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NMOSFET based Analysis of Radiated Electromagnetic Interference in Indian Railways

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Abstract

Background/Objectives: The relevance of this study is prescribed by the rapid congestion of residential complexes around railway tracks especially in metropolitan cities of India. Railway network ejects unwanted electromagnetic emissions and have adverse effect on human nervous system. Hence this study aims to measure and analyze the safety level of electromagnetic interference produced by Indian railway infrastructure. **Methods/Statistical Analysis:** The method involves detection of EMI using drift current of NMOSFET bed which is modulated from the antenna inputs. The output detecting signal can tell the EMI safety of an area after processing the drift current. EMI at different frequencies were recorded as change in drift current in accordance with standard EN:50121. The test simulation of NMOSFET drift current with increasing electromagnetic frequency resulted in abnormality in reverse recovery time of MOSFET verifying that EMI affects the drain current, therefore using NMOSFET bed various antennas reading where measured and plotted with respect to radiation value leading to conclusion that some values of radiated emission are exceeding the safety values. **Findings:** The comparison of radiated emission with the European safety standard proves radiated emission is exceeding the safety value. Majority of the radiated voltage which is exceeding the safety lies in Radio frequency region (120-200MHz) are crossing the safety value while minority fluctuations above in IF region is also observed. **Application/Improvements:** These finding can lead to development of economical yet effective device of indicating EMI safety of a particular area helping them implement various techniques mitigation against harmful EMI showers. It can also helpful in setting Indian EMI standard for railway infrastructure.

Keywords: Electrical Modeling, Electromagnetic Compatibility, Electromagnetic Safety, EN:50121, NMOSFET

1. Introduction

The term "Electromagnetic Interference" (EMI) refers to a disturbance produced by an electrical system that affects operation nearby electrical circuits. Conducted electric noise and radiated electromagnetic noise are majorly responsible for this disturbance. From last 50 years, unchecked electromagnetic energy leaking into the environment has grown exponentially despite acknowledging that electromagnetic interferences are affecting the human body[1]. The EMI is divided into frequency (f) bands, namely: Radio Frequency (RF) (100 kHz < f ≤ 300 GHz), Intermediate Frequency (IF) (300 Hz < f ≤ 100 kHz), Extremely Low Frequency (ELF) (0 < f ≤ 300 Hz)[2]. There is a separate section for environmental effects for each band. Most notable amongst them is high power lines (RF) causing cancers and tumors[3]. According to a study of suicide rates published in the *Western Journal of Medicine* on sample 138,905 male electrical workers shows that there is a relation between exposure to extremely low-frequency electromagnetic interferences and a significant increase in the risk of suicide[4]. A separate report by Pacific NW Laboratory postulates that exposure to ELF is a potential contributing factor in depression. ELF fields can interferes with hormonal secretions which may provokes depression contributing to a cause of depression[5]. Baboon is exposed to 60 Hz power lines expressed different behaviors according to Dr. Easley. The 60-Hz electric field changed the social behavior of baboons as because it increased a stress[5]. A railway system might pollute by injecting unwanted electromagnetic radiation into the surrounding environment hence causes

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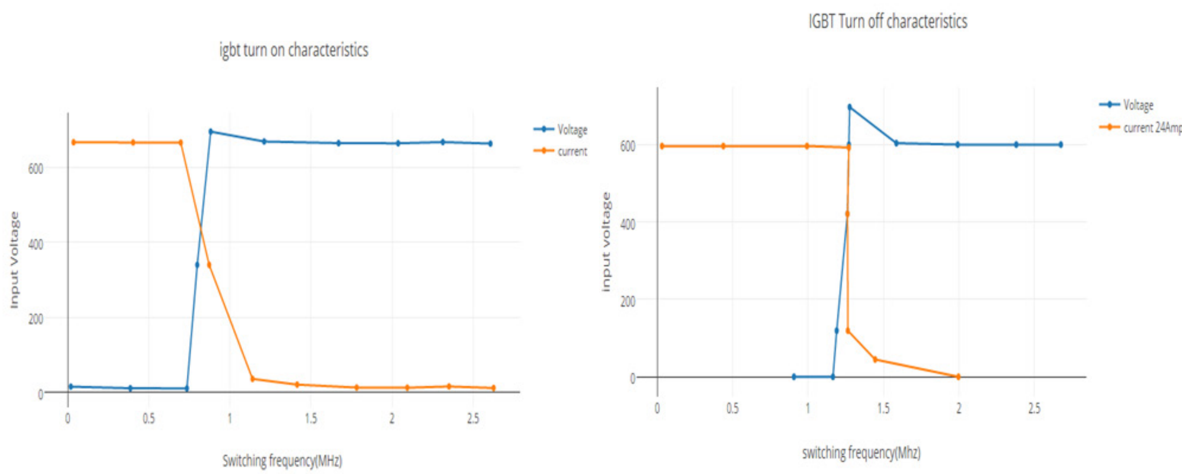

Figure 1. Spike in voltage during switching of railway power-electronics devices.

interferences with the environment and human body. Major contributors to the Radiated interference in a railway system are: Emissions radiated from converters with very high switching frequencies (for e.g. IGBT, thyristor) in equipments such as Traction convertors, auxiliary inverter, communication devices and brake chopper etc. Figure 1 shows the transient switching spike in voltage in traction devices[6].

The power supply line (cable) carrying energy behaves as an antenna, which radiates electromagnetic fields which proportional to the current flowing through the line and communication devices like radio equipment used in the locomotive are also source of EMI. Electromagnetic field near to a transmitter can be around 100V/m[6]. The major aim of this is create awareness about adverse effects of EMI by measuring easily in terms of MOSFET drain current and match safety standard limit for people living near to the railway tracks in India.

2. Materials and Methods

2. 1 MOSFET Characteristics

NMOS transistors designed in 90 nm free scale CMOS technology with thick oxide option. The gate length and width of NMOS are 1.52l m and 10l m. The nominal bias voltage is equal to 3.3V. When subjected to EMI of 1MHz (0.5v and V^{gs}=2.1v) to the Gate terminal (Figure 2) resulted a 47 % decrease in dc offset in linear region therefore drift in drain current.

Figure 3 shows the drain current shift due to EMI for V^{emi} = 0, 0.6, 1.2V. In all cases degradation of drain current was observed, higher the interference amplitude more is degradation of the immunity of MOSFET due to hot carrier charges injected into the channel[7,8].

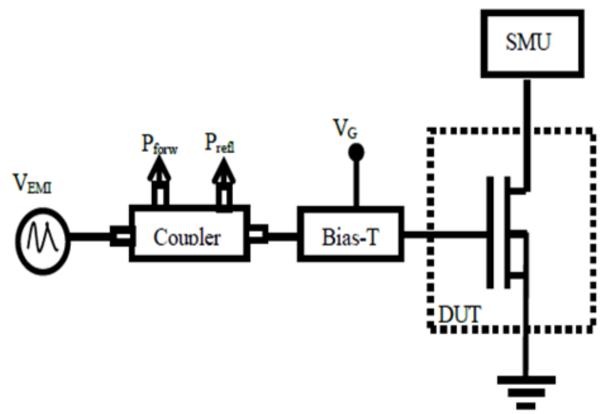

Figure 2. NMOSFET setup with V^{emi} on gate.

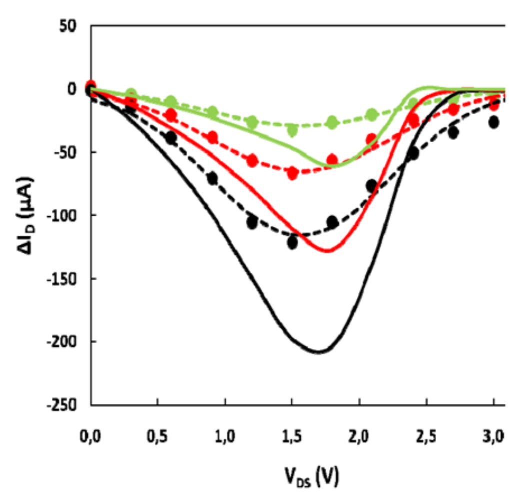

Figure 3. Drain current shift due to EMI.

2.2 Data Collection from the Environment

The real time radiated EM emissions is measured at a distance of 10m from the middle of the tracks (Figure 4). The mechanical centre of the antenna is set at a certain height with respect to the top of the rails. Radiated EMI are characterized by measuring the lateral component of the magnetic field over the frequency range 9 kHz-30 MHz, with the antenna height set in the range 1-2 m. On the other hand, the horizontal and vertical components of the electric field are measured over the frequency range 30 MHz-1 GHz, with the antenna height set to 3 m. Signals from the antennas are measured in the frequency domain, usually by means of spectrum analyzers[9]. The antenna height of 1-2 m reference to the magnetic field tests, while for electric field ones it is set to 3m[11].

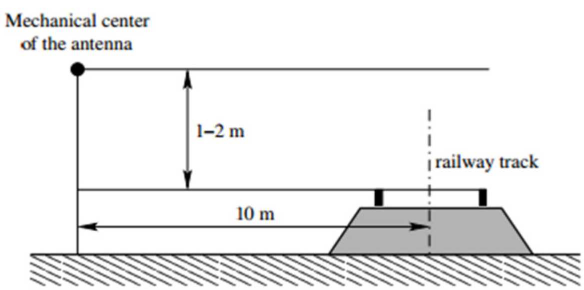

Figure 4. The setup required by the standard EN 50121 for measuring radiated Emissions from rolling stocks running on an electric railway track.

2.2.1 Antenna

In order to capture a wide range of frequency for radiated biconical antenna are used. The sample size is 9 to 300MHz. All antennas need their calibration factors (sometimes called transducer factors). Therefore their factor must be taken into account while calculating final values.

2.2.2 Measuring Radiated Voltage

Antenna usage for measurements on open sites like railway track suffers a lot ambient noises from the system. The actual radiated emission is measured using spectrum analyzer. The calibration factor for the cable connecting the antenna to the measuring instrument is taken from the cable datasheet. The final value of the radiated field is the sum of measured signal, antenna factor, cable factor and receiver factor.

2.3 MOSFET Detection of Radiated Emission

The Detector model is an array of free scale NMOSFET. Under the influence of EMI there is impedance mismatching in the MOSFET when the power is injected on to the MOSFET some of the power injected is reflected back hence there is change in drain current of MOSFET according to Sakurai-Newton model[12] as there is a change of EMI (voltage signal) at the gate of MOSFET at a particular frequency.

Sakurai–Newton parameters are given below:

$$Vdas = K \text{ x } (Vgs - Vth)^{\wedge} m$$

$$Idsat = B \text{ x } (Vgs - Vth)^{\wedge} n$$

when $V^{gs} < V^{th}$

$Id = 0A$

when $V^{gs} < V^{th}$

For $V^{ds} < V^{dsat}$

For $V^{ds} < V^{dsat}$ $$Id = Idsat \text{ x } (1 + \lambda Vds)\left(2 - \frac{Vds}{Vdsat}\right)$$

$$Id = Idsat \text{ x } (1 + \lambda Vds)$$

V^{gs}=gate-to-source voltage.
V^{ds}=drain-to-source voltage.
V^{th}=threshold voltage.
V^{dsat} =drain saturation voltage.
I^{dsat}=drain saturation current.
K,m=control the linear region characteristics.
n=saturated region characteristics.
B= transconductance.
K=finite drain conductance in the saturated region.

2.4 Simulation of MOSFET under Emission

A MOSFET circuit is modeled on simulink in which the noise of V^{emi} is fed as gate to source voltage and a freewheeling diode placed parallel with drain which gives us collector currents with time at different *Trr* (reverse-recovery of freewheeling diode placed with MOSFET) characteristics plotted to illustrate the high frequency disturbance changes in relation to *Trr* (Figure 5).

With the increasing *Trr*, the duration of the spike gets prolonged and the peak value goes up. However, the downward slopes are not same, as the blue and red lines are sharper than the rest two ones. This phenomenon is not only resulted from the Trr but also due to the system impact introduced by other components assumed to be

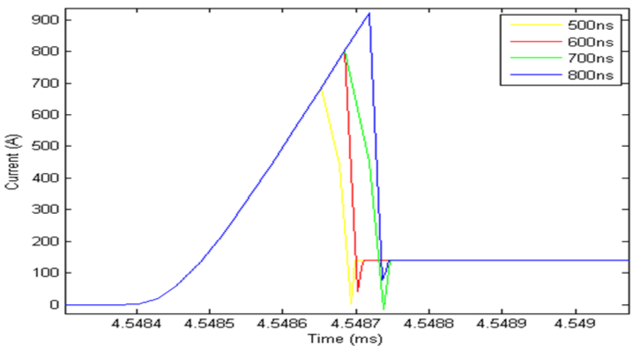

Figure 5. Collector current for different values of diode reverse-recovery time *Trr*.

2.5 Prototype for Indicating EMI Safety

Now as we have actual radiated data available hence the antenna measured values passes through a band pass filter which helps to set the range of frequencies wanted to be measured, the amplifier increases the magnitude of the signal (Figure 6.) and is evident that disturbance of V^{emi} on MOSFET changes the collector current once detector feeds the instantaneous drift collector current value to the processor, the processor compares the input with predefined safety values of collector current and displays the safety level of the environment onto the screen.

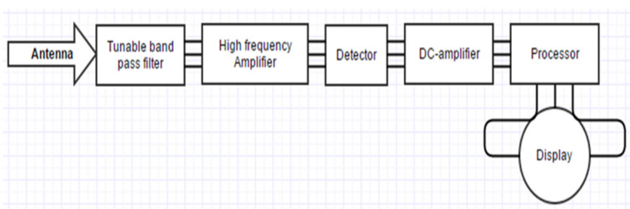

Figure 6. Block diagram of model used for measuring radiated emission.

The instruments required for support are: Loop antenna, 9MHz - 300 MHz. Power amplifiers Research, Model 25A 250A25 W, 10 kHz - 300 MHz. MOSFET based detecting circuit, Processing unit (Arduino) and a displaying unit.

3. Results and Discussion

The simulation result of MOSFET in Figure 7 shows that along the increasing Trr for the magnitude of spectrum below 5MHz is increasing. And at 5 MHz, the spectra are higher than 85 dBuA, which is relatively high. Before 5 MHz, the changes are nonlinear because the spectrum for 700 ns is lower than that for 600 ns. This spectrum information are used to evaluate the interference at high frequency[13]. The setup required by the standard EN 50121[11] Figure 4 gives the radiated emission voltage versus frequencies measured using spectrum analyzer. Figure 8 that shows a graph between actual radiated emission values captured using the antenna, we can see that it doesn't have any patterns as electromagnetic interferences are more like unwanted noises in the environment having a lot of harmonics but for the safety of the environment these values must not exceed the safety voltage limits which is 30dBμV/m in 50MHz -210MHz and 37dBμV/m above 210MHz.

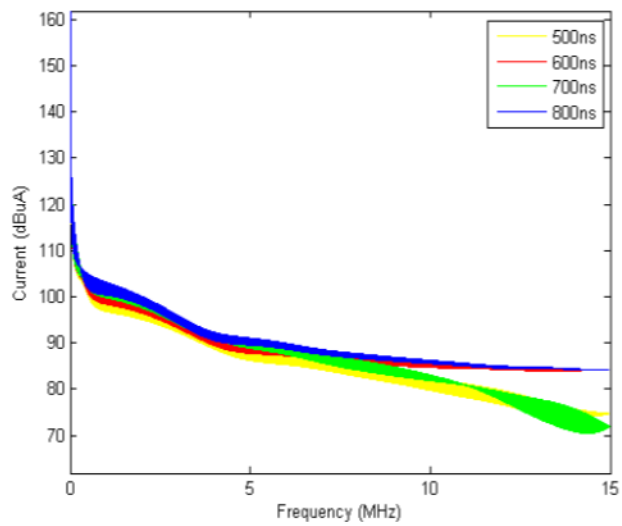

Figure 7. Spectrum of collector currents for different *Trr*.

When we enforce these conditions on graph (Figure 8), it can be concluded that some values of radiated emission are exceeding the safety values. The result of this graph is similar to test bench study conducted of previously[11].

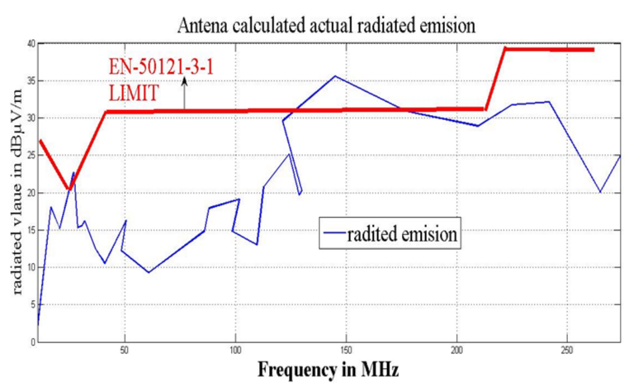

Figure 8. Measured electromagnetic radiation near the tracks.

The only difference between both the study is that in Indian railway infrastructure the radiated emission is exceeding the European safety standard. Majority of the radiated voltage which is exceeding the safety lies in Radio frequency region (120-200MHz) are crossing the safety value while minority fluctuations above in IF region is also observed.

The radio frequency radiated emission is harmful emission. Hence we move forward to develop our proposed model. These radiated emission data will be modeled into the change in drain current of the MOSFET according to the change observed with different Trr of the freewheeling diode, the change of drain currents are recorded at different frequencies and will justify the safety standard of experiment site, as Indian railways infrastructure is not in compliance with the European Standards EN 50121[10]. Therefore experimental setup as shown in Figure 6 will lead to develop a device which will indicate EMI safety of a particular area easily and economically unlike the complex measurement techniques available today.

4. Conclusion

Electromagnetic interferences on the nervous system a lot of exposure to these unwanted emission can lead depression in some cases therefore it is necessary to flag this pollution. As in early 19th century smoking was considered safe and even health, effect of EMI on human beings still is not taken seriously and many are in denial about its effects. Aside from ELF discussed earlier, EMI is not something which is produced by nature but by the human establishments. Never in the history of earth has there been so much electromagnetic energy in the environment which is residing today. People living near railway tracks specially in populated cities of India are more prone to these EMI showers as justified by result that radiated emission are crossing the safety standards in the radio frequency region. The methods available today for measuring safety involve large setup, involve a lot of computation hence time consuming therefore there is a need for low cost Electromagnetic radiation/interference indicating devices with respect to the safety of the environment making it possible for the people to establish low cost shielding setups such as Velcro tents which tend to absorb radio frequency emission across the residences which are near to the railway infrastructure. Recent techniques of measuring short noises[14] can be implemented with advance active power filters so that with unwanted harmonics, unwanted electromagnetic radiation can also be compared and mitigated.

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