Magnetic Field Generator For Simulation of a Vehicle Movement For a Wide Range of Velocities

Milan Stojanović, *Student Member, IEEE*, Jana Vračar, *Student Member, IEEE*, Ilija Neden Dimitriu, Ljubomir Vračar

***Abstract* — This paper describes the LTSpice model of a magnetic field generator needed for testing a vehicle detector. This simulator reproduces magnetic field distortion equal to a vehicle when passing over the detector located in the road in real conditions. The electric circuit of the simulator described in this paper is a solenoid, PWM generator, and filter capacitors. The different values of capacitors are given for different vehicle velocities. The switching matrix is used for selecting the appropriate capacitor values to achieve simulation of different vehicle velocities.**

***Index Terms* — Magnetic field generator, magnetic field distortion, LTSpice model, vehicle detection.**

I. Introduction

Vehicle detection is an essential part of traffic systems, especially in places of high population density. This system is used to get data about available parking spots and analyze traffic flow [1, 2]. Vehicle detection can be done by analyzing the magnetic field changes, which occur due to the vehicle presence [3]. Fig. 1 shows the placement of the magnetic field sensor on the road, and the changes of the magnetic field due to the passing vehicle over the sensor.

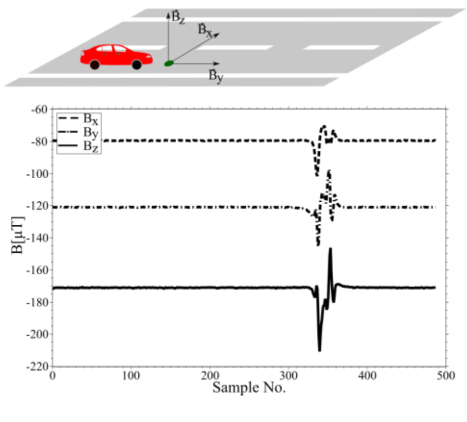

Fig. 1. The placement of the magnetic field sensor on the road, and changes of the magnetic field induced by the vehicle.

Milan Stojanović is with the Department of Microelectronics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia (e-mail: milan.stojanovic@elfak.ni.ac.rs).

Jana Vračar is with the Department of Microelectronics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia (e-mail: jana.vracar@elfak.ni.ac.rs).

Ljubomir Vračar is with the Department of Microelectronics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia (e-mail: ljubomir.vracar@elfak.ni.ac.rs).

Ilija Neden Dimitriu is with the Public Enterprise "Roads of Serbia", 11000 Belgrade, Serbia (e-mail: ilija.nedendimitriu@putevi-srbije.rs).

As shown, the vehicle induces magnetic field distortion along all axes (x, y, z). Determining the vehicle presence can be done by analyzing the measured values from one [4] or several axes [5]. The measured results show that when the vehicle passes over the sensor, it creates bigger changes in the magnetic field along the z-axis. Therefore, the values measured along this axis are taken within the analysis usually.

The reliability of the detector needs to be tested before installing it on the road. That includes testing the success of the detection of different types of vehicles moving at different velocities. A simulator capable of reproducing a magnetic change identical to vehicle-induced is useful to increase the efficiency of the testing process. The solenoid is the part of the simulator that generates the magnetic field, and this field depends on the waveform of the current flow through the solenoid, and it is directly proportional to it. The current of an arbitrary waveform can be obtained using the PWM generator of the variable duty cycle (DTC) [6, 7]. If that generator drives the solenoid, the magnetic field of arbitrary shape is created. The rest of the paper shows the magnetic field simulator, described by electrical circuits in the software tool LTSpice. The current flow through the solenoid changes as the magnetic field due to the passing of the vehicle.

II. The Theoretical Principle of Simulator Operation

Fig. 2 shows a relation between the current changes through the solenoid ΔI, and the DTC of PWM voltage, at the end of the pulse. As can be seen, the increase of DTC contributes to an increased value of ΔI. The showed values of ΔI are absolute, so the value of the current flow is equal to zero before a pulse arrival.

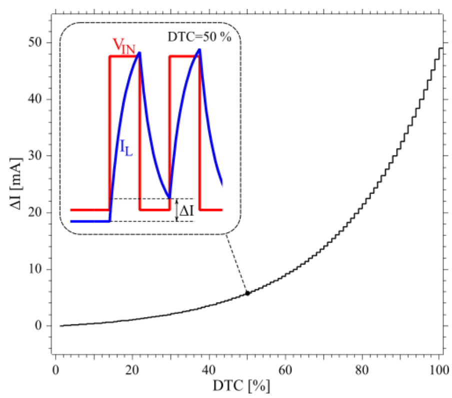

Fig. 2. Influence of duty cycle of PWM voltage to the intensity of the current through the solenoid.

The current flow through the solenoid is changed, by changing the duty cycle of PWM voltage. The current intensity can be controlled in this way, but the current always flows in the same direction. The coil should be connected to the two PWM generators to allow the change in the direction of the current flow and thus generate changes in the magnetic field as the vehicle does. Fig. 3 shows a simplified schematic of the simulator.

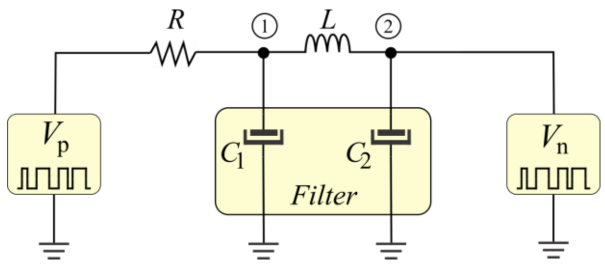

Fig. 3. Simplified schematic of the magnetic field simulator.

The simulations of current flow were done using LTSpice software. The ideal solenoid inductivity is 100 mH, and that value is used in the software. The resistor R limits the current intensity (magnetic field), and the value is 100 Ω. The capacitors C_1 and C_2 form a filter that suppresses sudden changes in a current flow when voltage level changes of both generators.

PWM generators are realized as PWL (Piecewise Linear) generators in LTSpice. The parameters of PWL generators were generated inside textual files. The textual file of every PWL generator contains couples of points (x, y), where x represents the time, and y represents voltage values. The generator makes pulses by reading values from the file.

A. PWM generators

The magnetic field that presents the passing of one vehicle is created by driving the solenoid by 100 pulses from the generators. The V_p makes positive, and V_n negative changes to the magnetic field.

The duty cycle of the PWM voltage of both generators is proportional to the changes in the magnetic field. The frequency of PWM voltage depends on the duration of the magnetic field distortion.

The duration of one pulse is calculated as

$$t_{pulse} = \frac{t}{100},$$

where t represents the time of magnetic field distortion. In this case, the distortion is induced by a vehicle, so t can be replaced by $t_{vehicle}$ and this value depends on the length ($l_{vehicle}$) of the vehicle and its velocity ($v_{vehicle}$)

$$t = t_{vehicle} = \frac{l_{vehicle}}{v_{vehicle}}.$$

So the duration of one pulse is

$$t_{pulse} = \frac{d_{vehicle}}{100 \cdot v_{vehicle}},$$

and the frequency of the pulse signal is equal to

$$f_{pulse} = \frac{1}{t_{pulse}} = 100 \cdot \frac{v_{vehicle}}{d_{vehicle}}.$$

The length of the vehicle is considered to be 4 m. The textual files of both PWL generator V_p and V_n are created based on the value of t_{pulse}. One pulse is defined by four points (x, y), as shown in Fig. 4.

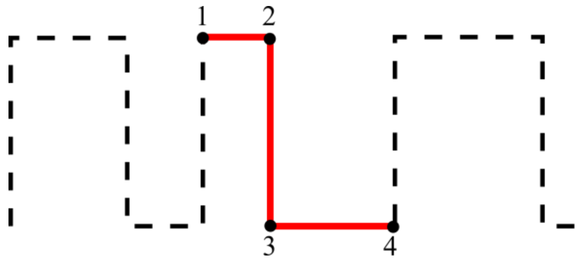

Fig. 4. Points that determine the frequency and duty cycle of one pulse of PWM voltage.

The x_1, y_1 are coordinates of the first point, x_2, y_2 the second, et cetera. The values of coordinates of all four points are calculated:

$$\begin{gathered}
(x_1, y_1) = \left((i-1)\cdot t_{pulse} + \Delta t, V_{ON}\right) \\
(x_2, y_2) = \left((i-1)\cdot t_{pulse} + DTC_j[i]\cdot \frac{t_{pulse}}{100} + \Delta t, V_{ON}\right) \\
(x_3, y_3) = \left((i-1)\cdot t_{pulse} + DTC_j[i]\cdot \frac{t_{pulse}}{100} + 2\Delta t, 0\right) \\
(x_4, y_4) = \left(i\cdot t_{pulse}, 0\right) \\
j \in \{p, n\}, i \in \{1, N\},
\end{gathered}$$

where N represents the number of pulses. Δt is the time interval needed to change the value of the generator voltage from 0 to V_{ON} and vice versa. This interval value is much smaller than the value of the t_{pulse}, so it does not affect the accuracy of the frequency of the generated voltage. The noted equations apply if the condition is met

$$DTC_j[i] \neq 0.$$

Otherwise, the voltage value at points 1 and 2 is equal to zero, and only point 4 within the current pulse is generated.

B. Filter capacitors

The capacitance values of C_1 and C_2 are equal, because the frequency of both generators is equal, and they are determined experimentally. Fig. 5 shows the current waveform through the solenoid for vehicle density of $1\frac{m}{s}$ and three different values of capacitors C_1 and C_2.

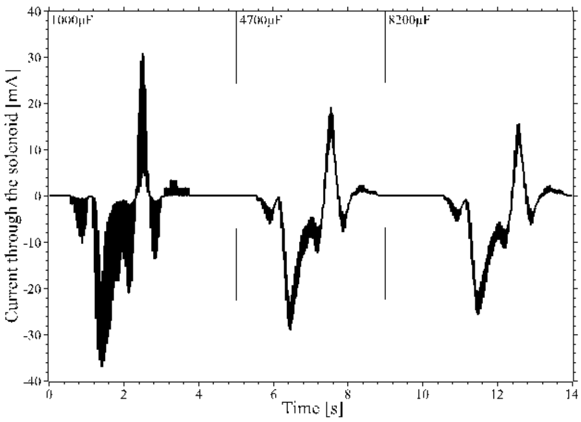

Fig 5. The waveforms of the current through the solenoid for vehicle velocity of $1\frac{m}{s}$ and three different values of C_1 and C_2.

If the capacitors C_1 and C_2 have a capacitance of 1000 µF there are unwanted high-frequency changes in the waveform of the current through the solenoid. These changes should be "smoothed" to get the required shape of the generated magnetic field.
In the other case, if the capacitors have too large values, such as 8200 µF, the amplitude of the current waveform becomes attenuated. So, the simulation shows that the appropriate values of C_1 and C_2 are 4700 µF for shown vehicle velocity.

In Fig. 6. the current through the solenoid for vehicle velocity from $1\frac{m}{s}$ to $5\frac{m}{s}$ is shown.

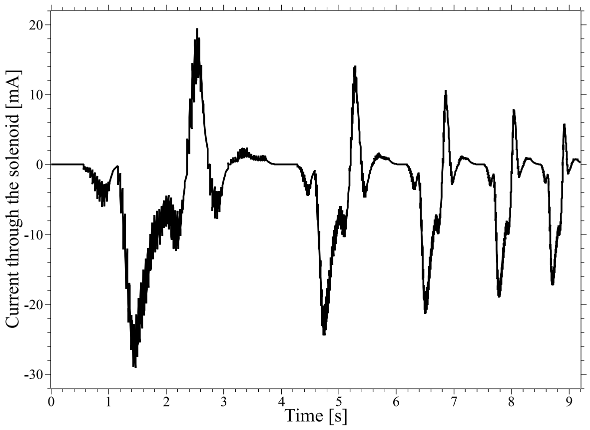

Fig. 6. The waveforms of the current through the solenoid for vehicle velocity from $1\frac{m}{s}$ to $5\frac{m}{s}$. The value of vehicle velocity increases from the left to the right side.

There are two problems when a vehicle's velocity rises. The amplitude of the current waveform decreases, but the waveform shape is degraded also. That happens because the capacitance values of C_1 and C_2 are too large. It is required to determine appropriate values of capacitors for all vehicle velocities, or for ranges of the velocity that is supposed to be simulated.

That is done experimentally, by creating the PWM generators of various frequencies. Table I shows the values of capacitors C_1 and C_2 which are depending on the vehicle velocity, whose movement is simulated.

TABLE I
VALUE OF FILTER'S CAPACITORS FOR DIFFERENT VEHICLE VELOCITY

Vehicle velocity [m/s]	Capacitance C_1 and C_2 [uF]
1	4700
2	1800
3	820
4 - 5	470
6 - 7	220
8 - 10	150
11 - 15	120
16 - 20	68
20 - 30	47
30 - 50	22

Capacitor values should be selected before starting the simulation.

III. SWITCHING MATRIX AND RESULTS

Changing capacitor values without interrupting the simulation and manual reconnection of new components can be made using the switching matrices, shown in Fig. 7. In this way, the capacitor value can be selected depending on the frequency of the PWM signal. It provides the ability to simulate an unlimited number of vehicles of different lengths and velocities.

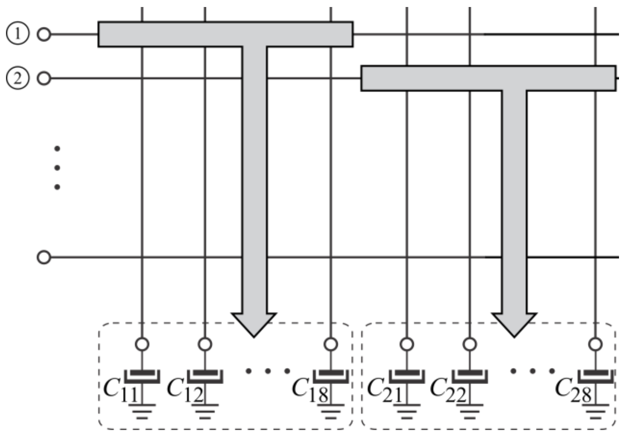

Fig. 7. The simplified block schematic of the switching matrix. The first and the second index of capacitors denotes the row and column of the switching element, respectively.

The complete switching matrix contains eight rows and 16 columns. In this case, two rows and the 8 columns of every row are used.

The necessary row number of the matrix determines the number of different capacitances connected simultaneously. Table I shows that the number of different values of capacitor capacitance is ten. The matrix contains eight columns, allowing the connection of up to eight various capacitors. The first row of the matrix is used instead of the capacitor C_1, and the second matrix instead of C_2. The capacitor values from C_{11} to C_{18} are shown in Table I, there the C_{11} is the biggest value. The capacitors connected in both rows are equal. The capacitance of C_{11} is equal to C_{21}, the C_{12} is equal to C_{22}, and so on. Because there are eight different capacitors in the circuit, and there are ten values that are needed for shown velocity range, two capacitances are missing. In this case, the capacitors of 68 µF and 220 µF are not connected because these values can be obtained as a combination of others. Two remaining capacitances are obtained by a parallel connection of connected capacitors, 68 µF as the sum of 47 µF and 22 µF, and 220 µF as the sum of 150 µF, 47 µF, and 22 µF.

The selection of the capacitors that need to be connected to the output is done by the components inside the matrix. In Fig. 8 is shown the simplified schematic of one row of the switching matrix. The microcontroller controls all rows and is positioned left out of the schematic for better visibility.

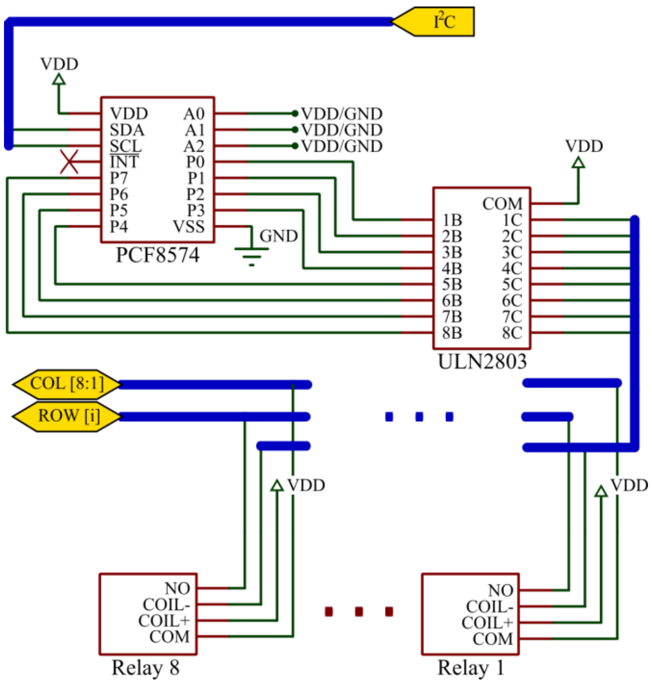

Fig. 8. The simplified schematic of one row of the switching matrix.

The input stage of a row is the I/O expander [8] that receives data from the microcontroller via I^{2}C communication. The received one byte of data determines which switching elements will be activated. This information is forwarded to the driver [9], which activates one or more appropriate switching elements (relays) [10]. The capacitors are connected to the output of the matrix, after the activation of relays. The PWM generators, after the selection of the capacitors, are activated. If the next simulated vehicle has velocity from another range, the appropriate capacitance is set again, and the simulation is repeated.

The current waveform through the solenoid is shown in Fig. 9, wherein the corresponding capacitor is used for each simulated vehicle velocity.

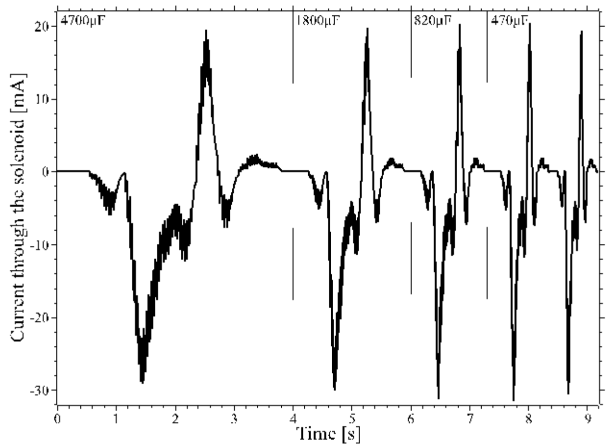

Fig. 9. The current through the solenoid for vehicle velocity from 1 m/s to 5 m/s, with a corresponding capacitor used for each simulated vehicle velocity.

Comparing Fig. 9 and Fig. 6 can be seen that using of switching matrix contributes to getting the current waveforms without degradations. The current through the solenoid has the same waveform for all simulated vehicle velocities. The current amplitude is also unchanged and does not depend on a vehicle's velocity.

IV. Conclusion

In this paper simulation for replicating a magnetic change identical to vehicle-induced is described. The simulator is described by the electrical circuit in LTSpice. The part of the simulator is a solenoid that generates the magnetic field. The PWM generators of variable DTC drive the solenoid to generate the current flow of arbitrary shape. That current flows through the solenoid and the magnetic field of the same waveform is generated.

Connecting the solenoid to the two PWM generators results in a change in the direction of the current flow. That change generates changes in the magnetic field equal to vehicle-induced changes in the magnetic field.

Degradation of generated magnetic field for different velocities are regulated by capacitor filter, with various values of capacitors C_1 and C_2. The values for capacitors are determined experimentally, and a part of the switching matrix for selecting the values for capacitors is used. When using the appropriate capacitor value, the amplitude and waveform of the current through the solenoid are unchanged for a wide range of vehicle velocities.

The future research will be based on expanding the scope of simulations for different types of vehicles. Also, one of the next steps in researching is the practical realization of the described simulator.

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