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Strip defect recognition in electrical tests of silicon microstrip sensors

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ABSTRACT

This contribution describes the measurement procedure and data analysis of AC-coupled double-sided silicon microstrip sensors with polysilicon resistor biasing.

The most thorough test of a strip sensor is an electrical measurement of all strips of the sensor; the measured observables include e.g. the strip's current and the coupling capacitance. These measurements are performed to find defective strips, e.g. broken capacitors (pinholes) or implant shorts between two adjacent strips.

When a strip has a defect, its observables will show a deviation from the "typical value". To recognize and quantify certain defects, it is necessary to determine these typical values, i.e. the values the observables would have without the defect.

As a novel approach, local least-median-of-squares linear fits are applied to determine these "would-be" values of the observables. A least-median-of-squares fit is robust against outliers, i.e. it ignores the observable values of defective strips. Knowing the typical values allows to recognize, distinguish and quantify a whole range of strip defects.

This contribution explains how the various defects appear in the data and in which order the defects can be recognized. The method has been used to find strip defects on 30 double-sided trapezoidal microstrip sensors for the Belle II Silicon Vertex Detector, which have been measured at the Institute of High Energy Physics, Vienna (Austria).

1. Introduction

Many high energy physics experiments equip their tracking sub-detectors with silicon microstrip sensors. These sensors have to be tested and their quality controlled, both during the development phase and during mass production.

The most thorough test of a silicon microstrip sensor is an electrical measurement of all strips of the sensor, trying to find defective strips. The analysis of the measurement data has to take into account the specifics of the sensors and the measurement procedure, and apply smart methods to find broken strips and recognize the defect types from their signatures in the data.

This contribution focuses on the algorithmic details of defect recognition of AC-coupled silicon microstrip sensors with polysilicon resistor biasing. The measurement procedure and the measured observables are explained in Section 2, while the fit algorithm, the defect types and the defect recognition work flow are explained in Sections 3, 3.1 and 3.2. Section 4 gives an overview about the number of defects found on 30 double-sided trapezoidal microstrip sensors for the Belle II Silicon Vertex Detector.

2. Measurement procedure

The measurement procedure at the Quality Test Center probe station at the Institute of High Energy Physics Vienna involves three micro-manipulators, which put needles on the AC pad of a readout strip, the DC pad of the same strip, and the DC pad of the adjacent readout strip. After performing all measurements, the *xyz*-table moves the sensor to have the needles make contact with the next readout strip. Two additional needles contact the bias rings on both sensor sides, which keep the sensors at full depletion inside a light-tight box during the whole measurement. A switching matrix system (Keithley 7001 with two 7153 matrix cards) connects the three needles to an electrometer (Keithley 6514), an SMU (Source Measure Unit, Keithley 2410) and an LCR meter (L: inductance, C: capacitance, R: resistance, Agilent 4284A). A detailed description of the measurement setup can be found in [1].

The measured observables are:

- Strip leakage current I_{strip}: The HI terminal of the electrometer is connected to the DC pad and measures the leakage current of the strip.
- Polysilicon bias resistor R_{poly}: The SMU is connected between bias ring and DC pad, applies a voltage of 1 V and measures the current. Then, the previously measured I_{strip} is subtracted. The

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resistance is calculated from the resulting corrected current.

- Current through the dielectric I_{diel}: The SMU is connected between the DC pad and the AC pad, and a potential difference of 10 V is applied. The measured current is the current through the dielectric of the strip's capacitor.
- Coupling capacitance C : The LCR meter is connected between DC pad and AC pad. An additional needle resting on the adjacent readout strip's DC pad is shorted with the DC needle of the current strip. That way, a short between the two readout metal lines shows a doubled capacitance value. The capacitance is measured at a frequency of 100 Hz. The LCR meter internally measures the impedance, and one can calculate the capacitance C_{p} and the resistance R_{p} assuming a parallel equivalent circuit, the dissipation factor D and the capacitance C_{s} and the resistance R_{s} in the series equivalent circuit. The series capacitance C_{s} is used in the analysis.[1]

Due to geometry reasons, first all odd readout strips are measured, and then the *xyz*-table is stepped in the opposite direction to measure the even readout strips. This means that the measurements of adjacent strips are taken at different times, with slight differences in temperature and humidity. Therefore, especially the current observables can show a wiggling behavior with a periodicity of two strips.

3. The algorithm

Some defect types (e.g. high leakage strips, broken capacitors) can be identified by applying absolute thresholds on the corresponding observables. However, to recognize and quantify some other defects, it is necessary to determine the “typical values” of the relevant observables, i.e. the values the observables would have without the defect. This is illustrated in Fig. 1.

When the typical value of an observable is known, one can apply thresholds which depend on the typical value. An example is a short between the implants of two adjacent strips: in this case one would see twice the strip's typical leakage current, and half the typical resistor value. It is not possible to automatically recognize this kind of defect signature with absolute thresholds.

As a novel approach, least-median-of-squares linear fits are used to determine the “would-be” values of the observables. A least-median-of-squares fit is robust against outliers, i.e. it ignores the observable values of defective strips. This fit is performed locally for sets of 32 adjacent strips, and separately for even and odd strips for some observables. In contrast to the commonly used least (sum of) squares fit, a least-median-of-squares regression minimizes the median of the squared deviations [2]. This leads to a computationally expensive but very robust algorithm. The linear least-median-of-squares fit used in this analysis returns an undisturbed fit line as long as the data contains less than 50% defective strips.

3.1. Defect types

The identifiable defect types and their data signatures are:

- Pinhole (AC defect): A short between strip implant and metal line. The signature is a high current through the dielectric above an absolute threshold: $I_{\mathrm{diel}} \geq 0.4$ nA. This defect can also spoil the measurements of C_{s} and R_{p}, which may misleadingly look like a “missing AC needle contact”.
- High current (DC defect): A large strip leakage current above an absolute threshold: $I_{\mathrm{strip}} \geq 50$ nA. Due to the current correction (see Section 2) this defect is often accompanied by a very low (but wrongly measured) bias resistance value.
- High resistor (DC defect): An interruption of the bias resistor. The signature is a resistance value above an absolute threshold: $R_{\mathrm{poly}} \geq 100\ \mathrm{M\Omega}$.
- Implant short (DC defect): A short between two strips' implants. The signature is a doubled strip leakage current: $I_{\mathrm{strip}} \in \left[2 \cdot I_{\mathrm{strip}}^{\mathrm{typ}} - 40\%, 2 \cdot I_{\mathrm{strip}}^{\mathrm{typ}} + 25\%\right]$ in connection with a halved bias resistance: $R_{\mathrm{poly}} \in \left[0.5 \cdot R_{\mathrm{poly}}^{\mathrm{typ}} - 10\%, 0.5 \cdot R_{\mathrm{poly}}^{\mathrm{typ}} + 12\%\right]$. The width of the allowed interval is calculated using percentages of the typical value, not the doubled or halved one. The sensors used in this analysis feature intermediate strips which are not read out, and so this signature does *not* occur on two adjacent readout strips.
- Metal short (AC defect): A short between two strips' metal lines. The signature is a doubled coupling capacitance: $C_{\mathrm{s}} \in \left[2 \cdot C_{\mathrm{s}}^{\mathrm{typ}} - 20\%, 2 \cdot C_{\mathrm{s}}^{\mathrm{typ}} + 20\%\right]$ or a doubled current through the dielectric: $I_{\mathrm{diel}} \in \left[2 \cdot I_{\mathrm{diel}}^{\mathrm{typ}} - 30\%, 2 \cdot I_{\mathrm{diel}}^{\mathrm{typ}} + 30\%\right]$. This signature only occurs when the two DC needles contact the two shorted strips. If such a signature is found, both the current and the next strip are marked as “metal short”. Metal open (AC defect): An interruption of a strip's metal line. The signature is a reduction of the coupling capacitance: $C_{\mathrm{s}} \in \left[0.1 \cdot C_{\mathrm{s}}^{\mathrm{typ}}, 0.8 \cdot C_{\mathrm{s}}^{\mathrm{typ}}\right]$ while the dissipation factor shows no deviation: $D \in \left[D^{\mathrm{typ}} - 10\%, D^{\mathrm{typ}} + 10\%\right]$. This makes sure that the capacitance measurement is okay, and that any deviation stems from a change of the capacitor area. The choice of thresholds allows to find an interruption located between 10% and 80% of the strip's length. The deviation $p = C_{\mathrm{s}}/C_{\mathrm{s}}^{\mathrm{typ}}$ from the typical value predicts the location of the interruption along the length of the strip.
- Implant open (DC defect): An interruption of a strip's implant. The signature is the same as for a metal open – a reduction of the capacitor area – but adds the requirement that the strip leakage current shows a proportional reduction: $I_{\mathrm{strip}} \in \left[I_{\mathrm{strip}}^{\mathrm{typ}} \cdot p - 5\%, I_{\mathrm{strip}}^{\mathrm{typ}} \cdot p + 5\%\right]$, where $p = C_{\mathrm{s}}/C_{\mathrm{s}}^{\mathrm{typ}}$. The deviation p from the typical value predicts the location of the interruption along the length of the strip. This defect also shows a “high resistor” if the DC pad is located on the opposite end of the strip, relative to the location of the bias resistor.[2]
- Low capacitance (AC defect): A capacitance below the value agreed on with the vendor: $C_{\mathrm{s}} \leq 0.8\ \mathrm{pF\,cm^{-1}\,\mu m^{-1}}$. The threshold is expressed per strip area in centimeters (strip length) times micrometers (strip width).
- No DC needle contact: This is not a defect, but a faulty measurement. The signature is a high bias resistance (same threshold as for “high resistor”) and a low strip leakage current: $I_{\mathrm{strip}} \leq 0.5$ nA. Additional signatures are measurement device errors like $I_{\mathrm{strip}} \leq 0$, a ridiculously large I_{strip} or NaN readings. A real missing DC needle contact makes any measurement impossible.
- No AC needle contact: This too is not a defect, but a faulty measurement. The signature is a very large or very small coupling capacitance: $C_{\mathrm{s}} \notin \left[0.8\ \mathrm{cm^{-1}\,\mu m^{-1}}, 100\ \mathrm{cm^{-1}\,\mu m^{-1}}\right]$ in connection with a very large or very small parallel resistance:

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[1] Some sensors suffer from increased contact resistance at the DC pads, and the parallel capacitance is sensitive to this. The series capacitance, however, is robust, and has the same value as the parallel capacitance for normal contact resistance.

[2] In this case, the interruption of the implant is located between the DC needle and the bias needle, and the measurement of the bias resistor will show no electrical contact.