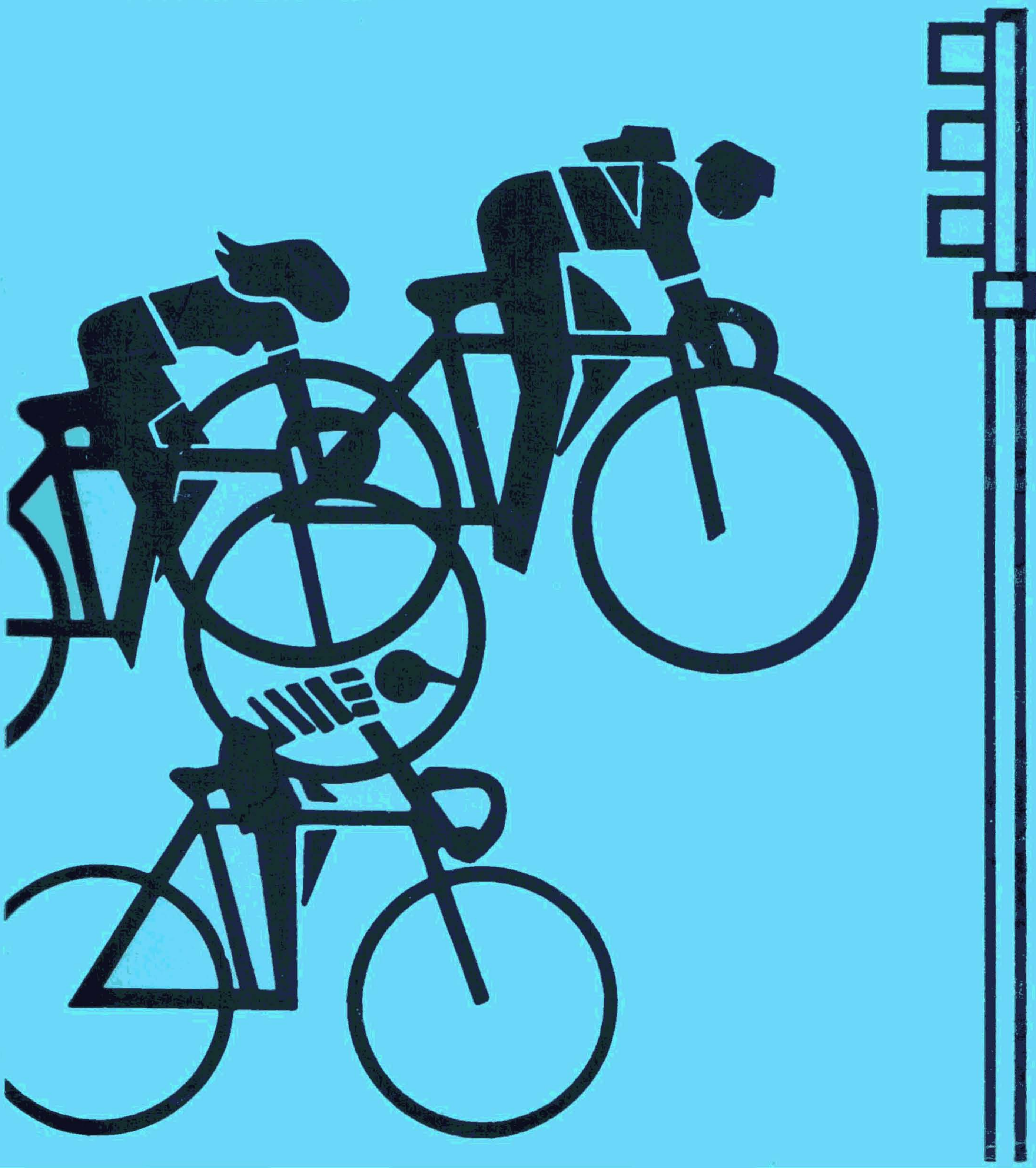
CITY OF SAN DIEGO

TRAFFIC SIGNAL BICYCLE DETECTION STUDY

FINAL REPORT



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EXECUTIVE SUMMARY

The purpose of this study was to evaluate various traffic signal bicycle detection schemes and to select a scheme for the City of San Diego that will be practical from the point of view of retrofitting existing signals and adaption to new signal construction. The objective was to adequately answer the City of San Diego's needs for bicycle detection at traffic signals.

The study made maximum utilization of existing knowledge concerning traffic signal bicycle detection and used this knowledge in the formulation of a bicycle detection strategy that can be adopted from a practical point of view by the City.

The study evaluated various existing bicycle detection strategies and recommends a specific scheme that the City should utilize.

The recommended detector types are State standard types already in existence (see Exhibit 1). The key to successful bicycle detection is to use the right type for a given location and to properly adjust the electronic sensitivity of the unit. Details are provided in the report.

A brief summary of the recommendations follows:

- On an interim basis, adjust the sensitivity of existing detectors and install pedestrian push buttons in certain cases.

- All new traffic signal system designs should specifically address the need to service bicycle traffic and the means by which this is to be accomplished. Vehicle detectors should be designed so that they are sensitive enough to detect all traffic, including bicycles, and detectors for the exclusive use of bicycles should be installed in bike lane approaches to the intersections. The incremental cost of adding these features is so small as compared to the overall project costs that their addition should be a design feature that satisfies the City's policy.

- Type D (modified quadrupole) and Type Q (quadrupole) detector loops should be the standard configurations to be used alone or in combination with Type A loops. Left turn lanes and minor side street applications should use State Type 5DA loop installations. Through traffic lanes that are shared by motor vehicles and bicycles should use Type D (modified quadrupole) loops. Detectors at the stop line that are used for presence or calling purposes are considered to be shared detectors. Advance detectors on arterials will not be expected to be shared by bicyclists; therefore, Type A loops are recommended. Bike lanes that require narrow areas of detection and sharp cut-off properties should use Type Q (quadrupole) loops.

- Pedestrian push buttons should only be used in locations where it is not possible to reliably detect the presence of bicycle traffic or as an interim measure to ensure safe passage of bicycles until adequate detection systems can be installed.

- Inductive loops should be marked at locations where the sensitivity is critical or where detection is not reliably achieved when the bicyclists ride in the approach lane in a position that is appropriate.

- The City should apply for and use TDA (Transportation Development Act) Article 3 funds to implement bicycle related facilities improvements that qualify. Other funds should also be obligated to facilities improvements; however, TDA funding should be used first to reduce the impacts of bicycle improvements on the General Funds or Gas Tax Funds.

- Detector sensitivity levels could be added to the traffic signal timing charts so that the regular maintenance personnel can maintain the required sensitivity levels as a routine procedure.

INTRODUCTION

This report has been prepared for the City of San Diego by MGA, Inc., Municipal and Transportation Engineering Consultants, to resolve problems associated with detecting bicycles at traffic signal systems within the City. The City has expressed a strong desire to resolve these problems and make the traffic signal systems responsive to the bicyclists' needs. To achieve this, the City applied for funding to sponsor this study.

The purpose of this study is to investigate the existing traffic signal systems and policies in regard to detecting bicycle traffic at existing and future traffic signals. Current practices of other agencies have been investigated along with results of their efforts and have been reported. The technical means required to reliably detect bicycles have also been investigated and documented. The means for engineers to initially design systems that will reliably detect bicycles has also been documented. Cost estimates are provided for hardware required to retrofit the existing systems as well as costs of incremental differences between detector systems in use and those designed to detect bicycles. Policy statements are provided for the City of San Diego to ensure that, upon their adoption, bicycle traffic will be considered in all future traffic signal designs as well as in current and future retrofit programs.

This project was made possible through the close cooperation of the City of San Diego, the San Diego Association of Governments (SANDAG) and their Bicycle Subcommittee. We appreciate their efforts, individually and collectively, without which this report would not be possible. Funding was provided through the Transportation Development Act (TDA Article 3) from funds set aside for pedestrian and bicycle facilities studies and construction.

INITIAL PROJECT MEETING

The initial meeting of the consultant team, the City staff and representatives of the SANDAG subcommittee on bicycle facilities was held on July 23, 1985. The concerns, background and other relevant data that is available, in either documentary form or verbal comments from the City staff and other representatives, concerning this study were discussed.

The meeting was attended by Larry Legrand, John Tsiknas and Bill Smith of the City of San Diego; by Steven Gottlieb and Gordon Shields representing the SANDAG sub-committee on bicycle facilities and local bicycle interests; and by Hank Mohle, Al Grover and Glenn Grigg of MGA.

The following points summarize the primary concerns of the City staff and bicycle interests (not necessarily in order of importance):

- o Bicyclists should enjoy the rights and privileges of a motorist as provided for in the California Vehicle Code and be subject, of course, to all of the duties and responsibilities thereof.
- o Existing traffic signal systems in San Diego should be made responsive to bicycle traffic in much the same manner as they are responsive to motor vehicle traffic.
- o The City does not currently provide specific detection systems for bicycles except in rare instances.
- o The City has a major investment in the existing traffic signal systems that cannot be discarded or abandoned.
- o Financing changes in the traffic signal systems to accommodate bicycles is not regarded as a major problem; however, prudent fiscal policies should be observed.
- o Efficiency of the the traffic signal system is very important to the City; therefore, modifications to these systems should be made with accessibility to bicyclists and efficiency in mind.
- o Changes in the traffic signal systems to enhance their usefulness by bicycles should not be made at the expense of the majority of road users.

- The bicyclists, representing SANDAG and local bicyclists' interests, suggested the following possible ways of achieving the equity that they desire:
  - Make the traffic signals responsive to bicycle traffic.
  - Add some device to the bicycle to make it easier to detect at traffic signals.
  - Mark the detectors at the intersections so that the bicyclists will know where to ride in order to activate the signal.

DEFINITION OF PROJECT OBJECTIVES AND GOALS

The results of the initial meeting and subsequent meetings on the working papers indicated that our original scope of work was a viable outline of the tasks to be accomplished. The working papers have defined, for the record, the specific results that are to be achieved by this study. They will be used to determine the extent to which this report has satisfied the various tasks of the study. Those objectives and goals are:

- A discussion of the various bicycle detection strategies currently in use.
- A discussion of types of bicycle detectors, including sensor units, with bicycle sensitivity field test results.
- A discussion of types of bicycle/vehicle detectors, including sensor units, with sensitivity field test results for both bicycles and high-bed vehicles.
- A discussion of bicycle detector locations based upon bicycle stopping distances and possible conflicts with other vehicles. The discussion should also include any need to provide carryover (extension time) for bicycle detection.
- A discussion on the possibility of installing a device on bicycles which would improve detection (magnetic tape, etc.).
- A discussion of possible interim measures that could be utilized to improve the detection of bicycles at existing signalized intersections, including costs (marking detectors, etc.).
- Development of a policy for the installation of bicycle detection, including costs, based upon the results of this study. The policy should cover both new signal installations and retrofitting existing signalized intersections.

BICYCLE DETECTION STRATEGIES CURRENTLY IN USE

There are a number of jurisdictions, Cities, Counties and States, that employ strategies to either detect the presence of bicycles at traffic signals or provide some other means by which the bicyclists can effect the operation of the signal so that the right-of-way can be transferred to the approach that they are using. The more prominent ones are as follows.

Inductive Loop Detectors

Existing loop detectors and detector amplifiers are being used to detect bicycles in traffic lanes and in left turn only lanes. Although this is technically achievable and can be done quite reliably, it depends upon the proper design and location of the loop and proper placement of the bicycle on the loop detector. This requires some knowledge of the location of the detector and how it works by the bicyclist. As an example, a square loop, Caltrans Type A (Exhibit 1), should be ridden over about three (3) feet to the left or right of the center of the lane while a quadrupole detector (Type Q) should be ridden over in the center of the lane.

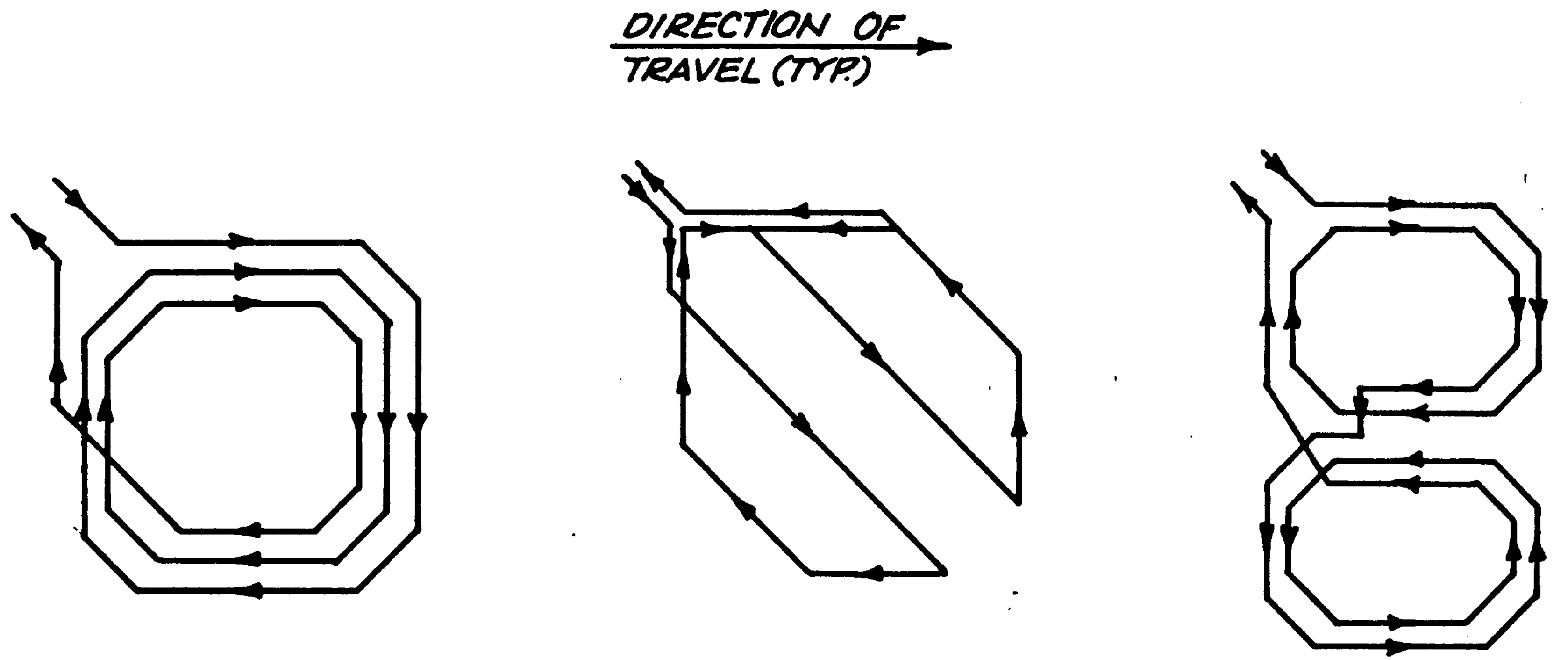
Where there are bike lanes, detectors are being placed in them where the bicycle is expected to ride. The area to be detected is confined and reliable detection is achievable. Sometimes these detectors are marked with a symbol to give added guidance to the bicyclists.

Pedestrian Push Buttons

Pedestrian push buttons are currently being used by bicyclists in the State of California by the Cities of Davis, Cupertino, Santa Cruz, Sunnyvale, Huntington Beach and others too numerous to mention. They are installed on the cross street facing the traffic or bike lanes for use by bicyclists desiring to cross the major street or in the left turn only lanes facing the bicyclists wishing to make left turns from those lanes.

In general, the push button "calls" the pedestrian interval timing for the phase to be used. The advantage of this is that the bicyclist is guaranteed the same amount of time that a pedestrian would get, provided of course that the button is used. The disadvantage is that most bicyclists require less time to cross than a pedestrian and some efficiency of operation is lost.

There are cases where the phase being used does not have a pedestrian signal associated with it, as with the left turn only lane and some split side street phasing



TYPE A

TYPE D

TYPE Q

NOTE: SEE CALTRANS STANDARD PLANS DATED JULY 1984 PP 210 AND 211.

EXHIBIT 1

RECOMMENDED CALTRANS LOOP TYPES FOR BICYCLE DETECTION

configurations. In these instances the pedestrian timing features of the controller can be used to provide additional start up and gap times for the bicyclists that are more than that provided for motor vehicles and less than what would be required for pedestrians, thus providing better efficiency.

In some cases an unused compatible phase is available for actuation by a bike button or bicycle detector. In these cases the original phase can provide standard vehicle and/or pedestrian timing and the compatible phase can provide the timing required by bicyclists.

The City of Sunnyvale uses a device they call a bicycle timer to provide a minimum time for bicyclists that is greater than the vehicle minimum and shorter than the pedestrian interval. A sample specification is included in Exhibit 2. Their device is currently activated by push buttons and will respond to the bicyclists' needs even when the signal is already timing the green interval of a phase. One device is used in the traffic signal cabinet and contains four (4) channels or phases of operation. This device can also be activated by an inductive loop detector or any equipment that provides a contact closure.

The cost of pedestrian push buttons is very low and no additional controller equipment is required. Theoretically speaking, if a pedestrian can be trained to push the button, then a bicyclist, with apparently more skill by virtue of the fact that he/she hasn't fallen down, can also. The obvious flaw to this theory is that too many pedestrians don't bother to push the button before crossing the street and bicyclists' behavior can probably be expected to be similar.

Pedestrian push buttons, in spite of their intrinsic value, should be regarded as supplements to adequate detector systems not replacements for them. As an example, a push button in a left turn only lane is a valuable aid to the bicyclist; however, in order to reach the button, the bicyclist is placed to the left of the lane allowing motor vehicle traffic to pass on the right. When the light turns green, the bicyclist must cross from the left of this lane, through the motor vehicle traffic, to the right side of the roadway to which the turn is made. With adequate detection the bicyclist would be in a better position in the lane to make the left turn. Push buttons on the right side of the roadway should be placed far enough in advance of the stop line so that the bicyclists desiring to go straight across can activate the signal and then move safely to the left of right turning vehicles.

Marking of Loop Detectors

Marking schemes are being employed by the Cities of San Luis Obispo, Cupertino, Palo Alto, Eugene and Boulder and by the Counties of Clarke County, Georgia and Santa Barbara. Some are self evident while others require a supplementary sign to describe what the marks on the pavement stand for (see Exhibits 3, 4 and 5 for typical examples). Any detector marking scheme employed should be self evident, requiring no additional signing or information. It should be obvious to the bicyclists, as well as the motorists, what the symbol stands for and should not be in conflict with or be confused with other standard pavement markings or legends.

The marking schemes of Clarke County, Santa Barbara County and the City of Boulder employ signs as a supplement. None of these marking designs has a symbol of a bicycle in it. The City of Cupertino experimented with arrow markings, that were one-fourth (25%) the size of standard pavement legends, placed on the detectors where detection of bicycles was assured. A review of timelapse films, taken before and after, shows no evidence that the bicyclists understood the purpose of the markings. From this we conclude that the most understood markings contain a bicycle symbol as do the markings in San Luis Obispo and the later design in Cupertino. Neither of these markings is supplemented by signs.

The symbol should be simple in design, easy to paint and repaint without blurring the image and reasonably inexpensive. We are recommending the symbol in "Standard Alphabets for Highway Signs and Pavement Markings" published by the U. S. Department of Transportation (Exhibit 6). This symbol appears to meet the criteria for simplicity and clarity. In addition, it seems to us that this will be the symbol that will eventually replace the word messages in standard bike lane designs. It also resembles the symbol for bicycling used in the Olympic Games which gives it an added recognition factor.

EXHIBIT 2

SPECIFICATION OF BICYCLE TIMER

MECHANICAL DESIGN

Each Bicycle Timer shall be completely enclosed in a sheet metal case with a protective paint finish or be card rack mounted with a standard four and one-half (4-1/2) inch high by eight (8) inch deep size for use with a Caltrans Model 170 controller. The design shall provide convenient access to the entire interior assembly and permit removal of printed circuit boards or modules with a minimum use of tools.

Manually variable timing controls shall be arranged on the front panel. The phase(s) to be affected by this timer shall be clearly and permanently marked on the front panel. Two (2) sets of indicator lights shall also be provided on the front panel. One (1) set shall be used to indicate that a call has been registered from a detector or push button. The second set of lights shall indicate that the Bicycle Timer is timing the interval for bicycle extension.

The Bicycle Timer shall provide for the logic to time four (4) separate intervals to be associated with up to four (4) separate phases (phases 2, 4, 6 and 8 in most cases). The intervals shall be adjustable from zero (0) to thirty-one (31) seconds in one (1) second increments.

FUNCTION

When a bicycle loop detector or bike push button has been actuated, the Bicycle Timer shall operate in the following manner:

- For calls received during the yellow or red intervals of a phase called, the logic will place and hold a vehicle call until the start of the next green interval for that phase. At the start of the next green interval, the vehicle call shall continue to be held until the expiration of the time set for that phase.

- For calls received during the green interval of the phase called, the Bicycle Timer shall begin timing immediately and place and hold a vehicle call until the expiration of the time set for that phase provided that bicycle timing has not previously occurred during that same green interval.

- Bicycle actuations received during the green interval while the bicycle timing is in effect, or after the bicycle timing has been completed, will not be remembered or carried over to the next cycle.

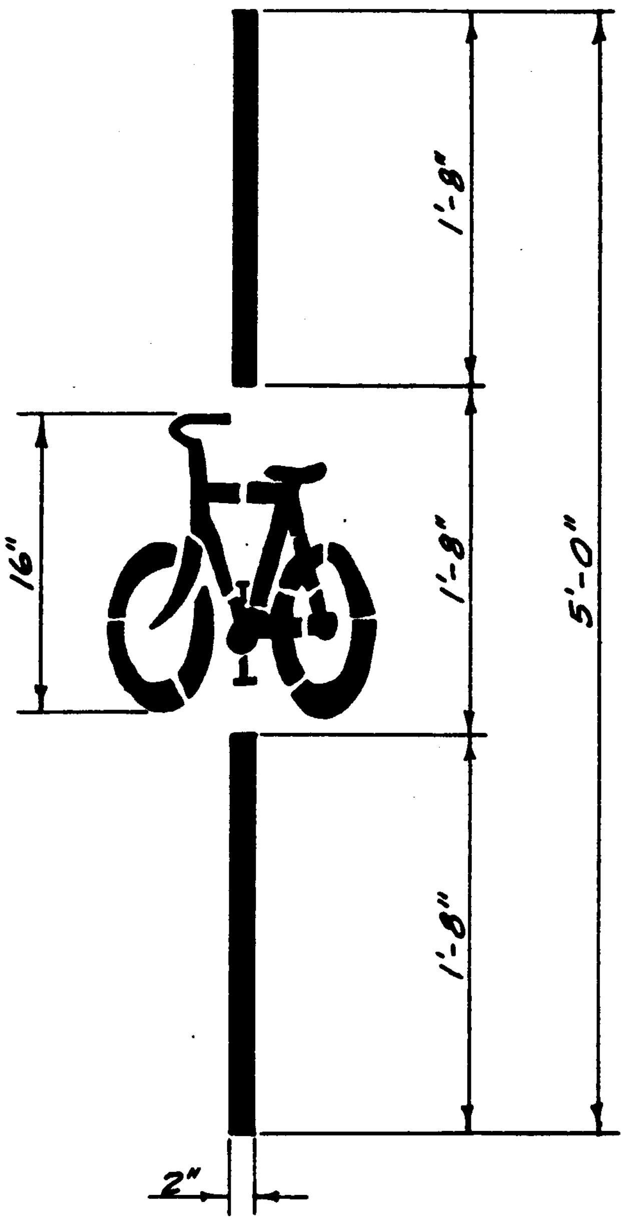


EXHIBIT 3

LOOP MARKING USED
IN SAN LUIS OBISPO

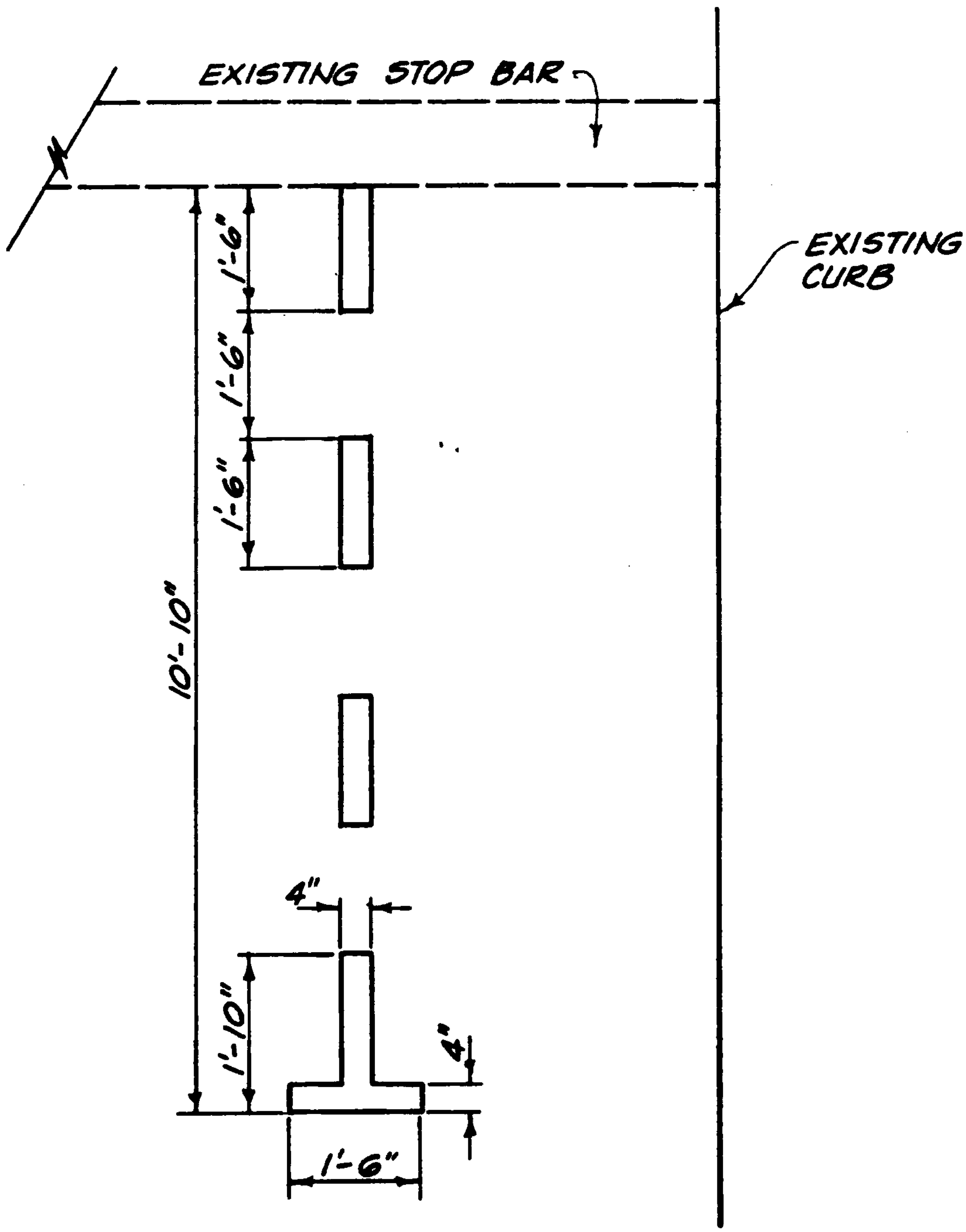


EXHIBIT 4

LOOP MARKING USED
IN CLARK COUNTY, GA.

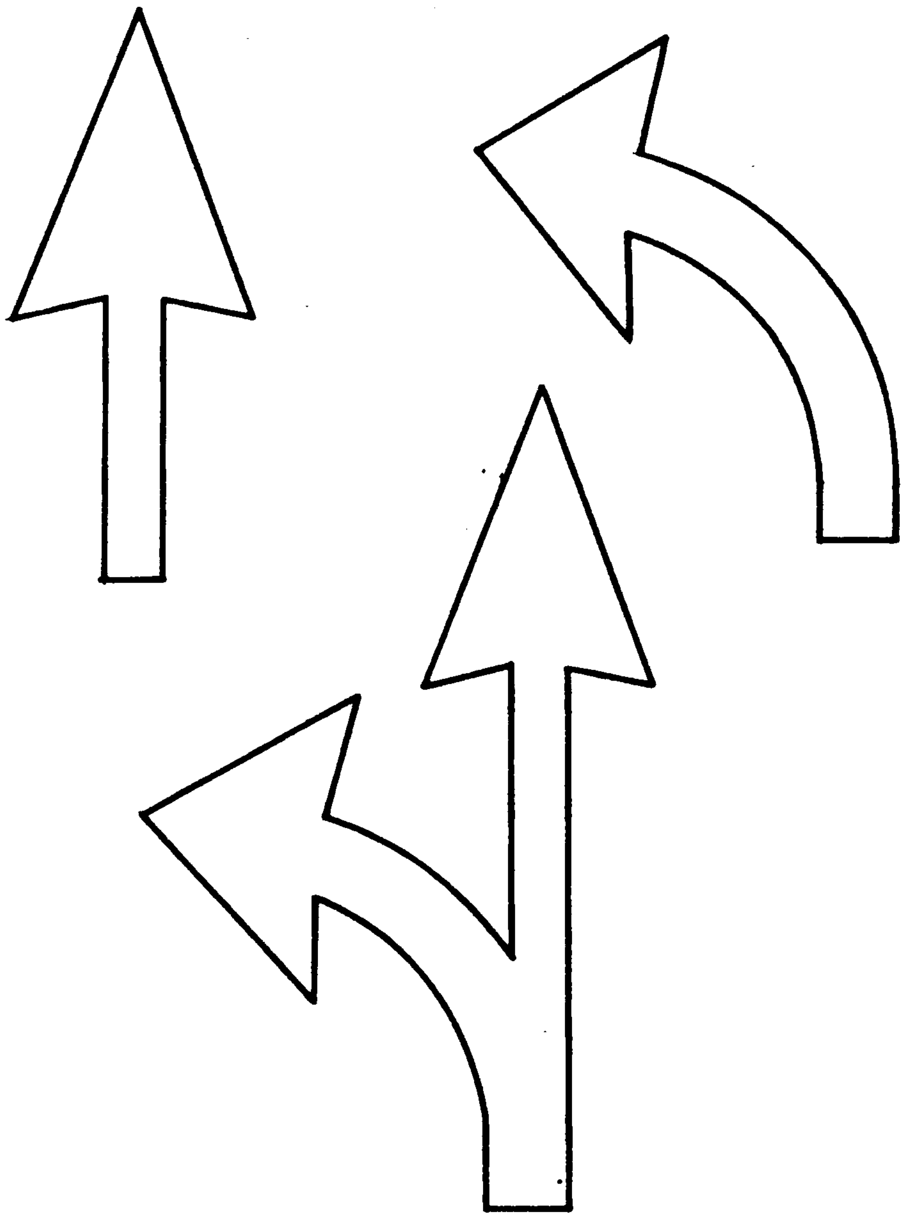


EXHIBIT 5

LOOP MARKING USED IN CUPERTINO

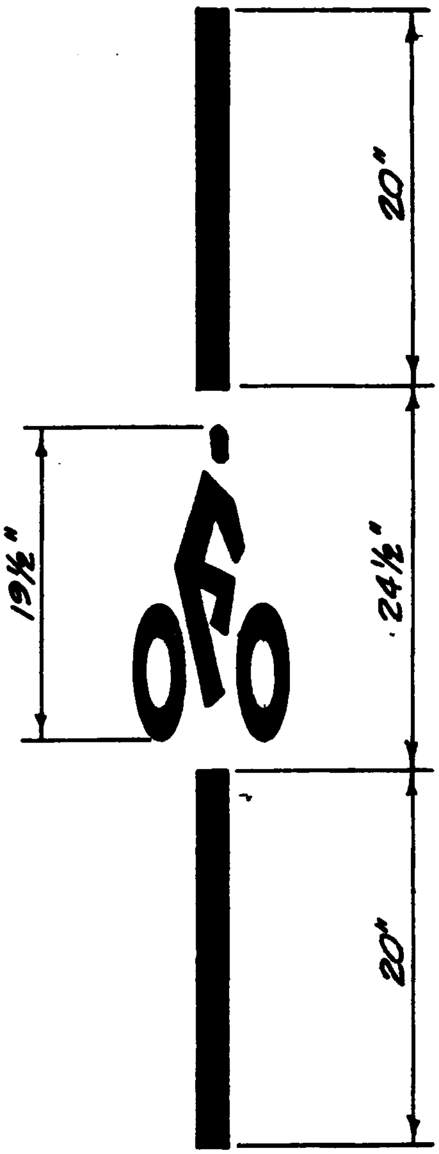


EXHIBIT 6

RECOMMENDED LOOP MARKINGS

BICYCLE DETECTOR ANALYSES

The most prevalent types of traffic signal detector systems are magnetic detectors, magnetometer detectors and inductive loop detectors. Adler's horn, despite its popularity in the early days of actuated signal control, is not one of these. Pressure sensitive detectors, radar detectors and ultrasonic detectors have all gone the way of Adler's horn because of reliability, economic and maintenance reasons.

Magnetic Detectors

The magnetic detector is the least used of the three predominant types due to the fact that long term presence mode detection is not possible with this system. These detectors function very well when pulse detection is required in uses such as traffic counting and speed trap measurements. For these reasons the magnetic detector is not one to be considered for detecting bicycles. We are not recommending that the use of this system be attempted.

Magnetometer Detectors

Magnetometer detectors will perform as well as inductive loop detectors. All of the features of the inductive loop detector are available such as long, medium and short term presence and various sensitivity levels. These systems, in fact, have no real faults and only one (1) serious limitation. The area of detection is confined around the detector probe and the number of probes per amplifier channel is limited to two (2). For motor vehicle detection it is generally acceptable to place two (2) probes in a traffic lane. This makes the magnetometer detector competitive functionally and economically with the inductive loop. However, in order to adequately cover a lane for detecting bicycles, three (3) or four (4) probes should be used. This requires two (2) amplifiers and additional probes to detect one (1) lane. At this point the magnetometer is not as cost effective as the inductive loop.

There will always be special occasions where the magnetometer detector will be advantageous to use. Detection on top of or even underneath bridge structures are such locations. We are recommending that magnetometer detectors be considered for use in special situations where the inductive loop itself could cause structural problems or where reinforcing steel or steel beams might shield the effects of the inductance shift required to detect bicycles and/or vehicles.

Inductive Loops

The inductive loop detector is by far the most popular detection system in America and in Europe. This system is being used to detect vehicles of all description from bicycles to the largest of trucks. Therefore, this is the system that will be discussed in the greatest detail and is the one that we are recommending for the City of San Diego.

There are three (3) basic elements to inductive loop detector systems: the loop(s), the lead-in cable and the detector amplifier. The loop is essentially an air core inductor or coil, the lead-in cable is the connector between the loop and detector amplifier that supplies power to the loop and transmits changes in inductance to the detector amplifier. The detector amplifier senses changes in the inductance of the loop and provides the switch closure to indicate to the traffic signal controller that a vehicle is present. The basics of the system are that when any vehicle enters the area of influence of the air core inductor, it creates eddy currents. The eddy currents cause changes in the electrical properties of the loop. These changes are measured and, if they are of a sufficient magnitude, the equipment creates the switch closure to activate the traffic signal controller.

Loops come in all varieties of size, shape and number of turns of wire in them. The number of turns and size of wire will determine the sensitivity of the loop and its ability to detect bicycles. The magnetic fields (effective sensitivity) of the loop increase with the number of turns. This is too easy. To detect small vehicles or bicycles, simply increase the number of turns in the coil. Well, it isn't so easy as there are limitations at both ends of the spectrum. There must be enough wire in the ground to detect the bicycle but the inductance of the combination of the loop and lead-in cable must fall within the range of limitation of the detector amplifier (30 to 700 Microhenries typically, although some have low limits of zero (0) Mh and high limits of 2,000 Mh). In addition, there are operation problems to consider such as adjacent lane detection. From a practical point of view we generally see that the loop will have from two (2) to four (4) turns of wire.

Generally speaking, a detector will detect to a height above the pavement of one-half the width of the loop. This means that a six (6) foot wide loop will detect to about three (3) feet above the surface. The statement is generally true of quadrupole loops with the reservation that sensitivity on the center wires is approximately three (3) times that of its edges. A six (6) foot wide quadrupole loop is essentially two (2) loops, three (3) feet wide with a common edge (the center). This loop will detect approximately one and one-half (1-1/2) feet above the pavement surface except on the center wires where the height of detection is slightly higher.

The standard width of a typical inductive loop was not selected arbitrarily but was deliberately set at six (6) feet to coincide with the width of standard size automobiles. Eddy currents generated in the relatively flat sides of the automobile have their own magnetic fields with polarity opposite that of the loop. The result is partial cancellation of the magnetic fields of the loop and a result is a decrease in inductance. Eddy currents in vehicles in adjacent lanes can cause detection when the vehicle is too close to a highly sensitive loop. This problem is more pronounced when a large flat sided truck, such as a furniture van, is in that adjacent lane.

The inductance of the loop is vital to its sensitivity and therefore to its ability to detect bicycles. Relatively high inductance values in the loop will allow lower sensitivity levels to be used on the amplifier. The inductance of an existing loop can be measured using an instrument costing less than $360.00. Exhibits 7-10 illustrate typical measurements and calculations on existing detectors. The frequency of the loop or loop lead-in combination is measured and the inductance in Microhenries is 372,500 divided by the square of frequency in Kilohertz (372,500/(f*f)). You can also determine the number of turns of wire that was actually installed by the contractor or maintenance person with the formulas listed below. This information, added to the inductance of the lead-in cable, to be discussed below, will let you know if the limitations of the amplifier have been violated.

By calculating the inductance, using the formula for square or rectangular loops L=P/4*((N)2+N) where inductance in Microhenries is the perimeter of the loop in feet, divided by four, times the sum of the number of turns of wire squared plus the number of turns of wire, you can design a loop system that meets the parameters required to detect bicycles. The formula for calculating the inductance of a quadrupole loop is the perimeter in feet times a constant plus the length of the center spoke in feet times a constant(L=P*K+C*K).

<u>CONSTANTS FOR LOOP INDUCTANCE CALCULATIONS</u>

No. of Turns	Constant(K)
1	0.5
2	1.5
3	3.0
4	5.0

EXHIBIT 7

MEASURED FREQUENCIES AND INDUCTANCE ON VARIOUS BICYCLE DETECTORS IN THE CITY OF CUPERTINO

BICYCLE ON CENTER WIRES OF QUADRUPOLE BIKE DETECTOR

LOOP TYP	LOOP SIZE IN FEET	NUMBER OF TURNS	LEAD-IN LENGTH	MEASURED FREQUENCY	MEASURED INDUCTANCE	MEASURED FREQUENCY	MEASURED INDUCTANCE	INDUCTANCE SHIFT IN % OF TOTAL	INDUCTANCE SHIFT TOTAL NANOHENRIES
QUADRUPOLE	2.0 x 10	2	25ft	61114 Hz	99.7 uH	61262 Hz	99.3 uH	.483 %	481
QUADRUPOLE	2.8 x 10	2	25ft	61573 Hz	98.3 uH	61783 Hz	97.6 uH	.679 %	667
QUADRUPOLE	2.9 x 10	2	25ft	65806 Hz	86.0 uH	66096 Hz	85.3 uH	.876 %	753
QUADRUPOLE	2.4 x 10	2	80ft	56333 Hz	117.4 uH	56494 Hz	116.7 uH	.569 %	668
QUADRUPOLE	3.6 x 10	2	80ft	58400 Hz	109.2 uH	58621 Hz	108.4 uH	.753 %	822
QUADRUPOLE	2.3 x 10	2	100ft	61647 Hz	98.0 uH	61877 Hz	97.3 uH	.742 %	727
QUADRUPOLE	2.0 x 10	2	110ft	61135 Hz	99.7 uH	61310 Hz	99.1 uH	.570 %	568
QUADRUPOLE	2.0 x 10	2	120ft	60001 Hz	103.5 uH	60140 Hz	103.0 uH	.462 %	478
QUADRUPOLE	3.2 x 10	2	120ft	59149 Hz	106.5 uH	59357 Hz	105.7 uH	.700 %	745
QUADRUPOLE	2.4 x 10	2	150ft	55673 Hz	120.2 uH	55822 Hz	119.5 uH	.533 %	641
QUADRUPOLE	3.3 x 10	2	150ft	54869 Hz	123.7 uH	55062 Hz	122.9 uH	.700 %	866
QUADRUPOLE	3.3 x 10	2	165ft	54754 Hz	124.2 uH	54940 Hz	123.4 uH	.676 %	840
QUADRUPOLE	2.0 x 10	2	175ft	55531 Hz	120.8 uH	55657 Hz	120.3 uH	.452 %	546
QUADRUPOLE	4.0 x 10	2	175ft	55379 Hz	121.5 uH	55600 Hz	120.5 uH	.793 %	964
QUADRUPOLE	2.2 x 10	2	180ft	55315 Hz	121.7 uH	55446 Hz	121.2 uH	.472 %	575
QUADRUPOLE	2.3 x 10	2	180ft	56550 Hz	116.5 uH	56711 Hz	115.8 uH	.567 %	660
QUADRUPOLE	2.1 x 10	2	200ft	52912 Hz	133.1 uH	53038 Hz	132.4 uH	.475 %	631
QUADRUPOLE	2.3 x 10	2	200ft	53691 Hz	129.2 uH	53818 Hz	128.6 uH	.471 %	609
QUADRUPOLE	2.5 x 10	2	200ft	56280 Hz	117.6 uH	56452 Hz	116.9 uH	.608 %	716
QUADRUPOLE	3.0 x 10	2	200ft	53460 Hz	130.3 uH	53621 Hz	129.6 uH	.600 %	782
QUADRUPOLE	3.3 x 10	2	200ft	53061 Hz	132.3 uH	53226 Hz	131.5 uH	.619 %	819
QUADRUPOLE	2.0 x 10	2	205ft	50491 Hz	146.1 uH	50588 Hz	145.6 uH	.383 %	560
QUADRUPOLE	3.3 x 10	2	205ft	52863 Hz	133.3 uH	52987 Hz	132.7 uH	.467 %	623
QUADRUPOLE	3.9 x 10	2	210ft	51551 Hz	140.2 uH	51743 Hz	139.1 uH	.741 %	1038
QUADRUPOLE	2.4 x 10	2	220ft	52448 Hz	135.4 uH	52582 Hz	134.7 uH	.509 %	689
QUADRUPOLE	2.5 x 10	2	220ft	50615 Hz	145.4 uH	50727 Hz	144.8 uH	.441 %	641
QUADRUPOLE	3.2 x 10	2	220ft	51646 Hz	139.7 uH	51806 Hz	138.8 uH	.617 %	861
QUADRUPOLE	3.0 x 10	2	230ft	51468 Hz	140.6 uH	51629 Hz	139.7 uH	.623 %	876
QUADRUPOLE	2.0 x 10	2	275ft	52164 Hz	136.9 uH	52300 Hz	136.2 uH	.519 %	711
QUADRUPOLE	3.2 x 10	2	300ft	44920 Hz	184.6 uH	45027 Hz	183.7 uH	.475 %	876
QUADRUPOLE	3.5 x 10	2	300ft	44543 Hz	187.7 uH	44640 Hz	186.9 uH	.434 %	815
QUADRUPOLE	3.6 x 10	2	300ft	47152 Hz	167.5 uH	47272 Hz	166.7 uH	.507 %	850
QUADRUPOLE	4.0 x 10	2	320ft	46193 Hz	174.6 uH	46329 Hz	173.5 uH	.586 %	1023
QUADRUPOLE	4.0 x 10	2	335ft	46713 Hz	170.7 uH	46783 Hz	170.2 uH	.299 %	510
QUADRUPOLE	3.2 x 10	2	350ft	47439 Hz	165.5 uH	47565 Hz	164.6 uH	.529 %	876
QUADRUPOLE	4.0 x 10	2	600ft	46846 Hz	169.7 uH	46950 Hz	169.0 uH	.443 %	751

EXHIBIT 8

MEASURED FREQUENCIES AND INDUCTANCE ON VARIOUS
BICYCLE DETECTORS IN THE CITY OF CUPERTINO

BICYCLE ON EDGE WIRES OF QUADRUPOLE DETECTOR

LOOP TYP	LOOP SIZE IN FEET	NUMBER OF TURNS	LEAD-IN LENGTH	MEASURED FREQUENCY	MEASURED INDUCTANCE	MEASURED FREQUENCY	MEASURED INDUCTANCE	INDUCTANCE SHIFT IN % OF TOTAL	INDUCTANCE SHIFT TOTAL NANOHENRIES
QUADRUPOLE	2.0 x 10	2	25ft	61114 Hz	99.7 uH	61123 Hz	99.7 uH	.029 %	29
QUADRUPOLE	2.8 x 10	2	25ft	61573 Hz	98.3 uH	61613 Hz	98.1 uH	.130 %	128
QUADRUPOLE	2.9 x 10	2	25ft	65806 Hz	86.0 uH	65850 Hz	85.9 uH	.134 %	115
QUADRUPOLE	2.4 x 10	2	80ft	56333 Hz	117.4 uH	56359 Hz	117.3 uH	.092 %	108
QUADRUPOLE	3.6 x 10	2	80ft	58400 Hz	109.2 uH	58446 Hz	109.0 uH	.157 %	172
QUADRUPOLE	2.3 x 10	2	100ft	61647 Hz	98.0 uH	61680 Hz	97.9 uH	.107 %	105
QUADRUPOLE	2.0 x 10	2	110ft	61135 Hz	99.7 uH	61156 Hz	99.6 uH	.069 %	68
QUADRUPOLE	2.0 x 10	2	120ft	60001 Hz	103.5 uH	60025 Hz	103.4 uH	.080 %	83
QUADRUPOLE	3.2 x 10	2	120ft	59149 Hz	106.5 uH	59192 Hz	106.3 uH	.145 %	155
QUADRUPOLE	2.4 x 10	2	150ft	55673 Hz	120.2 uH	55701 Hz	120.1 uH	.101 %	121
QUADRUPOLE	3.3 x 10	2	150ft	54869 Hz	123.7 uH	54897 Hz	123.6 uH	.102 %	126
QUADRUPOLE	3.3 x 10	2	165ft	54754 Hz	124.2 uH	54794 Hz	124.1 uH	.146 %	181
QUADRUPOLE	2.0 x 10	2	175ft	55531 Hz	120.8 uH	55548 Hz	120.7 uH	.061 %	74
QUADRUPOLE	4.0 x 10	2	175ft	55379 Hz	121.5 uH	55422 Hz	121.3 uH	.155 %	188
QUADRUPOLE	2.2 x 10	2	180ft	55315 Hz	121.7 uH	55336 Hz	121.6 uH	.076 %	92
QUADRUPOLE	2.3 x 10	2	180ft	56550 Hz	116.5 uH	56573 Hz	116.4 uH	.081 %	95
QUADRUPOLE	2.1 x 10	2	200ft	52912 Hz	133.1 uH	52932 Hz	133.0 uH	.076 %	101
QUADRUPOLE	2.3 x 10	2	200ft	53691 Hz	129.2 uH	53713 Hz	129.1 uH	.082 %	106
QUADRUPOLE	2.5 x 10	2	200ft	56280 Hz	117.6 uH	56305 Hz	117.5 uH	.089 %	104
QUADRUPOLE	3.0 x 10	2	200ft	53460 Hz	130.3 uH	53486 Hz	130.2 uH	.097 %	127
QUADRUPOLE	3.3 x 10	2	200ft	53061 Hz	132.3 uH	53086 Hz	132.2 uH	.094 %	125
QUADRUPOLE	2.0 x 10	2	205ft	50491 Hz	146.1 uH	50505 Hz	146.0 uH	.055 %	81
QUADRUPOLE	3.3 x 10	2	205ft	52863 Hz	133.3 uH	52897 Hz	133.1 uH	.129 %	171
QUADRUPOLE	3.9 x 10	2	210ft	51551 Hz	140.2 uH	51584 Hz	140.0 uH	.128 %	179
QUADRUPOLE	2.4 x 10	2	220ft	52448 Hz	135.4 uH	52466 Hz	135.3 uH	.069 %	93
QUADRUPOLE	2.5 x 10	2	220ft	50615 Hz	145.4 uH	50638 Hz	145.3 uH	.091 %	132
QUADRUPOLE	3.2 x 10	2	220ft	51646 Hz	139.7 uH	51674 Hz	139.5 uH	.108 %	151
QUADRUPOLE	3.0 x 10	2	230ft	51468 Hz	140.6 uH	51492 Hz	140.5 uH	.093 %	131
QUADRUPOLE	2.0 x 10	2	275ft	52164 Hz	136.9 uH	52178 Hz	136.8 uH	.054 %	73
QUADRUPOLE	3.2 x 10	2	300ft	44920 Hz	184.6 uH	44943 Hz	184.4 uH	.102 %	189
QUADRUPOLE	3.5 x 10	2	300ft	44543 Hz	187.7 uH	44552 Hz	187.7 uH	.040 %	76
QUADRUPOLE	3.6 x 10	2	300ft	47152 Hz	167.5 uH	47178 Hz	167.4 uH	.110 %	185
QUADRUPOLE	4.0 x 10	2	320ft	46193 Hz	174.6 uH	46221 Hz	174.4 uH	.121 %	211
QUADRUPOLE	4.0 x 10	2	335ft	46713 Hz	170.7 uH	46724 Hz	170.6 uH	.047 %	80
QUADRUPOLE	3.2 x 10	2	350ft	47439 Hz	165.5 uH	47462 Hz	165.4 uH	.097 %	160
QUADRUPOLE	4.0 x 10	2	600ft	46846 Hz	169.7 uH	46908 Hz	169.3 uH	.264 %	448

EXHIBIT 9

BICYCLE DETECTION PROJECT 1983 82-25 CUPERTINO: MARCH 6, 1984

LOCATION:	BUBB & SC	DE ANZA & SC	WOLFE & SC	STELLING & SC	MC & STELLING
DIRECTION:	EB	WB	EB	SB	NB
SIZE:	24"x10'	42"x10'	36"x10'	29"x10'	30"x10'
MEGAOHM:	100	100 +	100	100	100 +
OHM(RESISTANCE):	1.5	2.0	1.7	1.25	1.6
MEGAHERTZ-WITHOUT VEH:	52164	44543	51468	52448	50615
MEGAHERTZ-CENTER:	52300	44640	51629	52582	50727
MEGAHERTZ-SIDE:	52178	44552	51492	52466	50638

LOCATION:	BUBB & SC	BLANEY N OF SC	WOLFE & SC	STELLING & SC	MC & STELLING
DIRECTION:	WB	SB	WB	EB	SB
SIZE:	33"x10'	24"x10'	40"x10'	38"x10'	28"x10'
MEGAOHM:	100 +	100 +	100	100 +	100 +
OHM(RESISTANCE):	0.8	1.6	1.3	0.8	0.7
MEGAHERTZ-WITHOUT VEH:	61573	50491	53061	59149	61647
MEGAHERTZ-CENTER:	61783	50588	53226	59357	61877
MEGAHERTZ-SIDE:	61613	50505	53086	59192	61680

LOCATION:	85 OFF & SC	BLANEY @ SC	FINCH & SC	STELLING & SC	MC & STELLING
DIRECTION:	EB	SB	EB	WB	EB
SIZE:	48"x10'	40"x10'	38"x10'	43"x10'	24"x10'
MEGAOHM:	100 +	100 +	100 +	100 +	100 +
OHM(RESISTANCE):	2.0	1.2	1.8	1.6	1.0
MEGAHERTZ-WITHOUT VEH:	46193	52863	44920	47152	60001
MEGAHERTZ-CENTER:	46329	52987	45027	47272	60140
MEGAHERTZ-SIDE:	46221	52897	44943	47178	60025

LOCATION:	85 OFF & SC	BLANEY S OF SC	FINCH & SC	MC & STELLING	PEPPER & STELL
DIRECTION:	WB	NB	WB	WB	SB
SIZE:	48"x10'	24"x10'	38"x10'	24"x10'	28"x10'
MEGAOHM:	100 +	100 +	100 +	100 +	100
OHM(RESISTANCE):	1.7	0.7	1.2	1.0	1.2
MEGAHERTZ-WITHOUT VEH:	36713	61114	51646	55531	53691
MEGAHERTZ-CENTER:	36783	61262	51806	55657	53818
MEGAHERTZ-SIDE:	36724	61123	51674	55548	53713

LOCATION:	85 ON &SC	BLANEY @ SC	MC & BUBB	PORTAL & SC
DIRECTION:	WB	NB	NB	WB
SIZE:	48"x10'	35"x10'	29"x10'	39"x10'
MEGAOHM:	100 +	100 +	100 +	100 +
OHM(RESISTANCE):	2.5	0.5	1.8	1.2
MEGAHERTZ-WITHOUT VEH:	46846	65806	55673	54869
MEGAHERTZ-CENTER:	46950	66096	55822	55062
MEGAHERTZ-SIDE:	46908	65850	55701	54897

LOCATION:	MARY & SC	BLANEY & SC	MC & BUBB	PERIMETER & SC
DIRECTION:	EB	EB	SB	EB
SIZE:	38"x10'	48"x10'	30"x10'	26"x10'
MEGAOHM:	100 +	100 +	100 +	100 +
OHM(RESISTANCE):	1.8	1.1	1.1	1.1
MEGAHERTZ-WITHOUT VEH:	47439	55379	56280	55315
MEGAHERTZ-CENTER:	47565	55600	56452	55446
MEGAHERTZ-SIDE:	47462	55422	56305	55336

LOCATION:	MARY & SC	BLANEY & SC	MC & BUBB	PERIMETER & SC
DIRECTION:	WB	WB	EB	WB
SIZE:	43"x10'	47"x10'	25"x10'	36"x10'
MEGAOHM:	100	100 +	100 +	100 +
OHM(RESISTANCE):	0.8	1.2	1.4	1.2
MEGAHERTZ-WITHOUT VEH:	58400	51551	52912	53460
MEGAHERTZ-CENTER:	58621	51743	53038	53621
MEGAHERTZ-SIDE:	58446	51584	52932	53486

LOCATION:	STELLING & SC	PORTAL & SC	MC & BUBB	PEPPER & STELL
DIRECTION:	NB	EB	WB	NB
SIZE:	29"x10'	40"x10'	24"x10'	27"x10'
MEGAOHM:	100 +	18.0	100 +	100 +
OHM(RESISTANCE):	1.1	1.2	0.8	1.1
MEGAHERTZ-WITHOUT VEH:	56333	54754	61135	56550
MEGAHERTZ-CENTER:	56494	54940	61310	56711
MEGAHERTZ-SIDE:	56359	54794	61156	56573

EXHIBIT 10

SENSITIVITY LEVELS THAT ACHIEVED
BICYCLE DETECTION ON VARIOUS TYPES
OF INDUCTIVE LOOP DETECTORS

LOOP TYPE	LOCATION	LOOP SIZE IN FEET	NUMBER OF TURNS	CALCULATED LOOP INDUCTANCE	LEAD-IN LENGTH	CALCULATED LEAD-IN INDUCTANCE	TOTAL INDUCTANCE	SENSITIVITY LEVEL	MINIMUM ABSOLUTE CHANGE REQUIRED	MINIMUM PERCENT CHANGE REQUIRED
STATE TYPE I	ON CENTER	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	7	8 nH	.011 %
STATE TYPE I	ON EDGE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	2	256 nH	.337 %
STATE TYPE I	1ft OUTSIDE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	5	32 nH	.042 %
STATE TYPE I	ON CENTER	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	HIGH = 6	16 nH	.021 %
STATE TYPE I	ON EDGE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	LOW = 1	512 nH	.674 %
STATE TYPE I	1ft OUTSIDE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	HIGH = 6	16 nH	.021 %
STATE TYPE I	ON CENTER	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE I	ON EDGE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	LOW = 1	512 nH	.674 %
STATE TYPE I	1ft OUTSIDE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	HIGH = 6	16 nH	.021 %
STATE TYPE I	ON CENTER	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE I	ON EDGE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	LOW = 1	512 nH	.674 %
STATE TYPE I	1ft OUTSIDE	6.0 x 6	3	64.9 uH	50ft	11.0 uH	75.9 uH	HIGH = 6	16 nH	.021 %
STATE TYPE II	ON CENTER	6.0 x 6	3	129.8 uH	290ft	63.8 uH	193.6 uH	7	8 nH	.004 %
STATE TYPE II	ON EDGE	6.0 x 6	3	129.8 uH	290ft	63.8 uH	193.6 uH	2	256 nH	.132 %
STATE TYPE II	1ft OUTSIDE	6.0 x 6	3	129.8 uH	290ft	63.8 uH	193.6 uH	5	32 nH	.017 %
STATE TYPE II	ON CENTER	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	7	8 nH	.004 %
STATE TYPE II	ON EDGE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	2	256 nH	.131 %
STATE TYPE II	1ft OUTSIDE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	6	16 nH	.008 %
STATE TYPE II	ON CENTER	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	NO DETECTION	0 nH	.000 %
STATE TYPE II	ON EDGE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	LOW = 1	512 nH	.263 %
STATE TYPE II	1ft OUTSIDE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	NO DETECTION	0 nH	.000 %
STATE TYPE II	ON CENTER	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	HIGH = 6	16 nH	.008 %
STATE TYPE II	ON EDGE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	MED = 3	128 nH	.066 %
STATE TYPE II	1ft OUTSIDE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	HIGH = 6	16 nH	.008 %
STATE TYPE II	ON CENTER	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	NO DETECTION	0 nH	.000 %
STATE TYPE II	ON EDGE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	LOW = 1	512 nH	.263 %
STATE TYPE II	1ft OUTSIDE	6.0 x 6	3	129.8 uH	295ft	64.9 uH	194.7 uH	HIGH = 6	16 nH	.008 %
STATE TYPE III	ON CENTER	6.0 x 6	3	194.8 uH	440ft	96.8 uH	291.6 uH	NO DETECTION	0 nH	.000 %
STATE TYPE III	ON EDGE	6.0 x 6	3	194.8 uH	440ft	96.8 uH	291.6 uH	5	32 nH	.011 %
STATE TYPE III	1ft OUTSIDE	6.0 x 6	3	194.8 uH	440ft	96.8 uH	291.6 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON CENTER	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON EDGE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	4	64 nH	.023 %
STATE TYPE IV	1ft OUTSIDE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	7	8 nH	.003 %
STATE TYPE IV	ON CENTER	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON EDGE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	MED = 3	128 nH	.047 %
STATE TYPE IV	1ft OUTSIDE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON CENTER	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON EDGE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	MED = 3	128 nH	.047 %
STATE TYPE IV	1ft OUTSIDE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON CENTER	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
STATE TYPE IV	ON EDGE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	MED = 3	128 nH	.047 %
STATE TYPE IV	1ft OUTSIDE	6.0 x 6	3	259.7 uH	60ft	13.2 uH	272.9 uH	NO DETECTION	0 nH	.000 %
QUADRUPOLE	ON CENTER	5.0 x 16	2	139.5 uH	75ft	16.5 uH	156.0 uH	2	256 nH	.164 %
QUADRUPOLE	ON EDGE	5.0 x 16	2	139.5 uH	75ft	16.5 uH	156.0 uH	4	64 nH	.041 %
QUADRUPOLE	1ft OUTSIDE	5.0 x 16	2	139.5 uH	75ft	16.5 uH	156.0 uH	7	8 nH	.005 %
QUADRUPOLE	ON CENTER	5.0 x 16	2	139.5 uH	100ft	22.0 uH	161.5 uH	2	256 nH	.159 %
QUADRUPOLE	ON EDGE	5.0 x 16	2	139.5 uH	100ft	22.0 uH	161.5 uH	4	64 nH	.040 %
QUADRUPOLE	1ft OUTSIDE	5.0 x 16	2	139.5 uH	100ft	22.0 uH	161.5 uH	7	8 nH	.005 %
QUADRUPOLE	ON CENTER	6.0 x 6	2	62.5 uH	160ft	35.2 uH	97.7 uH	2	256 nH	.262 %
QUADRUPOLE	ON EDGE	6.0 x 6	2	64.3 uH	160ft	35.2 uH	99.5 uH	4	64 nH	.064 %
QUADRUPOLE	1ft OUTSIDE	6.0 x 6	2	64.3 uH	160ft	35.2 uH	99.5 uH	7	8 nH	.008 %
QUADRUPOLE	ON CENTER	6.0 x 16	2	144.3 uH	50ft	11.0 uH	155.3 uH	1	512 nH	.330 %
QUADRUPOLE	ON EDGE	6.0 x 16	2	144.3 uH	50ft	11.0 uH	155.3 uH	3	128 nH	.082 %
QUADRUPOLE	1ft OUTSIDE	6.0 x 16	2	144.3 uH	50ft	11.0 uH	155.3 uH	7	8 nH	.005 %

NOTE: ANY LINES WITH DUPLICATED DATA ARE THE RESULT OF DIFFERENT BRAND DETECTORS.

With a little experimentation, you will discover that inductance for square and rectangular loops can be calculated by multiplying the perimeter in feet by those same constants. Why engineers derive fancy formulas when simple ones work is beyond the scope of this project but worth mentioning.

Lead-in Cable

Although the lead-in cable is only the connector between the loop and the amplifier, it is an important element in the system in that it adds inductance to the system. The longer the lead-in the more the inductance. It is important to remember that it is the combination of loop inductance and lead-in inductance that must fall within the limitation range of the detector amplifier. In addition, the inductance value of the loop should be at least double that of the inductance of the lead-in cable in order to ensure reliable performance of the total detector system.

The inductance of the lead-in cable will be approximately 0.23 Microhenries per foot. By measuring inductance at the traffic signal cabinet and knowing the length of the lead-in cable you can determine the approximate inductance value of the loop itself. If the values are suspect, you can isolate each component by measuring at the pull box next to the loop. As an example, a 6 foot by 6 foot square loop with an inductance of around 36 Microhenries must be a two (2) turn loop. A lead-in cable length in excess of 80 feet would violate the rule that the loop inductance should be twice that of the cable (80*0.23=18.4)> (36/2=18.0). If this loop were replaced with one with three (3) turns, then a cable length of 150 feet could be supported (150*0.23 =34.5)<(72/2=36).

Detector Amplifier

The detector amplifier is the easiest and cheapest element in the detector system to replace. This is primarily due to the labor costs involved with the replacement of the loop itself or the lead-in cable. It is also the most important element in the system. There are two (2) basic logic circuits in general use: analog and digital. If bicycles are to be reliably detected, all detector amplifier units with analog circuitry should be replaced with digital circuit units. This is recommended as the analog amplifiers are reported to be unstable and cannot be relied upon to consistently detect bicycles at higher sensitivity levels. Replacement can occur as these amplifiers need repairs, when a specific problem is reported or as a result of the City's ongoing controller replacement program.

Digital detector amplifier units sense changes in inductance in two (2) ways: absolute change and percent change. When a metal mass crosses into the loop area, a change of inductance occurs. The amplifier that detects absolute changes in inductance does so regardless of the total inductance of the detector system. The amplifier that detects percent change does so by dividing the value of the inductance change by the value of the total inductance, which establishes the percent change to be compared to the threshold values of the detector amplifier.

The sensitivity ranges that determine the threshold values come in two (2) types also: three (3) steps and eight (8) steps. Typical threshold values are as follows:

TYPICAL DETECTION THRESHOLDS
AND SENSITIVITY SETTINGS

Sensitivity	1	2	3	4	5	6	7	8
Nanohenry	512nH	256nH	128nH	64nH	32nH	16nH	8nH	4nH
Percent nH	.257%	.129%	.086%	.064%	.032%	.021%	.016%	.011%
Sensitivity	LOW		MED			HI		
Percent nH	.32%		.08%			.02%		

The length of lead-in can become critical to the system that detects percent change as it increases the total inductance of the system. A typical bicycle will produce a change in inductance of approximately 16 nanohenries or less on a Caltrans Type A loop when ridden in the center of the loop. Sixteen (16) nanohenries divided by the total inductance of the system can produce a very small percent change. The bicycle used in the study by the City of Cupertino produced an inductance change of less than 16 nanohenries as only one (1) amplifier in four (4) detected that bicycle at the 16 nH threshold.

The detector amplifier that reacts to absolute change will sense the 16 nanohenry change whereas the other will divide the 16 nanohenry change by the total inductance of the loop and lead-in combination and sense the percent change. The longer the lead-in, the smaller the percent change and therefore the task of detecting bicycles becomes more difficult with the latter type of amplifier. For this reason we are recommending the amplifier that measures absolute shift. A sample specification is provided in Exhibit 11.

EXHIBIT 11

SPECIFICATION OF INDUCTIVE LOOP DETECTORS

Loop detectors shall conform to Section 86-5 of the Standard Specifications of the State of California dated July 1984 and Section 11 of the NEMA Standards Publication No. TS 1-1983.

Each detector unit may contain up to four (4) detector channels. Each channel shall automatically self tune to any loop and lead-in combination from twenty (20) to two thousand (2,000) microhenries.

The detector unit shall scan each channel in sequence and only one (1) channel input per unit shall be active at any point in time. Sequential scanning shall prevent crosstalk between channels of a detector.

The detector shall use absolute shift in inductance of the loop and lead-in combination as the means to compare actual inductance shift to threshold values to achieve an actuation. The detector shall cause an actuation to occur when an absolute shift in inductance of four (4) or more nanohenries is measured.

The detector shall have eight (8) separate sensitivity settings with threshold values of 4, 8, 16, 32, 64, 128, 256 and 512 nanohenries, respectively.

COMBINATION BICYCLE/VEHICLE DETECTOR SYSTEMS

The combination bicycle/vehicle detector system, in one case, is one where a vehicle detector that was designed to accommodate motor vehicles is compromised at the amplifier through tuning to also detect bicycles. The price to be paid for this compromise is often adjacent lane detection. The sensitivity of the detector amplifier is tuned to the higher levels and the area in which motor vehicles can be detected spills into the adjacent lane. If the lane is for vehicles traveling in the same direction, then the consequences are fairly minimal. However, when the lane is a left turn only lane or a lane for traffic in the opposite direction, the traffic signal phases can be extended by traffic actually leaving the intersection or a phase can be served when no traffic on the approach is present. This causes the intersection to operate inefficiently and creates calls to the maintenance people for malfunctions that are difficult to analyze and impossible to cure. Some correction to this problem can be made by narrowing the width of the loop. However, care must be exercised. As the loop gets narrower in the lane, the probability that bicycles and even motorcycles could bypass the loop and not be detected increases.

In the other case, the detector system is specifically designed to accommodate bicycles where all other traffic must be detected. Typically these systems will detect the other traffic on the roadway even though the area of detection above the pavement is lower. In the case of quadrupole detectors in particular the sensitivity on the center is high enough to detect some portion of any vehicle. High bed trucks will be detected at the axles and differential cases by these types of detector configurations. This can be a disadvantage if the purpose of the detection is to count or classify the vehicles. However, there is no particular problem created if the purpose is to activate a traffic signal. In fact, there is an arguable advantage if the volume density features of a controller are being used. When each axle of a truck is detected while approaching a red light, the added initial will create more time for the next green displayed. This allows more initial start up time for the slower acceleration rates of trucks.

BICYCLE DETECTOR LOCATION ANALYSIS

Detectors for bicycles must be placed in a position on the roadway where bicyclists can be expected to ride. On streets with bike lanes this is really an easy task. The bike lane area can be covered adequately by a quadrupole detector that will sense the presence of any bicycle as long as it is ridden in the lane. The adjacent traffic lane will not respond to this detector as a result of the cut-off characteristics of the quadrupole loop. Detectors in left turn only lanes and on approaches to intersections without bike lanes must be designed to accommodate both the bicycle and motor vehicles of all sizes while avoiding adjacent lane detection. This also is easy to accomplish if the bicyclist rides on the detector over the most sensitive area, directly over the loop wires.

Placement of bicycle detectors in advance of an intersection is done in at least two (2) ways. The detector is placed in advance of the intersection in the same manner as the vehicle detector is placed. That is, the distance from the stop line is determined by 1) approach speed, 2) reaction time and 3) stopping distance (see Exhibit 12). This is the method used by Caltrans, the City of Cupertino and the County of Santa Barbara and is illustrated in the Caltrans design manual. The distance of ± 50 feet is based on an average approach speed for bicycles of 16 mph. This method is particularly useful on arterial approaches where the phase is usually recalled and vehicles approaching will usually be seeing a green signal. If the general speeds of bicyclists vary from the average speeds used to determine the placement of the detector in the Caltrans manual, then the appropriate distance can be calculated for each approach of an intersection. Upgrade and downgrade approaches will have significantly different approach speeds than from level approaches. These are examples where the designer or engineer should alter the distance to accommodate slower or faster approach speeds. The age and physical condition of the majority of bicyclists using the facility can also alter these parameters.

A similar system in use in the City of Cupertino utilizes a detector placed in advance of the stop line, much like the above example, and another detector placed at the stop line. When the bicycle is detected on the first loop, extension time is provided to hold the signal green until it reaches the second, or loop closest to the stop line. When the detection is made at the second loop, extension time is again provided to be sure that the bicyclist is far enough into the intersection to safely clear before the end of the clearance interval (yellow plus any all-red indication). The particular detector

EXHIBIT 12

SUGGESTED DETECTOR DISTANCES FROM STOP LINE

CALTRANS FORMULAS FOR MOTOR VEHICLE TRAFFIC

SPEED MPH	SPEED Ft/Sec	DEC. TIME SECONDS	DEC. DIST FEET	TOTAL TIME SECONDS	TOTAL DIST FEET	DIST TO USE
8.0	11.7	.98	5.7	1.98	17.5	20
10.0	14.7	1.22	9.0	2.22	23.6	25
12.0	17.6	1.47	12.9	2.47	30.5	30
14.0	20.5	1.71	17.6	2.71	38.1	40
16.0	23.5	1.96	22.9	2.96	46.4	45
18.0	26.4	2.20	29.0	3.20	55.4	55
20.0	29.3	2.44	35.9	3.44	65.2	65
22.0	32.3	2.69	43.4	3.69	75.6	75
24.0	35.2	2.93	51.6	3.93	86.8	85
26.0	38.1	3.18	60.6	4.18	98.7	95
28.0	41.1	3.42	70.3	4.42	111.3	110
30.0	44.0	3.67	80.7	4.67	124.7	125
35.0	51.3	4.28	109.8	5.28	161.1	160
40.0	58.7	4.89	143.4	5.89	202.1	200
45.0	66.0	5.50	181.5	6.50	247.5	250
50.0	73.3	6.11	224.1	7.11	297.4	300
55.0	80.7	6.72	271.1	7.72	351.8	350

DESIGN STOPPING SIGHT DISTANCES FOR BICYCLES

DESIGN SPEED	FEET @ 0%	FEET @ 5%	FEET @ 10%	FEET @ 15%
10 MPH	50	50	60	70
15 MPH	85	90	100	130
20 MPH	130	140	160	200
25 MPH	175	200	230	300
30 MPH	230	260	310	400

amplifier in use in Cupertino also has a minimum timing feature that is used when a bicycle is on the detector while the signal is red. A discrete minimum time is provided that is greater than the vehicle minimum time and less than a pedestrian interval. Unfortunately, this unit is no longer manufactured; however, there are amplifiers on the market with extension and delay features that will function for most features of this design.

Detectors on minor approaches to the intersection should be placed at the stop line in a position where bicyclists are known to ride. In general, this will be near the right hand edge of the roadway, except on one-way streets. Where bicyclists desire to cross the major street there should be space enough between the detector and curb so that right turns by vehicles can be made on the right side of the bicyclist. This configuration is a prime candidate for detector location marking. The detector will be some distance from the curb and to the right of the vehicle through lane. The right edge of the vehicle lane most likely will not be marked and the bicycle detector will be difficult to locate. If adequate space is not available and it is found that right turning vehicles activate the signal, then delayed call features of a detector amplifier can be used to maintain the efficiency of the signal system by eliminating or reducing false detections from the side street. Bicyclists turning left should be in the lane nearest the center of the roadway, be it a left turn only lane or not. Therefore, it is important that the detector(s) being used for vehicles is/are also sensitive enough to detect bicycles.

INVESTIGATION OF DETECTION DEVICES ON BICYCES

A search has been made to determine if there is a device that could be installed on a bicycle to make it more detectable by existing detector systems. There has been talk of such a device and even an article written about how such a device would operate. One manufacturer has contacted us to inquire of our knowledge of such a device and its principles as they were interested in marketing new items in the bicycle equipment field. However, we have been unable to find any new technology that could be applied to this problem. It would seem that what is needed is a device to emulate the metal that creates the eddy currents created by vehicles.

There is a device available that is used to activate traffic signal loops to favor certain types of vehicles. It was designed for emergency vehicles, and is attached to them, so that intersections could be activated to favor their approach. This might be adaptable to the bicycle but would require a separate receiver in each traffic signal cabinet. The receiver costs approximately $400.00 and the unit mounted on the bicycle costs from $96.00 to $125.00. The transmitter, mounted on the bicycle, requires 12 volts DC to operate it. It is highly unlikely that every bicyclist can be convinced to expend the money required or be willing to carry the extra weight to be assured that the detectors in San Diego will respond to his/her bicycle. The cost to the City to install one (1) receiver in each cabinet that has an actuated traffic signal controller exceeds $300,000.00. At certain intersections there will be a need to install one (1) receiver for each phase. This approach is clearly not viable from an economic or functional point of view, as this same device would not work in another city and bicyclists visiting San Diego would be unable to activate the traffic signals without one.

Installing flat aluminum pieces in the frame members and/or discs on the wheels would probably improve the capability of the bicycle to create the eddy currents required to achieve detection. We have not experimented with this approach but the theory seems consistent with the way loop detectors work. Research and development in unknown areas can be extensive and time consuming and could produce no positive results. This kind of work is clearly beyond the scope of this project.

INTERIM BICYCLE DETECTION IMPROVEMENTS

Interim measures are those things that can be done immediately and at a relatively small cost (see Exhibit 13) to improve the usability of traffic signals by bicyclists. The intersections should be prioritized and those serving the most bicyclists should be reviewed first. Traffic signals adjacent to all schools and other identified bicycle traffic generators will be high on the priority list. The order of work should be as follows:

- o Adjust the existing detector amplifier to a higher sensitivity level. If this fails or causes other problems such as adjacent lane detection;
- o Adjust the minimum time on the phase and/or place that phase on recall. This is temporary until you can;
- o Check the terminal blocks for loose screws.
- o Check the loop splices for connections or corrosion.
- o Test the loop and lead-in combination for:
  - a. Initial loop frequency
  - b. Stability of frequency
  - c. Accuracy of frequency change
- o "Meggar" the detector to check resistance to ground (100 megohms minimum).
- o Install a new detector amplifier on the existing loop system. If this fails;
- o Mark the loop on the edge of a square detector and in the center of a quadrupole detector with a symbol that represents a bicycle.
- o Install pedestrian push buttons, with bicycle signs, facing the traffic side of the signal pole.

EXHIBIT 13

COSTS OF INTERIM MEASURES

Costs for implementing the interim measures listed in the text are based on actual invoice costs, wherever possible. Estimates have been made for the costs of existing maintenance personnel to perform adjustments and testing based on our experience as to the time required including travel times.

Adjust existing detector sensitivity	\$ 0 - 25.00
Adjust minimum time or set recall	\$ 0 - 25.00
Check terminal blocks and screws	\$ 0 - 25.00
Check loop and lead-in splices	\$ 25 - 100.00
Test loop and lead-in combination	\$ 25 - 100.00
"Megger" loop detector to ground	\$ 25 - 100.00
Install new detector amplifier	\$100 - 200.00
Mark detector with bicycle symbol	\$ 25 - 35.00
Install pedestrian push buttons	\$ 70 - 120.00

POLICY DETERMINATION AND RECOMMENDATIONS

The California Vehicle Code grants to the bicyclist all of the rights and privileges of a motor vehicle to operate upon the roadway. The bicyclist is subject to all of the duties and responsibilities of a motor vehicle in exchange for the rights and privileges. When a motor vehicle approaches a traffic signal, the driver has a reasonable expectation that within a certain amount of time the traffic signal will respond and the right-of-way will be transferred to that approach. The bicylist, having been granted the rights of a motor vihicle, has the same expectations, which are also reasonable. The technical means by which these expectations are met need not be identical to those applied to motorists; however, they should be recognized and satisfied as a matter of policy.

The policy of the City of San Diego should be to make all traffic signals usable by bicyclists through the use of traffic detector systems or other devices that will detect the presence or passage of bicycles of the lightest variety. This policy should be implemented at the earliest possible date while having due regard for fiscal constraints.

Interim measures, listed above, should be implemented on existing traffic signal systems immediately and maintained until such time as other required improvements can be made.

All new traffic signal system designs should specifically address the need to service bicycle traffic and the means by which this is to be accomplished. Vehicle detectors should be designed so that they are sensitive enough to detect all traffic, including bicycles, and detectors for the exclusive use of bicycles should be installed in bike lane approaches to the intersections. The incremental cost of adding these features is so small as compared to the overall project costs that their addition should be a design feature that satisfies the City's policy.

The City's traffic signal controller replacement program should continue or be accelerated in order to provide the most efficient and reliable equipment available for use in detecting bicycle traffic.

Type D (modified quadrupole) and Type Q (quadrupole) detector loops should be the standard configurations to be used alone or in combination with Type A loops. Left turn lanes and minor side street applications should use State Type 5DA loop installations. Through traffic lanes that are shared by motor vehicles and bicycles should use Type D (modified quadrupole) loops. Detectors at the stop line that are used for presence or calling purposes are considered to be shared use detectors. Type D loops used alone or in combination with one (1), two (2) or three (3) Type A loops should have five (5) turns of conductors. The Type 5DA loop installation has five (5) turns of conductors in the Type D loop. These combination loop detectors should be spliced in series with each other at the pull box. Advance detectors on arterials will not be expected to be shared by bicyclists; therefore, Type A loops are recommended.

Bike lanes that require narrow areas of detection and sharp cut-off properties should have Type Q (quadrupole) loops. These loops should cover as much of the lane as possible. The edges of the loop should be installed one (1) foot to the right of the bike lane line and six (6) inches from the gutter lip. The width will vary but it is not critical to the operation.

Pedestrian push buttons should only be used in locations where it is not possible to reliably detect the presence of bicycle traffic or as an interim measure to ensure safe passage of bicycles until adequate detection systems can be installed.

Inductive loops should be marked at locations where the sensitivity is critical or where detection is not reliably achieved when the bicyclists ride in the approach lane in a position that is appropriate.

Bicycle auxiliary timing devices should be considered in special cases such as crossing very wide arterials where long minimum times are detrimental to efficiency. They should be connected to the inductive loop detector amplifiers or to pedestrian style push buttons.

The City should apply for and use TDA (Transportation Development Act) Article 3 funds to implement bicycle related facilities improvements that qualify. Other funds should also be obligated to facilities improvements; however, TDA funding should be used first to reduce the impacts of bicycle improvements on the General Funds or Gas Tax Funds.

Detector sensitivity levels could be added to the traffic signal timing charts so that the regular maintenance personnel can maintain the required sensitivity levels as a routine procedure. Exhibit 14 illustrates how sensitivity levels might be incorporated in the City's standard timing chart.

Inductive loop amplifiers that measure absolute change in inductance and feature eight (8) sensitivity levels should be specified for use in new signal installations and should be used in a retrofit program.

TRAFFIC SIGNAL TIMING - BITS 152

PHASE TIMING

PHASE # →		1	2	3	4	5	6	7	8	PREEMPT	E	
WALK	0		7		7		7		7	RR1 DELAY		0
FLASH D/W	1		18		16		15		17	RR1 CLEAR		1
MIN GREEN	2	2.0	10.0		2.0	2.0	10.0		2.0	EV A DELAY	0	2
TYPE 3 DET	3									EV A CLEAR	3	3
ADD/VEH	4									EV B DELAY		4
VEH EXTEN	5	2.0	4.8		2.0	2.0	4.8		2.0	EV B CLEAR		5
MAX GAP	6	2.0	4.8		2.0	2.0	4.8		2.0	EV C DELAY	0	6
MIN GAP	7	2.0	0.2		2.0	2.0	0.2		2.0	EV C CLEAR	3	7
MAX EXTEN	8	30.0	60.0		40.0	30.0	60.0		40.0	EV D DELAY		8
MAX 2	9	30.0	60.0		40.0	30.0	60.0		40.0	EV D CLEAR		9
	A									RR2 DELAY		A
	B									RR2 CLEAR		B
REDUCE BY	C		0.1				0.1			[illegible]		C
REDUCE EVERY	D		0.7				0.7			[illegible]		D
YELLOW	E	3.0	4.5		3.0	3.0	4.5		3.0	[illegible]		E
RED CLEAR	F	1.0	1.0		1.0	1.0	1.0		1.0	RR DLY TMR		F
SENSITIVITY		3	4		5	3	4		5	RR DLY TMR		

MAX INITIAL (F-O-E) = 0　　KEYSTROKES: F • PHASE • LOCATION　　RED REVERT (F-O-F) = 5

PHASE FUNCTION FLAGS

		PHASE 1	2	3	4	5	6	7	8
PERMIT	0	X	X		X	X	X		X
RED LOCK	1								
YELLOW LOCK	2								
VEH RECALL	3		X				X		
PED RECALL	4								
[illegible]	5								
REST IN WALK	6								
RED REST	7								
DOUBLE ENTRY	8				X				X
MAX RECALL	9								
OVERLAP A	A								
OVERLAP B	B								
OVERLAP C	C								
OVERLAP D	D								
STARTUP	E		X				X		
(RESERVED)	F								

KEYSTROKES F • F • FUNCTION #

PHASE SEQUENCES

		PHASE 1	2	3	4	5	6	7	8
LAG 0 (FREE)	0		X		X		X		X
LAG 1	1								
LAG 2	2								
LAG 3	3								
LAG 4	4								
LAG 5	5								
LAG 6	6								
LAG 7	7								
LAG 8	8								
LAG 9	9								
COOR MAX RECALL	A								
COOR LAG RECALL	B								
SYNC PHASES	C								
HOLD	D								
NEXT PHASE	E								
FORCE OFF	F								

KEYSTROKES C • F • FUNCTION #

REMARKS:

Dwg. # 21574-14-D

LOC [illegible]　　DATE [illegible]　　PAGE 1 OF 2

EXHIBIT 14

SAMPLE SIGNAL TIMING CHART WITH SENSITIVITY VALUES

GLOSSARY OF TERMS

ACTUATION: The output from any type of detector to the controller unit.

ADDED INITIAL: Green time that is added to a phase by actuations of the vehicle detector during the red signal indication of that phase.

ADLER'S HORN: Detector unit activated by the sound of an automobile horn near its sensor. The sensor was accompanied by a sign that read "Stop - Sound Horn to Clear Signal."

AMPLIFIER, DETECTOR: A device that is capable of intensifying the electrical energy produced by a sensor. A loop detector unit is commonly called an amplifier even though its electronic function is actually different.

ANALOG: An electronic design that uses continuously variable quantities such as voltages, rather than numbers.

AREA DETECTION: The continuous detection of vehicles over a length of roadway wherein the call is intended to be held as long as there is a vehicle in the detection area.

AUXILIARY EQUIPMENT: Separate devices used to add supplementary features to a controller assembly.

CALL: A registration of a demand for right-of-way by traffic at a controller unit. The call comes to the controller from a detector unit that is outputting an actuation.

CHANNEL: Electronic circuitry which functions as a loop detector unit.

CONTINUOUS PRESENCE MODE: Detector output continues if a vehicle remains in the field of influence of the detector.

CONTROLLER ASSEMBLY: A complete electrical mechanism mounted in a cabinet for controlling the operation of a traffic control signal.

CONTROLLER UNIT: The part of the controller assembly which performs the basic timing and logic functions.

CYCLE: A complete sequence of signal indications for all approaches for which there is a demand or call by traffic.

DELAYED CALL DETECTOR: A detector that does not issue an output until the detection zone has been occupied for a period of time that has been set on the detector unit.

DELAYED OUTPUT: The ability of a detector to delay its output for a predetermined length of time.

DETECTOR: A device for indicating the presence or passage of vehicles, bicycles or pedestrians.

DETECTOR AMPLIFIER: See AMPLIFIER, DETECTOR.

DETECTOR MODE: A term used to describe the duration and conditions of the occurrence of a detection output.
a. Pulse Mode
b. Presence Mode

DETECTOR SYSTEM: The complete sensing and indicating group consisting of the detector unit, transmission lines and sensor.

DETECTOR SETBACK: Longitudinal distance between the stop line and the detector.

DETECTOR UNIT: The portion of a detector system other than the sensor and lead-in, consisting of an electronics assembly.

EDDY CURRENT: An electric current induced within the body of a conductor when it moves through a nonuniform magnetic field.

EXTENDED CALL DETECTOR: A detector with carryover output. It holds the call of a vehicle for a period of time that has been set on the detector unit.

EXTENSION TIME: Extra time resulting from detector actuations to allow safe passage of vehicles through an intersection.

INDUCTANCE: That property of an electric circuit or of two (2) neighboring circuits whereby an electromotive force is generated in one circuit by a change of current in itself or in the other. The ratio of the electromotive force to the rate of change of the circuit.

KHz: Kilohertz, or thousands of hertz. Hertz means "cycles per second", a measurement of frequency.

L: The change in inductance.

LEAD-IN CABLE: The electrical cable which serves to connect the loop to the detector unit.

LOOP DETECTOR: A detector that senses a change in inductance of its inductive loop sensor caused by the passage or presence of a vehicle near the sensor.

MAGNETIC DETECTOR: A detector that senses changes in the earth's magnetic field caused by the movement of a vehicle near its sensor unit.

MAGNETOMETER: A detector that measures the difference in the level of the earth's magnetic forces caused by the passage or presence of a vehicle near its sensor.

MEGGER: A device used to measure very high resistance to earth ground.

MEGOHM: One (1) million ohms, which is the unit of measure of electrical resistance.

MICROHENRY: One (1) millionth of a henry, from the unit of measure of inductance.

MINIMUM GREEN INTERVAL: The shortest green time allowed for an interval. The controller will not display a green interval less than the minimum time set.

NANOHENRY: One (1) billionth of a henry, from the unit of measure of inductance.

OHM: The unit of electrical resistance equal to the resistance through which a current of one (1) ampere will flow when there is a potential difference of one (1) volt across it.

PEDESTRIAN DETECTOR: A detector, usually a push button, that is responsive to operation by or the presence of a pedestrian.

PEDESTRIAN PHASE: A traffic phase allocated to pedestrian traffic either concurrently with a vehicle phase or exclusive of other phases.

PHASE: A part of the cycle allocated to any traffic movements receiving the right-of-way.

PHASE SEQUENCE: A predetermined order in which the phases of a cycle occur.

POINT DETECTION: The detection of vehicles as they pass a specific point on the roadway, also referred to as small area detection.

PRESENCE LOOP DETECTOR: An induction loop detector which is capable of detecting the presence of standing or moving vehicles within the effective area.

PROBE: The sensor form that is commonly used with a magnetometer type detector unit.

PULSE MODE: Detector output is a short pulse of approximately 100ms even when the vehicle remains in the effective area for a longer period of time.

QUADRUPOLE: A loop configuration that is essentially two (2) loops with a common side. The wires are wound continuously in a figure eight (8) pattern so that current flow in the common side is in the same direction. The design improves sensitivity to small vehicles and reduces adjacent lane detection.

RADAR DETECTOR: A vehicle detector activated by the passage of vehicles through its field of emitted microwave energy.

RADIO FREQUENCY DETECTOR: A vehicle detector consisting of a loop of wire imbedded in the roadway that is tuned to receive a preselected radio frequency from a transmitter located on a vehicle.

REJECTION (Adjacent Lane): The ability of a detector to not detect vehicles in an adjacent lane.

SCANNING DETECTOR: A multichannel detector in which the loop(s) of each channel are energized in sequence, one at a time, in quick succession.

SENSITIVITY: The setting on the detector unit that determines the amount of inductance shift required to actuate the detector. High sensitivities require low inductance shifts.

SENSOR UNIT: An electrical conductor ("loop") in the roadway designed such that the presence or passage of a vehicle causes a decrease in the inductance of the loop.

SONIC DETECTOR: A vehicle detector which emits high frequency sound energy and senses the reflection of that energy from a vehicle in its field.

SOUND SENSITIVE DETECTOR: See Adler's horn.

THRESHOLDING: A minimum level of change in inductance which occurs to produce an actuation.

ULTRASONIC DETECTOR: A detector that senses the presence or passage of vehicles through its field of emitted ultrasonic energy.

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