Workshop on Quality Issues in Current and Future Silicon Detectors

CERN, Geneva, Switzerland

Nov. 3-4, 2011

Session #1: Introduction and non-HEP Quality Issues

Welcome and Workshop Introduction

- Alan Honma, CERN, (Workshop Chairman)

- Announcements
- Workshop goals and quality issues
- Example of non-HEP quality issue
- The QART lab at CERN

Announcements

- Please pay for workshop dinner at the registration desk (80 Swiss Francs or 65 Euros), open until 11:00, 13:00-14:30

- Late presentation uploads: upload it yourself to Indico page or bring it to us on USB key (as soon as possible, please!)

Workshop Goals

- Identify problems areas of current generation of silicon detectors (hence choice of session topics)
- What were the quality related issues?
- How would one modify a quality assurance plan to prevent them in the future?

Industry and technical service viewpoint:

•Their implementation of quality planning
•Quality issue experiences with silicon detector related work
•Their advice to HEP silicon experts to avoid future problems

What are Quality Issues ?

Failures or problems occurring in:

Quality Management: Responsible for project organization and decision making needed to obtain required quality goals. – Very global

Quality Assurance: Planning and implementing the actions needed to assure quality in all aspects of the project. – Project oriented (we put most of our focus here)

Quality Control: Verification that processes and products meet the specifications and standards – Product oriented

What elements of QA are important in a project?

In the past: select some elements as considered useful for our QA planning

Typical project life cycle:

- -Concept
- -R&D
- -Design
- -Prototype
- -Specifications
- -Production
- -Testing
- -Installation
- -Commissioning
- -Operation

Risk analysis

"System" test

Reliability Testing

A good QA plan should avoid bad surprises before getting to this point

Design for Quality

Qualification

Industrial standards

Quality Audits

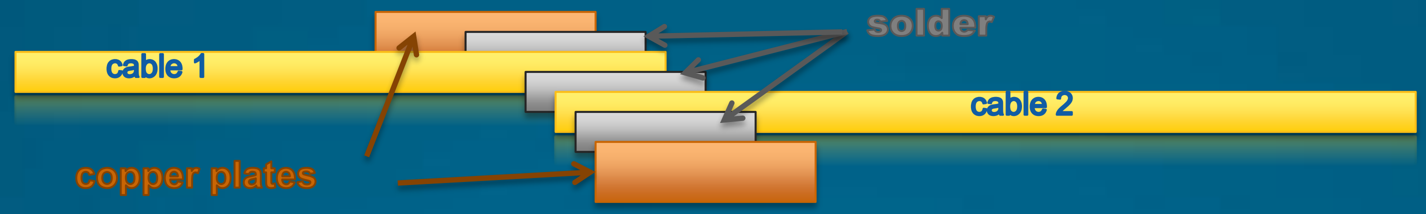
Quality Control

What went wrong?
Quality Improvement

Increased complexity, cost and long-term reliability required of silicon detectors imply a need to consider all these elements in QA planning.

An example of a well known "Quality Issue" at CERN

The project:



Solder the ends of cables together by overlapping the ends and putting solder in between and around. Add two copper covers plates over the joint and a machine will heat the joint to melt the solder.

If this is to splice together a good ground connection for your stereo system, then your quality assurance plan would not be too strict. Still, you would probably do a good visual inspection and measure the resistance across the joint.

However, the real project had a number of other requirements…

- A total of 10,000 of these solder joints are required.
- Each cable is superconducting and will carry 13,000 amps.
- If the superconducting cable joint fails the copper cover plates must be able to carry all the current.
- If one joint fails completely, you will probably destroy a lot of expensive equipment and the whole apparatus will be down for repair for at least 14 months (and about 7000 physicists will be very upset).

[LHC main magnets busbar splices]

The "QA" plan (consisting of 5 QC steps) used to determine the reliability:

1. Visual inspection of solder joint by the soldering machine operator (check that solder exits from copper shell).
2. Visual inspection by another QC inspector.
3. Sample testing (at about a 1% rate) of joints made with short test cable so that the joint could be cut open and inspected (no bad joints found).
4. Low sample testing (1 per mil?) of real joints with an x-ray machine
5. Low sample testing (1 per mil?) of test joints operating in real (cryogenic) conditions

Note: no resistance measurement in the QA plan!

Here is the required reliability level from LHC Splice Report 29 March 2004:

2.4 Reliability

As for all the components and operations of the LHC interconnections, the splices between the main superconducting cables have to reach a very high level of reliability. Failure of only one of the ten thousands splices would jeopardise the operation of the whole accelerator. The required reliability for the complete LHC interconnection system is 99.5 %. After apportionment between the main systems, the failure rate for one junction of the main busbars has to be lower than 10^{-8} *from the mechanical point of view.*

?!

A risk analysis based on the QA plan claimed the number of joints with high resistance requiring repair in the 10000 joints was less than 1 in ~10 years of operation, this was considered to be a satisfactory reliability. This is difficult to interpret without knowing the failure rate with time. I interpret this to mean that the probability of a splice being bad from the start to be 10^{-6} or less.

Was the risk analysis right?

A more realistic (to me) risk analysis:

QC step 1: visual inspection by splice machine operator
- My estimate for making a bad splice and missing it is around 2%.
QC step 2: visual inspection by an independent QC inspector
-Should be better, perhaps 1% chance of missing a bad splice at best.
QC step 3: "test" splices made at 1% level (so about 100 total), none bad found
-This only verifies that the rate of making a bad splice is <2% (which is consistent with my estimate above) but assumes that the exact same conditions exist for real and test splices (but the operator knows when he/she is making a test splice!).
QC step 4: X-ray analysis of real splices at 10^{-3} sampling level (10 splices checked)
-This has almost no statistical value for reducing the risk but checks inside a splice.
QC step 5: Cryo test of "realistic" splices (made on connections to real magnets during cryo testing) at 10^{-3} sampling level (10 splices checked)
-This only provides some evidence that presumably good splices don't go bad when taken to cryogenic temperatures. Useful but this was already assumed in the original risk analysis.

So, my estimate of the bad splice rate is 2×10^{-4} . However, the risk analysis implied a failure rate of $<10^{-6}$, more than 2 orders of magnitude lower.

But in the post-mortem of the Sept. 2008 "incident" we know:

The number of known bad splices is at least 6 (but only about half of the splices have been measured accurately). This implies a "measured" bad splice rate of about 10^{-3} . This clearly shows the risk analysis was very wrong and even my estimate was optimistic.

So was this a failure of QA? Yes, in the sense that a risk assessment is part of a QA plan. However, in this case, the faulty risk assessment made it appear that the QC steps of the QA plan were sufficient.

I consider this a Quality Management failure. The project management knew that the splices were a critical element. In my view, the risk assessment was clearly wrong and I don't believe one needs to be an expert in splice soldering to come to that conclusion. The problem was in calculating a $<10^{-6}$ probability of defective work based on two human visual inspections as the only serious QC. Therefore, the risk assessment was either never reviewed, improperly reviewed or the review was ignored. Furthermore, tests of the splice resistances in 2007, one year before the "incident", showed that a bad splice was detected (and fixed) in one sector. Despite the clear implications of this, the decision was taken to not measure the other 7 sectors since this would delay the start-up. This also was a serious QM failure since a QC step clearly identified a problem.

Lessons:

How does this apply to silicon detectors?

It is rarely the case that a single component can lead to a total silicon detector failure, nevertheless there are still useful lessons for our applications.

- Although we don't require 10^{-6} failure rates, in some cases 10^{-4} is needed. For such high reliability components and systems, an accurate and thorough risk analysis should be used to estimate the reliability of the system. The risk probabilities should be demonstrated and not based on crude estimates by those that designed the QA plan.

- Reviews of critical systems should include people knowledgeable in QA and who are not involved in the project. Negative reviews should not be ignored.

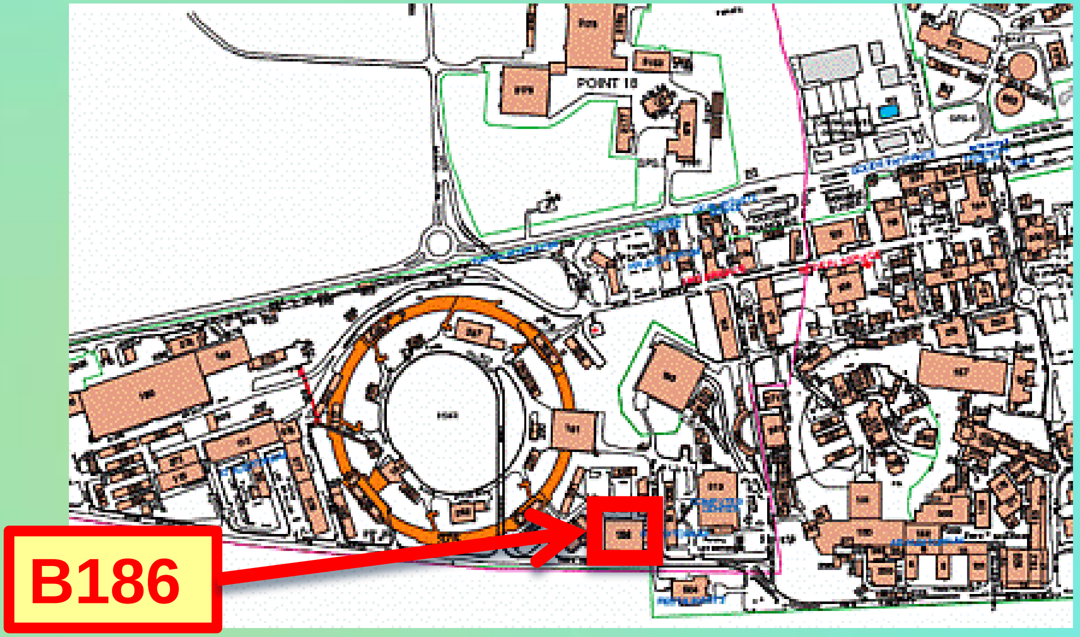
-Time and budget pressures surely affected the quality management of the splice work. The results speak for themselves. How about for silicon detector projects?

- A QA non-conformity that demonstrates that the reliability is orders of magnitude lower than required on a critical system should never be ignored.

The CERN Quality Assurance and Reliability Testing (QART) Lab

CERN DSF
QART and Bonding Lab

Location of QART lab is inside B186-R (ground floor) in the Departmental Silicon Facility



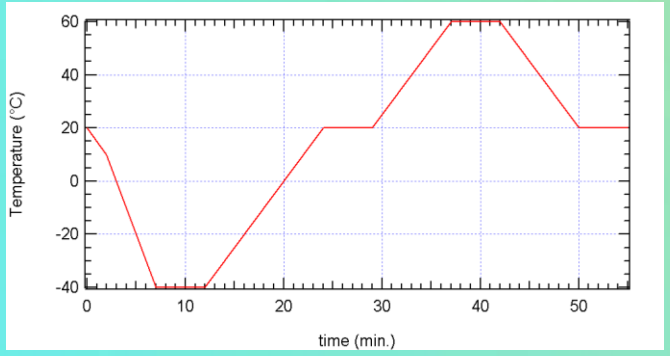
http://bondlab-qa.web.cern.ch/bondlab-qa/QA.html

The mission of the QART lab is to provide QA resources and advice as well as sophisticated reliability test equipment primarily to the LHC silicon detector community but to all of CERN as well.

CERN DSF
QART and Bonding Lab

Equipment: Climatic Chambers

Tests:
- Thermal cycling
- Accelerated lifetime
- Humidity tolerance
- Cold tolerance
- Stress screening
- Environmental simulation



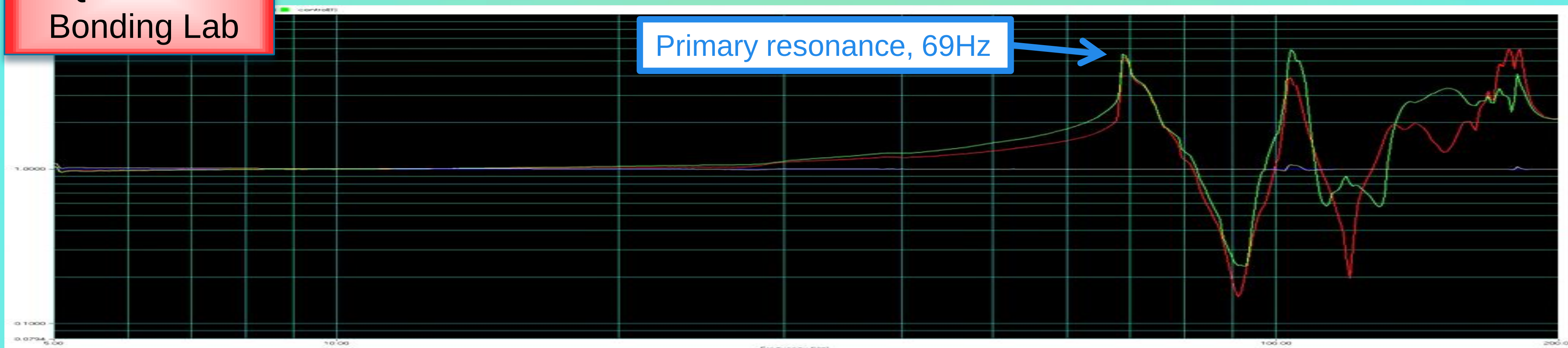
Thermal cycling test for hybrid lamination quality
-40˚C to +60˚C, 100 cycles

Climatic Chamber
Temp range: -70°C to +180°C
Hum range: 10% to 95%RH
Heating speed: 15°C/min
Cooling speed: 11°C/min

Thermal Cycling Chamber
Temp range: -40°C to +180°C
Heating speed: 5°C/min
Cooling speed: 6°C/min

CERN DSF
QART and Bonding Lab

Equipment: Vibration Tester



Mono-axial shaker with control system and analysis tools for Random, Sine, Shock, and Recorded vibration inputs.
Can perform:

- Destructive testing
- Stress screening
- Modal analysis
- Playback of transport and handling vibrations and shocks
- 30cm x 30cm head expander allows testing of large objects (CMS silicon tracker module)

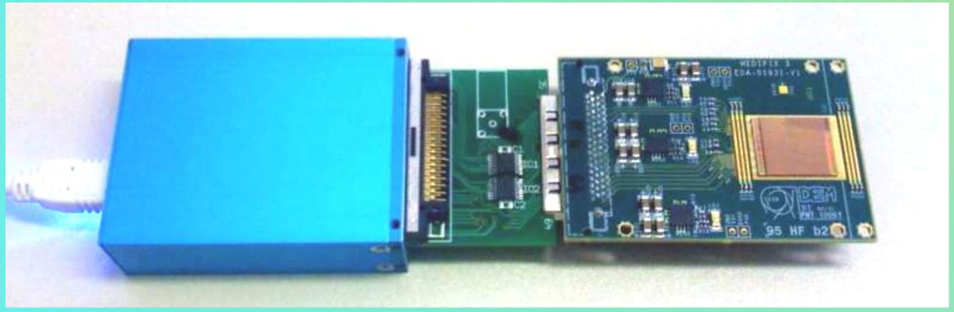
We have a variety of low mass accelerometers for measurements on light-weight structures

CERN DSF
QART and
Bonding Lab

Equipment: IR Video Camera

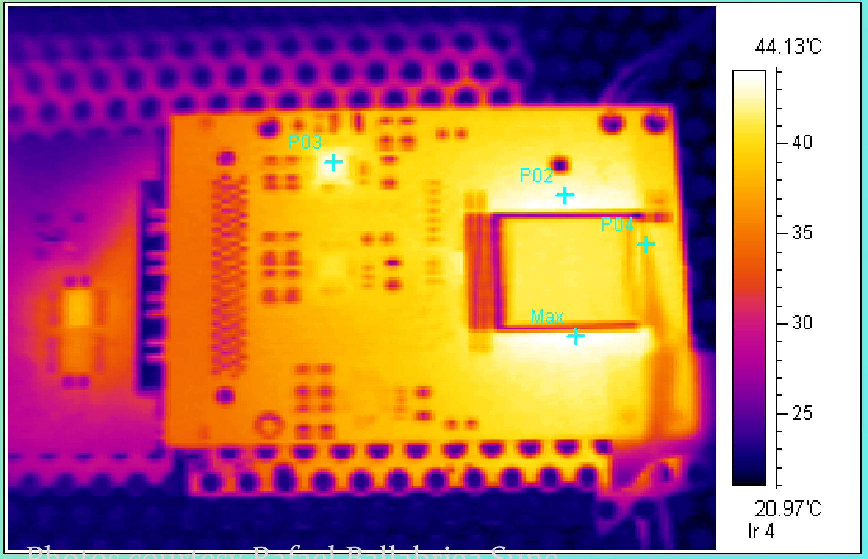
High sensitivity (0.1˚K) thermal imaging IR video camera.
160 x 120 pixels. Measurement range: -20˚C to +250˚C.
Expected uses:

- Identifying hot spots on silicon sensors or electronics
- Heat flow study on front-end PCBs and detector modules



Medipix detector with USB read-out:

- Thermally cycled in our climatic chamber
- Thermal map of powered device using IR camera



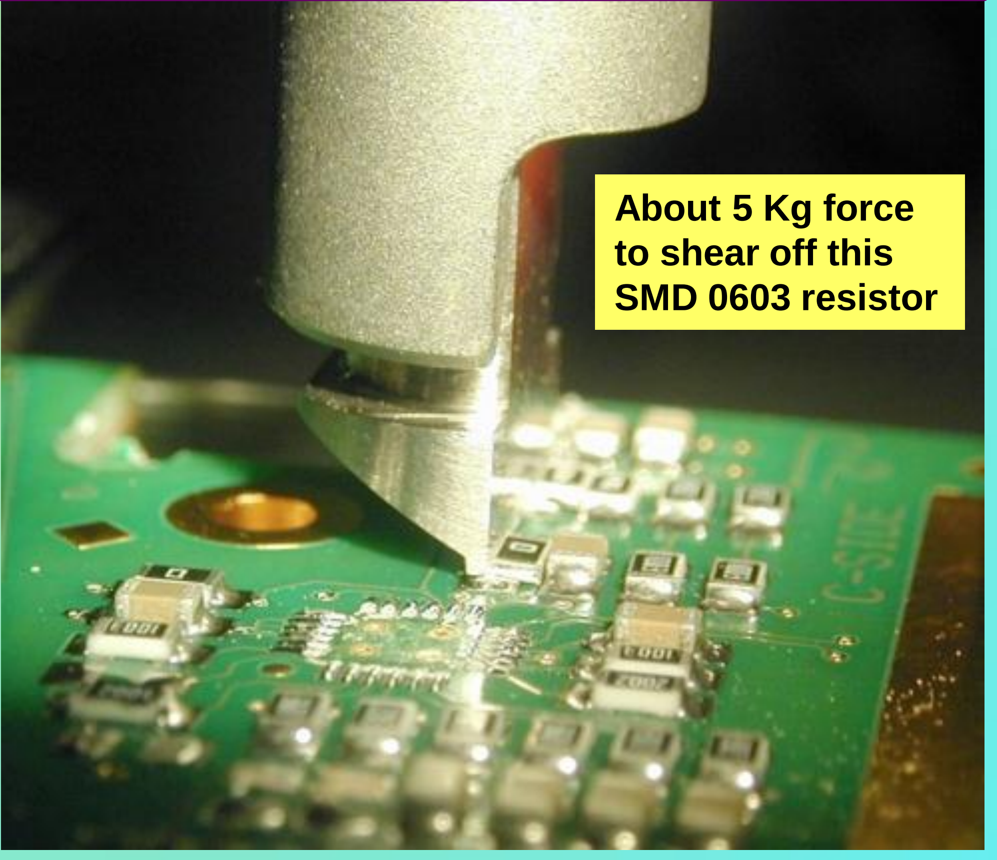
Photos courtesy Rafael Ballabriga Sune

CERN DSF
QART and
Bonding Lab

Equipment: Pull and Shear Tester

Pull testing is the only sure method to evaluate wire bonding quality. The DAGE 4000 pull tester requires manual positioning but the pull is automated. The machine can be quickly converted to do shear testing.

Shear testing is for checking die attach adhesion, bond wire adhesion and soldering quality for small components.



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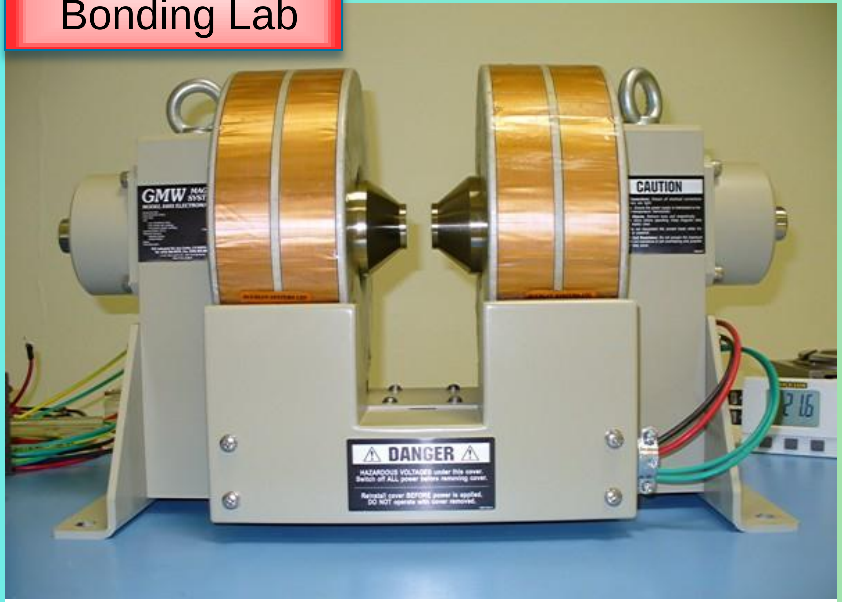
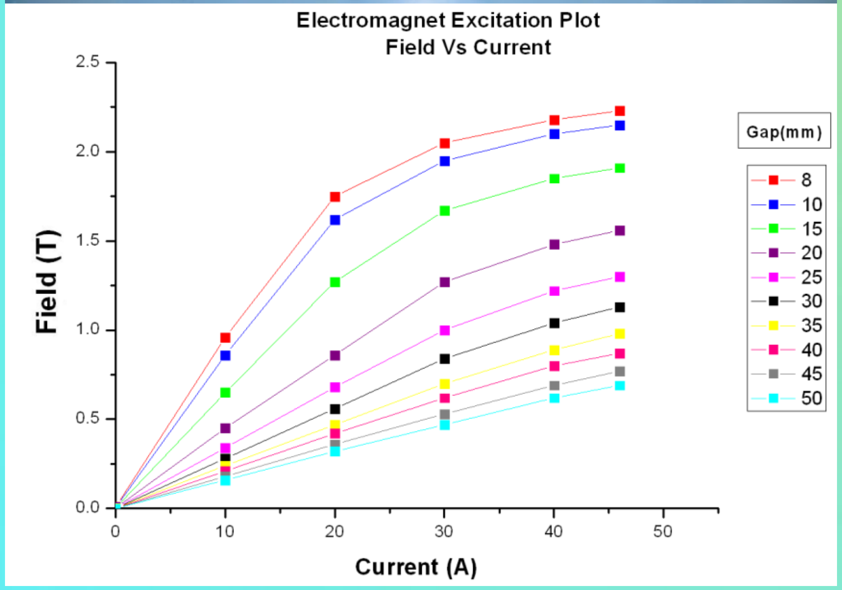
Equipment: High Field Magnet



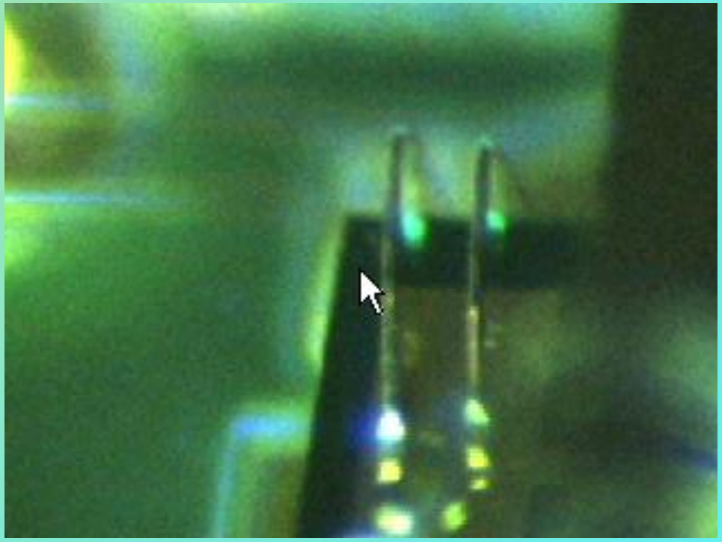


Small aperture laboratory electromagnet:

- Pole diameter: 38 mm
- Variable pole gap: 0-86 mm
- Magnetic field: 0-2T

Can test small components in high B field.
Study bond wire oscillations in B field.

Oscillations driven in bond wire of real CMS optical hybrid in 2T field of this magnet. Primary frequency is 22KHz (simulation said 21KHz).



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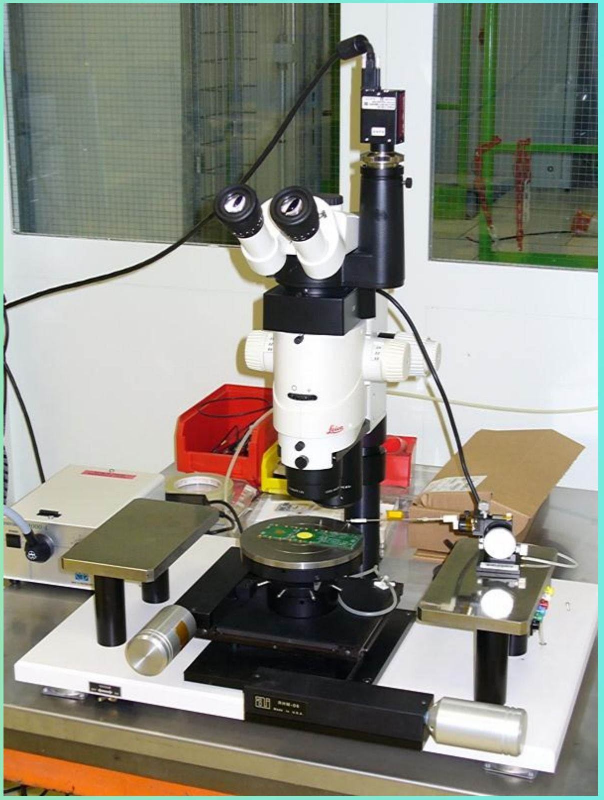
Bonding Machines, Inspection Microscopes

Two Delvotec 6400 automatic wire bonders set up for aluminium wedge wire bonding.



One high magnification stereo microscope with video camera. Three more stereo microscopes with lower magnification for routine inspection

Summary

- "Quality Issues" are inherent in all projects. As the scale and the stakes in a project increase, the need for an exigent and complete quality planning is crucial.
- Unlike the LHC splices, high risk components in silicon detectors are rare but the need for high long-term reliability and the impossibility of repair => good risk assessment and careful scrutiny of QA.
- The QART lab is at your service. You are invited to visit.

We look forward to excellent talks on Quality Issues: WELCOME!