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16. Abstract (Limit: 200 words)

This report looks at the effectiveness of microloops as replacements for the inductive loops that are used as advance detection sensors at actuated signalized intersections. It also evaluated whether different loop detector models from several manufacturers can operate satisfactorily and consistently when attached to the microloop, and also determined the performance accuracy of loop detectors attached to a one-probe microloop or to a two-probe microloop.

Research results support the hypothesis that microloops can function as a reliable replacement for inductive loops in advance detection applications. To achieve optimum results, the microloops must be used with Canoga C800 series vehicle detectors with version 1.2 firmware as part of a matched component system. Different brands of detector amplifiers do not perform as satisfactorily with the M701 microloop. Only the detectors that incorporate algorithms specifically developed for use with microloops demonstrated a performance that approaches the performance of inductive loops. These detectors also can be used in Presence Mode, thus allowing the traffic engineer to use the microloop in a broad range of applications.

The strong attributes of microloop-based traffic sensors include shorter installation time, less pavement invasion, and improved life-cycle costs compared to traditional saw cut inductive loops, while providing consistent and accurate performance under all environmental and road conditions.

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3M MICROLOOP FIELD EVALUATION REPORT

Final Report

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Field Evaluation Report – Executive Summary[1]

Comparison of 3M™ Canoga™ M701 Microloops and 1.7 m X 1.7 m Loops in an Intersection Advance Detection Application

Introduction

Almost all of the Minnesota Department of Transportation (Mn/DOT) traffic signals are actuated. The use of traffic-actuated signals has proven to be the best method of safe and efficient traffic control at high-speed intersections. The sensor that detects presence of vehicles is the key link to the successful operation of the system. Detector failures will degrade the good performance of a well-designed timing plan. Saw cut-installed inductive loops currently are the backbone of most traffic detection systems. Since they are installed in the surface of the road, they are vulnerable to pavement failure and milling operations.

Over the years, there has been a quest to find the "best" detection system. Loop detectors, magnetic (brass torpedo style) detectors, video imaging and radar detection are some of the types being used today. More recently, loops encased within non-metallic conduit (PVC) have been installed and used with success in bituminous and concrete pavements. All have their strengths and weaknesses. At some intersections, different types of detection have been used in an effort to minimize future maintenance.

With different types of detection available today, signal design strategy may be to select the best type of detector for various situations or requirements. Future signal design could include two or three different types of detection for a single intersection.

This study was performed to test the hypothesis that microloops can be effective replacements for inductive loops used as the advance detection sensors at actuated signalized intersections. Microloops can be located completely beneath the pavement, thereby avoiding damage resulting from pavement failure and milling operations. Pavement saw cuts are reduced or eliminated.

In the fall of 1993, 3M, the Rennix Corporation and the Minnesota Department of Transportation entered into a partnership to test the 3M™ Canoga™ M701 Microloops with the Canoga™ C400 rack-mounted vehicle detectors and the 3M™ Canoga™ Interface and Data Acquisition Software for setting and reading the detectors and for monitoring traffic remotely. Private partners supplied all the hardware and software; Mn/DOT provided installation of these materials and was responsible for the project.

Study Description

Field evaluations were conducted under the supervision of Chuck Auger (Rennix Corporation) and Jerry Kotzenmacher (Mn/DOT – Metro Division) to test the hypotheses put forward by Rennix Corporation – that the M701 microloop will perform satisfactorily when used as a replacement for saw cut inductive loops in intersection advance detection applications and that the satisfactory performance could be achieved with different brands of detector amplifiers. The field evaluations were performed at the intersection of Trunk Highway 36 (TH 36) at Hilton Trail in the City of Pine Springs, Washington County, Minnesota. TH 36 is a high-speed primary roadway, with horizontal and vertical curves leading to the intersection. Flanking

[1] This report does not constitute a standard, specification or regulation. Trade or manufacturers' names appear herein solely because they are considered essential to this report.
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advance warning flashers had been previously installed at this intersection, because of the limited sight distance on TH 36.

The study evaluated five vehicle detector amplifiers with M701 microloops: Sarasota Group 3, Sarasota Group 5, Detector Systems 224B, Canoga C424T and C824T vehicle detectors. Detector Systems 224B detector amplifiers were used as the reference detector for the first four tests. For the fifth test, the reference detectors were C824T vehicle detectors. Each reference detector was connected to a 1.7 m X 1.7 m inductive loop that was located in the same lane and in close proximity to the test microloop. All microloops and their lead-in cables were installed in the bituminous pavement at four inches in depth in an effort to avoid removal in future milling projects.

The study compared the vehicle counts obtained from each test detector connected to a microloop to the counts obtained simultaneously from the reference detectors connected to the standard inductive loop. The study also compared the performance of detectors with one or two microloops per lane. All the vehicle counts from the first four tests reported in this study were obtained from the Traconex 390 controller. For the fifth test, the counts were directly read from the reference detector, since it supported the binning of count and occupancy data and supported remote communication.

Jerry Kotzenmacher and Ron Christopherson (Mn/DOT – Electrical Services Section) also performed several random field observations.

Results and Analysis

Traffic counts for each individual detector were collected daily over a three-week period. A review of the data indicated that all the counts obtained from the microloop located in the eastbound left lane of TH 36 and from the near advance microloop located in the southbound lane of Hilton Trail consistently and significantly differed from the reference counts. In both locations, a large number of vehicles were observed to change lanes. Many eastbound vehicles on TH 36 turn left onto Hilton Trail and southbound vehicles on Hilton Trail turn right onto westbound TH 36 at this intersection. This data indicates that in areas of significant lane change and merging activity at least two microloop probes connected in series should be installed in each lane to increase lane coverage. The use of two microloop probes per lane also improves the consistent detection of motorcycles.

Test #1 used Sarasota 222T GP3 (Group 3) detectors. The counts from this detector, especially with microloops D2-2/D2-4 and D6-1/D6-3 sets (see printouts) differed markedly from the reference count. Mn/DOT is phasing out this detector.

In Test # 2, the Sarasota 224N GP5 (Group 5) detectors performed better. The counts from this detector were typically lower, but within 8% of the reference counts from the inductive loop when the data from the microloop located in the lane change location was excluded (D2-2/D2-4 set).

Test #3 used the Detector Systems 224B detectors. These units would only operate with microloops when long lead-in cables were used to increase the sensor-system Q high enough for the oscillator to be able to drive the inductive loop. The differences between the counts from the microloops and the reference counts from the inductive loops were more consistent than those from the Sarasota detector. The count differences were within 4% of the reference count, again when the data from the microloop located in the lane change area was excluded (D2-2/D2-4 set).

Test #4 used the C424T vehicle detectors. The differences between the counts from the microloops and the reference counts from the inductive loops were also more consistent than those from the Sarasota detector. The count differences were within four percent of the reference count when the data from the microloop located in the lane change area was excluded (D2-2/D2-4 set). Field observations indicated that the C424T vehicle detector connected to the microloop often double-counted large trucks (counted both axles).

Test #5 used the C824T-F vehicle detectors with the latest firmware (version 1.2) This firmware incorporates algorithm enhancements to improve its performance with microloops. The differences between the counts from the microloops and the reference counts from the inductive loops were the smallest and most consistent of all vehicle detectors: the microloop count was within 1% of the reference count when the data from the microloop set in the lane change area was excluded (D2-2/D2-4 set). The C824T-F detector connected to the microloop was configured in Presence Mode.

Summary and Conclusions

Test results indicate that the Sarasota Group 3 detectors detected vehicles unreliably when connected to the microloop. The counts were either too high or too low and varied to such an extent that finding an optimal setting was impossible. The unreliable vehicle-count data and the field observations support the conclusion that this vehicle detector should not be used with microloops.

The Sarasota Group 5, the Canoga C424 and the Detector Systems 224B vehicle detectors operated more consistently. Their count accuracy was more predictable and their performance more acceptable. Further fine-tuning of these detectors may have improved their performance.

The Canoga C824T vehicle detectors were the most accurate. The counts from microloops were virtually identical to those from the reference loops except in those two locations were vehicles tended to change lanes. In fact, the accuracy and the consistent performance of the C800 series vehicle detectors made it difficult to discern whether the count errors resulted from the reference detector and inductive loop or from the C800 series vehicle detectors and microloop.

The C800 series vehicle detectors connected to microloops will hold presence calls. All other detector amplifiers must be set to Pulse mode and fast recovery when attached to a microloop. Many amplifiers lack algorithms that can deal effectively with the inductance increases that nearby vehicle traffic causes. Therefore, the use of these detectors should be limited to situations where only extension calls are required or where a locking detector function is used; e.g. the loop detector can be set to pulse mode. In addition, the added initial feature on the intersection controller may need to be adjusted since detector amplifiers that lack algorithms specifically developed for use with microloops have a tendency to overcount when connected to a microloop.

The strong attributes of microloop-based traffic sensors are shorter installation time (only a single saw cut is needed), less pavement invasion and improved life-cycle cost compared to traditional 1.7 m X 1.7 m saw cut inductive loop installations. These strong points suggest that microloops and their matched Canoga C800 series vehicle detectors should be considered as an alternative to installing new or replacement saw cut inductive loops, especially in concrete pavements.

Field Evaluation Report

Comparison of 3M™ Canoga™ M701 microloops and 1.7 m X 1.7 m Loops in an Intersection Advance Detection Application

Introduction

This document reports the objectives, methods, results and conclusions of a field study designed to evaluate the performance of five different commercially available inductive loop detectors with the M701 microloop. The study was conducted by the Metro Division and the Electrical Services Section of the Minnesota Department of Transportation with support from Rennix Corporation and 3M.

Traffic responsive traffic control systems require accurate and reliable vehicle detectors that function consistently in all environments and are resistant to mechanical damage from traffic, pavement failure and pavement repair. The microloops meet the mechanical and environmental performance requirements. The primary goal of this evaluation was to determine whether the microloops also meet accuracy requirements. These evaluations tested the performance of microloops with different vehicle detectors and compared their performance to standard inductive loops.

Microloops are magneto-inductive sensors that are placed 460 mm to 610 mm beneath the road surface. Ferromagnetic (primarily steel) material in vehicles focuses the earth's magnetic field resulting in a decrease in the induction of the sensor. The vehicle detector detects the change in the microloop inductance. Each microloop senses a small area. Connecting several microloops in series (up to three microloops) in an across-the-lane configuration increases lane coverage.

3M offers two models of microloops. The M701 microloop probe is installed in small diameter hole that is typically 460 millimeters deep (see **Figure 1** and **Figure 2**). Its lead-in wire is placed into a saw cut that is filled in with a loop sealant and extends to the conduit at the side of the road. The M702 non-invasive microloop probe (see **Figure 4**) is placed in a protective, 76 mm diameter PVC or seamless polyethylene conduit located 530 mm below the pavement surface (see **Figure 3**). This standard conduit is typically installed using horizontal directional drilling which leaves the road surface intact (see **Figure 5**). Some traffic control is needed during the horizontal directional drilling process to allow a worker to periodically walk onto the road surface to measure the drill head depth. The conduit terminates in a handhole. Interlocking carriers are used to install the probes into the conduit. These 305 mm long carriers have receptacles to hold the non-invasive microloop probes firmly in place. The carriers are easily inserted into the conduit from the handhole at the roadside (see **Figure 6**). A locking mechanism prevents the carriers from rotating. With the M702 non-invasive microloop, there are no sensor components in the pavement. The non-invasive microloops can be inserted, removed, replaced or adjusted without disrupting the traffic flow.

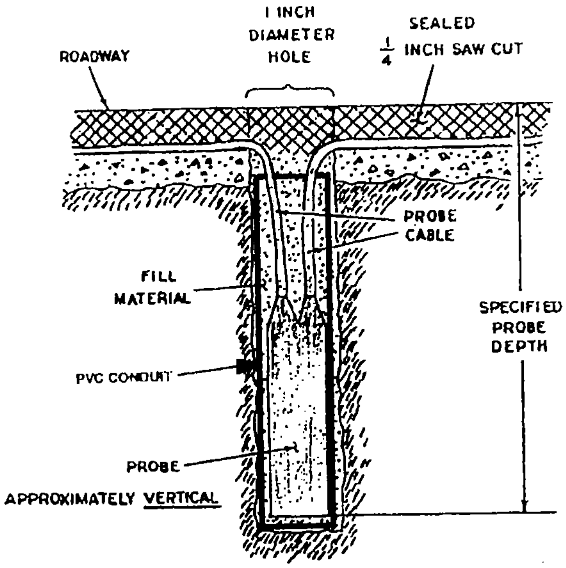

Figure 1 M701 Microloop Installation

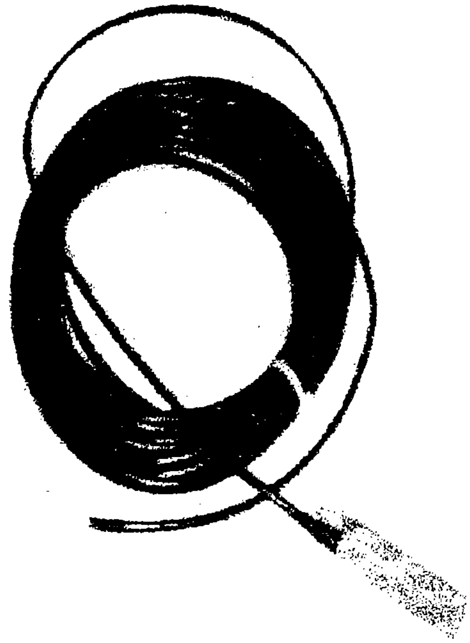

Figure 2 M701 Microloop Probe

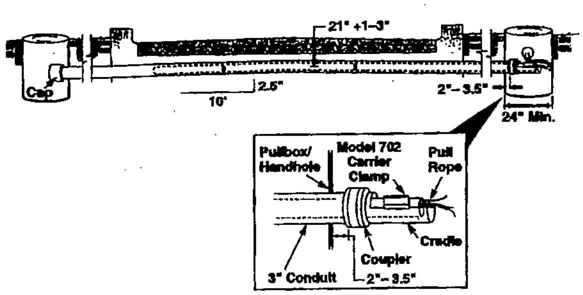

Figure 3 M702 Non-invasive Microloop Installation

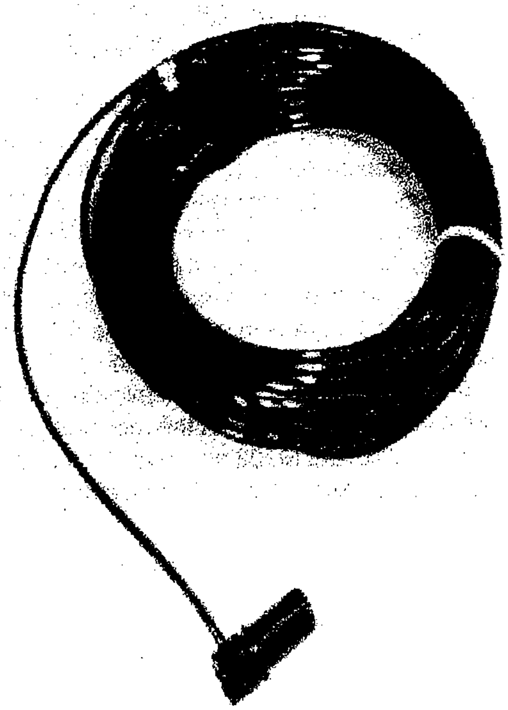

Figure 4 M702 Non-invasive Microloop

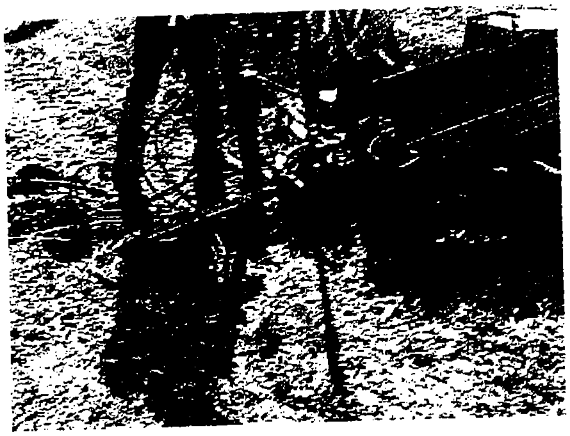

Figure 5 Horizontal directional drilling for installation of the Conduit for the M702 Non-invasive Microloop

Figure 6 Installing the M702 Non-invasive Microloop.

The M701 microloop is a low Q inductor with a Q = 3. Inductive wire loops typically have a Q > 5. Inductive loop detectors must be capable of driving low Q inductors to be used with M701 microloops. M702 non-invasive microloops typically have a Q > 5 and can be more readily interfaced with inductive loop detectors.

Only the M701 microloop was available when the evaluation was started. Results reflect the performance of this microloop. The M702 non-invasive microloop is smaller in size compared to the M701 microloop, but its sensitivity to changes in the earth's magnetic field is very similar. Subsequent evaluations of the M702 non-invasive microloop have indicated that its performance is similar to that of the M701 microloop when both are used with a matched Canoga C800 series vehicle detector.

Study Objectives

The main objectives of the study were:

1. To determine whether a microloop can be an effective replacement for an inductive loop in intersection advance detection applications.

2. To determine whether different loop detector models from several manufacturers can operate satisfactorily and consistently when attached to the microloop.

3. To determine the performance accuracy of loop detectors attached to a one-probe microloop or to a two-probe microloop.

The count accuracy of different loop detectors connected to the microloop was determined by comparing their counts with those obtained from reference detectors that were connected to 1.7 m X 1.7 m inductive loops located in the same lane and in close proximity to the microloops.

Project Approach and Report Organization

This study consisted of the following tasks:

1. Project Planning and Equipment Installation

2. Optimizing Loop Detector Settings

3. Data Collection

4. Data Analysis and Results

5. Discussion and Recommendations

This report follows the project approach and includes recommendations for using the microloops.

Project Planning and Equipment Installation

Vendor Installation Recommendations

Mn/DOT consulted with 3M Intelligent Transportation Systems and Rennix Corporation about the installation of microloops and about their use with loop detectors manufactured by different vendors. The following recommendations were received:

a. The M701 microloops should be installed in a vertical position with the bottom of the probe about 460 mm below the road surface.

b. A microloop consisting of two probes spaced 1.2 m apart and located 0.6 m on each side of the lane center will sense most motorcycles unless they are very close to the lane stripe, and will sense all other vehicles in the lane. Nearly all vehicles with at least one wheel in the lane will be detected.

c. A microloop consisting of one probe located in the middle of the lane can sense motorcycles near the middle of the lane and all other vehicles that are completely in the lane. Vehicles centered on the lane stripe or further out of the lane may not be detected.

d. Loop detectors designed only for use with inductive loops should be operated in Pulse mode. These detectors lack the detection algorithm that processes the microloop inductance increases caused by vehicles near, but not over the microloops. Pulse mode operation will limit stuck calls due to false adapts to about two seconds.

e. Canoga C800 vehicle detectors with version 1.2 firmware and later have an algorithm that allows the vehicle detector to be used in Presence mode, in all traffic conditions - from stop-and-go to high speed traffic.

Selection of Reference Counting System

A reference counting system was needed to compare the counts from vehicle detectors connected to microloops to actual traffic counts. All parties agreed that a 1.7 m X 1.7 m loop attached to a reliable, properly set loop detector would provide a reasonable count reference. Ideally, the microloop probe sets should be placed within the 1.7 m X 1.7 m reference loop to minimize errors caused by vehicles changing lanes. However, the partners decided to place the microloops 1.8 meters upstream from the 1.7 m X 1.7 m loops for the following reasons:

a. Loops crosstalk to microloops. The small magnetic field generated by loops is sensed by microloops. To eliminate this crosstalk, the loop and the microloop within it would have to be connected to the same loop detector. However, this type of connection would have required Mn/DOT to use nonstandard cabinet wiring to allow connections with multiple sensors in each lane and at each sensing location.

b. Depending on the level of drive current to the loop, frequency separation may not be sufficient to reduce crosstalk to an insignificant level when the microloops and the reference loops are located at the same spot and are attached to different loop detectors.

For these reasons, a spacing of 1.8 m (the average distance between loops in adjacent lanes) was considered to be a reasonable separation between the reference loop and microloop. At this spacing, crosstalk is lessened. In addition, the site can be used to monitor vehicle speeds. The decision acknowledged that the 1.8 m separation could result in different vehicle counts reported for the microloop and the reference loop due to vehicles switching lanes at each detection site.

Site Description and Installation

Based on these recommendations the plans shown in Figure 7 were prepared. A contractor installed the sensors in the summer of 1995 according to these plans. The M701 microloop probes were installed at the recommended depth of 460 mm from the pavement surface to the bottom of the probe. The microloop lead-in cables were buried at a depth of 100 mm below the pavement surface in an attempt to permit future resurfacing without cutting the lead-in cables.

Lanes were closed to install the microloops. However, the lane closure time for M701 microloop installation was significantly less than that required to install the 1.7 m X 1.7 m loops. Subsequent to the installation, there have been no lane closures for either loop or microloop maintenance. Installations of M702 Non-Invasive Microloops done after this test required only very short lane closures for checking the depth of the boring head during the horizontal directional drilling (see Introduction on Page 1).

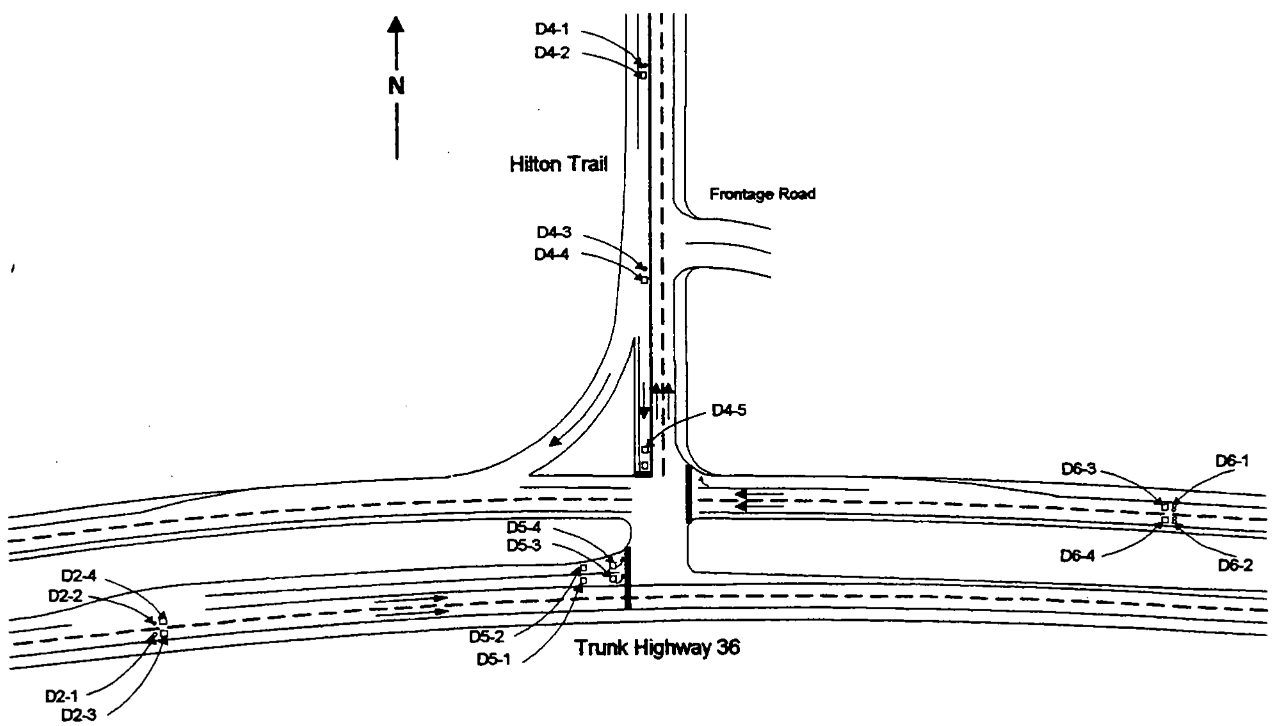

Figure 7: Intersection Layout - TH 36 at Hilton Trail, Pine Springs, Washington County (not to scale)

Dimensions:

a. The 1.7 m X 1.7 m loops, D2-3 and D2-4, are 145 m from the stop bar.

b. The one-probe M701 microloops, D2-1 and D2-2, are 1.8 m upstream from the upstream edge of their respective 1.7 m X 1.7 m loops, D2-3 and D2-4.

c. The 1.7 m X 1.7 m loops, D5-3 and D5-4 are 3 m back of the stop bar and are separated from D5-1 and D5-2 by 7.3 m.

d. The 1.7 m X 1.7 m loops, D6-3 and D6-4, are 145 m from the stop bar.

e. The two-probe M701 microloops, D6-1 and D6-2, are 1.8 m upstream from the upstream edge of their respective 1.7 m X 1.7 m loops, D6-3 and D6-4.

f. The first 1.7 m X 1.7 m loop of D4-5 is 1.5 m back from the stop bar. The second 1.7 m X 1.7 m loop of D4-5 starts 2.7 m upstream from the upstream edge of the first 1.7 m X 1.7 m loop.

g. The 1.7 m X 1.7 m loop on southbound Hilton Trail, D4-4, starts 53 m from the stop bar.

h. The one-probe M701 microloop, D4-3, is 1.8 m upstream from the upstream edge of D4-4.

i. The far advance 1.7 m X 1.7 m loop on southbound Hilton Trail, D4-2, starts 122 m from the stop bar.

j. The far advance dual probe M701 microloop is 1.8 m upstream from the upstream edge of D4-2.

This test site has geometric situations that are likely to cause deviations in the count comparisons between the loops and microloops:

1. Vehicles traveling eastbound on TH 36 in the left lane expecting to make a left turn onto northbound Hilton Trail change lanes at the D2-2 and D2-4 sensing location. Many of them have only a portion of the vehicle in the lane. Since one-probe microloops cover a smaller area of the lane than the 1.7 m X 1.7 m loop, they may miss vehicles that travel only partly in the lane. As a result, one-probe microloops are expected to count fewer vehicles than the 1.7 m X 1.7 m loops at this location.

2. Westbound vehicles on TH 36 tend to switch lanes at the D6-1/D6-3 sensing location to prepare for a right turn onto northbound Hilton Trail. This lane change activity may impact the count comparison between loop and microloop. However, this impact is likely insignificant since the number of vehicles turning north onto Hilton Trail is a small percentage of the westbound traffic.

3. Southbound vehicles on Hilton Trail, at the D4-3/D4-4 sensing location, tend to move out of the lane to make a right turn onto westbound TH 36. Again, lower counts are expected on D4-3 than on D4-4. In addition, traffic turning left from the frontage road to southbound Hilton Trail or to westbound TH 36 will make count comparisons at D4-3/D4-4 erratic.

4. The right eastbound lane on TH 36, the left westbound lane on TH 36 and the far advance detection location on southbound Hilton Trail are expected to give consistent count comparisons.

Traffic was rarely observed to back up to the loops or microloops on TH 36 and vehicles seldom stopped over these sensors.

Optimizing Loop Detector Settings

Detector Systems Model 224B loop detectors were used to obtain the counts from all reference loops except for the test of the Canoga C824 vehicle detector when other C824 vehicle detectors were used as reference detectors. The detector rack slot assignments are summarized in **Figure 8**. The reference detectors are shown in bold and the detectors attached to microloops are shown in bold italic.

D6-3	**D2-3**	D4-5	**D4-2**	D5-3	D5-1	***D6-1***	***D2-1***	NC	***D4-1***	NC	Opticom™ Priority Control	NC	Opticom™ Priority Control		
D6-4	**D2-4**	Off	**D4-4**	D5-4	D5-2	***D6-2***	***D2-2***	NC	***D4-3***	NC	Opticom™ Priority control	NC	Opticom™ Priority Control	PED	PED
Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9	Slot 10	Slot 11	Slot 12	Slot 13	Slot 14	Slot 15	Slot 16

Figure 8: Detector Rack - Sensor Assignments by Slot

Microloop and Inductive Loop Properties

Two important inductive properties were measured for each inductive loop and microloop: first, the inductance of each inductive loop (lead-in cable and loop wire) and microloop (lead-in cable and probe) and second, the inductance change generated by an average passenger vehicle passing over each vehicle sensor. The C400 vehicle detector was used to obtain these measurements. The data was read from the detector with C400 Interface and Data Acquisition Software. The resistance was measured with an ohmmeter. Table 1 summarizes the measured data from the inductive loops and microloops.

Loop Data				
Sensor	L (Sensor + Lead-in) (microhenries)	Typ. Auto delta L (nanohenries)	delta L (%)	Resistance (ohms)
TH36, EB, Rt Ln: D2-3 (Loop)	361	15,000	4.2	
TH36, EB, Rt Ln: D2-1 (1P μL)	254	1,000	0.39	
TH36, EB, Lt Ln: D2-4 (Loop)	364	15,000	4.1	
TH36, EB, Lt Ln: D2-2 (1P μL)	259	500	0.19	
TH36, EB, Rt Lt Turn Ln: D5-1 (Loop)	245	4,000	1.6	
TH36, EB, Rt Lt Turn Ln: D5-3 (Loop)	234	3,500	1.5	
TH36, EB, Lt Lt Turn Ln: D5-2 (Loop)	216	3,000	1.4	
TH36, EB, Lt Lt Turn Ln: D5-4 (Loop)	226	4,000	1.8	
TH36, WB, Lt Ln: D6-4 (Loop)	302	14,000	4.6	
TH36, WB, Lt Ln: D6-2 (2P μL)	230	750	0.33	10.0
TH36, WB, Rt Ln: D6-3 (Loop)	295	13,000	4.4	
TH36, WB, Rt Ln: D6-1 (2P μL)	231	850	0.37	9.8
Hilton Tr, SB, Stop Bar: D4-5 (Loop)	344	9,800	2.8	
Hilton Tr, SB, Near Adv: D4-4 (Loop)	251	13,000	5.2	
Hilton Tr, SB, Near Adv: D4-3 (1P μL)	150	450	0.30	12.0
Hilton Tr, SB, Far Adv: D4-2 (Loop)	295	11,000	3.7	
Hilton Tr, SB Far Adv: D4-1 (2P μL)	225	750	0.33	

Table 1: Loop and Microloop Measurements (EB – eastbound; WB – westbound; SB – southbound; Rt – right; Lt – left; Ln – lane; μL – microloop; 1P – one probe; 2P – dual probe)

General Rules for Setting Detectors

The detector channels connected to the reference loops were set to the customary mid-range sensitivity, 4 (0.08%). The count activity was observed to ensure that each channel counted all vehicles, didn't double count tractor-trailer units, and did not count adjacent lane traffic.

3M provided the following detection rules to assist the project team in setting of detectors:

Inductive Loops

- The peak inductance change of trucks is about ½ of that caused by a typical car.
- Small motorcycles generate a signal change of about 1/32 of that caused by passenger vehicles.
- The weakest signal for a tractor-trailer combination is about 1/8 of the tractor-trailer combination peak signal strength.
- The weak signal region of a tractor-trailer combination represents a distance of about 4.3 m in length. At 45 mph (72 kph), this represents a travel time of 0.21 seconds (gap time).

Based on this information, to prevent tractor-trailer units from being double-counted, the channel sensitivity should be set to detect a signal at least as small as 1/16 (1/2*1/8 = 1/16) of the signal provided by a passenger vehicle when attached to a loop. This sensitivity setting may not detect all motorcycles since their signal strength is 1/32 of the signal generated by a passenger vehicle. The setting of 0.08% actually used on the Detector Systems 224B attached to the reference loops resulted in detecting a change about 1/55 of a typical passenger car. This setting detects all motorcycles and a majority of bicycles.

Microloops

- Signals from trucks are about twice as large as signals from passenger vehicles.
- Small motorcycles generate a signal change about 1/8 of that caused by a passenger vehicle.
- The weakest signal of a tractor-trailer combination is often zero (no signal). The duration of this region (gap time) is 0.21 seconds at a speed of 45 mph (72 kph).

The channel sensitivity, when attached to a microloop, should be set to detect a signal about 1/8 the size of the signal change caused by a passenger vehicle. The bridge time should be set to cover the largest expected gap time (4.3 m divided by the slowest expected speed), but should not exceed 0.5 seconds, since some vehicles are separated by as little as 0.5 seconds. The calculated bridge time will bridge the "zero signal" signal region between the tractor and its trailer without bridging passenger vehicles.

Based on the above detection rules, the optimal sensitivity setting for most vehicle detectors with microloops was about 0.04%.

Note that to follow these guidelines, the loop and microloop properties must be measured and calculated prior to setting the detection channels. These guidelines were followed for setting the sensitivity of detectors attached to microloops when the detector units would permit it. For some detectors, it was necessary to use sensitivity settings lower than those recommended by 3M. These settings typically cause more vehicles to be double-counted and typically cause some vehicles with small signals to go undetected.

Setting the Detectors

Sarasota 222T GP3 Loop Detectors:

Sarasota 222T GP3 loop detectors were the first units tested with M701 microloops. They were set to High Frequency, Pulse Mode, and Sensitivity 3 (0.16%). High frequency gives the highest Q, which helps the detector oscillator to work with low Q sensors such as the microloop. Pulse mode ensures that a detector channel will not lock-up due to a false adapt to an inductance increase. Several sensitivity settings were tried. The sensitivity was changed systematically to find one setting that would not result in false calls, but would still detect all vehicles. After each change, count performance was visually verified. The sensitivity selected was a compromise between avoiding false calls and still detecting nearly all vehicles. Sensitivity 3 was used on all channels attached to microloops.

Sarasota 224N GP5 Loop Detectors:

These units were set to High Frequency and Pulse Mode. The search for an "optimum" sensitivity led to the use of Sensitivity 4 (0.48%) for microloops D6-1, D6-2, D2-1, D4-1 and D4-3. Sensitivity 5 (0.32%) was used for D2-2.

Detector Systems 224B Loop Detectors:

These units were set to High Frequency and Pulse Mode. The units would not function on D4-1 and D4-3. 3M conducted a laboratory analysis of the detector unit and found that the Q on both microloop/lead-in combinations was too low for the oscillator. As a result, data from D4-1 and D4-3 microloops is not available except for the reference data from the C824T-F detector. The "optimum" sensitivity on the 224B units was found to be 2 (0.32%) for the channels attached to the microloops on TH 36.

Canoga C424T Vehicle Detectors:

These units were set to Medium Frequency, Pulse Mode and Microloop Mode. Sensitivity was set to 4 (64 nanohenries or about 0.026%) to ensure detection of all vehicles (small motorcycles are about 1/8 the signal of an automobile). Observation of traffic confirmed that the settings were appropriate.

C424T Channel Settings										
Sensor	Sensitivity	Mode	Microloop Mode	Ref. Setback (sec)	Bridge Time (sec)	In Call Rephase (sec)	Out of Call Rephase (sec)	Threshold Mult.	Slope Timer (sec)	Slope Divisor
D2-1	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4
D2-2	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4
D6-1	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4
D6-2	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4
D4-1	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4
D4-3	4 (64 nH)	Pulse	ON	0.5	0.4	2	0.5	8	0.05	4

Table 2: Canoga C424T Channel Settings (other values were Power-Line Filter disabled, Oversampling = 1, Overscan disabled, Background Adapt Rate = 0.5 threshold/sec, Recovery Method = normal, and Pulse Rephase Time = 1.9 sec).

Canoga C824T-F Vehicle Detectors, Version1.2:

These units were set to Medium Frequency, Presence Mode and Microloop Mode. Presence Mode was used since the microloop algorithm version 1.2 operates properly under all traffic conditions. Sensitivity was set to 4 (64 nanohenries or about 0.026%) for all channels except the channel on D2-1, which was set to 3 (128 nanohenries or about 0.05%). Observation of traffic confirmed that the settings were appropriate. Complete settings are shown in Appendix A [in Full Report only.].

C824T-F Channel Settings										
Sensor	Sensitivity	Mode	Microloop Mode	Ref. Setback (sec)	Bridge Time (sec)	In Call Rephase (sec)	Out of Call Rephase (sec)	Threshold Multiplier.	Slope Timer (sec)	Slope Divisor
D2-1	3 (128 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4
D2-2	4 (64 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4
D6-1	4 (64 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4
D6-2	4 (64 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4
D4-1	4 (64 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4
D4-3	4 (64 nH)	Pres.	ON	0.5	0.4	2	0.5	4	0.15	4

Table 3: Canoga C824T-F Channel Settings (other values were Power-Line Filter disabled, Oversampling = 1, Overscan disabled, Background Adapt Rate = 0.5 threshold/sec, Recovery Method = normal, and Pulse Rephase Time = 1.9 sec.).

Settings Summary:

The loop detector settings used in these tests are summarized in **Table 4**.

Loop Detector Settings							
Sensor Type	Sensor Designation	Detector Type	Detector Channel	Sensitivity	1/16 L or 1/8 μL of Typ. Auto. % delta L	Mode	Frequency
Lp-1.7mX1.7m-4T	D2-3	DS 224B	1	4 (0.08%)	0.263	Presence	Med High
μL-1 Probe	D2-1	Sar 222T GP3	1	3 (0.16%)	0.049	Pulse	High
μL-1 Probe	D2-1	Sar 224N GP5	1	4 (0.48%)	0.049	Pulse	High
μL-1 Probe	D2-1	DS 224B	1	2 (0.32%	0.049	Pulse	High
μL-1 Probe	D2-1	3M C424T	1	4 (64nH=0.025%)	0.049	Pulse	Medium
μL-1 Probe	D2-1	3M C824T-F	1	4 (64nH=0.025%)	0.049	Presence	Medium
Lp-1.7mX1.7m-4T	D2-4	DS 224B	2	4 (0.08%)	0.257	Presence	Low
μL-1 Probe	D2-2	Sar 222T GP3	2	3 (0.16%)	0.024	Pulse	High
μL-1 Probe	D2-2	Sar 224N GP5	2	5 (0.32%)	0.024	Pulse	High
μL-1 Probe	D2-2	DS 224B	2	2 (0.32%	0.024	Pulse	High
μL-1 Probe	D2-2	3M C424T	2	4 (64nH=0.025%)	0.024	Pulse	Medium
μL-1 Probe	D2-2	3M C824T-F	2	4 (64nH=0.025%)	0.024	Presence	Medium
Lp-1.7mX1.7m-4T	D6-4	DS 224B	4	4 (0.08%)	0.290	Presence	Low
μL-2 Probe	D6-2	Sar 222T GP3	2	3 (0.16%)	0.041	Pulse	High
μL-2 Probe	D6-2	Sar 224N GP5	4	4 (0.48%)	0.041	Pulse	High
μL-2 Probe	D6-2	DS 224B	4	2 (0.32%	0.041	Pulse	High
μL-2 Probe	D6-2	3M C424T	4	4 (64nH=0.028%)	0.041	Pulse	Medium
μL-2 Probe	D6-2	3M C824T-F	4	4 (64nH=0.028%)	0.041	Presence	Medium
Lp-1.7mX1.7m-4T	D6-3	DS 224B	3	4 (0.08%)	0.275	Presence	Med High
μL-2 Probe	D6-1	Sar 222T GP3	1	3 (0.16%)	0.046	Pulse	High
μL-2 Probe	D6-1	Sar 224N GP5	3	4 (0.48%)	0.046	Pulse	High
μL-2 Probe	D6-1	DS 224B	3	2 (0.32%	0.046	Pulse	High
μL-2 Probe	D6-1	3M C424T	3	4 (64nH=0.028%)	0.046	Pulse	Medium
μL-2 Probe	D6-1	3M C824T-F	3	4 (64nH=0.028%)	0.046	Presence	Medium
Lp-1.7mX1.7m-4T	D4-4	DS 224B	2	4 (0.08%)	0.324	Presence	Low
μL-2 Probe	D4-3	Sar 222T GP3	2	3 (0.16%)	0.038	Pulse	High
μL-2 Probe	D4-3	Sar 224N GP5	2	4 (0.48%)	0.038	Pulse	High
μL-2 Probe	D4-3	3M C424T	2	4 (64nH=0.043%)	0.038	Pulse	Medium
μL-2 Probe	D4-3	3M C824T-F	2	4 (64nH=0.043%)	0.038	Presence	Medium
Lp-1.7mX1.7m-4T	D4-2	DS 224B	1	4 (0.08%)	0.233	Presence	Med High
μL-2 Probe	D4-1	Sar 222T GP3	1	3 (0.16%)	0.042	Pulse	High
μL-2 Probe	D4-1	Sar 224N GP5	1	4 (0.48%)	0.042	Pulse	High
μL-2 Probe	D4-1	3M C424T	1	4 (64nH=0.028%)	0.042	Pulse	Medium
μL-2 Probe	D4-1	3M C824T-F	1	4 (64nH=0.028%)	0.042	Presence	Medium

Table 4: Detector Settings Summary Table

Data Collection

For the first four tests, the counts were sampled using the Traconex 390 traffic signal controller. The data was collected via dial-up telephone line from the Oakdale operations center and printed out by the Traconex TMP390 Data Base Reporter. Data was taken on multiple days for each unit. The printed data was manually entered into Microsoft® Excel™ spreadsheets for analysis. In all tests, the counts were collected in 15-minute intervals.

For the evaluation of the performance of the C824T-F with the microloop (fifth test), the reference detectors were C824T-F vehicle detectors connected to inductive loops. Road conditions during these tests ranged from excellent to poor. The staff in the Oakdale operations center used the C800 Interface and Data Acquisition Software to collect the count and occupancy data directly from the test and reference detectors via the dial-up telephone in the cabinet. Remote data collection via phone lines from the C800 series vehicle detectors is possible since they have an RS232 communication port and can store binned count and occupancy data in their memories.

The TMP390 reporting system used different reference mnemonics than were used at the cabinet. A cross-reference table, analysis spreadsheets and the raw data are provided in Appendix C [in Full Report only].

The table below shows the dates and times that data were obtained for analysis:

Test Dates and Times									
Sarasota 222T GP3		Sarasota 224N GP5		Detector Systems 224B		Canoga C424T		Canoga C824T-F V1.2	
Date	Time	Date	Time	Date	Time	Date	Time	Date	Time
9/29/95	12:00 - 22:45	10/5/95	8:15 - 22:45	10/10/95	15:30 - 22:45	11/2/95	8:00 - 22:45	2/17/98	12:59 - 22:44
10/2/95	6:00 - 12:30	10/6/95	6:00 - 8:45	10/11/95	6:00 - 22:45	11/3/95	6:00 - 8:30	2/18/98	5:59 - 22:44
10/2/95	15:15 - 22:45	10/7/95	11:30 - 16:45	10/12/95	6:00 - 22:45	11/5/95	8:00 - 16:45	2/19/98	5:59 - 22:44
10/3/95	6:00 - 22:45	10/8/95	7:00 - 16:45	10/13/95	6:00 - 11:00	11/6/95	6:00 - 22:45	2/20/98	5:59 - 12:44
10/4/95	6:00 - 22:45	10/9/95	6:00 - 8:00			11/7/95	6:00 - 22:45	2/21/98	20:14 - 22:44
10/5/95	6:00 - 9:15	10/9/95	9:15 - 22:45			11/8/95	6:00 - 8:00	2/22/98	5:59 - 22:44
		10/10/95	6:00 - 9:45			11/9/95	10:15 - 22:45	2/23/98	5:59 - 8:14
						11/10/95	6:00 - 10:45	2/24/98	5:59 - 22:45
						11/12/95	7:00 - 16:45	2/25/98	5:59 - 11:44
						11/13/95	6:00 - 22:45	2/26/98	21:44 - 22:44
						11/14/95	6:00 - 11:15	2/27/98	5:59 - 22:44
						11/16/95	8:45 - 22:45	2/28/98	5:59 - 9:44
						11/17/95	6:00 - 9:15	3/1/98	5:59 - 22:44
								3/2/98	5:59 - 22:44
								3/3/98	5:59 - 8:44

Table 5: Test Dates and Times

Data Analysis

Microloop Counts Compared to Loop Counts

The data analysis compared the vehicle counts from the reference detectors attached to loops to those obtained from detectors attached to microloops. The percent of count difference was calculated according to the following formula: (((count of detector attached to microloop minus count of reference detector attached to loop)/count of reference detector attached to loop)*100). Next, the percent difference was plotted against the count from the reference detector attached to the loop (see **Figure 9**). In this plot a negative percent count difference indicates that fewer vehicles were detected over the microloop than the reference loop while a positive percent difference indicates that more vehicles were detected over the microloop than the reference loop. The plots show the detector performance as a function of the traffic volume (traffic counts on the reference loop).

It is important to note that for purposes of this analysis the count from the reference loop was assumed to represent the actual vehicle traffic (100 percent accuracy).

Some illustrative graphs comparing reference loop count to microloop count for each model of detector are attached as Appendix B [Appendix B in the Full Report contains all graphs.]. The graph for one comparison is shown here to explain the data analysis and presentation:

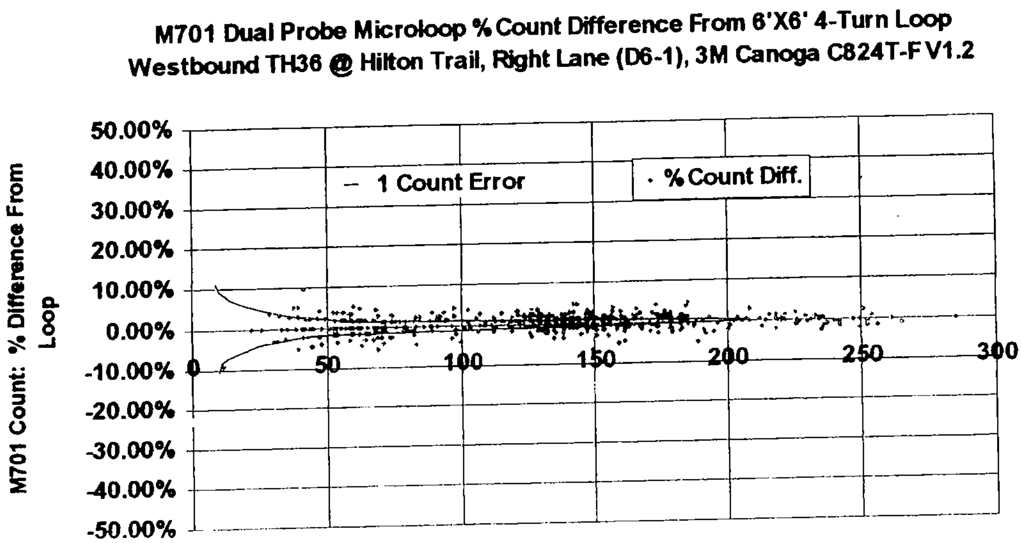

Figure 9: Microloop Count versus Loop Count for Right through Lane of Eastbound TH 36

The red line in **Figure 9** represents the percent difference that can result from one-count differences at the crossover from the current to the next 15-minute interval (interval boundary): a vehicle count may be assigned to one 15-minute interval for one detector and to the next 15-minute interval for the other detector.

Because of the installation geometry, a vehicle is first detected by the microloop and shortly afterwards by the reference loop. If the time of detection is just before the interval boundary, the count for detection over the microloop is placed in the bin about to be terminated. As the interval boundary is crossed and a new bin started, the vehicle detected on the reference loop is placed in the new bin. As a result, the microloop detector appears to have overcounted by one in the old bin and undercounted by one in the new bin Thus, a +1 count and a –1 count difference is created at the interval boundary. However, these count differences result from the binning process and do not reflect counting errors by the detector. It is impossible to determine whether differences of +1 count or –1 count are real count errors or differences caused by the binning process at the interval boundary. If the occurrence of the +1 and –1 count errors is consistent, it is likely that most of the errors resulted from count differences occurring at the interval boundary.

Average Error and Standard Deviation of Error

To compare the performance of different detector models attached to the microloops, the average error and the standard deviation of the errors were calculated. This analysis also compared count accuracy of a detector with either one (1P) or two probes (2P). The data from the one-probe microloops is represented by the orange hue (light shading) while the data from the two-probe microloop by the green hue (dark shading). The results are shown in **Figure 10** and **Figure 11**.

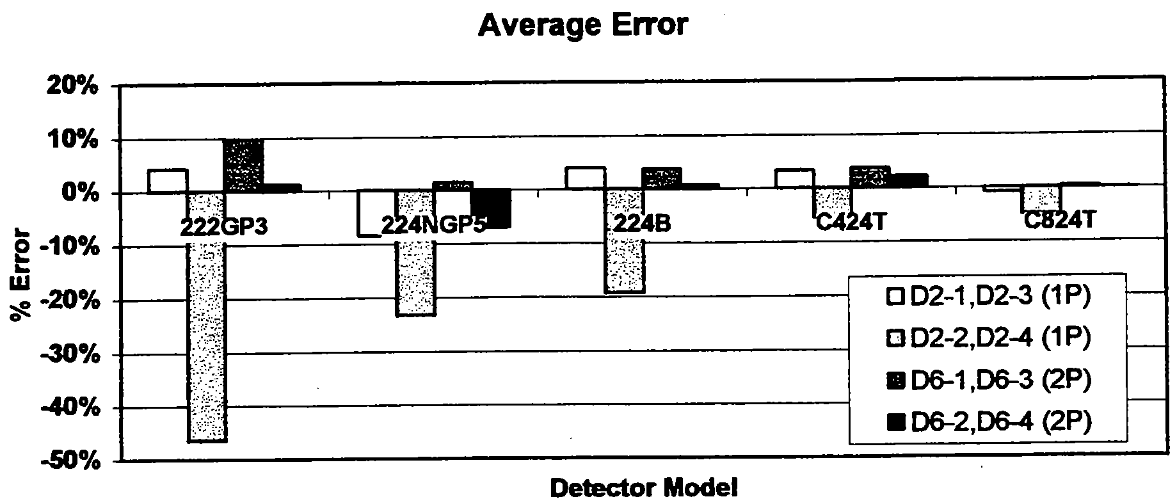

Figure 10: Average Error for Each Detector Model (1P = one-probe microloop, 2P = two-probe microloop)

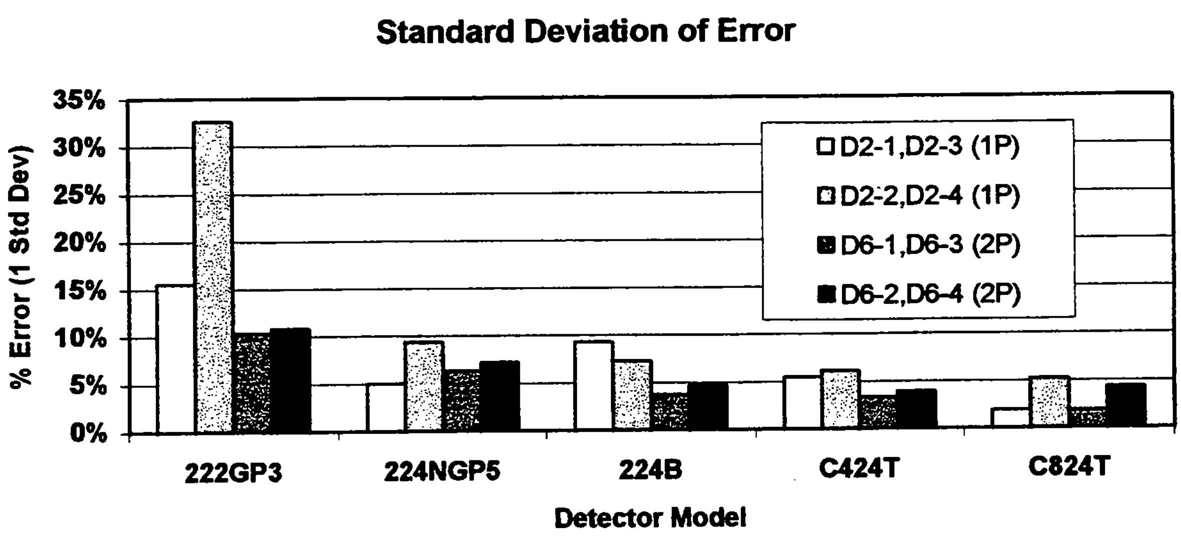

Figure 11: Standard Deviation of Percent Count Error for Each Detector Model (1P = one-probe microloop, 2P = two-probe microloop)

Ranking of Detector Models

The detector models were assigned a numeric rank based on their performance. The following criteria were used to assign a rank for each sensing location: the highest ranking (Rank = 1) was given to the