K4 studies

The k4 Team

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1. Motivation.

The K4 hybrid was design to overcome some deficiencies detected in the previous version of the hybrid (K3) for the SCT forward modules. The main goals were to improve the thermal properties of the hybrid in order to reduce the chips' temperature and, consequently, the electronics noise, to fully implement the bypass scheme, and make the high voltage distribution meet the IPC specifications for 500V.

The K4 hybrid was delivered by DYCONNEX at the beginning of 2001. Twelve modules have been built with this hybrid, as listed in Table 1.1. One hybrid (K4−205) was irradiated in April 2001 and in June 2001 a module (with K4−218) was irradiated. All the modules were *baseline* modules apart from two of them: K4−212, had implemented a screen on the spine between all the fan−ins and a Vcc rail screen from construction, and a second one (K4−???) which had a split substrate.

The module functionality is OK either through opto or redundant links. The input noise is now much closer to specification. This implies that the chip temperature is now cooler. The irradiated module is OK. However, all of them show some discontinuities in the s−curves above 0 fC threshold.

In order to understand the origin of these features and to try and find an easy solution that could bring the K4 modules into stable and save operation, a list of modifications was elaborated and implemented across a number of institutes. This report describes those tests.

Institute	*Hybrid*	*Chip set*	*Substrate*	*Split*	*Module*
CERN/GVA	K4−206	3T	CF	wiggly	Outer
	K4−218	3TA	CF	wiggly	Outer
UK	K4−208	3T	CF	wiggly	Middle
	K4−217	3TA	CF	wiggly	Middle
	K4−219	3TA	CC	straight	Middle
	K4−220	3TA	CC	straight	Middle
NIKEF	K4−209	3T	CF	wiggly	Inner
	K4−229	3TA	CC	straight	Inner
	K4−234	3TA	CF	straight	Inner
Freiburg	K4−200	3T	CF	wiggly	Outer
	K4−203	3T	Carbon−Carbon	wiggly	Outer
Valencia	K4−212	3T	CF	wiggly	Outer

Table 1.1 Modules built with the K4 hybrid.

1.1. Symptoms.

All the modules show distinctive features in the form of discontinuities in the efficiency curves obtained both in the noise occupancy scans and in the calibration charge injection scans. The discontinuities are of two types: a sudden drop in the tail of the s−curve, as shown in Figure 1.2, and as dips in the efficiency plateau, as shown in Figure 1.3.

It has been observed that the discontinuities, specially the dips, usually depend on the injected charge −in the case of the calibration runs− on the capacitive load of the front−end and on the trimming selected for the chips.

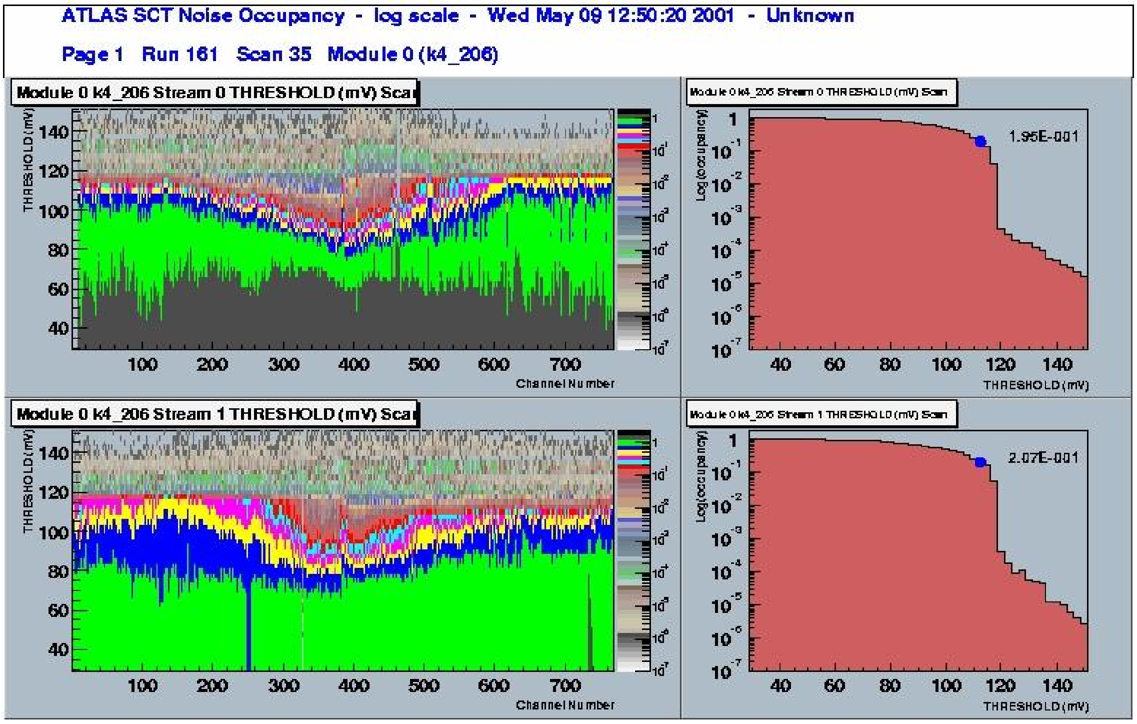


Figure 1.1 Example of discontinuity in the efficiency. It is observed as a drop in the tail of the s−curve at about 110 mV.

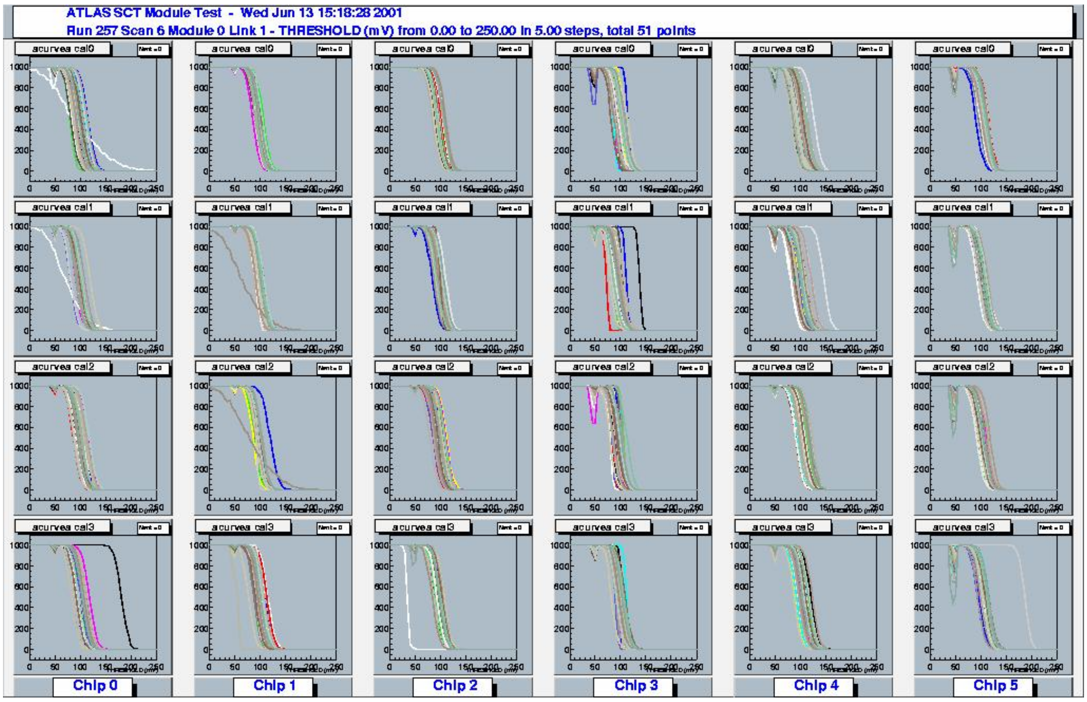


Figure 1.2 Example of dips in the efficiency when a small calibration charge is injected in the front end.

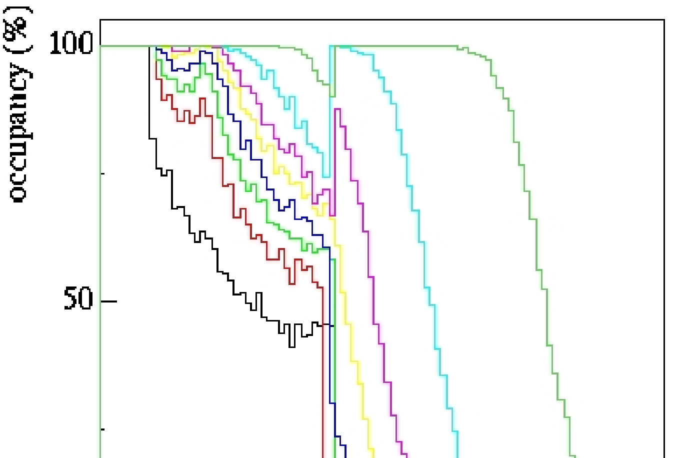


Figure 1.3 Set of s−curves from the same chip showing both the dips and the drops. It can be observed that the discontinuities in the efficiency curves all appear in the same place.

Figure 1.3 shows a collection of s−curves measured for a chip trimmed for 1 fC at 90 mV. The presence of dips and drops is evident. Moreover, one can observe that the discontinuities appear always at the same threshold, slightly above 1 fC in this case.

1.2. Interpretation.

The origin of the inefficiencies can be understood as a global effect that affects to most of the chips in the hybrid. The basic assumption being that the switching of an ABCD channel in the input register produces a current spike which causes a sudden variation of digital voltage and ground. This variation couples, somehow, with the front–end and ends up in a positive feedback. When the threshold is bigger than this pick–up the number of switches decreases and the feedback disappears. The amplitude of the pick–up will depend upon the number of channels that change state with respect to the previous time bin. We have made a small toy simulation model that implements this idea. The results of the simulation for different amplitudes of the pick–up are shown for a noise scan and a 2 fC injected charge in one calibration address in Figure 1.4.

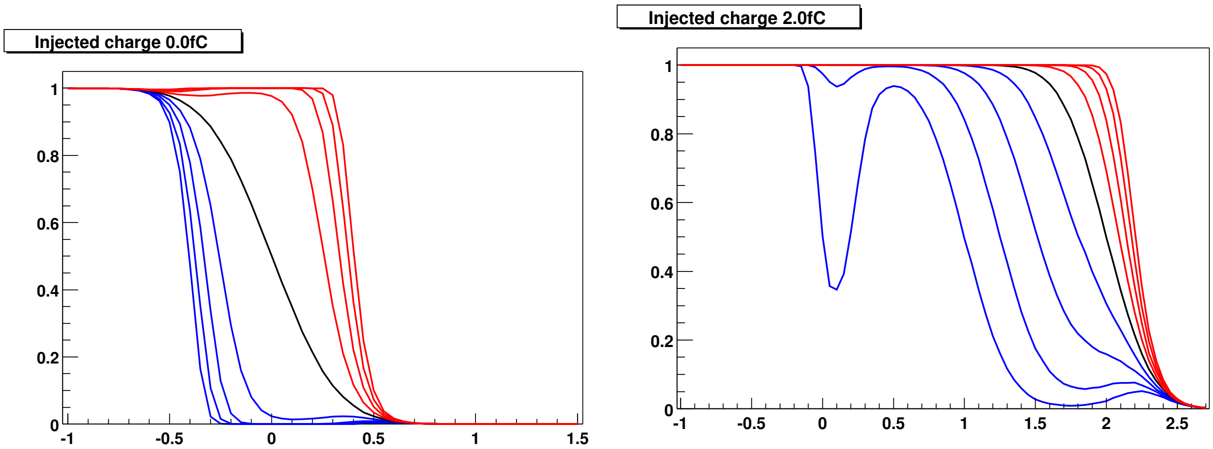


Figure 1.4 Simulated effect of different amplitudes of the pick–up on the shape of the resulting s–curve.The set of s–curves at the left correspond to a noise scan and the ones at the right to a threshold scan with an injected charge of 2 fC in one calibration address.

For the noise scan one can see that dips and drops appear when the pick–up has positive polarity –the last 4 curves. The curve in black corresponds to an ideal situation with no feedback. The first curves correspond to a negative polarity of the pick–up.

For a calibration pulse, a dip appears, for the pick–ups with negative polarity, at the moment in which the threshold for the channels in the other three calibration lines is at the 50% point, where the number of state changes is maximum and, hence, the pickup amplitude. This will produce an artificial decrease of the signal and the s–curve will start to drop, until the threshold is higher that the pick–up. At that moment the signal baseline is restored and the s–curve moves back to the plateau.

2. Tests made.

In view of the first results on the K4 modules, a number of questions arose. At the moment we did not know whether there is a fundamental feature in the K4 hybrid design, like topology, central cooling block or layout, which would make success very difficult. Comparing to the barrel hybrid design, which works, one wonders if a double sided hybrid is the wrong approach or whether one needs separate substrates, if the end–tap geometry is intrinsically more susceptible to instabilities than a center–tap one, etc.

In the next subsections we review all the test made to understand the instability problem in the K4 hybrid.

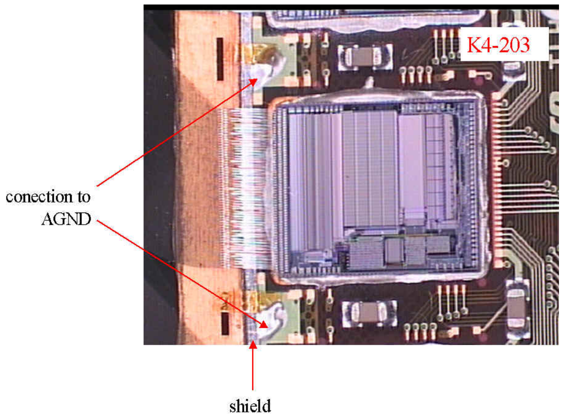
2.1. AGND–DGND close to each chip.

It is evident that the connection between analogue and digital ground plays an important role in the module performance. To understand this a systematic study was made on the dependence of the instability upon the strength of this connection. The tests were performed at Freiburg (K4–200), Liverpool (K4–208,K4–218) and Geneva (K4–206). The modules were very unstable when no connection was made between AGND and DGND. In Liverpool and Geneva they tried with different number of bond wires between the ground pads. The result was that the module was still unstable, and increasing the number of bonds did not help. For all the modules, using conductive glue for the connections proved to be a better solution. However, the conductivity of the glue degraded with time and after some time the modules became unstable again. At Freiburg, an attempt was made to implement the connection with inductances(L=100nH,R=20Ω) with no apparent improvement.

The conclusion is that for best performance the AGND–DGND must be tightly connected, but due to the layout of K4 this is not achievable.

2.2. AGND screen over Vcc rail in front of ASICs.

In the K4 hybrid there is a Vcc rail, in layer 2, that runs in front of the chips and under the wire bondings between the chips and the fan–ins. It was thought that there could be some pick–up on the Vcc bus from the wire bondings. To remedy this a screen was added on top of the Vcc rail, as shown in Figure 2.1, in some of the modules: K4–208 (Liverpool), K4–203 (Freiburg) and K4–212 (Valencia). The screen was connected to ground. The Liverpool and Freiburg modules had a single screen, added manually after the module construction, in front of three chips and no change was observed. The Valencia module had the screen, added during the module construction, in front of all the chips. The screen is connected to AGND close to each chip. This screen was set so that it could be easily removed afterwards if needed.



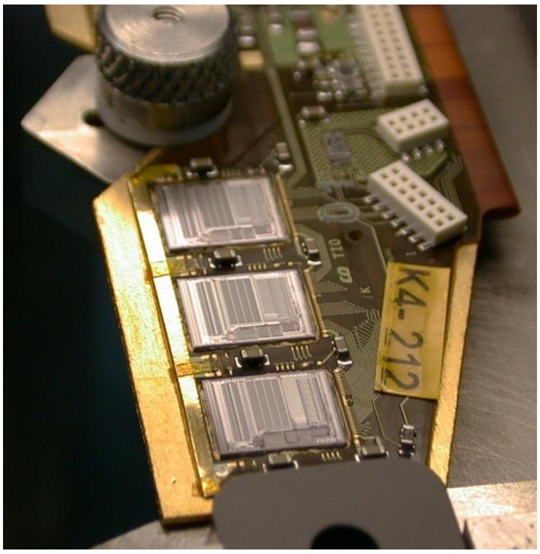


Figure 2.1 Addition of a Vcc screen beneath the chips–fan–in bond wires. At the left a detailed view of the screen insertion at K4–203 module. The right shows the K4–212 module.

The addition of the screen showed no improvement in K4–203 and reduced the magnitude of the dips in K4–208, but the instabilities are still there in all the three modules. The same conclusion was reached with the K4–212 module.

2.3. Screen between fan–ins.

Possible cross–talk between the channels on both sides of the hybrid is a concern. In order to study this problem it was decided to isolate the fan–ins from opposite sides. At Liverpool the screen between the fan–ins was done by using a 100 μm Aluminium foil ~ 2mm wide which was then *pushed* under the bonds between the chips and fan–ins . The foils where secured at either end by conductive glue to the AGND pads adjacent to the front end of the ABCDs. This was only done on the top side of the the module, to cover the 2 blocks of 3 chips. At Freiburg, a copper foil was used instead and was also connected to AGND. At Valencia an adhesive copper foil was glued onto the AlN cross, in the place where the fan–ins would sit, in both sides of the AlN, as shown in Figure 2.2, during the module construction and connected to HV instead.

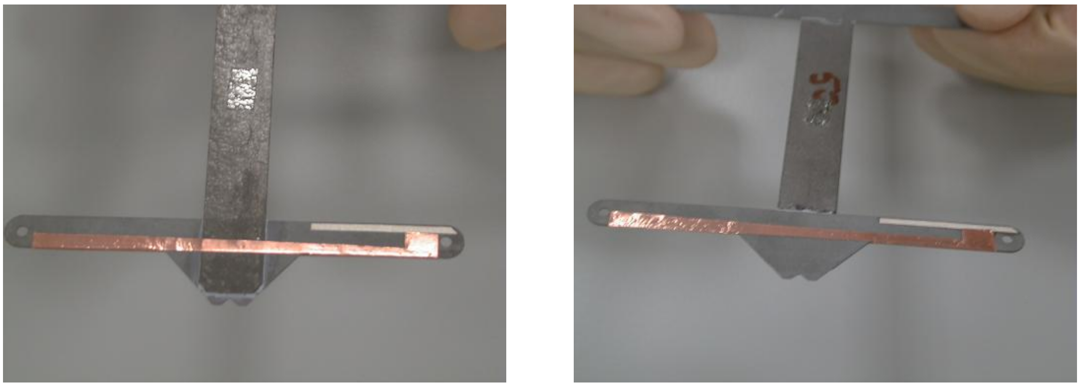


Figure 2.2View of the AlN on the spine in the K4−212 module showing how the screen between fan−ins was implemented during the construction of the module..

The addition of the screens, in Liverpool and Freiburg, reduced the size of the dips observed and also the coupling between top and bottom channels. The noise remained the same. The K4−212 module shows small instabilities with only one 6cm detector bonded to the top side of the module. On that module a study of channel by channel correlations was performed in order to understand whether the screen on the fan−ins or on the Vcc rail was adding some extra coupling between the channels. The data was taken with all the channels trimmed to 0 fC and setting the threshold to that value. Figure 2.3 shows the results of the analysis. On the right picture the correlation matrix is shown, with the elements in the diagonal and those compatible with zero correlation removed. It can be observed that the first channels of the chips are more correlated to the rest of the channels than those at the other extreme. The reason could be the AGND connection close to the chips to the Vcc screen. From the average hit multiplicity shown in the right picture one can estimate the the common mode noise for the channels bonded to the detector is of the order of 450 e^{-}ENC.

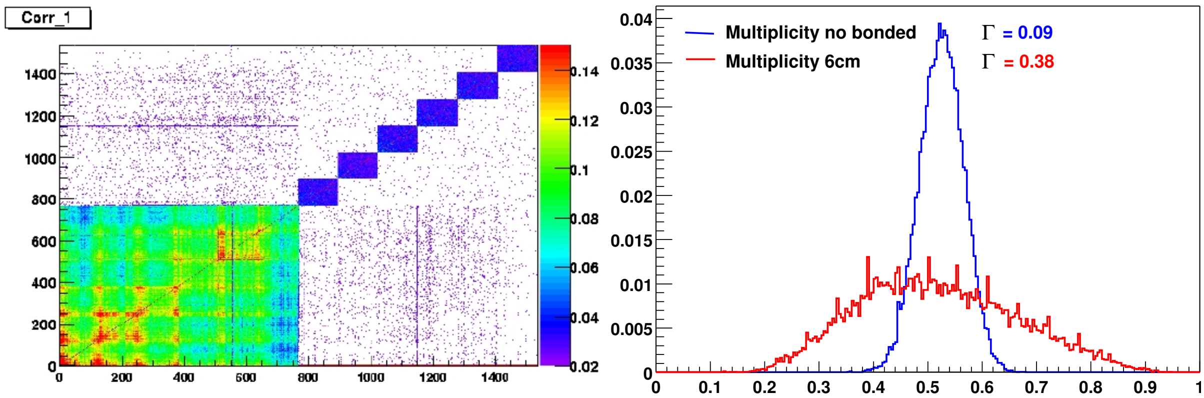


Figure 2.3 Left. Correlation matrix between all the channels in the module. In the matrix the elements in the diagonal have been removed as well as the elements for which the correlation factor was compatible with no correlation. Right. Average channel multiplicity when setting the threshold to 0 fC. The width of the distributions indicate that the common mode noise is of the order of 450 e^{-}ENC for the bonded channels and about 100 e^{-}ENC for the open channels.

2.4. Dependency on strip capacitance.

An important aspect is the dependence of the stability with capacitive load of the front−end. This was studied varying the bias voltage of the detectors and changing, consequently, the capacitance seen by the front−end. This studies were performed both with K3 modules in the system test, to have a sort of reference, and with K4 modules. The K4 modules were tested at Freibug (outer modules) and NIKEF (inner modules).

The results of the bias voltage scan on the K3 modules is summarized in Figure 2.4, where one can observe that the front−end parameters remain stable once a *reasonable* capacitance, and consequently noise level, is seen by the front−end. The module was stable until detector bias voltages of less than 20 V.

In Freiburg and NICKEF the same analysis was performed. The instabilities do not disappear but the position of the drops changes with bias voltage and stabilizes above the depletion voltage. This can be seen in Figure 2.5 and Figure 2.6.

The interpretation of that is that changing the detector capacitance, the input RC circuit changes and so it does the phase of the pick–up with respect to the clock. The direction of the change of the drops will depend on the polarity of the pick–up.

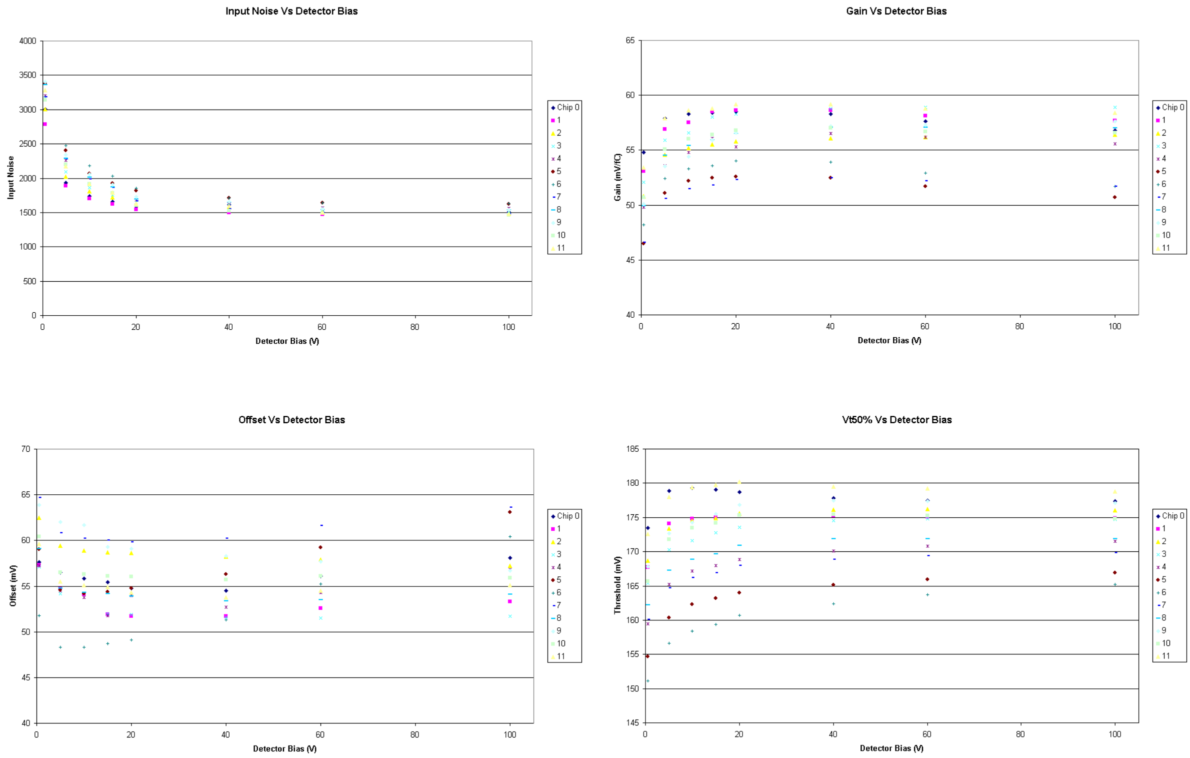


Figure 2.4 Variation of the K3 parameters with the detector bias voltage.

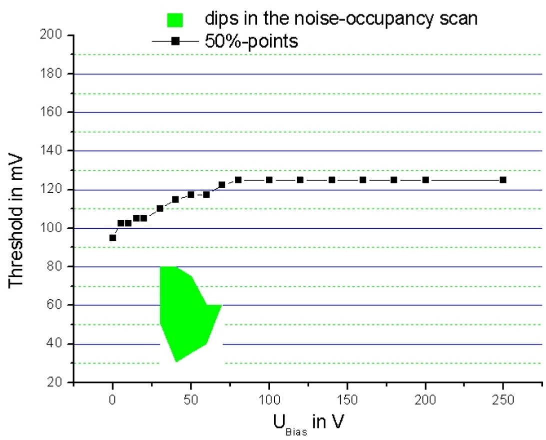


Figure 2.5Variation of the position of the drops with the detector bias.

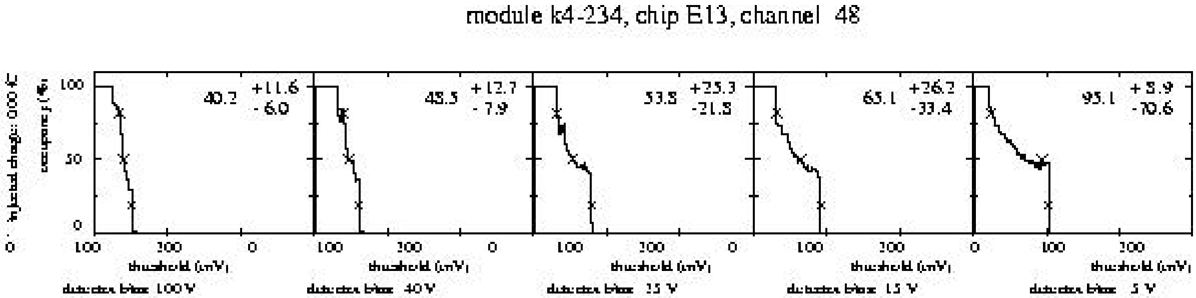


Figure 2.6Variation of drop position with detector bias in the NIKEF inner module

2.5. Split substrate.

In order to explore whether the hybrid topology had an impact on the performance of the modules a K4 hybrid was built with a split substrate so that the top and bottom sides would be isolated. The substrate is shown in Figure 2.7.

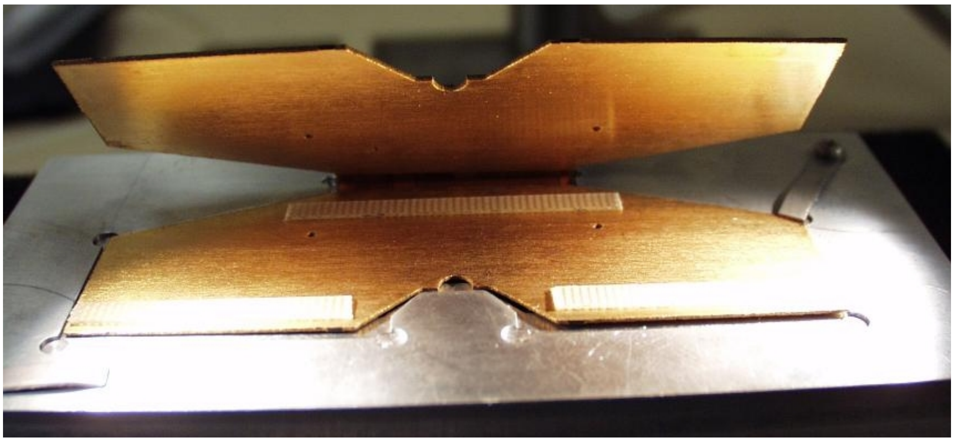


Figure 2.7Split substrate

It was assembled, at Manchester, into a middle module. The module was built with a plastic spine 1.6 mm thick to match the thickness of the hybrid substrate. The W22 detectors are not connected electrically to anything – the plan is to bias them from the front side. The W21s could also be biassed by connecting from the front side via the W22s. The W21 detectors are also connected by silver glue to copper foils stuck on to the short cross–arms of the spine. A tab hangs out from each copper foil which will allow anyone to easily make or break a good electrical connection between the front W21 and the back W21.

2.6. Systematic comparison between K3 and K4 modules.

In the light of the K4 results, a systematic study was started on the available K3 modules on the system test. The objective was to seek for similar features that could have been overlooked at the moment in which the K3 modules where studied. None of these symptoms were observed on those modules.

2.7. Influence of opto–chips on stability.

The possible effect of the opto–chips on the performance of the K4 modules was also study. To this end the K4–208 module, at Liverpool, and the K4–206 module, at Geneva, were used. In the case of the K4–208 no difference was observed when switching from optical readout to electrical readout. In the case of the K4–206 module the bonds wires of both opto–chips were removed with no noticeable effect.

2.8. Simulation of the hybrid and hybrid+chips.

The possibility to simulate the electrical performance of the hybrid has been considered. For that the SPECTRAQuest signal integrity analysis tool from CADENCE is planed to be used with the help of the IT/CE group at CERN. This tool will allow to simulate the bus lines (reflections, crosstalk, noise margin...), the ground bounce voltage, etc. This is, certainly a long term project and can be used in the future for the K5 hybrid. Currently there is some progress and the migration to the file formats required by this tool is being finished.

3. Conclusion.

The K4 discontinuities in the efficiency have been studied in a systematic way trying to explore all the possible origins of them. Not a single reason has been found that could produce, by its own, those features in the hybrid although, taken collectively, they could impinge upon the overall performance. Some of them have been pinpointed in our studies and are listed below:

- Power/Ground planes are hatched. This does not allow for a low enough impedance power supply.
- The linking together of the AGND–DGND planes is achieved by the use of long, narrow traces (inductive), especially those from DGND.
- VCC Power line profile is not ideal.
- No AGND plane at the front–end of the ABCD. Maybe not so critical, but the addition can only help to add more material to the AGND plane.
- Review layout of Power/Ground planes.
- The Power/Ground connections to the chips are not ideal. The VDD/DGND connections for some chips are made using long narrow traces, e.g. S3 DGND connection and S2 VDD connection etc. The VCC/AGND decoupling appears to be ok and can only improve once the Power/Ground planes are changed.
- As Carbon–carbon has been selected for the hybrid substrate, whose resistivity is greater than that of a normal electrical conductor I would no longer consider it ideal to use this substrate as a Ground Plane. This substrate should only be used as a heat sink. This means that the ABCDs should be glued on to AGND pads on the Kapton, using electrically conductive glue.
- Cooling of the chips is still an issue, since the cutouts present in the K4 design have proven not to be a good idea.