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Feasibility studies for a wireless 60 GHz tracking detector readout

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ABSTRACT

The amount of data produced by highly granular silicon tracking detectors in high energy physics experiments poses a major challenge to readout systems. At high collision rates, e.g. at LHC experiments, only a small fraction of data can be read out with currently used technologies. To cope with the requirements of future or upgraded experiments new data transfer techniques are required which offer high data rates at low power and low material budget.

Wireless technologies operating in the 60 GHz band or at higher frequencies offer high data rates and are thus a promising upcoming alternative to conventional data transmission via electrical cables or optical fibers. Using wireless technology, the amount of cables and connectors in detectors can be significantly reduced. Tracking detectors profit most from a reduced material budget as fewer secondary particle interactions (multiple Coulomb scattering, energy loss, etc.) improve the tracking performance in general.

We present feasibility studies regarding the integration of the wireless technology at 60 GHz into a silicon tracking detector. We use spare silicon strip modules of the ATLAS experiment as test samples which are measured to be opaque in the 60 GHz range. The reduction of cross talk between links and the attenuation of reflections is studied. An estimate of the maximum achievable link density is given. It is shown that wireless links can be placed as close as 2 cm next to each other for a layer distance of 10 cm by exploiting one or several of the following measures: highly directive antennas, absorbers like graphite foam, linear polarization and frequency channeling. Combining these measures, a data rate area density of up to 11 $\mathrm{Tb/(s \cdot m^2)}$ seems feasible. In addition, two types of silicon sensors are tested under mm-wave irradiation in order to determine the influence of 60 GHz data transmission on the detector performance: an ATLAS silicon strip sensor module and an HV-MAPS prototype for the Mu3e experiment. No deterioration of the performance of both prototypes is observed.

1. Introduction

Today's and future high energy particle physics experiments have to face high event rates in order to improve the sensitivity for Standard Model precision measurements and to increase the discovery potential for physics beyond the Standard Model. Detectors with ever-increasing granularity have to be used in order to enhance sensitivity limits due to spatial and momentum resolution. Constraints on space, material budget, power consumption and radiation hardness are nowadays the main limitation for the detector construction and the data readout bandwidth. Thus, there is an increased demand for new readout techniques that allow data transfer at extremely high rates.

Today, wired electrical and optical readout systems are used in particle detectors at colliders. Within the last decades, wireless data transmission has evolved significantly and data rates are becoming comparable with wired data links. Nonetheless, presently used wireless systems like WIFI or LTE are not suitable for particle detectors because of the limited data throughput and the large antennas. But at higher carrier frequencies a wireless detector readout seems feasible. A large bandwidth of 9 GHz provided in the 60 GHz band allows data rates of several Gb/s even with simple modulation schemes. Due to the short wavelength of $\lambda \approx 5$ mm antennas have a very small form factor.

Commercial chips for the 60 GHz frequency band are available on the market, but none of them is foreseen to be used in particle physics experiments as the following requirements are usually not met: the transceiver chip has to be radiation hard; it must be operated at low power and should provide a high bandwidth at the same time. For that reason a new 60 GHz transceiver ASIC for particle physics applications is currently designed [1,2].

Wireless readout of a tracking detector for a fast track- trigger application was proposed in [3]. The authors describe how

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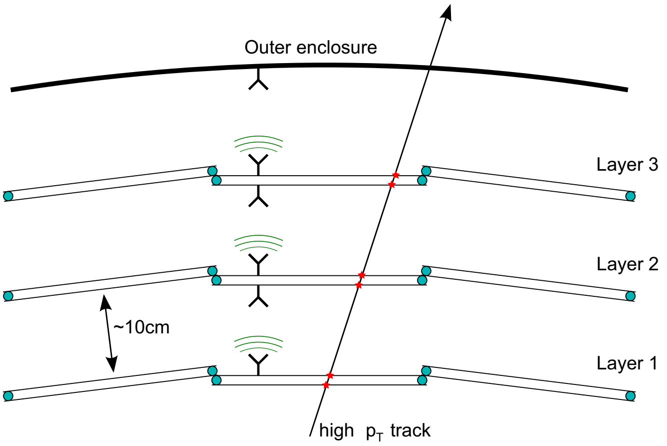

Fig. 1. Conceptual sketch of a wireless radial readout of a cylindrical tracking detector, adapted from [3].

wireless readout can be exploited to transmit hit information between several highly granular silicon tracking layers to enable a fast trigger decision. The readout scheme, depicted in Fig. 1, assumes a radial data transfer from the inner detector layers to the outside, thus facilitating the implementation of track finding algorithms in on-detector logic.

In this paper we present feasibility studies regarding the integration of the 60 GHz wireless technology in a silicon tracking detector. Several aspects relevant for the implementation of 60 GHz links are studied: transmission losses, interference effects, absorbing materials and the influence of the antenna design. In particular, we study how wireless signals can be directed with low material horn antennas and how unwanted reflections from detector modules can be attenuated. From these studies we estimate the maximum density of wireless links that can be operated in parallel between detector layers. In addition, the influence of 60 GHz waves on a silicon pixel sensor prototype and on a silicon strip detector module is tested and it is found that the detector performance is not degraded.

2. 60 GHz transmission and reflection tests

In order to maximize the data throughput of a wireless readout system, as depicted in Fig. 1, links have to be packed densely and the maximum possible bandwidth should be fully exploited by every single link. The main challenge is to avoid cross talk between parallel and subsequent, chained links. The latter is granted as radio signals in the 60 GHz band do not pass detector layers with metal layers implemented. A first study of transmission of mm-waves through an ATLAS SCT module [4], see Fig. 2, showed that mm-waves cannot penetrate tracking detector modules [3]. We repeat this measurement with increased sensitivity and also with a different type of silicon detector modules.

2.1. Tests with an ATLAS SCT barrel module

A spare silicon strip detector module from the ATLAS barrel detector, depicted in Fig. 2, is mounted on a 2D movable stage and placed in line of sight (LOS) of two horn antennas for transmission and reception. The module is irradiated with linearly polarized waves in the range from 57.3 GHz to 61.3 GHz.[1] The intensity transmitted through the module is measured with a spectrum analyzer in the radio frequency band without down conversion. The transmitted intensity is normalized to the intensity without module in-between. The setup is able to resolve transmission losses down to −55 dB at a minimum power of about −90 dBm over the frequency range mentioned above. To avoid distortions of the measurement by accidental reflections or diffraction aluminium plates and graphite foam is used as shielding.

Spectra of the transmission loss through the barrel module at positions A, B and C are shown in Fig. 3 together with the noise limited sensitivity of the spectrum analyzer. The region of most interest is region B, as a 60 GHz transceiver would have to be placed on the readout electronics hybrid. Especially with highly directive antennas, most of the wireless signal intensity would be focused within this region. No transmitted signal can be measured at the positions under test, corresponding to a transmission loss of more than −50 dB over the entire frequency range.

Fig. 4 shows the transmission loss averaged over the chosen frequency band at various positions along the module. Again, no transmission is observed independent of the polarization of the radio signal.

2.2. Tests with an ATLAS SCT endcap module

The measurement is repeated with a spare ATLAS SCT endcap module [6], see Fig. 5. A position scan is performed only in the

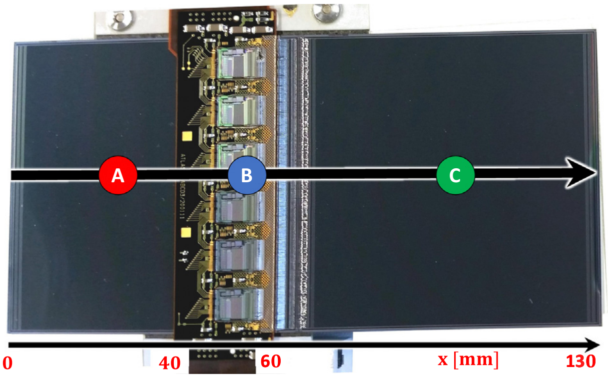

Fig. 2. The ATLAS SCT barrel module [4] under test. Positions for frequency scans are denoted by (A), (B) and (C). A position scan is performed along the black arrow.

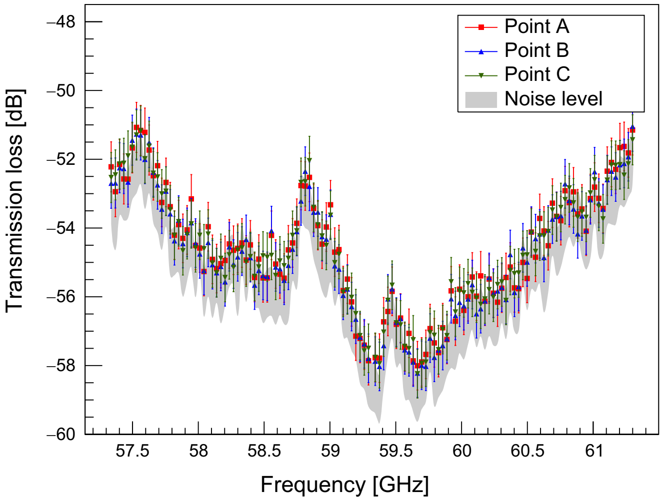

Fig. 3. Transmission loss through the ATLAS SCT barrel module as function of the frequency at positions A, B and C (see Fig. 2) and the noise limited sensitivity of the spectrum analyzer. The uncertainties of 1 dB are due to intensity variations observed with the spectrum analyzer in the power range of −90 dBm.

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[1] If not stated otherwise, all of the following tests are done with the HMC6000/6001 transmitter and receiver chips by Hittite [5].