Radar Technology for Distinguishing Between Bicycles and Cars

California Department of Transportation

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Radar Technology to Distinguish Bike/Car

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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Radar Technology to Distinguish Bike/Car

The Issue: Caltrans must provide minimum bicycle timing (per CA MUTCD 4D-109 (CA)).

- If no detection exists, the **required additional bicycle timing** may impede traffic flows if there are no bicycles present. → *Inefficient* (resulting in increased vehicle delays, greenhouse gas emissions, fuel costs, etc.)
- Type D inductive loop detectors can detect bicycles but can't distinguish between bicycles and cars/trucks. Therefore, there still may be too much green time when not needed → *Inefficient*
- The ability to ***distinguish between bicycles and cars/trucks*** enables more efficient traffic signal timing so that the minimum bicycle timing is provided *ONLY IF* a bicycle is present. → *More efficient*

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Table 4D-109(CA) Signal Operations - Minimum Bicycle Timing (English Units)

$G_{min} + Y + R_{clear} \geq 6$ sec + (w+6 ft)/14.7 ft/sec, where
G_{min} = Length of minimum green interval (sec)
Y = Length of yellow interval (sec)
R_{clear} = Length of red clearance interval (sec)
W = Distance from limit line to far side of last conflicting lane (ft)

Distance from limit line to far side of last conflicting lane	Minimum phase length (minimum green plus yellow plus red clearance)
Feet	**Seconds**
40	9.1
50	9.8
60	10.5
70	11.2
80	11.9
90	12.5
100	13.2
110	13.9
120	14.6
130	15.3
140	15.9
150	16.6
160	17.3
170	18.0
180	18.7

California MUTCD

(Manual for Uniform Traffic Control Devices)

Radar Technology to Distinguish Bike/Car

Limitations of Type D loop detector for Bicycle Detection:

- Can't distinguish between cars and bikes
- *False calls* (FP) due to "splash-over" from adjacent lane (bus) when bus or right-turning car crosses into a bike lane

Limitations of any Inductive Loop Detector for Detection:

- In-pavement, requires lane closures
  → impedes traffic, increases delay
- In-pavement, wears with the roadway deterioration
- More risk (exposure to traffic) to Maintenance staff
- Inability to directly measure vehicle speeds

Radar Technology to Distinguish Bike/Car

Currently Caltrans requires limit line detection to be replaced with Type D inductive loop detectors *if at least 50%* of an intersection is being modified. Although this complies with the law (CVC* 21450.5), it does not aid in efficient signal timing.

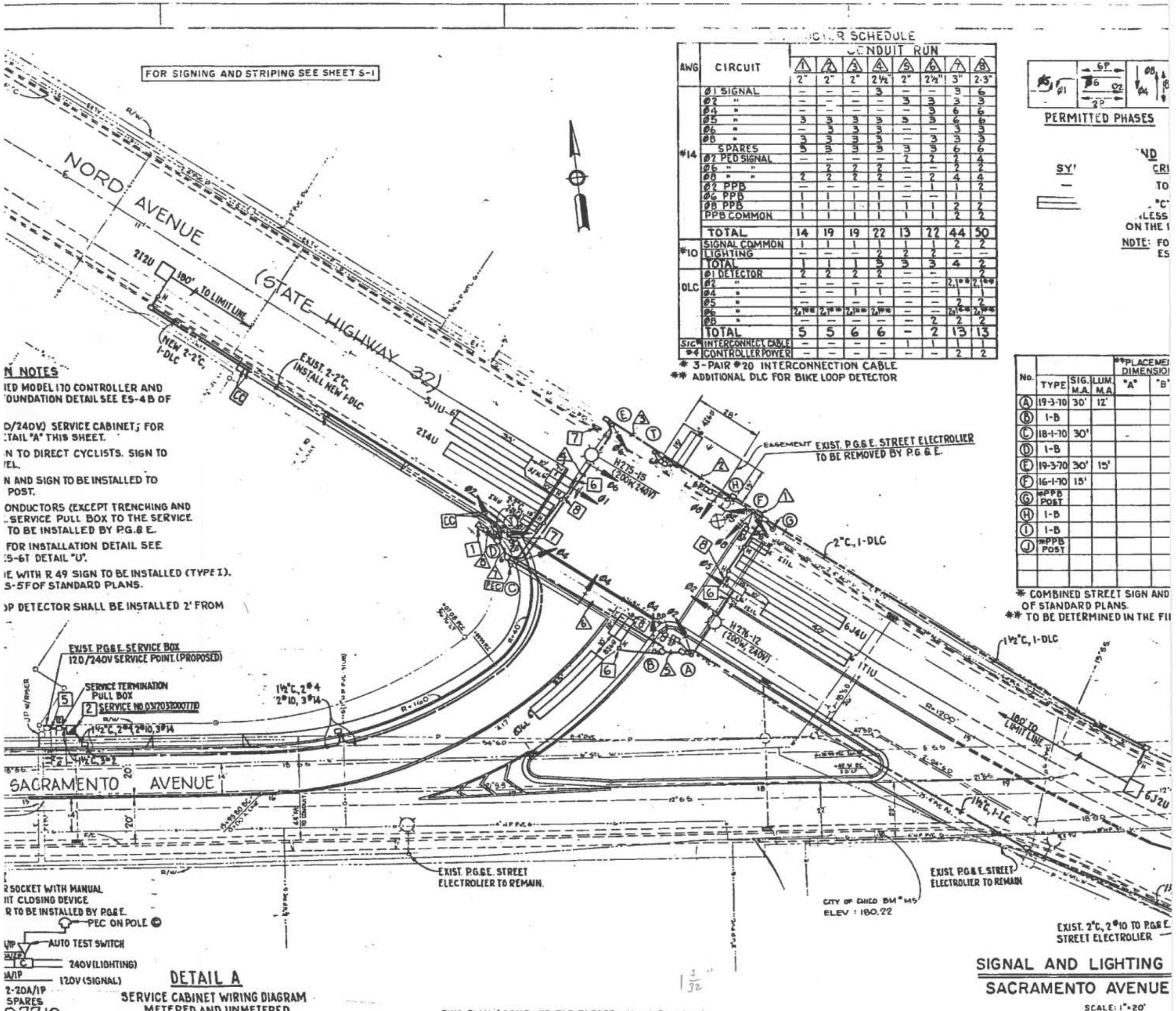
Caltrans began to evaluate the MS Sedco Intersector radar detector in 2012.
The study resulted in 3 phases:

1. Comparison with Inductive Loop Detector Data in city of Chico over several months. Statistical analysis done to document accuracy.
2. Installed in city of West Sacramento, to run a signalized intersection using radar detectors exclusively (disconnected loops) for a few hours.
3. Permanently installed in city of Huntington Beach to actuate a signalized intersection where there are bicycles known for violating red traffic signal.

*CVC: California Vehicle Code

Caltrans Chico Bike Detection Test Location

(see poster for better view)



Chico, California, approx. ~1mile from Chico State University

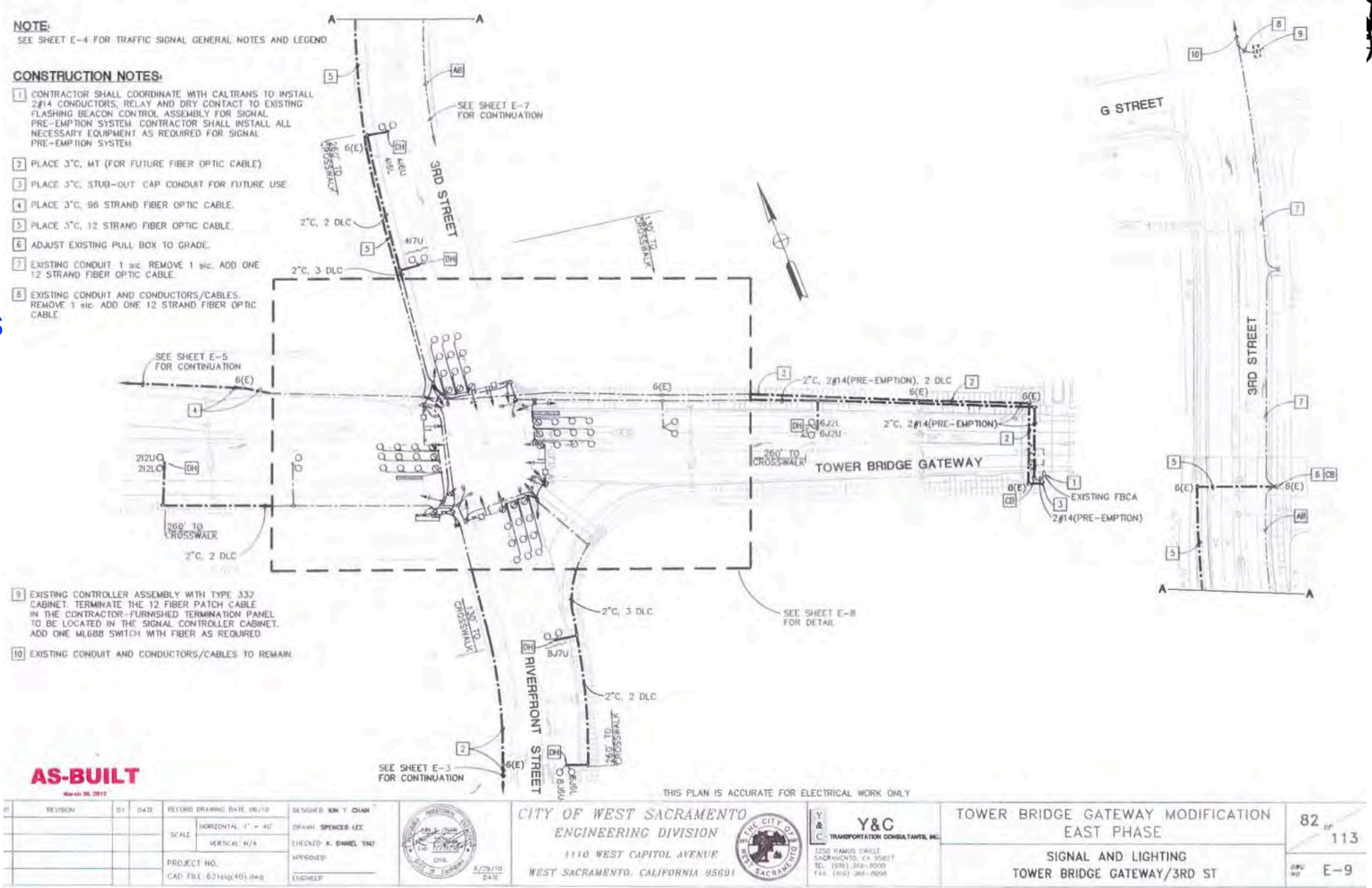
Intersector radar units installed on the NB traffic signal mast arm (at 18'), and SB traffic signal pole shaft (at 16'6").

Video cameras also installed.

Caltrans West Sacramento Bike Detection Test Location

Location ~1 mile from State Capitol. High bike commuters from city of Davis.

(see poster for better view)



Radar Technology to Distinguish Bike/Car

The Radar Technology (MS Sedco Intersector)

Weight: 5 lbs
Size: 11" x 8.5" x 7" (L x W x H)
Detection range: 50' min – 425' max (latest version 600')
Frequency: 24.75GHz 4 outputs (8 zones max)

Cost: < $5K each (~$19K for 4-leg intersection)

- >42 States currently using INTERSECTOR
- Almost 3,000 units deployed in USA, >300 in California (~50% use for bicycles)
- Not affected by weather, nor sun glare

TC-CK1-SBE
Motion and Presence Sensor

Note: Average cost of Inductive Loop Detector System for 4-approach, 2-lane highway (+ 1 left-turn lane) is >$60K. (per District 3)
Cost of installing off-pavement detection (such as radar) is ~$34K.

Radar Technology to Distinguish Bike/Car

Definition of Successful Bike Detection

- Although detection must be for just a 6’x6’ zone, we have chosen to make radar detection zone width of bike lane *and* thru-lanes and varying depth (to 105’ from the stopbar/limit line).
- Successful bike detection is during a red interval (bike waiting for green interval) so that additional green (minimum bicycle timing) may be given for bikes;

→ *Missing a bike during a green interval is NOT an issue.*

CONSENSUS FROM BICYCLE COMMUNITY

Criteria for Bike Detection: **Any cyclist crossing bike zone during** Red **or** Yellow **interval, slowing down** (<5 mph, intent is to stop), ***we want to detect***

If cyclist turns Right, cyclist does not plan to stop; doesn’t slow down much

→ *Don’t serve*

Location for Cyclist Detection: Bike lanes, as well as *Through-lanes and Left-turn lanes*

Radar Technology to Distinguish Bike/Car

Chico Results Summary

All data (Loop detector and Radar) recorded using the LOG170 software using a Model 170 Controller. *(big, cumbersome)*

Detection data (loop & radar) and video recorded:

December 2012 (2 weeks; 7 one-hour blocks analyzed in great detail),
April 2013 (3 weeks; 5 one-hour blocks analyzed)
May 2013 (1 week; a one-hour block analyzed)
June 2013 (1 week; 2 one-hour blocks analyzed).

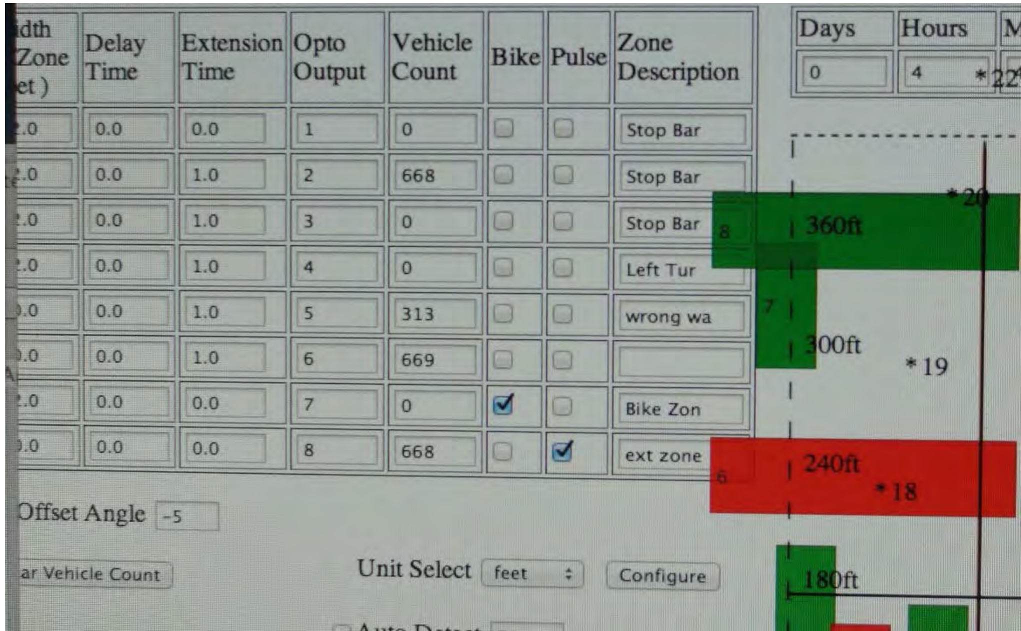
Analyzed hours of data chosen based on bike volumes or Time of Day.

Highest hourly bike volume: ~30.

Based on conservative "ground truth" values of vehicle volumes

Vehicle Presence Detection ~99-100% accurate.

Bicycle presence detection ~95-97% accurate.



Radar Technology to Distinguish Bike/Car

West Sacramento Results Summary

All data (Loop detector and Radar) initially recorded using the LOG170 software using a Model 170 Controller. Data later recorded using the **C1 Reader** (much smaller) that can record ALL data (inputs/outputs).

Detection data (loop & radar) and video recorded:

February 2015 (1 three-hour block analyzed in great detail),
March 2015 (3 three-hour block analyzed)
June 2015 (1 two-hour block analyzed analyzed).
September 2015 (1 hour block analyzed analyzed).

Analyzed hours of data chosen based on *Bike Volumes* or *Time of Day*.

Average hourly bike volume: ~16-28.

Mounting Height = 16'

Based on conservative "ground truth" values of vehicle volumes

Bicycle presence detection 87-100% accurate.

Results: 90-100% in the EB/WB direction, and 86-100% in the NB/SB direction.

Therefore, error (bikes missed during Red): 0-14% (0-10% in EB/WB and 0-14% in NB/SB)

Time Savings: Assuming no congestion or bikes & no demand in left-turn: ~20% (4.8sec/cycle) → 11.5min/hour

(if green time extended for bikes, every time those phases are served)

Radar Technology to Distinguish Bike/Car

West Sacramento Results

Some bicyclists may exceed top speed threshold of radar definition for bicyclist (30km/hr = 18.6 mph) December 2014 data indicated several high-speed bicyclists that were “missed” by the radar but detected as *CARS*.

→→ *Misclassified bicyclists as cars.* These cyclists may not need the additional bike green time.

Manufacturer was contacted regarding a *user-settable threshold* (>18.6mph) so that these fast cyclists may be properly detected as bikes. Manufacturer agreed to modify radar unit with threshold set to 21 mph (if desired).

Some bicyclists are initially detected but then “lost” (dropped) because rather than stopping at red traffic signal, bicyclist moves completely into crosswalk. A large percentage of cyclists continue to ride in circles, but are no longer in the “bike zone” or they run through the red signal.

*Need awareness that the law is *“to detect **lawful** bicycle or motorcycle traffic on the roadway.”*

Some bicycles detected but then occluded by large vehicles.
Further investigation of Occlusion Zone Protection (OZP and DBM).

Radar Technology to Distinguish Bike/Car

West Sacramento Radar and Inductive Loop Detection Study

** Treating bikes properly by the signal means detecting them during the Red phase and providing bike extended time.*

Tues. June 9 *NB* *(9am-10am)*	**Radar Bike Detections**	*Average Bike Vol per hour*	**Radar Missed Bikes during Red**	**Radar:** Missed Bikes during **Green**	**Total Bikes**	**Radar: FP during Red**	**Radar: FP during Green**	***Radar: % bikes detected***	***Radar ACCURACY*** *% bikes that would have been treated properly by the signal **	***Radar % bikes MISSED***	***Radar: ERROR % bikes MISSED during RED***	**FP% during RED**
NB Thru	60	*60*	1	1	62	13	8	96.8%	**98.4%**	3.2%	1.6%	61.9%
NB Left-Turn	30	*30*	0	0	30	3	0	100.0%	**100.0%**	0.0%	0.0%	100.0%

Tues. June 9 *SB* *(9am-10am)*	**Radar Bike Detections**	*Average Bike Vol per hour*	**Radar Missed Bikes during Red**	Radar: Missed Bikes during **Green**	**Total Bikes**	Radar: **FP during Red**	Radar: **FP during Green**	*Radar:* ***% bikes detected***	***Radar ACCURACY*** *% bikes that would have been treated properly by the signal **	***Radar % bikes MISSED***	***Radar ERROR % bikes MISSED during RED***	**FP% during RED**
SB Thru	55	*55*	1	1	*57*	10	10	96.5%	**98.2%**	3.5%	1.8%	50.0%
SB Left-Turn	0	*0*	11	1	*12*	0	0	0.0%	**0.0%**	**100.0%**	**100.0%**	0.0%

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West Sacramento Radar and Inductive Loop Detection Study

** Treating bikes properly by the signal means detecting them during the Red phase and providing bike extended time.*

DATE (EB & WB combined) Fri. FEB. 27	Radar Bike Detections	Average Bike Vol per hour	Radar Missed Bikes during Red	Radar: Missed Bikes during Green	Total Bikes	Radar: FP during Red	Radar: FP during Green	Radar: % bikes detected	Radar ACCURACY %bikes that would have been treated properly by the signal*	Radar % bikes MISSED	Radar: ERROR % bikes MISSED during RED	FP% during RED
WB 15:00	15	5	0	0	15	0	0	100.0%	100.0%	0.0%	0.0%	0.0%
EB 15:00	9	3.0	1	0	10	0	0	90.0%	90.0%	10.0%	10.0%	0.0%
WB 16:00	18	6	2	1	21	0	0	85.7%	90.0%	14.3%	10.0%	0.0%
EB 16:00	15	5	1	0	16	0	0	93.8%	93.8%	6.3%	6.3%	0.0%
WB 17:00	15	5	0	1	16	0	0	93.8%	100.0%	6.3%	0.0%	0.0%
EB 17:00	1	0.3333	0	0	1	0	0	100.0%	100.0%	0.0%	0.0%	0.0%

DATE (EB & WB combined) Fri. FEB. 27	LOOP Bike Detections	Average Bike Vol per hour	Loop Missed Bikes during Red	Loop: Missed Bikes during Green	Total Bikes	Loop: FP during Red	Loop: FP during Green	Loop: % bikes detected	Loop ACCURACY %bikes that would have been treated properly by the signal*	Loop % bikes MISSED	Loop ERROR % bikes MISSED during RED	FP% during RED
WB 15:00	13	4.3	2	0	15	0	1	86.7%	86.7%	13.3%	13.3%	0.0%
EB 15:00	9	3.0	1	0	10	0	0	90.0%	90.0%	10.0%	10.0%	0.0%
WB 16:00	19	6.3	0	2	21	0	0	90.5%	100.0%	9.5%	0.0%	0.0%
EB 16:00	13	4.3	1	2	16	0	0	81.3%	92.9%	18.8%	7.1%	0.0%
WB 17:00	15	5.0	0	1	16	0	0	93.8%	100.0%	6.3%	0.0%	0.0%
EB 17:00	1	0.3	0	0	1	0	0	100.0%	100.0%	0.0%	0.0%	0.0%

DATE (EB & WB combined 3pm-6pm)	Radar Bike Detections	Average Bike Vol per hour	Radar Missed Bikes during Red	Radar: Missed Bikes during Green	Total Bikes	Radar: FP during Red	Radar: FP during Green	Radar: % bikes detected	Radar ACCURACY %bikes that would have been treated properly by the signal*	Radar % bikes MISSED	Radar: ERROR % bikes MISSED during RED	FP% during RED
Fri. March 13	81	27	1	5	87	29	71	93.1%	98.8%	6.9%	1.2%	29.0%
Mon. March 16	85	28.3	1	8	97	9	39	87.6%	98.8%	9.3%	1.2%	18.8%
Tues. March 17	48	16	2	4	54	6	88	88.9%	96.0%	11.1%	4.0%	6.4%

West Sacramento Radar and Inductive Loop Detection Study

** Treating bikes properly by the signal means detecting them during the Red phase and providing bike extended time.*

DATE (*EB & WB combined 3pm-6pm*)	**LOOP Bike Detections**	*Average Bike Vol per hour*	**Loop Missed Bikes during Red**	Loop: Missed Bikes during Green	**Total Bikes**	Loop: **FP during Red**	Loop: **FP during Green**	*Loop:* ***% bikes detected***	***Loop ACCURACY*** *%bikes that would have been treated properly by the signal**	***Loop %*** ***bikes MISSED***	*Loop ERROR % bikes MISSED during RED*	**FP% during RED**
Fri. March 13	80	26.7	3	1	87	7	41	92.0%	96.4%	4.6%	3.6%	14.6%
Mon. March 16	79	26.3	1	2	97	5	29	81.4%	98.8%	3.1%	1.3%	14.7%
Tues. March 17	46	15.333	2	6	54	7	67	85.2%	95.8%	14.8%	4.2%	9.5%

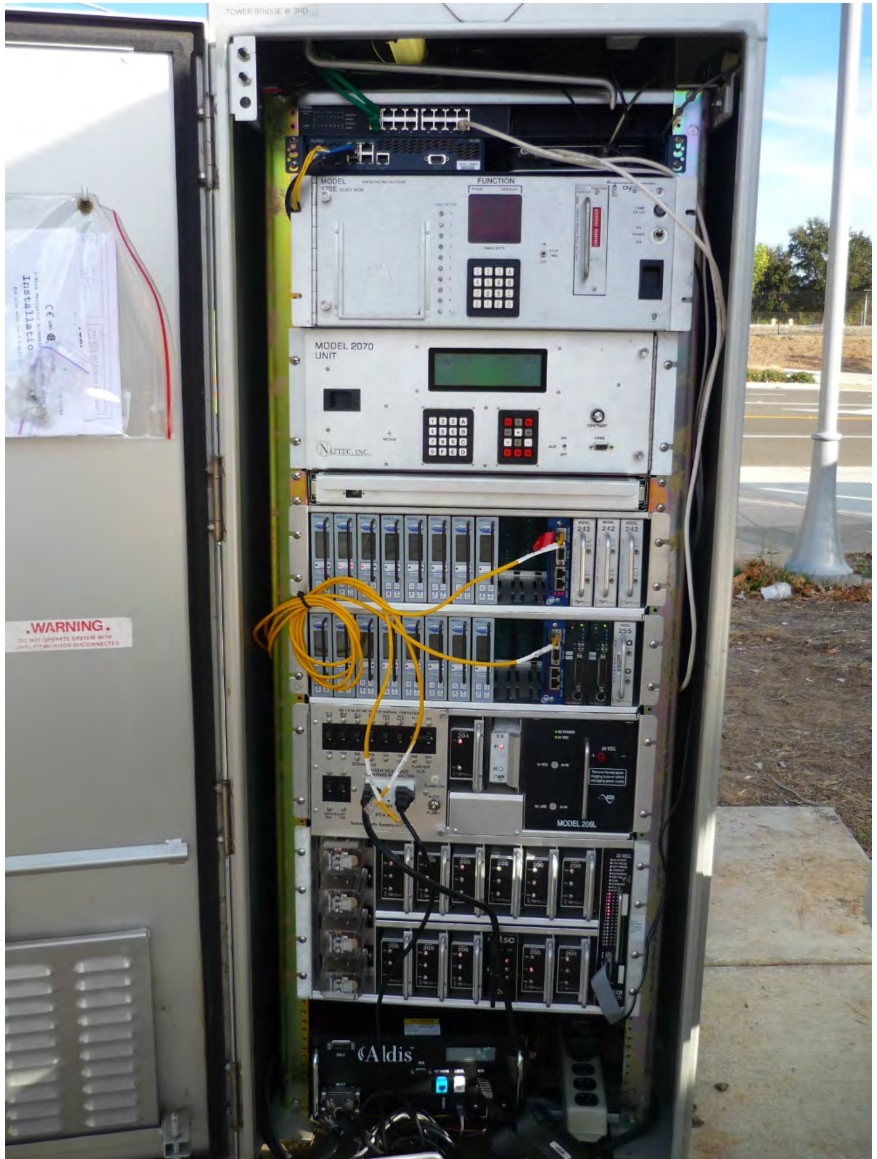
DATE (*NB or SB*) *Tues. June 9*	**Radar Bike Detections**	*Average Bike Vol per hour*	**Radar Missed Bikes during Red**	Radar: Missed Bikes during Green	**Total Bikes**	Radar: **FP during Red**	Radar: **FP during Green**	*Radar:* ***% bikes detected***	***Radar ACCURACY*** *%bikes that would have been treated properly by the signal**	***Radar % bikes MISSED***	*Radar ERROR % bikes MISSED during RED*	**FP% during RED**
9-10am NB Thru	60	60	1	1	62	13	8	96.8%	98.4%	3.2%	1.6%	61.9%
9-10am NB Left-Turn	30	30	0	0	30	3	0	100.0%	100.0%	0.0%	0.0%	100.0%
9-10am SB Thru	55	55	1	1	57	10	10	96.5%	98.2%	3.5%	1.8%	50.0%
9-10am SB Left-Turn	0	0	11	1	12	0	0	0.0%	0.0%	100.0%	100.0%	0.0%
NB 10-11am	22	11.0	2	1	25	17	6	88.0%	91.7%	12.0%	8.3%	73.9%
SB 10-11am	18	9.0	3	2	23	27	8	78.3%	85.7%	21.7%	14.3%	77.1%
NB & SB 10-11 combined	40	20.0	5	3	48	44	14	83.3%	88.9%	16.7%	11.1%	75.9%

DATE (*Time*)	**Radar Bike Detections (Actual Bikes)**	*Average Bike Vol per hour*	**Radar Missed Bikes during Red**	**Radar:** Missed Bikes during Green	**Total Bikes**	**Radar: FP during Red**	**Radar: FP during Green**	***Radar: % bikes detected***	***Radar ACCURACY*** *%bikes that would have been treated properly by the signal**	***Radar % bikes MISSED***	*Radar: ERROR % bikes MISSED during RED*	**FP% during RED**
Mon. Sept 21 SB (9:15-9:25am)	13	N/A	0	0	18	2	2	100.0%	100.0%	0.0%	0.0%	10.0%
Mon. Sept 21 SB (9:30-9:40am)	17	N/A	0	0	24	6	0	100.0%	100.0%	0.0%	0.0%	20.0%

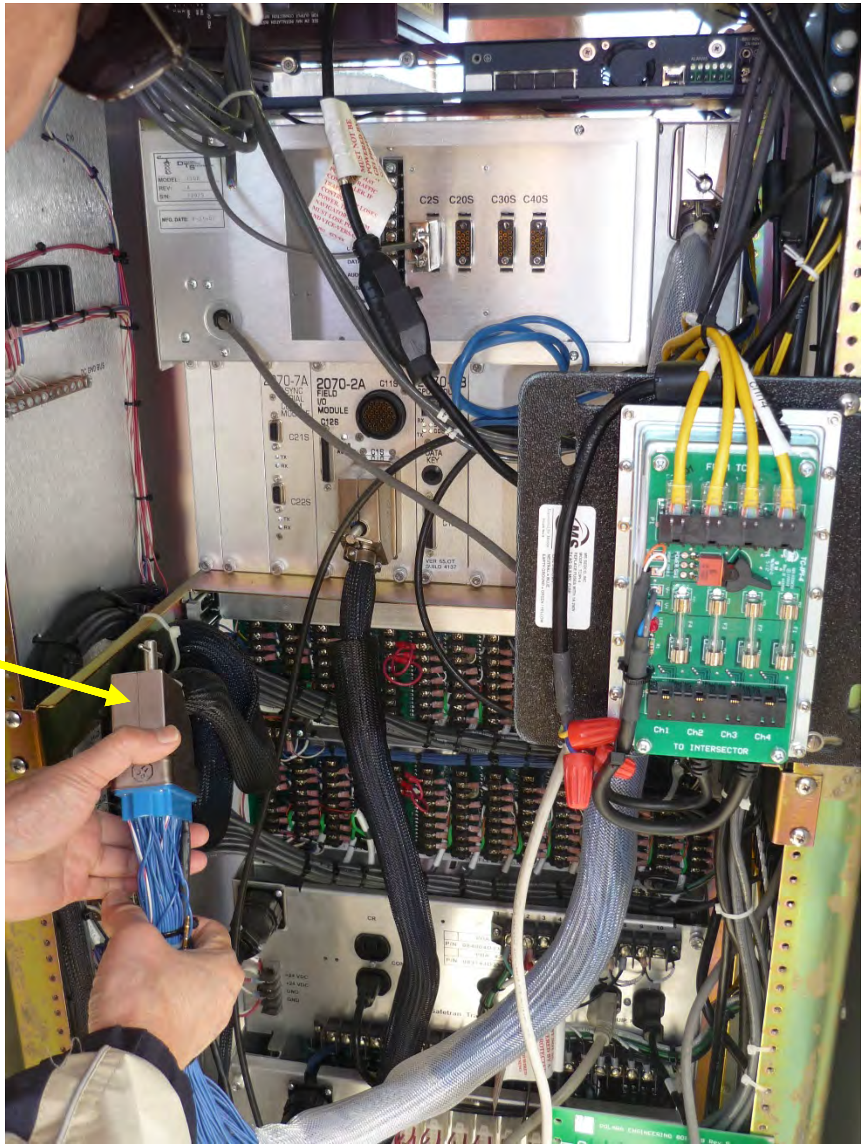
Radar Technology to Distinguish Bike/Car

West Sacramento

Front side of controller cabinet



C1 connector



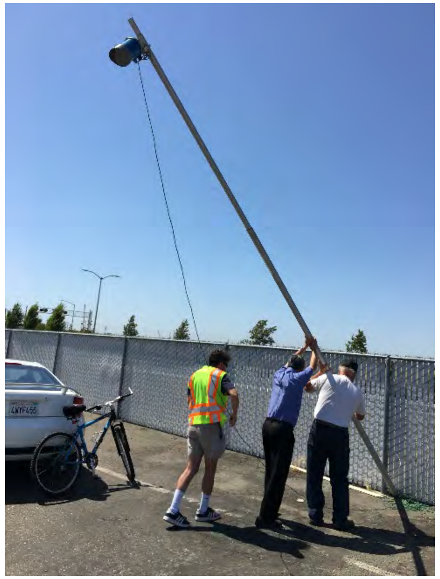
Back side of controller cabinet

Radar Technology to Distinguish Bike/Car

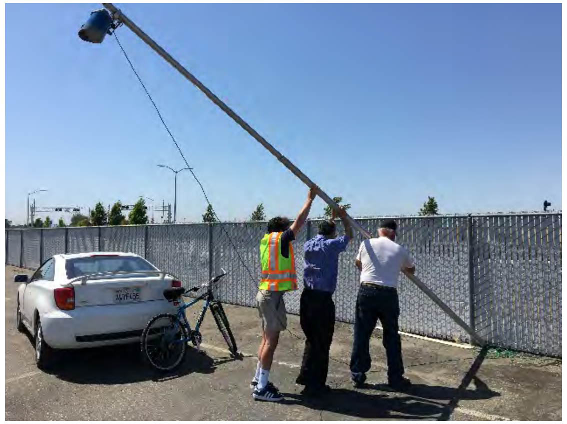
OCCLUSION

Occlusion may be a problem with Radar. Large vehicles may block "view" of radar detector. *Solution*: Mount radar detector at higher level and/or use the OZP (Occlusion Zone Protection) and DBM (Delay Before Max) feature available.

This feature was extensively tested at a Caltrans Maintenance yard (formerly McClellan AFB).



Pole was lowered and mounting height of radar detector raised to 20 feet



Occluding Vehicle: Total Length approx. 50' x Total Height approx. 13'

Radar Technology to Distinguish Bike/Car

OCCLUSION (con't.)

The Radar unit was installed at various heights to verify features: Occlusion Zone Protection (OZP) and Delay Before Max (DBM).

Both the OZP and DBM are important *to "protect" a bicycle* if it has been detected by the radar but then is blocked (occluded).

The option of using *"Red Lock"* has been used by many signalized intersections in the USA but is not an ideal solution since the blocked vehicle may leave the area (such as a bicycle or car turning right), thereby potentially placing an unnecessary call to the controller.

Bicyclist may be seen in gap between back of truck and trailer

Sequence of approaching bicyclist under *Saturation Conditions* (stopped occlusion, truck and trailer).

Radar Technology to Distinguish Bike/Car

OCCLUSION (con't.)

Test #	Description	Distance from Radar Pole to Limit Line	Mounting Height	DBM (sec)	OZP (sec)
1A	Saturation Testing (assume 100 sec cycle length)	80'	16'	80	20
1B	Saturation Testing (assume 100 sec cycle length)	80'	20'	80	20
2	No Occlusion testing with bicycle (assume 100 sec cycle length)	80'	20'	80	20
3	Rolling Occlusion after bicycle already detected, waiting at limit line (assume 100 sec cycle length)	80'	20'	80	20
4A	Rolling Occlusion while bicycle approaching limit line (assume 100 sec cycle length)	80'	20'	80	20
4B	Rolling Occlusion while bicycle approaching limit line (assume 130 sec cycle length)	80'	20'	80	50
5	No Occlusion testing with 2 cars (assume 130 sec cycle length)	80'	20'	80	50
6	Rolling Occlusion testing with 2 cars (assume 130 sec cycle length)	80'	20'	80	50
7	Rolling Occlusion testing with bicycle at increased distance (assume 130 sec cycle length)	120'	20'	50	50
8	Rolling Occlusion while bicycle approaching limit line (assume 130 sec cycle length)	120'	20'	50	50
9	Rolling Occlusion while bicycle approaching limit line (assume 130 sec cycle length)	120'	24'	50	50

The table summarizes all the various scenarios and includes the specific distance from the radar pole to the limit line, mounting height and the times set for both Delay Before Max (DBM) and Occlusion Zone Protection (OZP).

It appears that the OZP feature does indeed "hold" a vehicle, whether a bicycle or car, when it has been occluded.

Occlusion of truck while bicycle approaches limit line (photo on left side) and occlusion immediately removed (truck drives straight through, photo on right side).

Radar Technology to Distinguish Bike/Car

C1 READER

The C1 Traffic Detector Reader and Analyzer: Inexpensive tool developed by Caltrans DRISI to diagnose (& troubleshoot) vehicle detector problems while they are online and reporting data to the TMC. Tool to **collect** 100% of the **real-time data** flowing between traffic controllers and controller cabinets and then **validate** by comparing to video ground truth.

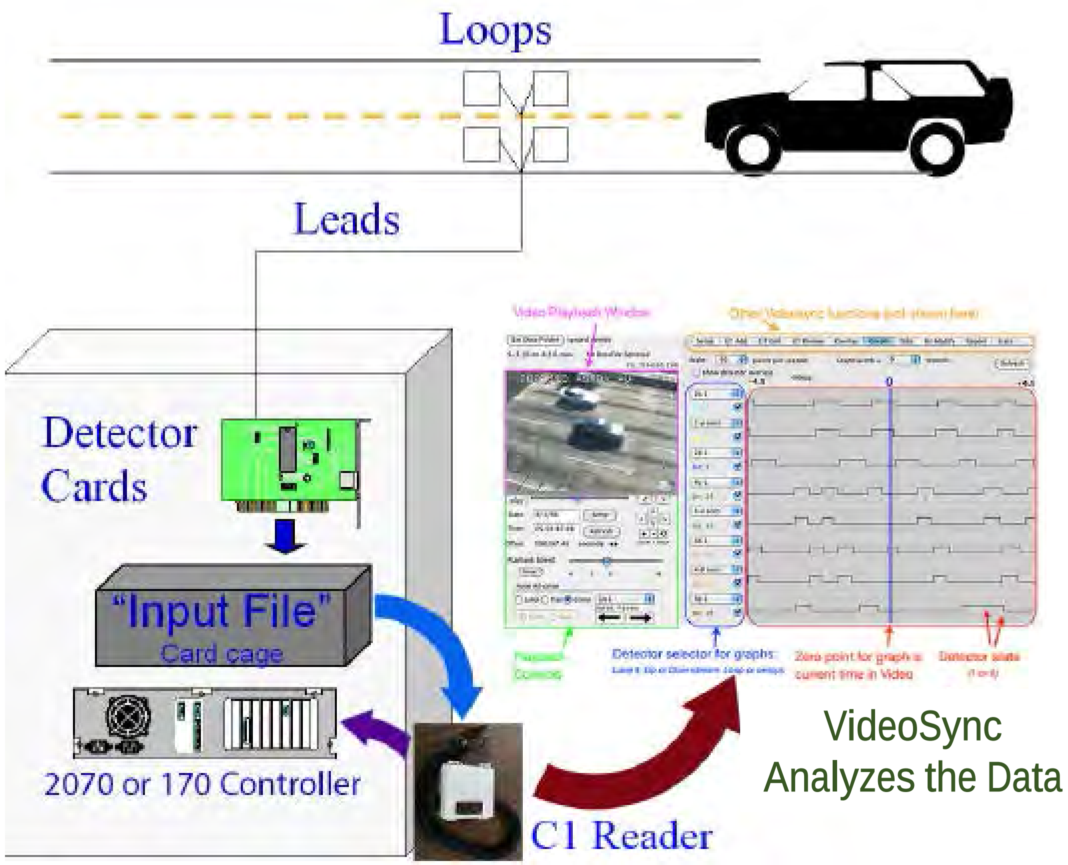
Electronic circuit: Samples all logic signals flowing in and out of a controller via a flex cable, makes individual contacts *with each C1 connector pin (104)*. Data is stored by a Raspberry Pi microcontroller, transmits to local USB thumb drive and/or web server program via TCP/IP.

Components: Mounted in environmental enclosure, includes female C1 connector which plugs into standard male C1 connector from cabinet. Assembly plugs into the controller via another standard C1 connector. Installation transparent to controller and cabinet.

Analyze captured data: *VideoSync* displays ground truth video alongside graphical representation of logic C1 pin signals.

Radar Technology to Distinguish Bike/Car

C1 READER



The C1 Reader collects the sensor data and transmits it to the VideoSync program.

Recorded video is synchronized with captured data and *VideoSync* displays ground truth video with graphical representation of logic signals on selected C1 pins.

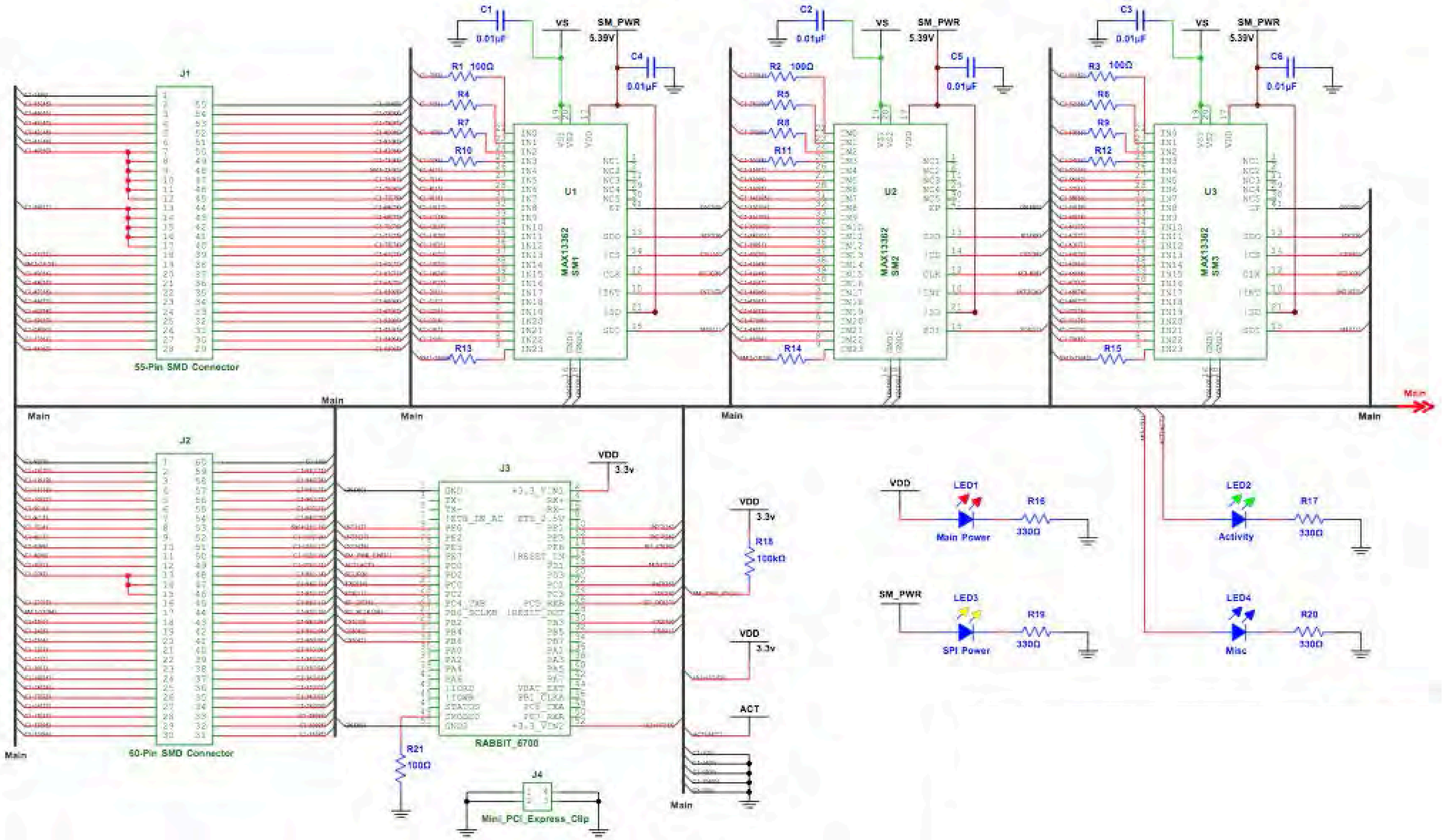
False detections (false positives), missed detections (false negatives), double counts and other errors reported by detectors are readily visible.

VideoSync software may be used to analyze data and generate statistics on the accuracy of any vehicle detector under test.

The combination of recorded video and detector data may be used to *verify and validate proper installation of vehicle detection systems.*

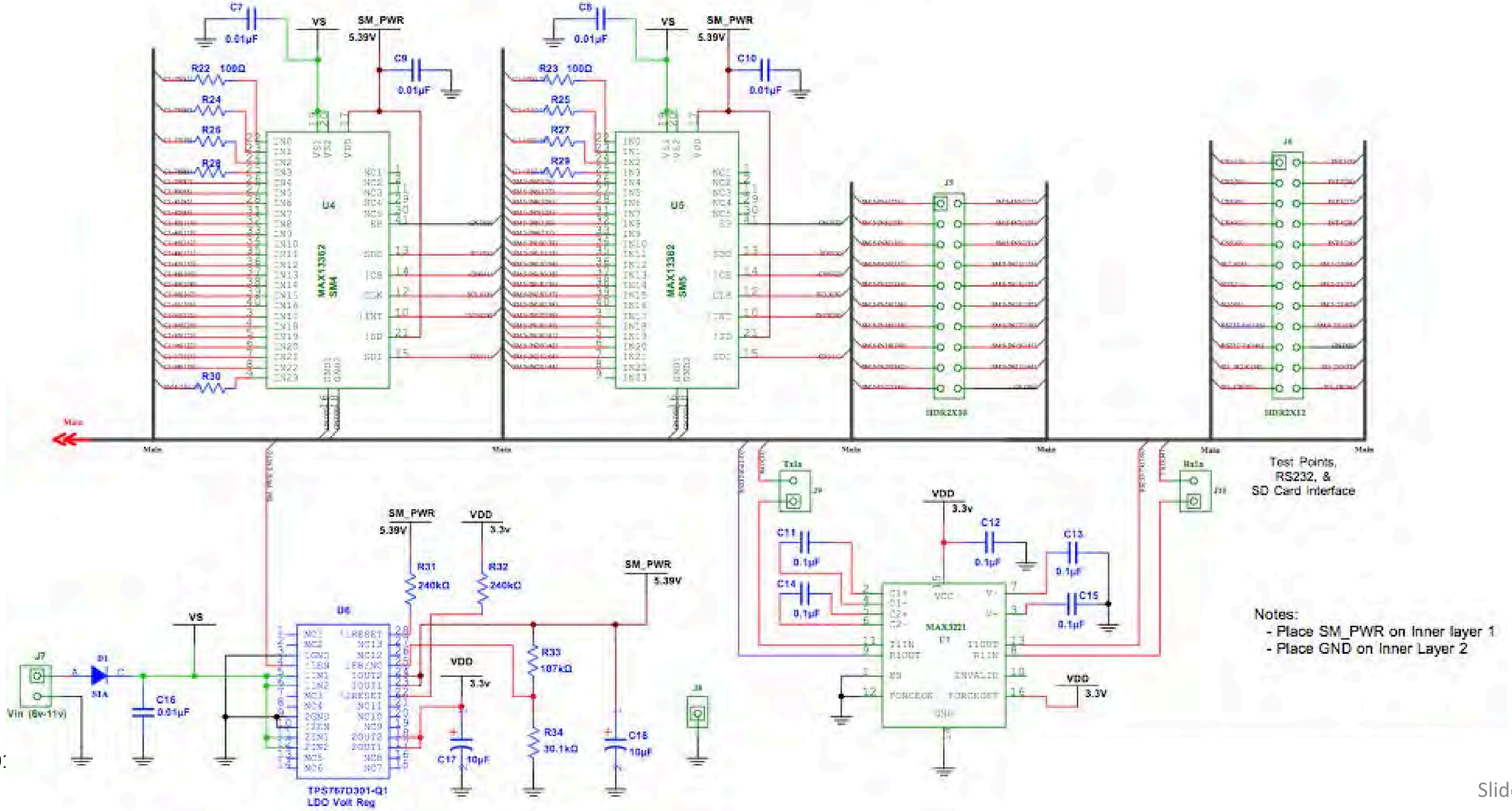
Radar Technology to Distinguish Bike/Car

C1 Reader ver. B5.1 **Schematic Diagram**



Radar Technology to Distinguish Bike/Car

C1 Reader ver. B5.1 Schematic Diagram



Radar Technology to Distinguish Bike/Car

C1 READER SPECIFICATIONS

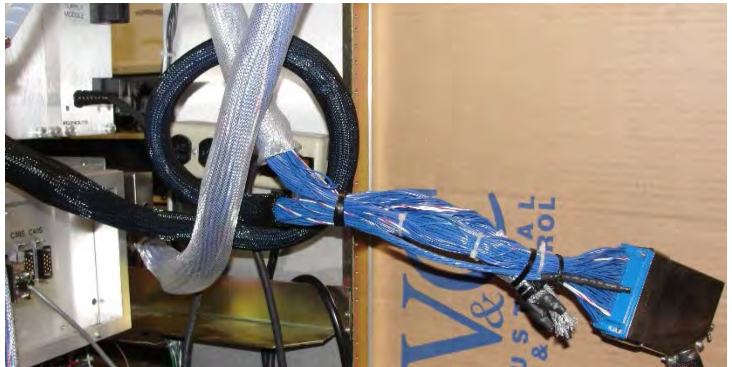
How much does a unit cost?
Since the C1 Reader is an engineering prototype, the cost is understandably high: $145 each for C1 Reader fabrication, includes printed circuit board, components, and populating. Most of the components are surface mounted, which requires precision machine.

How do you get one?   The C1 Reader is currently not being mass produced. It is a working engineering prototype, manually assembled: requires soldering **104 pins** to the connector, installing the *cooling fan, Raspberry Pi, Ethernet hub*, etc.
All the subassemblies are installed inside a 6”x6”x4” box.

Functional Specifications: Read all the C1 pins and make the data available via Ethernet or via a flash drive;
be small enough to be mounted in a small 6”x6”x4” box and placed inside the traffic controller cabinet.

- The C1 Reader reads all 100 active pins in *read-only mode.*
- The high-impedance inputs of the C1 Reader ensures that it *does not interfere with the traffic controller’s operation*.
- Additionally, can read from 2 external 20 and 24 pin headers, that may be connected directly to back terminals of the Input File, hooked into to the 2070's auxiliary C11 connector, or used to read external I/O not connected directly to the cabinet (such as an experimental detector).

The current objective is to build and test enough of them so that Caltrans knows specifically what functions are needed for which end-use applications.



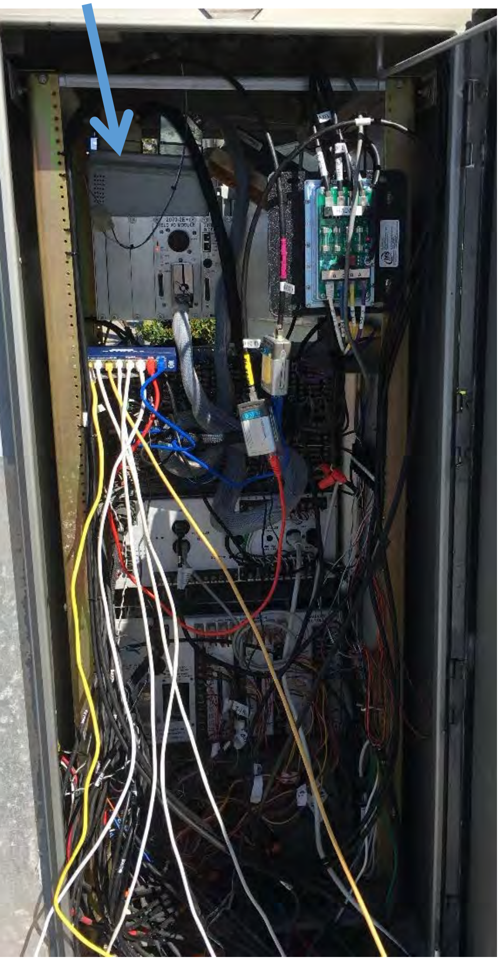
“Y-Cable” used pre-C1 Reader

Radar Technology to Distinguish Bike/Car

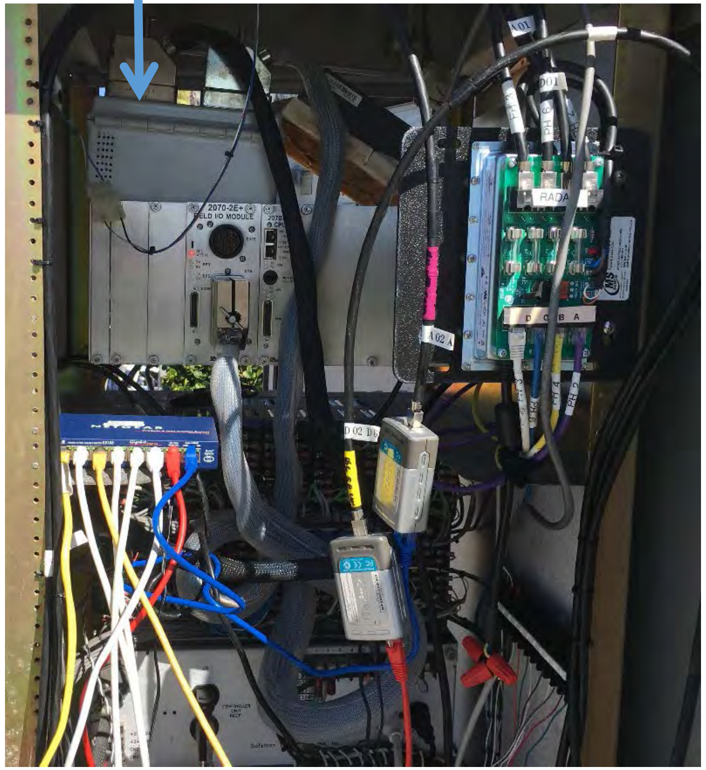
Huntington Beach Results

All data recorded using the C1 READER.
System was installed in October 2016. Video and radar data were recorded and analyzed. Several issues were discovered and so the system was modified in February 2017, video and radar data were again recorded.

C1 READER



C1 READER



Backside of Controller Cabinet

C1 READER

Front side of Controller Cabinet (see C1 Reader on top of 2070 controller)

Radar Technology to Distinguish Bike/Car

Huntington Beach Results

A sign was created and posted on each leg of the intersection to hopefully educate and *modify bicyclist behavior* (increase compliance to red traffic signal).

Mounting Height = 24’

Sign Designation Pending

ENGLISH UNITS (inches)

A	B	C	D	E	F	G	H	J
36	24	.625	.94	2.50	10	1.5	3C	2.25

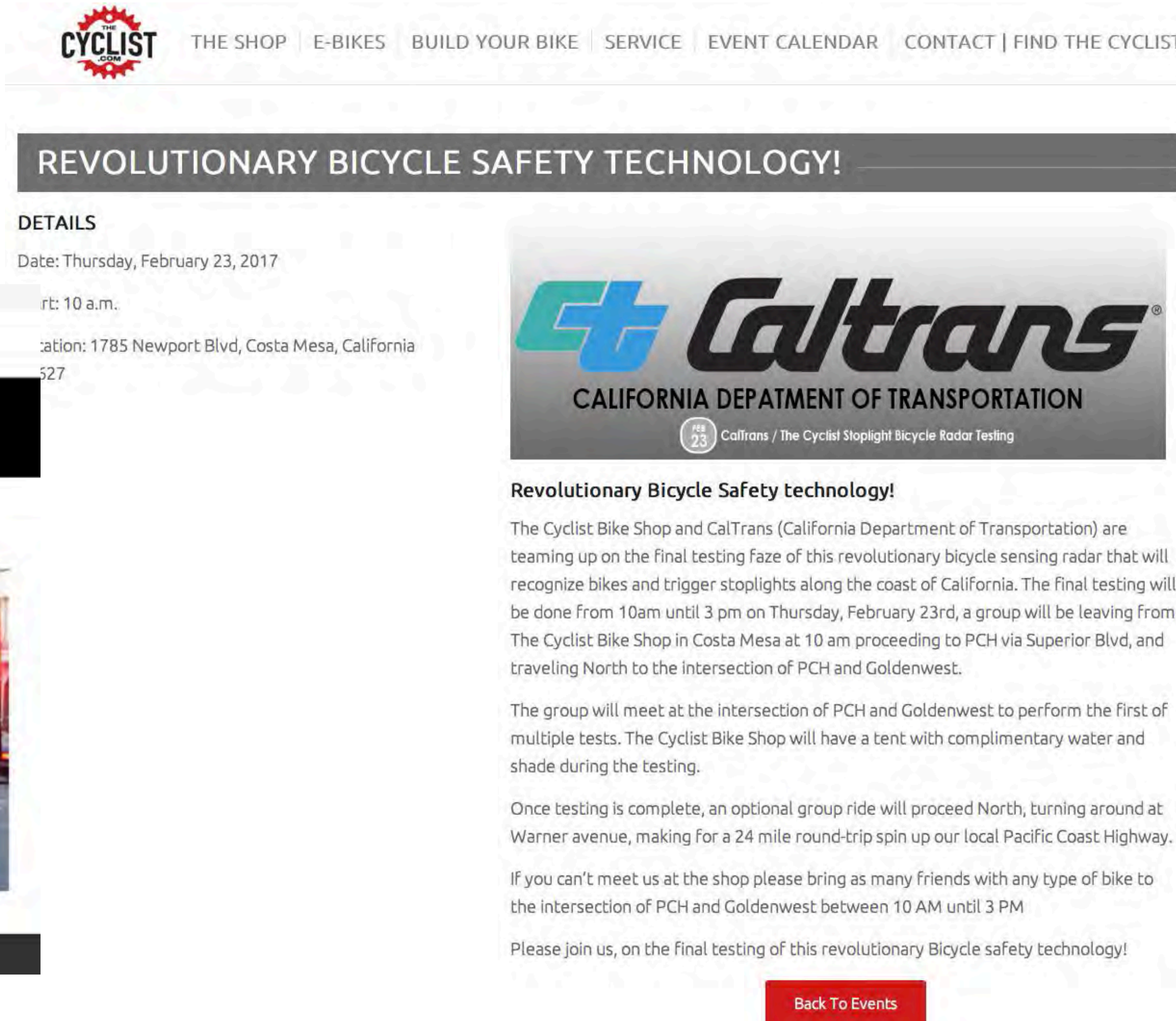
Radar Technology to Distinguish Bike/Car

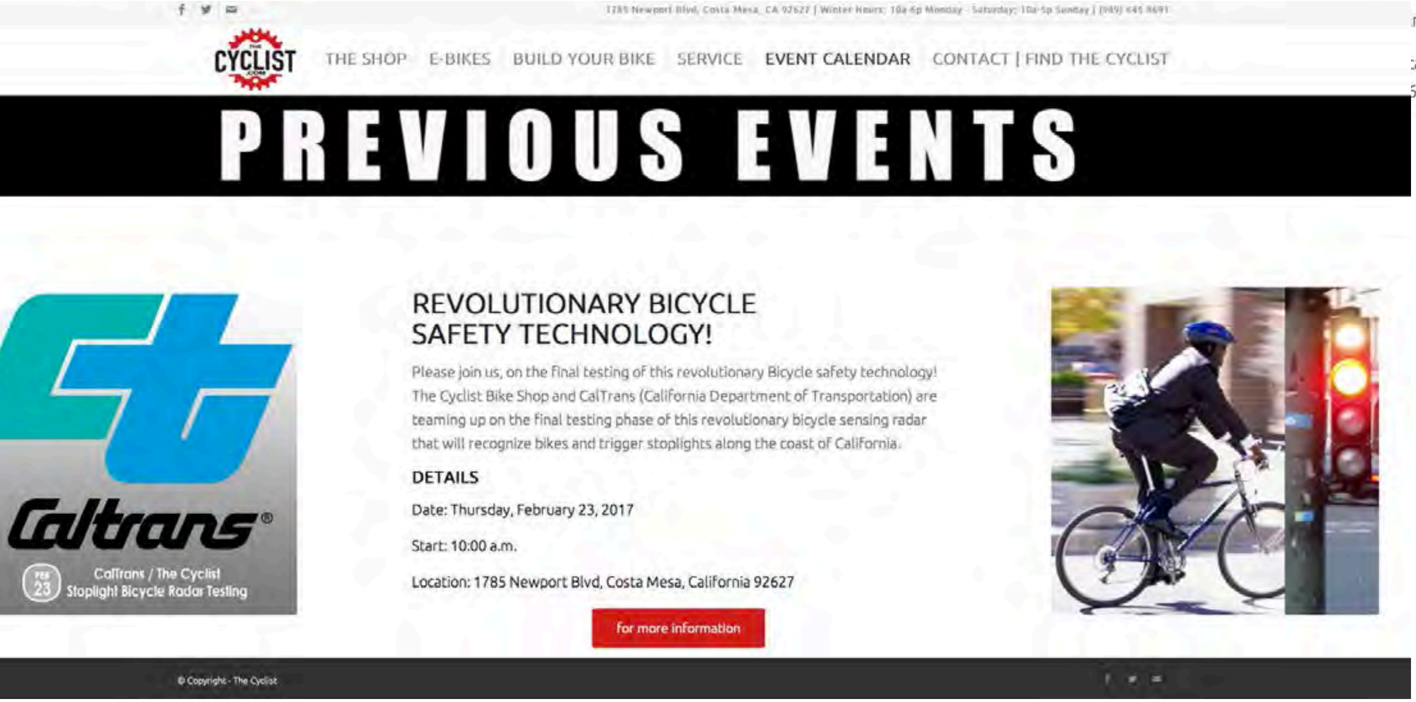
Huntington Beach Results

In order to have “real” bicycle data, the bicyclist community was invited to participate on Thursday, February 23, 2017.

The owner of “CycleGuy.com” invited participation.

The response was very positive.





Radar Technology to Distinguish Bike/Car

Huntington Beach Results

Positive response to public outreach

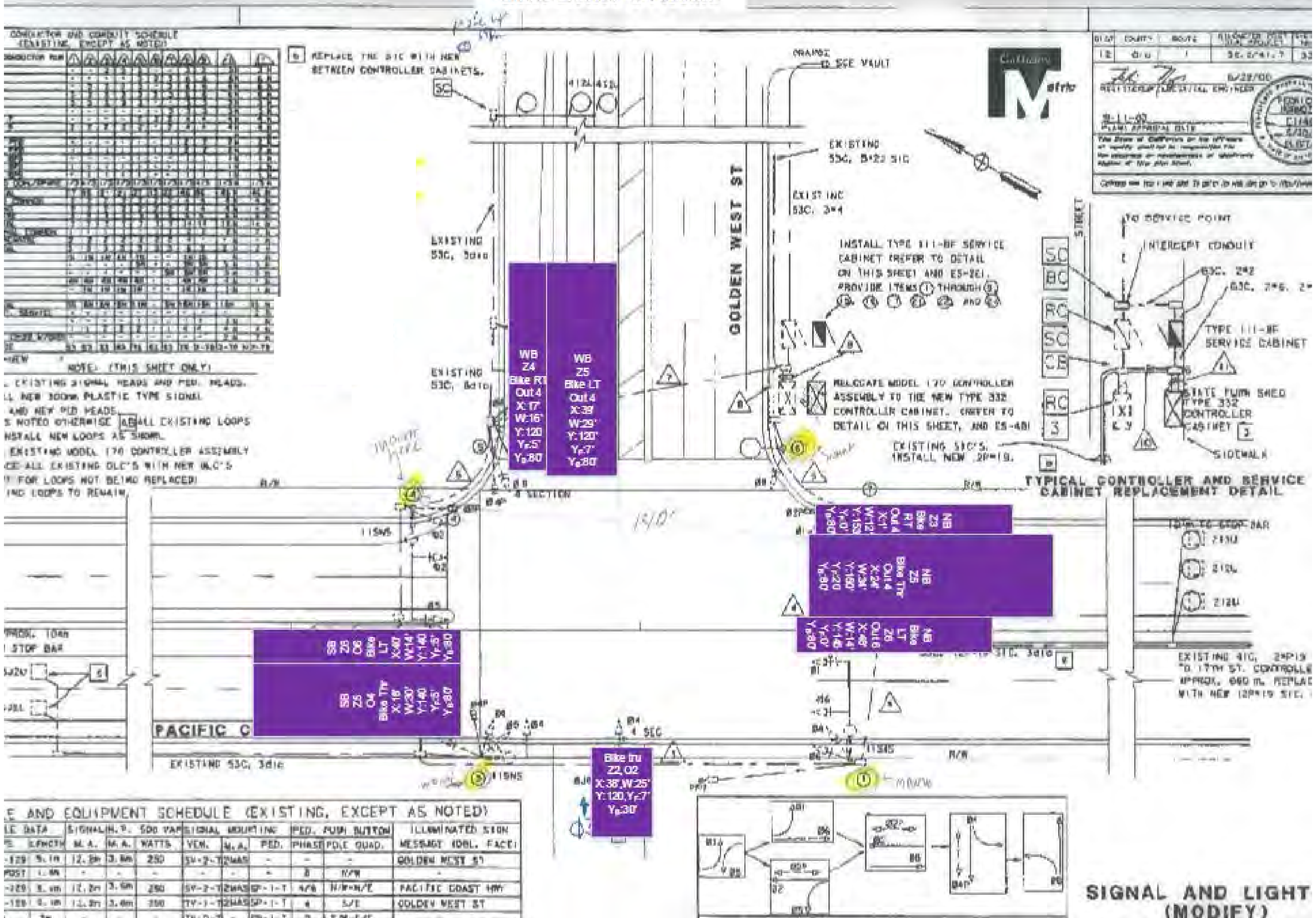
Radar Technology to Distinguish Bike/Car

Huntington Beach Results

Radar Detection Zones

Intersector	Zone	Description	Length	Width	Flags
NB	1	RT	90	14	
NB	2	LT	90	12	
NB	3	Bike RT	80	12	Bike
NB	4	Advance	20	48	Pulse
NB	5	Bike Thru	100	34	Bike
NB	6	Bike LT	80	14	Bike
NB	8	Thr	95	31	
WB	1	RT	85	18	
WB	2	LT	85	24	
WB	3	Advance	20	48	Pulse
WB	4	Bike RT	85	16	Bike
WB	5	Bike LT	87	29	Bike
SB	1	Thru	105	22	
SB	2	LT	105	14	
SB	4	Advance	20	48	Pulse
SB	5	Bike Thru	85	30	Bike
SB	6	Bike LT	85	14	Bike
EB	1	Thru	25	25	
EB	2	Bike Thru	37	25	Bike

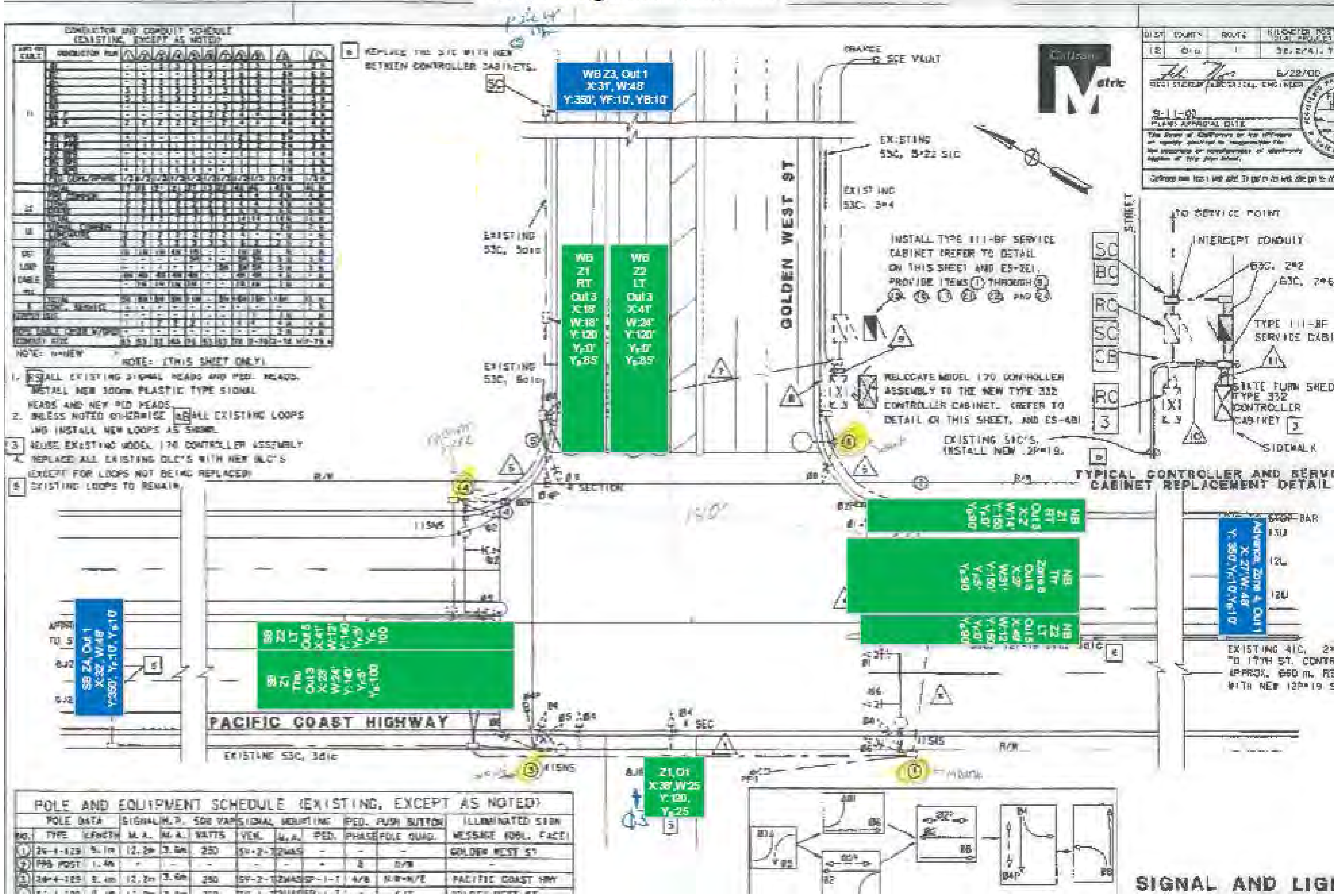
Bike Zones Overlaid



Radar Technology to Distinguish Bike/Car

Huntington Beach Results

Remaining Zones Overlaid



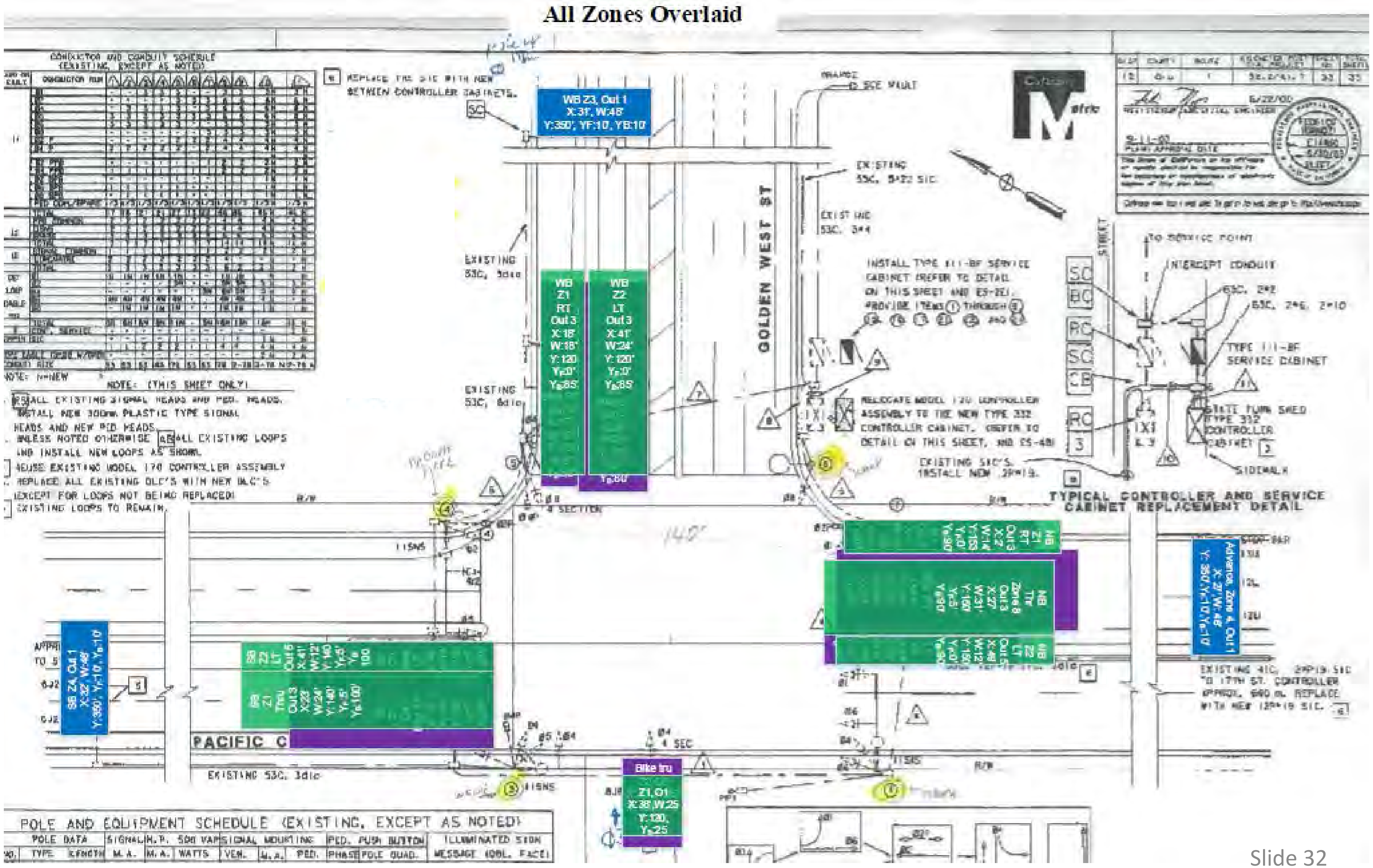
Cars/Truck Vehicle

Detector zones

Note: Advance Detection

Radar Technology to Distinguish Bike/Car

Huntington Beach Results

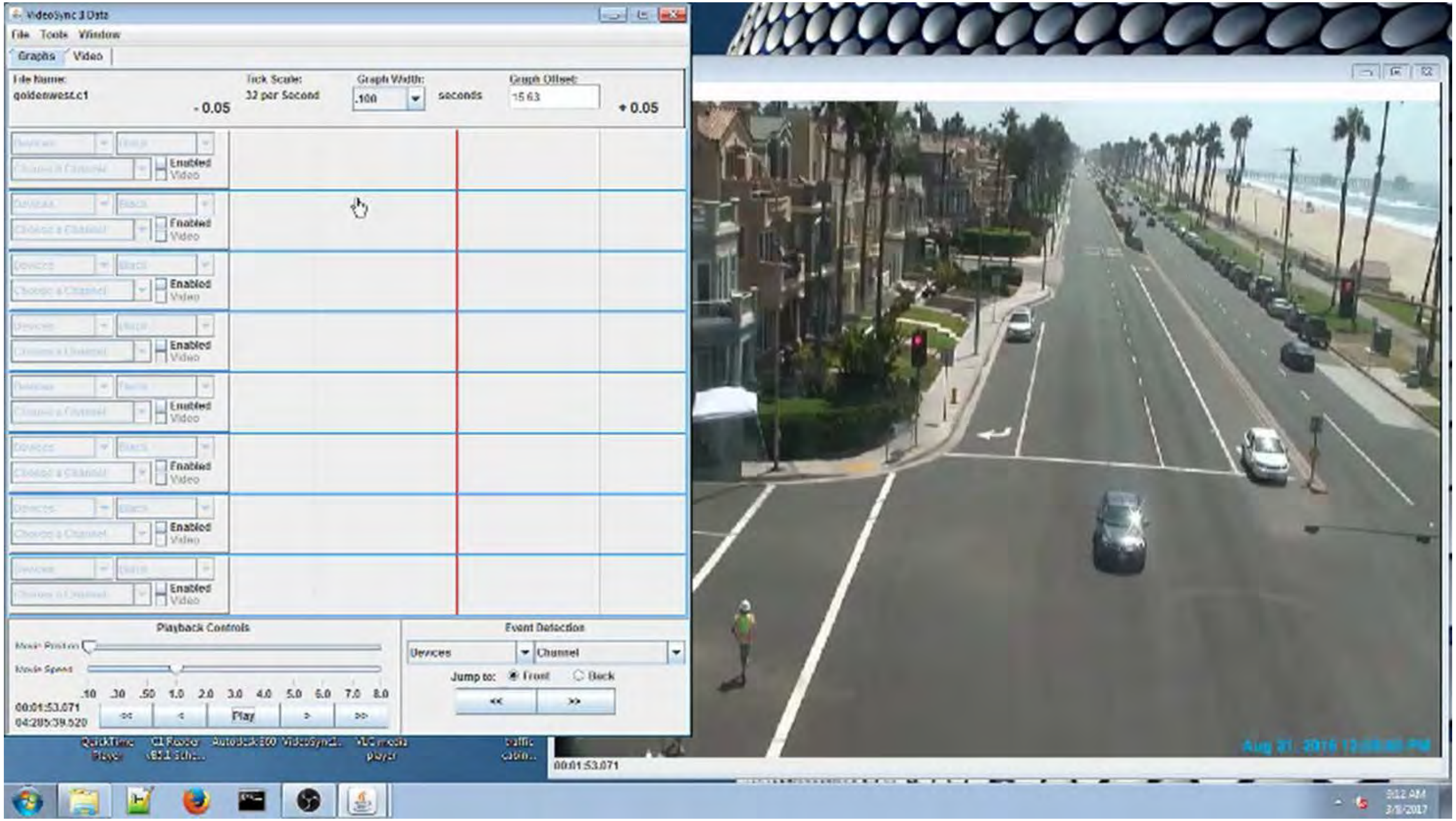


Cars/Truck Vehicle Detector zones shown on top of bicycle (purple) detection zones

Radar Technology to Distinguish Bike/Car

Huntington Beach Results

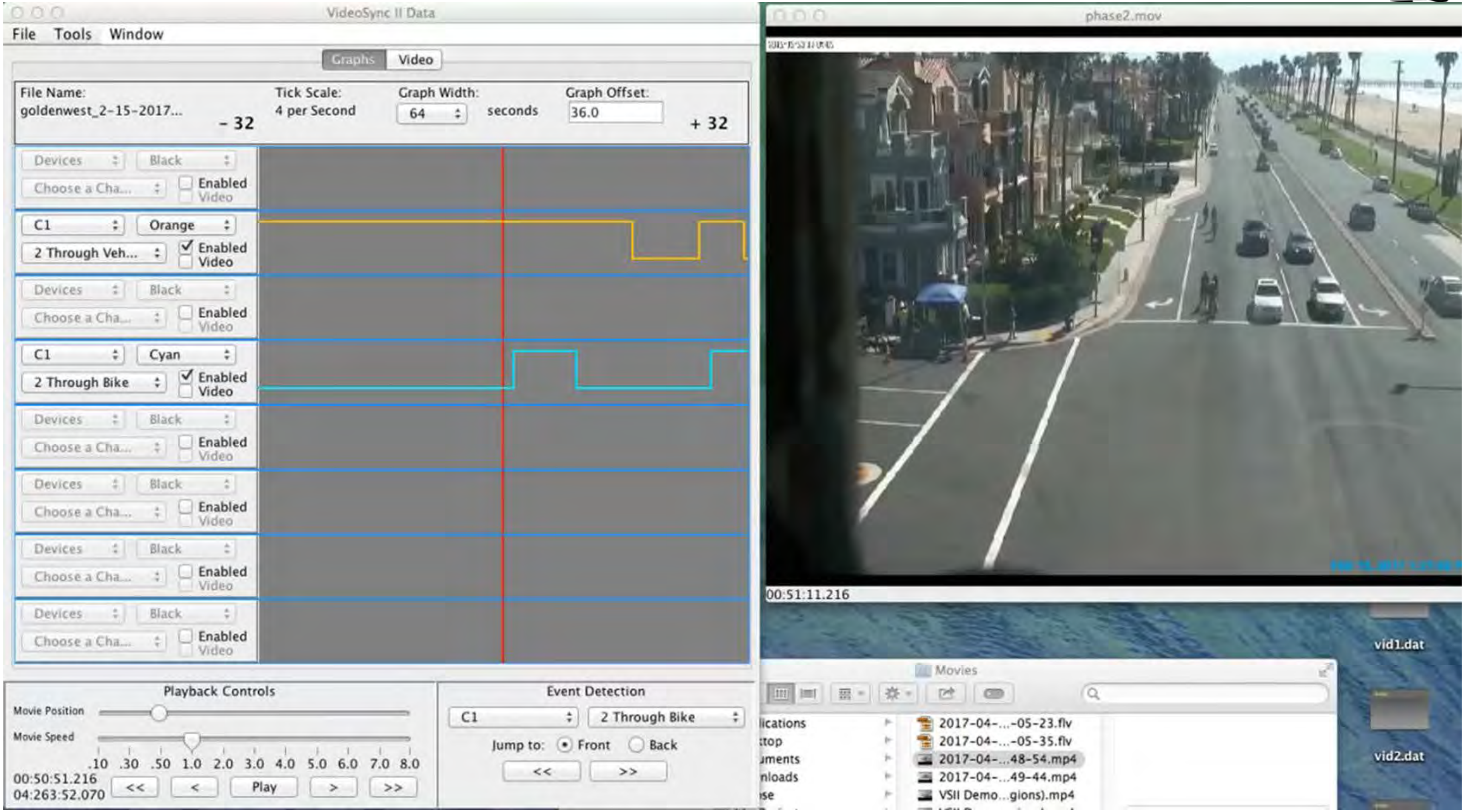
Simplified demonstration of *VideoSync* SET-UP, displaying Right-turn car movement video along with radar detection pulses.



Radar Technology to Distinguish Bike/Car

Huntington Beach Results

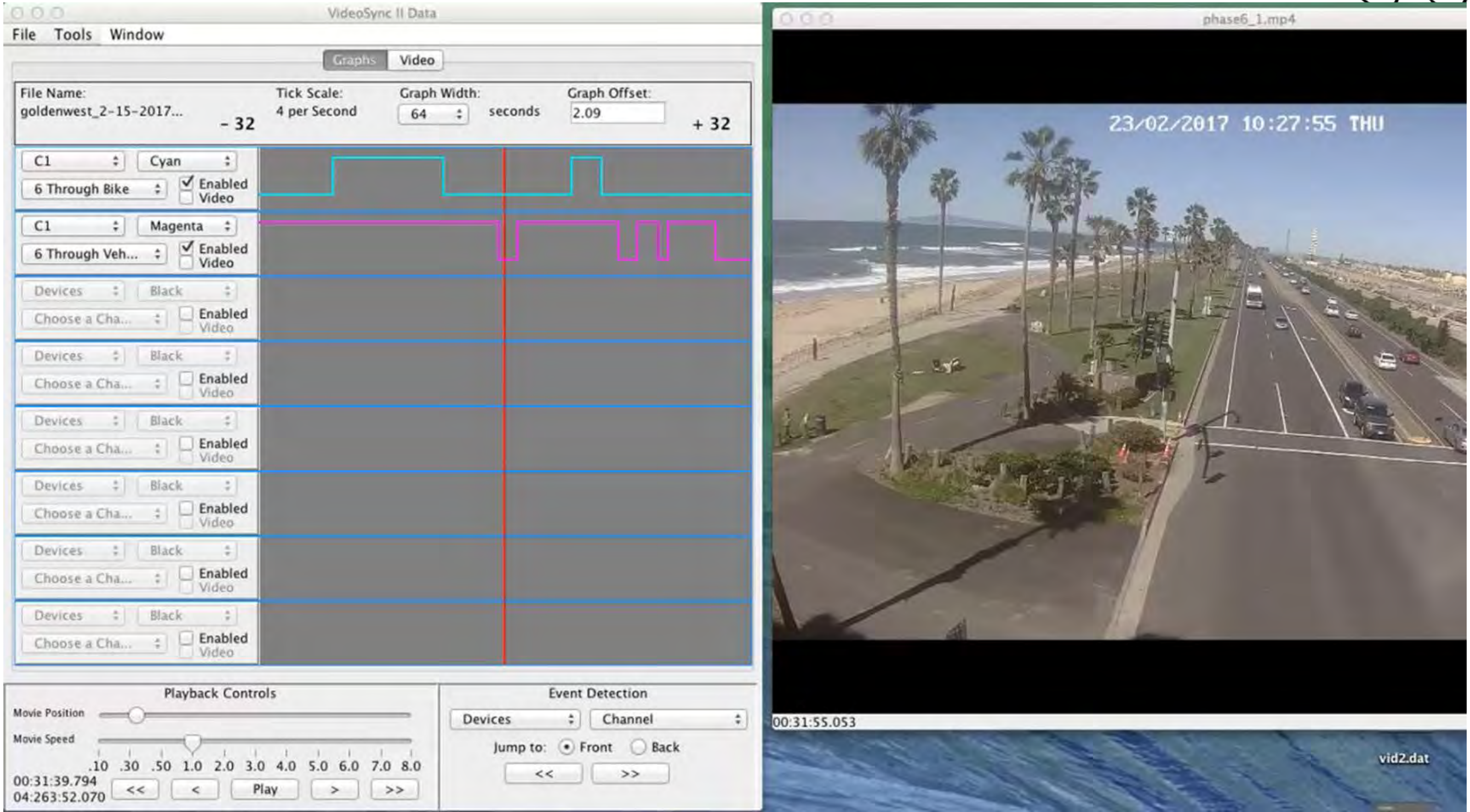
02/24/17: Example of *Northbound* *traffic: radar data both bikes and cars/trucks*



Radar Technology to Distinguish Bike/Car

Huntington Beach Results

02/24/17: Example of Southbound *traffic: radar data both bikes and cars/trucks*



Radar Technology to Distinguish Bike/Car

Huntington Beach Results

Modifications made because of October data analysis:

1. Left-turn Bike Zone *widened* by 2 feet (into through-lane)
2. Northbound Bike Zone extended out by 20 feet (past limit line): *no crosswalk*
3. Increased size/speed of Ethernet switch
   (to properly record all 4-legs simultaneously)

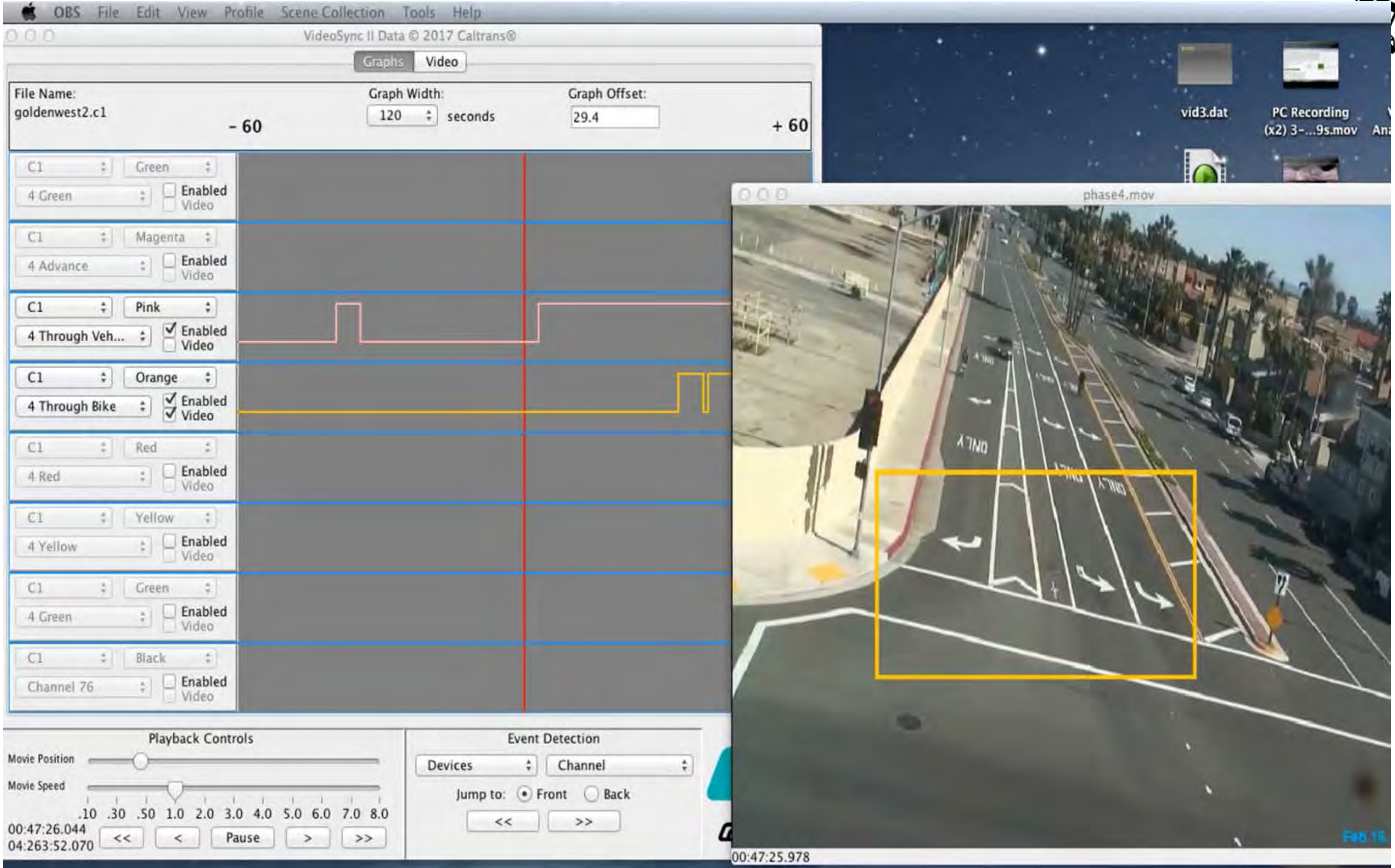
Setting of DBM = 110 sec and OZP = 20 seconds

More Video Clips of February 24th, along with Radar data shown through *VideoSync (show group of bicyclists)*

Radar Technology to Distinguish Bike/Car

False Negative:
Missed Bike
(not detected)

Motorized Bike may exceed threshold; group of bicycles *detected as car (misclassified)*



Radar Technology to Distinguish Bike/Car

Huntington Beach Results

Data Analysis & Results

- Overall accuracy for detecting cars/trucks 100%;
- Overall accuracy for detecting bicycles *potentially* ~99% if includes bikes detected but misclassified as cars); ~93% if include misclassifications
- A group of >1 bicycle traveling very closely together may appear as a car to the radar detector.
- Bicycles that exceed 30km/hr (18.6 mph) will be misclassified as cars.
- Very important to verify/validate after installation, for better setting of detection zones

Radar Technology to Distinguish Bike/Car

Huntington Beach Results

February 23, 2017

Total Bicycle Events (pulses) from 12:30pm to 4:30pm

Phase	Total: TP + FN	Legal Detections	Servicable Detections*	**Total TP**	**Total FN**	Green FN	Red FN	**Legal Red FN**	Total FP	Green FP	Red FP
1	5	5	5	5	0	0	0	0	43	35	8
2	35	34	33	31	4	1	3	2	44	35	9
3	38	38	38	37	1	0	1	1	6	2	4
4	53	53	52	40	13	1	12	12	39	26	13
5	19	19	19	16	3	0	3	3	8	5	3
6	29	28	17	15	14	11	3	2	48	39	9
Totals	179	177	164	144	35	13	22	20	188	142	46

Misclassified and/or "Phantoms"

Hourly Bike Pulse Counts

	Ground Truth	Hourly TP	Hourly FN	Green FN	Red FN	**Legal Red FN**	Hourly FP	Green FP	Red FP
12:30pm to 1:30pm	39	33	8	2	6	6	57	43	14
1:30pm to 2:30pm	66	56	14	4	10	10	35	25	10
2:30pm to 3:30pm	53	49	9	4	5	4	50	40	10
3:30pm to 4:30pm	6	6	4	3	1	0	46	34	12
Totals	164	144	35	13	22	20	188	142	46

Serviceable Detections: Legally riding bikes that slow down with intent to stop and wait for green signal (TP + Legal Red FN)*

Vehicle Volume Per Hour and Per Phase

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Total Count
12:30pm to 1:30pm	33	91	19	58	18	165	384
1:30pm to 2:30pm	23	85	28	36	9	131	312
2:30pm to 3:30pm	33	80	33	46	17	195	404
3:30pm to 4:30pm	34	115	17	47	18	199	430
Totals	123	371	97	187	62	690	1,530

Ground Truth: *Total number of events*

Legal Detections: *Total number of events capturing legal behavior (TP + Green FN + Legal Red FN)*

Serviceable Detections: *Total number of events where a bike should be serviced (TP + Legal Red FN)*

TP: True Positive	*Bike is correctly detected*
FN: False Negative	*Missed Bike (not detected)*
FP: False Positive	*Detected a bike, but no bike present (phantoms)*
Red FN:	*Missed Bike during Red phase*
Legal FN:	*Legally-abiding bicyclist not detected*

Radar Technology to Distinguish Bike/Car

Huntington Beach Results (con't.)

February 23, 2017

TP: True Positive	*Bike is correctly detected*
FN: False Negative	*Missed Bike (not detected)*
FP: False Positive	*Detected a bike, but no bike present ("phantoms")*
Red FN:	*Missed Bike during Red phase*
Legal FN:	*Legally-abiding bicyclist not detected*

Misclassifications

Phase	Total Bikes Misclassified as Cars	Legally Behaving Bikes, Misclassified as Cars	Legally Behaving Bikes, Misclassified as Cars, *During RED*	Cars Misclassified as Bikes	Totals
1	0	0	0	42	42
2	2	2	2	16	18
3	1	1	1	3	4
4	10	10	9	35	45
5	2	2	2	2	4
6	7	6	2	7	14
Total	22	21	16	105	127

True Event Counts (Misclassifications Removed)

Phase	Total FN	Legal FN	**Legal Red FN**	FP	Totals
1	0	0	**0**	1	1
2	2	1	**0**	28	30
3	0	0	**0**	3	3
4	3	3	**3**	4	7
5	1	1	**1**	6	7
6	7	7	**0**	41	48
Total	13	12	**4**	83	96
	"completely missed bikes"		***Legal Missed Bikes***	*"Phantoms"*	

Radar Technology to Distinguish Bike/Car

Huntington Beach Results (con't.)

Accuracy of Bicycle Pulses

Likelyhood that the Radar Detector Identifies a Bicycle = TP / (TP + Legal_Red_FN)

With Misclassifications Included = (TP + Misclassifications) / (TP + Legal_Red_FN)

Phase	Accuracy	Total Bike Events	Phase	Accuracy	Total Bike Events
1	100.00%	5	1	100.00%	5
2	93.94%	31	2	100.00%	33
3	97.37%	37	3	100.00%	38
4	76.92%	40	4	94.23%	49
5	84.21%	16	5	94.74%	18
6	88.24%	15	6	100.00%	17
Totals	**87.80%**	144	Totals	**97.56%**	160
Without Phase 4	***92.86%***		*Without Phase 4*	***99.11%***	

Phase	Actual Bike Counts
1	11
2	53
3	52
4	73
5	18
6	44
Total	**251**

(hand-counted from video)

Bike Counts by Hour

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Total Count
12:30pm to 1:30pm	0	16	10	21	0	20	67
1:30pm to 2:30pm	5	22	22	31	6	13	99
2:30pm to 3:30pm	4	11	19	20	11	7	72
3:30pm to 4:30pm	2	4	1	1	1	4	13
Totals	11	53	52	73	18	44	**251**

Radar Technology to Distinguish Bike/Car

Huntington Beach Results (con't.)

February 23, 2017

Cars Misclassified as Bikes By Hour

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Total Count
12:30pm to 1:30pm	14	7	1	11	0	0	33
1:30pm to 2:30pm	6	2	0	9	1	0	18
2:30pm to 3:30pm	15	1	1	8	0	0	25
3:30pm to 4:30pm	7	6	1	7	1	7	29
Totals	**42**	16	3	35	2	7	105

FP per hour (No Bikes nor Other Vehicles present) - "Phantom" Detections

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Total Count
12:30pm to 1:30pm	1	4	0	0	1	18	24
1:30pm to 2:30pm	0	7	0	0	1	9	17
2:30pm to 3:30pm	0	9	2	0	2	12	25
3:30pm to 4:30pm	0	8	1	4	2	2	17
Totals	1	**28**	3	**4**	6	**41**	83

FP may lead to placing *false calls* – but at this intersection phases 2 and 6 are both on "recall."

Radar Technology to Distinguish Bike/Car

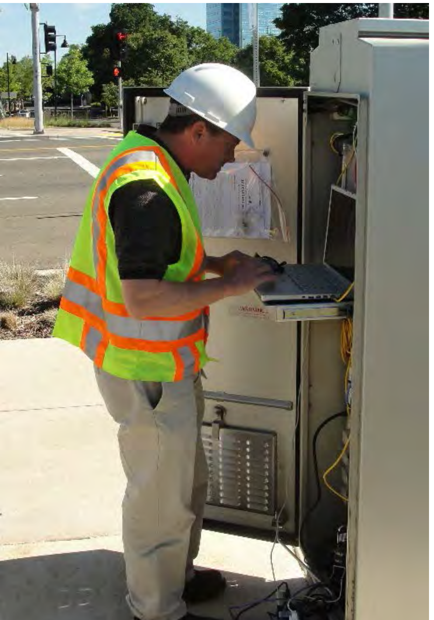
Results Summary

Chico: Radar detector extremely accurate for detecting cars. Bicyclist accuracy was also high.

West Sacramento:

- Some bicyclists were detected as cars; these exceeded the radar threshold of 30km/hr (18.6 mph). Vendor responded that threshold may be modified if needed.
- Bicyclist community agreed on:
  - Bicycle detector need only detect bicyclists that are slowing down to wait during the red signal.
  - Bicycles that are traveling too quickly to go through an intersection during a green interval or turn right need not be detected by the radar.

The issue of occlusion was discovered and addressed (OZP and MBX).



Huntington Beach:

It is important to verify/validate detection zones.

It is a good idea to widen the left-turn bicycle zone beyond limit-line.

Where there is no crosswalk, it is a good idea to extend the bicycle detection zone beyond the limit line.

To attempt to change bicyclist behavior (to respect traffic signal), a traffic sign is a good idea.

Overall accuracy of detecting bicycle or other vehicle potentially 99%, and discrimination ~90%.

Radar Technology to Distinguish Bike/Car

Next Steps

Caltrans District 12 may be installing more radar detection systems to accommodate bicycle detection, as part of a rehab. project for multiple traffic signals along Pacific Coast Highway.

It is important to have a validation/verification system when installing any "new" vehicle detection system to ensure proper installation and to verify the system is working as intended.

Use of C1 Reader and VideoSync will be key for recording vehicle data *("new technology")* and compare with ground truth (video recorded) data.