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A COMPARATIVE STUDY OF VARIOUS TYPES OF VEHICLE DETECTORS

Marcel Singleton
John E. Ward

Massachusetts Institute of Technology
Cambridge MA 02139

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Author(s)
ircel Singleton & John E. Ward

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Abstract

This report is a comparison between the different types of vehicle detectors d associated equipment. It covers practically all of the presence and motion tectors either being sold commercially or actively researched at this time, and cludes radar detectors, ultrasonic detectors, induction-loop detectors, magnetic-adient detectors, pressure-sensitive detectors, and magnetometers. The theoretical d practical aspects of the different classes of detectors are presented, including inciples of operation, detection parameters, installation requirements, and rela-ve costs. The survey is based on information obtained from manufacturers and e technical literature. Typical detector specifications and the characteristics traffic-analyzer equipment are contained in the appendixes.

Key Words
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tion, Radar, Ultrasonic, Induction
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PREFACE

The M.I.T. Electronic Systems Laboratory, as a result of competition for an exploratory study under the U.S. Department of Transportation's Advanced Research Program (TARP), has prepared a series of documents.

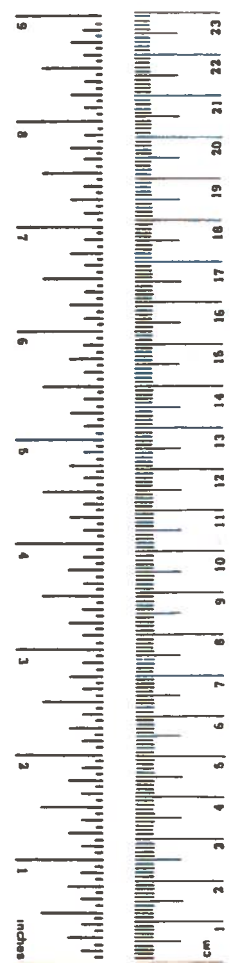
This particular document is based on a thesis, "A Comparative Study of Various Types of Vehicle Detectors," by Marcel Singleton, submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science, June 1975, with some new material added.

We are grateful to Diarmuid O'Mathuna and Ann Muzyka of the Transportation Systems Center, U.S. Department of Transportation, and to John Fearnsides of the Office of the Sentry of Transportation, for their most valuable criticisms, discussions, encouragement, and support.

METRIC CONVERSION FACTORS

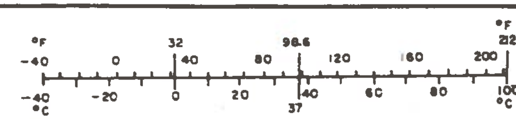
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

This report is a survey of available highway-vehicle detectors and a comparison of their detection characteristics, physical installation parameters, operational characteristics, and relative costs. Detectors fall into four groups based on the fundamental physical principle used to obtain a signal from a vehicle without any active participation on its part: (a) magnetic detection (including induction loops), (b) electromagnetic detection (radar), (c) acoustic detection, and (d) direct pressure of the vehicle wheels (electromechanical). Each of these four groups is further subdivided into devices using different physical principles in their operation or measuring different vehicle parameters (e.g., presence only, presence plus speed, height, and so forth). Table 1 illustrates the range of detectors and detection principles.

The survey was conducted by requesting information from 15 companies active in the field of highway-traffic measurement, all of whom responded in a generous fashion with literature, technical papers, and in some cases, equipment manuals. The companies surveyed and the equipment they manufactured are shown in Table 2. In addition to the company survey, a liaterature search was made for useful technical papers and reports on vehicle detectors and measurement of traffic parameters, and several meetings were held with personnel at the U.S. Department of Transportation, Transportation Systems Center, to discuss their development of loop detectors for airport-taxiway instrumentation, and their experience with the detectors used in the Maine experimental facility.

The report is organized as follows: section 2 discusses all the various types of detectors based on magnetic coupling with the vehicle, a group which represents the bulk of the detectors in use because of their generally satisfactory performance for vehicle-presence detection and reasonable installed cost. Section 3 presents the radar and sonic detectors, which have the advantage over the magnetic detectors (including induction loops) in being able to measure speed directly by means of the Doppler principle. A general comparison of the relative advantages of the various detectors is given in section 4. Two appendixes show typical catalog specification data for the various detector types, and for traffic analyzers which use detector data to develop traffic parameters (density, occupancy, etc.) used in various types of traffic-control systems.

Pressure-actuated road tubes not suitable for permanent installation (i.e., the types taped to the roadway for spot traffic analysis) are not discussed in the body of the report. They are usually of pneumatic type; however, a new type based on the generation of an electrical signal by the application of pressure to a coaxial cable has been introduced by one company. Its operation is described in Appendix B.

TABLE 1 -- SURVEY OF AVAILABLE VEHICLE DETECTORS

Type	Operation
Inductive Loop	Senses Relative Phase-Shift in Loop Because of Vehicle Presence
Magnetic:	
Passive	Senses Remnant Magnetic Field of Vehicle
Magnetometer	Measures Change in Earth's Magnetic Field Caused by Vehicle
Magnetic Gradient	Measures Field Induced in Vehicle by Detector Electronics
Sonic and Radar	Detects Doppler Shift and Amplitude of Signal Returned from Transducer (Antenna)
Electromechanical	
Pressure Treadle	Switch Sensitive to Vehicle-crossing
Coaxial	Vehicle-crossing Pressure Produces Electrical Discharge in Cable Dielectric

TABLE 2 -- COMPANIES SURVEYED AND THEIR PRODUCTS

Eagle Signal	Loop and Magnetic Detectors, Controllers and Systems
LFE Traffic Control Div.	Loop, Magnetic, Magnetometer, Radar, Sonic and Pressure-Treadle Detectors, Traffic Analyzers
Sarasota Engineering Sales, Ltd. (England)	Loop Detectors, Traffic Analyzers
International Prodata Systems Corp.	Loop Detectors, Traffic Analyzers
Streeter-Amet	Loop Detectors, Traffic Analyzers
Sarasota Engineering Co.	Loop Detectors
Crouse-Hinds Co.	Loop and Magnetic Detectors
Canoga Controls Corp.	Loop and Magnetometer Detectors
General Railway Signal Co.	Ultrasonic Detectors
Honeywell Traffic Control	Magnetic Gradient Vehicle Detectors (Prototypes for FHA Tests in Washington DC)
Transportation Data Corp.	Noisy Cable Detectors, Traffic Analyzers
Econolite	Handles TDC Equipment (Above)
Multisonics	Traffic Analyzers and Controllers
SDS Technical Services, Ltd. (Canada)	Traffic Analyzers
Greenshields, Inc.	In-Car Traffic Analyzers

2. INDUCTION-LOOP AND MAGNETIC DETECTORS

Loop detectors, which operate on the principle of the detuning of a resonant circuit by the presence of a vehicle within its magnetic field, are the most widely used vehicle detectors, and have a good deal of flexibility in detection parameters because the physical configuration and dimensions of a buried wire loop can be varied to suit the needs of a particular application. However, it is difficult to design a loop detector for a very small detection area because sensitivity tends to be proportional to loop area. (It is also often difficult to detect small vehicles such as motorcycles.) Loop-detector technology is described below (section 2.1).

Other types of magnetic detectors have been developed which have good "spot" and small-vehicle coverage, but sometimes have to be used in multiples to provide edge-to-edge coverage of a single traffic lane. The two basic types of "passive" magnetic detectors are described below (section 2.2).

A new concept is an active magnetic detector which combines some of the advantages of both induction-loop and magnetic detectors, and eliminates some of their respective disadvantages. This device, called the magnetic-gradient vehicle detector (MGVD) is described below (section 2.3).

2.1 Induction-Loop Detectors

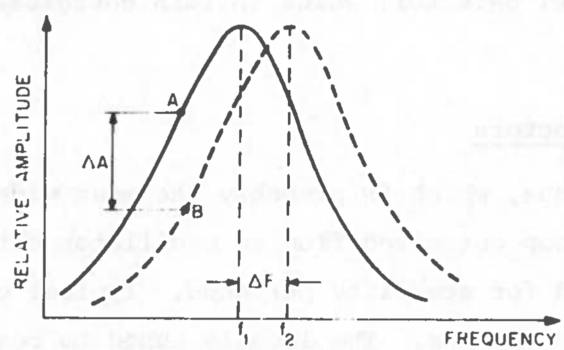
The sensing element of a loop detector consists of a number of turns of wire (usually two to four) installed in a saw-cut slot in the pavement, which is refilled with an epoxy sealer. The ends of the loop are brough out to the roadside and run to the associated electronics, which are generally installed in a controller cabinet, together with other intersection-controller equipment. The electronics can be located at distances of 750 feet from the loop. Loop size can vary from about 4 feet square to as much as 20 x 100 feet. The main limitation on loop design is the range of inductance (including the lead-in cable) which can be handled by the associated electronics.

There have been several loop-detector concepts designed around the principle of a change in inductance of the detection loop. First, there is the self-tuning detector, where the loop is part of a parallel-tuned tank circuit, and where a feedback loop is used to adjust the oscillator frequency to keep the detector automatically tuned to the same amplitude point on the resonance curve. A second design is a bridge-balance detector, which uses the loop as one leg of a balanced bridge circuit. Any vehicle crossing the loop unbalances the bridge circuit, and this produces a change in the signal amplitude which is used to indicate vehicle presence. The third type is the phase-shift detector, which is similar to the self-tuning type and uses the pavement loop as part of a parallel-tuned circuit. However in this detector, the change in the relative phase shift in the tank circuit, which is produced by a vehicle changing the loop inductance, is used as an indication of vehicle presence. A more detailed description of these three electomagnetic loop-vehicle detectors follows.

2.1.1 Self-tuning detectors

The self-tuning detector uses both a pavement loop as part of a parallel resonant tank circuit and also a closed-loop feedback circuit which automatically adjusts a voltage-tuned oscillator to a predetermined frequency relative to the resonant frequency of the tank. Any change in the loop inductance shifts the resonant frequency of the tank circuit, which in turn causes a change in the feedback voltage. This change is used to provide an indication of vehicle presence, usually by energizing a relay. The a-c voltage versus frequency response of the tank circuit is the resonance curve associated with a parallel resonant-tuned circuit. The frequency at which maximum voltage occurs is the resonant frequency of the combination of the loop inductance plus the lead-in inductance, in parallel with the fixed capacitance of the lead-in and fixed capacitors in the detector package. The a-c voltage across the tank circuit is rectified, filtered, and fed to one input of a d-c differential amplifier. A reference voltage is applied to the other input of the amplifier and is used to establish the detector-operating point on the resonance curve. This voltage is amplified, passed through a time-delay network, and used to control the frequency of the oscillator. The polarity of feedback is such that when the loop inductance changes, the oscillator frequency will be driven in the direction which will maintain the same operating point on the resonance curve.

When there is no vehicle over the loop, the detector will self-tune to point A (as shown in Fig. 1) on the low frequency side of the resonance peak. A vehicle present in the loop field will decrease the self-inductance of the loop, increasing the resonant frequency from f_1 to f_2. This shift causes an instantaneous decrease in the tank voltage, causing a step-increase in the output of the d-c amplifier. This voltage is delayed by the time-constant circuit before it is applied to the voltage-controlled oscillator. The difference between the input and output signal of the time-delay circuit is derived by the comparator circuit and is used as a pulse-presence signal. This difference is maximum at the instant a vehicle enters the loop, and will gradually reduce to zero if the vehicle remains on the loop. The rate at which the voltage equalizes depends on the time constant of the delay circuit and the loop gain of the feedback circuit. By varying the time constant of the delay circuit, the pulse-presence time can be altered. Increasing the loop gain of the feedback loop reduces the pulse-presence time.



SOLID LINE - RESONANT CURVE OF TANK CIRCUIT WITH NO CAR ON THE LOOP
DOTTED LINE - RESONANT CURVE OF TANK CIRCUIT WITH CAR ON THE LOOP
A - OPERATING POINT WITH NO CAR ON THE LOOP
B - OPERATING POINT WITH CAR ON THE LOOP
ΔA - THE DROP IN RELATIVE AMPLITUDE
ΔF - THE SHIFT IN RESONANCE FREQUENCY

Figure 1 SELF-TUNING LOOP OPERATION

In designing a detector of this type, the Q of the tank circuit must be kept sufficiently low that the combination of the lead-in impedance variations, plus the maximum change in loop inductance expected because of the presence of a vehicle, does not cause the operating point to be forced over the resonant peak. This will cause positive feedback and force the detector into saturation.

2.1.2 Bridge-balance detectors

The bridge-balance loop-detector technique uses the inductance of the loop mounted in the pavement as one leg in a bridge circuit. The other leg of the bridge is a fixed inductor having approximately the same inductance and Q as the pavement loop (see Fig. 2). The unbalanced voltage, developed as a vehicle drives over the loop, is fed to the input of a high-gain a-c amplifier. Two other signals which serve as fine balance voltages are also fed into this amplifier. One of the two reference voltages used to develop the balancing signals is shifted in phase by 90 degrees. Therefore, the two balance controls R_1 and R_2 can be used to balance out both small resistive and reactive differences between the loop and the reference inductance. During operation, the output of the amplifier is nulled by a combination of switching in the proper reference inductance and adjusting R_1 and R_2. The gain of the amplifier is then adjusted so that the passage of a vehicle causes an amplifier output sufficient to activate the level detector, which in turn energizes the relay driver and relay.

2.1.3 Phase-shift detectors

The phase-shift technique, which is probably the most widely used in loop-vehicle detectors, uses a loop energized from an oscillator circuit, which is generally crystal-controlled for stability purposes. Typical operating frequencies vary between 85 and 115 kHz. The loop is tuned to resonance with respect to the oscillator-operating frequency by a variable tuning capacitor connected in parallel with the loop. This variable capacitor generally consists of a bank of fixed capacitors connected to a set of selector switches, which in most cases is located in the detector itself, so that the inductive portion of the tuned circuit includes the self-inductance of the lead-in.

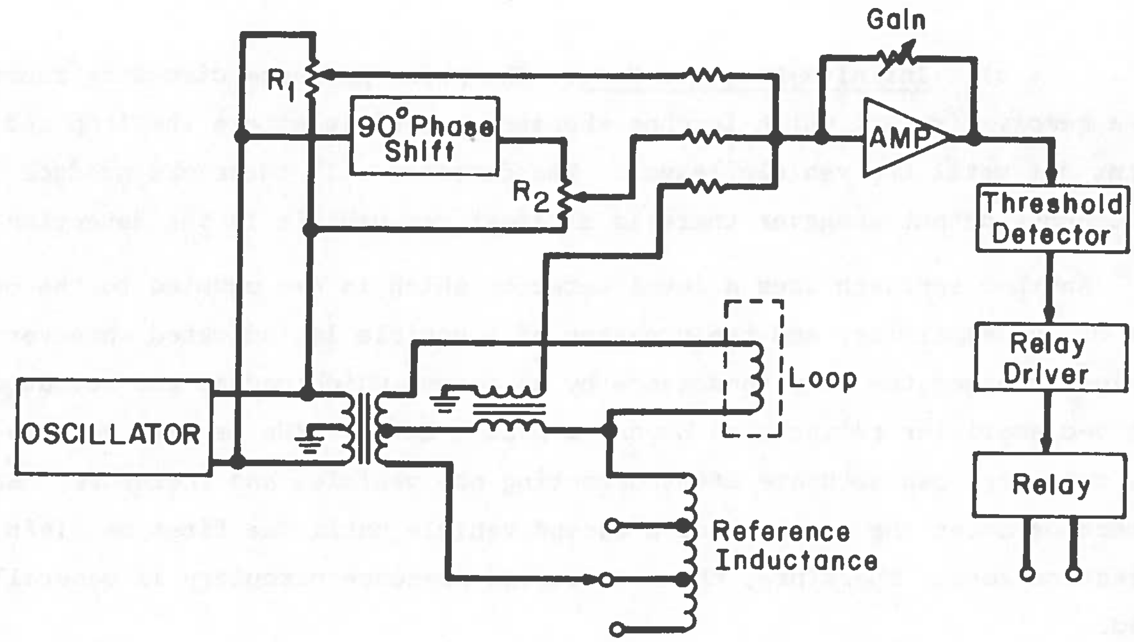


Figure 2 BRIDGE-BALANCE LOOP DETECTOR

The phase of the voltage in the loop-tank circuit is compared to a reference signal derived directly from the oscillator, so that when a vehicle moves within the field of the loop and detunes the tank circuit, the resulting phase shift produces a change in output from the phase-detector circuit. This output is amplified by a variable-gain d-c amplifier, and then fed into an a-c coupled pulse-presence circuit. In many of the phase-shift loop detectors, the pulse-presence circuitry can be operated in various modes which are selectable by means of a front panel switch. Possible modes are:

a) Presence Mode. A short pulse (1/2 to 1 second) is generated whenever a vehicle moves into the detection area, causing a sharp positive increase in the d-c amplifier output. This output drives the relay driver, and the relay contacts close for approximately the same length of time.

b) Limited-Presence Mode. Essentially, the limited-presence mode is the same as the pulse-presence circuitry, except that the time intervals are longer. Typical interval lengths are 5 minutes for the short mode, 10 minutes for the medium mode, and 40 minutes for the long mode.

c) Infinite-Presence Mode. The pulse-presence circuitry functions as a memory circuit, which latches whenever a vehicle enters the loop and remains set until the vehicle leaves. The detector will therefore produce a continuous output whenever there is at least one vehicle in the detection area.

Another approach uses a level detector which is d-c coupled to the output of the amplifier, and the presence of a vehicle is indicated whenever the vehicle changes the loop inductance by an amount which causes the output of the d-c amplifier to increase beyond a preset level. THe problem here is that the cuiruitry can saturate after detecting one vehicle, and therefore, cannot detect or count the presence of a second vehicle until the first has left the detection zone. Therefore, the a-c coupled presence circuitry is generally used.

2.2 Magnetic-Vehicle Detectors

One type of magnetic detector consists of a single winding of a large number of turns of wire on a ferr-magnetic core and detects the remnant magnetic field carried by a vehicle as a result of its prior movements in the earth's magnetic field (operating as the ship detectors used in magnetic-mine fuses). The signal signature will therefore vary as a function of the speeds and directions of travel of a vehicle prior to its approaching the detector.

The other magnetic-detector principle (the magnetometer) measures the minute local increase in the earth's magnetic-field intensity caused by the presence of a vehicle. The small cylindrical magnetometer probes buried at the monitored sites sense magnetic-field intensity and convert it to an electrical signal. That signal is then conducted via electrical cable to a central electronic unit which accomplishes vehicle presence/absence discrimination. The magnetometer unit has three windings on a core: (a) the sensing winding, (b) an excitation winding, and (c) a bias winding. The sensor-unit configurations for magnetic and magnetometer detectors are shown in Figure 3. The following discussion pertains to magnetometer detectors.

Most magnetometer detectors have several operating modes:

a) Presence. Channel actuation is maintained for the full period of time a vehicle is sensed at any site monitored by the channel.

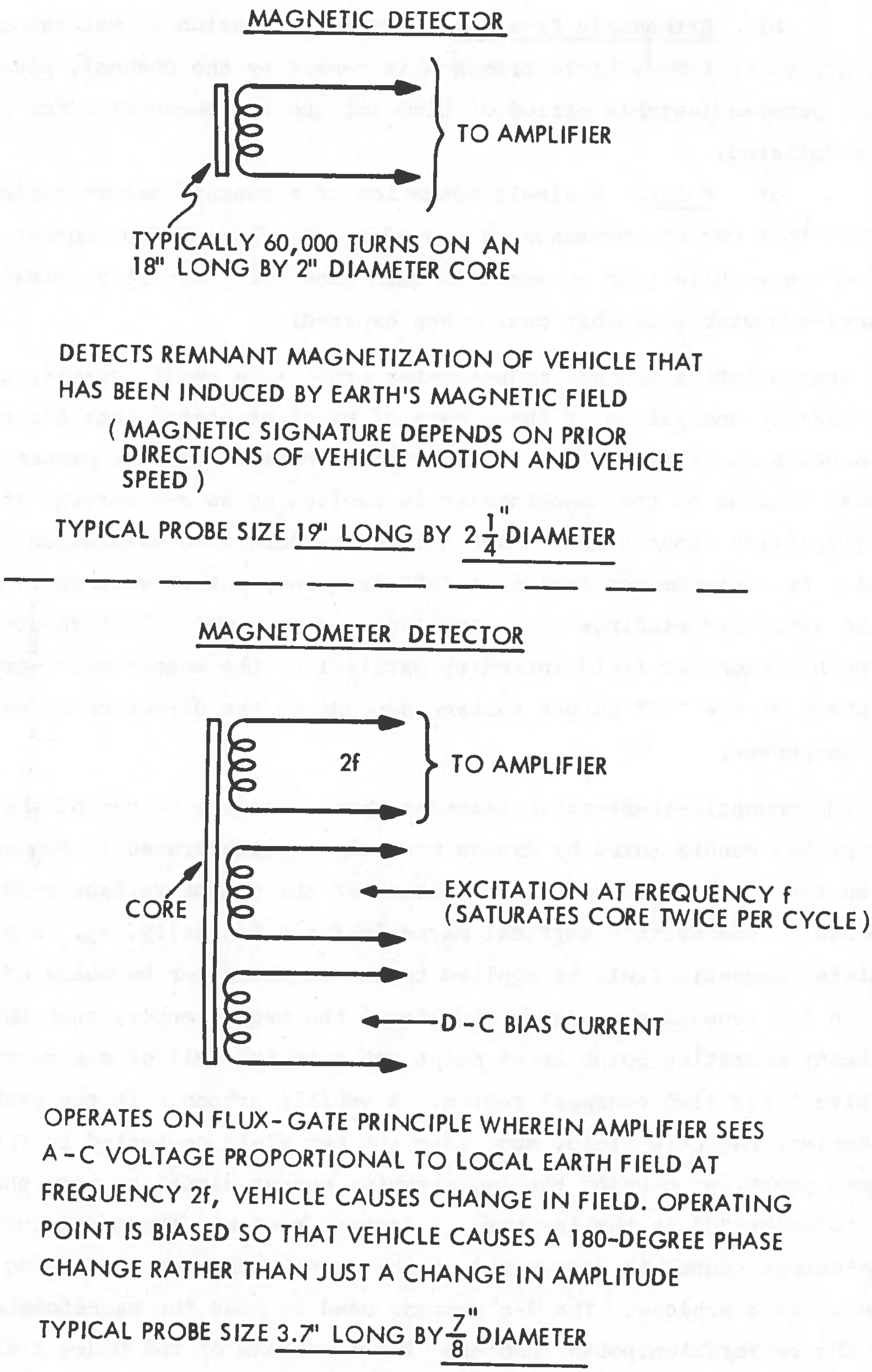


Figure 3 MAGNETIC SENSOR-UNIT CONFIGURATIONS

b) Extendable Presence. Channel actuation is maintained for the full period of time vehicle presence is sensed by the channel, plus an additional panel-adjustable period of time (of about 5 seconds) after presence has terminated.

c) Pulse. A single actuation of a channel occurs during the first 75 msec that vehicle presence is sensed by the channel (subsequent actuation cannot occur while that presence is maintained or after it terminates until a panel-adjustable inhibit period has expired).

Sealed into a typical magnetometer probe is a small, stable, transformer-like element consisting of three sets of windings placed over a core material which has been treated to obtain special saturable magnetic properties. The primary winding of the magnetometer is excited by an a-c current at a frequency "F" (typically about 5 kHz) which drives the core into saturation twice per cycle. By magnetometer action, a "2F" frequency-output voltage is developed in the secondary windings whose amplitude is proportional to the component of earth's magnetic-field intensity parallel to the magnetometer-probe axis. The phase of the "2F" output voltage depends on the direction or polarity of this component.

The magnetic-to-electric transfer characteristic of one of the magnetometer probes manufactured by Canoga Controls is illustrated in Figure 4. Point "A" on the curve indicates the magnitude of the output voltage produced in response to the earth's vertical magnetic-field intensity, H_V. A precisely regulated magnetic field is applied to the magnetometer by means of d-c current in its secondary windings and biases the magnetometer, such that its quiescent operating point is at point "B" near the null of the curve in the negative field (180 degrees) region. A vehicle presence at the probe adds to the ambient magnetic field, such that the net field presented to the probe becomes positive, causing the magnetometer output signal to pass through the null to point "C" in the in-phase (0 degree) region. The phase change in the probe-output signal is recognized at the central unit as indicating the presence of a vehicle. The d-c current used to bias the magnetometer comes from the calibration potentiometer, The magnitude of the biase field required depends upon the intensity of the ambient field. The process of calibration is, in effect, one of adapting the probe to the local magnetic environment.

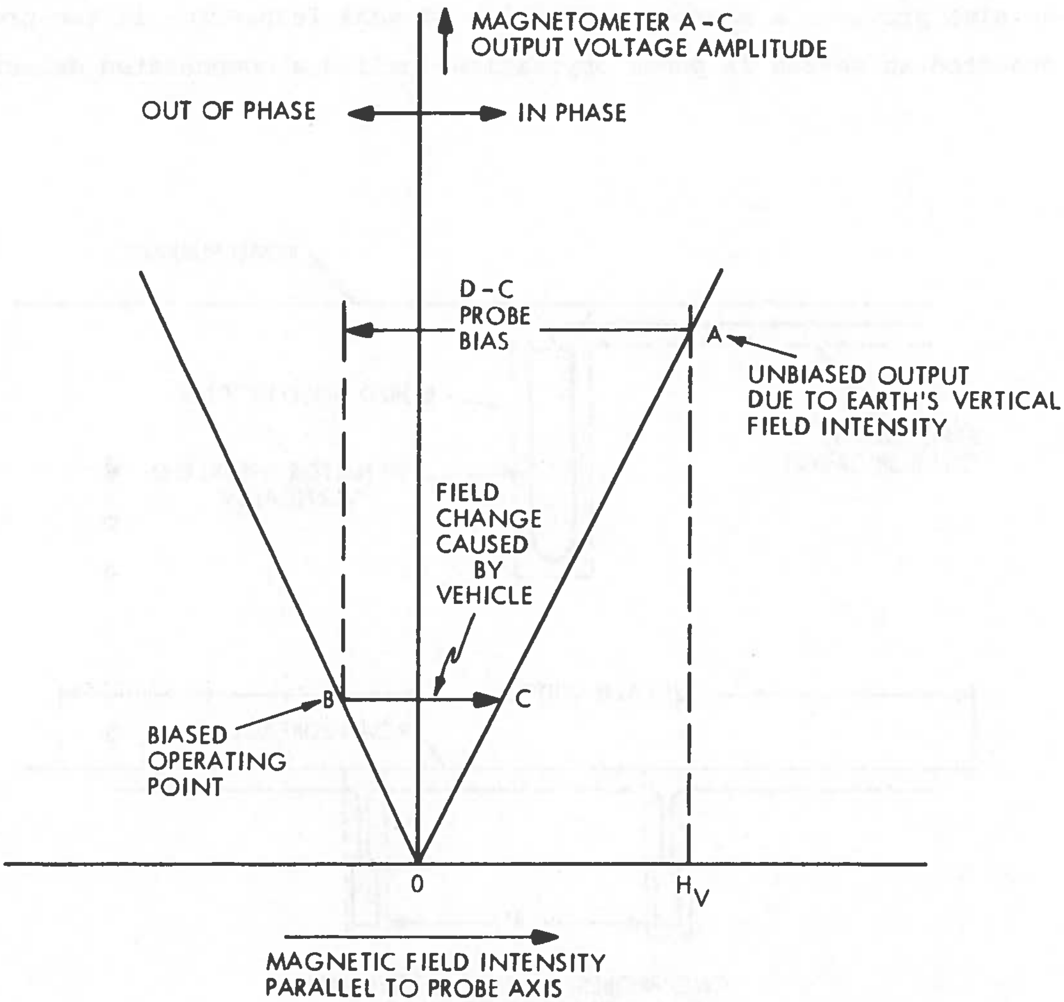


Figure 4 MAGNETOMETER OPERATION

Typical installation of magnetic detectors is shown in Figure 5. As shown, a typical detection zone for a magnetic-or-magnetometer detector is about a 4-foot diameter, thus at least two probes are needed to cover fully a 12-foot travel lane. Probes can be paired in the travel direction (usually about 1 foot apart) to provide direction discrimination if needed. Such pairing also provides a sharper indication of vehicle passage if two probes are connected in series in phase opposition (called a compensated detector).

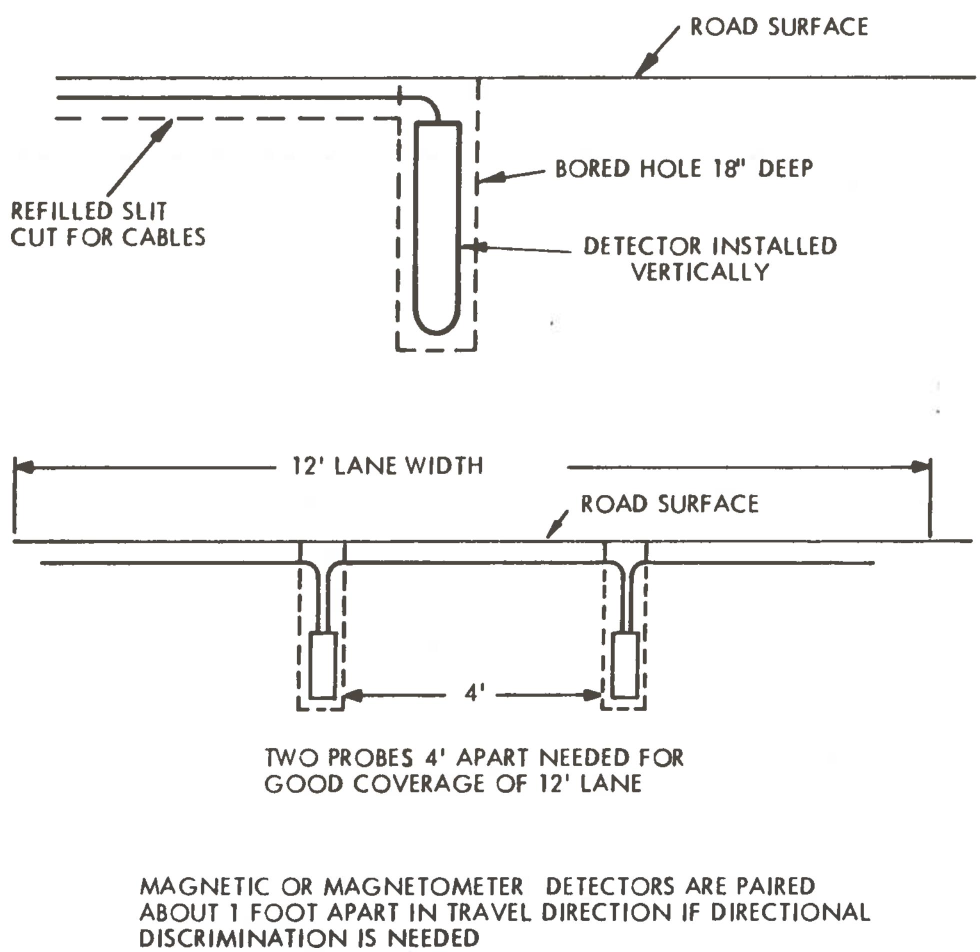


Figure 5 MAGNETIC-AND-MAGNETOMETER DETECTOR INSTALLATION

2.3 Magnetic-Gradient Vehicle Detector

The magnetic-gradient vehicle detector (MGVD) is a recent concept and has yet been only installed on an experimental basis,[1] but it also seems to have good possibilites for developing into a usable detector which selectively combines the characteristics of loop-and-magnetic detectors to produce a detection area which is narrow in the longitudinal travel direction and wide in the lateral direction, and has a much greater percentage signal change as a result of vehicle presence than a loop detector (which may result in more stable operation once installed and adjusted). The MGVD differs from the magnetic- and-magnetometer detectors in that it is "active" -- it induces currents in the vehicle structure, and senses the fields created by those currents.

A typical MGVD[1] consists of a 208.3 cm (82 inches) X 3.81 cm (1.5 inches) X 1.27 cm (o.5 inch) transducer, dual triaxial "lead-in" cables, and roadside-detector electronics. The transducer is installed in a 1.52 cm (0.6 inch) wide X 4.45 cm (1.75 inches) deep slot in the pavement surface, transverse to the direction of vehicle travel. As a vehicle approaches the transducer, eddy currents are induced in the vehicle's undercarriage, front, and possibly side surfaces, and the resulting magnetic field is sensed by the transducer. A simplified configuration diagram is shown in Figure 6 (not shown is a coil-matching network contained in the detector unit).

The MGVD operates basically as follows: A 500-mA peak-to-peak sinusoidal current is generated at 100 kHz by a crystal-controlled, constant-current transmitter. The transmitter signal is transformer-coupled to a triaxial cable which connects to a transmitter coil in the transducer enclosure. The magnetic field generated by the transmitter coil induces approximately equal voltages in the two differentially connected colinear receiver coils (connected in phase opposition), such that the sum voltage of the two coils is near zero. Eddy currents induced in any nearby conducting material generate a magnetic field, which couples into the receiving coils, such that the induced sum-voltage signal of the receiving coils is much larger than zero.

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[1] Superscripts refereto references.

When a large target like a vehicle is detected, a maximum voltage of 5 mV is available at the output of a receiver coil-matching network. This low-level voltage is transmitted by the receiver triaxial cable to a tuned transformer-coupled 100-kHz receiver (1 kHz, 3dB bandwidth). In the receiver, the signal is amplified with a gain of 30,000 and converted to a d-c level by a peak-to-peak detector. The resulting d-c level is threshold-detected and used to drive a relay-indicating detection. An alternative mode of detection is to sense the phase of the receiver signal as compared to the transmitter signal. The output of the phase detector is integrated and threshold-detected.

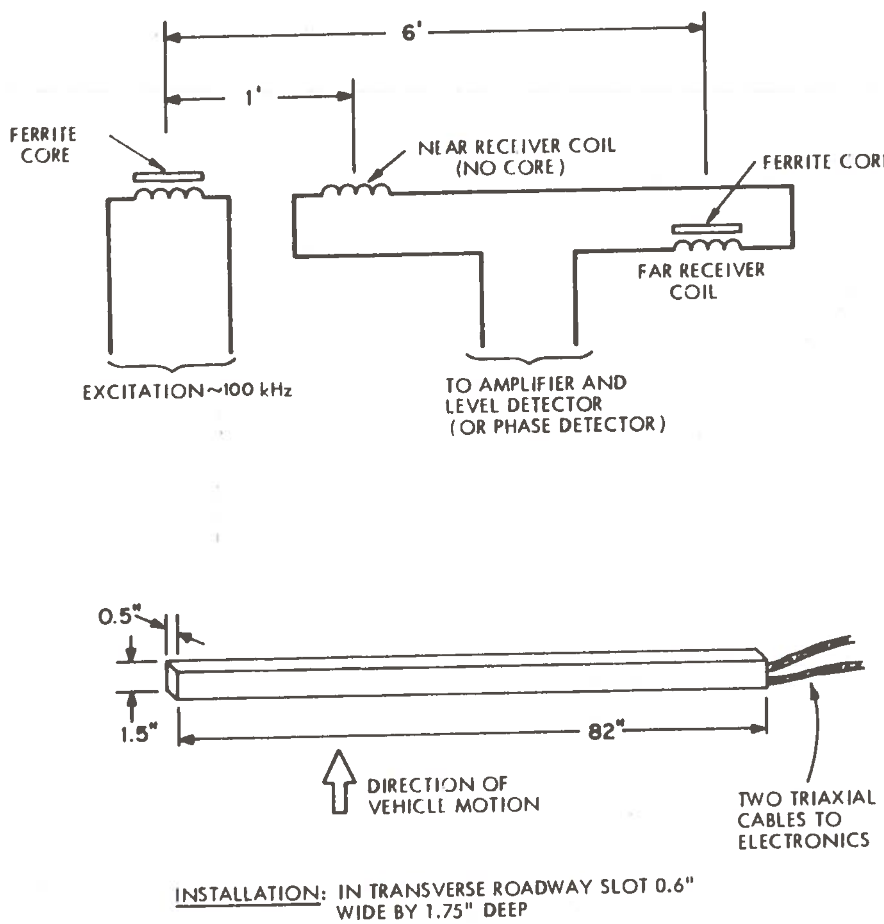
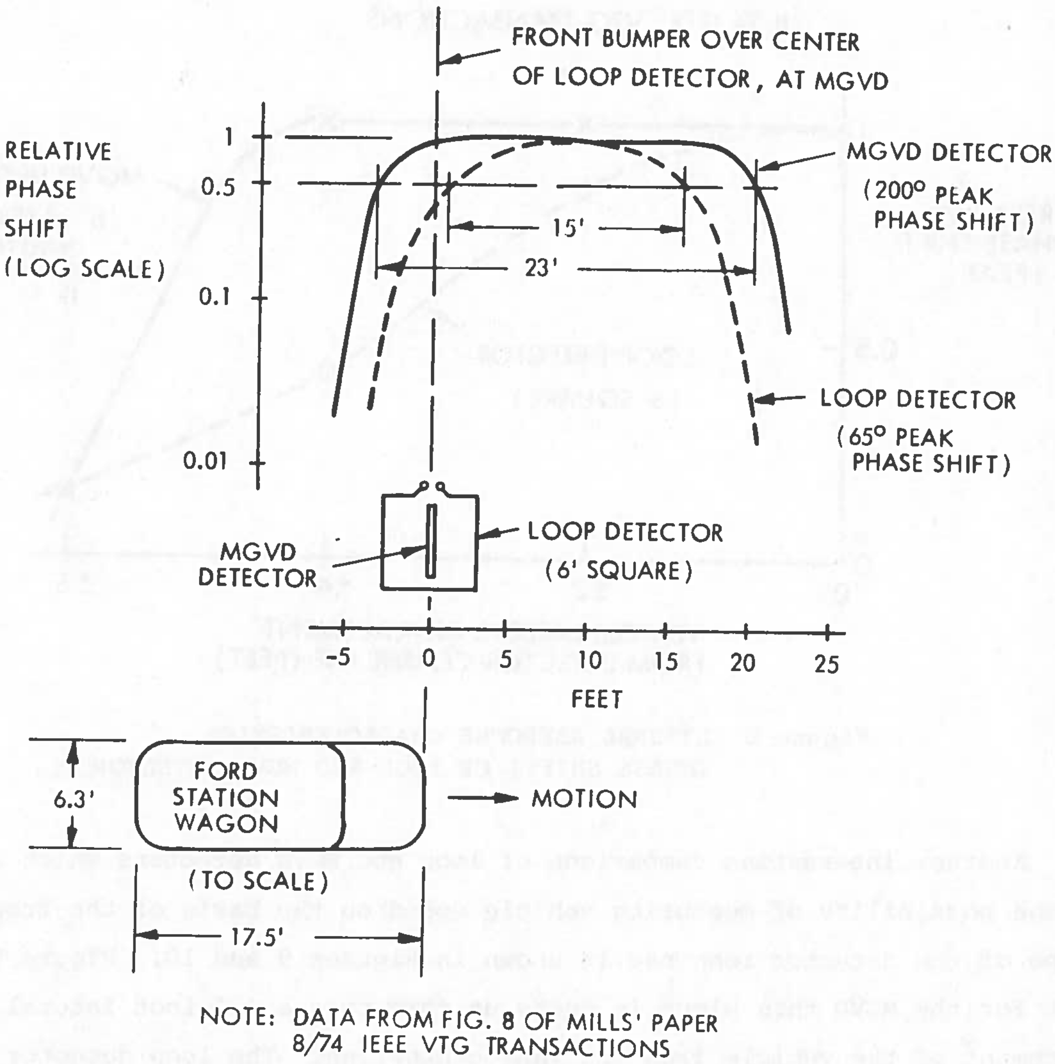


Figure 6 MAGNETIC-GRADIENT VEHICLE DETECTOR

It is of interest to compare the detection characteristics of the MGVD with that of a typical six-foot-square loop, using data published by Mills,[1] the developer of the MGVD. Figure 7 compares the longitudinal responses for a loop detector and an MGVD, and illustrates that the MGVD develops full output at the front bumper, and maintains it until the rear bumper, whereas the loop develops full output only when it is located under the center of the vehicle.



NOTE: DATA FROM FIG. 8 OF MILLS' PAPER
8/74 IEEE VTG TRANSACTIONS

Figure 7 CENTERLINE (ZERO LATERAL OFFSET) PHASE-SHIFT RESPONSES OF LOOP AND MGVD DETECTORS

Figure 8 illustrates the greatly improved lateral detection characteristics of an MGVD compared to a loop detector. For a 7-foot (82 inches) MGVD, full output is maintained for vehicles offset up to ± 4 feet from the lane centerline, and output falls sharply thereafter (desirable to prevent adjacent-lane detection). The loop output however falls off almost linearly with lateral displacement, making it difficult to obtain good full-lane coverage without also detecting vehicles in adjacent lanes.

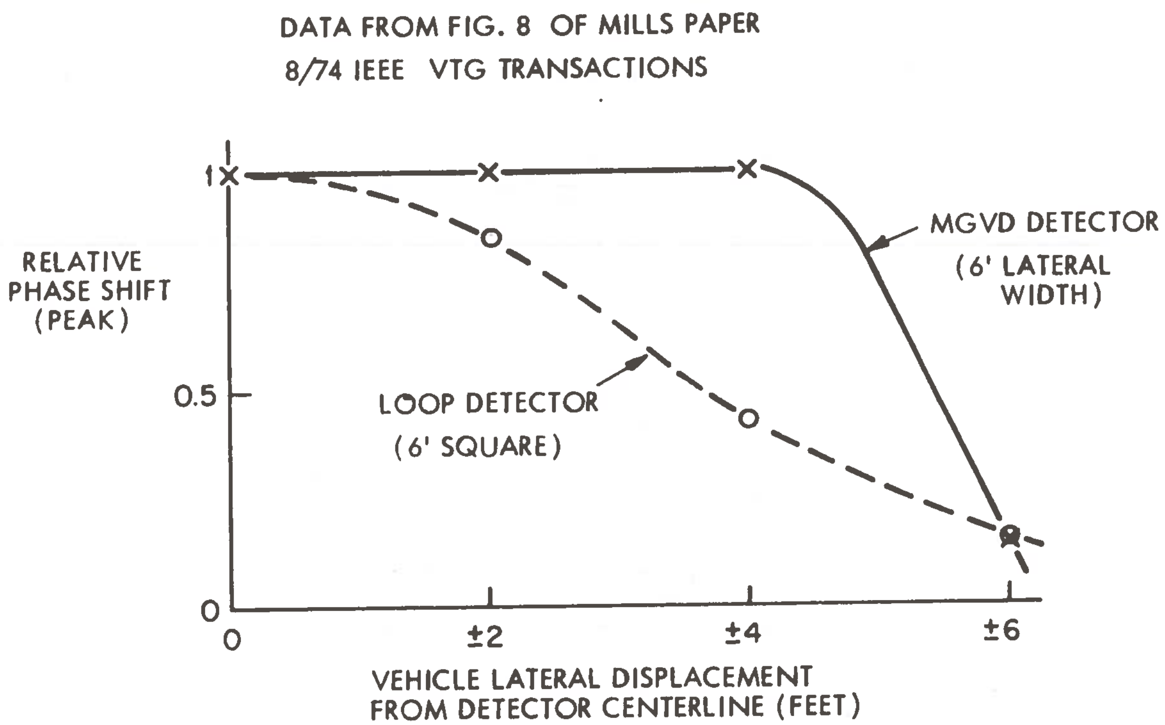


Figure 8 LATERAL RESPONSE CHARACTERISTICS (PHASE SHIFT) OF LOOP AND MGVD DETECTORS

Another interesting comparison of loop and MGVD detectors which relates to the possibility of measuring vehicle speed on the basis of the front-end slope of the detector response is shown in Figures 9 and 10. Figure 9 shows that for the MGVD this slope is quite uniform over a ± 4-foot lateral displacement of the vehicle from the lane centerline. The loop detector has a non-uniform lateral response characteristic (see Fig. 8), and this results in the front-end slope of the loop detector varying almost linearly with lateral displacement (Fig. 10 shows that the slopes for centerline and ± 4 feet vary

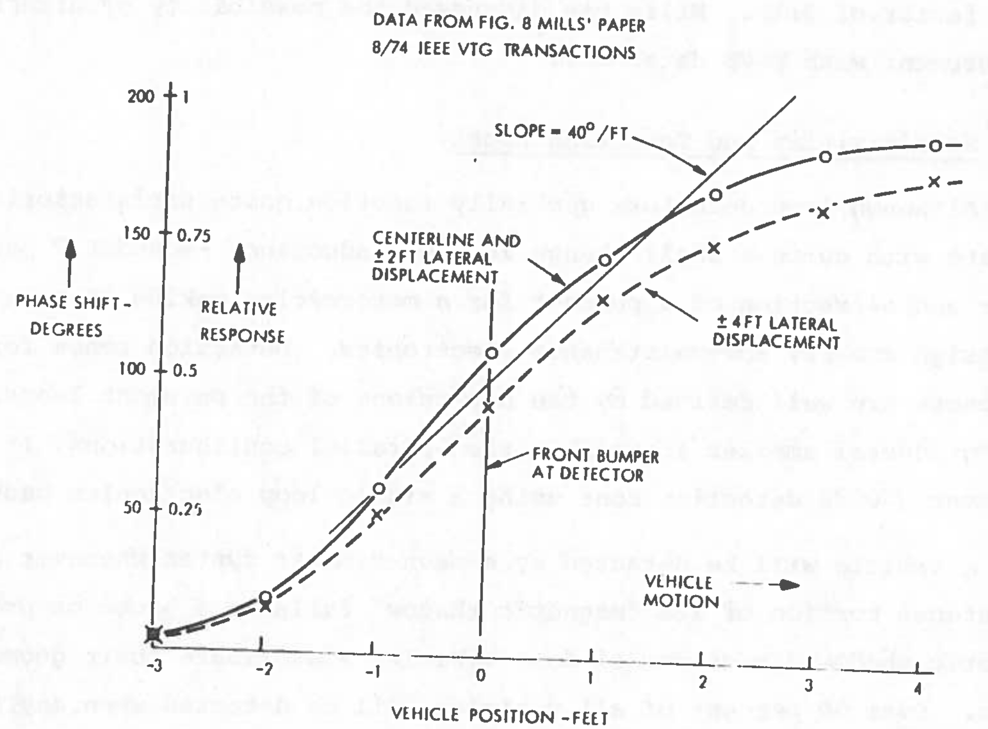


Figure 9 FRONT-END SLOP OF PHASE-SHIFT RESPONSE FOR MGVD DETECTOR

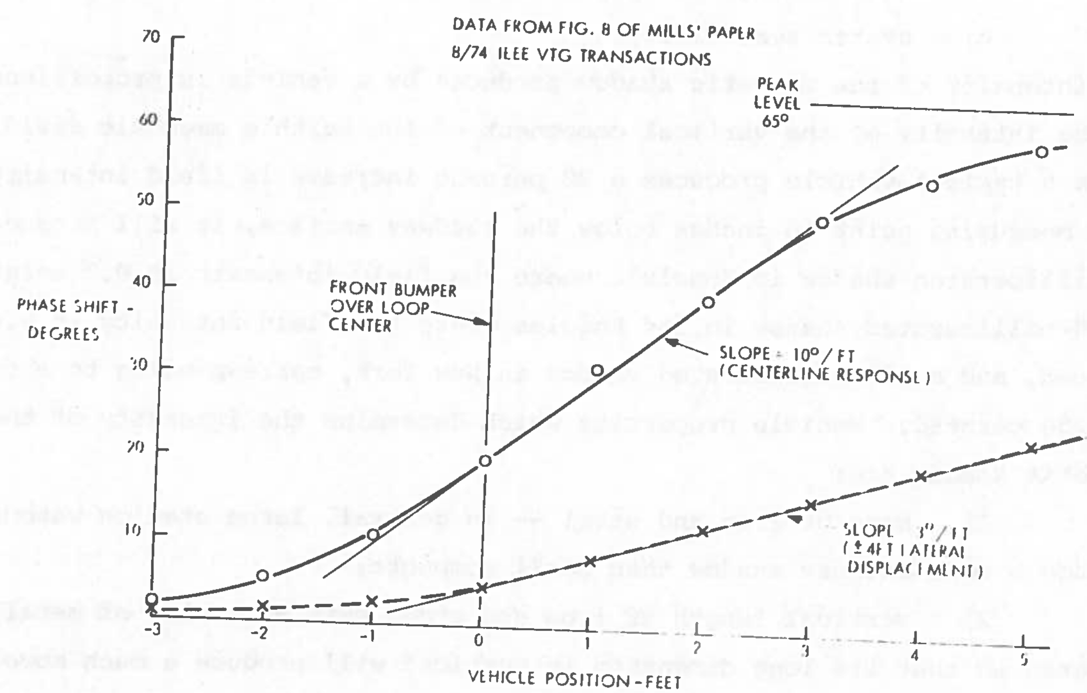


Figure 10 FRONT-END SLOP OF PHASE RESPONSE FOR LOOP DETECTOR (6-FOOT SQUARE)

by a factor of 3:1). Mills has discussed the possibility of direct speed measurement with MGVD detectors.[1]

2.4 Sensitivities and Detection Zones

Although loop detectors generally function quite satisfactorily, they operate with quite a small change in loop inductance -- about 2 percent for a car and a fraction of a percent for a motorcycle, making it more difficult to design stable, low-maintenance electronics. Detection zones for loop detectors are well defined by the dimensions of the pavement loops. By combining several smaller loops in series-parallel configurations, it is possible to cover a wide detection zone using a single-loop electronics package.

A vehicle will be detected by a magnetometer system whenever a sufficiently intense portion of its "magnetic shadow" falls on a probe or probes. The magnetic shadow dimensions of most vehicles approximate their geometric dimensions. Over 90 percent of all vehicles will be detected when any portion of the vehicle's body overhangs the probe. The sufficiency of magnetic shadow intensity is determined by three factors:

a) ambient field intensity,

b) vehicle magnetic properties, and

c) system sensitivity.

The intensity of the magnetic shadow produced by a vehicle is proportional to the intensity of the vertical component of the earth's magnetic field. Since a typical vehicle produces a 20 percent increase in field intensity at a measuring point 18 inches below the roadway surface, it will produce a 40-millioersted shadow in Honolulu where the field intensity is 0.2 oersted, an 84-millioersted shadow in Los Angeles where the field intensity is 0.42 oersted, and a 108-millioersted shadow in New York, corresponding to a field of 0.54 oersted. Vehicle properties which determine the intensity of the magnetic shadow are:

1) mass of iron and steel -- in general, large station wagons produce a more intense shadow than small compacts,

2) vertical length of iron and steel mass -- a slab of metal, oriented so that its long dimension is vertical will produce a much more intense shadow than the same slab will with its long dimension horizontal,

3) height of the mass -- the closer the measuring point is to the mass, the greater the shadow intensity (intensity approximately doubles when probe depth is decreased from 18 to 6 inches),

4) remnant magnetism -- determined by factors in the production, use, and repair of the vehicle (proximity to large man-made electromagnetic field also), and

5) electromagnetism caused by current flow in the electrical equipment of the vehicle.

To show the effect of system sensitivity, suppose a given system has a pre-set channel sensitivity which is more than 4 times that necessary to detect a typical vehicle at the 0.42-oersted ambient vertical field level in Los Angeles. Now in a single-probe-per-channel arrangement, the entire channel sensitivity is available at the one probe. But as the number of probes per channel is increased, the sensitivity at each probe is decreased, such that $S_p = S_c/N$, where S_p = probe sensitivity, S_c = channel sensitivity, and N = the number of probes per channel. For example if four probes are connected to a channel, total channel sensitivity remains unchanged, but the sensitivity at each probe will be reduced to one-fourth of the channel sensitivity. Therefore in the four-probe-per-channel arrangement at Los Angeles, each probe alone will have sufficient sensitivity to detect the magnetic shadow of the typical vehicle. However in a similar eight-probe-per-channel arrangement where the probe sensitivity is one-eighth of the channel sensitivity, it will be necessary that the magnetic shadow fall on at least two of the probes simultaneously.

Since virtually all automobiles, busses, trucks, etc., are wider than 5 feet, a single probe centered in a lange provides good performance in lanes of 10 feet in width. This same setup in a 12-foot lane will allow a few small vehicles at extreme lane positions to be missed so it is then advisable to use two probes placed no farther than 5 feet from each lane boundary. Motorcycles, bicycles, and the like have narrow magnetic shadows and require correspondingly closer spacing of probes. Spacings of 18 to 30 inches have proven satisfactory for this application.

3. RADAR-AND-ACOUSTIC VEHICLE DETECTORS

Radar-and-acoustic detectors are generally more expensive on an installed-cost basis than the detectors described in section 2, and must be mounted either over or alongside the roadway (requiring structures). On the other hand since they operate by reflecting energy off a vehicle, they can be designed to measure speed directly via the Doppler effect as well as provide presence information.

The detection zones for radar-and-acoustic detectors are in general described in terms of lane coverage as opposed to the fairly rigidly defined zones associated with loop detectors, magnetic detectors, and MGVD's. Radar detectors can be oriented so as to cover from one to three lanes, and acoustic detectors have single- or dual-lane-coverage capability.

3.1 Radar Detectors

Two classes of radar detectors will be described: presence detectors and speed-responsive detectors.

3.1.1 Radar-presence detectors

Radar-presence detectors operate by beaming continuous-wave (CW) microwave energy on an area of roadway from an overhead transmitter and detecting the energy reflected by vehicles. By comparing the transmitted energy with the energy reflected from a moving vehicle, a Doppler beat note for a 2.45 -GHz radio frequency (rf) is approximately 7.3 Hz per mile per hour, corresponding to vehicle movement in line with the rf transmission. If the antenna is mounted over the roadway and beamed essentially down on the roadway, either slightly toward oncoming or departing traffic, the resultant Doppler is subjected to a reduction by the cosine of the angle between the direction of travel and propagation of the RF wave. When V is expressed in miles per hour and at 2.45 GHz, the formula for the Doppler beat note F_D is $F_D = 7.31V\cos\theta$.

Under the above conditions, a vehicle traveling under the antenna will intercept waves such that the cosine of the angle goes through 90 degrees.

The resultant Doppler frequency response in the detector goes through very low values approaching zero, regardless of the speed of the vehicle under the antenna. If one limits the maximum frequency response of the receiver to a very low value on the order of 7 Hz, the unit can be made to respond only when vehicles travel under the antenna. Because the antenna assembly may be a broadside multiple-dipole array designed to provide radiation patterns having from 20 to 60 degrees between half-power points, the antenna can be mounted at a convenient height of from 16 to 20 feet above the roadway and still illuminate from one to three lanes of traffic.

3.1.2 Speed-responsive radar detectors

The most common form of the vehicle radar-speed sensor is the radar-speed meter. It is constructed electrically the same as the simple radar detector just described but there are two major differences in its method of operation. First, the r-f signal is kept in line with the direction of travel of the target vehicle, with the cosine of the angle very close to 1; and second, there is a substitution in the output of a frequency meter calibrated to read linearly in miles per hour. There are also automatic radar-speed sensors which provide output pulse lengths inversely proportional to speed. This form of output is readily transmitted over conventional telephone lines and is in a form desired for processing in central-processing computers.

In a speed-responsive detector, the Doppler signal is divided into a low-frequency portion, indicative of the detection of a passing vehicle, and a high-frequency portion, indicative of the speed of the passing vehicle, and the high-frequency speed portion is blocked until the low-frequency portion has terminated. The speed portion is then received while the vehicle travels a known distance, and the length of time required for the vehicle to travel this distance is a measure of the vehicle speed. The location of the radar-sensor antenna is the same as for the simple-presence detector with the additional restriction that the beam be directed downstream to provide the sequence of low-frequency Doppler signals followed by the high-frequency Doppler signal.

There are two major electrical design differences between this radar-speed sensor and the simple radar-vehicle detector: the speed sensor requires an elliptical antenna pattern because even though only one lane of the roadway is illuminated, the vehicle echo must extend for a considerable distance downstream in the direction of travel (one such antenna pattern uses half-power points of 20 and 90 degrees), and considerably more logic is needed for processing the Doppler beat note because of the separate processing of the high- and low-frequency components.

3.2 Acoustical Vehicle Detectors

Acoustical vehicle detectors are also of two types: presence- and motion-sensing. They differ from radar detectors in that because of the much slower speed of propagation of sound waves in air, it is practical to use pulse-ranging for presence detection, rather than as in the radar detectors having to detect when a Doppler beat passes through zero although the same principle can also be used acoustically. Motion (speed) detectors do use the Doppler principle however.

Acoustic motion detectors operate by sensing the shift in the frequency of an ultrasonic tone which occurs when the tone is reflected from a moving vehicle. The transceiver produces a signal at approximately 18 kHz which is beamed from an ultrasonic transducer into the desired vehicle-detection zone. The presence of a moving vehicle in this zone will cause the beam to be reflected back to a separate receiving transducer at a frequency different from that of the transmitted signal because of the frequency shift created by the Doppler effect. If the vehicle is stationary, no shift occurs. Shifts in frequency caused by the Doppler effect are directly proportional to the vehicle speeds through the relation $\nu = \nu_0(1 + \frac{V}{C})$. If one lets $\frac{V}{C} = \beta$, then $\beta > 0$ means that the vehicle is receding.

The detector consists of an electronic transceiver and a sensing head. The sensing head contains separate transducers for transmitting and receiving, and may be located either on a mast arm or a span wire over the traffic lane, or on a structure mounted at the shoulder of the road (for this side-fire mounting, the head should be 6 to 8 feet above the road surface). The head is connected by cable to the electronic equipment which may be remotely located (up to 200 feet away) in a weatherproof cabinet. In most instances, the sensing head is aimed toward the oncoming traffic. Signals reflected from approaching traffic are shifted higher in frequency, and those from departing vehicles are shifted lower in frequency. Therefore by detecting only signals shifted higher in frequency and ignoring all other signals, directional detection is obtained.

Acoustical vehicular detectors have two unique electrical design requirements. Firstly, in order to provide overall system signal-to-noise requirements in the ultrasonic range, the excitation of the transmitting transducer should be approximately 5 volts into 10 ohms at 18 kHz. Highly efficient electromechanical transducers are required to provide the electrical-to-acoustical energy transfer for propagation of the wave in air, and conversely, the conversion of the received acoustical- to electrical-energy. Secondly, the transmitting- and receiving-transducers should have a beam-width of a minimum of 20 degrees between half-power points.

Presence-responsive acoustical detectors operate by pulse-ranging (the same principle as conventional radar-and sonar-equipment) except that the transmitted energy packet is in the low-ultrasonic 19 kHz range. The time for the roundtrip of the transmitted signal to the target vehicle and back to the receiver is measured. Any target within the gated range will produce an output, and for this case, a single transducer can be used for both the transmission pulse and the received signals. The velocity of sound in air of approximately 1 foot/msec is used to range-gate if a target is located within a selected distance from a transmitter-receiver unit.

Transducer requirements are the same as for the motion-responsive acoustical detector. An acoustical lens may be placed in front of the transducer element to modify the nominally circular beam pattern of about 18 degrees between half-power points to an elliptical beam with its long dimension laterally across the roadway (typical beamwidths longitudinally and 30 degrees laterally across the roadway, both between half-power points). This permits two lanes to be covered with one transducer. Also, transducers associated with the presence-responsive units are beamed either straight down (vertically) or perpendicularly across (horizontally) the roadway. This insures that a minimum Doppler shift is imparted to the received signal, allowing a narrow bandwidth to be used in the receiver to improve the signal-to-noise ratio.

4. GENERAL COMPARISONS

The purpose herein is to present some general comparisons of the detectors described in sections 2 and 3 on the basis of overall operational capabilities, comparative ease (or difficulty) of installation, and economic considerations. The data to be presented are not new and are mostly drawn from several previously published studies.

Table 3, which is basically the same detector evaluation done by Barker,[2] and Table 4 which is taken directly from Mills,[3] together gave a very good comparison of the various types of detectors. Even though these tables depict circumstances existing five years ago, they are still quite valid. Although the actual prices of various types of detectors (including installation costs) are now higher than they were five years ago, the relative prices (say, an inductive loop detector compared to a magnetometer) are approximately the same. (Note in Table 3 that the figures with asterisks indicate two detectors in sequence in the travel direction.)

The general thrust of the literature which has been examined in the study indicates that acoustic, pressure-sensitive, and radar detectors are generally regarded as inferior to electromagnetic loop detectors, MGVD's and magnetometers in terms of traffic-control applications. Table 3 shows that these types of detectors rate lower on the average than the loop- and magnetic-detectors in terms of performance, and Table 4 shows that installation time and costs are greater for these types of detectors. Information on various acoustic and radar detectors available today is included in appendix A. The remainder of the discussion is a more detailed comparison of magnetometers, loop detectors, and MGVD's since they appear to be the viable detectors of the future.

At the present time, inductive-loop detectors are the most widely used of all the various types. However, Table 3 shows that the performance of magnetometers puts them in the same class with loop detectors, and other magnetic detectors in general are just a little below this level. At the time of the Barker article,[2] the MGVD was non-existent (thus, it is not shown in

TABLE 3 -- DETECTOR EVALUATION

Type	Single-Lane Count	Direction	Single-Lane Coverage	Multi-Lane Coverage	Speed	First Cost and Install.
Inductive-Loop	1	1* 4	1	1	2* 2	1
Magnetic	1	3* 4	2	1	3* 4	1
Magnetometer	1	1* 4	1	2	2* 2	1
Radar	2	2* 4	2	1	1	3
Sonic	2	2	2	2	2	3
Pressure-Treadle	1	1	1	2	1* 2	2

Type	Ease of Install.	Ease of Maint.	Tolerance to Envir.	Tolerance to Interference	Reliability and Life	Power Req.
Inductive Loop	1	1	1	1	1	2
Magnetic	1	1	1	1	1	1
Magnetometer	1	1	1	1	1	1
Radar	2	2	1	1	2	2
Sonic	2	2	2	1	2	2
Pressure-Treadle	3	1	2	1	2	2

Notes: 1 = Good, 4 = Unsatisfactory
* = Two detectors in sequence in travel direction.

TABLE 4 -- DETECTOR COST COMPARISONS
(1970 FIGURES)

Type	Installation Time	Cost to Install	Detector Cost	Total Cost
		$ dollars $		
Pressure Treadle	2-3 Days	625	250	875
Magnetic	4-12 Hours	200-300	200	400-500
Magnetometer	3-4 Hours per Hole	235	175	410
Sonic Radar	2-3 Hours (If Pole Exists)	100-700	500	600-1200
Inductive Loop	2-4 Hours	385	175	560

Table 3), but recent research and tests have shown that it is also in the same class with loop detectors. In fact, Mills[1] shows that the MGVD has several advantages over the loop detector. These advantages are:

a) reduced transducer installation time and costs (since installation costs will tend to increase with rising labor rates, this is an important point);

b) greater sensitivity; i.e., maximum phase shifts of 170 degrees from an MGVD transducer output compared to 68 degrees from a 6-by-6 inch inductive loop when detecting a station wagon, see Figure 7 (the necessity for sensing bicycles and motorcycles places difficult sensitivity requirements on loop detectors);

c) improved detection stability allows direct coupled (infinite presence) mode of operations, which is independent of vehicle speed and results in improved accuracy in measuring vehicle pulse length; i.e., vehicle pulse length from loop detectors is not independent of vehicle type and speed because of the time constant associated with a-c coupling;

d) detection sensitivity is essentially independent of "lead-in" cable length, whereas loop-detector sensitivity decreases proportionally to "lead-in" cable length;

e) improved accuracy in determining vehicle speed from a single transducer by processing the rise time of the signature using a constant slope versus vehicle position, which is assumed because of the approximately vertical front of the bodies of most vehicles (i.e., the MGVD detects the entire undercarriage of a vehicle and initially detects the vertical front section of the vehicle body, the resulting signature from the vehicle is less complex and changed by vehicle lateral position than the signature obtained from loop detectors);

f) the possibility of uniquely identifying and classifying vehicles by processing vehicle amplitude and/or phase signatures from an MGVD transducer;

g) the possibility of one- and/or two-way communication between the detector system and a vehicle because of isolated transmission and reception means in the transducer (i.e., emergency vehicles could be identified by transmitting a coded signal to the MGVD, and appropriate traffic control commands could be transmitted by the MGVD); and

h) the amplitude detection zone of the MGVD is less sensitive to large targets near the sensing strip than targets at least one foot away, which allows partial rejection of wire mesh near the sensing strip.

The MGVD is still under development by the Federal Highway Administration, but such positive early results appear to forecast a bright future for MGVD's.

Table 5, prepared by Hulscher,[4] is a useful comparison between an inductive-loop detector and a flux-gate magnetometer. From this chart, it is obvious that the magnetometer is at least the equal of the loop detector and possibly superior. The main advantage that the inductive-loop detector has is that a loop configuration can be chosen to cover a large detection zone, whereas the area-detection capability of a single magnetometer is restricted, and many transducers are required for extended area coverage. Therefore, the cost of a magnetometer system can be greater than that for a comparable loop-detector system depending on the desired area of coverage.

No matter how detailed one makes a comparison between inductive-loop detectors, MGVD's, and magnetometers, a final decision favoring one of these types for a particular application cannot be reached without extensive information regarding the physical makeup of the desired detection zone (width of lanes, strength of the pavement, etc.), how the detector will be used (to indicate presence, passage, speed, or any combination thereof), and economic considerations.

TABLE 5 -- COMPARISON BETWEEN INDUCTIVE LOOP AND FLUX-GATE MAGNETOMETER DETECTORS

Property	Magnetometer	Inductive Loop
Detection Criterion	Detection zone depends on magnetic outline of vehicle. Nonferrous metals not detected. Ambient field must exceed 16A/m (0.2 oersteds)	Detection zone closely matches geometric outline of metal bod
Area-Detection Capability	Restricted- many transducers required for extended area coverage.	Good - loop configuration can be chosen desired detection zone
Point-Detection Capability	Good - owing to small aperture view of traffic.	Poor - sensitivity suffers for very compact loops
Nature-of-Detection Phenomenon	Bipolar (cannot be self-adaptive for presence operation)	Unipolar (can be self-adaptive)
Inherent-transducer Sensitivity	Good - the average vehicle causes a 20-percent increase in magnetic-flux density. This is amplified by the switching characteristic of the saturable core.	Poor - the average vehicle causes a 2-percent decrease in inductance (in a 11 m^2 loop). A small motorcycle causes only a 0.01-percent decrease in inductance
Signal/Noise Ratio of Transducer Output	Good in most environments	Poor in most environments
Memory Time	Infinite and independent of vehicle speed	Less than 30 minutes for average traffic; less than 5 minutes for small motorcycles at speeds above 1 km/
Resolution (Lane-to-Lane and Bumper-to-Bumper)	High resolution owing to its small aperture view of traffic, enhanced by magnetic-depletion effect of vehicle	Inherently poor resolution owing to area coverage of loop, especially for loops which are no longer than vehicle-vehicle spacing.

TABLE 5

(Continued)

Property	Magnetometer	Inductive Loop
ffect of Pavement uality	Can be installed in inferior-road pavements	Pavement quality must be high for good loop life
ffect of Metals Below avement Area	Not affected by (homogeneous) metal environment	Sensitivity can be severely reduced by subterranean metal objects
ransducer ulnerability	The transducer is typically located 0.3 m below the pavement surface; depth of transducer cable does not affect operation	Loop wire vulnerable to damage as transducer sensitivity is highest at the pavement surface
ktent of Weakening of avement Caused by Trans-ucer Installation	Less than for loop (using sawcut for transducer cable)	More than for magnetometer (depends on loop configuration)
imatic Influences	Immune to effects of rain, snow, ice, or temperature	Sensitive to interference of weather
nteraction Between djacent Transducers	No interaction	Inherently subject to interaction but the effect can be overcome by suitable design
ximum Permissible paration Between ansducer and Elec-onic Unit	1500 m	From 90 to 370 m depending on design and tolerable reduction in sensitivity
nsitivity to Magnetic-eld Variations	Sensitive to magnetic-field variations; effect of a-c fields at power frequencies can be minimized by suitable design	Insensitive to magnetic fields, but strong fields at power frequencies will cause desensitizing
nsitivity to Elec-ic-Field Variations	Immune to radio-frequency noise	Sensitive to radio-frequency fields
sceptability to ghtning Damage	Extremely low risk owing to small pick-up area	Large pick-up area of loop can receive destructive energy from lightning discharges

TABLE 5

(Continued)

Property	Magnetometer	Inductive Loop
Setting-Up Procedure	Manual threshold setting is critical for presence operation	Can be made entirely sel-fadjusting
Effect of Main's Power Interruption	Immediately operational	Incorrect operation may occur until electronic threshold level has been set
Radio-Interference Generation	No risk. Maximum conversion efficiency occurs about 60 kHz, but operating frequency is kept well below this figure to allow good separation between transducer and electronic unit	Slight. Maximum conversion efficiency occurs in the range from 10 to 100 kHz

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APPENDIX A

TYPICAL DETECTOR SPECIFICATIONS

1. INDUCTIVE LOOP DETECTORS

a. International Prodata Systems Corp., Prodata PR 73

1) Completely automatic and continuously self-tuning over an inductance range from 40 to 800 μH.

2) Answer-back feature: The proper functioning of all detectors can be checked periodically by a test signal created and sent out by the control computer. A working detector replies to such a test signal by momentarily inverting its present output; i.e., if it were indicating no occupancy it will and vice versa.

3) Detectors may be located up to a thousand feet away from their loops, because of low-detector frequencies and small-phase angles only the inductive component of the lead-in cable impedance is effective.

4) Environmental changes affecting the inductance of loop or lead-in cable have no influence on the operation of the detector.

5) Fail-safe relay closure provides output in case of power failure.

6) Presence indicator is a burn-out proof LED mounted on the printed circuit board.

7) Automatic tuning period is less than two seconds and is shown by the indicator light being on during that time.

8) Sensitivity 0.1 percent, optional 0.02 percent; the sensitivity is maintained continuously over the entire operating range from -30 degrees to 75 degrees C.

9) Three presence modes: pulse (100 msec.), medium (10 min.), and 20 (min.).

10) Recovery time after a vehicle occupancy is very short, typically one-thousandth of the occupancy time.

11) Available in nine fixed frequencies with a frequency separation of 4 Khz. Because of the large number of fixed frequencies there will be no interference between adjacent loops. Frequency ranges from 24 to 56 kHz.

12) Detection speed from 1 to 150 mph.

13) Available in two versions, either in individual metal housing with front-mounted controls and self-contained power supply, or as a space-saving printed circuit board with or without its own line-power supply. Both versions have integral lightning protection.

b. LFE Corporation (Automatic Signal Division) Model LD-215B

1) Detectors will operate loop and lead-in systems whose composite inductance falls between 20 and 700 μH.

2) Depending on dimensions, the loop may be located up to 1000 feet from the detector.

3) Circuit design combines exceptional detection sensitivity and reliability with a high degree of immunity to roadway reinforcement and ambient-temperature variations.

4) Fail-safe design furnishes a constant detection signal in the event of loss of power to the unit.

5) Tuning: by means of single knob and indicator light, on front panel only upon installation - external tools, meters not required (indicator light also serves as detection-signal indicator). Once tuned, the unit automatically tracks inductance changes up to 5 percent.

6) Sensitivity: 3-position switch selectable - maximum (normal), medium or minimum (used to ignore adjacent-lane vehicles, bikes or other objects) - in accordance with operating requirements at intersection. Maximum is 0.02 percent change in loop inductance. Provides positive detection of all types of vehicles from motorcycles to tractor-trailer combinations.

7) Presence: 3-position switch selectable-maximum, medium or minimum. - proportional loop size, speed and length of vehicle. Maximum exceeds one hour at 1 percent inductance change, 2 minutes at 0.05 percent inductance change. Presence switch controls the rate at which detector tracking circuits cause the unit to tune out a stationary vehicle over the loop. "Maximum" is normally used except in special applications, where it is desirable to restrict the time in which the detector responds to a stationary vehicle over the loop. Subsequent vehicles passing over the unoccupied portion of the loop are detected after the stationary vehicle has been tuned out.

8) Operating frequency: in range from 25 to 170 kHz-selectable by 3-position made switch. Allows two or more detectors to operate in same cabinet without interaction.

9) Lightning protection for the loop, line, and earth circuits is self-contained within the unit.

c. <u>Canoga Controls Corp</u>. <u>Proximitor 104</u>

1) Automatically and instantaneously self-tuning, no burn-in or warm up is required. Unit tunes itself during the time that the operator installs its mating connector. Also self-tunes immediately following a power failure or significant voltage fluctuation. Continuous tracking or environmental changes.

2) Inductance range: the maximum loop and lead-in inductance which can be connected to a channel depends on which sensitivity setting is used. In high sensitivity, the inductance limit is 500 μH. In normal sensitivity, the inductance limit is extended to 2,000 μH. There is no minimum inductance limit.

3) Detectors may be located up to a thousand feet from the loops.

4) Sensitivity: high-sensitivity setting is generally required for detection of small motorbikes. Normal setting is used for (a) elimination of bicycle and small motorbike detections, (b) desensitization to avoid unusual environmental noise conditions such as underground trains, locally buried high-current wires, etc., (c) eliminate detection of undesired vehicles such as may be encountered when loops are positioned too near adjacent traffic movement.

5) Two operating modes, pulse or presence. In pulse mode, each new vehicle produces an output pulse of 225-millisecond duration. A vehicle remaining over a loop for more than 2 seconds is instantly "tuned out" allowing uncompromised operation of other loops connected on the same channel. In presence mode, "call" output duration corresponds to the period of vehicle presence over a loop. Vehicle hold times exceeding one hour can be achieved.

6) No crosstalk: High-rate sequential scan, activating one channel at a time eliminates crosstalk. No padding or other frequency selection ever required.

7) Speed range from 0 to 80 mph.

8) Output options: Designed to allow factory incorporation of any one of four different output switching options; relay (fail-call), relay (fail-no call), solid state, or optically isolated solid state. Relay - particularly suitable for heavy-duty applications or for switching loads of indeterminate polarity. In either version, a vehicle presence is indicated by contact closure. The two versions differ in the output state that will result during a power failure. The relay (fail-no call) version has open contacts.

Solid state: Offers the dual advantages of electronic switching speed and greatly extended output device life. It is particularly suitable for interfacing with solid-state equipment, either digital or analog.

Optically isolated solid state: Intended to interface with digital equipment and computers, this option offers a floating logic compatible output.

Lightning protection: Special circuits guard each channel.

Broken-loop alert mode: During normal detector operation, the state of the output indicator corresponds exactly to the state of the output transistor or relay. The presence of a vehicle will cause the output to be conducting and the indicator to go on. If, however, a loop circuit is ever broken on a particular channel, then that channel will automatically go into alert mode. The output for that channel will continuously call in the case of relay units and will intermittently call in the case of solid-state units. Alert mode can be defeated on unused channels by shorting the loop-input terminals for that channel.

9) Temperature range: from -35° to 165°F.

d. Sarasota Engineering Sales Limited Mark 15 Series Vehicle Detectors

1) Tuning range: Loop and feeder-system inductance from 20 to 700 μH.

2) Sensitivity: Detects 0.02 percent inductance change. The sensitivity control adjusts the level at which the detector will respond to reductions in the loop plus feeder inductance. In the maximum sensitivity position, the detector will respond to a change in inductance of 0.02 percent, in the medium position a 0.1 percent change will be detected and the minimum position the detector is sensitive to a 15 percent change.

3) Temperature stability: Range from -40° to 70°C.

4) Detectors can be supplied either as individual boxed units or as plug-in modules.

5) Tuning is accomplished in a simple, two-step operation using the 22-turn "tuning" knob and the "set-up" switch. Only one initial tuning is required. Thereafter automatic tuning circuits keep the 15 tuned in. A pilot light indicates detection.

6) Three-position "sensitivity" and "presence" time controls allow adjustment for special conditions.

7) Two-position "mode" switch provides positive frequency separation. The sensitivity control adjusts the level at which the detector will respond to reductions in the loop plus feeder inductance. In the maximum sensitivity position, the detector will respond to a change in inductance of 0.02 percent in the medium position a 0.1 percent change will be detected and in the minimum position the detector is sensitive to a 0.5 percent change.

8) Lightning protection: Zener-diode protection for over-voltage induced on loop leads. Flash-over protection from internal circuit to earth. Line filter.

9) The "presence" switch enables the operator to adjust the time for which the presence of a vehicle will be detected. The presence time given depends on the amount of change in inductance caused by the vehicle, which in turn depends on the size of the loop, the length of the feeder, the type of vehicle and its position over the loop. If a "presence" switch is fitted, the presence time in maximum position will be at least 2 hours for a 2 percent change, in the medium position it will be 10 minutes, and in minimum position 1/2-minute.

10) Frequency range: From 20 to 160 kHz.

11) Lead in cable length: To 1,000 feet.

Mark 16 Series Dual Vehicle Detectors

Ideal for situations requiring two independent detectors in one housing. For example, a vehicle-actuated traffic-signal controller might use one detector for the main road and the other for the side road.

Mark 16L: Designed for applications where it is necessary to distinguish between vehicles moving in opposite directions. Two loops are installed and if they are actuated in the sequence AB, one of the output relays operates, but the other relay will operate if a vehicle crosses the loops in the BA direction.

Mark 16S: Contains two detectors that have been carefully matched for speed-measuring applications. Mark 16 series detectors have basically the same operating specifications as the Mark 15 series.

Mark 225S and 225D Inductive Loop Detectors

The Mark 225S and 225D models are based on the Mark 15 series except that the Mark 225S is capable of sustaining a presence output up to 30 seconds (from 0 to 30 seconds adjustable range) after a loop becomes unoccupied and the Mark 225D does not give a presence output until a vehicle has occupied its loop continuously for more than a preset time (from 0 to 30 seconds adjustable range). When the vehicle leaves the loop, the output will cease and the loop must again be occupied for more than the preset time before another output is given. In both of these models, it is possible to inhibit the timers so that the units function as ordinary presence detectors. Basically, same operating specifications as Mark 15 series except for extended temperature range: from -20° to 70° versus from -40° to 70°C.

2. MAGNETOMETER VEHICLE DETECTOR SYSTEMS

a. Canoga Controls Corp., Proximitor II-S

1) Operating mode: Three modes are available. Presence -- "call" is held throughout vehicle presence -- for unlimited time. Extended presence -- "call" is held for a panel-selected time (from 0 to 5 seconds) after the vehicle leaves. Pulse -- "call" is a single 30- to 50-millisecond pulse for each new detection.

2) Over one-mile probe to central unit cabling distance capability.

3) Sensitivity

Probe Location: The number of probes required per lane and their optimum crosslane position is determined by the lane width and the size of vehicles to be detected. Per-probe sensitivity decreases as the number of probes per channel is increased. Each channel shall be sufficiently sensitive to detect a Schwinn "Varsity" bicycle passing across any location along a continuous 4-foot span when the channel is connected to two probes buried 18 inches and spaced 3 feet apart along the span. Using three probes per lane, each channel shall be capable of detecting automobiles in up to four traffic lanes.

Probe depth: Optimum depth of probes is determined by the type of detection required. Deep placement, from 10 to 24 inches, results in good continuous detection even for slowly moving vehicles. Shallow placement provides increased sensitivity, but in the case of slow-moving vehicles, 20 mph or less, may yield some multiple counts. "Tube" probes (installed in 1-inch diameter bored holes) used for deep placement applications and "tag" probes (installed directly in roadway surface saw slots) used for shallow placement applications.

4) Each channel shall detect vehicles traveling at speeds from 0 to 100 mph.

5) Parked or stalled traffic over probes of one channel shall have no effect on the operation of the other channel. Also, damage to probes or associated cable of one channel shall have no effect on the operation of the other channel.

6) Output options: Designed to allow factory incorporation of any one of three different output switching options: relay, solid-state, or optically isolated solid-state.

7) Operates properly at temperatures from -30° to 160°F at relative humidity to 99 percent and when probes are exposed to power line a-c magnetic fields to 100-millioersted peak-to-peak.

8) Central Unit Dimensions

Height 2 3/4 inches
Width 5 1/2 inches
Depth 9 1/4 inches.

3. <u>ULTRASONIC DETECTORS</u>

a. <u>General Railway Signal Co.</u>

<u>Chekar Type T-SVDM Vehicle Motion Detector</u>

Chekar is a general-purpose, solid-state detector which provides dependable detection of moving vehicles with useful ability to discriminate direction of motion. Ideal for use with vehicle-actuated traffic signals. Detects approaching vehicles moving at speeds as low as 2 mph, yet offers a high degree of immunity to any receding vehicle entering the detection zone. Detection of a vehicle deenergizes an output relay which in turn may be used to operate a signal controller, traffic counter, or similar device. With no vehicle approaching in the detection zone, the relay remains energized. Normally energized relay operation is used so that in event of a blow fuse, or interruption of a-c power, the detector "fails safe;" that is, the relay releases to place a continuous call, thus permitting traffic to move.

1) Temperature Range: from -20 to 160°F, ambient.

2) Coverage (range) Two lanes-overhead or side-fire.

3) Cable Length: not more than 200 feet recommended. Transceiver dimensions 3-1/2 inches high, 10 inches wide, and 9 inches deep.

<u>Chekar Type USD-SCP</u>
(Sensing-Classification-Presence Detection)

<u>Speed-Sensing</u>: Each time a vehicle passes beneath the USD-SCP sensing unit, relay contacts close in the transceiver. One relay operates for passenger cars; two, for trucks. Contact closure-time span is directly proportional to vehicle speed and length.

<u>Classification</u>: Every vehicle, regardless of height, causes the passenger car (all-vehicle detection) relay to operate as it passes beneath the sensing unit. A truck or any vehicle which is higher than the height as adjusted for all-vehicle detection causes the truck (high-vehicle detection) relay to operate also.

<u>Presence detection</u>: The relay operation can, of course, also control counting devices and traffic-actuated signals. The USD-SCP is a true-presence detector vehicle. Motion is not necessary. One gets reliable, consistent detection of

every vehicle that enters the targeted area, under all conditions, moving at expressway speeds or at a standstill.

1) Temperature range: from -20 to 165°F, ambient.

2) Coverage: (range: single traffic lane).

3) Cable length: Not more than 400 feet recommended.

4) Automatic circuitry compensates for sound-velocity changes caused by temperature variations.

5) High-noise immunity rejects transients, operates reliably even in high-noise environments. Transceiver can be installed in the same cabinet with a-c powerlines, controllers, flashers, and other signal equipment. No special shielding required.

6) High-lightning immunity - no special protective devices needed.

Type SOP Ultrasonic Detector

1) Detects the presence of vehicle within a predetermined spotting zone.

2) Can provide two distinct types of service: (a) conventional vehicle detection, as for signal actuations, and (b) accurate measurement of vehicle-occupancy time, such as required for a computer input to enable lane-occupancy percentage, and average lane-speed computations from data supplied by the detector.

3) Features positive occupancy detection regardless of vehicle speed - a sharply defined and controllable detection zone with no "miss" areas, and high-noise immunity.

4) For accurate measurement of vehicle occupancy time, the detector is installed overhead to monitor a single traffic lane. Features a fixed reset time following the last vehicle-detection pulse - the duration of each detection is an accurate indication of the time required for the vehicle to pass through the coverage zone, plus a 200-millisecond pulse extension. Average lane speed computed from detection time.

5) Transceiver automatically compensates for temperature variations to allow for sound-velocity changes.

6) Environmental immunity: rejects transients, operates reliably in high electrical noise surroundings - man-made or by nature. No special

shielding or protective devices are needed. Transceiver can be installed in the same cabinet with a-c powerlines, traffic controllers, flasher, etc.

7) Temperature range: from -20° to 165°F, ambient.

8) Detection range: Adjustable up to 16 feet in diameter for overhead installation (detects vehicles on 26 foot roadway). For side-fire installation, adjustable from 9 to 40 feet from sensing unit for vehicles up to 80 mph. Transceiver Dimensions 3-1/4 inches high, 10 inches wide, and 7-1/4 inches deep.

b. LFE Corporation Sonic Vehicle Detector
(Model SPDR-1)

Registers the presence or passage of vehicles in one or more traffic lanes of a roadway. Ideally suited for vehicle detection in an actuated traffic-signal application, traffic-counting, and traffic-monitoring, or surveillance. Adjustment of the detection zone (from 9 to 26 feet for mast-mounted transducer or side-fire) as well as length of response after the vehicle has departed the detection zone is accomplished by controls on the front panel without the need for tools or meters.

1) Temperature range: from -30° to 170°F.

2) Coverage: One or two lanes.

3) Cable length: Up to 400 feet.

4) Fail-safe design furnishes a constant detection signal to the control equipment in the event of loss of power to the unit. Transceiver dimensions: 3 inches high, 6 inches wide, and 10-3/8 inches deep.

4. RADAR VEHICLE DETECTORS

a. LFE Corporation Radar Vehicle Detector
(Model RD-2)

Registers the passage of moving vehicles in one or more traffic lanes. All types of vehicles will actuate the detector, but pedestrians, parked cars, and extraneous noise will not. Produces two short sensing impulses per vehicle - one when the vehicle enters the detection zone and another when it leaves. This eliminates overlapping or loss of impulses from other detectors connected on the same traffic phase. In addition, a "pulsing" feature enables the RD-2 to compensate for heavy traffic in two or three adjacent lanes. Pulsing is at a rate of one every 1-1/2 seconds - as long as there is continuous movement in the detection zone. This feature assures maximum operating efficiency in volume-density controller application under severe overload conditions with slow-moving "bumper-to-bumper" traffic.

1) Coverage: Beamwidth adjustable to cover one, two or three lanes effectively.

2) Speed range: For one or two 12 foot lanes - from 2 to 80 mph.

3) Transmitter frequency: 2.455 Gigahertz.

4) Maximum recommended distance between the sensitivity control assembly and the detector is 80 feet but may be increased to 150 feet if no other power or signal cable is included in the same conduit.

APPENDIX B

SPEED-MEASURING AND ANALYSIS SYSTEMS

a. Sarasota Sales Ltd.

The Speed Measuring Systems (SMS II) - gives a digital readout of the speed of each vehicle crossing its loops by processing the time delay between the operation of the two detectors. Accuracy is better than 2 percent and the unit can be calibrated in either kilometers per hour or miles per hour. A camera-trip module gives a contact closure for every vehicle which exceeds the speed set on its dial. To ensure that the relevant vehicle is in the correct position for the photograph, the camera-trip output can be delayed by up to 50 msec.

The Speed Analysis System (SAS) - comprises several speed discrimination units (maximum speed detectors) with their outputs fed to counters. The threshold speed of each unit is adjustable by means of a switch on its front panel and by setting these switches to different values on each unit, the number of vehicles passing in various speed bands can be recorded. The SAS is ideally suited to applications where it is necessary to know the percentage of vehicles passing in various speed bands.

The Coding Unit - Performas almost the same function as the speed analysis system, but the output information is presented in the form of a three-bit binary number. Vehicle speeds are grouped into seven equal bands.

Example:	No assessment	000
	0 - 20 k.p.h.	001
	20-40 k.p.h.	010
	40-60 k.p.h.	011
	60-80 k.p.h.	100
	80-100 k.p.h.	101
	100-120 k.p.h.	110
	120	111.

Available Options

a. The output can either be updated by each vehicle or it can be given only upon receipt of a "read" signal, when it would be relevant to the last vehicle that had passed.

b. The "read" and "output" signals may either be 5 v positive logic or alternatively impedance changes, so that the logic equipment may be separated by up to 500 meters of line from the other data terminal. In this case, high voltage (up to 50 v) signals can be used to reduce the effects of noise pickup on the lines.

c. A count output is also provided.

The coder would be applicable where a continuous monitoring of traffic speed was required, when the data would typically be transmitted to a computer. Alternatively, the data could be stored by decoding the outputs and feeding them to counters or traffic recorders. The measurement accuracy of this device is about 98 percent.

Automatic Signal Modular Solid State Master Control Equipment for Coordinated and Traffic-Actuated Systems

Model M-200 Volume Computer: Provides a running average volume indication. Selector switch provides choice of averaging times from 1 to 10 minutes. Meter calibrated in percent with 12 position selector switch providing range of adjustment from 400 to 4800 actuations per hour at 100 percent reading.

Model M-210 Density Computer: Provides short-term density for single detector location by dividing average volume measurement by average speed. Scale from 0 to 200 vehicles per lane.

Model M-220 Speed Computer: Contains provision for measuring and indicating "last-car" speed by actuation of pushbutton. Normally, provides running average of measured speeds. Scale calibrated from 0 to 100 mph. Selector switch provides means for adjusting the "number of cars" averaged for running indication of average speed.

Model M-230 Density Averaging Computer: Averages the output of two or more M-210 Density Computers. Equipped with "response-time" switch for selection of "averaging time" from 1 to 10 minutes in 1-minute steps. Scale: from 0 to 200 vehicles per lane.

b. International Prodata Systems Corporation

Prodata PR 250 Time Matrix Recorder

Data Acquisition: The PR 250 records data on a standard 9-track magnetic tape which allows an average data rate of about 1600 detector signals per second. This is the speed at which the system records data on tape. The maximum input rate is much higher, allowing up to 1,000 inputs per second for each channel. Typically, one channel is assigned for a loop-entry signal, and a second channel records the loop-exit signal. In its maximum configuration, the PR 250 can be equipped with 250 channels sufficient to accept signals from 125 loops. Since accurate speed data require a double loop, a maximum of 62 measuring sites can be monitored simultaneously. For complex installations involving the analysis of acceleration/deceleration, it is customary to provide several double-loops for each lane.

A vehicle entering a detector loop activates the first of the two channels assigned to that loop. Since all installed channels are scanned one every millisecond, such a channel activation can be associated with a time count to a resolution of one millisecond. The fact that a channel was found activated causes three 8-bit characters to be recorded into memory, first a data marker, always 253, then the time count, ranging from 0 to 249, and finally, the channel address. To maintain a reference to real time, a time marker 250 is written into memory every 250 milliseconds, after which the time counter starts again from zero. If there are no vehicles to cause channel activations, only time markers are written into memory maintaining an accurate time matrix for later processing. Subsequent activations of other channels are caused in the same fashion by the vehicle leaving the first loop and entering and leaving the second loop. The system is fully buffered and accepts simultaneous signals from multiple channels.

Representation of Results: The choice of format in which results are presented depends on the program package used. One such program gives a listing of data for individual vehicles. For every vehicle of a given lane, this print-out contains (a) the gross time gap to the vehicle ahead, measured front to front (headway); (b) the net time gap to the vehicle ahead, measured rear to front (vehicular gap); (c) local speed; (d) electrical vehicle length (this is the product of vehicle speed times average loop occupancy minus the length of the loop); (e) vehicle type (car/truck discrimination by vehicle length); and (f) special codes externally entered (i.e. spiked tires, fog lights, etc.).

From these data other information can be computed such as: (1) volume/density, (2) 85th percentile, (3) 10-mph pace. Data from the programs are also used for the graphic display of empirical speed-distribution functions. Other available programs allow the evaluation of vehicle queueing, headway, road capacity, and influence of trucks.

Prodata PR 22 Traffic Analyzer

Separates vehicle flow in four basic classes: (1) cars, (2) trucks S, (3) trucks M, (4) trucks L, and also separates traffic flow into 6-speed ranges. Speed ranges are easily programmable and can be varied over a wide spectrum. Individual ranges do not have to be of uniform size.

c. Transportation Data Corp. Traffic Analyzer Systems

Designed to provide reliable data from as many as four independent traffic lanes simultaneously from one unit. This information includes traffic volume, speed, speed distribution, lane straddlers, density, vehicle classification, and a very accurate time base. The same information can be provided from three, two, or just one lane if desired. It can also be obtained for one or both directions depending on the road type and data requirements. The TDC traffic analyzer system has three components: (1) programmer, (2) traffic data recorder, and (3) vehicle sensors. After the sensors have been installed in the traffic lanes and connected to the data recorder, the programmer is used to initialize the system. During the initialization period, the following information is stored in digital form on the magnetic tape: lane identification, weather conditions, operator identification, date, time, road type, lane markings, and speed limits. Since 9,999 codes are available, other data can be coded as desired by the user.

TDC has developed a cable sensor which is portable and can be installed at any location in less than one minute per lane. It operates on the principle that when pressure is applied to a coaxial cable, a voltage is generated which is proportional to the applied pressure, and also, to the length of cable over which the pressure is applied. The cable sensor input goes into the Tire Patch Reproduction and Self-Tuning Electronics section which automatically adjusts for cable length, temperature, and capacitance variations. The signal is reconstructed to simulate the applied pressure which is threshold-detected when the signal is above a preset voltage (Pressure). It is then passed on to the Analog-to-Digital Converter which provides a relatively high-transition rate (50 µsec) from a logic high to a low when the threshold is exceeded. The converter also provides a Dynamic Threshold Control as a feedback to the Threshold Detector Section. This signal is used to minimize the detection of tire-ripple and high-frequency tire-tread noise. The digital pulse from the converter section is compatible with the Traffic Data Recorder and TDC Counter. The pulse width is dependent on the tire patch length and the speed of the vehicle. Although the cable sensor was designed to go with the TDC Traffic Analyzer System, the system is also compatible with other sensor types. Cable Sensors are used with the model "S" Traffic Data Recorder, and the loop and magnetometer sensors are used with the Model "L" Traffic Data Recorder. The processed data from the various types of sensors will be the same except for vehicle class. The loop-and-magnetometer sensor data classify the vehicle by length while the strip-sensor data classify the vehicle by the number of axles. Vehicle separation is accomplished by measuring the speed of the first axle, and then, counting each succeeding axle space until 28 to 32 feet have been measured. At this time, the vehicle is terminated by the TDR, and the classification data are posted on magnetic tape.

<u>Technical Features of TDC's Model "S" Traffic Data Recorder</u>

<u>Capacity</u>: Using standard Phillips-type cassettes designed for digital computer recorder field, approximately 50,000 vehicles may be contained on each cassette. (With sampling option, this can be extended as high as 500,000 vehicles per cassette.)

<u>Maximum Flow Rate Per Lane</u>: Over 7,000 vehicles per hour at 60 mph and and over 2,000 vph at 16 mph. (Above this rate, vehicles may be misclassified but total axle count will be correct.) System has a 50 percent

probability of classifying perfectly to flow rates over 14,000 vph at 60 mph.

Vehicle Identification: Between 16 and 99 mph, each vehicle will be identified as to its lane, speed, and number of axles. Below 16 mph each and every axle will be recorded along with the lane identification of that axle. Note: In the standard recommended computer processing of the tapes, the axles below 16 mph will be distributed back into vehicles assuming the same distribution of multi-axle vehicles exists in each class as exists in the speed range between 16 mph and the median speed for the previous hour.

Lane Straddlers: Lane straddlers will be segregated and identified on tape as to their speed, class, and common lanes.

Speed Range and Accuracy: System will operate as described above over a range of speed from 0 to over 150 mph; however speeds will be recorded only over a range from 16 to 99 mph in 1-mile increments. Vehicles over 99 mph will be recorded as 99 mph. The error in computation of speed in the Model S is less than 0.4 percent of indicated speed over the range from 16 to 99 mph and over the operating temperature range of the system, plus the quantization error chosen for processing. This does not include the sensor placement error which normally should not exceed 1 percent of the speed measured.

Output Format: The magnetic-tape output is recorded in a dual-channel format (ones in one channel and zeros in the other) with nine data bits and a marker bit at the beginning and end of each set of nine data bits. This format is referred to as the Bit Marked Sequence (BMS). Note: The ninth bit is only used for odd mile per hour storage, so the tape may be processed over standard communications terminal via phone lines using an eight-bit format with minimum vehicle speed quantization going from one to two mph.

Environment: External temperature is between -4° to 115°F although special high-temperature cassettes should be used above 100°F. Lower temperatures may be achieved by applying external power (approximately 10 watts) to internal optional heater through standard external connector.

d. Streeter Amet (Division of Mangood Corp.)

MR Traficounter: Machine readable records can be processed to interface with high-speed data-processing equipment. It is available in models to suit a variety of sensing methods: road tubes, inductance loop, magnetic, sonic, radar, and other detectors. MR Traficounter simultaneously prints a machine-readable optical code of count adjacent to a digital record of count and time for immediate on-site visual editing. Accumulating- and recording-intervals are adjustable at 5-, 15-, and 60-minute periods. Maximum count rate: 20 vehicles per second.

MR Traficounter System: This system uses the MR Traficounter to count and record vehicles, then uses an MR Translator/Reader to convert optically the binary decimal-line code printed on the MR traficountertape into signals compatible with a variety of data-processing equipment.

Traffic Classifer: (Model 401) The model 401 determines the number, types, or speeds of vehicles using a roadway. It senses, counts, and classifies vehicles into six categories according to vehicle type or velocity to provide detailed data for analysis. Classifier has two modes of operation. The more accurate mode uses two pnematic road tubes plus a sub-surface loop-vehicle detector. The other mode, using only road tubes, and thus, not requiring the installation of a loop, provides good accuracy when vehicle speeds are above 20 mph. Vehicles with a wheel base shorter than 11 feet are classified as cars, those with longer wheel bases or those having 4 or more axles are categorized as trucks.

Classification: (1) Two-axle car, (2) Two-axle car with trailer, (3) Two-axle truck, (4) Three-axle truck, (5) Four-axle truck, and (6) Five-axle truck.

Velocity: mph (typical - other ranges available), (1) Under 25, (2) 25-35, (3) 35-45, (4) 45-55, (5) 55-65, and (6) over 65. Count Registers, six digits, resettable Count Capacity, zero to 999,999.

e. SDS Technical Devices Ltd. MPT Computer (Multi-Parametric Traffic Computer)

The MPT computer is a completely solid-state electronic instrument giving three important traffic engineering data by a single survey: (1) traffic volume, (2) vehicle delay, and (3) the queued number of vehicles. In addition, it can also be used for (4) gap, (5) headway, and (6) speed surveys. Information is automatically provided on the front panel by illuminated numerical readout devices. As an optional feature, computer compatible readouts may be provided on paper or magnetic tape for analytical purposes. The MPT computer may be operated manually by field observers or automatically from vehicle-sensing detectors.