Tera-Pixel APS for CALICE

Sensor Testing Specification

ASIC1.1

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2. INTRODUCTION

This document details the tests which will be needed for the first round of MAPS sensor production (ASIC1). The tests will be split into groups and these will be performed at physically different locations. The first “basic” tests will be done in RAL Technology and will check the functionality of the sensor. The more “detailed” tests will then be done (assuming the sensor is functioning). Tests for comparison with the sensor simulations will be performed at RAL PPD, while tests of the sensors in terms of physical detectors with radioactive sources and cosmics will be done at Imperial and Birmingham, respectively.

3. ITEMS WHICH NEED TO BE TESTED

It is important to identify the key items that will need to be verified when testing the sensor. These are listed below and a reference is given to the section where the relevant test is detailed.

Test	Section
Test Structures	Basic
Pixel digital circuit functionality • Check new SRAM write logic is working correctly at 3.3v supply.	Basic
Comparator functionality • Check new trim bits are working correctly (if implemented)	Basic
Global digital circuit functionality and data I/O	Basic
Power consumption	Basic
Effect of substrate connection	Basic
Charge diffusion	Simulation
Crosstalk	Simulation
Charge collection time	Simulation, possibly source
ILC timing operation	Basic, source
Noise rate vs. threshold	Basic (qualitative test, observation), source, cosmics (quantitive tests, statistics)
Relative efficiency vs. threshold	Simulation, source

Relative efficiency vs. time	Source
Time-correlation of noise hits, noise vs. clock rate	Source, cosmics
Uniformity of threshold, temperature and time dependence	Basic (qualitative tests, observation), source (quantitive tests, statistics)
Uniformity of gain, temperature and time dependence	Source
Uniformity of noise rate, temperature and time dependence	Source, cosmics
Magnetic field effects; operation in fields up to 5T as available	Source (setup moved to location of magnet)
Absolute MIP calibration	Cosmics

4. BASIC TESTS

These tests will be done at RAL Technology. The main aim is to check the basic functionality of the new sensor.

4.1 Schedule

The specific schedule of functional tests will ultimately depend on the circuits that are manufactured, but a typical indicative schedule is presented below:

PCB bare test	Basic verification of bare PCBs prior to bonding. Undertake revised set of modification for ASIC1.1 (some changes will no longer apply, but some resistor values will still need changing)	1 week (in advance)
Bonding	Glue & bond new chips to new PCBs	2 weeks
Power-on PCB with bonded chip	FPGA holds board in idle (safe) state. Set adjustable current biases. Measure current consumption & voltages at pads, compare with expected/simulation values.	1 day
Shift register tests	Test program sensorLoad inserts random configuration data and reads back, checking for errors.	
Comparator test structure	Test structure comparator inputs driven with typical pixel-level input signals and output checked for correct operation.	
Monostable test structures	Test program triggers monostables which can be observed on test outputs (proves design error is fixed)	
Full frame tests: continuous mode	Regular bunch train operation using DAQ software proves that ORE signals emerge from all columns. Override mode + logic analyser will be necessary to ensure data integrity: Bias for sense amplifiers will need to be adjusted to compensate for design change in this reference. Monitor current in VDD2V5dig (3.3v, SRAM) power rail to check the level-shift logic fix has worked correctly and is not drawing excessive power from the 3.3v supply.	3 days
Threshold scan	Automated scan of threshold voltage with sensor held in the dark, gives first indication of quality of sensor / correct operation of bulk pixels	2 days

5. SENSOR SIMULATION TESTS

Trim calibration	Per-pixel threshold scan data taken and used to generate trim file for each sensor & histogram pedestal spread for reference.	2 weeks
Gain uniformity	Per pixel uniform stimulation with pulsed laser	4 weeks
Analog test pixel performance	Scan of laser position across single test pixels: analog performance recorded	1 week
Deep p-well evaluation	Repeat of above on non-deep p-well sensor for comparison with simulation	1 week
Crosstalk	Laser analysis of pixel hits due to neighbouring charge deposits	
Charge collection time	Subtle analysis of hit timestamps with respect to laser firing	
Sensitivity to fractional MIP	Extension of gain uniformity study	

6. SOURCE TESTS

Triggered mode	Using scintillators	
Free-running mode	Bunch train running	

7. COSMIC TESTS

(See appendix 3)

DAQ READOUT SYSTEM

All test setups require a readout system for the sensor and a single design will be used which is common for all. This will consist of a PCB to hold the sensor, a control board to operate it and a PC to run the control board. There is no requirement to change the DAQ system for the new ASIC 1.1 sensor.

7.1 Sensor PCB

As used for ASIC1. The table below details the current list of PCB modifications, and which should be applied to the sensor PCBs for the ASIC1.1 revision sensor.

PCB MOFICATION: ASIC1.0	REQUIRED FOR ASIC1.1 ?
R86 Fit 0ohm in VDD opt	ü (same)
Lift pins 1 & 2 on IC17. Add 2k2 between the vacated pads and ground.	ß (bug fixed in sensor) IC17 should be fully fitted. R65 value subject to review.
Change R67 to 5K1	R67 value subject to review (bug fixed in sensor).
Change R66 to 5K1	R66 value subject to review (bug fixed in sensor).
Change R68 to 560R	ü
Change R70 to 560R	ü
Change R71 to 560R	ü
Change R72 to 20K	ü
Change R69 to 13K	ü
Change R73 to 100K	ü
Change R74 to 6K2	ü
Change R75 to 100K	R75 value subject to review (bug fixed in sensor)
Change R79 to 560R	ü
Change R78 to 560R	ü
Change R80 to 560R	ü
Change R77 to 5K1	R77 value subject to review (bug fixed in sensor).
Remove TR1. Add 2k2 between pin3 and ground.	ß (bug fixed in sensor) TR1 should be fitted. R85 value subject to review.
Change R82 to 560R	ü
Change R81 to 560R	ü
Change R83 to 20K	ü
Change R84 to 110R	ü
FIT POWER MODULE to supply 2.65v through J1.	ß (bug fixed in sensor) J1 should now be fitted.

7.2 Control board

USB-DAQ board as used for ASIC1

3x80 way ribbon cables as used for ASIC1

Responsibility for FPGA firmware development will remain with Imperial College. Some support will be necessary on receipt of new sensors in case of changes/debug.

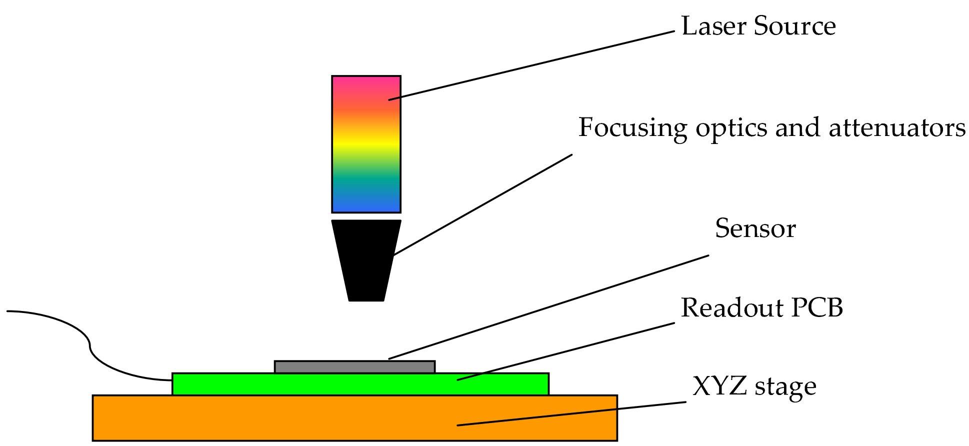
- Debug/test routines
    - No new routines required: existing set sufficient.

8. APPENDIX 1: SENSOR SIMULATION SETUP

These tests will be done at RAL PPD. The main aim is to measure the sensor parameters which can be compared with the sensor simulation at pixel level. The parameters of interest are collected charge by individual pixels against spatial coordinates of hits, crosstalk among neighbouring pixels, sensitivity to fraction of MIP and collection time.

8.1 Test setup

The test setup will consist of a programmable pulsed Laser coupled with a microscope and XYZ stages housed in a dark enclosure kept in a thermally stable environment.



A laser beam of selectable parameters (wavelength, intensity and beam size) will be used initially in the mid IR mode (1064 nm). The intensity of the beam will be set to a level corresponding to MIP generation in Si. The size of the laser beam can be selected from a minimum of around 1x1 µm to 25x25 µm at the maximum magnification but different optics arrangements will allow even 50x50 µm, so as to illuminate a single or a small group of pixel.

8.2 Charge collection efficiency

The beam will be scanned over the surface of the detector with the same, or finer, XY resolution used in simulation (4.1 µm for a 25 µm cell). A digital camera coupled to the microscope will allow visual indication as to where the laser will be focused. If the material on top of the sensor does not allow the beam to get through an alternative would be to hit from the back (i.e. from the substrate) and determine the spot location by measuring the collected charge.

On each location the laser will fire at a maximum rate of 50 Hz for a number of times to allow enough statistics to be built then will move onto the next adjacent location. In this way a 3D representation of charge collected can be compared with simulation results. The process will be fully automated using a PC running some dedicated VIs written in Labview to control the whole system. The laser system will allow input and output triggering to synchronize with readout phases.

8.3 Crosstalk

By firing the laser onto a known location within a pixel and measuring the charge collected by the neighbouring pixels (3x3 groups or even bigger) an indication of crosstalk (i.e. charge sharing) can be obtained.

8.4 Sensitivity to fractional MIP

The intensity of the beam, calibrated against detectors of known characteristics, can be varied regardless of the beam spot size to correspond to fractional equivalent MIP.

8.5 Charge collection time

Charge collection time of individual pixels can be determined once the temporal shape of the laser pulse and impulse response of the readout electronics is known.

The pulse width of the laser is known to be about 4 – 5 ns max but its actual shape will be determined using a combination of fast detectors and amplifiers, operating in the GHZ range. The pole locations of the readout electronics should be known from simulations or can be determined by directly exciting appropriate input stages of the readout.

The temporal evolution of charge collection would require access to the analogue output from the readout electronics. Alternatively, and more simply, only the temporal digital delay of the comparator's output against its threshold should be known (again from simulation or from other direct measurement). Once the laser is fired with a set level of energy corresponding to a known comparator's threshold, any further delay seen at the output is related to the delay in charge collection. The method then would be to provide triggering to the sensor by the Q-switch signal of the laser (see below) and make sure that the comparator starts sampling immediately after the laser pulse (which should correspond to a known and repeatable time delay from the Q-switch signal), at the peak of collection charge process. The delay seen at the output will be a combined delay due to charge collection process and known readout delay. Alternatively, with a clocked sample comparator, then varying the sample time after the laser signal will provide the same measurement.

8.6 Rates

To compare simulations with test results a minimum number of 13 x 13 = 169 samples / pixel are needed, for a 50 x 50 μm cell. For a group of 3x3 cells this corresponds to 1521 hits. If 100 hits are needed for each location, at the maximum laser pulse rate of 50 Hz this corresponds to 3042 sec. Assuming a maximum number of threshold scans of 10 on each location, this would correspond to 30420 sec. Taking into account the time required for each step motion, assumed in the order of 0.5 sec, it follows that around 8.7 hrs are needed for a charge collection and pixel crosstalk test. In reality, the time could be much less, as there is no need to continue on each location with an increased higher threshold when that the rate of positive hits (i.e. hits that flip the comparator) has decreased to a low level.

This test analysis will be simplified by having the option of masking all pixels except for the group of 3x3 cells centred around the pixel of interest. The data rates will be dependent on the threshold level set. Assuming a maximum rate of 50 hits/sec and 5 bytes/pixel, at the lower threshold level without using the mask, around 10^4 pixels would result, corresponding to 2.5MBytes/sec, which sets the maximum DAQ rate for these tests.

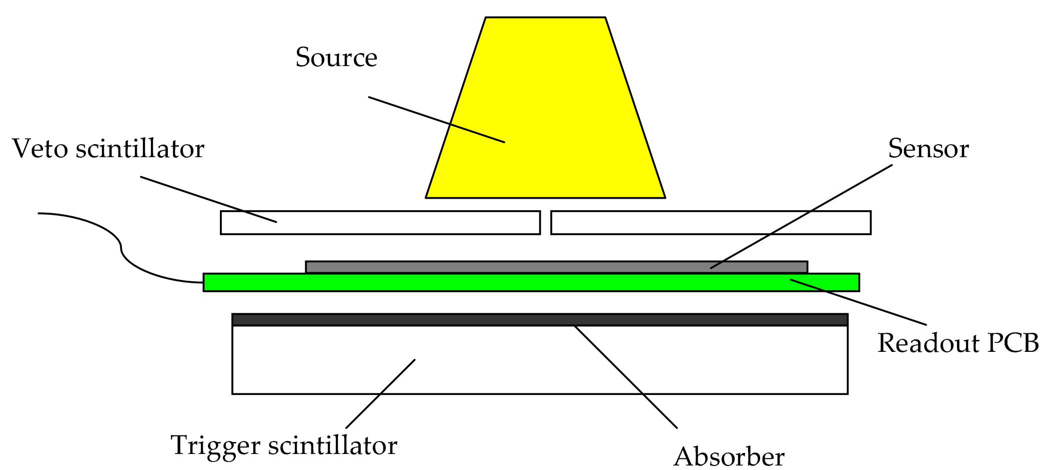
The trigger to the readout can be provided by the internal Q-switch of the laser. This is a 5V 6 μs wide pulse that occurs when the Q-switch is energized. The laser pulse will exit the cavity around 80 ns after the rising edge of this pulse. The reset phase of the sensor could be started by the rising edge of this signal if it does not last longer than say 50 ns, before the laser fires. The exact delay of the laser beam exiting the cavity after the Q-switch signal will be determined during the calibration and assessment of the laser system.

9. APPENDIX 2: RADIOACTIVE SOURCE TEST SETUP

These tests will be done at Imperial College London. The main aim is to characterise the response to a physics energy deposit similar to a MIP as well as measure the efficiency as a function of the threshold setting. Some tests of noise rate and ILC timing can also be done.

9.1 Test setup

The test setup will be a single sensor with associated DAQ system, a source and some triggering.



A β source with a reasonable maximum energy, such as ^{90}Sr, will be used. A scintillator on the far side of the sensor, possibly behind a thin absorber, will provide a trigger or timing reference. A further scintillator on the source side of the sensor with a small hole could act as a veto collimator. There would be two basic modes of operation: triggered and free-running. Both would be operated with the sensor between the source and the trigger and also with the sensor placed well away, to give a measurement of background rate.

9.2 Triggered mode

This mode would operate with the lower trigger scintillator providing a bunch crossing signal to the sensor. The time between the trigger and the bunch crossing signal would need to be adjusted so the comparator samples at the peak of the collected charge. (In principle, this delay could be scanned to give a measurement of the charge collection although it can be more accurately done with the laser system described above.) Following each trigger, the sensor readout is performed, giving at most one timestamp per pixel. The sensor is then reset and the trigger cycle repeated. It would also be possible to send two or three more bunch crossing signals following the trigger, spaced by around 150ns, to allow the decay of the physical signal with time to be observed. This mode would be used for most of the source measurements, as it gives a more efficiency collection of source hits than the free-running mode.

9.3 Free-running mode

This mode would run the sensor with timing similar to that expected for ILC operations. This will allow a check that the signal size is not sensitive to the sensor timing. In this mode, following a sensor reset, around 10^4 bunch crossing signals will be generated at around 6MHz. The "trigger" scintillator will not be used as a trigger but the time of the hits in it (and the veto scintillator if used) will be recorded by a multi-hit TDC. This time measurement allows the source hit to be associated with a particular timestamp; in fact, the TDC measurement should be accurate enough to give information on the phase of the trigger relative to the 6MHz clock and so on the efficiency as a function of the time offset. Only a few threshold values, rather than a full scan, will be required to cross-check the triggered mode results.

9.4 Rates

A threshold scan of around ten values would be sufficient. If each value requires of order 100 source hits per pixel, then for 128×128 pixels, i.e. around 10^4 pixels, this is around 10^7 source hits. To gather this in one day (around 10^5 secs) needs a rate of around 100Hz.

The DAQ system needs to be able to sustain this rate. Each source hit should give one or two pixels per trigger. Each pixel hit will need to be read out as five bytes, to contain the timestamp and the row and column locations.

In triggered mode, then with a noise rate of 10^{-5} , each trigger will only give around 0.1 noise hit at the nominal threshold. However, for the lower threshold values in the scan, a much higher rate will be seen, potentially up to a significant fraction of all 10^4 pixels. These runs set the required DAQ capability and so, at these thresholds, this would give a data volume per readout of 50kByte and hence a rate of around 5MByte/s at 100Hz.

In free-running mode, a full ILC-type bunch train of around 10^4 samples within 2ms would give around 10^3 noise hits for thresholds close to nominal and this would be repeated at a rate of 10Hz. This then requires around 10 source hits per bunch train to achieve the desired source hit rate of 100Hz. This corresponds to a source hit rate of 5kHz within the 2ms bunch train. The readout data rate is dominated by the noise and corresponds to around 5kByte per bunch train. Overall, this is 50kBytes/s but requires the data to be transferred off the sensor within around 2ms after the bunch train before the DRAM lose the data. The rate off sensor is then 2.5MByte/s.

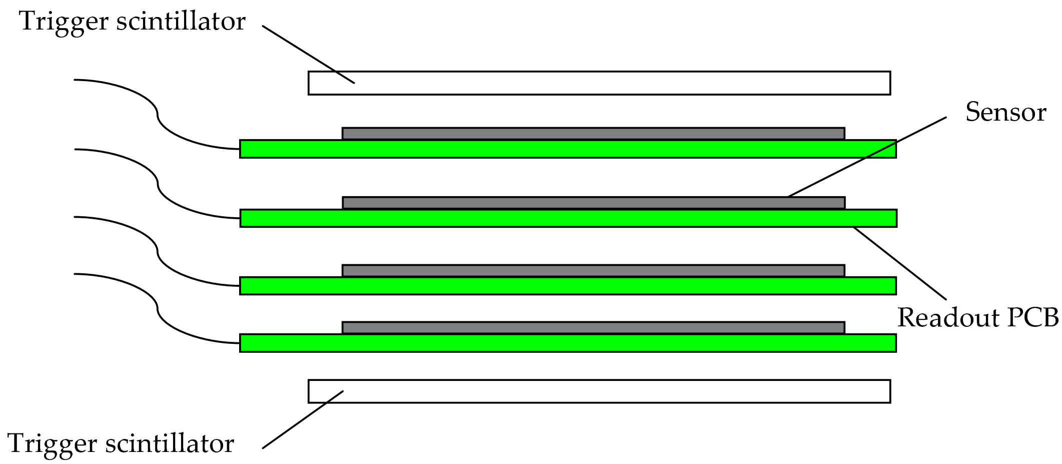
To give a usable source hit rate of 5kHz in free-running mode, the source will need to be at least 10^5 Becquerel (3 μCurie). This will clearly satisfy the triggered mode requirement also.

10. APPENDIX 3: COSMICS TEST SETUP

These will be done at Birmingham. The main aim is to give an absolute measurement of the response to a MIP and hence the MIP efficiency vs threshold. Because of the low rate of cosmics, only part of the threshold range near the likely operating point will be scanned, with the source results being used to extrapolate to other thresholds. To ensure that individual sensor variation is accounted for, at least one sensor would be tested in both the source and the cosmic test systems.

10.1 Test setup

The test setup will consist of a cosmic ray telescope of four (or more) layers with a pair of trigger scintillators above and below.



The trigger scintillators would provide the bunch crossing signal and the sensor readout would follow immediately after this, in a similar way to the source trigger mode. During a threshold scan, the threshold would be adjusted in a single layer (or possibly even or odd layers) at a time, allowing an fixed-efficiency track reconstruction in the layers not being scanned. This would allow the absolute efficiency of the scanned layer(s) to be determined by interpolation or extrapolation.

10.2 Rates

The rates will be low so the setup for this test would need to be dedicated to this one measurement and left to run stably for a significant period. The physical rate of cosmics in such a telescope, with dimensions around 1×1 cm^2, would be of order 0.01Hz. To do a scan over four threshold values with at least 10^3 cosmics per value would take around 10^6 secs, i.e. two weeks. This would have to be done four times, once per layer (or possible twice, once for even and once for odd layers).

The DAQ rate at 0.01Hz would be much smaller than for other tests and so will not be an issue, even with four sensors being read. However, frequent noise runs at each threshold value using a non-cosmic (higher rate) trigger to check background noise rates will be needed, to ensure any time and temperature variations over the long periods of the test are correctly compensated.