EMC Problems due to Transit-Time Oscillations in Bipolar Power Devices

Ralf Siemieniec[1], Paul Mourick[2], Josef Lutz[3]
[1]Technical University of Ilmenau, PO BOX 100565, D-98684 Ilmenau
[2]Consulting Engineer, Auerbacher Weg 12, D-69427 Oberscheidental
[3]Chemnitz University of Technology, D-09107 Chemnitz
GERMANY

Abstract

Transit time oscillations may occur in the turn-off phase of power devices and cause high-frequency oscillations. This paper investigates the deterioration of the EMC behavior due to two mechanisms which lead to this type of oscillations: the dynamic impact ionization transit time (impatt) oscillation and the plasma extraction transit time (pett) oscillation. These oscillations should be avoided because they cause an noteworthy increase of electromagnetic emission. Possibilities for the avoidance of the oscillations are briefly discussed .

Introduction

EMC problems caused by LC oscillations, for instance as a result of a snap-off during the reverse recovery of freewheeling diodes, are commonly known. Solutions deal with an improvement of the device design and lead to a new generation of fast diodes avoiding a snap-off even under low current condition. Unlike these issues, the degradation of EMC properties due to high-frequency oscillations, as shown for example in figures 1a and 1b, are less well-known. Just because of improvement in the design of devices and of modules, such effects may come to the fore.

Oscillation Mechanism

Dynamic impatt oscillation

The oscillations shown in figure 1 is related to dynamic impact ionization. Dynamic impatt oscillations may occur in devices whose carrier lifetime is adjusted with irradiation processes using improper radiation parameters. The oscillations are caused by temporarily positively charged donor-states, which is one of the generated centers created by irradiation processes for carrier lifetime control. During the turn-off process, the generated donor-states remain positively charged and enhance the n^--doping, which usually sustains the blocking voltage, and therefore reduce the reverse blocking capability. Avalanche breakdown occurs at the pn-junction region and generates electrons as schematically shown in figure 3. These electrons counterbalance the positively charged donor-states and hence stop the avalanche generation of carriers (see figure 3). Due to the electric field, the electrons are transported to the nn^+-junction and again, avalanche generation starts at the pn-junction [1]. The oscillation frequency depends on the n^-

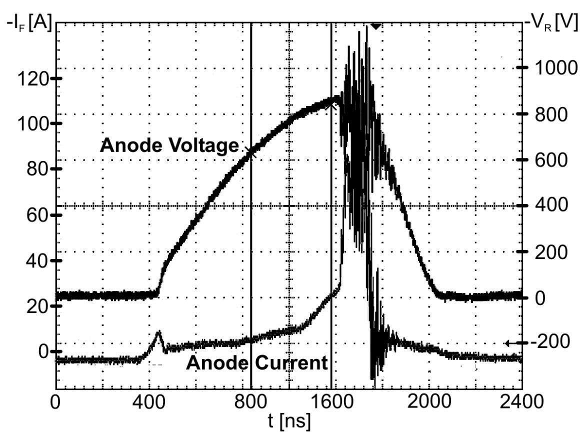

Figure 1: Measurement of a dynamic impatt oscillation at an electron-radiated freewheeling diode SC45

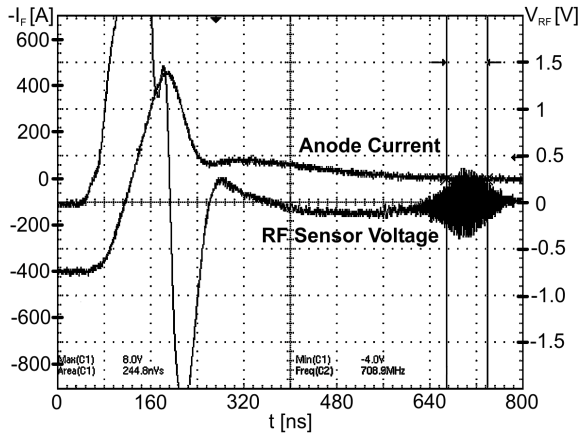

Figure 2:Measurement of a pett oscillation in a power module GAR with two paralleled diode chips

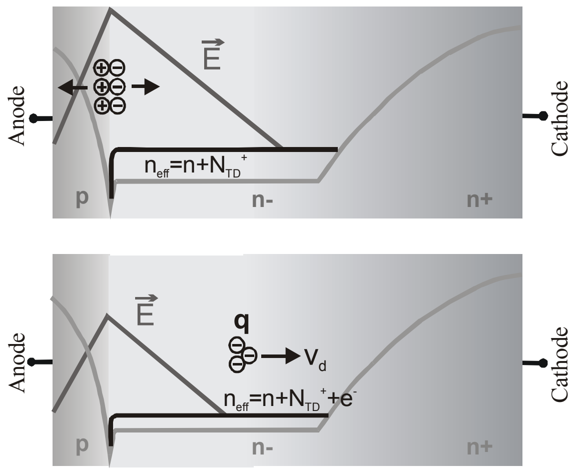

Figure 3: Origin of dynamic impatt oscillation

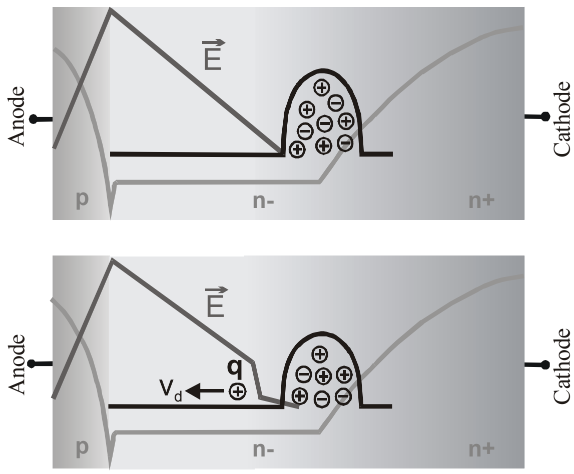

Figure 4: Origin of pett oscillation

-region width w_B of the semiconductor device and the drift velocity v_d of the carriers: $f \approx v_d / w_B$. With a drift velocity of app. 10^7cm/s, the frequency is in the range of 300-900MHz depending on the device thickness. Dynamic impatt oscillations cause a high RF output power because a large number of carriers is generated which consequently lead to a strong modulation of the electric field [2].

Pett oscillation

Pett oscillations are a recently discovered effect [3] which may occur in a lot of power modules. The stored excess carriers in the remaining plasma of the device during the turn-off process are injected into the space charge region as shown in figure 4. The hole flow through the already formed space charge region causes a change in the gradient of the electrical field. Due to the discontinuous flow of the holes in form of packets, the dE/dw is increased in the location of the packet and decreased in the remaining part of the middle zone as shown in figure 4. This results in a small negative voltage for the transition of a carrier packet. Oscillations occur if this negative differential resistance is larger than all other positive resistances in the complete circuit. Pett oscillations need an external LC circuit whose resonance frequency is close to the transit frequency. The inductance of this LC circuit is usually formed by the bond wires while the capacitance is mainly caused by the device itself.

The oscillation frequency depends on the width of the n^--region w_B and on the carriers drift velocity v_d and is usually again found in the frequency range of 300-900MHz. The output power of pett oscillations is low due to the relatively small number of travelling carriers [4].

Measurement Setup

The EMC measurements presented here try to give an estimation of the emission caused by high-frequency oscillations in power semiconductors. The permissible limit as well as the measuring method for ISM equipment are defined by the European standard EN55011 (international standard IEC CISPR 11) [5]. This standard was taken into account for the EMC

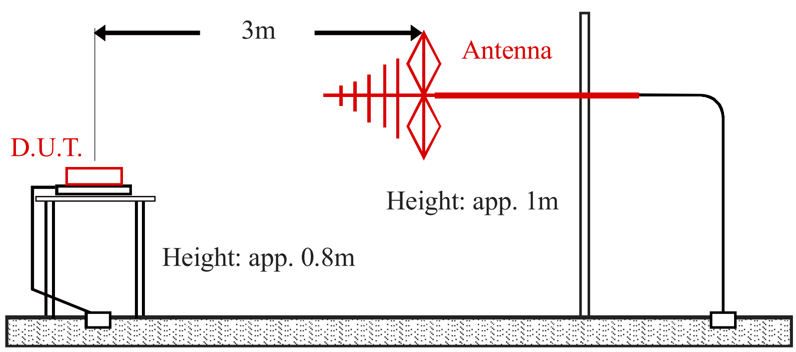

Figure 5: EMC measuring configuration

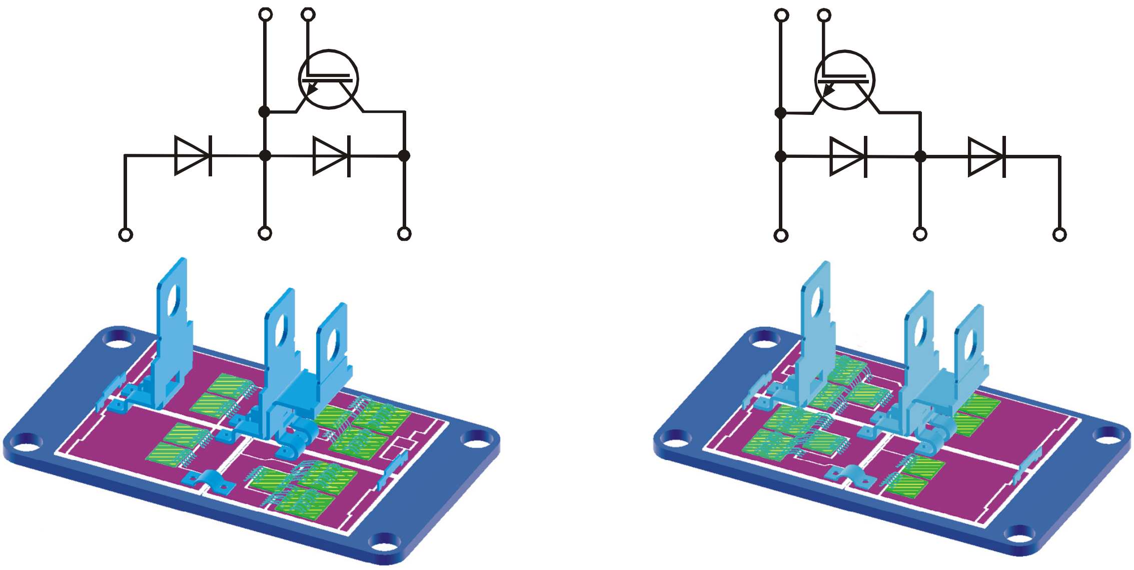

Figure 6: Internal circuit and module layout of high-side switch GAR (left) and low-side switch GAL (right)

measurements, but according to the objective target of the measurements some changes were applied as follows:

- The measurements were done in a usual, unshielded lab because of the high effort for transportation of the whole equipment needed for the transient characterization of fast–switching, high-voltage power devices. Therefore, the so-called environmental electromagnetic emission caused by typical emission sources such as mobile phones, broadcast, computers etc. has to be considered
- The distance between D.U.T. and antenna is reduced to 3m instead of 10m
- The measurements were taken in a frequency range of 200MHz-3GHz instead of 30MHz-1GHz

Figure 5 shows the basic configuration as used for all of the EMC measurements. For the measurements we used a logarithmic-periodical antenna manufactured by EMCO, Model 3147, and a Rohde&Schwarz spectrum analyzer, Model ESPI3.

Device Overview

For the investigations of the dynamic impatt oscillation, different irradiated freewheeling

Table I: Devices used for EMC Measurements in case of IMPATT Oscillation

Device	Irradiation Type of FWD	Nominal Current	Nominal Voltage
SC45	Electrons, E=4.5MeV, d=$1 \cdot 10^{15}\,\mathrm{cm}^{-2}$	100A	1200V
SKCD47C120I	SEMIKRON CAL-Diode	100A	1200V
SC14	Helium ions, E=11.6MeV, d=$1.4 \cdot 10^{12}\,\mathrm{cm}^{-2}$	9A	1200V
SKCD11C120I	SEMIKRON CAL-Diode	9A	1200V

Table II: Devices used for EMC Measurements in case of PETT Oscillations

Device	Type	Nominal Current	Nominal Voltage
GAR	High side switch	600A	1200V
GAL	Low side switch	600A	1200V

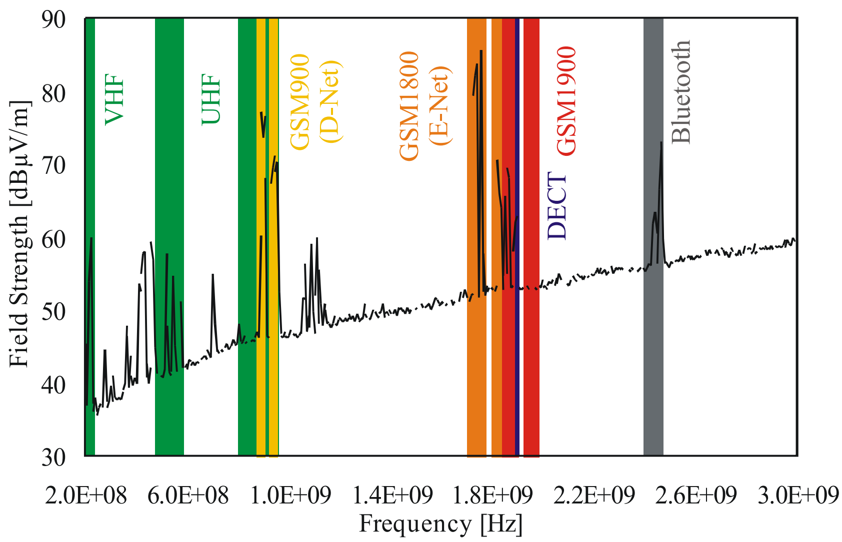

Figure 7: EMC measurement of environment

diodes were compared with commercially available devices with identical voltage and current range. Table I gives an overview about the different device types. The freewheeling diodes are paired with an appropriate IGBT chip in a high-side switch configuration.

For the investigations concerning pett oscillations, experimental power modules from SEMIKRON were used. The ratings of both module types, GAR (high-side switch) and GAL (low-side switch), are given in table II. In these devices, two freewheeling diodes (FWD) as well as two IGBTs are either paralleled in one group at one DCB (direct copper bonding) substrate, while again two groups are paralleled in one module.

Figure 6 shows the internal circuit and the layout of the two power modules.

Measurement Results

Figure 7 shows the measurement of the environment to depict other present emission sources. The colored bars mark frequency ranges used by broadcast and telecommunication. Obviously, the largest interfering signals are caused by mobile communication equipment.

Figure 8 gives the comparison of the emission of SC45, exhibiting dynamic impatt oscillations, and of SKCD47C120I without any RF

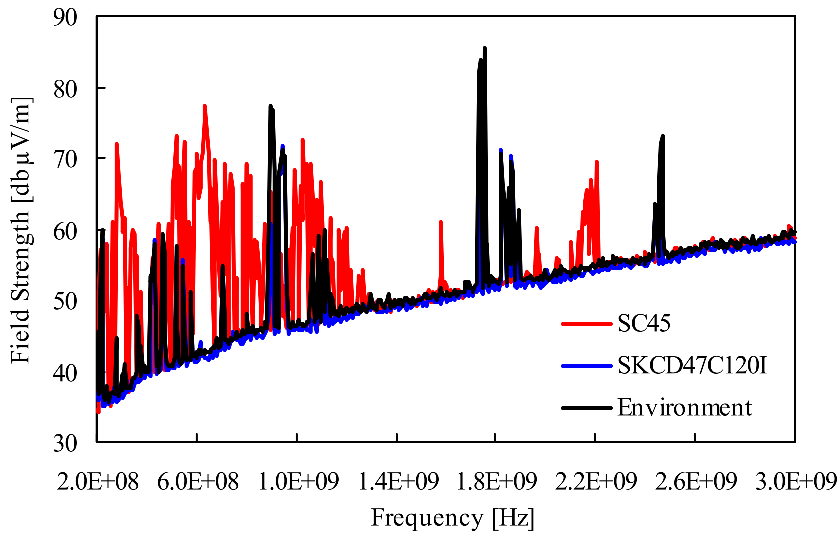

Figure 8: EMC measurement of electron-radiated device SC45 (impatt) and SKCD47C120I (no impatt) in comparison with environment

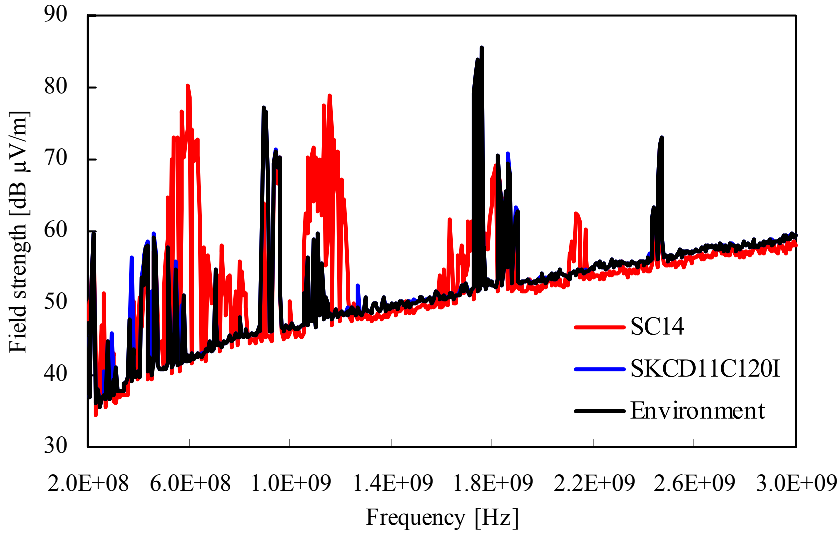

Figure 9: EMC measurement of helium-radiated device SC14 (impatt) and SKCD11C120I (no impatt) in comparison with environment

oscillations. The signals measured with SKCD47C120I are almost identical to the environment, whereas the impatt oscillations appearing while turning off the over-radiated device SC45 cause a large increase in the emitted electromagnetic spectrum. The emitted power leads to faults in the driver circuit. These malfunctions were prevented by additional shielding to enable these measurements.

Figure 9 shows the comparison of the helium-radiated sample SC14 in comparison with the appropriate device SKCD11C120I. Now, the signals generated by dynamic impatt oscillation are less widespread and show a fundamental frequency of 600MHz as well as the first and second harmonic. The emitted power is less than in case of SC45 and no problems were experienced even by using an unshielded driver circuit.

The pett oscillation shown in figure 10 during the turn-off of a module GAR (high-side switch configuration) causes two sharp peaks in the frequency spectrum, appearing at 700MHz and 1.4Ghz, respectively. In comparison, no oscillations are found in module GAL (low-side switch configuration), indicating the influence of the power module layout.

All signals generated by the impatt or pett oscillations are sufficiently large to exceed the limits set by the EMC standards and have to be avoided. Even the electromagnetic emission due to the pett oscillation, which is substantially

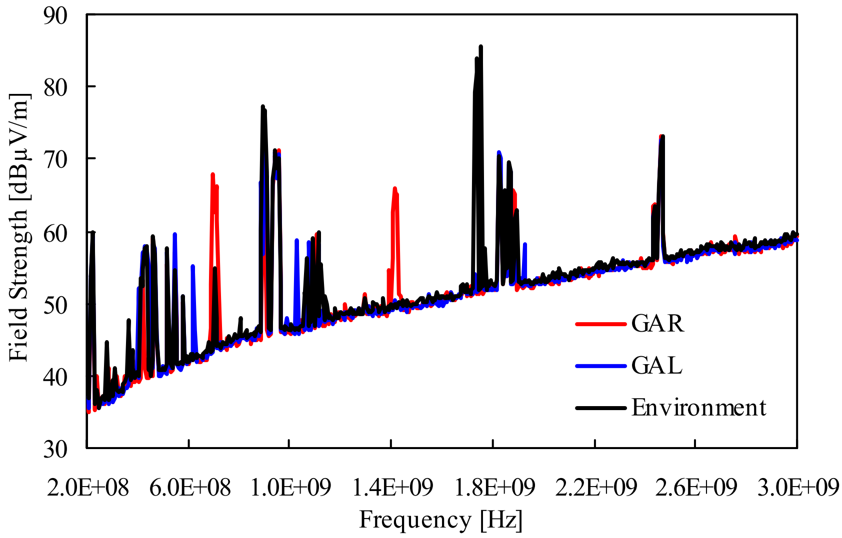

Figure 10: EMC measurement of GAR (pett) and GAL (no pett) in comparison with environment

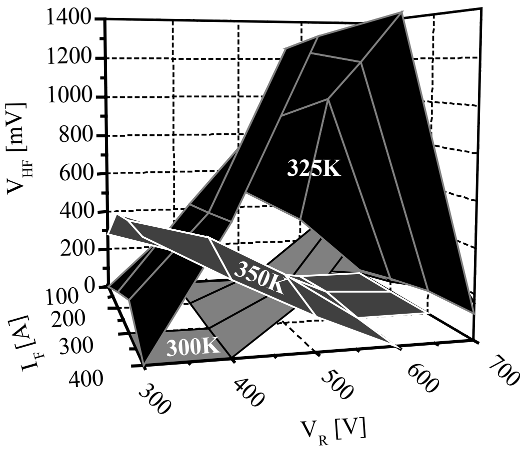

Figure 11: RF sensor voltage dependence for R_G=5Ω

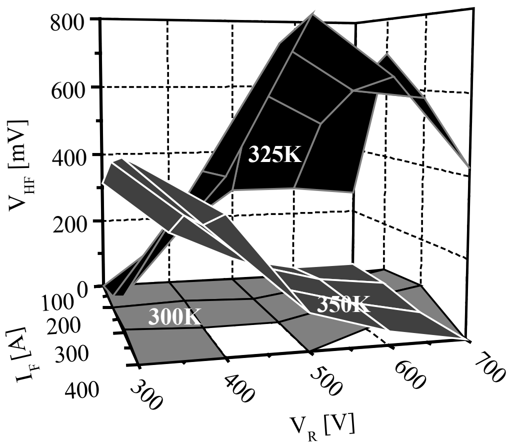

Figure 12: RF sensor voltage dependence for R_G=15Ω

lower then in case of impatt oscillation, may cause an exceeding of the limits if more than one power module is used in the equipment which is expected to be the typical case.

Avoidance of Transit-Time Oscillations

Dynamic impatt oscillations can be safely avoided by a proper device design if the parameters of electron- and helium irradiation are carefully chosen [1]. Special care must be taken since dynamic impatt oscillations are more likely to occur at low temperatures, which in case of occurrence might affect appliances such as building cranes or electric locomotives which work under rough environmental conditions

The prevention of pett oscillations is more difficult to the high number of parameters which take influence whether the oscillation occurs or not [4]. As examples, figure 11 and figure 12 depict the dependence of the measured RF sensor voltage on reverse voltage V_R, forward current I_F and temperature T - shown for two different values of the gate resistor R_G of the IGBT. In general, the design of the device and of the power module should result in a mismatch of internal and external resonance conditions. Known possibilities are the increase of the parasitic inductance between the individual chips by applying highly permeable materials [6] or by adding extra bond wires for direct connection of the chips [7].

Conclusion

High-frequency transit-time oscillations in bipolar power semiconductor devices may occur during the turn-off process. The oscillations investigated here are caused by charged deep traps or by carriers extracted from the excess carrier region remaining during the tail current phase due to interaction with parasitic inductances. The influence of these undesirable oscillations on the electromagnetic emission is studied by using common EMC measurements. The results show a strong increase of the total generated emission due to the RF oscillations. It is recommended to avoid these oscillations since they may cause EMC limits to be exceeded.

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