Re-Evaluating Traffic Signal Detector Loops

by Alan Wachtel

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"Evaluating Traffic Signal Detector Loops," by Don Wood (Bicycle Forum #45),[1] is a welcome addition to a fairly small body of literature. As the article demonstrates, Santa Clara County, California, where Wood works, and where I've lived for almost 30 years, takes a progressive attitude toward serving bicyclists at traffic signals. In 1981, the County Board of Supervisors adopted a policy that:

1. *All future signal installations be bicycle sensitive.*
2. *Loop detectors be identified where (a) the outline of the loop is not identifiable on the surface of the roadway, or (b) where it is unclear which of the identifiable loops will activate the signal.*
3. *When signal equipment is being replaced, the replacement unit be bicycle-sensitive.*

The round and diamond loops that Wood recommends seem, for the most part, to detect bicycles well. Nonetheless, as Wood acknowledges, the tests were neither extremely detailed nor exhaustive, and I think there is reason to be cautious about the results.

A note to Wood's article reports that original data from the tests is no longer available. Fortunately, a memo including this data was circulated in 1991 to the City of Palo Alto and its Bicycle Advisory Committee, and I have a copy in my files. In this article, I'll take another look at it.

Loop Types

The California Department of Transportation (Caltrans) uses the following designations (except S) for loop types (see Figure 1):

- A *A 6-ft (1.8-m) square with corner crosscuts.*
- S *Square. Similar to A, but with rectangular corners.*
- B *Diamond. Similar to S, but 4 in. (0.1m) smaller, and rotated through 45°.*
- E *Round. A 6-ft (1.8-m) circle.*
- D *Diagonal. Similar to A, but with three or four parallel diagonal windings in the interior. Some corners of the square may be missing.*

A number indicates the number of turns in the loop. For instance, E3 means a three-turn round loop.

Types A, S, B, and E all produce dipole fields: that is, the magnetic field lines, which form circles around the wires, add in the center to resemble a permanent magnet held vertically. Type D is basically a rotated quadrupole, which consists of two dipoles side by side, of opposite polarity. Close to the quadrupole, magnetic field lines travel horizontally from the north pole of one dipole to the south pole of the other; farther away, the two dipoles tend to cancel each other out.

The tests did not include Type Q (figure-eight) quadrupole loops, which are known to detect bicycles over most of their interior.[2] Wood reports only that the county's experience with an array including a Type Q loop at the head "was not particularly successful."

As a rule, bicycles can be expected to travel in the same lanes as other traffic. The ideal loop would:

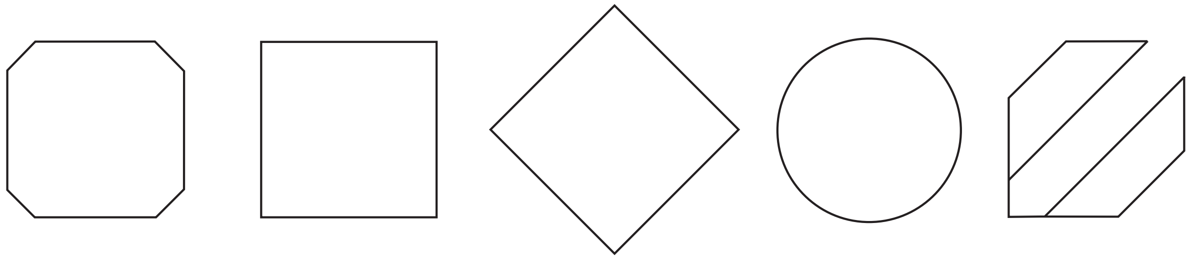
- *Detect bicycles, mopeds, and motorcycles, which not only contain comparatively less metal than cars, but are narrow and vertical. To detect these vehicles, the magnetic field needs a left-right component that cuts through the plane of the bicycle.*
- *Detect four-wheel vehicles. Their size and mass normally make this easy to do, but high-body trucks and sport-utility vehicles are best detected by a vertical magnetic field.*
- *Ignore traffic in adjacent lanes. Doing this requires confining the field as much as possible within a single lane.*
- *Be easy to install, and minimize pavement damage.*

Although one way to reconcile these conflicting demands is to install two independent loops in the same lane, one for bicycles and one for motor vehicles[3], most agencies are likely to prefer one all-purpose loop they can use everywhere.

The Tests

Table 1 presents, in condensed and modified form, the results of the bicycle tests conducted by Wood, along with Tony Rucker and Stuart Leven. Where a combination of connected loops was tested, the head loop (closest to the intersection) appears first, and the tested loop (in this test always the head loop) is in italics.

The presence of a metal object near a loop causes a minuscule change in its inductance (L). In the bicycle test, a bicycle was rolled through each loop at three different positions: at the center, at the left edge, and halfway in between. Table 1 shows the measured fractional change in inductance ($\Delta L/L$) in parts per 100,000 (ppht).[4] For each test, the greatest deviation is shown in bold.



Type A **Type S** **Type B** **Type E** **Type D**

Figure 1. Loops Tested by Santa Clara County

Table 2 shows tests on a metal object (described in the memo as a metal platform) at various heights, intended to simulate a high-body vehicle. The platform was raised until it could no longer be detected by a standard vehicle detector. All loops were tested as part of combinations, and the middle loop as well as the head loop was tested. Although the height at which detection was lost is shown as a decimal, actual measurements were in feet and inches.

General Loop Characteristics

As expected, increasing the number of turns in a loop produces a greater response (except for a minor anomaly in loss height for the B3 loop, which Wood reports exhibited frequency instability during the test). When comparing loops, it is important to allow for the number of turns.

Table 1 shows that area detection (placing loops in a series combination), which is the typical application, substantially reduces the response of the head loop to bicycles.[5] This, too, should be taken into account in comparisons. The response of the trailing loops for metal object detection is not significantly affected by the type of loop at the head.

Bicycle Detection

The four dipole loops (Type A, square, diamond, and round) are roughly similar in shape, and all are responsive to bicycles on their outside edges, either alone or in combination with two A3 loops.[6] The conventional Type A loop is most responsive, since the bicycle lies directly above the wire, and the lines of magnetic force cut directly through the plane of the bicycle.

The square loop is not quite as responsive as Type A. The round loop is a little less responsive still, and needs four turns to be nearly as good on the edge as a three-turn square loop. Diamond loops, even with five turns, are much less responsive at the edge than the other dipole loops, and this isn't surprising, since the wires are farther away from the bicycle.

Diamond and round loops also respond well to bicycles halfway between the center and the edge. The diamond loop, in fact, is most responsive at this point.

All dipole loops are very unresponsive at the center: not only is this point farthest from the edges, but the magnetic field there tends to lie in the plane of the bicycle.

As expected, the diagonal loop, whose quadrupole magnetic field has a significant horizontal component,

TABLE 2. METAL OBJECT TESTS

Loop Type	*Combination*	*ΔL/L (Parts per 100,000)* 0 ft	1 ft	2 ft	3 ft	*Loss (ft)*
Type A	*A3* A3 A3	974	557	214	92	6.67
	A3 *A3* A3	624	300	122	43	3.42
Square	*S3* A3 A3	583	323	127	40	4.00
	S3 *A3* A3	715	363	144	57	5.08
Diamond	*B5* A3 A3	1292	666	261	98	4.50
	B5 *A3* A3	528	267	124	52	6.25
	B3 A3 A3	672	345	131	53	5.42
	B3 *A3* A3	680	363	138	58	5.50
Round	*E4* A3 A3	1188	556	189	53	5.00
	E4 *A3* A3	632	325	148	65	5.92
	E3 A3 A3	767	353	129	45	4.83
	E3 *A3* A3	750	364	157	56	5.33
Diagonal	*D5* A3 A3	1475	239	33	—	2.17
	D5 *A3* A3	505	259	113	53	4.58
	D3 A3 A3	891	125	53	—	2.08

Italics = tested loop

TABLE 1. BICYCLE SENSITIVITY TESTS

Loop Type	*Combination*	*ΔL/L (Parts per 100,000)* Center	Halfway	Edge
Type A	*A3*	18	87	**411**
	A3 A3 A3	12	31	**147**
Square	*S3*	12	61	**311**
	S3 A3 A3	12	35	**156**
Diamond	*B5*	21	**279**	155
	B5 A3 A3	13	**137**	91
	B3	12	**145**	105
	B3 A3 A3	6	**69**	52
Round	*E4*	30	202	**275**
	E4 A3 A3	12	71	**124**
	E3	19	121	**211**
	E3 A3 A3	17	62	**90**
Diagonal	*D5*	**155**	75	91
	D5 A3 A3	**93**	60	40
	D3	**115**	55	30

Italics = tested loop
Light shading = detection expected at high sensitivity
Darker shading = detection expected at medium sensitivity
Bold = most responsive part of loop

provides good, fairly uniform response to bicycles across most of its area.

Metal Object Detection

Every combination tested detected the metal object up to 2 ft. The diagonal loop fails beyond that point, because its field tends to be horizontal. The square loop was good up to 4 ft; all other head loops (Type A, diamond, and round) and all middle A3 loops were good to 4.5 ft or better, except for the middle Type A in an array of three. A detection distance of 4 ft seems ample, especially considering that the metal test platform must have been much less massive than a typical truck body, and that a truck's wheels, axle, and cab are usually closer to the pavement than 4 ft.

The three-turn Type A, square, round, and diamond configurations all perform in a very similar way, with the Type A head loop a little more responsive than the others. The variation in shape seems to be unimportant when all or most of the loop area is covered by the metal platform.

Comparing Loops

All loops tested are capable of detecting bicycles, but the diagonal loop fails to detect high-body vehicles. The Type Q quadrupole, which was not tested, would probably resemble the diagonal loop. Of the remaining four, Wood favors the round and diamond loops because "they have excellent sensitivity, a very good detection pattern, including the detection height and bicycle sensitivity," and are least likely to cause pavement damage. But Wood's evaluation raises several pertinent questions.

To interpret the test data in practical terms, we need to know whether a given inductance shift triggers the detector unit to send a call for green to the signal controller. The threshold for this detection depends on the detector's sensitivity setting. At values well below the threshold, no detection occurs; well above it, detection is reliable, and greater deviation provides no additional benefit. Near the threshold, detection is erratic.

The metal platform test noted the loss of detection, and the data in Table 2 suggest a threshold inductance shift of about 20 ppht (0.020 percent); the exact value is not critical. For common detector units, this corresponds to a relatively high sensitivity setting, though not the highest.[7] Values in Table 1 that exceed this high-sensitivity threshold are shaded. At this sensitivity, all dipole loops, alone or in combination, can reliably detect bicycles at the edge and halfway to the center.

But there is another factor to consider, which Wood's tests did not measure—false detections in the adjacent lane (also called spillover or splashover). High detector sensitivity makes it easier to detect bicycles (and high-body vehicles), but increases spillover. Conversely, lowering the sensitivity to reduce spillover may compromise bicycle (and high-body) detection.

The diagonal loop would be expected to perform well on adjacent-lane rejection, because its quadrupole field is concentrated in the interior of the loop and weakest at the edge. Wood suggests that the round and diamond loops should also do well, because their edges are relatively distant from adjacent lanes, but no actual measurements were performed.[8]

As a rough approximation, an automobile in the adjacent lane produces an inductance shift of 60 ppht.[9] Allowing for larger vehicles and a margin of error, to avoid spillover the detector should be set to a threshold of about 90 ppht (0.090 percent), a value that corresponds to a medium sensitivity setting.[10] Entries in Table 1 that exceed 90 ppht are shown with darker shading.

At this sensitivity setting, E3 (round) and B3 (diamond) combination loops become inadequate for bicycle detection, no matter where the bicycle is. High-body detection is also lost somewhere between 2 and 3 ft. S3 (square), A3, B5 (diamond), and E4 (round) combinations, in decreasing order of responsiveness, should still be able to detect bicycles in the most favorable location (near the edge for Type A, square, and round, halfway between center and edge for diamond). These combinations also provide high-body detection to 4 ft or higher. This performance seems to make them the best all-purpose choices among loop combinations, but for round and diamond loops the number of turns is critical.

The Type A loop responds at least twice as strongly to bicycles over its edge as it does to adjacent-lane traffic. This is fortunate—it means it should usually be possible to adjust existing Type A installations to detect bicycles, without incurring adjacent-lane interference.

If round and diamond loops are really better at preventing spillover than Type A, their detection threshold might be reduced from 90 ppht, improving bicycle and high-body performance for these loops. Bear in mind, though, that detector sensitivity settings are coarsely spaced, often jumping by a factor of two between adjacent levels. Fine tuning may not be possible, and efficient detection may be as much a function of the match between loop and detector as of either one independently.

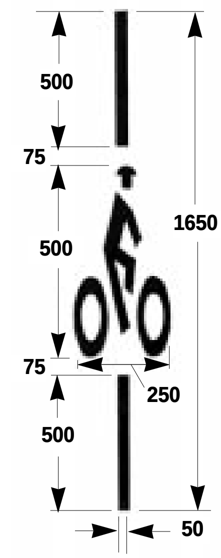


Figure 2. Caltrans Bicycle Loop Detector Symbol

Because loop inductance, response to various objects, susceptibility to spillover, and detector threshold levels vary, it is impossible to specify detector settings in advance. Bob Shanteau, a consultant in Seaside, California, recommends setting the detector sensitivity to the highest level that does not detect a panel truck in the adjacent lane. This adjustment has to be made in the field.

Marking the Loops

Even when a loop has enough turns and detector sensitivity is set correctly, bicyclists can call the signal only if they can find the right spot on the loop. Loops can be difficult to locate if they have been paved over or there are multiple pavement cuts, and any cut is hard to see at night. Besides, most bicyclists, like most motorists, don't know how loops work. The responsive area needs to be marked with paint or tape.

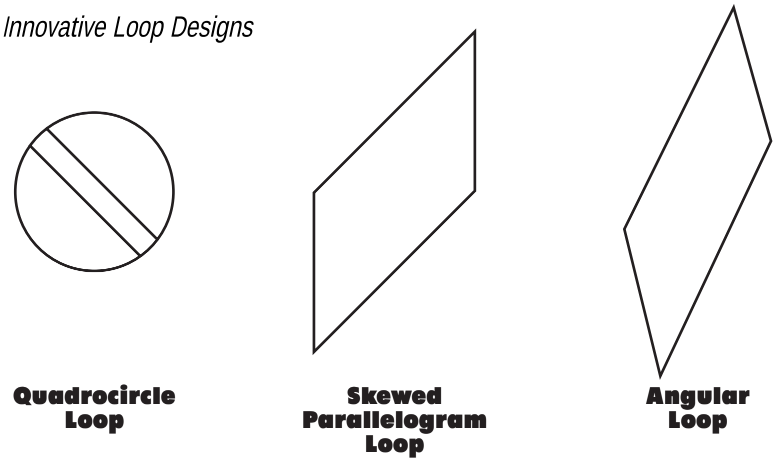
Since Santa Clara County's policy already includes this provision, Wood may have felt it unnecessary to mention it. Other agencies considering loop installation or adjustment should be sure to include this step. The State of California has approved a standardized marking for this purpose, shown in Figure 2. This marking has also been used in Missoula, Montana[11]; stencils and precut markings are available commercially. Workers applying the marking can help further by verifying, by means of a test bicycle, that the loop detects bicycles in the marked location.

New Ideas

The loop configurations that Wood tested (plus the Type Q quadrupole) are not the only ones possible. The innovative loops shown in Figure 3 combine the following ideas (which are also present in the bicycle-responsive diagonal loop):

- *They incorporate windings that are oblique to traffic, so the bicycle cuts across magnetic field lines almost no matter where it stops.*
- *They concentrate the field within the lane, through either the winding pattern or physical compression of the loop shape. This concentration increases field strength for same-lane detection and minimizes spillover, enabling the use of higher detector sensitivities.*

Figure 3. Innovative Loop Designs



Ashok Aggarwal, traffic engineer for the City of Palo Alto, designed a circular loop with a diagonal cut (or "spoke") in the middle, wound in a figure eight pattern.[12] The spoke fills in the dead spot at the center of the circle, where the magnetic field is weakest. Palo Alto's experience indicates that three-turn head loops detect bicyclists better than both Type A and Type Q loops, and as well as diagonal loops. Although these loops have a quadrupole winding, Aggarwal reports no problems detecting high-body vehicles. For Aggarwal's informal measurements of field strength and direction for various loop shapes, made with a frequency meter, see Figure 4.

Hamm and Woods found that a 6-ft parallelogram, with two sides skewed at 45 degrees to the direction of travel, could detect passenger vehicles, high-profile trucks, bicycles, mopeds, and motorcycles accurately on both medium and high sensitivity settings.[13] Bicycles were detected throughout the entire loop area, including 1 ft on either side.

Duemmel found that a parallelogram whose long axis was rotated 9 degrees from the direction of travel detected all vehicles, including high-bed trucks and bicycles, on the medium sensitivity setting.[14] The medium setting is highly desirable, because it minimizes both spillover to the adjacent lane and detection time needed by older detectors.

The acute angles in these parallelograms may increase the risk of pavement damage and loop failure. But since Duemmel found these spots to be unresponsive for bicycle detection anyway (the opposing currents nearly cancel each other), damage could be minimized by crosscutting or coring the corners. The spoked circle incorporates no angle greater than 90 degrees.

Until newer technologies like wireless magnetometers and radar, infrared, ultrasound, and video detection become widely adopted—and have been evaluated for their ability to detect bicycles—these innovative designs, for those willing to try something new, may offer the best of all possible worlds.

Acknowledgments

I thank Gordon Renkes of Ohio State University for referring me to the papers by Hamm and Woods and by Duemmel; Ashok Aggarwal of the City of Palo Alto for permission to cite his experience

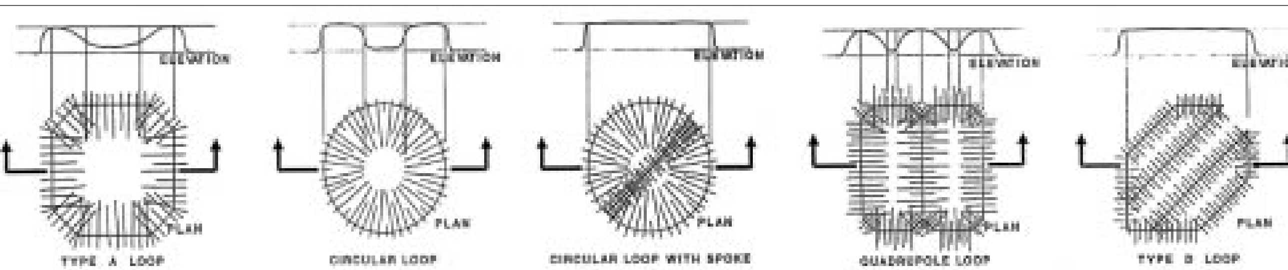


Figure 4. Magnetic Field Strength and Direction for Various Loops

with spoked circle loops and to reproduce his field measurements; George Palm of 3M Canoga for extensive technical information about the properties of 3M Canoga detectors, inductance values of loop configurations, and the shift produced by different vehicles; and Bob Shanteau for copies of relevant portions of the NEMA TS-1 standard, specifications for detector sensitivity settings, and much other technical information.

Notes

1. Don Wood, "Evaluating Traffic Signal Detector Loops," Bicycle Forum 45 (June 24, 1997), 4-5.
2. Glenn Grigg, "Cupertino Tests Its Detector Loops," Bicycle Forum 10 (Summer 1983), 12–13.
3. The City of Missoula, Montana, has done this. See Pamela J. Maki and Peter S. Marshall, "Accommodating Bicycles at Signalized Intersections with Loop Detectors: A Case Study and Example," Compendium of Technical Papers for the 67th ITE Annual Meeting, 1997 (CD-ROM).
4. Wood's equipment measured the shift in resonant frequency of an oscillator. I've converted his frequency shift values, which he reported in the customary percent, to fractional inductance changes (twice the fractional frequency change), and expressed them in parts per 100,000 to allow the use of whole numbers.
5. The greater inductance of the combination makes changes harder to discriminate. Grigg (note 2) remarks, "Higher sensitivity adjustments on the amplifier are required as more loops are added to a combination." The same effect occurs with a long lead-in wire.
6. To help distinguish two different concepts, I will refer to the responsiveness of the loop (the size of the signal generated by the wire buried in the pavement) and to the sensitivity of the detector (the detection threshold of the electronics in the cabinet).
7. For instance, setting 6 (the fourth most sensitive of 10 settings) on a Detector Systems Model 910 detects an inductance change of 20 ppht. Setting 5 on an ICC Series 3DLD (the third most sensitive of eight settings) detects 22 ppht.

   3M Canoga detectors measure ΔL directly rather than $\Delta L/L$. For a three-turn loop with an inductance of 70 μH, the second most sensitive of eight settings, 16 nH, corresponds to a $\Delta L/L$ of 23 ppht.

   Graphs presented by Robert A. Hamm and Donald L. Woods, "Loop Detectors: Results of Controlled Field Studies," ITE Journal, Nov. 1992, 12-16, show high sensitivity for several detectors ranging from 15 to 30 ppht.

   For comparison, the NEMA TS-1 standard for inductive loop detectors represents a small motorcycle as a deviation of 130 ppht, a large motorcycle as 320, and a passenger car as 3200.
8. Contrary to what Wood says, the round loop should be superior, because it can be inscribed inside the diamond loop, and also requires fewer turns for comparable detection.
9. This represents an inductance change of 40 nH in a 70-μH Type A loop. Round and diamond loops might perform somewhat better.
10. Setting 4 on a Detector Systems Model 910 corresponds to 80, setting 2 on an ICC Series 3DLD to 87, and the 64-nH setting on a 3M Canoga detector to 91. Hamm and Woods show medium sensitivity on their detectors ranging from about 80 to 100.
11. See Maki and Marshall (note 3).
12. Grigg presents details of Cupertino's adaptation of Aggarwal's design, which he calls Type QC, in Bicycle Forum 33 (August 1993), 15.
13. See Hamm and Woods (note 7).
14. Robert Duemmel, "Angular Design Detection," International Municipal Signal Association Journal, July-August 1991.

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continued from page 3

Commuter choices

■ On April 21st, President Clinton signed an Executive Order requiring federal agencies to implement "commuter choice" programs in order to reduce traffic congestion and air pollution and to improve commuting alternatives. By October 1st, Federal agencies will encourage employees to use mass transportation and van pools through tax-free transit benefits and non-monetary incentives.

Federal agencies in the National Capital Region will also implement a "transit pass" program equal to their commuting costs. In addition, the Department of Transportation, the Environmental Protection Agency, and the Department of Energy will participate in a 3 year "transit pass" pilot program in the Washington, DC region.

A study of the impacts on single occupancy vehicle travel and regional traffic congestion will be done before determining whether the 3 year program should be extended to other Federal employees nationwide.

Although public agencies and private businesses have had similar commuter choice options for several years, the Executive Order is anticipated to help many more employees take advantage of the program and pay for their commuting costs with pretax dollars.

Source: 4/25/00 Transfer

From the Surface Transportation Policy Project's e-mail newsletter, Transfer . To subscribe, e-mail: transfer@transact.org. Include your mailing address, organization name, phone and fax numbers. Web: www.transact.org Phone: (202) 466.2636

CT right turn law

■ The Connecticut Bicycle Coalition reports their "right turn" bill passed the House and Senate, waiting only the governor's signature. Here's the text:

"No person operating a vehicle who overtakes and passes a person riding a bicycle and proceeding in the same direction shall make a right turn at any intersection or into any private road or driveway unless the turn can be made with reasonable safety and will not impede the travel of the person riding the bicycle."

The Coalition lists some instructive things that happened during the process:

1 As always, the blessed "steal this book" philosophy/wealth of our Thunderhead Alliance Network. Thanks Bicycle Colorado for providing the launchpad text that got CT's wheel rolling.

2 Elimination of any specified distance as safe, eg. 100 or 150 feet.

3 Cyclists are truly everywhere. We even appear as 6 House Republicans who stood up to amend the bill on the floor with "and shall not impede the travel of the cyclist."

4 The point of the legislation is EDUCATION. We can roll this into our DMV "Sharing the road with Bicycles" chapter; doing presentations for Police Departments and Drivers Ed teachers; and it can be rolled into EC Instruction

5 In the event of a crash of this nature, the offense is punishable by fine and can be used in court to support the cyclist's legitimate standing and demanded remedies

Source: CT Bike Coalition

For more information, contact the Coalition via email at: <CTBIKECOAL@aol.com>