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Vehicle Detection Using a Magnetic Field Sensor

STANLEY V. MARSHALL, MEMBER, IEEE

Abstract—**The measurement of vehicle magnetic moments and the results from use of a fluxgate magnetic sensor to actuate a lighting system from the magnetic fields of passing vehicles is reported. A typical U.S. automobile has a magnetic moment of about 200 A-m^2 (Ampere-meters^2), while for a school bus it is about 2000 A-m^2. When the vehicle is modeled as an ideal magnetic dipole with a moment of 200 A-m^2, the predicted results from an analysis of the sensor-vehicle geometry agree closely with observations of the system response to automobiles.**

I. INTRODUCTION

THIS PAPER results directly from experimental work by the author during the last four Christmas seasons in connection with the use of a fluxgate magnetic sensor as a traffic sensor for automatic switching of Christmas lights in front of the author's residence. The object has been to have the lights turn on just as the people in the car are in a good position to appreciate the scene, and to switch off after they pass by. Cars on either side of the street, i.e., traveling in either direction, actuate the lights.

Initially, the results were not too satisfactory, primarily because the vehicle magnetic field was not properly understood. To measure the vehicles, a sensor was located on an overpass directly above a traffic lane of a city street. It immediately became evident that all vehicles measured were magnetized with a south pole on top, and that the strength of the field is roughly proportional to the size of the vehicle. The polarity is as expected for an earth induced field in the northern hemisphere. From the quantitative field measurements and the known height of the sensor above the traffic the magnetic moments were computed for each vehicle, making it possible to then predict traffic sensor performance for given locations and orientations of the sensor. Predicted performance quite closely matched the observed performance, i.e., a visual check of the position of the vehicle when the lights were switched on compared to that predicted from calculations. This has led to a somewhat tutorial treatment of the magnetic traffic sensor, following a brief description of the Christmas lighting system.

II. DESCRIPTION OF CHRISTMAS LIGHTING SYSTEM

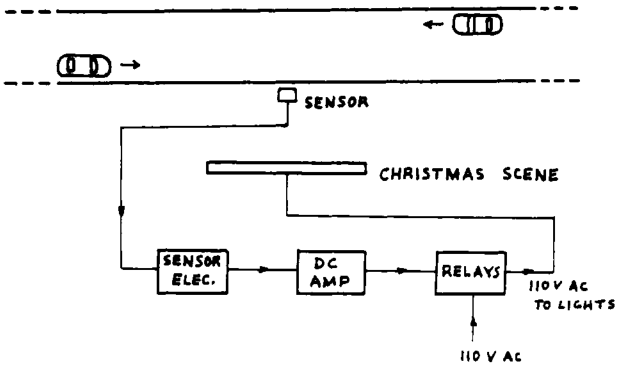

Fig. 1. Block diagram of vehicle-actuated Christmas lighting system.

The system block diagram is shown in Fig. 1. The sensor is located at curbside directly in front of the scene to be lighted, about 10-20 feet (3-6 meters) from the two lanes of traffic and below the centers of the vehicles by about 0.75 meter. The sensor assembly includes a permanent magnet on the sensor axis for compensating for the earth's magnetic field. The magnetic is spring loaded against an adjusting screw for fine adjustment of the compensating field. The sensor assembly was buried just beneath the ground surface for protection against misalignment and with the sense axis nearly vertical.

The fluxgate sensor and sensor electronics used in this experiment have been described in a previous publication [1]. The dc output from the sensor electronics required additional amplification to actuate a small relay at the arbitrary field level of 0.016 Ampere/meter (20 gammas) chosen as the best compromise between sensitivity to passing vehicles and insensitivity to movements of cars in neighboring driveways. The small relay in turn operated a larger relay used for switching the few kilowatts of power required to operate the lights. Solid-state components could of course have been used in place of the mechanical relays.

III. MAGNETIC FIELD FROM A VEHICLE

The magnetic fields from highway vehicles were studied using a sensor located on an overpass twenty-one feet directly above a traffic lane. Field readings were recorded for each vehicle as it reached a point directly beneath the sensor. From the known distance of the sensor from the vehicles, the magnetic moments were computed. From these measurements, it was concluded that a typical U.S. automobile has a magnetic moment in the range 100-300 A-m^2 (Ampere-meter^2) in SI units. The moment is vertical with the south magnetic pole on top (this is as expected in the northern hemisphere), and the magnitude of the moment appears to be somewhat proportional to the size of the vehicle, although the magnetic moment for a school bus is ten times that for an automobile while its weight is only five to six times as great. It should also be mentioned that this moment, which is induced from the earth's field, should be a function of latitude, being maximum

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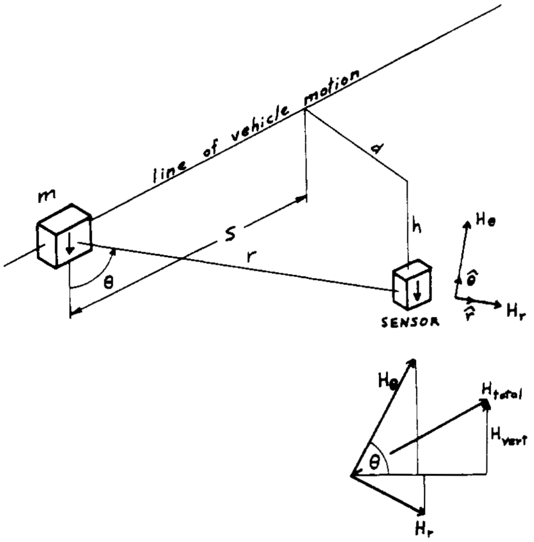

Fig. 2. Sensor-vehicle geometry.

at the magnetic poles and zero at the magnetic equator. In subsequent calculations involving the magnetic field from a highway vehicle, the vehicle is modeled as an ideal magnetic dipole having a moment of 200 A-m², with a vertical axis and with its south pole on top.

Referring to Fig. 2 for defining the variables, the field from a dipole is given by [2]

$$H = \frac{|m|}{4\pi r^3}\{2\cos\theta\hat{r} + \sin\theta\hat{\theta}\}\,\frac{\text{Ampere}}{\text{meter}} \tag{1}$$

where $|m|$ is the magnitude of the magnetic moment in ampere-m² and H is measured in amperes/meter.

For $h = 0$ and with the sense axis vertical, the magnitude of the sensed field is

$$H = \frac{|m|}{4\pi r^3}, \tag{2}$$

and when (2) is solved for r for $H = 0.016$ Ampere/meter,

$$r = \left(\frac{200}{4\pi(0.016)}\right)^{1/3} = 9.98 \text{ meters}$$

$$= 32.7 \text{ feet}.$$

A correction for the location of the sensor being about 0.75 m below the vehicle centerline gives a value of 29.75 feet for the critical distance for triggering the circuit for the Christmas lights. For a very small car, let us say 50 A-m², or a truck, let us say 800 A-m², the critical distances would be 19 feet and 47 feet, respectively. Observations of the vehicle positions for relay acutation tended to confirm the above calculations. A small car on the far side of the street barely triggered the system.

Calculated fields versus time are the Gaussian shaped pulses shown in Fig. 3 for a vehicle traveling past the sensor at 20 mph, where d is either 10 feet or 20 feet, and for $h = 0$. The critical field of 0.016 A/m is exceeded for 2.1 seconds and 1.8 seconds, respectively.

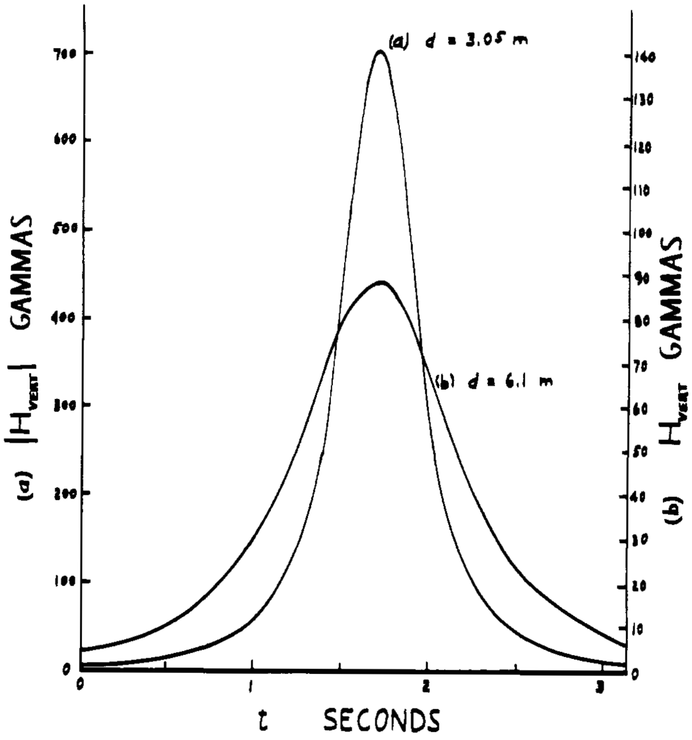

Fig. 3. Responses curves for 20-mph vehicle.

IV. SENSOR LOCATION

Sensor response is a function of its direction from the vehicle magnetic moment as well as orientation of the sensor axis. In this discussion the sensor axis is assumed to be vertical, thus only the vertical component of the field from the vehicle will be sensed. Referring to Fig. 2,

$$H_{\text{vert}} = H_\theta \sin\theta - H_r \cos\theta$$

$$= \frac{|m|}{4\pi r^3}[-2\cos^2\theta + \sin^2\theta]. \tag{3}$$

Plots of H_{vert} for various values of d and h are given in Figs. 4 and 5. Note that the polarity of the sensed field reverses as θ changes from 0° to 90°. The angle at which this reversal occurs, i.e., where $H_{\text{vert}} = 0$ is 54.75°, and is found by setting H_{vert} equal to zero and solving for θ from (3). This is the case depicted in Fig. 5 for $d = 3.6$ m, $h = 2.59$ m, and also in Fig. 6 for the field from vehicle no. 2 where the sensor is directly above vehicle no. 1 and whose axis is orthogonal to the field lines from vehicle no. 2.

For a curbside sensor, the maximum response is obtained for $h = 0$, i.e., the sensor should be at the same height as the center of the vehicle. When the sensor is 3.05 m (10 feet) from a traffic lane, a change in sensor height from $h = 0$ to $h = 1$ meter will reduce the sensed field from 700 to 430 gammas, a reduction of 39 percent. This is shown by plots in Fig. 5. Maximum response is for a sensor to be located directly above or below the traffic lane. The effect of the vehicle deviating by 0.5 m and 1.0 m from the center of the traffic lane is shown by the set of curves of Fig. 4 for a height of 2.59 m for the sensor. When the traffic lane is 3.66 meters (12 feet) from a line 2.59 m directly above or beneath the sensor, the sensed

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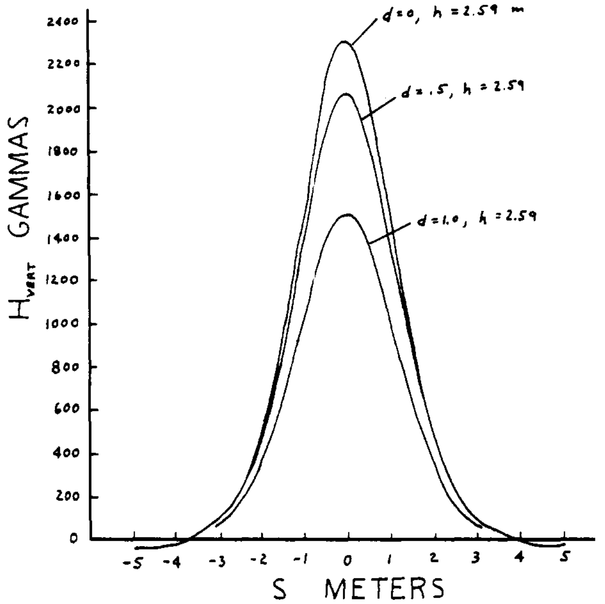

Fig. 4. Response for sensor above or below vehicle, showing effect of offset from vehicle path.

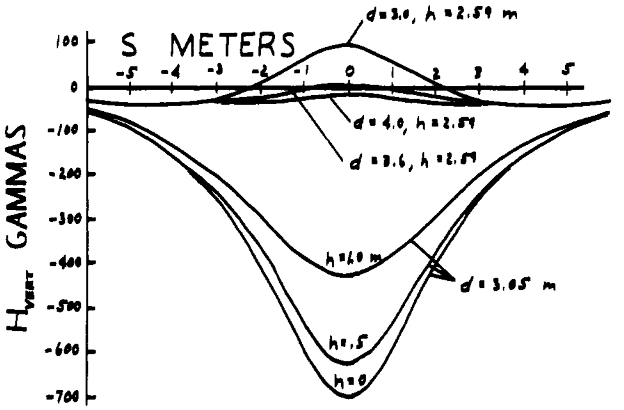

Fig. 5. Response curves for various heights and offsets of sensor from traffic lane.

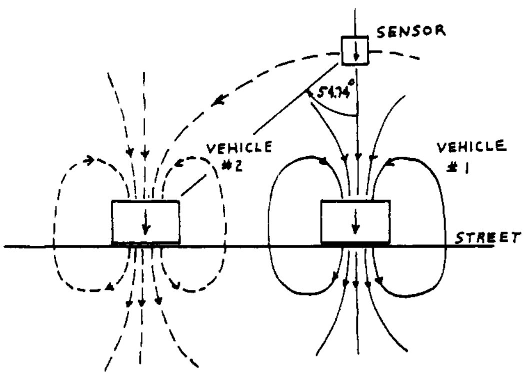

Fig. 6. Illustrating location of sensor for rejecting signals from adjacent lane.

field is exactly zero at the point of closest approach although there is a field of about 30-40 gammas sensed when the vehicle is four or five meters either side of this point. Refer again to the $d = 3.6, h = 2.59$ curve of Fig. 5. Advantage may be taken of this feature to locate sensors such that they will sense traffic in one lane and be very insensitive to traffic in an adjacent lane. The threshold could be set at 200 gammas which would actuate the system for everything in the traffic lane except possibly a small motorcycle, and would not actuate even for a large truck in an adjacent lane.

V. TIMING APPLICATIONS

The author is aware that in at least one application where the time period between successive signals from two different sensors was very critical as it was used to determine the speed of the vehicle, magnetic sensors were rejected [3]. One can gain some insight into this problem by referring to Fig. 4. If for example the vehicle passed directly above one sensor and one meter to the left or right of a point directly above the other sensor, the threshold level of say 200 gammas would be reached at $S = -2.6$ m for the first sensor and at $S = -2.4$ m for the second sensor. If the sensors were twelve feet apart, this could cause an error in $\Delta\tau$ on the order of 5 percent and the same proportional error in the computation of speed. The lower the threshold setting, the smaller the error in $\Delta\tau$ due to a change in vehicle path.

If the sensor is too close to the vehicle, it can sense individual magnetic moments within the overall framework of the total vehicle, and the field pulse due to motion of the vehicle past the sensor will then have multiple peaks or at least be broadened over those plotted in this paper. This might be undesirable for any timing application. The minimum distance for the sensor for good response pulse shape has not been determined in this study but is probably on the order of 1.5 meters for the average automobile.

VI. SOME ADDITIONAL CONSIDERATIONS

A few years ago the fluxgate magnetometer was mass-produced and widely deployed for detecting weapons at airport security gates. Traffic sensor applications could use much of the same basic components. The fluxgate sensor is inherently a simple and rugged sensor, and although publications have dealt with the extreme effort required to produce a stable sensor for space applications [4], sensors for traffic applications, as was the case for airport security, may be constructed from commercial grade tape cores.

The fluxgate sensor can be easily packaged in a container smaller than a pack of cigarettes. No active components are required in the sensor assembly. The power consumed by the sensor electronics is almost entirely that required for the amplifiers as the basic excitation and detection requires only on the order of a 100 milliwatts. Since no contact with the vehicle is required, the sensor can be protected from the weather.

The fluxgate sensor is basically a dc device or presence indicator, i.e., it does not require motion to produce an output.

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This can be a problem if a vehicle parks near the sensor, creating a continuous "trigger." However, it is simple to ac couple the output of the detector to the amplifier, or where long time stability is critical and where presence indication for stationary vehicles is undesired to use a long time constant integrator in a feedback loop to provide an automatic zeroing compensate field by supplying current to a solenoidal compensate winding around the sensor. This replaces the permanent magnet earth field compensation used by the author and would be more practical for highway installation. In fact, with the electronics one could program to zero the sensor for a trigger signal greater than a specified number of seconds in duration.

VII. CONCLUSION

A fluxgate magnetic sensor used as a traffic sensor to automatically trigger some Christmas lights has provided a demonstration relatively easy to visually verify. Calculations, based on measured magnetic moments of vehicles, provide a much more complete picture of the potential of the magnetic sensor and some of the important considerations such as the orientation of the sensor and its distance from the vehicle. Applications may be suggested to the reader for which he did not previously have the necessary quantitative data to consider. It is conceded that for certain precise timing applications magnetic sensors may not be able to meet all the requirements, but the convenience of a small concealed weatherproof fluxgate sensor should not be overlooked as a possible option for counting or sensing the presence of highway vehicles.

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During World War II he served as an Electronics Technician in the U.S. Navy. Upon joining Bell Telephone Laboratories in 1954, he became associated with the development and testing of radars for the Nike guided missile systems. From 1961 to 1963 he was engaged in evaluation of the performance of the Nike Zeus system at Kwajalein, Marshall Islands. He joined the Electrical Engineering Department of the University of Missouri-Rolla in 1967, where he has been conducting developmental work with fluxgate magnetic field sensors.

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