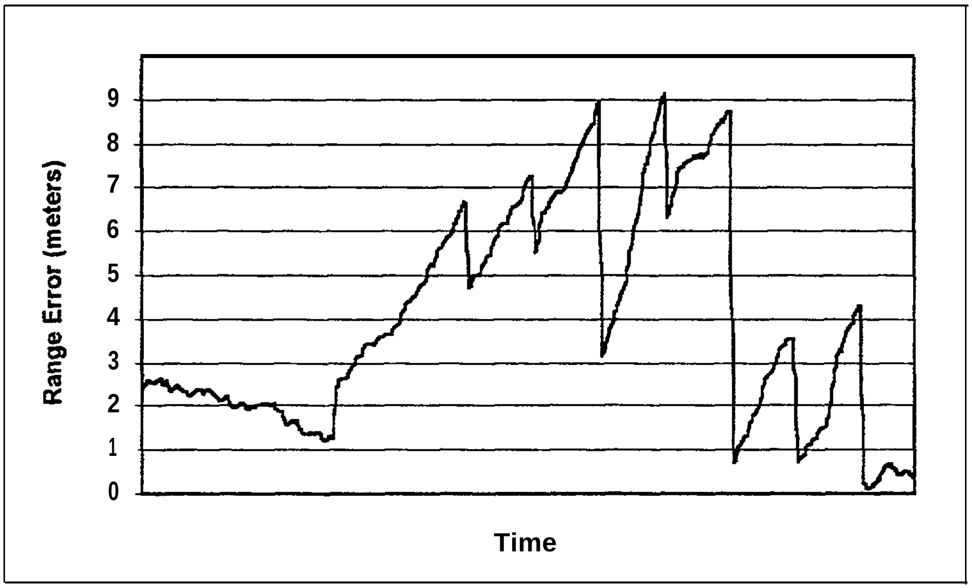

Figure 39-2 Test 39, Range Error Measurement

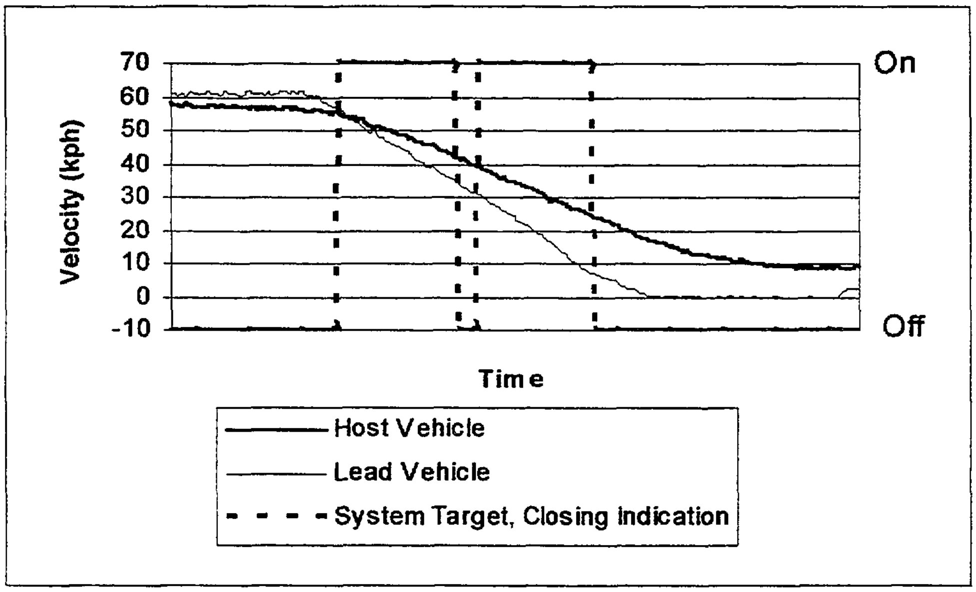

Figure 39-3 Test 39, Absolute Velocity Measurement

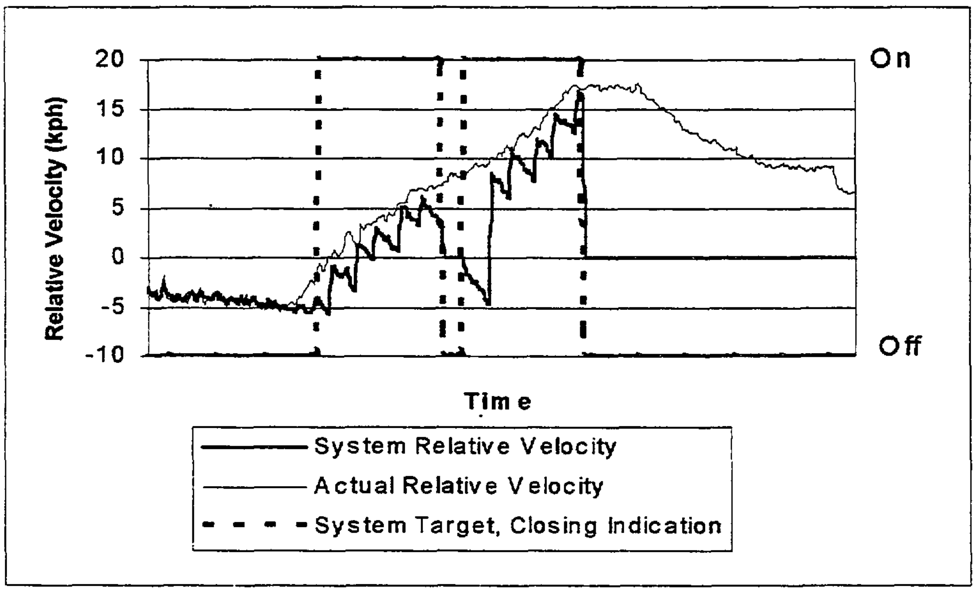

Figure 39-4 Test 39, Relative Velocity Measurement

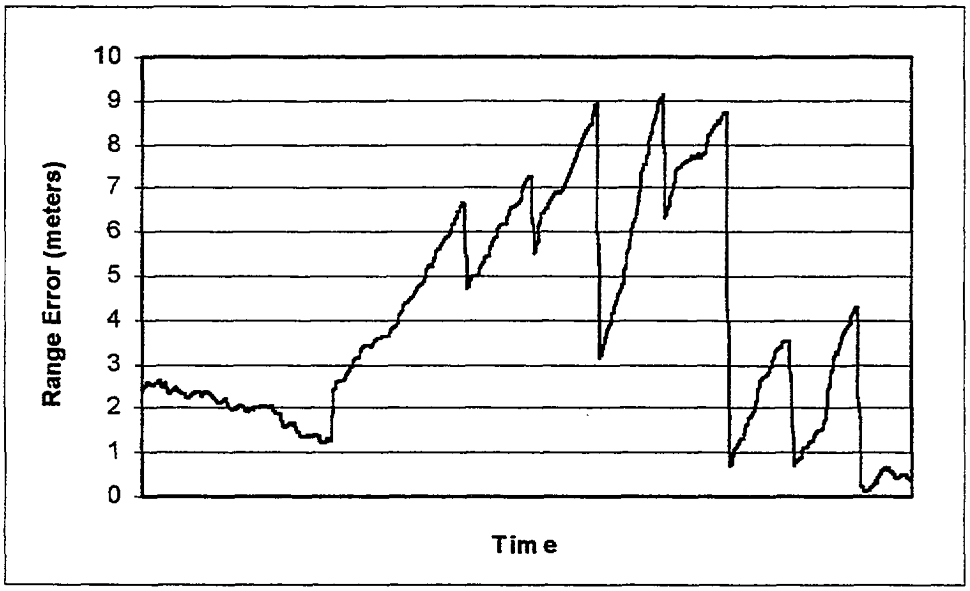

Figure 39-5 Test 39, Relative Velocity Error Measurement

Test Number 40: Lead Vehicle 60 kph, .75g decel & stopped. Host Vehicle 60 kph, .25 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 40-1. The range error is shown in Figure 40-2. The absolute velocity of the two vehicles is shown in Figure 40-3. The actual relative velocity as well as the system relative velocity is shown in Figure 40-4. The relative velocity error is shown in Figure 40-5. The range alarm from the system was detected at 50 meters, 13 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 11 kph.

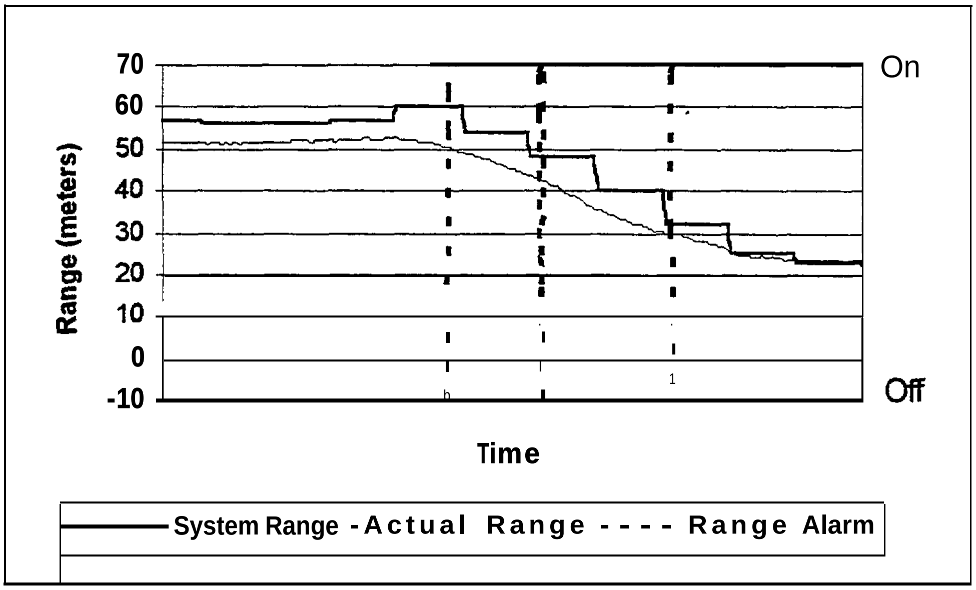

Figure 40-1 Test 40, Range Measurement

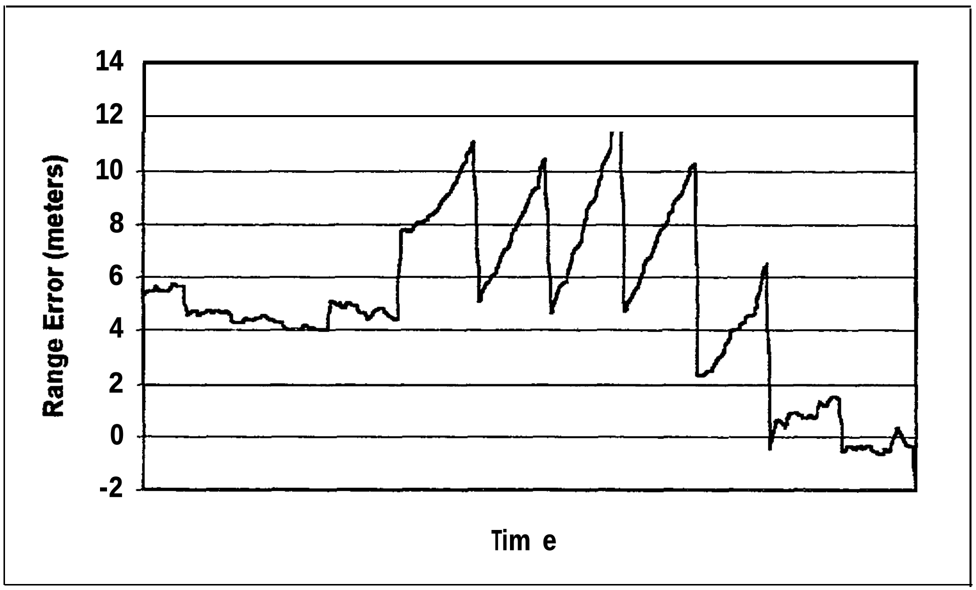

Figure 40-2 Test 40, Range Error Measurement

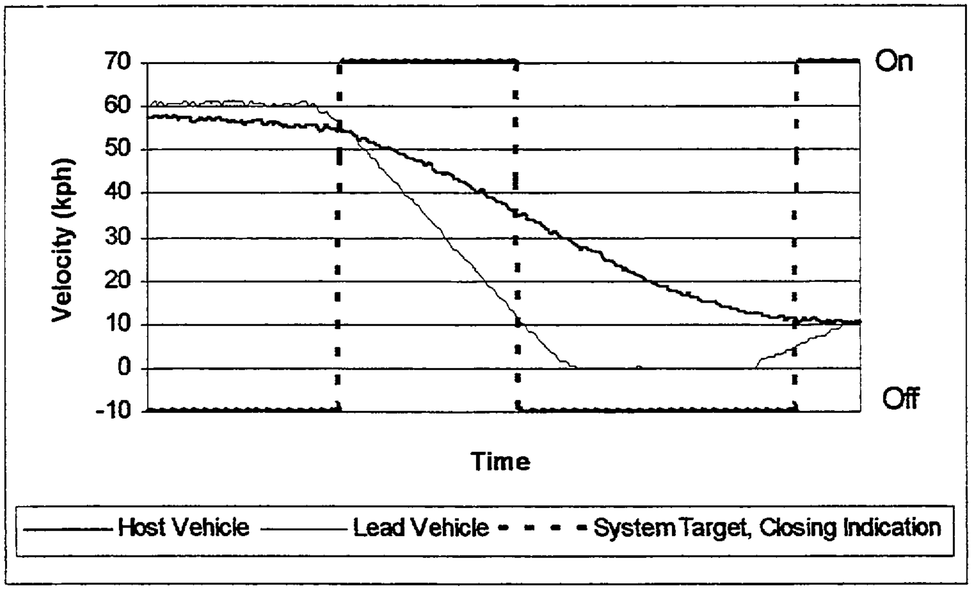

Figure 40-3 Test 40, Absolute Velocity Measurement

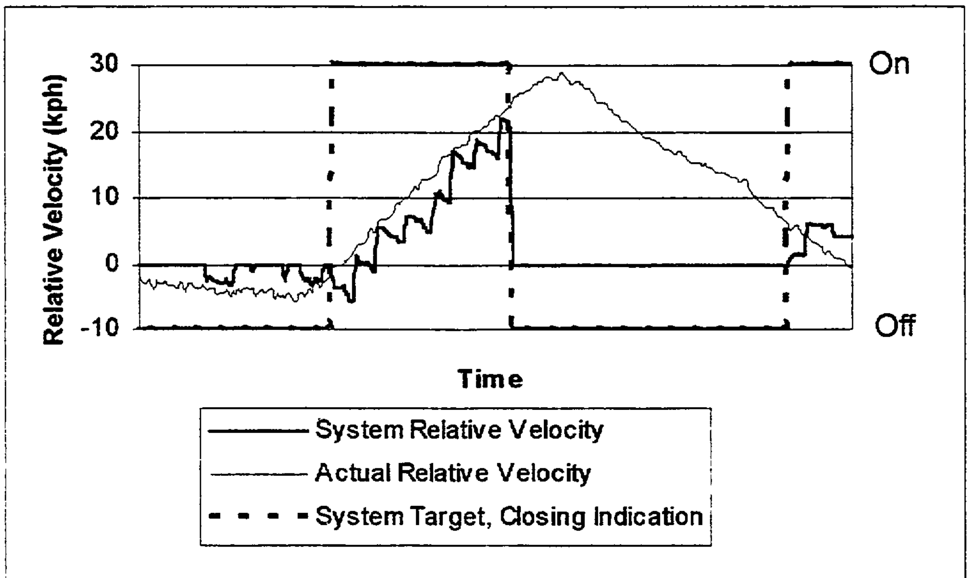

Figure 40-4 Test 40, Relative Velocity Measurement

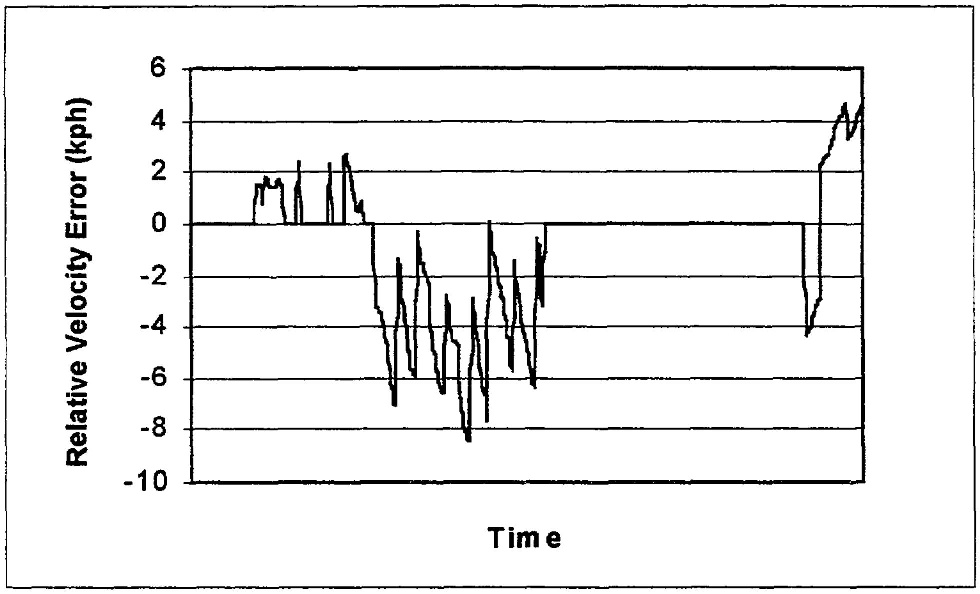

Figure 40-5 Test 40, Relative Velocity Error Measurement

Test Number 41: Lead Vehicle 60 kph, .75g decel & stopped, Host Vehicle 60 kph, .5 g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 41-1. The range error is shown in Figure 41-2. The absolute velocity of the two vehicles is shown in Figure 41-3. The actual relative velocity as well as the system relative velocity is shown in Figure 41-4. The relative velocity error is shown in Figure 41-5. The range alarm from the system was detected at 42 meters, 13 kph from the lead vehicle. The system relative velocity sensor dropped lead vehicle when the lead vehicle velocity was 7 kph.

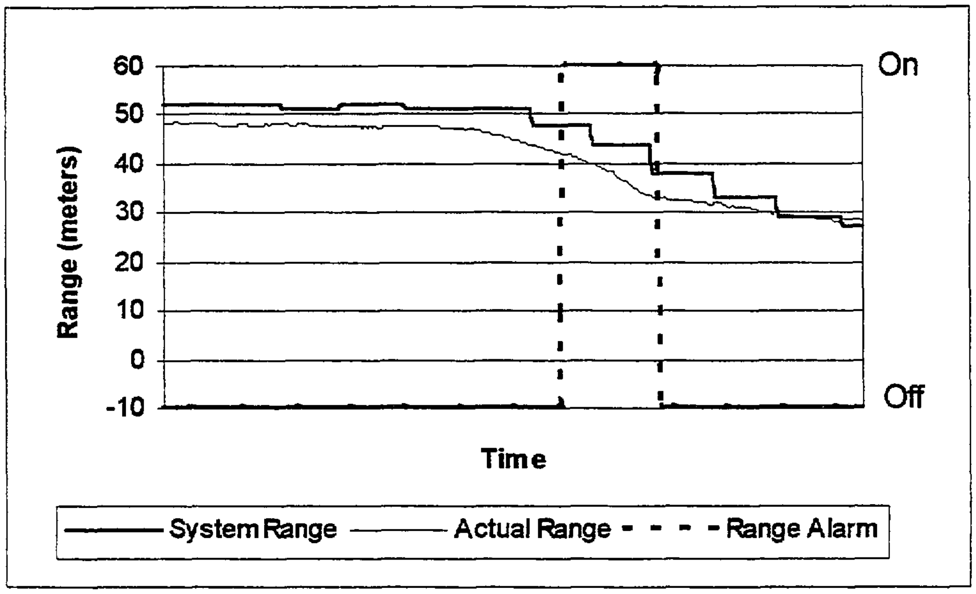

Figure 41-1 Test 41, Range Measurement

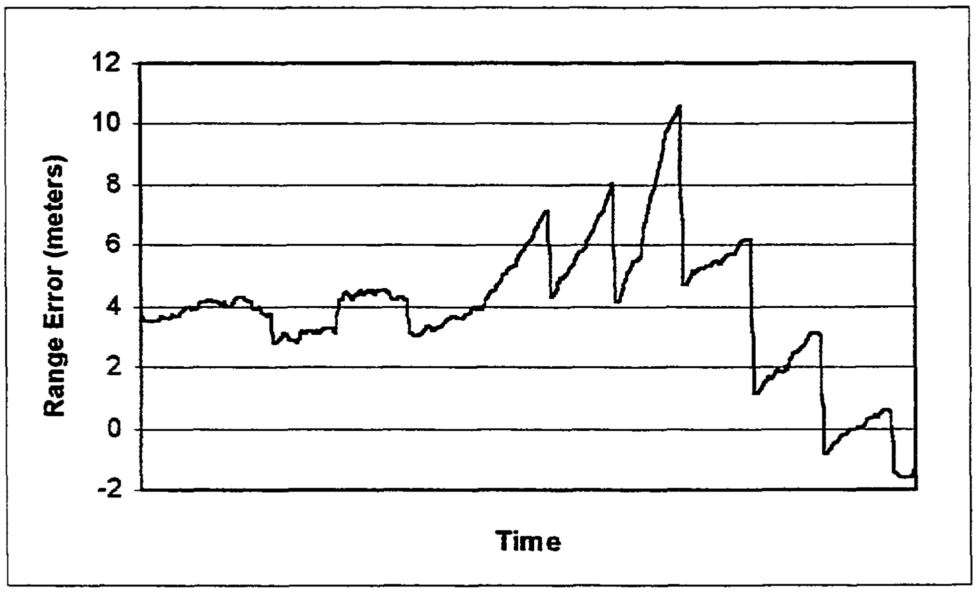

Figure 41-2 Test 41, Range Error Measurement

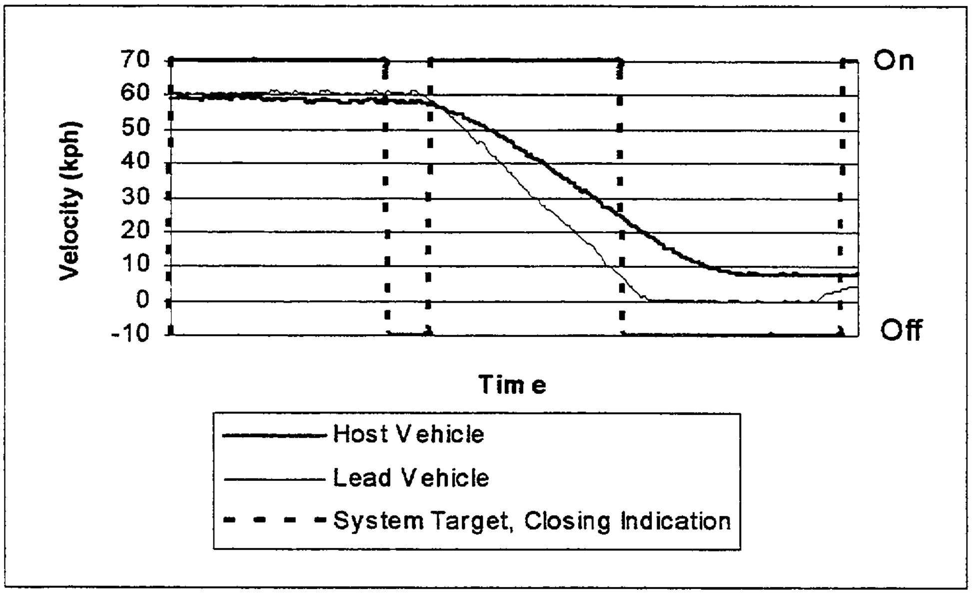

Figure 41-3 Test 41, Absolute Velocity Measurement

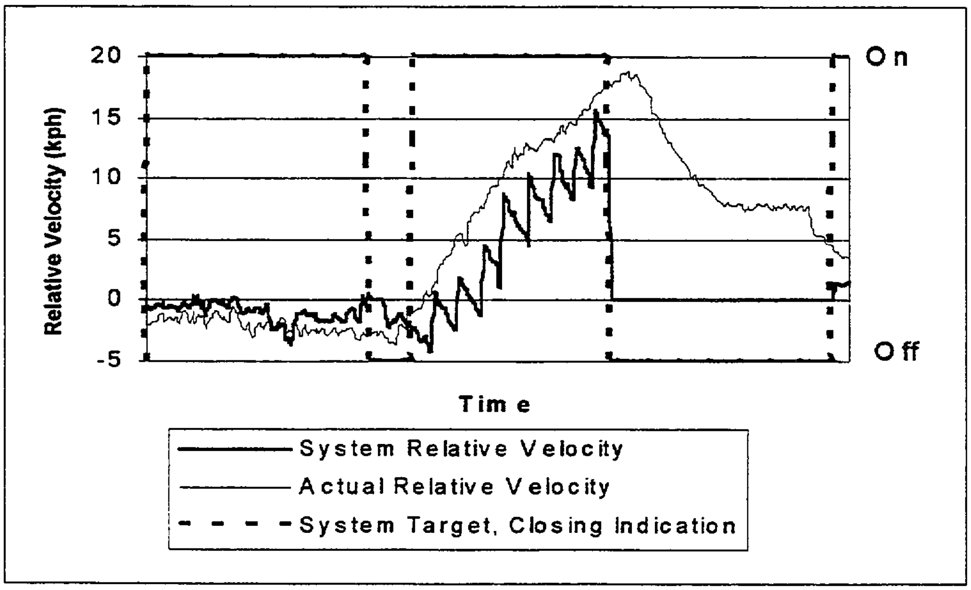

Figure 41-4 Test 41, Relative Velocity Measurement

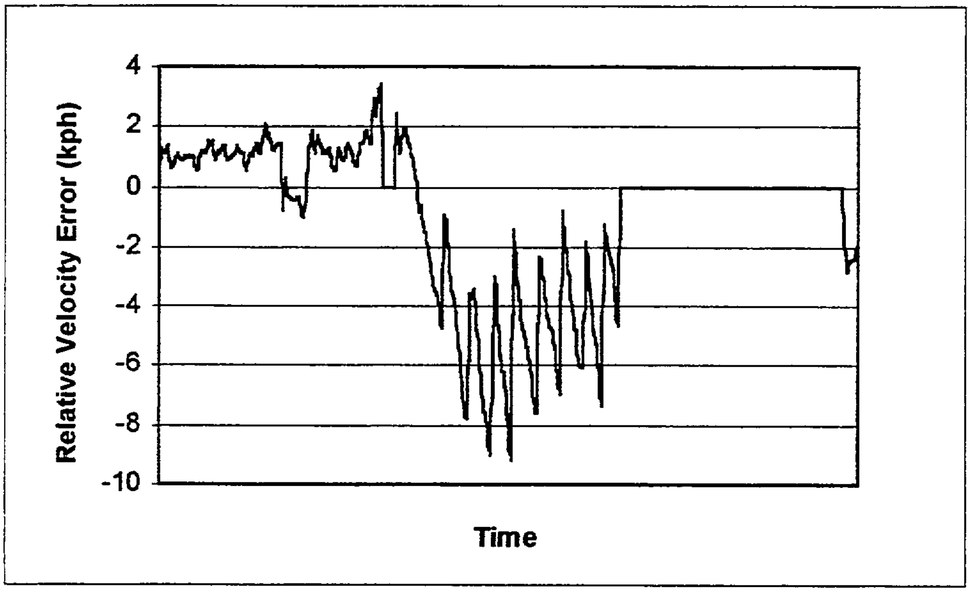

Figure 41-5 Test 41, Relative Velocity Error Measurement

Test Number 42: Lead Vehicle Stopped. Host Vehicle 10 kph, adjacent lane

The actual range, the measured range from the system is shown in Figure 42-1. The range error is shown in Figure 42-2. The absolute velocity of the two vehicles is shown in Figure 42-3. There was no range alarm indication from the system. The system relative velocity sensor does not sense stopped vehicles. As can be seen from Figure 42-1, the system did detect the vehicle in the adjacent lane, and change the displayed range as a result.

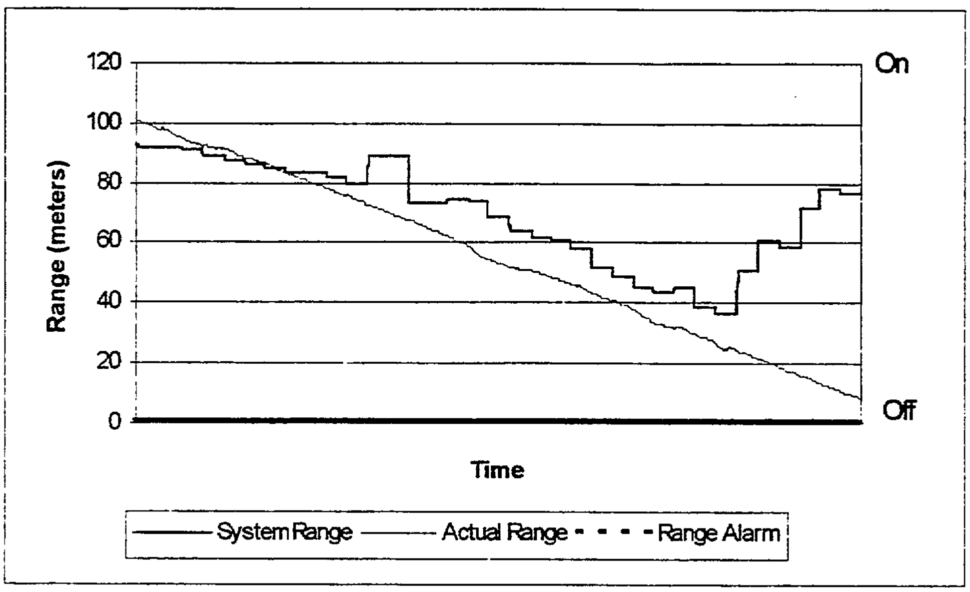

Figure 42-1 Test 42, Range Measurement

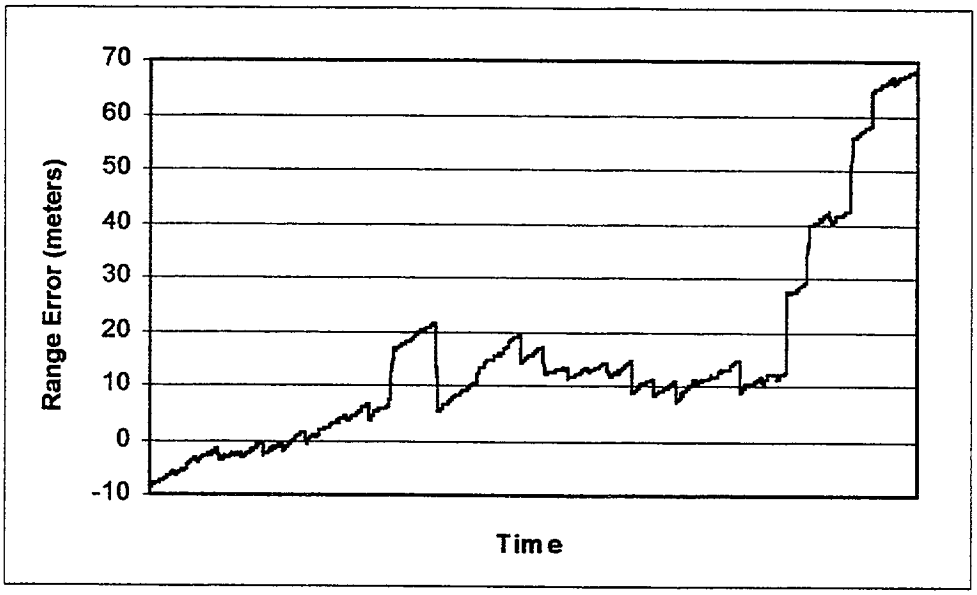

Figure 42-2 Test 42, Range Error Measurement

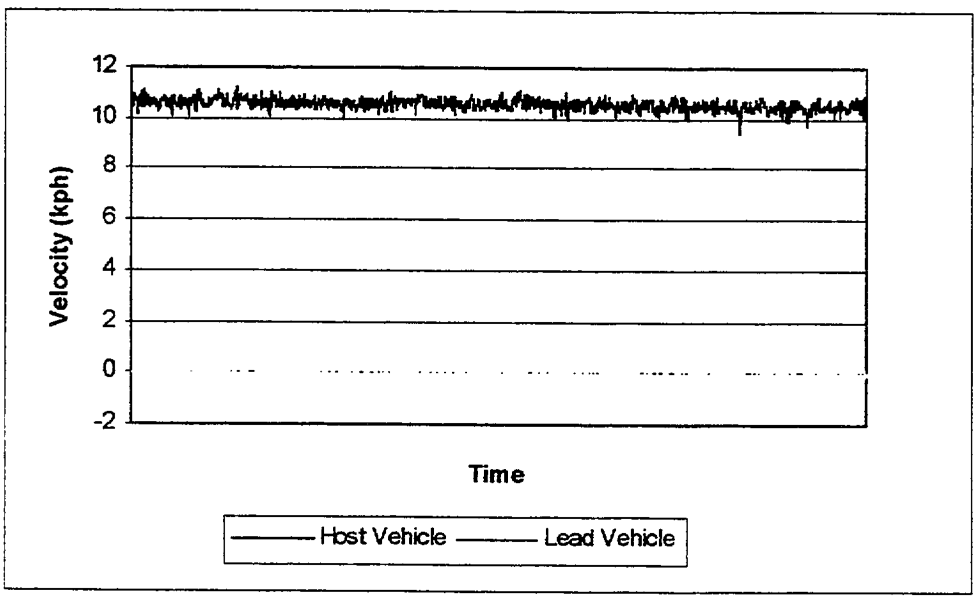

Figure 42-3 Test 42, Absolute Velocity Measurement

Test Number 43: Lead Vehicle Stopped, Host Vehicle 50 kph, adjacent lane

The actual range, the measured range from the system is shown in Figure 43-1. The range error is shown in Figure 43-2. The absolute velocity of the two vehicles is shown in Figure 43-3. There was no range alarm indication from the system. The system relative velocity sensor does not sense stopped vehicles. As can be seen from Figure 43-1, the system did detect the vehicle in the adjacent lane, and change the displayed range as a result but no alarm was issued.

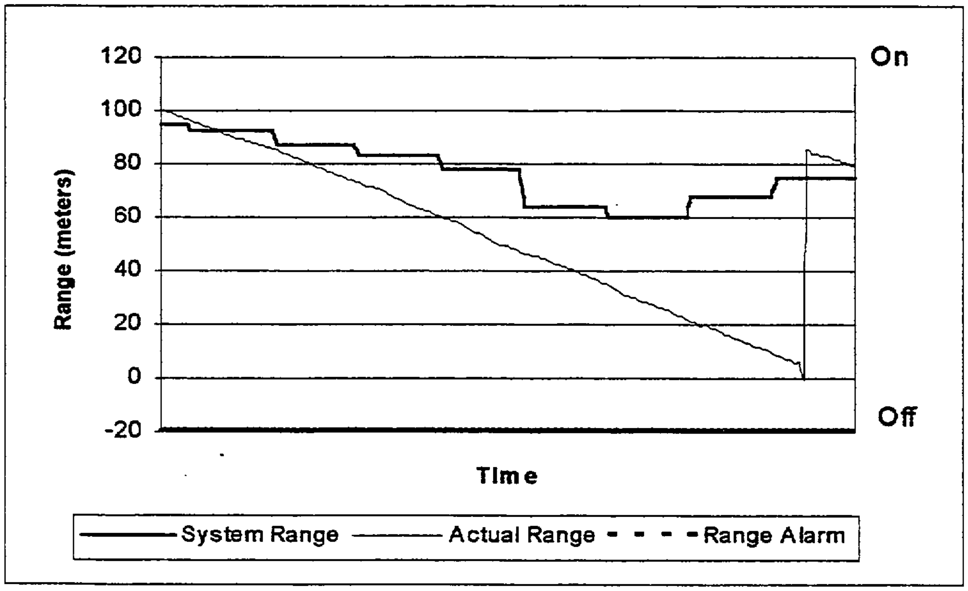

Figure 43-1 Test 43, Range Measurement

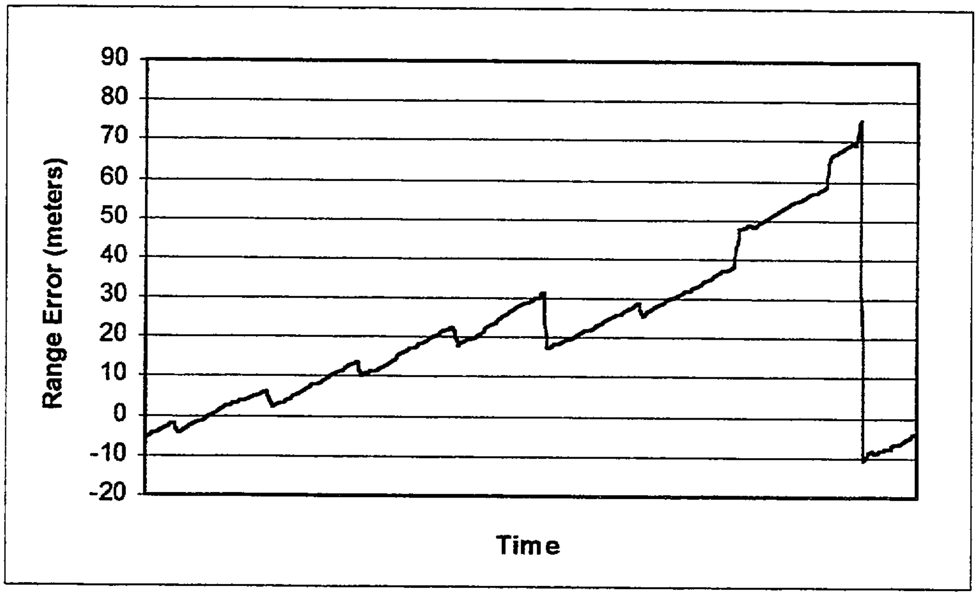

Figure 43-2 Test 43, Range Error Measurement

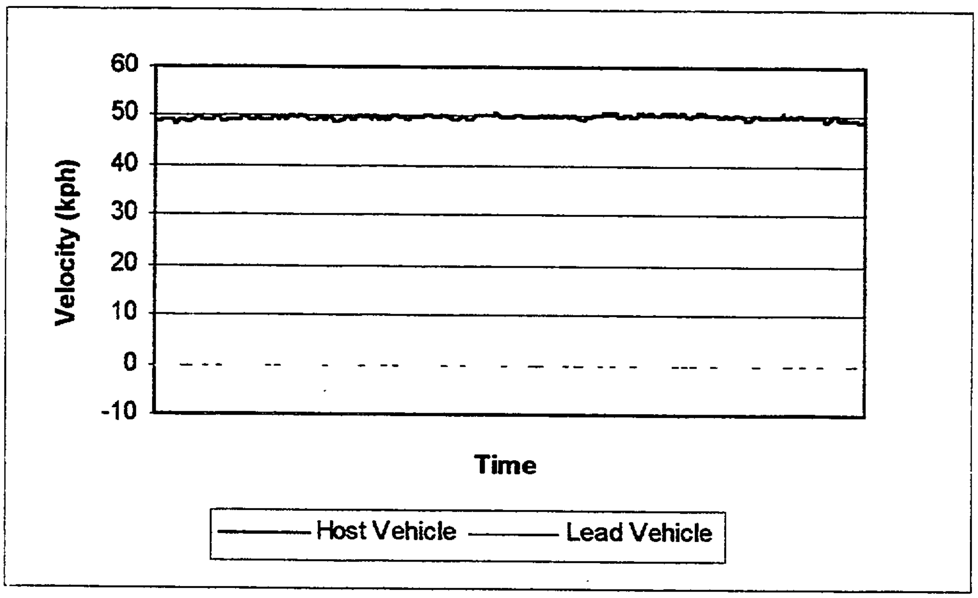

Figure 43-3 Test 43, Absolute Velocity Measurement

Test Number 44: Lead Vehicle Stopped. Host Vehicle 100 kph. adjacent lane

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other adjacent lane tests.

Test Number 45: Lead Vehicle 30 kph, Host Vehicle 50 kph, adjacent lane

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 45-1. The range error is shown in Figure 45-2. The absolute velocity of the two vehicles is shown in Figure 45-3. The range alarm from the system was detected at 48 meters, 19 kph from the lead vehicle. The vehicles were in adjacent lanes.

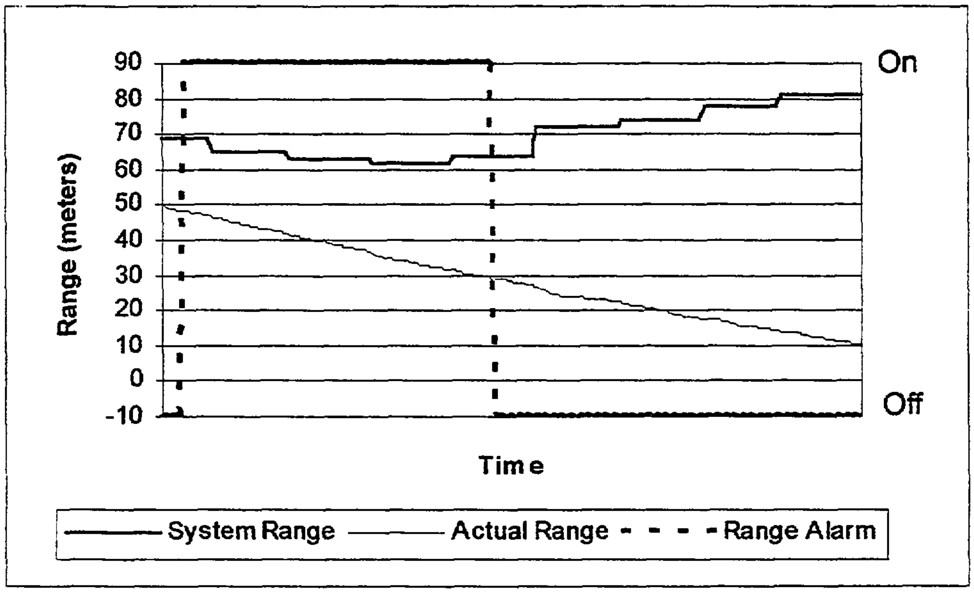

Figure 45-1 Test 45, Range Measurement

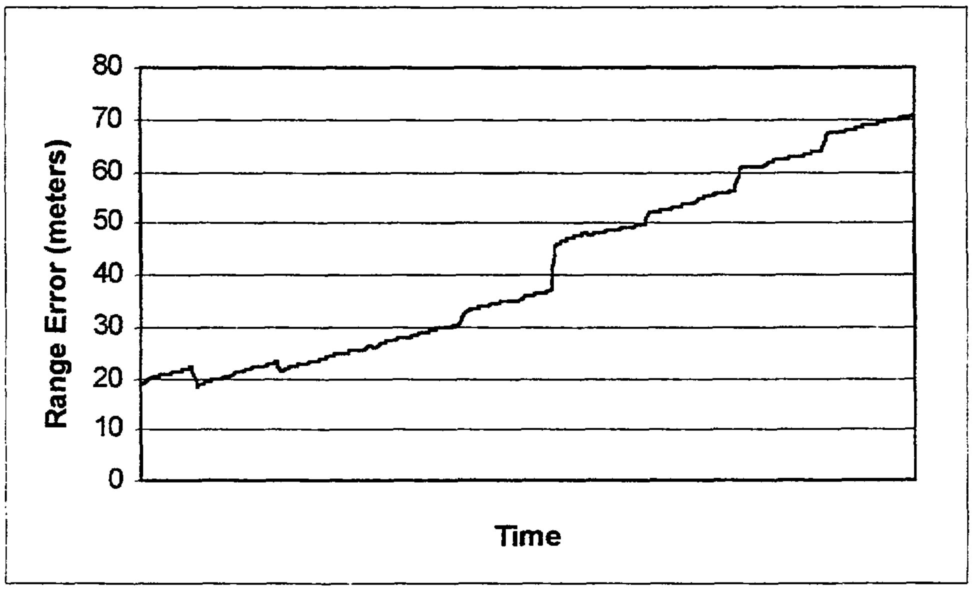

Figure 45-2 Test 45, Range Error Measurement

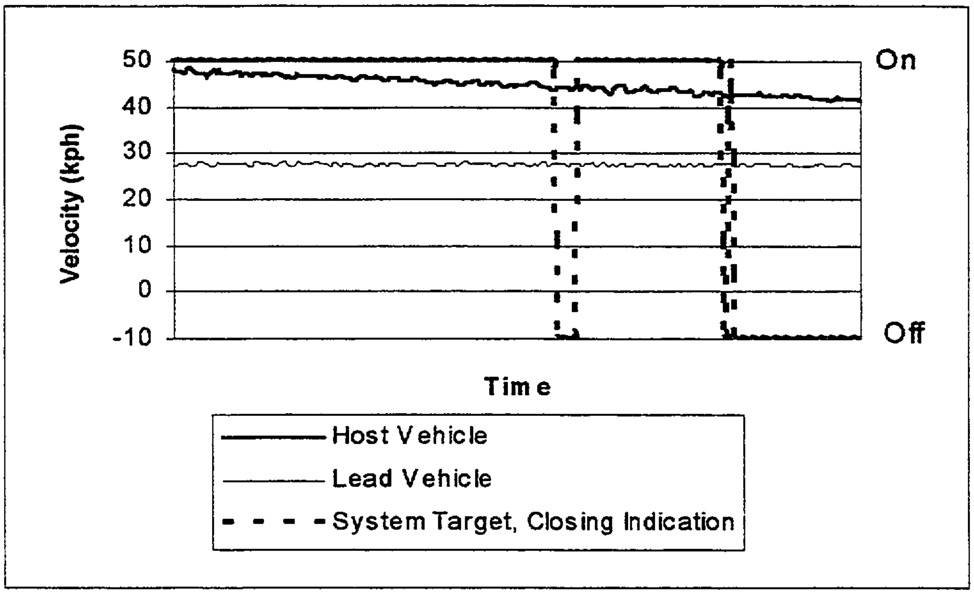

Figure 45-3 Test 45, Absolute Velocity Measurement

Test Number 46: Lead Vehicle 30 kph, Host Vehicle 100 kph, adjacent lane

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other adjacent lane tests.

Test Number 47: Lead Vehicle 60 kph, Host Vehicle 100 kph, adjacent lane

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other adjacent lane tests.

Test Number 48: Lead Vehicle Stopped. Host Vehicle 10 kph, curved, same lane

The actual range, the measured range from the system is shown in Figure 48-1. The range error is shown in Figure 48-2. The absolute velocity of the two vehicles is shown in Figure 48-3. There was no range alarm detected from the system. The system relative velocity sensor does not sense stopped vehicles. The range sensor did see the lead vehicle, and adjusted the range display accordingly. Curve performance is poor by the high amount of range error.

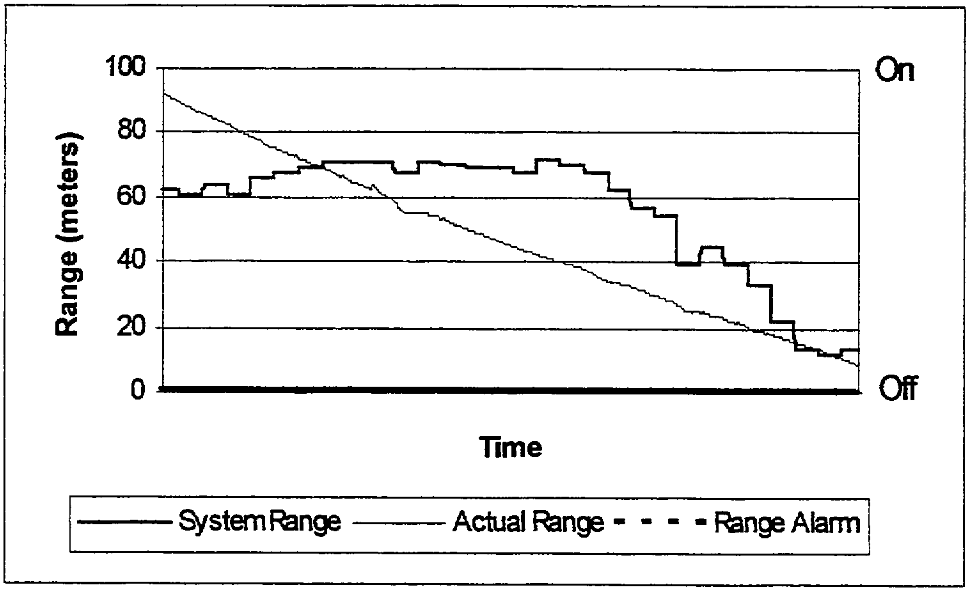

Figure 48-1 Test 48, Range Measurement

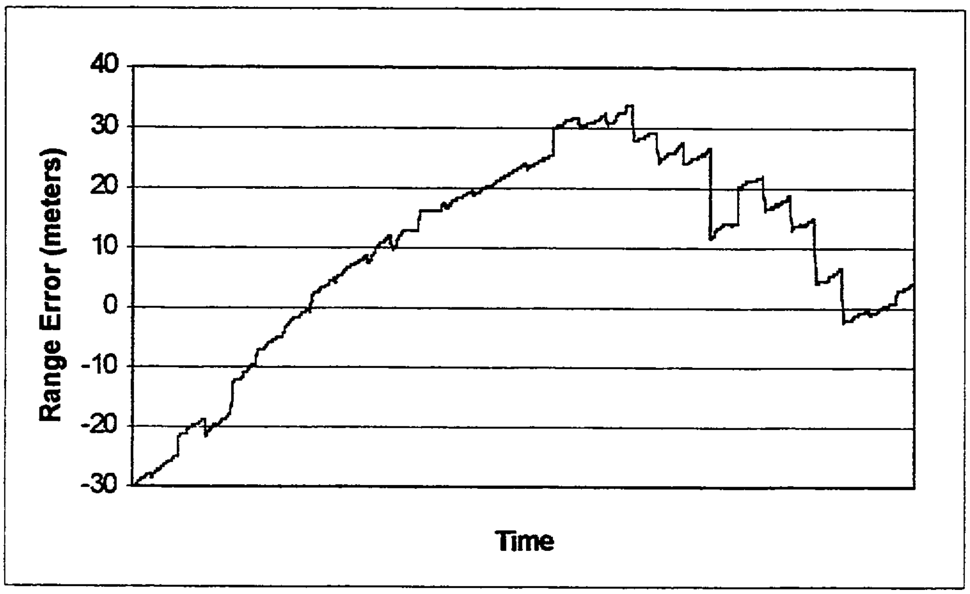

Figure 48-2 Test 48, Range Error Measurement

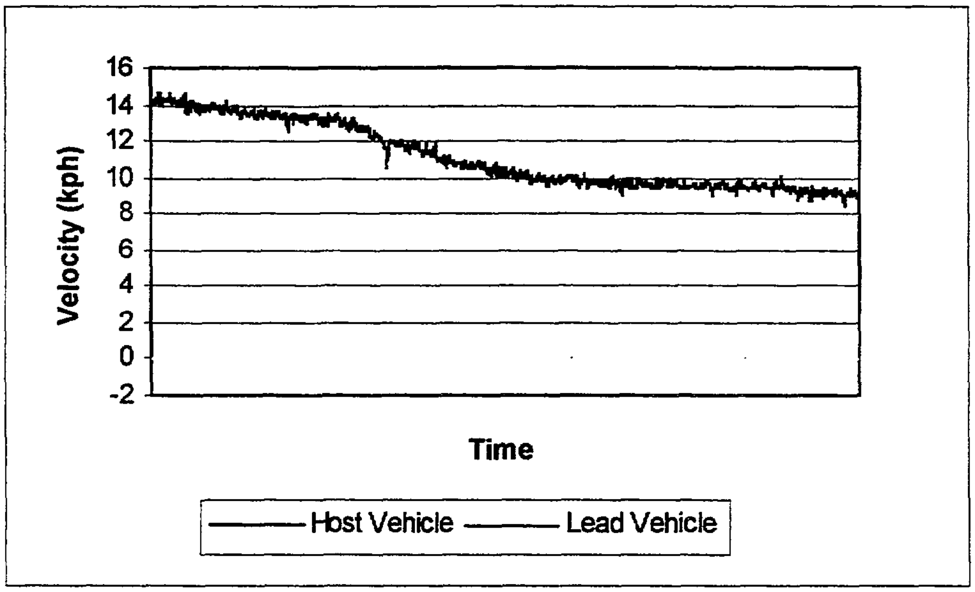

Figure 48-3 Test 48, Absolute Velocity Measurement

Test Number 49: Lead Vehicle Stopped, Host Vehicle 50 kph, curved, same lane

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 49-1. The range error is shown in Figure 49-2. The absolute velocity of the two vehicles is shown in Figure 49-3. The range alarm from the system was detected at 26 meters, 42 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

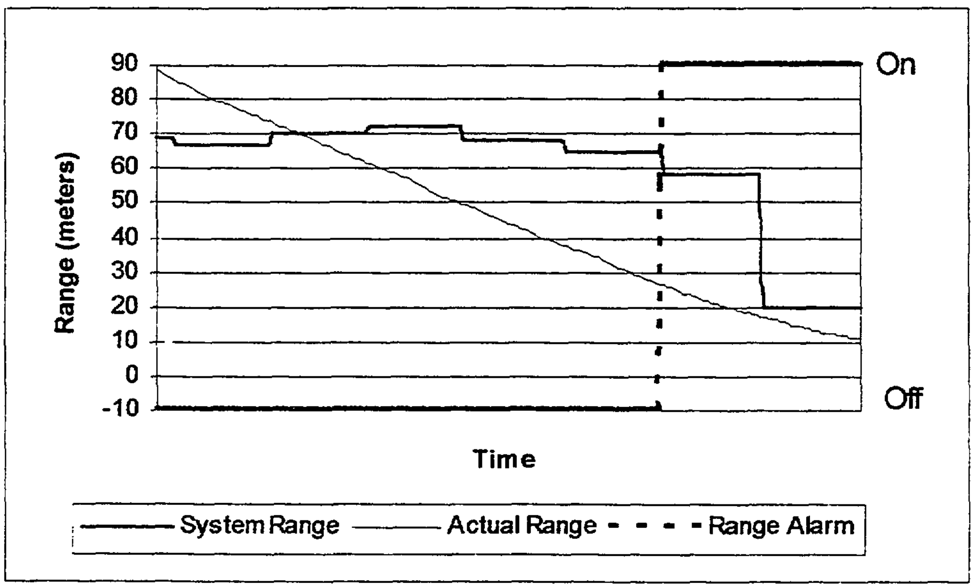

Figure 49-1 Test 49, Range Measurement

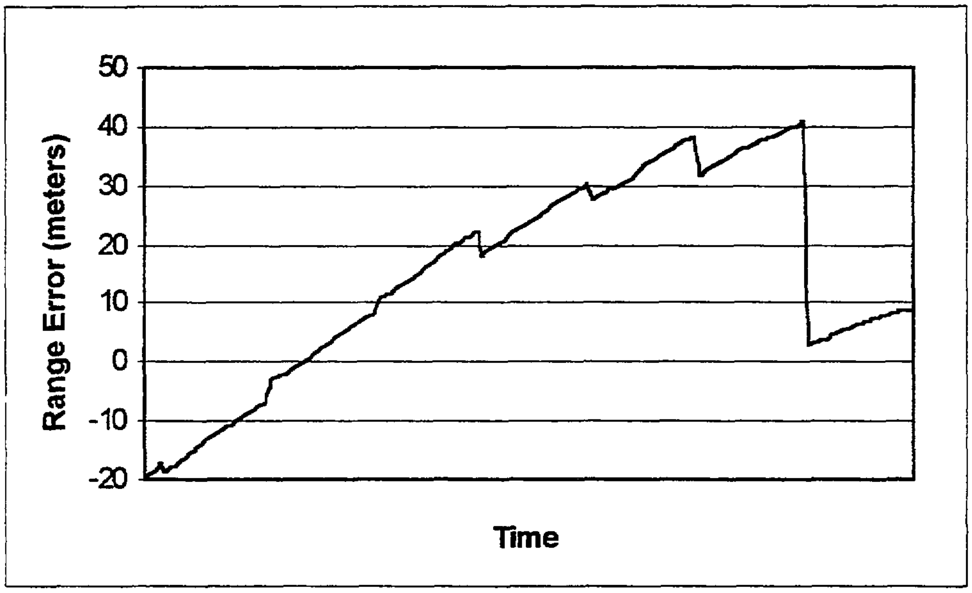

Figure 49-2 Test 49, Range Error Measurement

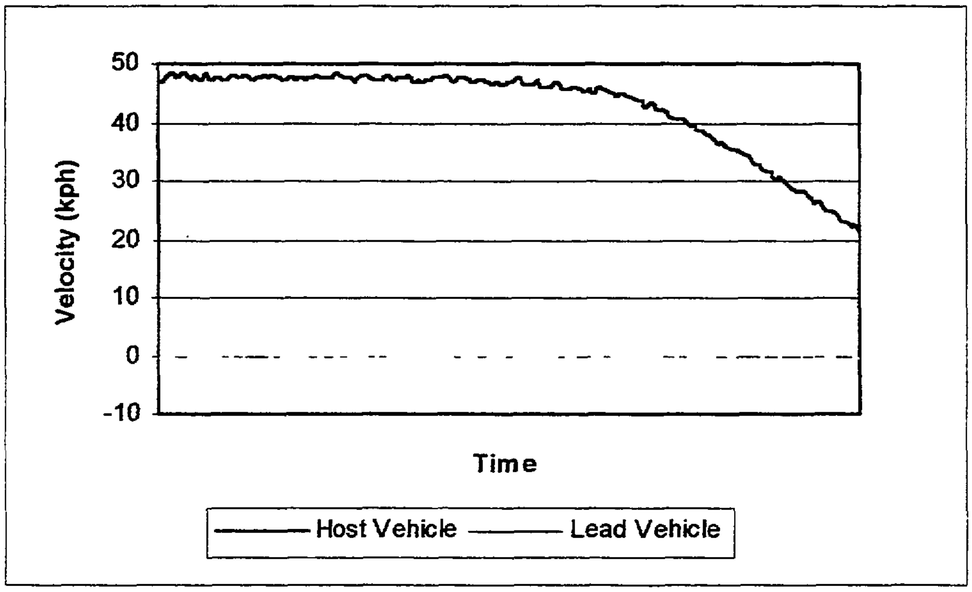

Figure 49-3 Test 49, Absolute Velocity Measurement

Test Number 50: Lead Vehicle Stopped. Host Vehicle 100 kph. curved, same lane

Test not performed due to safety considerations.

Test Number 51: Lead Vehicle 30 kph, Host Vehicle 50 kph, curved, same lane

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 51-1. The range error is shown in Figure 51-2. The absolute velocity of the two vehicles is shown in Figure 51-3. The actual relative velocity as well as the system relative velocity is shown in Figure 51-4. The relative velocity error is shown in Figure 51-5. The range alarm from the system was detected at 31 meters, 21 kph from the lead vehicle.

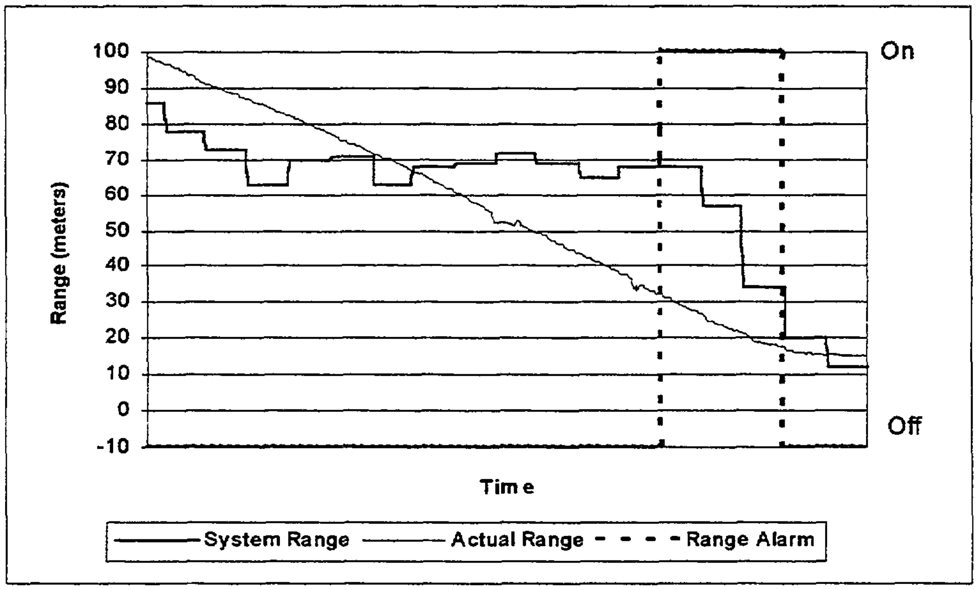

Figure 51-1 Test 51, Range Measurement

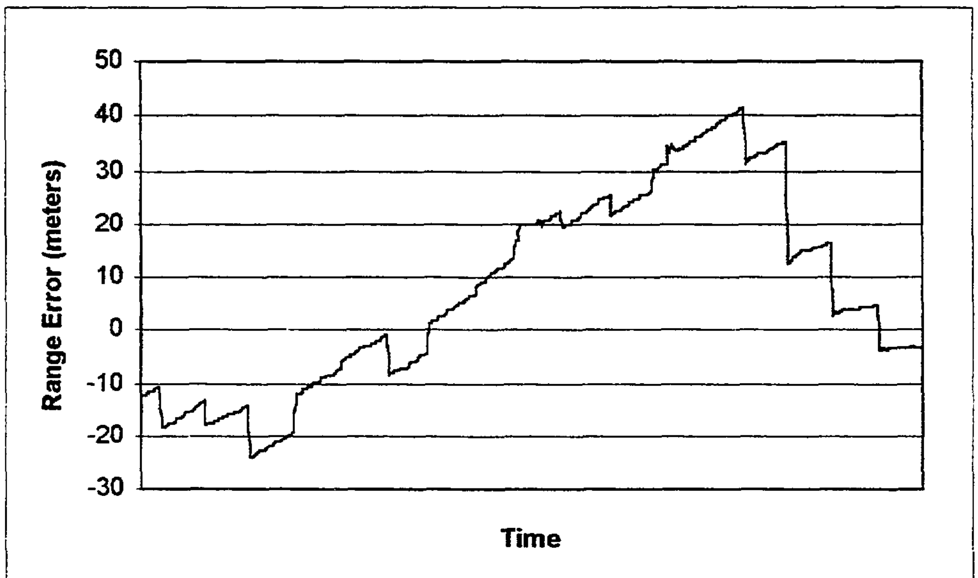

Figure 51-2 Test 51, Range Error Measurement

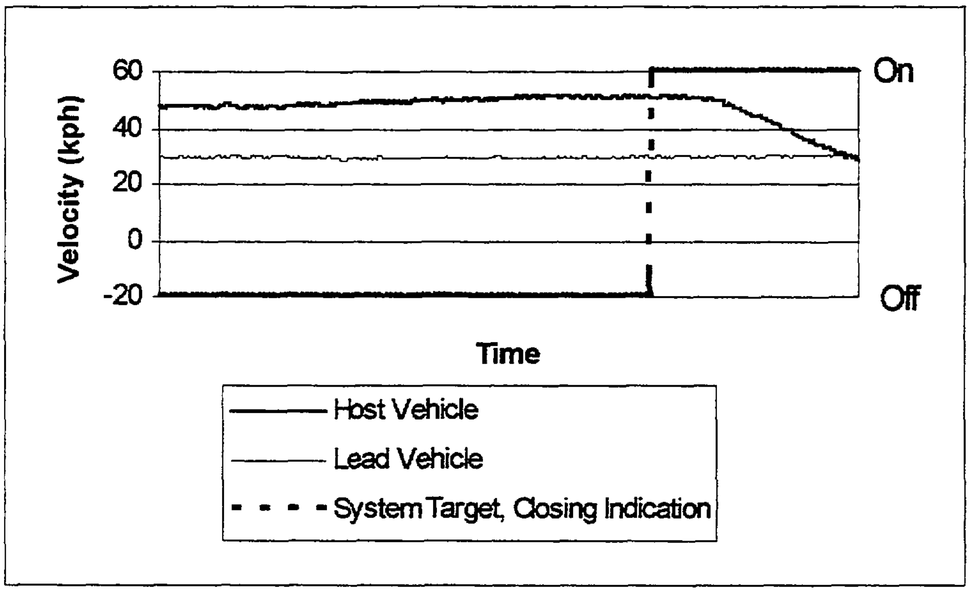

Figure 51-3 Test 51, Absolute Velocity Measurement

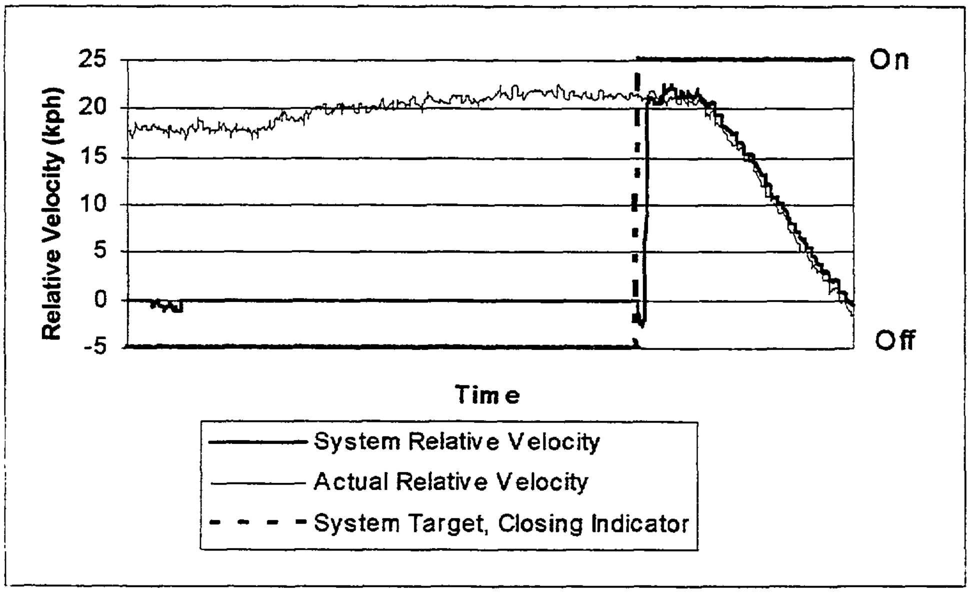

Figure 51-4 Test 51, Relative Velocity Measurement

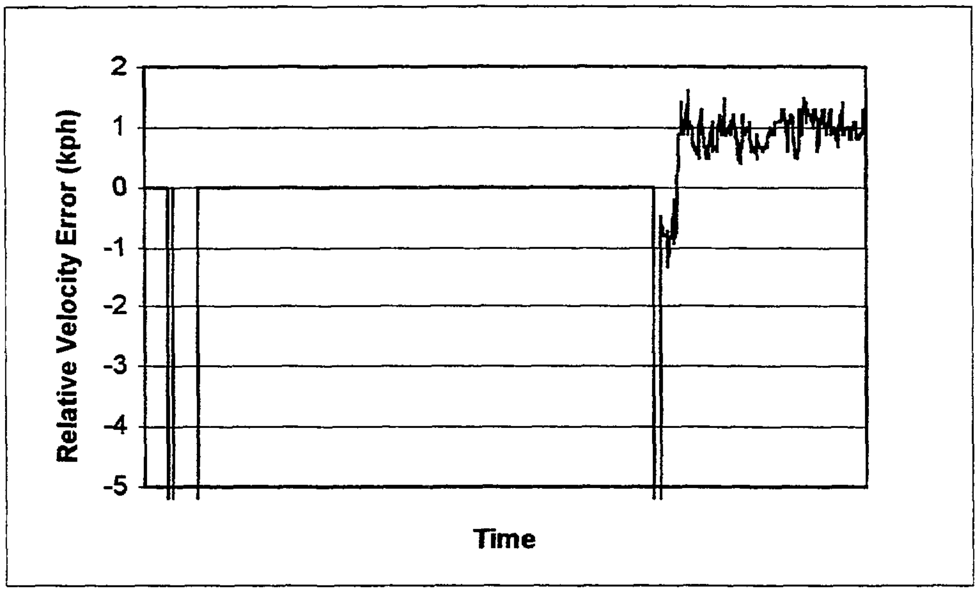

Figure 51-5 Test 51, Relative Velocity Error Measurement

Test Number 52: Lead Vehicle Stopped. Host Vehicle 10 kph, curved, adjacent lane

The actual range, the measured range from the system is shown in Figure 52-1. The range error is shown in Figure 52-2. The absolute velocity of the two vehicles is shown in Figure 52-3. There was no range alarm from the system. The system relative velocity sensor does not sense stopped vehicles.

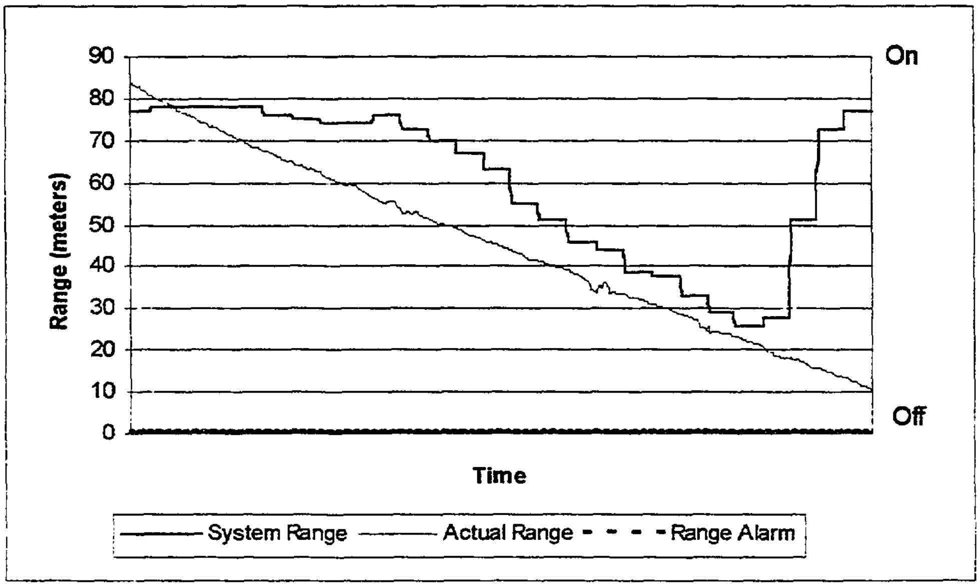

Figure 52-1 Test 52, Range Measurement

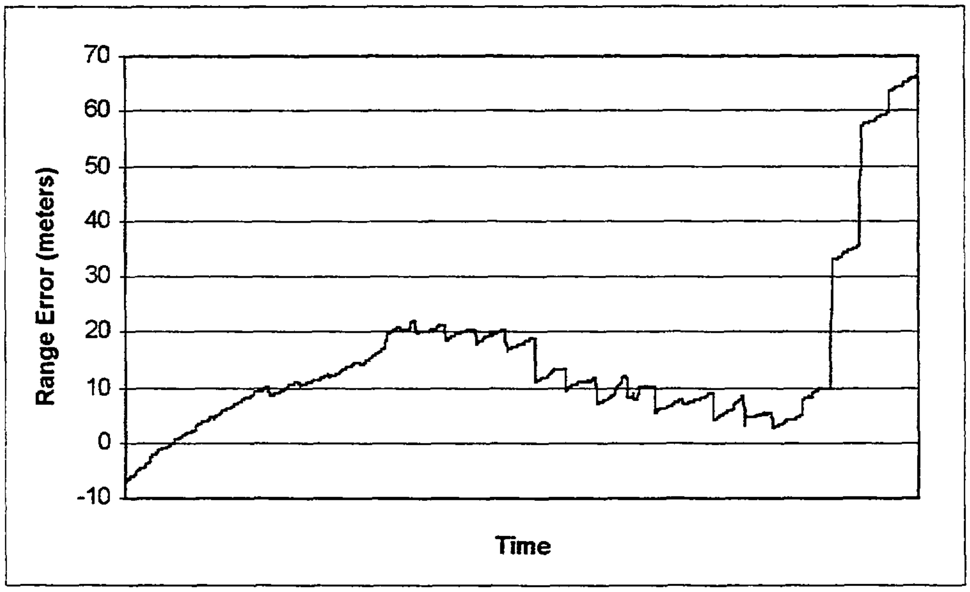

Figure 52-2 Test 52, Range Error Measurement

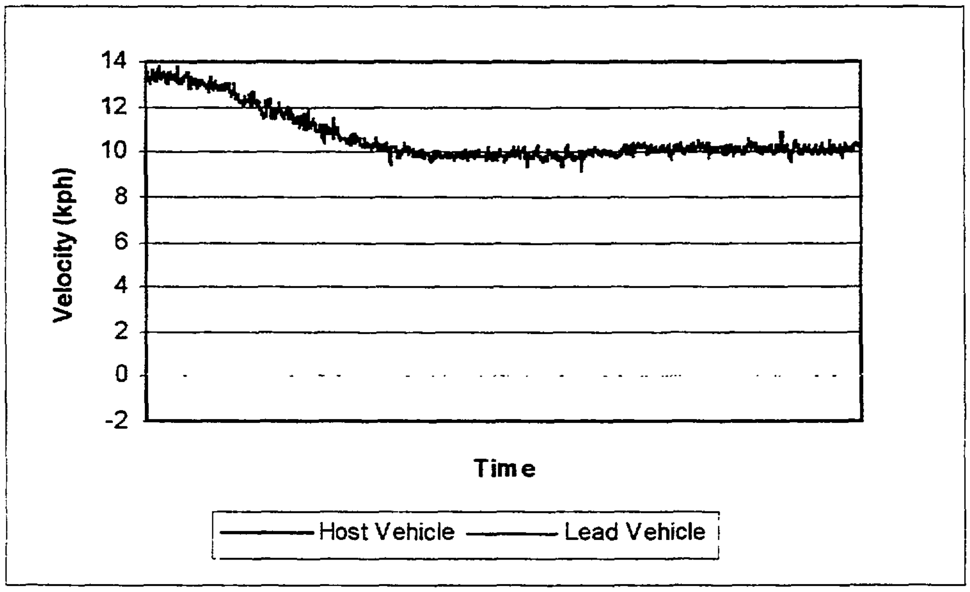

Figure 52-3 Test 52, Absolute Velocity Measurement

Test Number 53: Lead Vehicle Stopped, Host Vehicle 50 kph, curved, adjacent lane

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 53-1. The range error is shown in Figure 53-2. The absolute velocity of the two vehicles is shown in Figure 53-3. The range alarm from the system was detected at 37 meters, 54 kph from the lead vehicle. The system relative velocity sensor does not sense stopped vehicles.

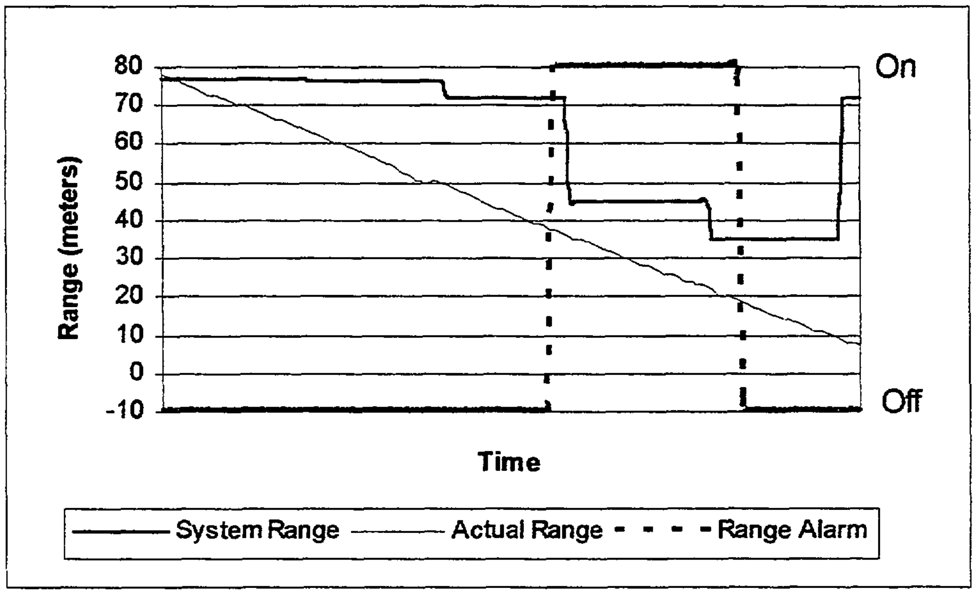

Figure 53-1 Test 53, Range Measurement

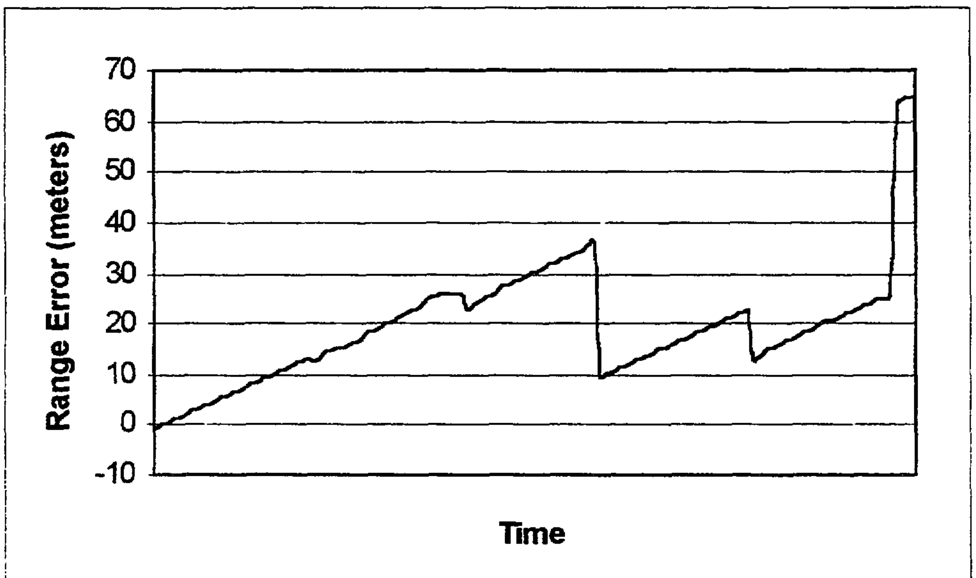

Figure 53-2 Test 53, Range Error Measurement

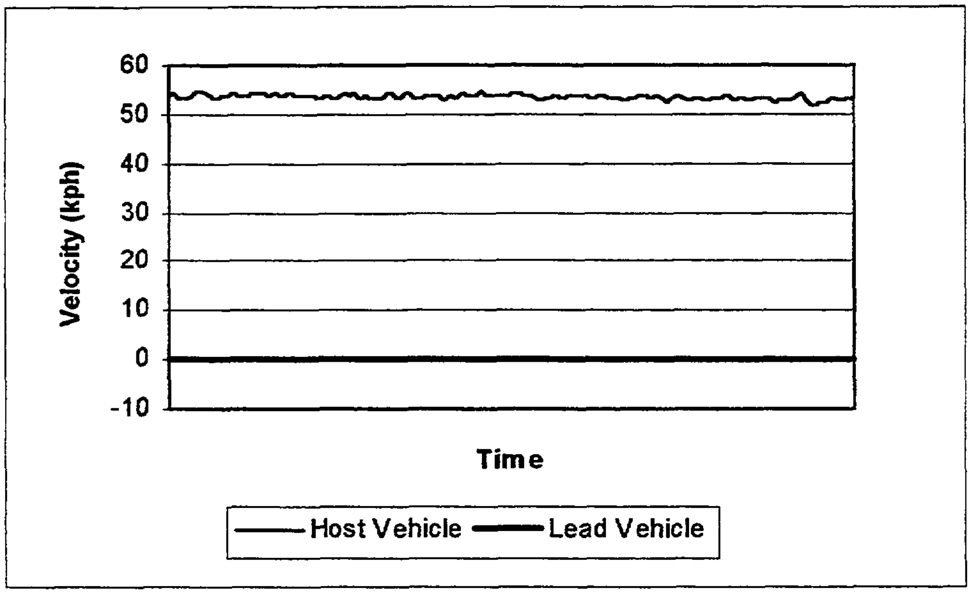

Figure 53-3 Test 53, Absolute Velocity Measurement

Test Number 54: Lead Vehicle Stopped, Host Vehicle 100 kph, curved, adjacent lane

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other lead vehicle stopped tests.

Test Number 55: Lead Vehicle 30 kph, Host Vehicle 50 kph, curved, adjacent lane

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 55-1. The range error is shown in Figure 55-2. The absolute velocity of the two vehicles is shown in Figure 55-3. The actual relative velocity as well as the system relative velocity is shown in Figure 55-4. The relative velocity error is shown in Figure 55-5. The alarms compared to the steering angle is shown in Figure 55-6. The range alarm from the system was detected at 50 meters, 20 kph from the lead vehicle.

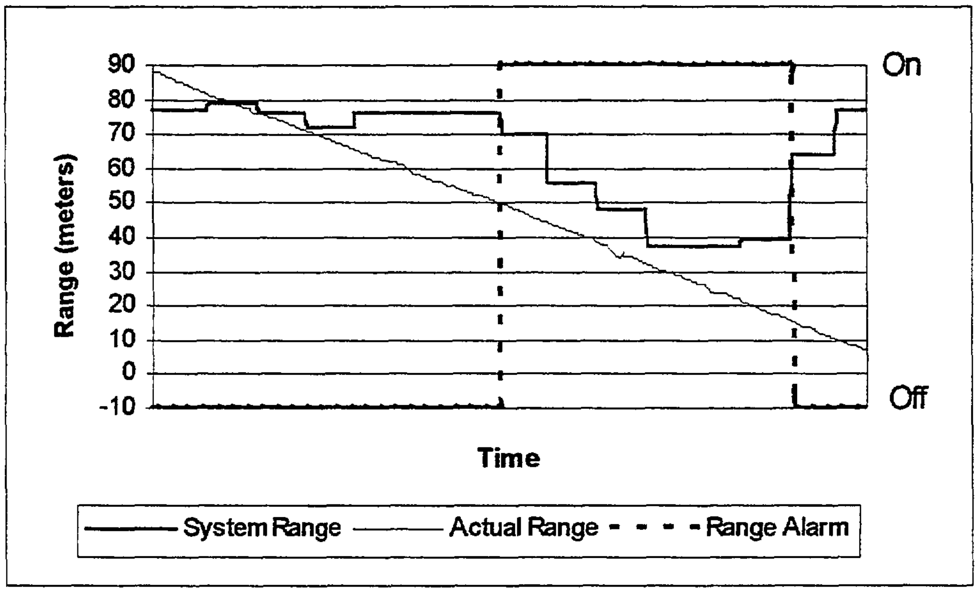

Figure 55-1 Test 55, Range Measurement

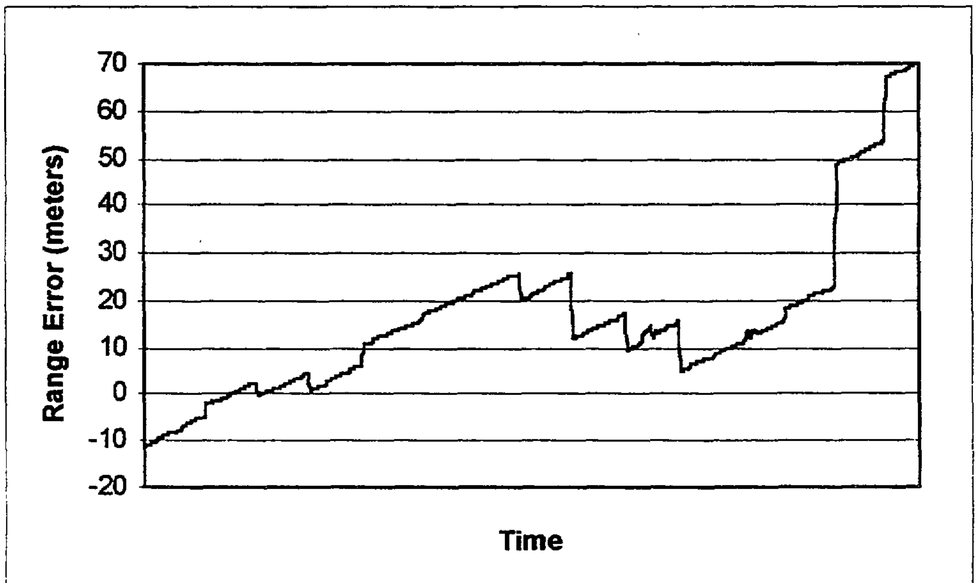

Figure 55-2 Test 55, Range Error Measurement

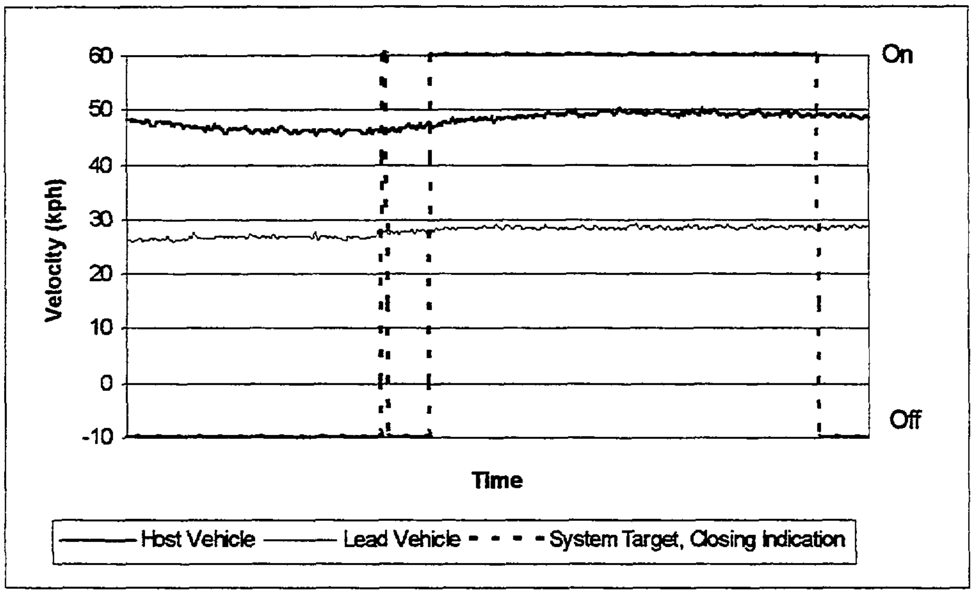

Figure 55-3 Test 55, Absolute Velocity Measurement

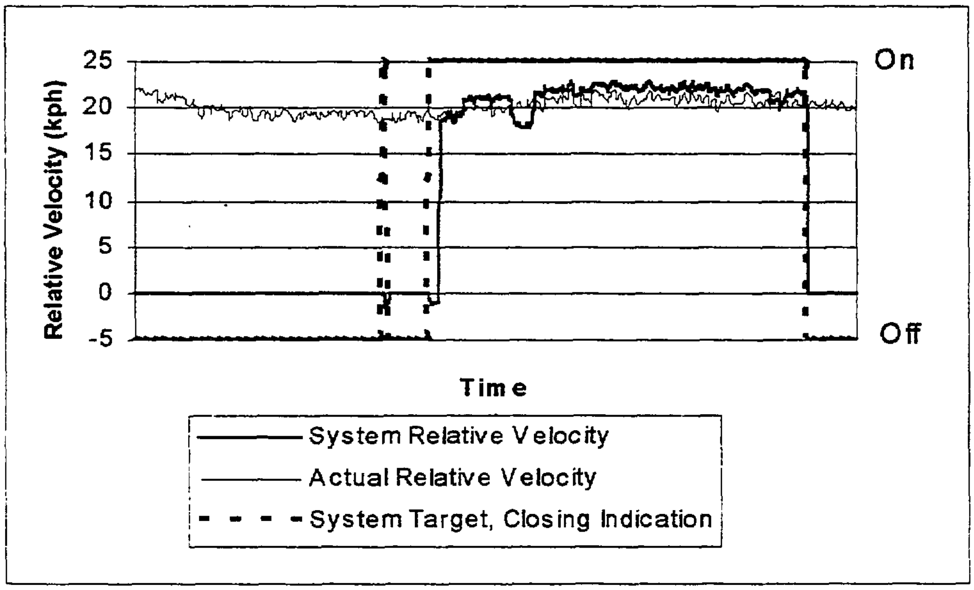

Figure 55-4 Test 55, Relative Velocity Measurement

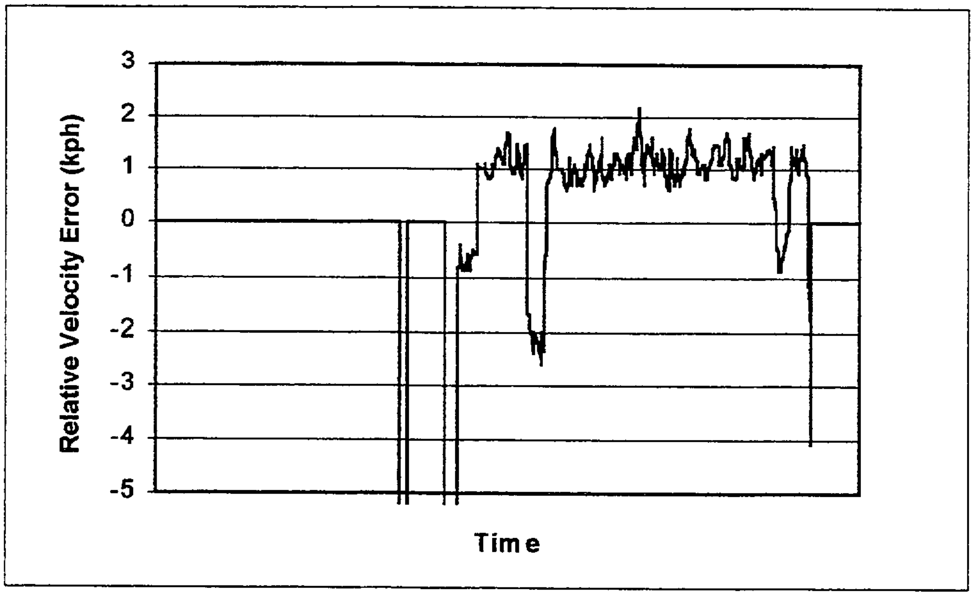

Figure 55-5 Test 55, Relative Velocity Error Measurement

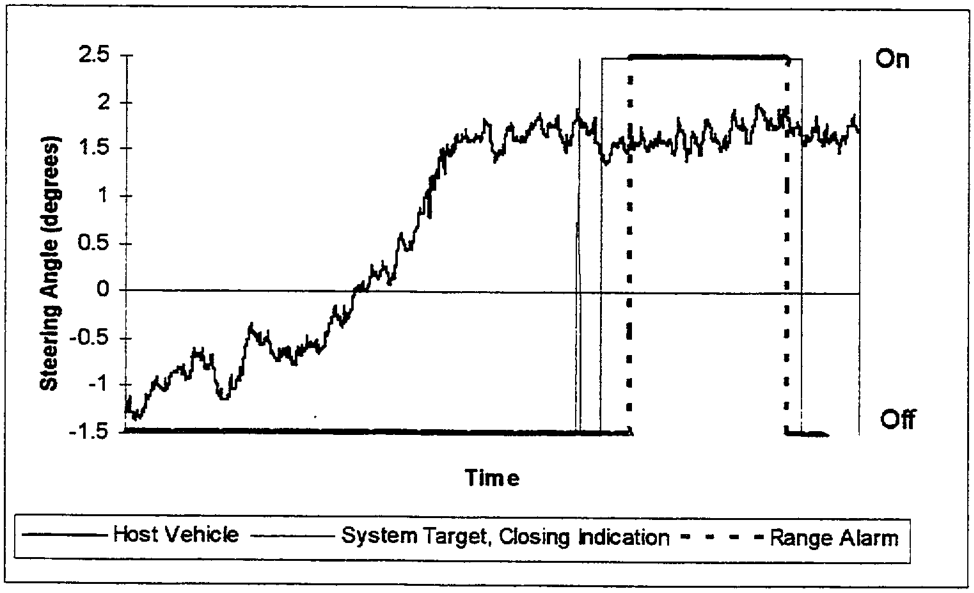

Figure 55-6 Test 55, Steering Angle Measurement

Test Number 56: Lead Vehicle Stopped. Host Vehicle 10 kph, Sag

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam, tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 57: Lead Vehicle Stopped, Host Vehicle 50 kph, Sag

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam, tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 58: Lead Vehicle Stopped, Host Vehicle 100 kph, Sag

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam, tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 59: Lead Vehicle 30 kph, Host Vehicle 50 kph, Sag

A drive through of some sharply rolling hills was performed to assess the ability of the system to track the lead vehicle through hill and sags. The measured pitch from the host and lead vehicles, as well as the system target indication is shown in Figure 59-1. As can be seen, numerous drops of the target occurred due to the hills and sags.

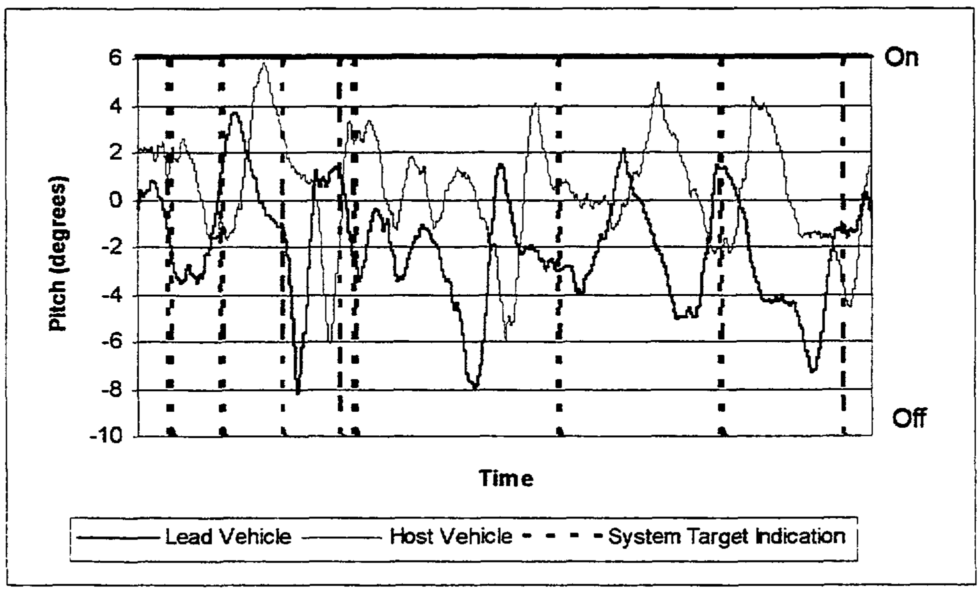

Figure 59-1 Test 59, Pitch Angle Measurement

Test Number 60: Lead Vehicle Stopped, Host Vehicle 10 kph, Hill

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam, tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 61: Lead Vehicle Stopped, Host Vehicle 50 kph, Hill

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 62: Lead Vehicle Stopped, Host Vehicle 100 kph, Hill

Due to the short time frame available to complete the tests, a suitable location was unavailable to perform this test. However, since the system uses a circular shaped beam, tests for hills, sags, and grades should be equivalent to tests performed on curves.

Test Number 63: Lead Vehicle 30 kph. Host Vehicle 50 kph, Hill

A drive through of some sharply rolling hills was performed to assess the ability of the system to track the lead vehicle through hill and sags. The measured pitch from the host and lead vehicles, as well as the system target indication is shown in Figure 63- 1. As can be seen, numerous drops of the target occurred due to the hills and sags.

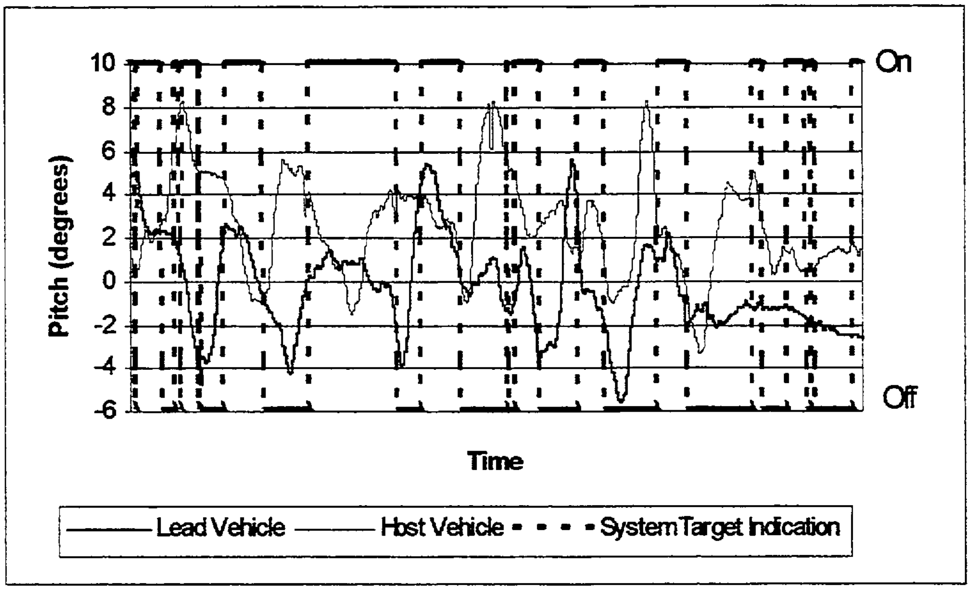

Figure 63-1 Test 63, Pitch Angle Measurement

Test Number 64: Lead Vehicle, 50 kph, Merging Ahead. 0.3g deceleration, Host Vehicle 40 kph

The actual range, the measured range from the system is shown in Figure 64-1. The range error is shown in Figure 64-2. The absolute velocity of the two vehicles is shown in Figure 64-3. The actual relative velocity as well as the system relative velocity is shown in Figure 64-4. The relative velocity error is shown in Figure 64-5. No range alarm from the system.

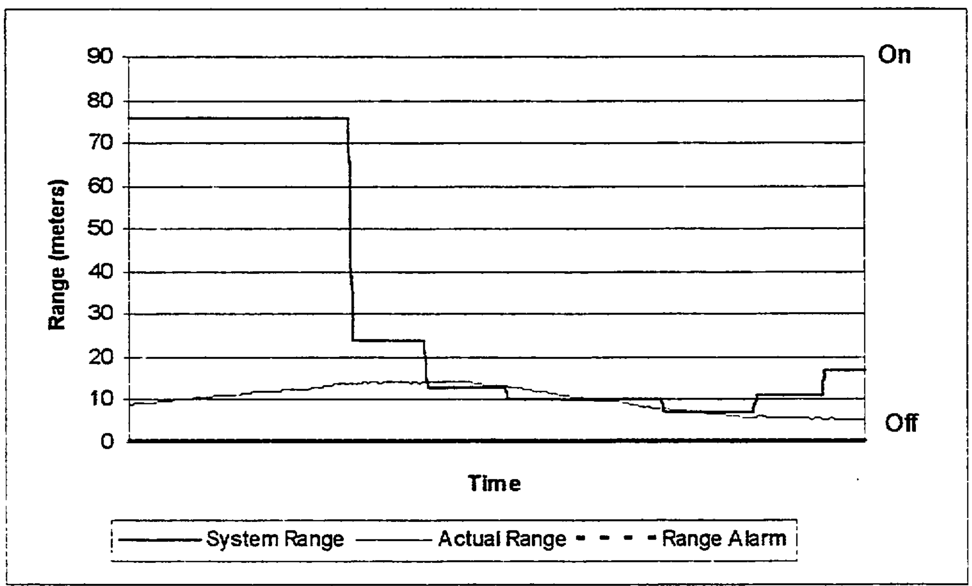

Figure 64-1 Test 64, Range Measurement

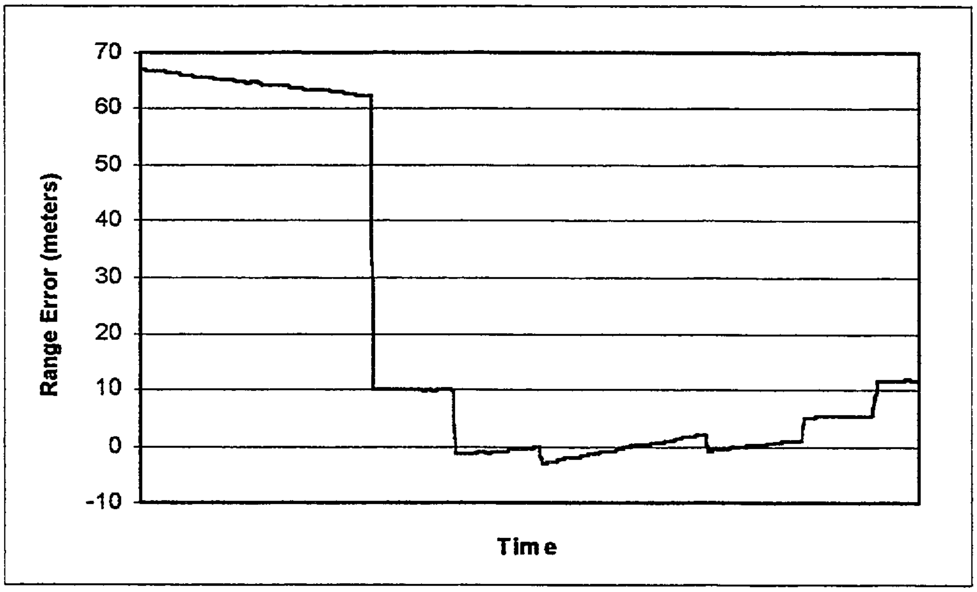

Figure 64-2 Test 64, Range Error Measurement

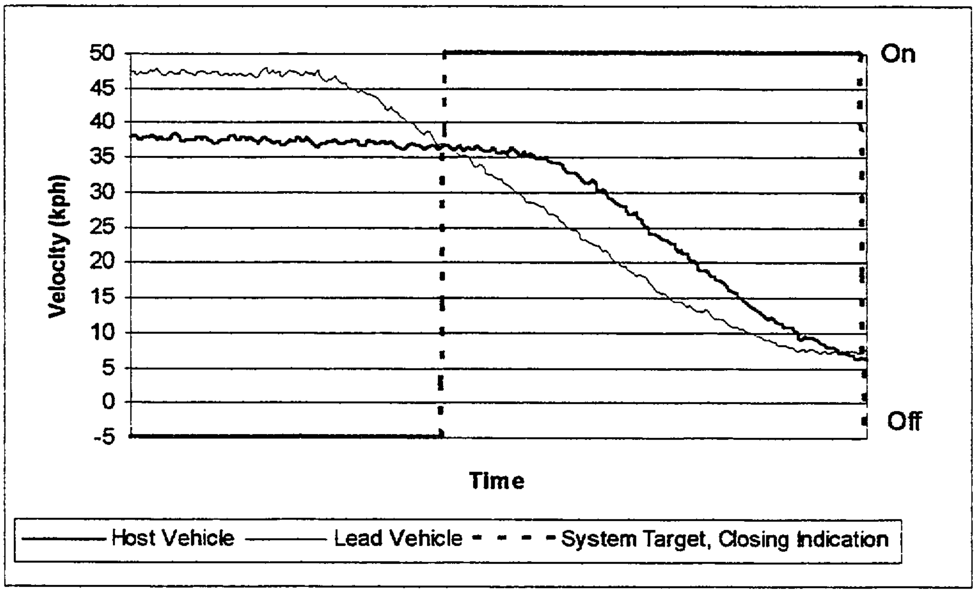

Figure 64-3 Test 64, Absolute Velocity Measurement

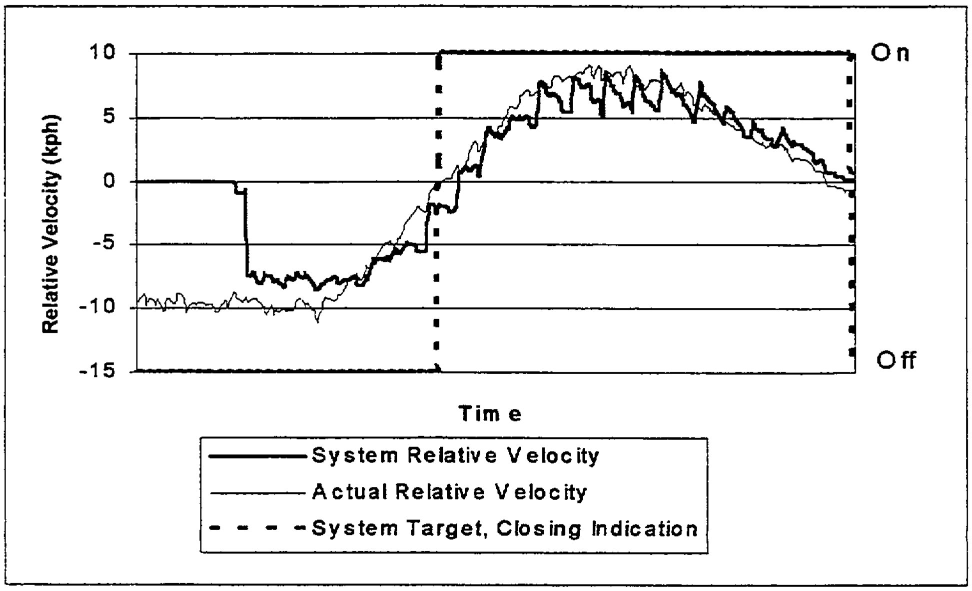

Figure 64-4 Test 64, Relative Velocity Measurement

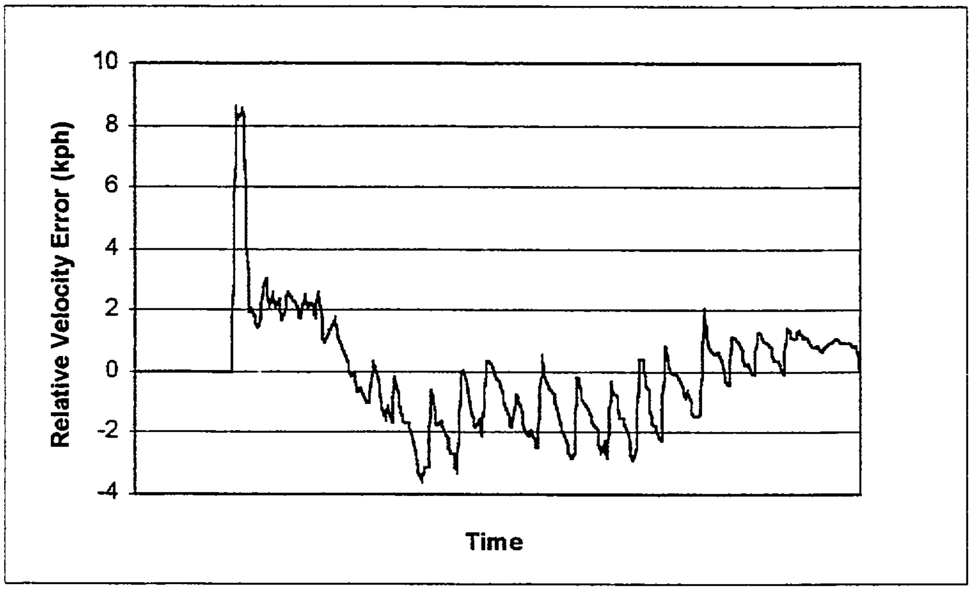

Figure 64-5 Test 64, Relative Velocity Error Measurement

Test Number 65: Lead Vehicle, 75 kph, Merging Ahead, 0.3g deceleration, Host Vehicle 60 kph

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 65-1. The range error is shown in Figure 65-2. The absolute velocity of the two vehicles is shown in Figure 65-3. The actual relative velocity as well as the system relative velocity is shown in Figure 65-4. The relative velocity error is shown in Figure 65-5. The range alarm from the system was detected at 22 meters, -1 kph from the lead vehicle.

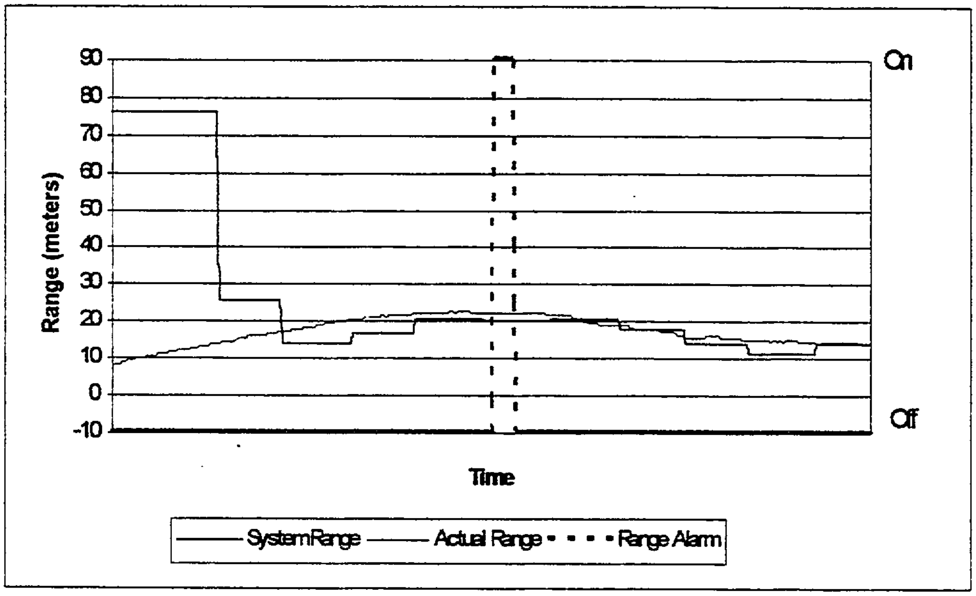

Figure 65-1 Test 65, Range Measurement

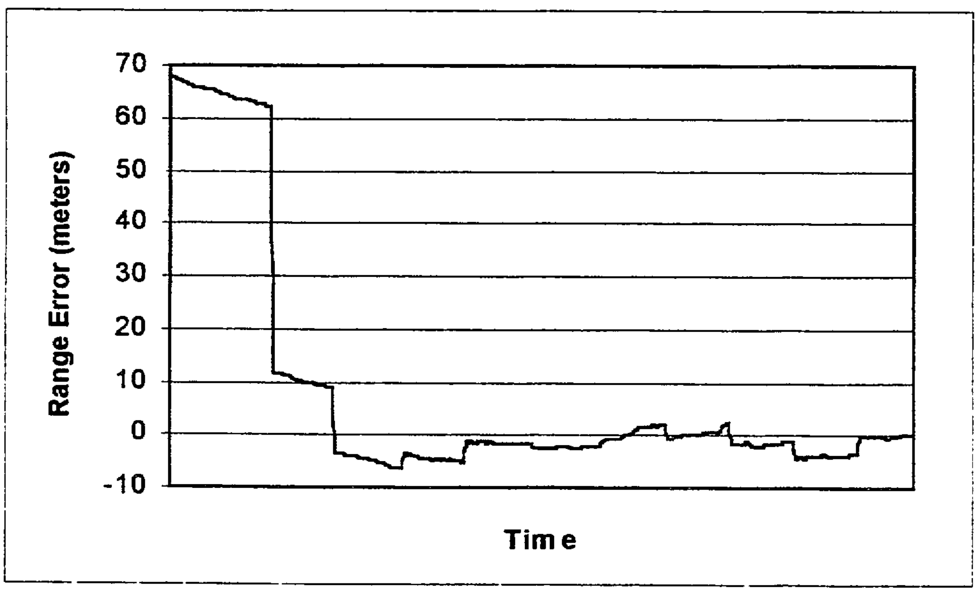

Figure 65-2 Test 65, Range Error Measurement

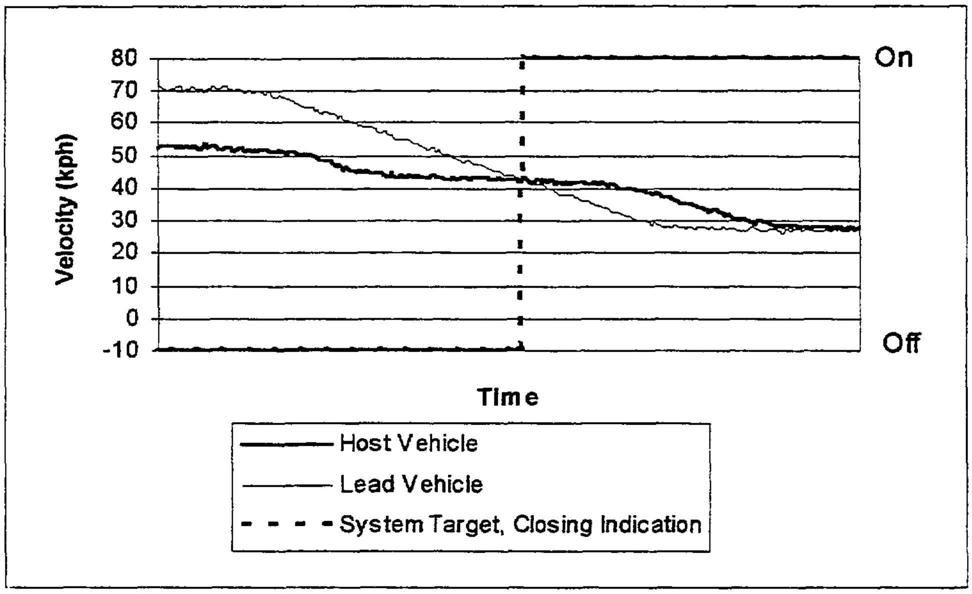

Figure 65-3 Test 65, Absolute Velocity Measurement

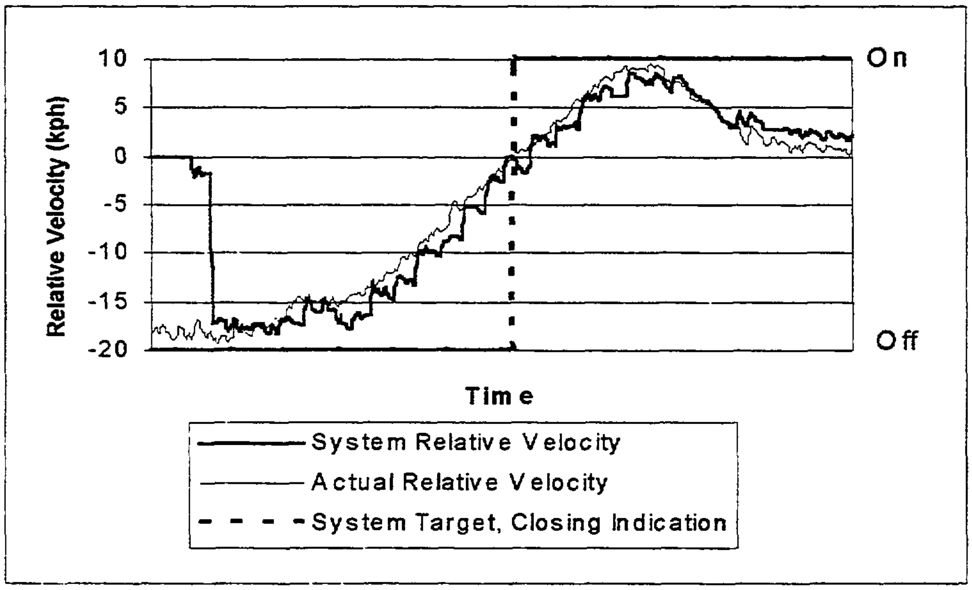

Figure 65-4 Test 65, Relative Velocity Measurement

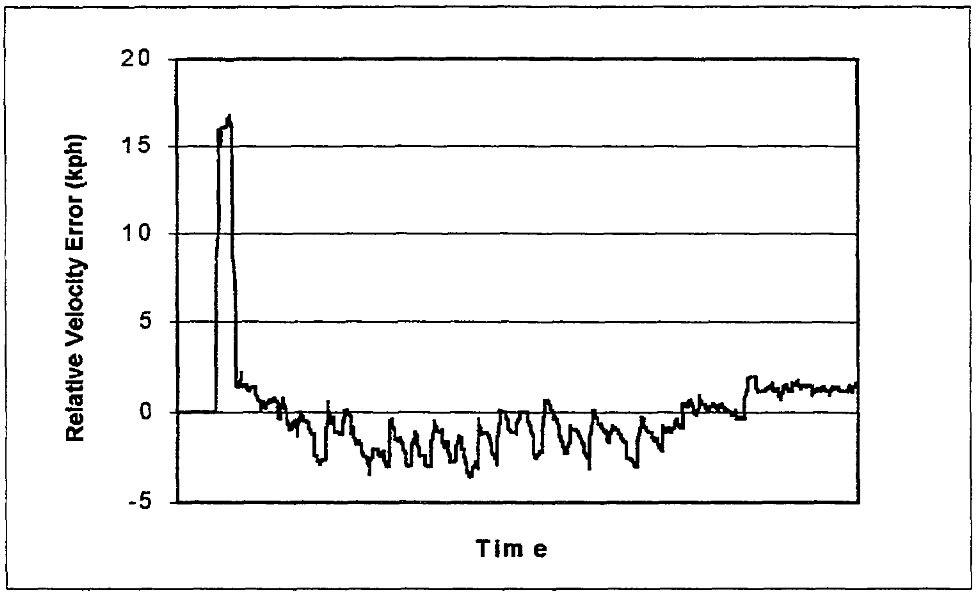

Figure 65-5 Test 65, Relative Velocity Error Measurement

Test Number 66: Lead Vehicle, 100 kph, Merging Ahead, 0.3g deceleration, Host Vehicle 60 kph

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other merging tests.

Test Number 67: Lead Vehicle, 100 kph, Merging Ahead, 0.3g deceleration, Host Vehicle 80 kph

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other merging tests.

Test Number 68: Lead Vehicle 40 kph, Host Vehicle 50 kph, Merging behind, 0.3g deceleration

The actual range, the measured range from the system, as well as the range alarm from the system is shown in Figure 68-1. The range error is shown in Figure 68-2. The absolute velocity of the two vehicles is shown in Figure 68-3. The actual relative velocity as well as the system relative velocity is shown in Figure 68-4. The relative velocity error is shown in Figure 68-5. The range alarm from the system was detected at 15 meters, -3 kph from the lead vehicle.

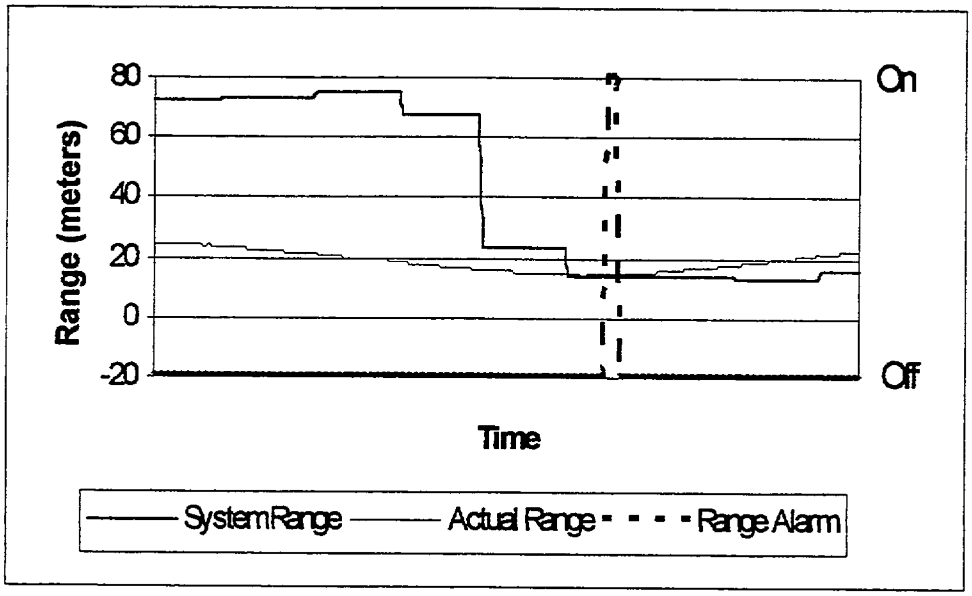

Figure 68-1 Test 68, Range Measurement

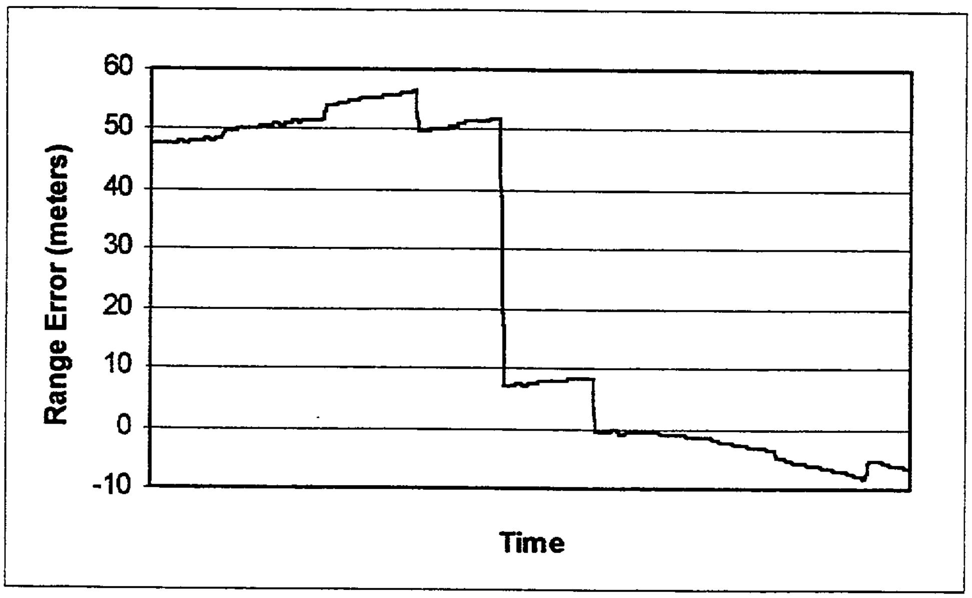

Figure 68-2 Test 68, Range Error Measurement

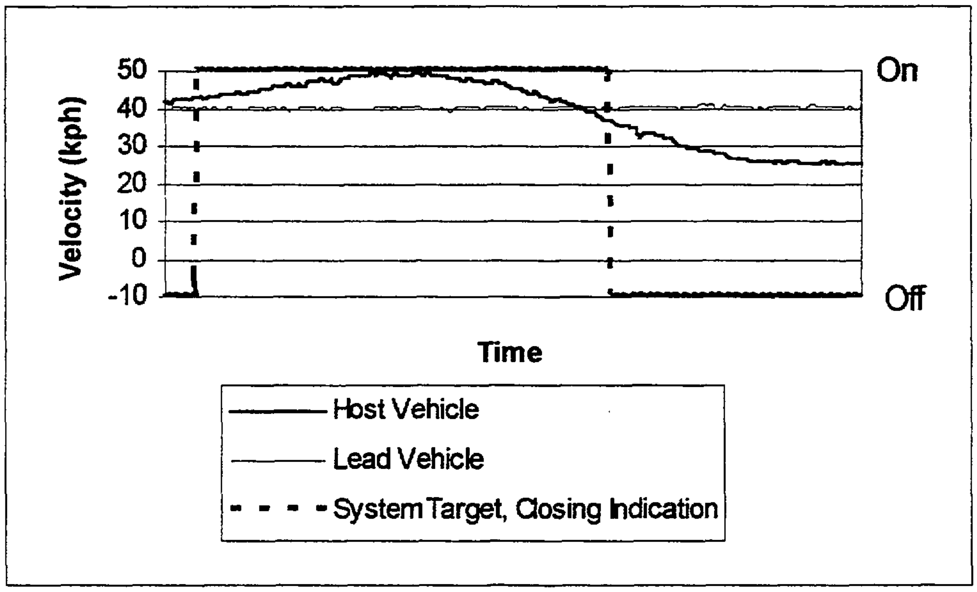

Figure 68-3 Test 68, Absolute Velocity Measurement

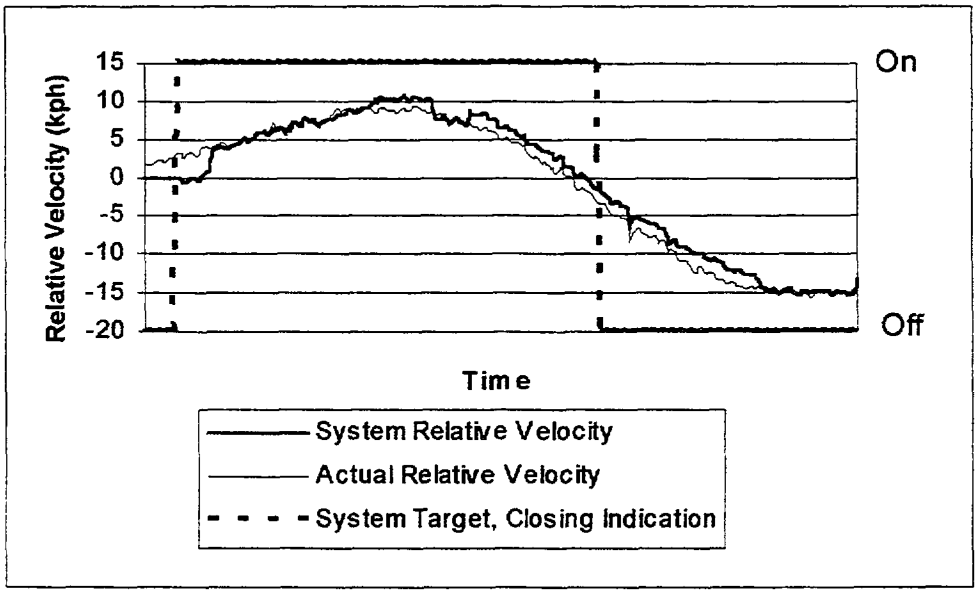

Figure 68-4 Test 68, Relative Velocity Measurement

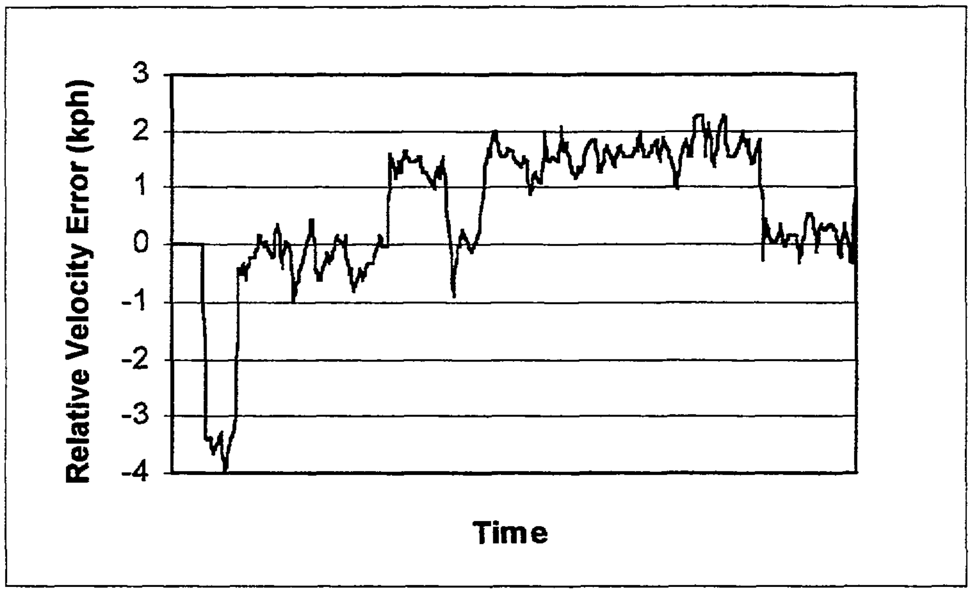

Figure 68-5 Test 68, Relative Velocity Error Measurement

Test Number 69: Lead Vehicle 60 kph, Host Vehicle 75 kph, Merging behind, 0.3g deceleration

The actual range, the measured range from the system is shown in Figure 69-1. The range error is shown in Figure 69-2. The absolute velocity of the two vehicles is shown in Figure 69-3. The actual relative velocity as well as the system relative velocity is shown in Figure 69-4. The relative velocity error is shown in Figure 69-5. There was no alarm from the system.

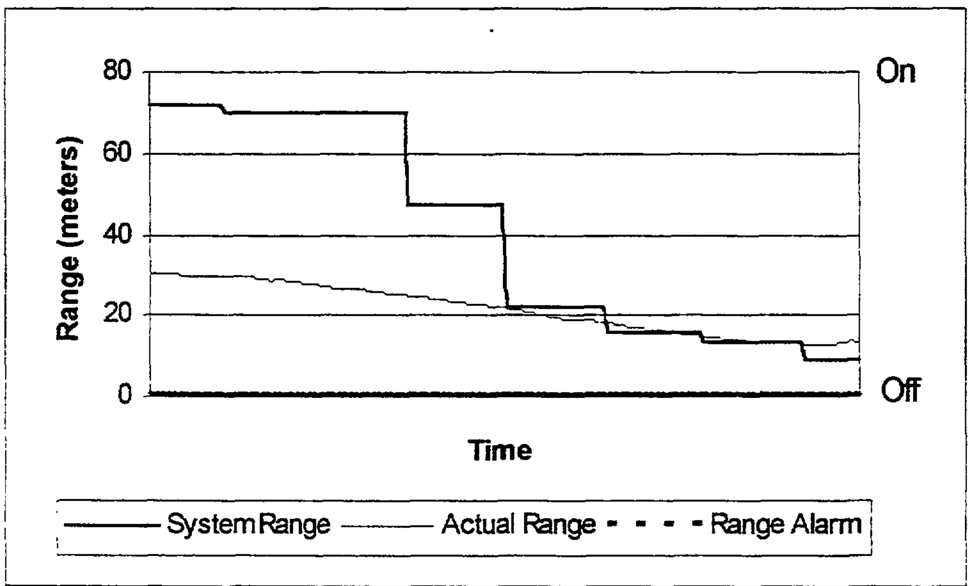

Figure 69-1 Test 69, Range Measurement

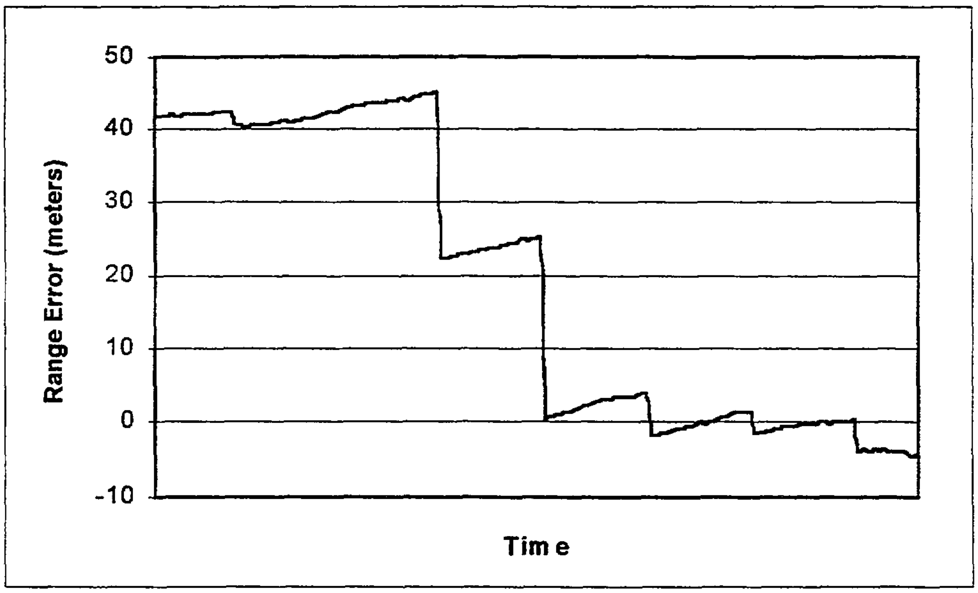

Figure 69-2 Test 69, Range Error Measurement

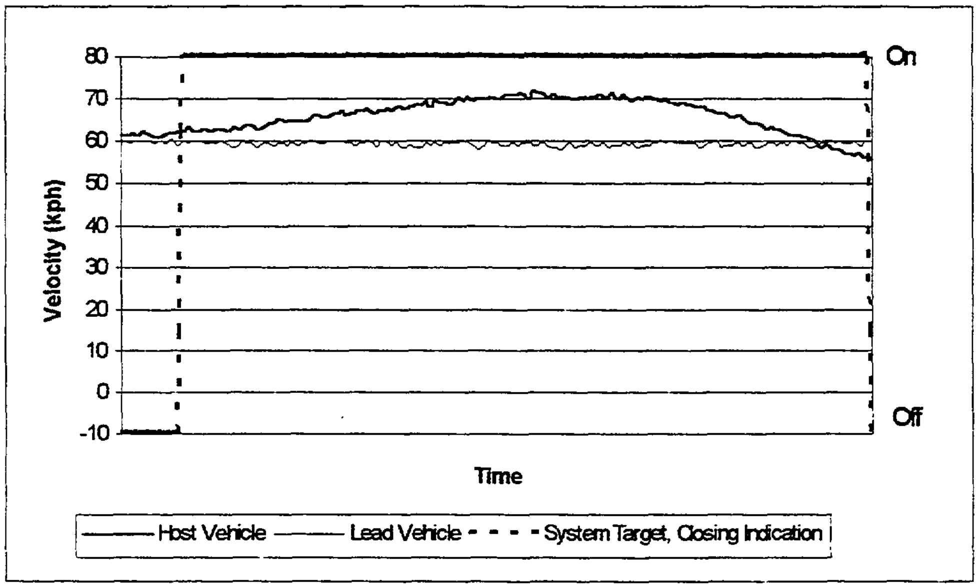

Figure 69-3 Test 69, Absolute Velocity Measurement

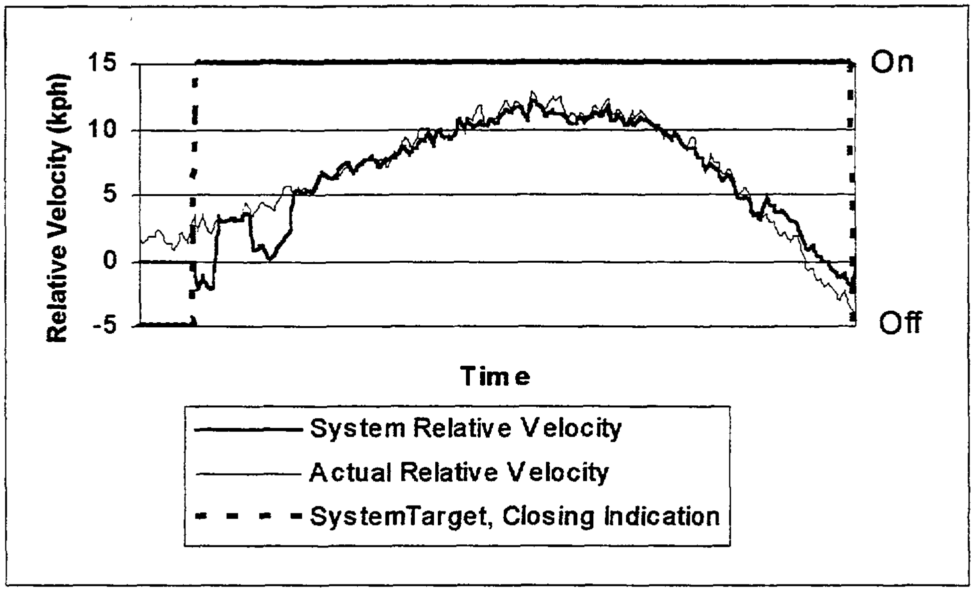

Figure 69-4 Test 69, Relative Velocity Measurement

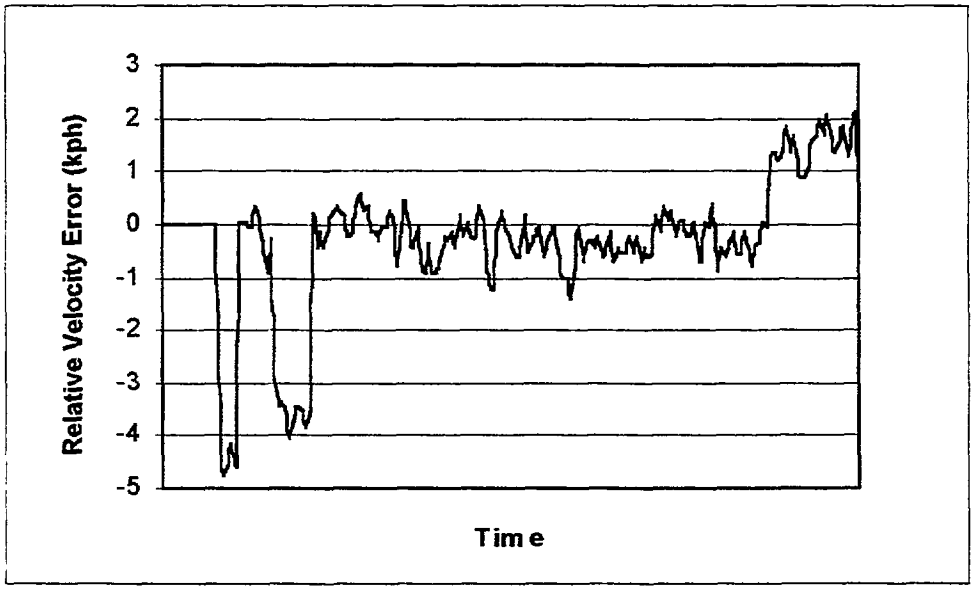

Figure 69-5 Test 69, Relative Velocity Error Measurement

Test Number 70: Lead Vehicle 60 kph, Host Vehicle 100 kph, Merging behind. 0.3g deceleration

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other merging tests.

Test Number 71: Lead Vehicle 80 kph, Host Vehicle 100 kph, Merging behind, 0.3g deceleration

Test not performed due to safety considerations. Since the system alarms at a fixed range, it is felt that this test would be redundant to the other merging tests.

Test Number 72: Lead Vehicle Stopped, Host Vehicle 10 kph, Rain

Target of opportunity test not available during testing.

Test Number 73: Lead Vehicle Stopped, Host Vehicle 50 kph, Rain

Target of opportunity test not available during testing.

Test Number 74: Lead Vehicle Stopped, Host Vehicle 100 kph., Rain

Target of opportunity test not available during testing.

Test Number 75: Lead Vehicle Stopped Host Vehicle 10 kph, Snow

Target of opportunity test not available during testing.

Test Number 76: Lead Vehicle Stopped, Host Vehicle 50 kph Snow

Target of opportunity test not available during testing.

Test Number 77: Lead Vehicle Stopped, Host Vehicle 100 kph, Snow

Target of opportunity test not available during testing.

Test Number 78: Lead Vehicle Stopped. Host Vehicle 10 kph Fog

Target of opportunity test not available during testing.

Test Number 79: Lead Vehicle Stopped Host Vehicle 50 kph. Fog

Target of opportunity test not available during testing.

Test Number 80: Lead Vehicle Stopped, Host Vehicle 100 kph, Fog

Target of opportunity test not available during testing.

Test Number 81: Lead Vehicle Stopped, Host Vehicle 10 kph, Dust

Target of opportunity test not available during testing.

Test Number 82: Lead Vehicle Stopped, Host Vehicle 50 kph, Dust

Target of opportunity test not available during testing.

Test Number 83: Lead Vehicle Stopped, Host Vehicle 100 kph, Dnst

Target of opportunity test not available during testing.