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Estimates of the effects of the beam splash on SCT sensor

Technical Note by

A.Chilingarov, Lancaster University, UK

The aim of this Note is to estimate crudely the effects of an intense charge deposition inside ATLAS SCT sensor, which may happen during a beam loss. The following assumptions are made in the estimates.

The capacitance between a single sensor strip and the backplane C_{sb}=1.5 pF, bias resistor from the strip implant to the bias rail R_b=1.4 MΩ, decoupling capacitance between the implant and Al readout strip C_{dec}=120 pF. Two sensors connected to a hybrid have an external capacitance between their backplanes and the ground C_{bp}=50 nF and a series resistor between this capacitance and the voltage source R_s=5 kΩ. The total capacitance of two sensors is 1.5 pF/strip x 770 strips x2 = 2.3 nF << C_{bp}. The time to restore the bias voltage at the backplane $\tau_{bias}=C_{bp}R_s$=50 nF * 5 kΩ = 250 μs. The MIP ionisation density is 22000 (e-h pairs)/300μm = 3.5 fC/300μm = 1.17 10^{-2} fC/μm. Typical collection time of the deposited ionisation $t_{col} \approx 300\mu m/v_{sat}$ =0.03 cm / 10^7cm/s= 3 ns. In all estimates the ionisation deposited under a strip is assumed to be the same for every strip in the sensor.

1. Instantaneous charge deposition

Consider charge Q_s deposited under one strip during the time much shorter than the collection time ~3 ns (and thus the bias restoration time ~250 μs). To distort the electric field inside the sensor the charge should be comparable to a charge at the fraction of the C_{bp} corresponding to one strip 50 nF/(2*770)=32 pF. Assuming bias voltage of 150 V this charge is Q_{bias} =32 pF*150 V= 4800 pC (equivalent to 4800 pC/3.5 (fC/MIP) = 1.4*10^6 MIPs). When Q_s exceeds this value the electric field inside the sensors will decrease during the collection time ultimately stopping the collection process. If Q_s<<Q_{bias} the whole charge Q_s will arrive to the strip within t_{col} time.

The implant is connected to the ground via decoupling capacitance and bias resistor. The RC time of this system is τ_{str}=120 pF *1.4 MΩ = 170 μs. Since this time is much longer than the collection time the whole charge Q_s will go to the decoupling capacitance. Even for $Q_s=Q_{bias}$=4800 pC the potential at the decoupling capacitance will be 4800pC/120pF = 40 V that is much less than 100 V that C_{dec} is specified to tolerate.

2. Prolonged charge deposition

Now consider charge Q_s deposited under one strip uniformly in time during the beam splash time T_{sp}. There are two distinct situations depending on whether the T_{sp} is much shorter or much longer than the bias recovery time τ_{bias} ~ 250 μs. For comparison the beam revolution time in LHC is ~90 μs.

2a) Short splash

If $T_{sp} << \tau_{bias}$ the situation is very similar to that considered for the instantaneous charge deposition. The current will flow to the strip implant during the time T_{sp} instead of collection time t_{col} but the maximum charge that may be collected at the strip is still the same, Q_{bias}=4800 pC, and the maximum implant potential to the ground is still ~40 V. If the punch-through protection (PTP) is activated above its onset voltage (~15V) the decoupling capacitance may discharge partially via the PTP gap but the above estimate sets an upper limit for the C_{dec} potential.

2b) Long splash

When $T_{sp} >> \tau_{bias}$ the sensor operates in a steady current mode and the characteristic parameter is the current, I_s, created by the ionisation deposition per strip. The series bias resistor R_s=5 kΩ limits the maximum current through two sensors. For bias voltage of 150 V the maximum current is I_{lim} ~150V/5kΩ = 30 mA which corresponds to the current per strip in one sensor of I_{stlim} ~ 30mA/(2*770)=20μA. This current will result in the implant potential of I_{stlim}*R_b = 20μA*1.4MΩ= 28 V which is again small compared to the tolerance of 100 V. If the current exceeds the above values the bias at the sensor practically disappears after the time of ~ τ_{bias} . The maximum charge collected by one strip in this case may be estimated as I_{stlim}* τ_{bias} ~

$20\ \mu A * 250\ \mu s = 5000$ pC. Not accidentally this value is close to the Q_{bias} used above. In fact this is the same number calculated in a different way.

The current $I_{stlim} = 20\ \mu A$/strip corresponds to the ionisation of $20\ \mu C$ /strip/s, which in turn corresponds to $20\mu C/3.5fC = 5.7*10^9$ MIPs/strip/s or $4.4\ 10^{12}$ MIPs/sensor/s.

Let's consider briefly how the above estimates will be affected by a bias increase from 150 to 450 V. The changes are in fact minimal. The same deposited charge Q_s or the current I_s will produce the same signal as calculated above. The self-shutdown limits will grow by factor 3 but the corresponding voltages at the decoupling capacitors (40V and 28V) will not grow by factor 3 because in this case they will be limited by the PTP mechanism.

In conclusion the sensor/module design should prevent the electrical damage to the sensor in case of intense ionisation deposition (beam splash). Possible thermal/mechanical damage to the module and survival of the front-end electronics are beyond the scope of this Note.

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Estimates of the effects of the beam splash on SCT sensor: Appendix A

The aim of this Appendix is to estimate the effects of reducing the bias voltage during nonoperational period. As an example 20 V and 50 V values are considered. The undepleted part of the sensor bulk is considered to be completely insensitive to the deposited ionisation.

Let us introduce two reduction factors: $r_{bias}=U_{bias}/150V$ and $r_d=d/w$ where *d* is the depleted region and *w* full sensor thickness. Normally $r_d=\mathrm{sqrt}(U_{bias}/U_{dep})$. For the estimates below the full depletion voltage U_{dep} is assumed to be 70 V. In this case $r_d>0.5$ for $U_{bias}>20V$ and thus the capacitance to the back plane for two sensors in the module is <2.3nF/0.5=4.6 nF, which is still small compared to the C_{bp}=50 nF.

Thus for a short splash (or instantaneous charge deposition) the effects of a reduced bias can be estimated as follows. The maximum charge that can arrive at a strip is r_{bias}*4800 pC, the potential it causes at the strip $U_{strip}=r_{bias}$*40 V and the number of MIPs to create this charge $N_{MIP}=1.4\ 10^6\ r_{bias}/r_d$. The numerical results are collected in Table 1.

Table 1. Typical parameters for a short splash

U_{bias}, V	r_{bias}	r_d	U_{strip}, V	N_{MIP}, 10^6
20	0.13	0.53	5.2	0.34
50	0.33	0.85	13	0.54

For a long splash the relevant parameters have to be modified as follows. The maximum current (cut-off current) per strip $I_{max}=r_{bias}$*20μA/strip, which corresponds to the MIP rate (r_{bias}/r_d)*5.7 10^9 MIP/(strip s). It results in a voltage at the strip $U_{strip}=r_{bias}$*28 V. The numerical results are presented in Table 2.

Table 2. Typical parameters for a long splash

U_{bias}, V	r_{bias}	r_d	U_{strip}, V	MIP rate, 10^9/str s
20	0.13	0.53	3.6	1.4
50	0.33	0.85	9.2	2.2

In conclusion the maximum voltage at the strip decreases proportionally to the bias voltage and is always well below 100V limit. Note however that all the above estimates assume that the whole module is covered with the beam splash. If the particle flux covers only a fraction, ν_s, of the sensor strips the voltage at these strips will increase as $1/\nu_s$.