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Vehicle Ignition System Immunization against Electromagnetic Waves

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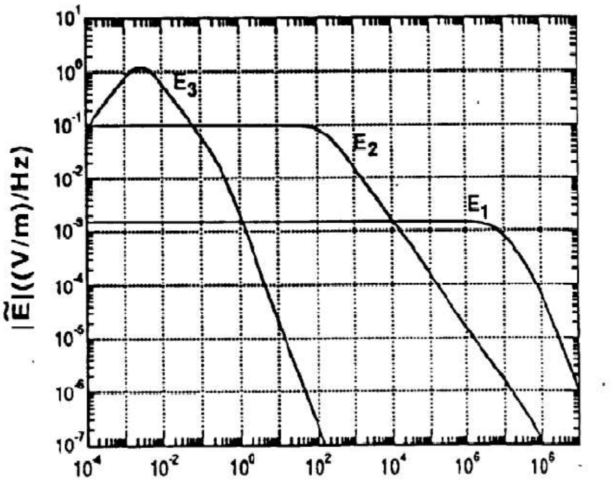
ABSTRACT
Electromagnetic threats are new threats challenging today's societies; these threats include intense electromagnetic disturbances used to cause damage to electrical and electronic systems. This paper aims at describing the electromagnetic threats HEMP and HPEM and the implications of the field and discussing the impacts of the threats on ignition system of fuel-injected vehicles and the results of the simulation are used to examine ways to avoid disruption in the vehicle engine management system.
Keywords: *electromagnetism, injector, threats, cable, pulse*

INTRODUCTION
In today's world conflict,as the most complicated and difficult form of interaction between countries, has changed from a one-dimensional conflict in a battle field into an all-out confrontation in all areas of military, economy, culture and technology. As a result, equipping army forces and governments with the last military weapons is not sufficient to deal with emerging threats, in other words, it is necessary for communities to be equipped with knowledge and unarmed defense tools in non-military fields to confront the threats. Passive defense refers to measures not requiring the use of weapons and its implementation will prevent financial damage to vital and sensitive military and civilian facilities and casualties and or the extent of the damage and losses may be reduced to a minimum. These measures should be designed so that ultimately leads to the loss of motivation for conflict in the warring sides.
Today we are in a situation where all vehicles are dependent on electronic components and semiconductors. Although this technology has increased the speed and the quality of service at different levels for motor vehicle drivers and users, on the other hand the increased use of this technology can lead to the development of new threats in this area. According to what was previously mentioned, defensive considerations regarding developed use of this technology must be considered at different levels.
Given that one non-lethal method to stop the vehicle and the failure of electronic systems is the use of high-power electromagnetic sources, These sources, using the radiofrequency interference with electronic circuits of vehicles, disable the internal combustion performance of modern and diesel engines. Severe impairment in vehicle electronic control unit can cause engine stalling and thus prevent re-ignition in engine of the vehicle. In this paper, we first reviewed the electromagnetic threats and electromagnetic generators of carstop and then the vehicle ignition system and its sensitivity to electromagnetic radiation was studied.

Electromagnetic threats from nuclear explosions.
In general, electromagnetic pulse (EMP) is a kind of pulsed electromagnetic wave with large amplitude. One factor causing the electromagnetic pulse can be nuclear explosion which will lead to the production of nuclear electromagnetic pulse (NEMP). This wave can be described as an electromagnetic phenomenon of a plane wave with direct propagation that is caused by nuclear explosions at an altitude abovethe Earth's surface. Nuclear explosions have an electric field with horizontal and vertical components a rise time of 50 kv/m, 20 kv/m, and 5 to 10 nanoseconds (ns), respectively [1].
There are several types of electromagnetic pulses from nuclear explosions. One of the most effective types isthe high altitude electromagnetic pulse that occurs because of the nuclear explosions at altitudes of tens to hundreds of kilometers of above the Earth's surface. High-altitude electromagnetic pulse occurs due to

the reaction of high-energy photons (gamma rays) with atmospheric molecules that produce Compton electrons (Compton in 1925 while studying atoms, proposed the idea of an electronic bomb. Compton believed that with the excitation of a high-energy photon flow, projectile electron flow can be created). The electrons are deviated in the Earth's magnetic field and release photons during this process [2].
Surface burst EMP is another form of electromagnetic pulse that is resulted from the explosions at the Earth's surface or at an attitude of less than 200 meters. Electromagnetic pulse resulting from the explosions can be defined in two source and radiation regions. The maximum energy of the field is in the frequency range below the range of the high-altitude electromagnetic pulse [2].
System generated EMP by the is also another form of electromagnetic pulse which is resulted fromthe direct interaction between X- and gamma raysand an electrical or electronic systems with metal chamber.
Internal EMP, cavity EMP and Compton loading are other phenomena associated with the direct radiation of gamma rays to a system and the production of an electromagnetic pulse. This type of pulse is important because it has great de-amplification at lower atmospheric heights and its effects on satellite systems and missiles flying out of the atmosphere, is important [3].
2.1. Study of HEMP medium based on standard-61000-2-9 IEC
Electromagnetic mediums that are defined by the standard 61000-2-9 include three types of electromagnetic pulses called quick time wave E1, average time waveE2 and delay time wave E3. Each waveform has quite been analyzed at the standard. In Figure 1 waveforms are drawn in time domain. It should be noted that the waveform E1 is the temporal signal resulted from gamma rays,The field is caused by the movement of Compton electrons created by instantaneous gammas of explosion. The mechanism lasts for microseconds (us). Between 1 microsecond and 100 microseconds, fields generated by the already distributed gamma are more important. This effect is located at E2 both instantaneous and distributed gamma signals are usually displayed by plane waves with approximate amplitude.
In general, E1 has a frequency ranging from1MHz to1GHz and is able to make a coupling with data, and feed lines and directly with electronic equipment. Generally this threat is easily coupled on local antennas, equipment inside buildings (through pores), and short and long conductor lines. The coupling happens strongly at MF, HF, VHF and UHF bands.
Wave E2 affects long steel transmission lines, vertical antenna towers and large structures. The wave is at LF and VLF frequency range. E2 frequency range even overlaps with AC frequency and frequency of sound spectrum and as the result, filter design will be difficult in electromagnetic protections.
E3 wave affects long communication and power lines included on intercontinental submarine cables. Also, because of the low frequency (below Hz) shielding and insulation is difficult in this area [5].



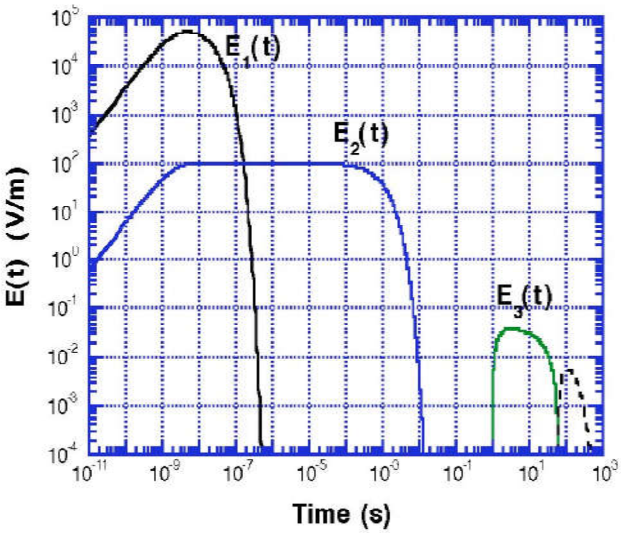


Figure 1: Time domain waveforms of standard61000-2-9- IEC [5] Figure 2: frequency range of standard IEC-61000 -2-9- in the frequency domain [5].

The above descriptions follow that if we want to protect a system against the effects of EMP, the design should be based on EMP medium. If the medium is not defined, it is recommended that the standard 61000-2-9-IEC shown in Figure 1 is used. This waveform is a model of free field behavior which has been developed by the IEC. MIL-STD-2169and MIL-STD-464are other documents explaining the details of the wave behavior. In a nuclear war it is likely that most military systems are exposed to EMP, that is why these medium s need to be identified when designing [6].

As discussed above wave HEMP can be divided into waves E1, E2, E3 where E1 is short pulse with a rise time of a few nanoseconds and a td of about 10 to several hundred nanoseconds. E1 wave is shown as the following expression for IEC standard civilian trials [5]. For simulation and analysis of EMP on vehicles, the medium has been used by specifications of a standard EMP pulse generated using MATLAB software and simulation software CST. It should be noted that the number of high power electromagnetic pulse field is 50kV/m. In the simulation, the field is included in a radiation source that is a plane wave of in (3).

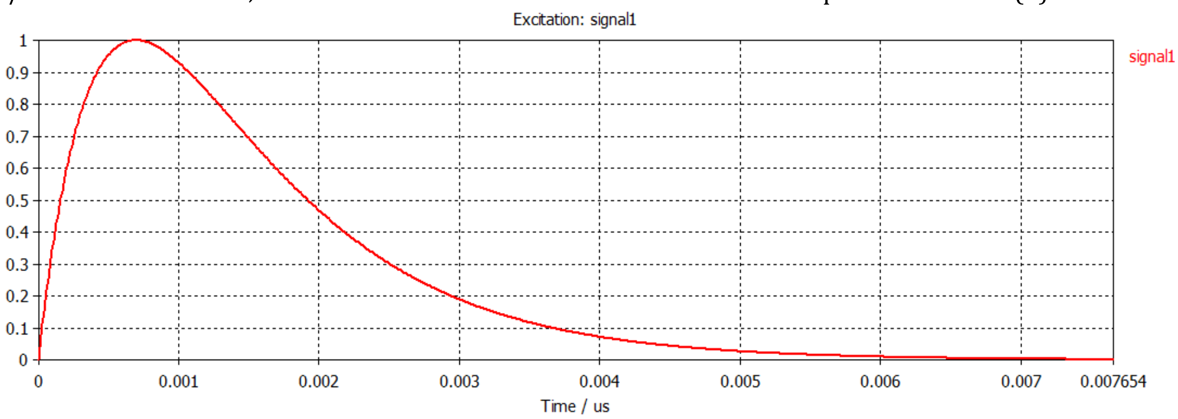


Figure 3: the generated EMP medium

$$E(t) = E_0\left(e^{-at} - e^{-bt}\right)u(t) \quad (1)$$

$$E_0 = E_{01}k = 1.3 \times 5 \times 10^4 \quad (2)$$

$$E(\omega) = E_0\left(\frac{1}{a+j\omega} - \frac{1}{b+j\omega}\right) \quad (3)$$

$$a = 4 \times 10^7 \qquad b = 6 \times 10^8 \quad (4)$$

This value represents the pulse with the amplitude of 50Kv/m, the rise time ofts=25ns the peak time oftp =418ns and the bandwidth of td=23ns.

3. Electromagnetic pulses caused by electromagnetic weapons

Electromagnetic bombs or E-BOMBs are a type of electromagnetic weapons that can be a controlled source of EMP.

Because of development of techniques generating high power electromagnetic pulse and technology of high power microwave (HPEMP) sources, electromagnetic bombs have become possible in terms of manufacturing technique. This weapon as a strategic weapon is concerned to be used in the wars of the

future. It can also be considered as a non-nuclear weapon. The E-BOMB is known as an electromagnetic threat of the future and the electromagnetic compatibility for the systems should be considered in the design of electronic systems and communications [2].
Technology used in the design of these bombs is different from the techniques used in nuclear weapons. Technologies used in the design of electromagnetic bombs are very diverse and in some cases are fully developed. Technologies in this area include:

1. Magnetic flux compression generators (FCG)
2. Magneto hydrodynamic (MHD) generators triggered explosion.
3. High power microwave (HPM) devices, among which the largest and the most important one is virtual cathode oscillator (vircator).

HPM signals with high power cause disturbances and damage to electrical, electronic, and telecommunication systems, data processing and equipment used in a system. Unlike EMP sources, HPEM sources have high frequency and relatively small bandwidth. Working frequency of HPEMs is usually above 1 GHz. And because of the generator sources have small bandwidth. For this reason, the analysis of their effects is easier than that of broadband threats in the frequency domain. It can be said HPEM sources cover a wide range of frequencies (from 1-60GHz). Thus, it is considered as an effective disturbing source.
In general, the term HPEM is referred to man-made electromagnetic ***medium*** created to cope with the proper functioning of electronic devices. That can sometimes be a pulse wave generated by microwave energy (often as high power microwave HPM signal) and Subsequently, it is sometimes generated as a wave with a wide frequency range (UWB) is generated [11]. The following products are generally based on HPEM technology.
3.1. HPEM case: Compact and efficient HPEM source that is installed in a case, It is used to disable alarm and computer systems by Special Forces and also at checkpoints and customs. Figure (4)

Figure (4): HPEMcase [7]

3-2 stopping car by HPEM generator: the generators are used to stop moving vehicles [7]. Figure (5)

Figure (5): HPEMcarStop [7]

3.3. HPEM checkpoint sources: These sources are a combination of vehicle stopping sources and very powerful HPEM that are used to stop the vehiclesat checkpoints and at the entrance of sensitive infrastructure [7]. Figure (6)

Figure (6): HPEM checkpoint System

A commercial example of generators used to stop the vehicles is shown in Figure 5. The generators have an output signal as Figure 7 and the specifications given in Table 1. And for the simulation we should be able to generate this signal to perform simulations using CST software based on the generator.

Because the signal is a damped sinusoid and the magnitude of *a* is unknown to simulate the signal, two points where the sinusoid amplitudes are equal should be considered to obtain the unknown quantity. The points are marked with t1 and t2 in the following equation. By doing this, the sinusoidal amplitudes are identical at the waveforms and are removed. In the article, the magnitude of signal electromagnetic amplitude is 350kV/m, the amplitude is considered 350kV/m for signal V1 and for signal V2 is assumed 35kV m. having the frequency in Table 1, we can easily obtain the unknown quantity and having all values signal is obtained to perform simulation using MATLAB software and its behavior on passenger cars can be obtained by CST software.

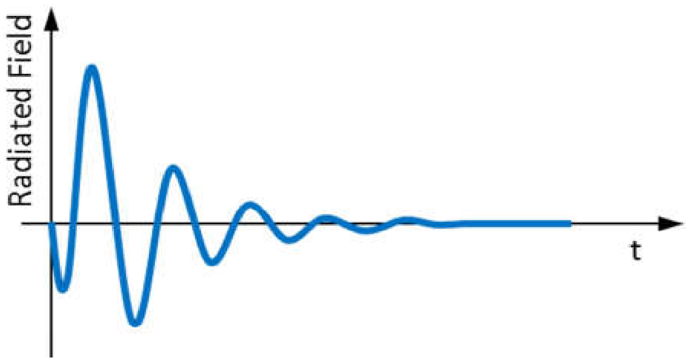


Figure 7: Output signal of commercial generators Stop Car [7]

Max. peak radiated power	4 GW
Repetition rate	60 Hz
Centre frequency	350 MHz
3 dB bandwidth	50 MHz
Maximum burst length	180 sec
Typical values	

Table 1 specifications of output signal of generators Stop Car [7]

$$V = -e^{-a}$$
$$V_1 = -e^{-}$$
$$V_2 = -e^{-}$$
$$\frac{V_1}{V_2} = e^{-a(t_1 - t_2)} \frac{si}{si}$$
$$\frac{V_1}{V_2} = e^{a}$$

$a = f \ln$

$a \approx 350 \times 10^6 \times \ln 10$

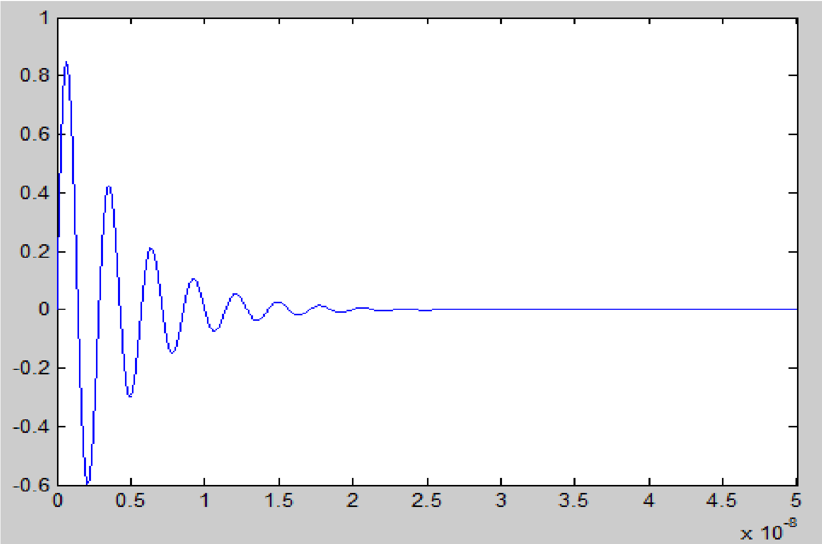


Figure (8) generator signal generated by MATLAB software

Describing ECU operational process

ECU unit has two major functions including fuel injection timing control and fuel injection volume control. In fact, the central engine control unit or ECU determines when and how much fuel should be injected. The process is done by signals sent from the sensors to the ECU. The fuel injection timing determines when the fuel is injected into the cylinder which is determined by the initial spark signal. Injection volume control system , determines the amount of fuel injected into the cylinder, which must be. Unlike the injection timing which is constant at normal conditions; injection volume can be changed or modified during operation of the engine and based on the conditions.

As previously discussed, fuel-injected vehicles are vulnerable to electrical and magnetic fields due to different electronic modules and sensors but it should be noted that various electronic parts such as ECU are protected against electromagnetic fields and have high electromagnetic compatibility. This field has the greatest impact on communication cables usedfor the transfer of data and the sensor status and giving commands to operators.

Simulation

In simulation, a cable is examined both with and without duct. In this simulation, a complete vehicle was usedto obtain results closer to reality. It is noteworthy that the material of the vehicle partsis considered in accordance with their real material. The excitation signal is anEMP signal radiated from a plane-wave source to the front of the vehicle. In Figure 9, the vehicle has been fully demonstrated.

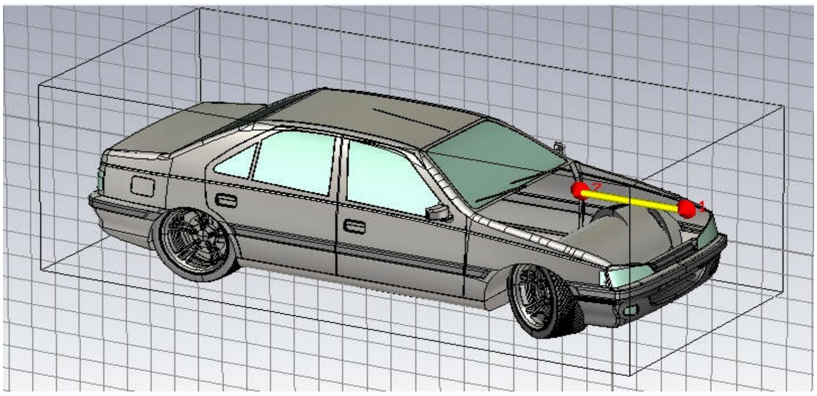
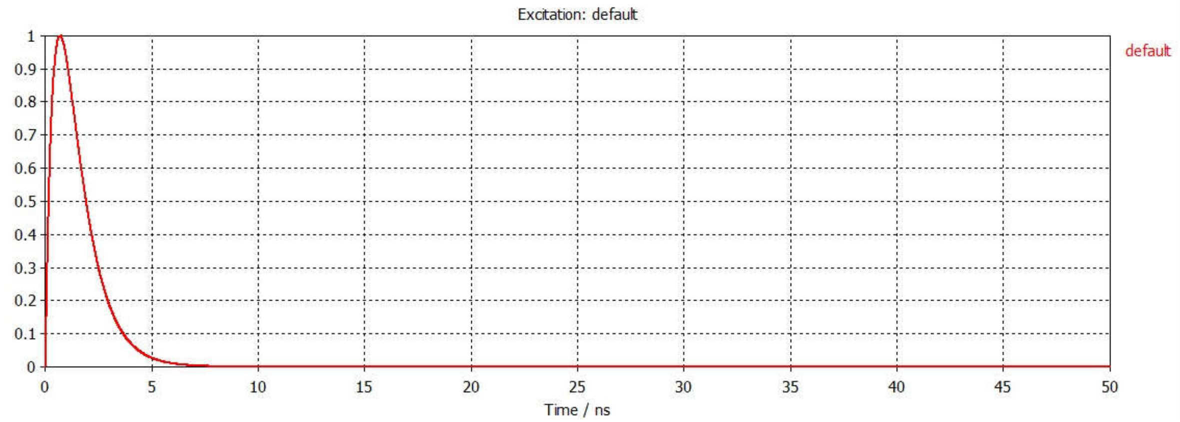


Figure 9: full illustration of the vehicle, given the material used for different parts

Wave source that is emitted from the front to the car with the excitation signal can be seen in figure 10.



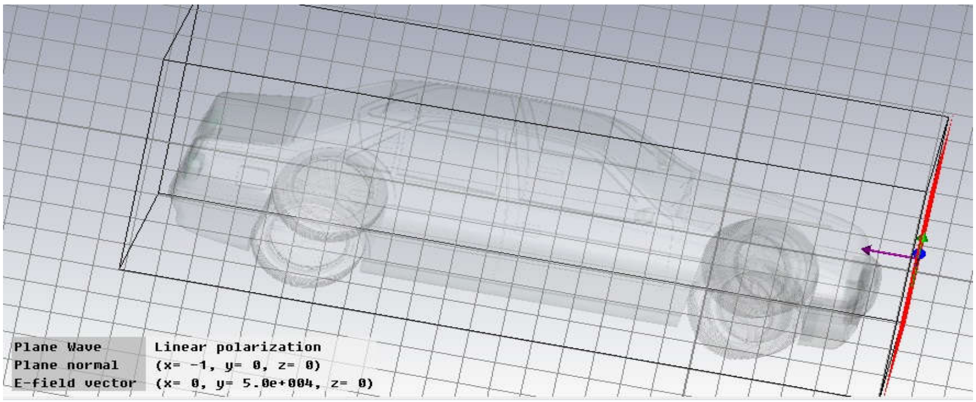


Figure 10: specifications of the radiation source with its excitation signal.

In figure 11,cable placed in the vehicle engineand ports 1 and 2 used to measure the voltage can be seen. Figure 12 shows voltage signal measured at this stage of the test.

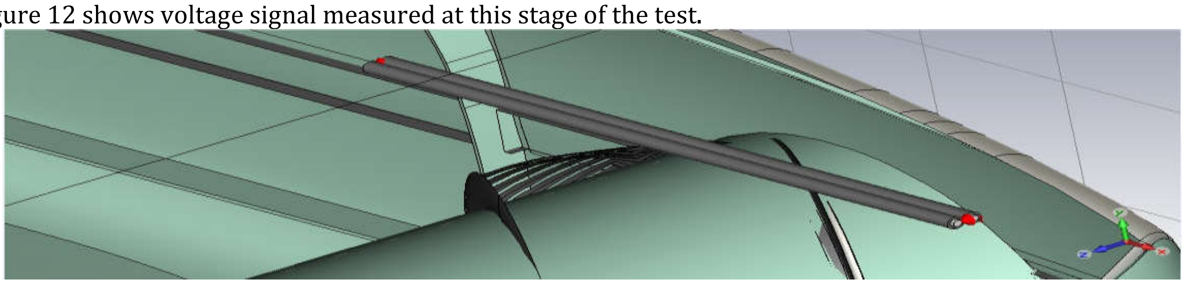


Figure 11: Cable placed in the vehicle with the voltage measuring ports.

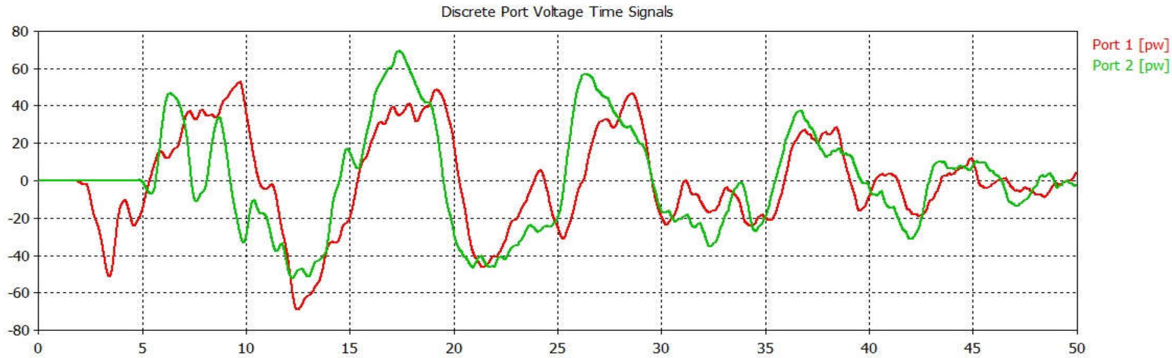


Figure 12: voltage measured by ports 1 and 2.

Figure 13 showscable placed in the vehicle engineand a metal duct that is around it. The measured signal in this case is shown in Figure 14.

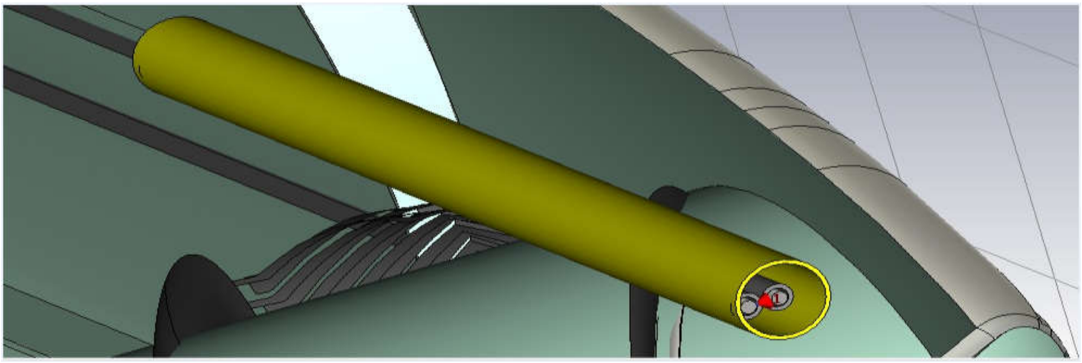


Figure 13: Cable placed in the metal duct.

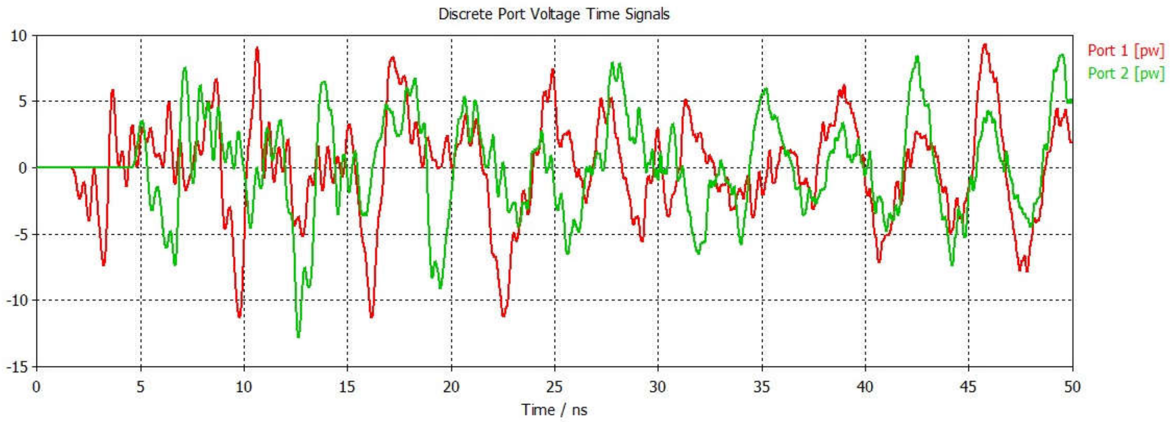


Figure 14: Measured signal by ports 1 and 2 as the cable is placed in the metal duct.

6. Conclusion

The study conducted in this paper on HEMP and HPEM threats shows that the maximum pulse amplitude of HEMP threat is50kv/m with a frequency range between 1MHz and1GHz. Similarly, for HPEM threat the maximum amplitude is 100kv/m or is higher in its narrowband type with a frequency range higher than1 GHz. The amplitude of the wave reached the vehicle and vulnerable devices is affected by physical factors such as distance from the threat source, the polarization of the incident wave, producing source, climate, terrain type, location of equipment and cables, etc.

However, according to the explanations it can be concluded that cables and connectors as input and output of systems and electronic equipment in fuel-injected vehicles are affected by electromagnetic inductions and radiations and can impose unwanted signals to the system. Thus, cables must be protected as conductor penetrating into the electronic pieces. The remarkable thing is that any cable other than optical cable, is known as a conductor penetrating into electronic equipment including single wire, pair wire, coaxial cable. It must not be forgotten that the input of fiber optic cables is considered as an aperture and should be appropriately filtered.

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