Electronic stability of silicon front-end hybrids

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Abstract

Stability of front-ends hybrids is often not well understood. Multiple feedback loops are mostly the source of instabilities. The power distribution and ground system are the major common part of the circuit and play a dominant role in the oscillation. Adding only decoupling capacitors does not work, since power distribution foils of a Kapton hybrid have a very low Ohmic impedance. In addition ground-foil AC-current summation gives additional amplification. This results in instabilities when the number of operating front-end chips is greater than a critical number.

I. INTRODUCTION

Multichip front-end hybrids are used in the high energy physics as part of detector modules. The electronic stability of front-end hybrids is not well understood. Positive feedback is a common source of the instability. There are often different feedback loops active. Practically, the oscillations are very complex. The power distribution and ground system are the major common part of the circuit and always play a dominant role in the instabilities.

II. THE ELECTRICAL CIRCUIT OF A HYBRID

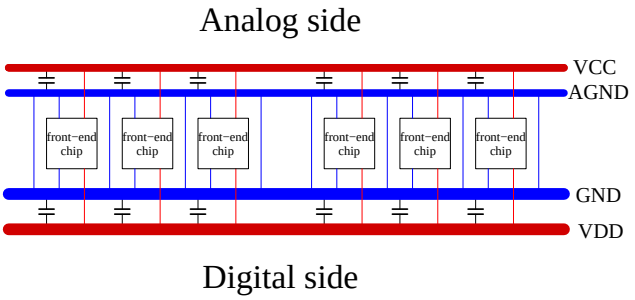

Figure 1: Power distribution

The power distribution circuit of a hybrid is shown in Fig. 1. It consists mostly of two power-distribution systems:

- an analog supply for the analog front-end
- a digital supply for the digital and output part

The analog supply and the digital-supply ground are connected. The resistance of those connections must be carefully chosen. When the resistance is too low, voltage noise over the digital ground is injected in the analog ground. When the resistance is too high, the common mode voltage between analog and digital ground disturbs the front-end chip.

The printed circuit of a hybrid is mostly made of a multilayer Kapton printed circuit. The ground and power distribution are wide foils on adjacent layers. The power distribution above the ground foil can be seen as a stripline circuit. For instance, $l = 5$ mm wide power trace, isolated with $w = 25$ micron Kapton, has an impedance Z_o of

$Z_o = (377 / \varepsilon_r)^* (w/l) = 0.55$ Ohm $(w/l<0.1)$ [1]

In practice many power distribution foils are wider. Thus we can conclude that: the small distance between the power distribution layers of a Kapton hybrid creates a very low Ohmic power distribution transmission line.

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III. Low Ohmic-power distribution

It is very difficult to filter such a low Ohmic power distribution. Practically, the attenuation of the decoupled power distribution transmission line is so low that the power supply current-modulation of a front-end chip is only partly delivered by the local decoupling capacitor(s). Fig. 2 shows an impedance plot. The other fraction of the current modulation is supplied by the remaining power decoupling capacitors. These create AC-currents through the ground and power foils and generate an AC voltage gradient over the ground and power distribution foils. In the case when only a single front-end chip is operating, the ground foil AC-currents do not affect the operation of the hybrid. But, when many chips are operating at the same time, the power supply current modulation of all operating front-end chips are summed up in the ground and power foils. This ground-foil AC-power summation delivers the additional amplification of the front-end chips analog input signal, in order to start oscillation when the number of operating front-end chips is greater then an critical number.

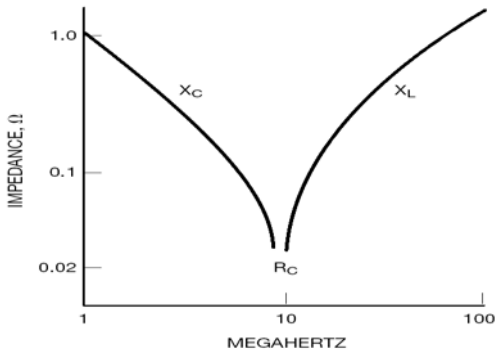

Figure 2: impedance decoupling capacitor

IV. SCALING LIMITATIONS

In many front-end systems the ground system AC-current summation creates a scaling problem. Every front-end system, above a critical size, starts to oscillate, when you do not break the ground system AC power summation. There are more possible solutions than I can describe in this paper. I just give a few general solutions to start a discussion.

By carefully planning the layout of the ground system, it is possible to control the flow of large AC currents such that they do not flow in the critical parts of the ground system. This is achieved by local filtering of the power supplies by placing enough impedance in the power distribution system. Then, all the power supply current-modulation is delivered by the local decoupling capacitor(s). A power-plane does not deliver enough impedance in the power distribution system. A high impedance power distribution can be made of small traces, with enough width to deliver the supply current to the local decoupling capacitor(s) or, when you need more margin, use small chokes in the power supply system. In order to keep the ground clean, use balanced output signals. Balanced signals do not use the ground system as return path.

V PRACTICAL EXAMPLES

A. ALICE silicon strip hybrid

Each detector has its own requirements. For example the Alice Silicon Strip Detector has a very low mass budget. Due to carefully planning we have designed a single sided Kapton hybrid circuit for the electrical circuit of the Alice Silicon Strip Detector hybrids, which is a double-sided very low mass detector module with 768 channels on each side. See Fig. 3. A description of the used Kapton cable technology can be found I a status report [2]. The power distribution is a single trace in the single sided Kapton circuit and has an impedance of 80 Ohm. The ground system consist of multiple traces that are much wider. Prototypes have been made and are successfully operated from the first prototype without any sign of instability.

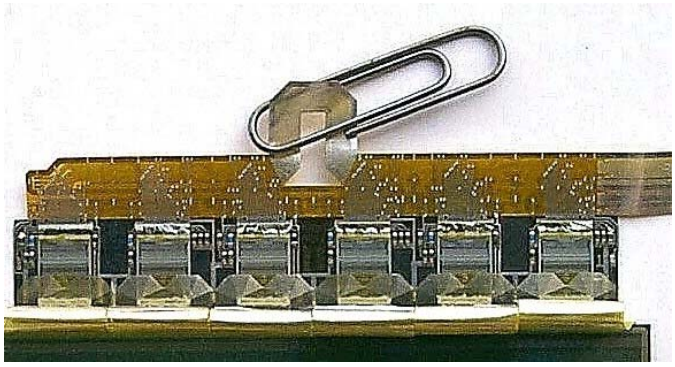

Figure 3: ALICE slilicon strip hybrid

B. ATLAS SCT hybrid

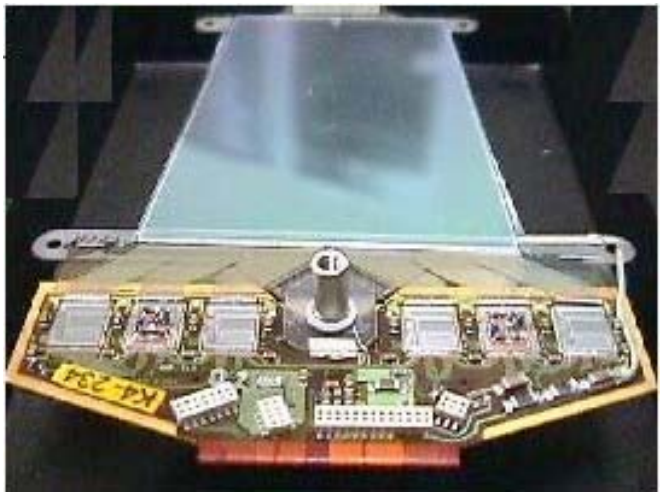

Figure 4: Partly modified short K4 module

Some versions of the SCT hybrids have known stability problems. We have tested the fourth version (K4) of the SCT prototype hybrid (Fig. 4). The modules are functional, but they show some instabilities [3]. Different groups within the collaboration are working on the stability problem. At NIKHEF it has been shown that noise entering the power distribution from the digital logic was a source of the instability. Extra decoupling of the power distribution was required. A small project was started to understand the problem before a new hybrid is designed. The biggest problem was finding space for the needed components. There was no space on the Kapton hybrid. Instead, we used a small (5 mm x 6 mm) Kapton circuit, which was glued directly on the active part of the ABCD Integrated Circuit. The mini-Kapton has a single copper layer with electrical connections to the chip made by wire bonding.

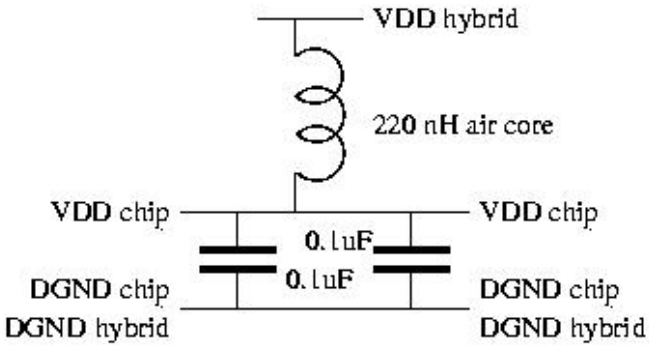

Figure 5: Filter circuit

The electrical circuit of the modification is shown in Fig. 5. An air-core choke of 220 nH isolates the digital power supply of each ABCD chip from the digital supply on the hybrid. Two capacitors decouple the local digital supply. The ground bound-pads of the ABCD chip are direct bonded

to the hybrid ground as to the mini-Kapton ground. This two-way bounding reduces the ground bounce on the ABCD chip. Nearly all AC-current modulation, of the ABCD chip is filtered by the local decoupling capacitors. Fig. 6 shows the Kapton circuit layout and bondings.

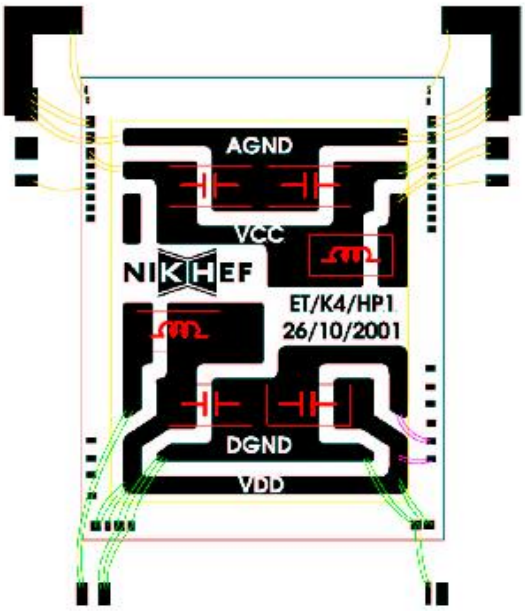

Figure 6: Kapton layout and bonding

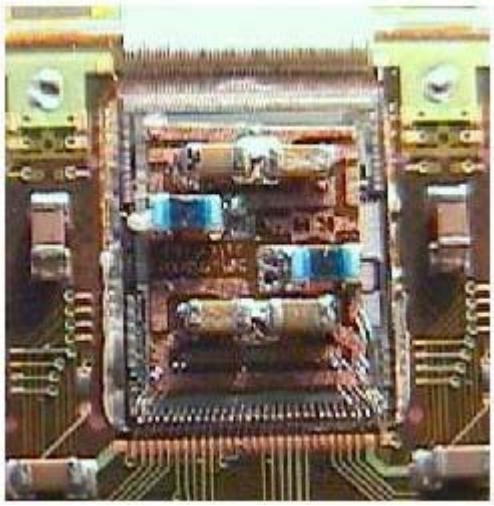

Figure 7: Close up of a modified chip

Modification of a module with short silicon wafers was very successful, resulting in the first stable short-wafer module. (Fig. 7). Fig. 8 shows the not modified hybrid and Fig. 9 shows the modified hybrid S curve measurement. The same recipe was tried on a long silicon-wafer module, which considerably reduced the instabilities but unfortunately failed to cure them totally. The used module was already heavy modified before our test. Many of those modifications where not reversible and a long unmodified module was not available. In the meantime the development of a new six-layer hybrid was started, with good results in initial tests.

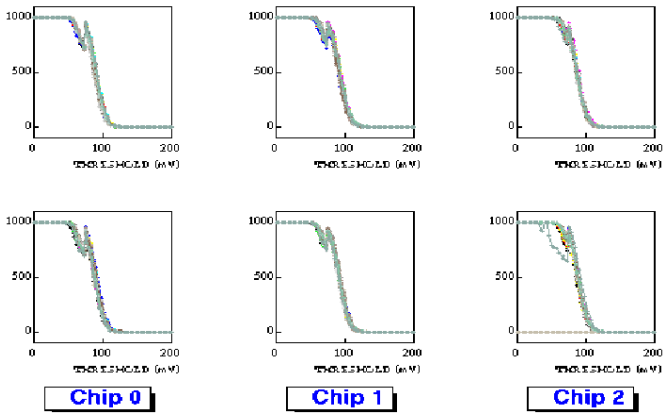

Figure 8: 12 chips on, 25V bias, no modifications

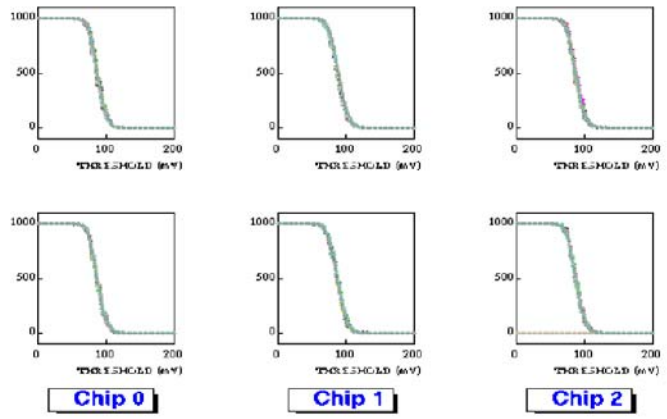

Figure 9: 12 chips on, 25V bias, digital power supply filter

VI. Source of the Instabilities of the SCT Hybrid

But why is it so difficult to build a stable SCT hybrid? One of the problems is the large digital power-supply current modulation of the 128 channel comparator circuits of the ABCD chip. (Fig. 10) The first comparator stage is a bipolar balanced transistor stage. The next three gain stages are not balanced and use small CMOS inverters. The input signal to the first CMOS inverter is a small analog signal.
When the difference between the detector signal and the comparator is smaller than 100mV, about 1.5 MIPs, one or more inverters remain at last a few hundred nanoseconds in the linear region. The quiescent current, which is the supply current of the CMOS inverter in the linear region, is the source of the large supply current modulation of the ABCD chips.

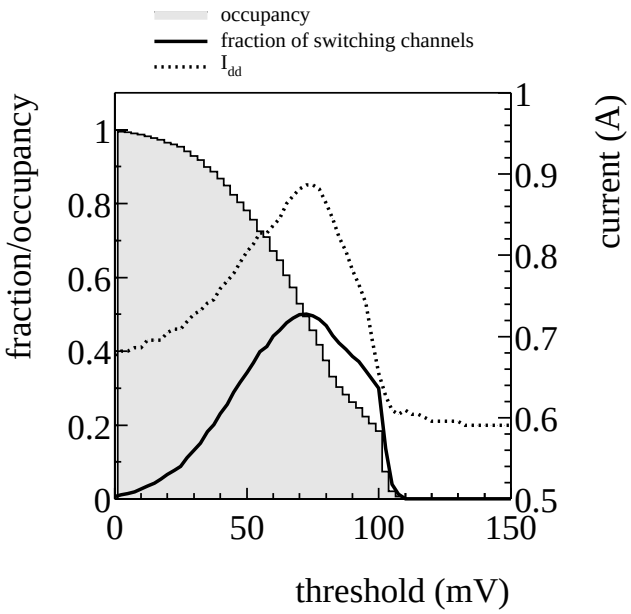

Figure 10: Noisy VDD supply current of the ABCD chip

VII. CONCLUSIONS

Practice has showed that it is very difficult to design stable hybrids with front-end chips with a large power-supply modulation. This paper shows that minimizing the supply current modulation of front-end chips is one of the requirements for designing front-end hybrids. Careful analysing electrical measurements of the previous prototype hybrid [4] resulted directly in the in this paper described modifications. We have successfully showed that a small modification could solve instabilities of the K4 hybrid.

VIII. REFERENCES

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[4] Tony Smith Ashley Greenall, Power dip and other effects on ABCD VDD, http://hep.ph.liv.ac.uk/~smithy/altlas/gndshld/pwrdip.html