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Influence of High-Frequency Magnetic Fields on the Noise Behavior of CMS 2S Module Prototypes

C. Dziwok, L. Feld, K. Klein, M. Lipinski, A. Pauls, O. Pooth, and N. Roewert on behalf of the CMS Tracker Group

Abstract

For the CMS tracker Phase-2 upgrade new modules with silicon strip sensors are being developed. Each module features a Service Hybrid (SEH), which is responsible for the distribution of low voltages to the module components using a two stage DC-DC conversion scheme. For modules equipped with the latest generation of SEHs an increase in module noise has been observed. A setup for inducing radiative noise with external magnetic fields that are frequency- and location-dependent is presented. Measurements carried out on modules from different prototyping phases show that the sensitivity is similar across generations, which indicates that radiative coupling into the sensor or readout electronics is not responsible for the observed noise increase.

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Abstract: For the CMS tracker Phase-2 upgrade new modules with silicon strip sensors are being developed. Each module features a Service Hybrid (SEH), which is responsible for the distribution of low voltages to the module components using a two-stage DC-DC conversion scheme. For modules equipped with the latest generation of SEHs an increase in module noise has been observed. A setup for inducing radiative noise with external magnetic fields that are frequency- and location-dependent is presented. Measurements carried out on modules from different prototyping phases show that the sensitivity is similar across generations, which indicates that radiative coupling into the sensor or readout electronics is not responsible for the observed noise increase.

Keywords: Front-end electronics for detector readout; Detector grounding; Particle tracking detectors; Radiation-hard electronics

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1 Introduction

During the upgrade of the LHC to the High Luminosity LHC the current strip tracker of the CMS experiment [1] will be entirely replaced by a new system as part of the tracker Phase-2 upgrade [2]. In this context a new type of module, the so-called 2S module, is currently being developed of which 7608 units will be installed in the barrel and endcap region of the future Outer Tracker. A schematic drawing of a module is shown on the left side of figure 1.

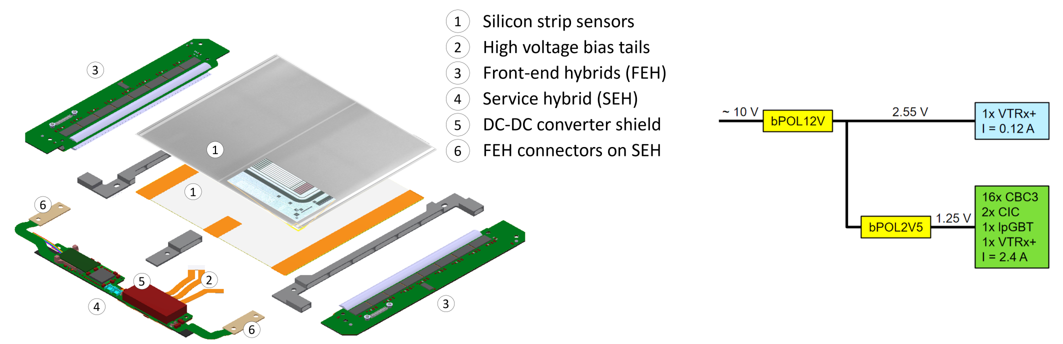

Figure 1. Drawing of a 2S module (left) and the two-staged DC-DC conversion scheme (right).

The module is equipped with two vertically stacked silicon strip sensors each with two rows of 1016 strips having a length of 5 cm and a pitch of 90 µm. The sensors have n-in-p type polarity and are depleted via high voltage bias tails, which are wire bonded to the sensor backsides. Wire bonds are also used to electrically connect the strips of the sensors to the Front-end Hybrids (FEH), which provide a binary readout of hit signals. The data from each of the two FEHs are then sent to the Service Hybrid (SEH). It is responsible for the communication with the tracker back-end via an optical link. Additionally, it supplies various components of the module with power.
A two-stage DC-DC conversion scheme is used to convert a 10 V input voltage to 2.55 V via the bPOL12V chip and to 1.25 V using the bPOL2V5 [3]. This scheme is illustrated on the right side of figure 1. Both converter stages are covered with a common aluminum shield on the SEH.

For modules using the most recent hybrids (namly SEH V3.2 and 2S-FEHs), an increase in the module noise of about 35% has been observed compared to hybrids from the previous prototype generation (namely SEH V3.1 and 8CBC3.1 FEHs). As a first step to investigate this observation, differential measurements of the ground potentials between the FEH connectors on the most recent SEH V3.2 were carried out. The results are depicted in figure 2. Significant contributions of harmonics of the DC-DC switching frequencies between 1 and 100 MHz can be seen compared to the previous SEH V3.1. This indicates an increase of the coupling of the DC-DC converter noise into the module ground.

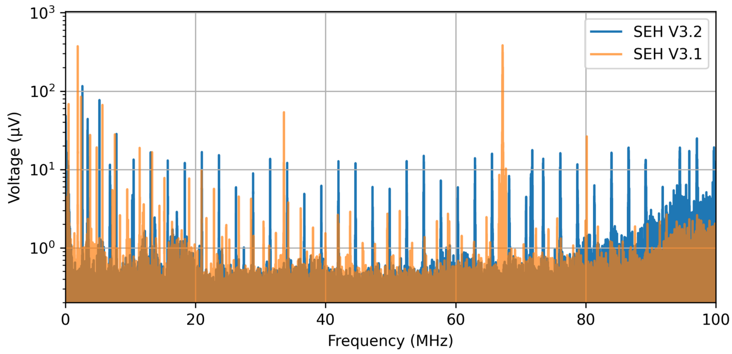

Figure 2. Fast Fourier transformation of differential measurements of the ground plane potential between the FEH connectors on the most recent (V3.2) and previous (V3.1) version of the SEH.

Since the emission of noise from the DC-DC converter stage is comparable across SEH generations, a dedicated setup was developed to investigate the sensitivity to radiative noise sources. This will be described in the following section together with corresponding measurements and results.

2 Induction of High-Frequency Magnetic Fields

2.1 Description of the setup

By using a signal generator (Hameg 8135) connected to an induction coil (ETS-Lindgren 7405-903, 1 cm loop diameter), magnetic fields are generated in a controlled way with frequencies comparable to the harmonics observed in figure 2. An amplifier (BONN BSA 0125-25) connected between generator and coil allows the adjustment of the signal height. The working point is chosen so that the strength of the generated fields is comparable to the maximal radiation measured at the SEH close to a design-related slot in the DC-DC converter shield. The induction coil is mounted on an XY-stage to allow for precise spacial movement above the surface of the module. For the following measurements the coil is positioned just above the mid-point of the SEH as shown in figure 3. For better visualization the coil is shown well above the SEH in the figure. For measurements, however, the coil is placed 1.3 cm above the surface of the DC-DC shield. Additionally, the coil can be rotated to change the orientation of the emitted magnetic fields. To illustrate this, the setup is shown in figure 3 in a configuration where the field lines inside the loop of the coil are pointing in the z-direction, where the coordinate system is given in the figure.

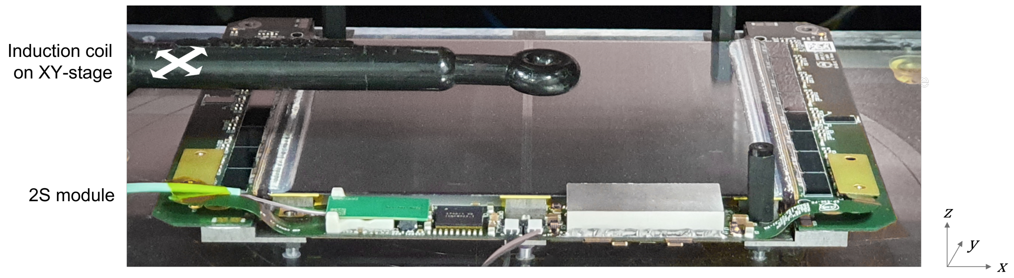

Figure 3. Induction coil positioned above a 2S module. The orientation of the field lines emitted by the coil refers to the coordinate system on the right side.

The readout of the module is realized by a custom test procedure written by using the standard tracker readout framework. After all channels are calibrated to ensure a uniform response behavior, the raw hits measured by the module are recorded. For the following studies the threshold is chosen so that the mean occupancy from noise without external radiation is about 10%.

2.2 Generation of common mode noise

The effect of radiating high-frequency fields onto a module can be seen in the event displays in figure 4. They show the hit structure for 127 strips of one chip. Each blue dot corresponds to a hit of a strip in one of the 200 recorded events. The baseline measurement on the left side shows an average occupancy of 10% with few neighboring hits. After activating the coil the occupancy is significantly higher and a line structure (consecutive hits in the chip) is observed, indicating the presence of common mode noise

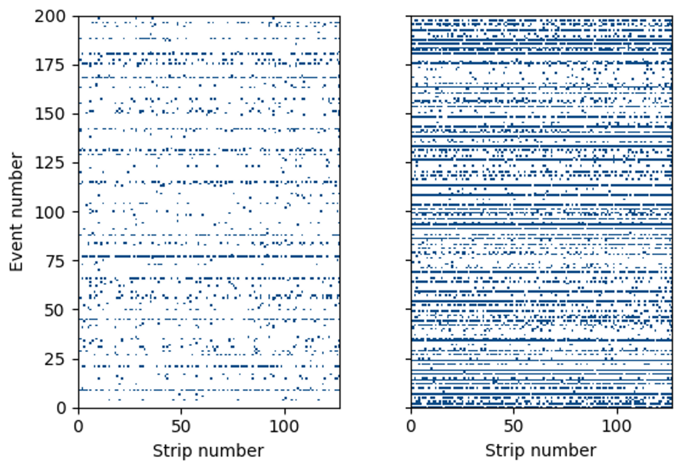

Figure 4. Event display for the baseline measurement (left) and with external high-frequency radiation (right). Each dot represents a hit in a strip during a particular event. Adjacent hits in a single event indicate common mode noise.

For this measurement a fixed frequency of 30 MHz was used. In order to record the response of the module to different frequencies of the magnetic fields the generator signal was changed automatically in 0.25 MHz steps from 1 to 60 MHz. For each step 1000 events were recorded and the average occupancy of the whole module was calculated. The resulting response curve is depicted in figure 5, which shows that the module is responding to external fields for frequencies between 10 and 60 MHz. Together with the measurement from figure 2 this means that the module is sensitive to the frequencies of the harmonics of the DC-DC converters. However, this response curve could not be calibrated in absolute terms to the emission characteristics of the induction coil. Therefore, the measurement was repeated using two other coils with loop diameters of 3 and 6 cm, yielding comparable curves and indicating that the general shape of the curve is valid.

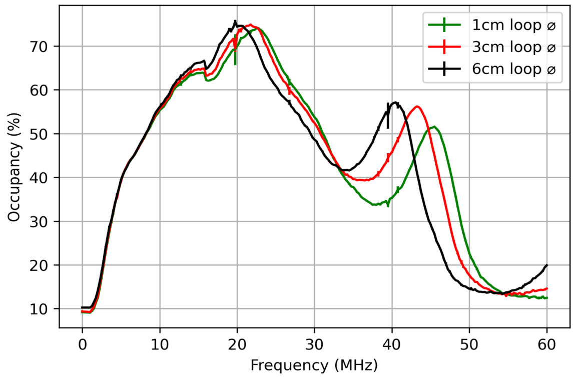

Figure 5. Response curve of a module to radiative noise emitted from three different induction coils.

2.3 Spacial and frequency dependency

In the next step the XY-stage was used to move the induction coil with 1 cm loop diameter to various positions above a module with the lastest SEH and FEHs. For each position the previous response measurements were repeated and the value of the maximal occupancy, always achieved for 23 MHz, was used to create a two dimensional response map. Two of these maps are shown in figure 6 overlaid with a schematic sketch of a 2S module. On the left side, the coil is oriented so that the fields lines are pointing in the z-direction as depicted in figure 3, resulting in occupancy changes from the baseline of 10 to up to 72%. The darker colored areas on the SEH and FEHs indicate the regions of the module where the occupancy was the greatest. On the right side of figure 6 the map of a measurement is shown, where the coil was rotated so that the field lines point in the y-direction. Here, a high response from the module can be observed especially in the sensor area. These differences in characteristics of the maps are expected due to the orientation of for example the PCB ground lines and sensor strips, which form induction loops for certain orientations of the magnetic fields.

The z- and y-direction measurements are complemented by a measurement with the field lines being oriented in the x-direction. The corresponding map is illustrated on the left side of figure 7. It shows a large response again at the FEHs and especially in the area of the FEH connectors on the SEH. This result from a three dimensional shape of the flex Kapton PCB as shown in figure 1.
A replication of these measurements with a module equipped with hybrids from the previous prototype generation yields similar maps. One example from these measurements is shown on the right side of figure 7, where the field lines are again pointing in the x-direction. Since all maps are comparable in shape and scale for both modules, it can be assumed that the coupling of external fields into the module did not change across generations.

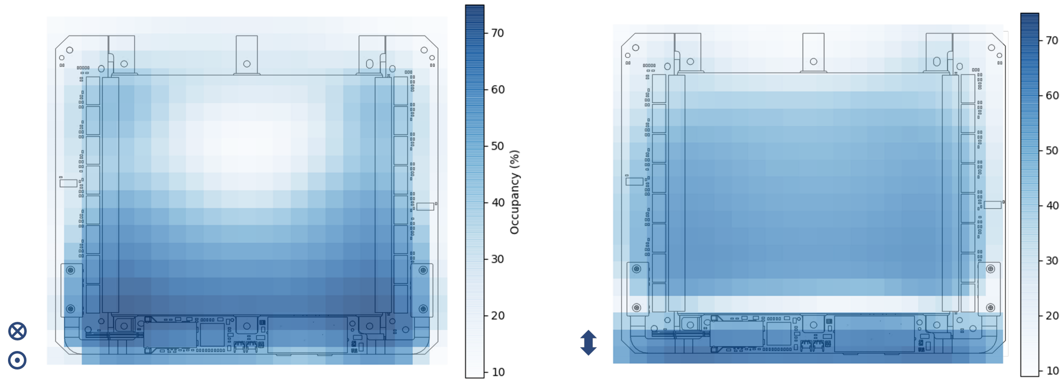

Figure 6. Two dimensional response maps with the field lines oriented in the z-direction (left) and in the y-direction (right).

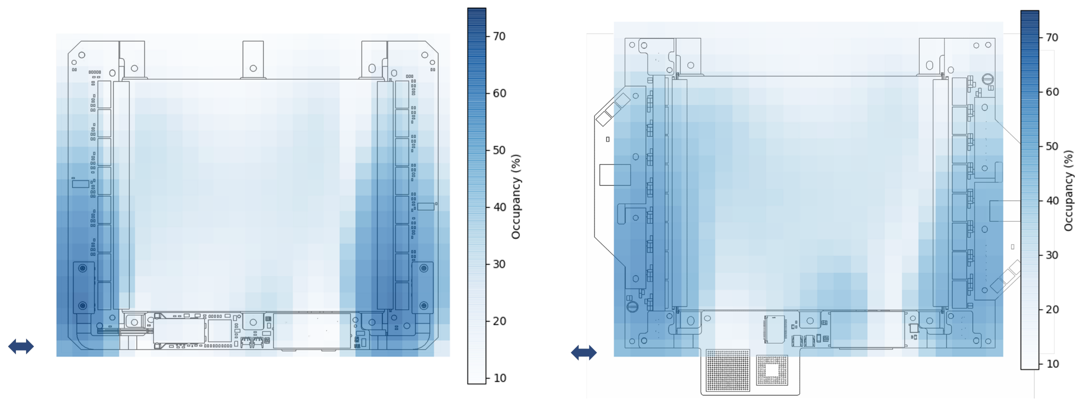

Figure 7. Two dimensional response maps of a module with the most recent (left) and previous (right) generation of hybrids. The field lines are pointing in the x-direction for each map.

3 Summary and Outlook

In conclusion, this contribution presents a setup for inducing radiative noise into a silicon strip module. The measurements provide insights into the response of CMS 2S modules to high-frequency magnetic fields including dependencies on the frequency, position, and orientation of the fields. Applying this technique to a previous prototype module it can be concluded that the basic coupling mechanism of radiative noise into the module did not change across generations. Since the radiation field from the DC-DC converter is comparable across generations it appears unlikely that a radiative coupling of noise directly in the sensors or readout electronics is responsible for the noise increase.

The presented measurements focus on the response to radiation applied to the top side of the modules. Measurements from other groups [4, 5] indicate that the high voltage tails, which are placed on the bottom side of the SEH below the DC-DC converters, play a crucial part in the noise increase. Therefore it will be of interest to repeat these measurements on the bottom side of modules using the setup described in this note. Finally, it should be noted that this measurement is very general in that it can be applied to other types of detector modules.

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