Wirebond Encapsulation Methods for ATLAS Pixel Modules

Amanda Deisher

September 1, 2004

1 Introduction

The following is a description of wirebond encapsulation testing completed at Lawrence Berkeley National Laboratory September 2003 - March 2004. The testing involved four main phases:

- Verification that unencapsulated wirebonds of same type and geometry used in the ATLAS pixel detector, when carrying oscillating current in a magnetic field, will break at frequecies of order 10kHz in both barrel and disc orientations.
- Testing the effectiveness of two encapsulation methods at reducing failure percentages near resonance.
- Testing the effectiveness of irradiated encapsulant.
- Testing the effectiveness of amount of encapsulant.

2 Motivation

The ATLAS inner detector will operate in a 2T magnetic field to aid in the determination of charged particle momentum. Therefore, current carrying elements of the detector will be subject to Lorentz forces. As current oscillations can drive mechanical oscillations of detector elements, it is prudent to study ATLAS wirebond behavior near their natural resonances.

Mechanical oscillation has been identified as cause of failure during detector operation at CDF [2]. Work done by Tom Barber [1] has already demonstrated that bonds of dimensions similar to those used in ATLAS's inner detector are susceptible to the same type of failure. In addition to software based protections such as a veto of trigger frequencies near resonance, the ATLAS collaboration is considering hardware based protections such as encapsulation. The purpose of this study was to test the effectiveness of different encapsulant methods in protecting the wirebond connections in the event of operation at resonant frequency.

3 Apparatus Description

A schematic of the setup used may be found in Figure 1. The main components were as follows:

Magnet The magnet used was a permanent dipole magnet with a gap size of 5mm. The field strength was 1.4 T in the center of the gap.

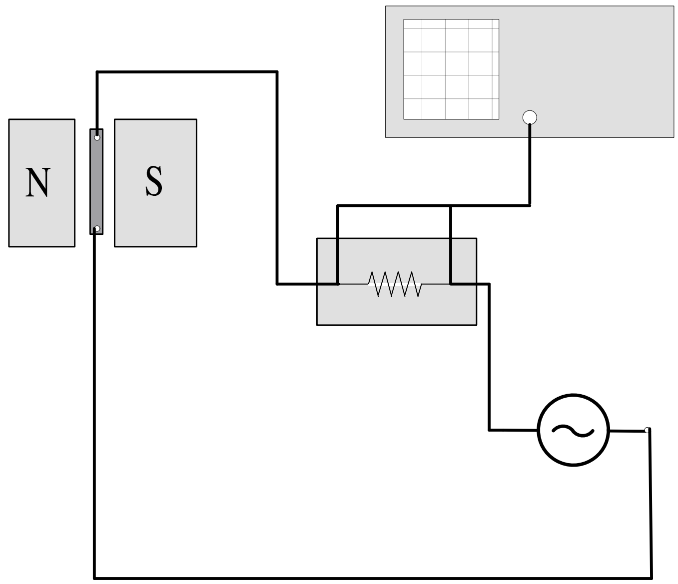

Figure 1: Schematic of the setup

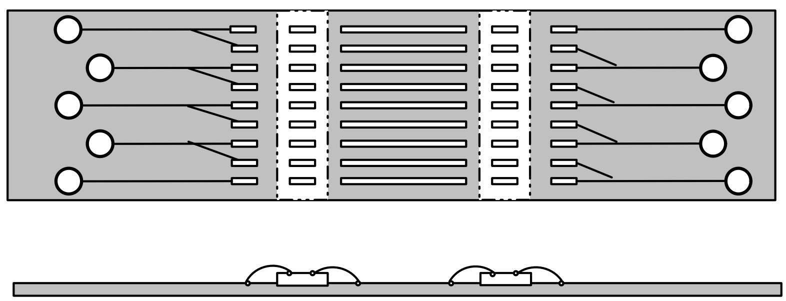

Figure 2: Top: Top view of test board. Bottom: Side view of test board. Actual dimension of board 5mm X 40mm

Test Boards The test boards contained the wirebonds tested in this experiment. See Figure 2 for the geometry. A single board was 5mm by 40mm, as it had to fit in the gap of the permanent magnet. The boards have two layers at different heights to mimic the elevation change seen by module wirebonds. Each test board contained 9 rows of bonds with four bonds in series per row. Note that the connectors available for soldering were arranged to make operation of a single row or several rows in series possible. The dimensions of the bonds used on the test boards are similar to the ones that will bring power from the pixel module flex to the readout chips. A module wirebond's diameter is 25 μm, and the length is 2.9-3.1 mm.

Not shown are the two mounting devices designed to hold the board centered in the magnetic field in the disc and barrel orientations.

After board assembly and wirebonding, the encapsulation method for each board was chosen. The encapsulant used was Dymax 9001 v.3.1. The three options were no encapsulant, center encapsulant, and both feet of wirebonds encapsulated. See Figure 3. In the later part of testing, a second layer of encapsulant was applied to both feet of the wirebonds. This is referred to as double encapsulation.

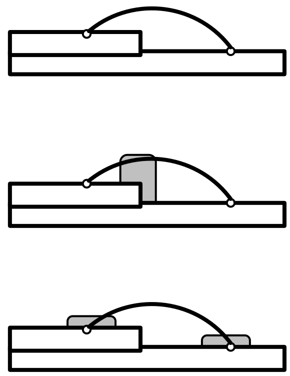

Figure 3: Bonds with no encapsulant, encapsulant applied to the center only, and encapsulant applied to both feet.

A follow-up study of encapsulant performance after 50 MR of gamma radiation was also performed on boards with both feet encapsulated, both barrel and disc orientations.

Function Generator The function generator produced sine waves with amplitude and frequency modulation options. The wirebonds were operated at single amplitude while a frequency range was scanned. The amplitude was then incremented, and the frequency scan was repeated. The frequency modulation rate was set so equal time was spent in each frequency interval.

Resistor A 39.5 Ω resistor was used to limit current. The potential difference across the resistor was used to calculate the current in the circuit.

Oscilloscope The oscilloscope monitored the status of the waveform in the circuit. The probe was connected across the resistor. The frequency of the generated sine wave was calculated and displayed by the oscilloscope. The trigger level was set sufficiently high to capture the last waveform before a failure occurred. In this way, continuous human monitoring was not required in most cases. However, there were instances when the two pieces of a broken wirebond reconnected, the circuit was closed momentarily, and information about the frequency of last waveform was lost.

4 Failure Description

A bond failed when the wire, fatigued by oscillation, broke and the electrical circuit opened. Observation has shown that a break in an unencapsulated wirebond usually occurred at the heel of the bond, where the wire had already been stretched and bent [2].

As the four wire bonds in a row on the test board were in series, a maximum of one bond per row could break. The failure fractions were calculated as follows. If all nine rows were connected in series and no bonds failed, then the failure fraction was 0/36. If all nine rows were connected in series and one bond broke, then the failure fraction was 1/33 bonds. The three other bonds in the broken row, no longer accessible for testing, were removed from consideration.

Some encapsulated wirebonds exhibited a time dependent failure mode. When the break was inside the encapsulant, it was possible for the two pieces of a broken bond to make contact and form a temporary electrical connection at non-resonant frequencies. However, as the function generator continued to modulate the frequency, contact was again broken at the resonant frequency.

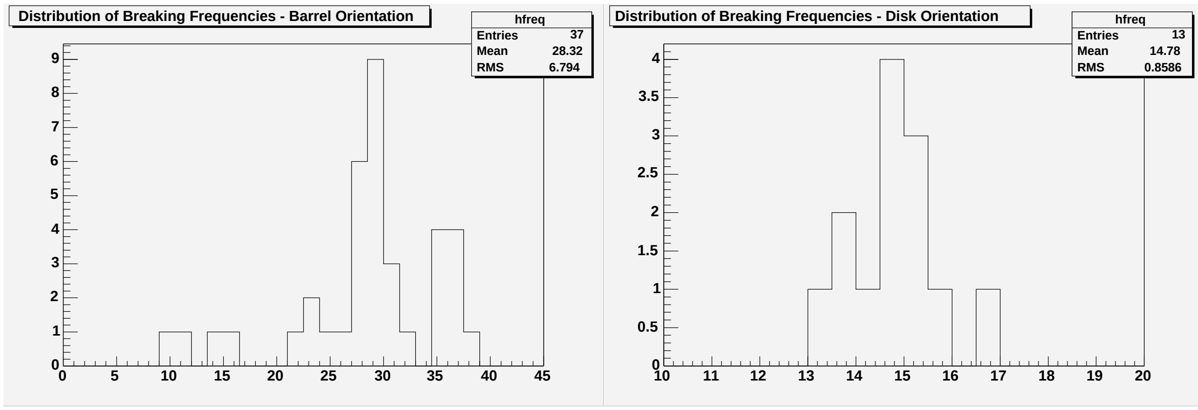

Figure 4: Distribution of resonant frequencies of unencapuslated wirebonds in the barrel (left) and disc orientations

The time spent in any 100Hz interval is recorded in this report as a conservative estimate of the time spent on resonance. The full width half maximum of the resonance peak of unencapsulated bonds was shown by other experiments [1] to be 100Hz. Because the encapsulant broadened the resonance peak, the time spent on resonance during a linear frequency scan was greater than the time spent in any 100Hz interval.

5 Results

5.1 Test I: Frequency Scan of Unencapsulated Wirebonds

The purpose of this test was to verify that unencapsulated wirebonds were vulnerable to failure at frequencies on the order of 10kHz. The distribution of resonant frequencies found during this test was used to determine the frequency scan ranges for tests II, III, and IV.

Unencapsulated wirebonds carrying a 135mA (peak-peak) oscillating current were placed in the gap of the permanent magnet in barrel orientation. The function generator swept through a large frequency range. The frequency at which each bond broke was recorded.

The test was repeated with 100mA for bonds in the disc orientation. See Figure 4 for histograms of the results.

5.2 Test II: Amplitude Scan of Unencapsulated and Encapsulated Wirebonds

The purpose of this test was to determine the failure fraction at different current amplitudes. The procedure for each board tested was as follows.

- The board outputs were wired so all 36 bonds were connected in series.
- The amplitude (p-p) of the initial current oscillation was set at 20mA in the 1.4T field of the test magnet.
- The generator swept swept through a set range of frequencies.
- When a bond broke, the circuit was opened. The breaking frequency was recorded, if the waveform was frozen on the oscilloscope screen. The board outputs were rewired so the remaining rows were connected in a series.

Table 1: Barrel Orientation Results (scaled to the ATLAS field)

Sine Amplitude, p-p in 2T field	No Encapsulation	Middle Only	Both Feet
7mA	1/20	-	0/36
14mA	2/14	1/33	0/36
21mA	5/9	3/27	0/36
28mA	6/6	5/5	0/36
70mA	-	-	0/36

Table 2: Disc Orientation Results (scaled to the ATLAS field)

Sine Amplitude, p-p in 2T field	No Encapsulation	Middle Only	Both Feet
14mA	-	1/33	0/36
21mA	-	1/33	0/36
28mA	-	7/7	0/36
35mA	-	-	0/72
49mA	-	-	2/62
56mA	-	-	13/29

- When no additional bonds broke after several frequency cycles, the amplitude of the oscillation was increased by 10mA.

Boards with no encapsulant, center encapsulant, and both feet encapsulated were tested. Both barrel and disc orientations were tested.

The results of the tests are listed in Tables 1 and 2. Note that the same Lorentz force driving an oscillation at 20mA in the 1.4T test magnet would be generated by a 14mA current in ATLAS's 2T field. All results in the tables are scaled to their equivalent ATLAS currents.

The wirebonds that failed without encapsulant and with middle only encapsulant spent less than 20 seconds on resonance. The wirebonds with both feet encapsulated in the barrel orientation survived 70mA for 112 hours. This corresponds to 8.4 minutes spent on resonance.

5.3 Test III: Amplitude Scan of Irradiated Encapsulated Wirebonds

The purpose of this test was to verify that the encapsulant performance was not affected by radiation.

The amplitude scans of Test II were repeated on bonds with both feet encapsulated that were exposed to 50MR of gamma radiation.

Table 3: Irradiated Barrel Orientation Results - Both Feet Encapsulated

Sine Amplitude, p-p in 2T field	Failure Fraction	Time on Resonance
70mA	0/36	9.75 min

Table 4: Irradiated Disc Orientation Results - Both Feet Encapsulated

Sine Amplitude, p-p in 2T field	Failure Percentage	Time on Resonance
14mA	0/36	18.5 min
21mA	0/36	10.4 sec
28mA	9/9	

Table 5: Disc Orientation Results - Both Feet Double Encapsulated

Sine Amplitude, p-p in 2T field	Failure Percentage	Time on Resonance
21mA	0/36	14.1 min
28mA	0/36	26.0 sec
35mA	0/36	28.2 sec
42mA	0/36	31.4 sec
49mA	2/30	9.3 min
56mA	2/30	70.4 sec
63mA	4/24	3.2 min
70mA	4/24	4.8 min

The irradiated boards in the barrel orientation with both feet encapsulated were operated for 65 hours at 100mA (scaled to 70mA in an ATLAS field) in the frequency range [10kHz, 50kHz], at least 9.75 minutes of which were on resonance.

The irradiated bonds in the disc orientation started breaking at the 28mA setting after less than 1.2 seconds on resonance. The maximum seperation between bond breaking for the next 8 bonds was 6 seconds on resonance. The minimum seperation was again 1.2 seconds.

5.4 Test IV: Amplitude Scan of Double Encapsulated Wirebonds in the Disc Orientation

The purpose of this test was to gauge the effectiveness of double encapsulation in preventing wirebond breaking in the disc orientation. Double encapsulated bonds have a second layer of encapsulant applied over the first. This yields bonds with $\sim 50\%$ of the wire exposed.

After two bonds broke at 49mA, the remaining 28 bonds were on resonance for 9.3 minutes before the amplitude was incremented. After two more bonds broke at 63mA, the remaining 20 wirebonds were on resonance for 3.2 minutes before the amplitude was incremented. The 20 wirebonds were on resonance at 70 mA for 4.8 minutes without breaking.

After electrical testing, the broken bonds were visually inspected. All four broken bonds broke at the booundary of the encapsulant on the lower foot. They were also the four bonds with the least length of wire covered by encapsulant. Eighteen bonds on the test board had their upper heels lightly encapsulated. The broken bonds had the least lower heel encapsulant of those 18 bonds.

That the bonds with the least encapsulant were most vulnerable to fatigue and breaking is not suprising, as the amplitude of the oscillation is proportional to “free” wire $length^4$ [1].

6 Conclusions and Recommendations

Without encapsulation the wirebonds in the pixel detector will be vulnerable to oscillation from a/c currents as low as 7mA p-p. The encapsulation of both feet fully protects irradiated wirebonds in the barrel orientation from a/c currents of 70 mA p-p at the resonance frequency for at least 9.75 min. However, wirebonds in the disc orientation are vulnerable at lower current when covered with a single layer of encapsulant. Thorough double encapsulation has the potential to fully protect disc oriented wirebonds.

Independent of trigger vetos near the resonance frequency and other softward controls that may be used, it is recommended that hardware based protection of the pixel detector wirebonds be used. Modules in the barrel orientation should have wirebonds with both feet encapsulated. Modules in the disc orientation should have wirebond with both feet double encapsulated.

References

[1] Tom Barber, *Investigating Bond Wire Resonance in ATLAS*, 26 September 2003, http://agenda.cern.ch/askArchive.php?base=agenda&categ=a021567&id=a021567s1t9/document/Resonant_Wire_Bond.pdf, 25 August 2004.

[2] Reid Mumford, *CDF Silicon Detector: Wire-bond Failures Induced by Resonance Vibrations*, 23 June 2003, http://ssd-rd.web.cern.ch/ssd-rd/bond/talks/reid_cdf.pdf, 25 August 2004.