Preamplifiers for the Liquid Argon Calorimeter

Production Readiness Review
April 26, 1999

1. Introduction

The preamplifiers described by this document are the ones usually called "warm preamplifiers (0T)" in the ATLAS terminology. They are part of the front-end electronics for the EM calorimeters and FCAL and are located outside the detector cryostat.

An overview of the liquid argon (LAr) readout electronics is illustrated in Fig. 1. The preamplifiers are shown at the input of the Front End Board (FEB) and are connected via a transmission line to the detector electrodes. The space allocated on the FEB for the preamplifiers have dictated the aspect ratio of the circuits and, up to certain extent, the technology adopted for the production.

Each FEB contains 128 channels of amplification, 64 channels on each side of the card grouped in two block of 32 channels each. The preamplifiers are moreover grouped in block of four channels and have been realized in a hybrid package the dimension of which are 53.3 mm in length and 23.0 mm in width. The preamplifier hybrids are independent units that plug into the FEB. The total height of the hybrid when inserted must be 5 mm or less. This height is part of the FEB requirements.

Brookhaven National Laboratory (BNL) and INFN Milan are the two responsible parties for the development, testing, production and qualification of the preamplifiers.
BNL has the responsibility of manufacturing 50% of EM and 100% of FCAL calorimeter preamplifiers. INFN Milan has the responsibility of manufacturing the remaining 50% of the EM calorimeter preamplifiers.

To accommodate the different characteristics of the detector, three types of warm preamplifiers must be used. These three type of preamplifiers share a same general circuit diagram which has been properly "optimized" for the different sections of the calorimeter. What type and how many preamplifiers are needed for the experiment, are better explained in the next sections.

2. Requirements and Specification

The warm preamplifier requirements and specifications are described in detail in the Technical Design Report [Sec. 10, 401-410] and have been subsequently reviewed in a note produced jointly by BNL and INFN Milan at the conclusion of the Preamplifier Design Review held at CERN, Geneva, on July 1997.

The preamplifiers are the first amplification stage in the LAr readout architecture, which set the noise performance of the calorimeter. They amplify the analog signal generated at the calorimeter electrodes. As the signal duration is long compared to the shaping time, current preamplifiers are used which provide a voltage output directly proportional to the input current.

More than one type of preamplifier is needed to achieve optimum performances. The detector structure (i.e. impedance, capacitance, etc.), the estimated maximum energy deposited per readout cell as a function of rapidity, together with the need of a maximum output signal of about 3 to 4 Volt, determine how many preamplifier types are needed.

Table 1 identifies what type and how many preamplifiers are needed for each calorimeter section. It summarizes the capacitance (C_D); the maximum currents (I_{max}) estimated for the various detector sections, as well the input impedance (Z_{in}) and the transimpedance of the preamplifiers. Three preamplifier types will be needed in the experiment. They are identified with the letter A, B, D, or with their Z_{in}/I_{max} combination in the remaining of this document.

TABLE 1.

Type	Cal. Section	C_D [pF]	I_{max} [mA]	Z_{in} [Ω]	Transimp. [Ω]	No. of channels (*)	Responsible party
A	Front & Presampler	160 - 500	1	50	3 K	94336	BNL and Milan (50% each)
B	Middle & Back (low current)	300 - 2000	5	25	1 K	43904	BNL and Milan (50% each)
D	Middle (medium current) & Back (high current)	400-2000	10	25	500	35608	BNL and Milan (50% each)
B	FCAL	300 - 2000	5	25	1K	4992	BNL

(*) The number of hybrids is equal to the number of channels divided by four

The most important requirements can be summarized as follow:

-Noise: as low as possible with respect to pile-up.
Rnoise = 10 Ω
ENI (typical values) see Table2.

TABLE 2.

Type	ENI [nA]
B	65 @ C_D = 400 pF, tp = 40 ns
A	270 @ C_D = 2200 pF, tp = 40 ns

-Uniformity: TDR: < 5 % in amplitude for trigger sums (< 1 % meas.)
TDR: < +/- 2 ns timing (< +/- 1 ns measured)

-Power Dissipation: TDR: < 100 mW/ch

-Environment: must tolerate 20 Gy/year (2 krad/year) and 10^{12} n/cm^{2}year

-Reliability: < 0.5 % missing channel per year

-ESD discharge: must withstand 4 mJ multiple discharge without damage
(I.e. 2 KV on 2 nF typical)

-Stability: must be stable even in case of presence of faults in the signal chain
(short, open)

-Ouput impedance: must be able to drive a 50 Ω load (i.e. the shaper input impedance)

-Dynamic range: up to 10 mA, depending on rapidity range

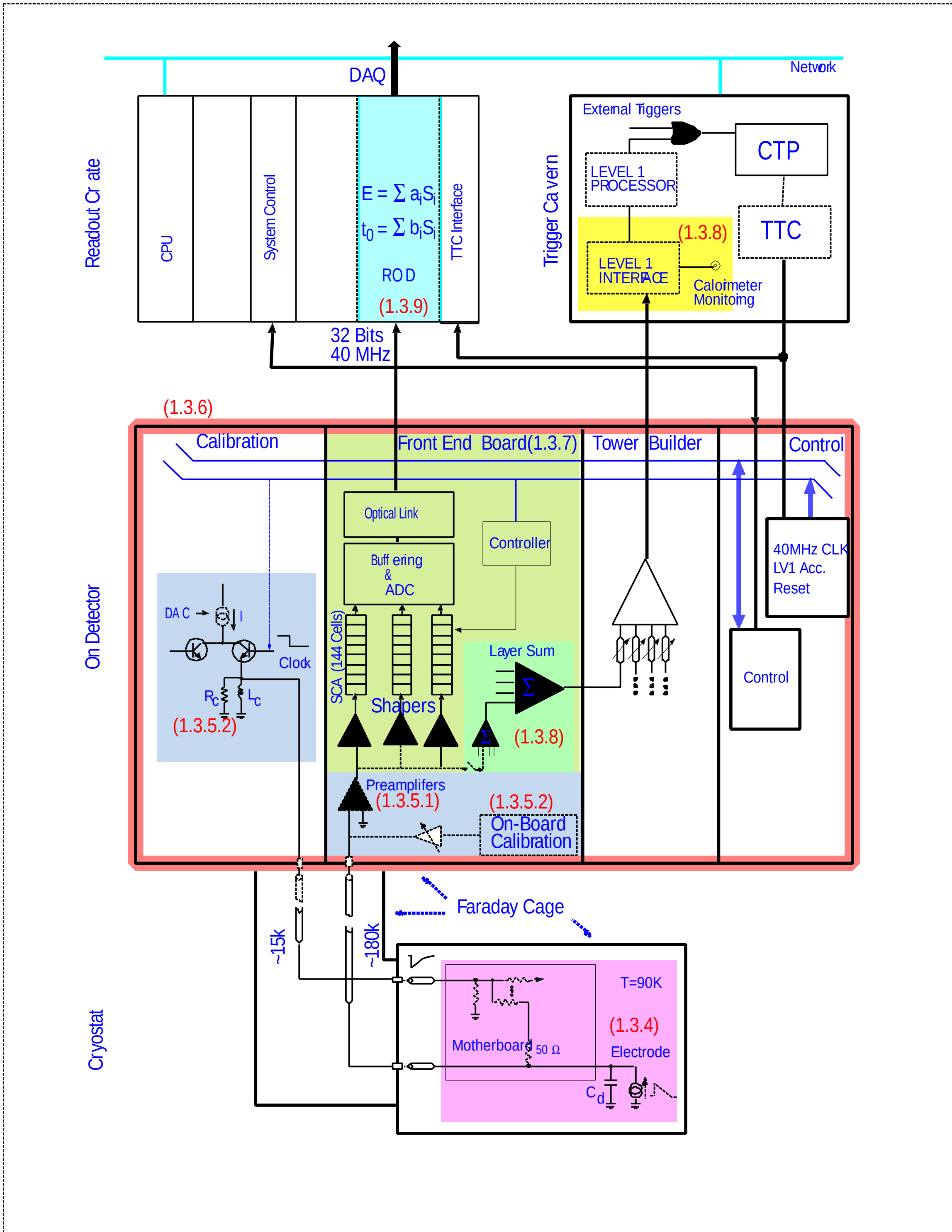


Figure 1. LAr Calorimeter Readout Overview

3. Design of the Preamplifier

The principle of preamplifier coupling to a high capacitance detector is discussed in:

R.L. Chase, C. de La Taille, S. Rescia and N. Seguin, “Transmission Line Connections Between Detector and Front End Electronics in Liquid Argon Calorimetry”, *Nucl. Instrum. & Meth.*, A330, pp. 228-242, 1993.

A subsequent paper

R. L. Chase and S. Rescia; A Linear Low Power Remote Preamplifier for the ATLAS Liquid Argon EM Calorimeter; BNL 63745; IEEE Trans. Nucl. Sci. Vol. 44, No. 3, June (1997) 1028.

describes the ATLAS implementation.

The main characteristic of the ATLAS preamplifier is the use of a local feedback in the input stage to attribute the functions of low noise and high dynamic range to two different transistors. This circuit configuration allows to improve the linearity and to reduce the noise while reducing the power dissipation by a factor of three (to about 50 mW) with respect of the first generation RD3 preamplifier. The gain (i.e., the transresistance) and the input impedance can be chosen independently without changing the power supply voltages and power dissipation.

The circuit schematic is shown in Fig. 2.

3.1. Technology

The preamplifier has been manufactured by means of thick film hybrid technology.

The choice of the technology has several benefits:

- Proven technology
- Predictable time schedule for production
- Multiple vendors to choose from
- High reliability as proven in many HEP experiments
- Each device can be chosen to optimize its function (e.g. low noise)
- Use of different type of devices (NPN, PNP, decoupling capacitors, etc.)

The channel density allows for the larger size of the circuit. Use of a more advanced monolithic technology was rejected because of the higher development costs (a complementary bipolar process featuring low noise, radiation resistant transistors is necessary) and higher risks associated with the R&D, both in terms of performance and schedule.

The design has been carried out with very conservative design rules (10 mils line, 10 mils separation) to both expand the pool of manufacturers and to improve the production yield. The layout is shown in Fig. 3.

3.2. Preamplifier measured characteristics

A pre-production run of 97 units (388 channels) of IO823 (Type A) preamplifiers and 84 units (366 channels) of IO824 (Type B) has been burned-in and its performance has been measured and analyzed.

Measured were performed with the conditions summarized in Table 3.

TABLE 3.

	IO823 – Type A	IO824 – Type B
Detector Capacitance (C_d)	330 pF	1.5 nF
Cable Length (ns)	16	19
Cable Type	RG174 (Z_0=50 Ω)	2 x RG174 in parallel (Z_0=25 Ω)

On a different production run also the input impedance has been measured and characterized on 50 preamplifiers (200channels) each of IO823 (Type A), IO824 (Type B) and IO826 (Type D) preamplifiers.

The parameters measured are (see Table 4, 5, 6):

- Gain
- Peaking time
- Noise
- Input Impedance

TABLE 4. IO823 – Type A - 50Ω/1 mA

Parameter	MEASURED			
	Average	Tolerance	rms	% within +/-3 σ
Gain	981.8 mV	+/-1.13%	2.99	99%
Peaking Time	45.8 ns	+/-.339 ns (+/- 0.74%)	0.14 ns	100%
ENI	49.3 nA	+/-6%	0.54 nA	99.2%

TABLE 5. IO824 – Type B - 25 Ω/5 mA

Parameter	MEASURED			
	Average	Tolerance	rms	% within +/-3 σ
Gain	612 mV	+/- 1.45%	3.3 mV	100%
Peaking Time	52.6 ns	+/- 0.7 ns (+/- 1.3%)	0.3 ns	100%
ENI	124 nA	+/- 1.9%	0.8 nA	100%

TABLE 6. Input Impedance

Type	Z_{in}	Tolerance
IO823	51.4 Ω	+/- 2.9%
IO824	25.8 Ω	+/- 1.8%
IO826	26.3 Ω	+/- 1.7%

The measured performances meet the specification requirements. Some of the distributions obtained are included at the end of the section.

Stability analysis has been also performed and the results are discussed in:

G. Battistoni, D.V. Camin, N.Fedyakin, P. Ramaioli and R. Shuvalov, "Stability of a line receiver (0-T) preamplifier, connected to a capacitive detector via a transmission line", *Nucl. Instrum. & Meth.*, A424, pp. 533-544, 1999.

The preamplifiers were found stable for any value of cable length and detector capacitance foreseen for the LAr calorimeter.

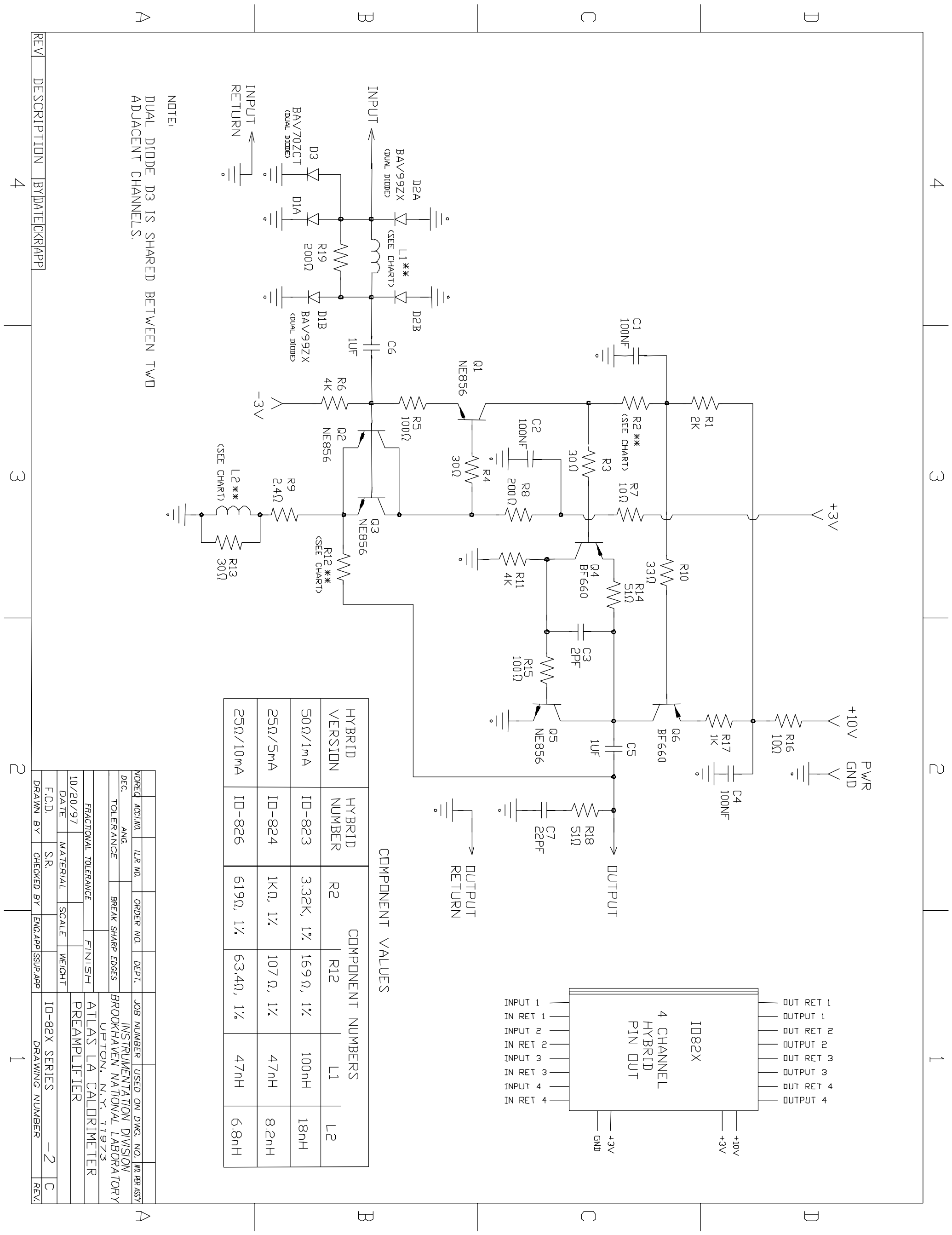
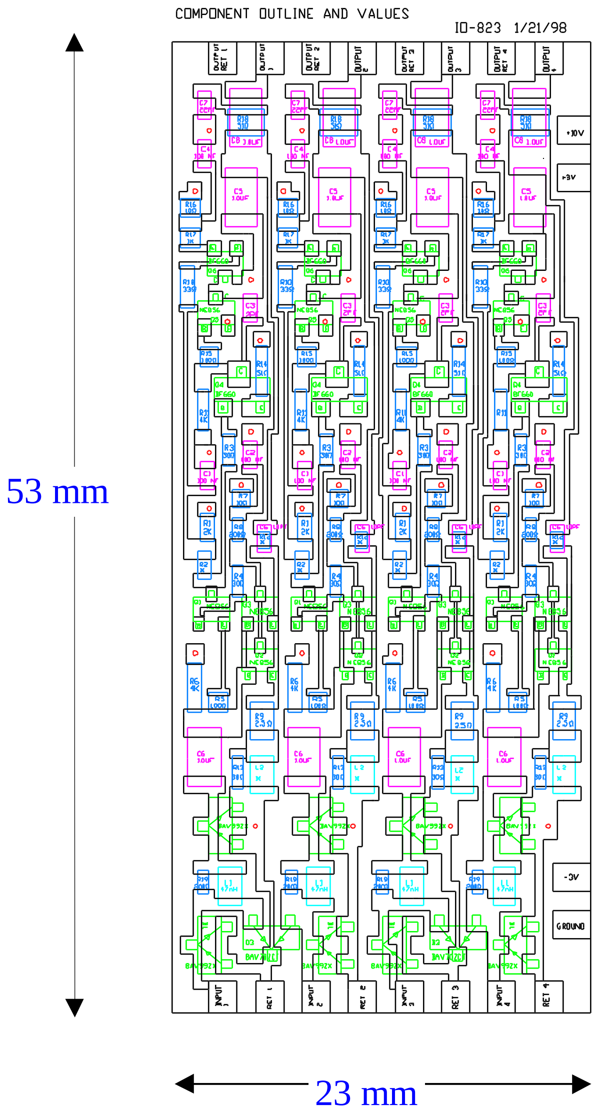


Figure 2. Preamplifier Schematic



Design Rules:

Lines: 10 mil
Spaces: 10 mil

Ceramic Thickness: 40 mil

Pins:

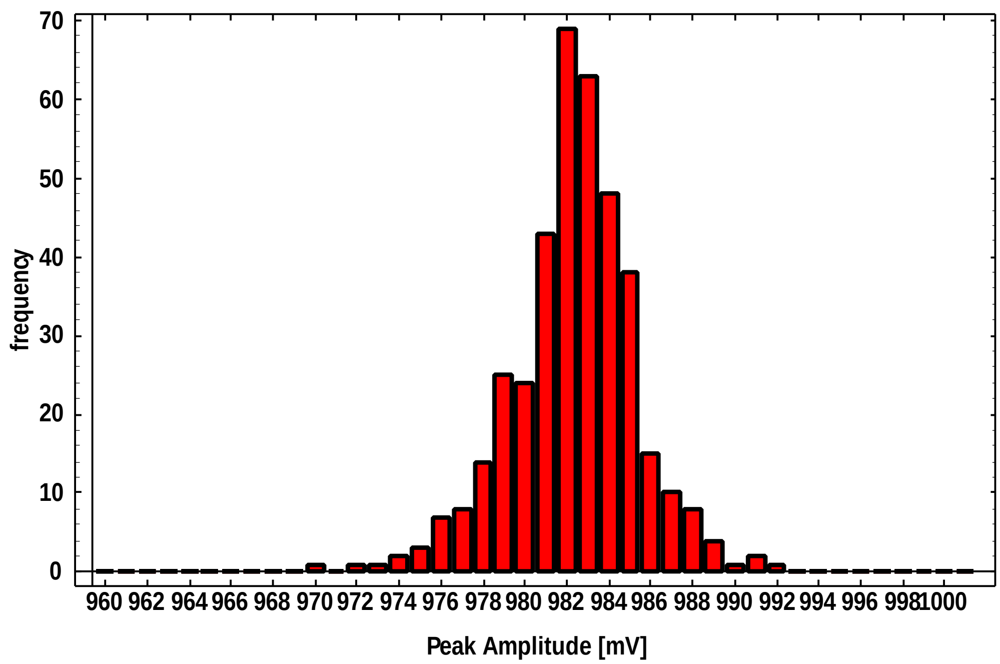
No: 20
Grid: 100 mil

Power Supply:

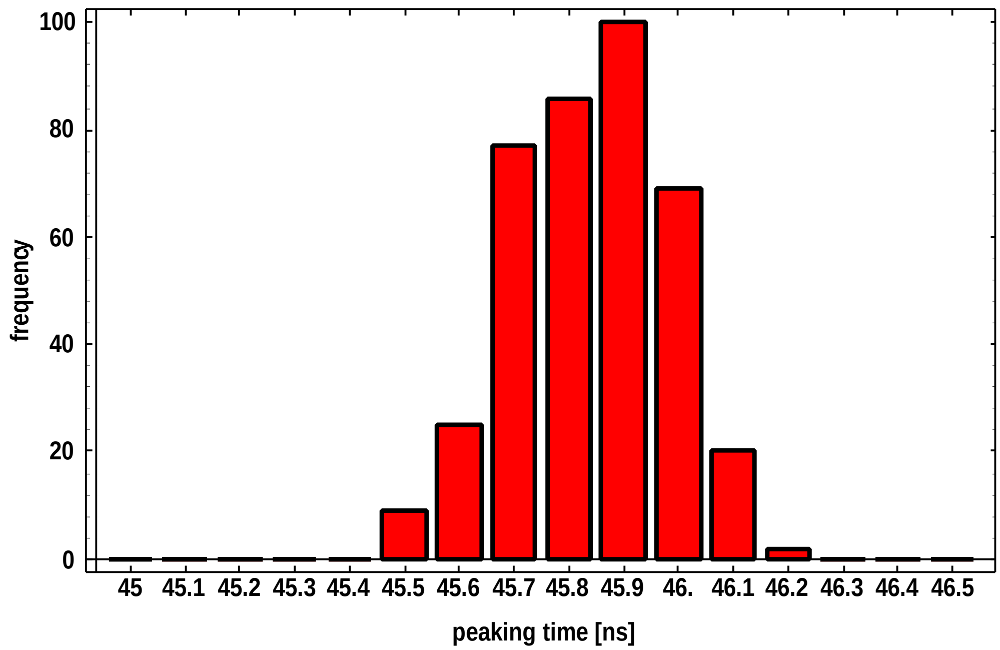
+ 10 V
+ 3 V
- 3 V

Figure 3. Hybrid Layout

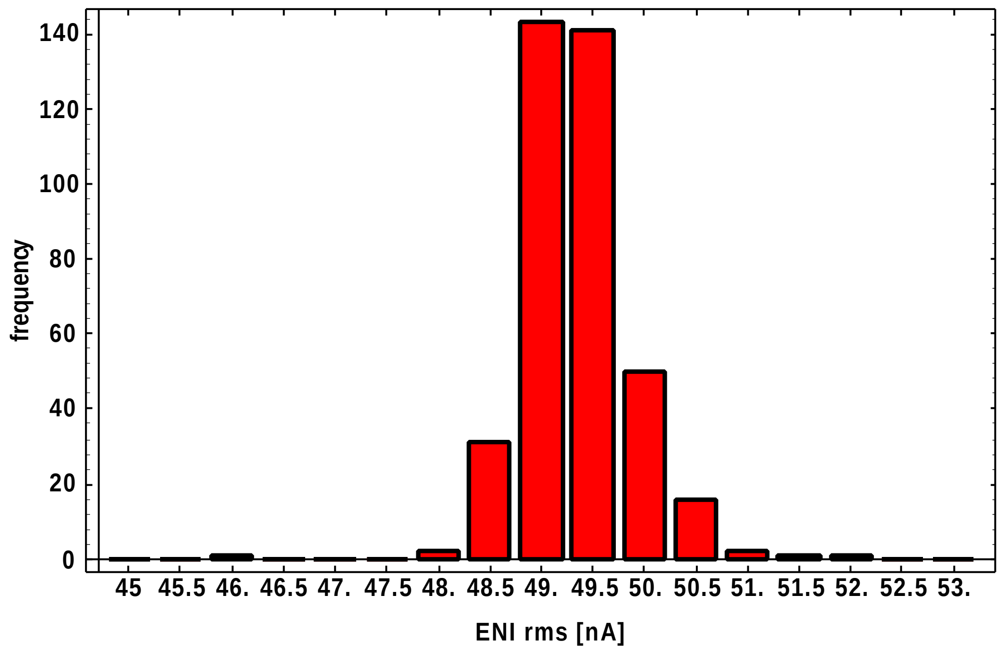
IO823 RP0T 50 ohm Io,max=1mA preamplifer C_det=330 pF td_line=16ns (RG174)
peak amplitude for tp_tr~46 ns (tau=30 ns)
Average[Vpeak]=981.807
rms[Vpeak]=2.98776



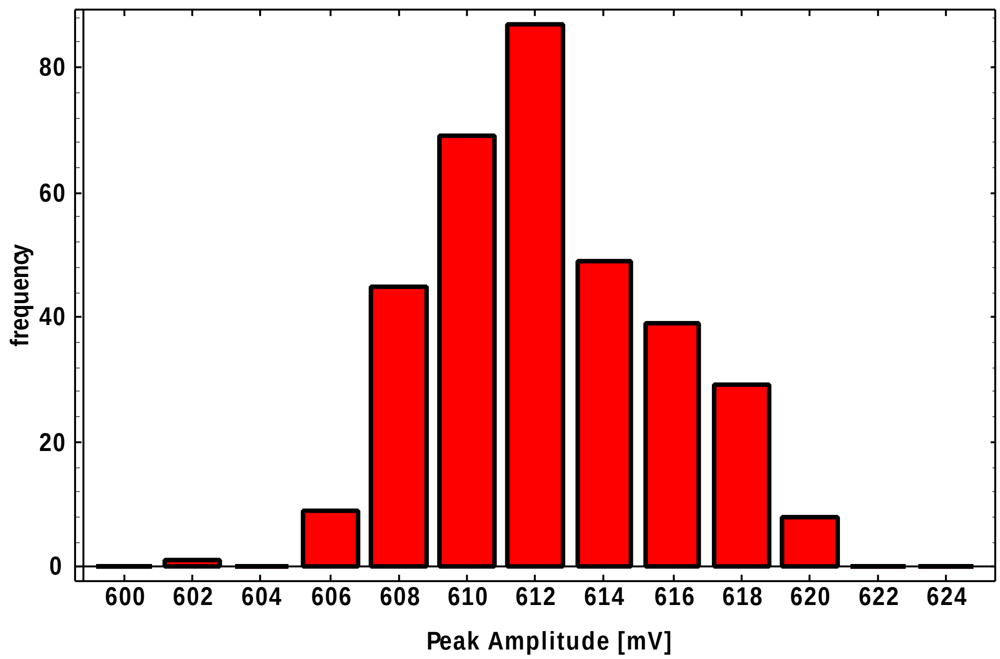
IO823 RP0T 50 ohm Io,max=1mApreamplifer C_det=330 pF td_line=16ns (RG174)
peaking time fortp_tr~46 ns (tau=30ns)
Average[t_peak]=45.8398
rms[t_peak]=0.137095



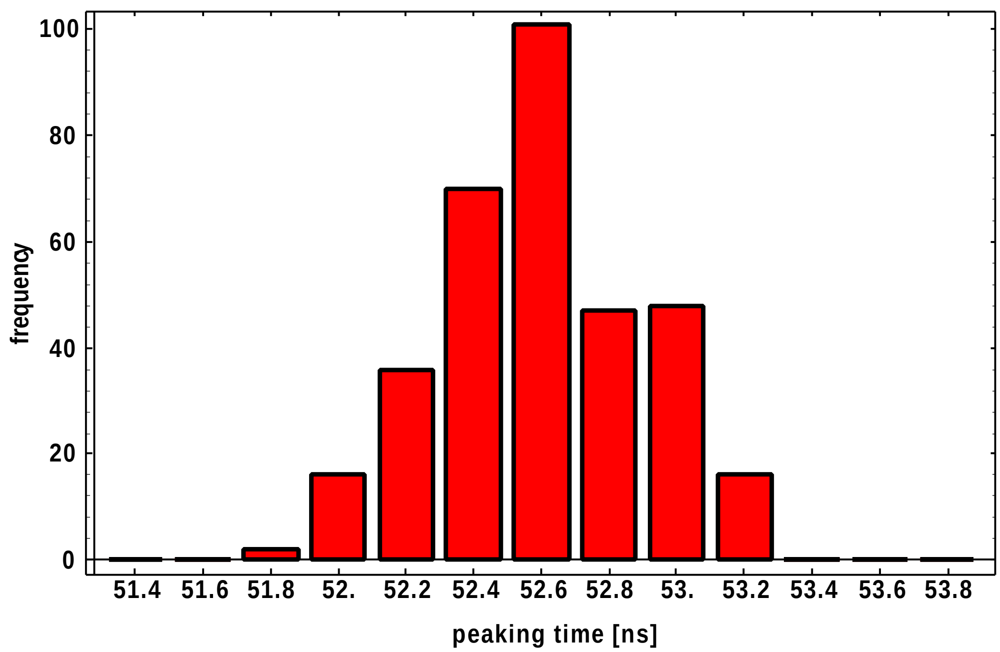
IO823 RP0T 50 ohm Io,max=1mA preamplifer C_det=330 pF+1_cable (RG174)
ENI[nA] (tau=30ns)
Average[ENI]=49.3458
rms[ENI]=0.538541



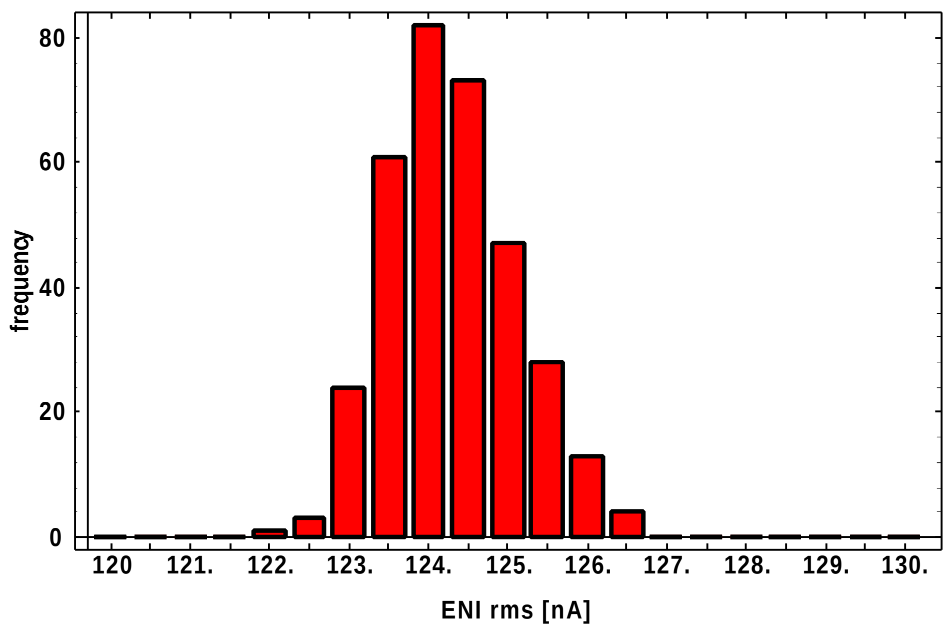
IO824 RP0T 25 ohm Io=5mApreamplifer C_det=1.5 nF td_line=19ns (2xRG174)
peak amplitude for tp_tr~51 ns (tau=30 ns)
Average[Vpk30]=612
rms[Vpk30]=3.29



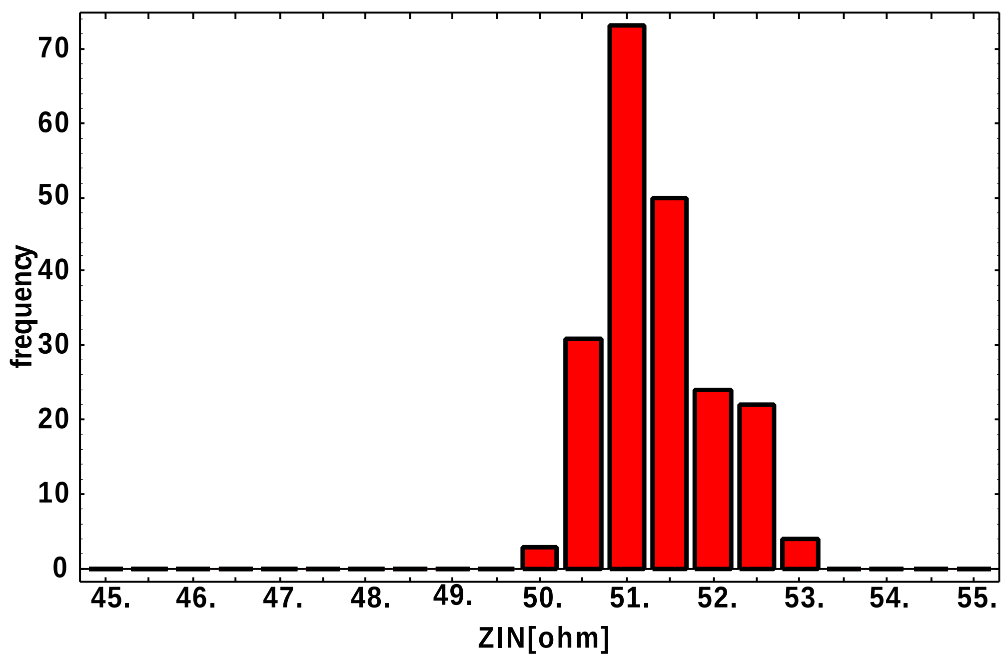
IO824 RP0T 25 ohm Io=5mA preamplifer C_det=1.5 nF td_line=19ns (2xRG174)
peaking time of tp_tr~52 ns (tau=30ns)
Average[Tpk]=52.6ns
rms=.3



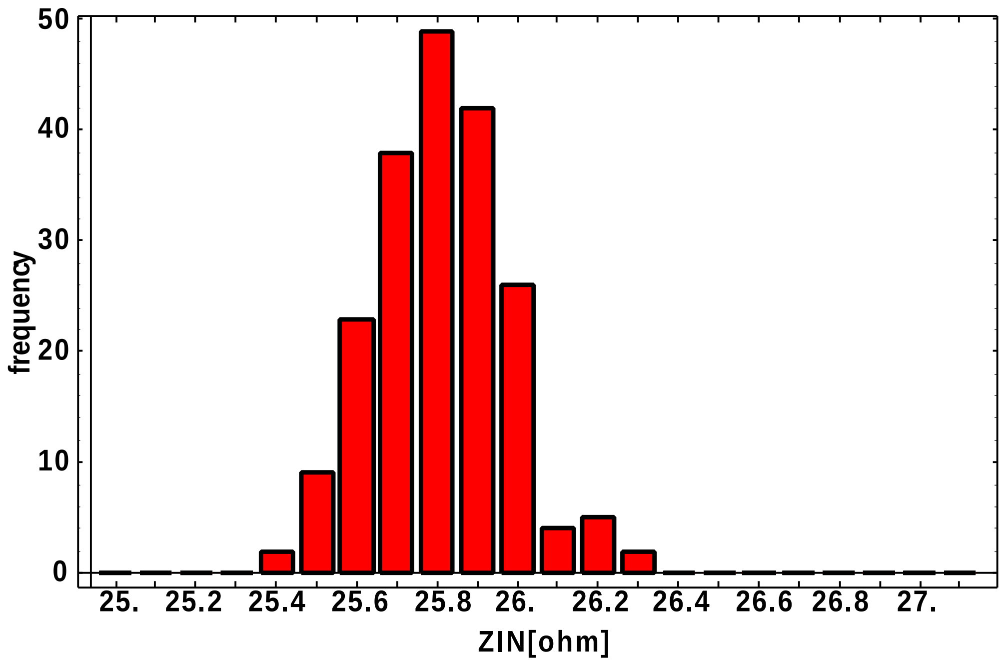
IO824 RP0T 25 ohm Io=5mA preamplifer C_det=1.5 nF t_d=19 nsec (2xRG174)
ENI[nA] (tau=30ns)
Average[ENI]=124.3
rms[ENI]=.8



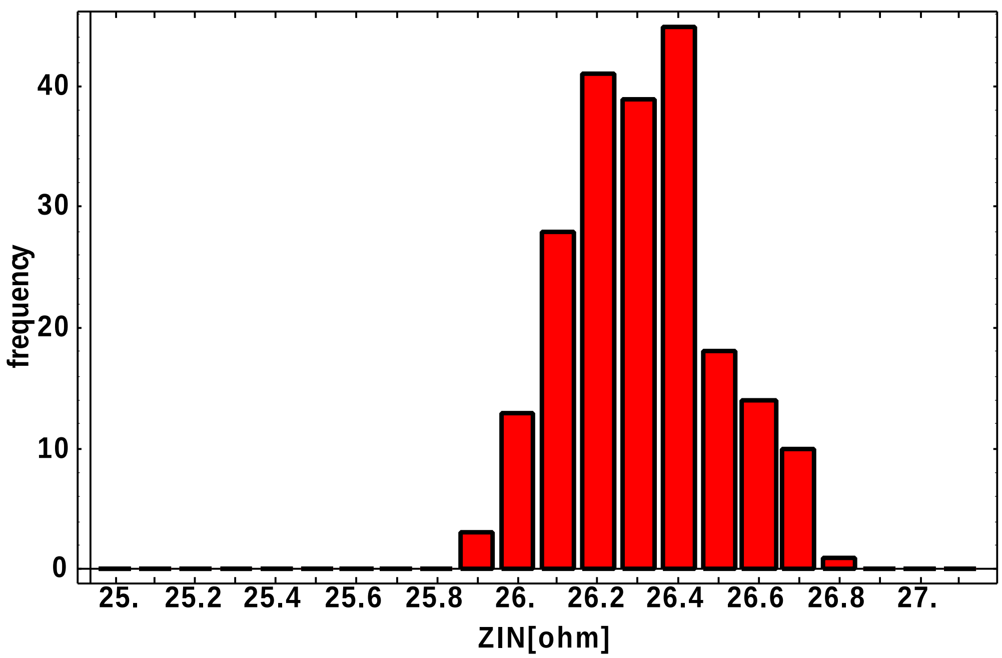
IO823 50ohm/1mA
Samples: 50 preamps (200) hsc
Average(Zin)=51.4ohm
rms(Zin)=0.6ohm
Tolerance(Zin)=+/-2.9%



IO824 25ohm/5mA
Average(Zin)=25.8ohm
rms(Zin)=0.17ohm
Spread(Zin)=+/-1.75%



IO826 25ohm/10mA
Average(Zin)=26.3ohm
rms(Zin)=0.19ohm
Spread(Zin)=+/-1.7%



4. Components

The components selected for the preamplifiers are commercial “components out of the shelf” or silk-screened resistors deposited by the fabricators during manufacturing.
The component list for the three different preamplifier types is reported. The list has been extracted by the design part list used at BNL for the production of the hybrids for the Mod0 test.

The component data sheets are included as appendix to this document with no special numbering in place. The component procurement strategy will be described in Section 7.

ATLAS HYBRIDS COMPONENT VALUES.

Resistors	IO823 (Type A)	IO824 (Type B)	IO826 (Type D)
R1	2K	2K	2K
R2	3.32K	1K	619 OHM (R2 IS A CHIP RESISTOR)
R3	30 OHM	30 OHM	30 OHM
R4	30 OHM	30 OHM	30 OHM
R5	100 OHM	100 OHM	100 OHM
R6	4K	4K	4K
R7	10 OHM	10 OHM	10 OHM
R8	200 OHM	200 OHM	200 OHM
R9	2.4 OHM	2.4 OHM	2.4 OHM (R9 IS A CHIP RESISTOR)
R10	33 OHM	33 OHM	33 OHM
R11	4K	4K	4K
R12	169 OHM	107 OHM	63.4 OHM (R12 IS A CHIP RESISTOR)
R13	30 OHM	30 OHM	30 OHM
R14	51 OHM	51 OHM	51 OHM
R15	100 OHM	100 OHM	100 OHM
R16	10 OHM	10 OHM	10 OHM
R17	1K	1K	1K
R18	51 OHM	51 OHM	51 OHM
R19	200 OHM	200 OHM	200 OHM

CAPACITORS:

C1	100 NF	100 NF	100 NF
C2	100 NF	100 NF	100 NF
C3	2 PF	2 PF	2 PF
C4	100 NF	100 NF	100 NF
C5	1.0 UF	1.0UF	1.0 UF
C6	1.0 UF	1.0 UF	1.0 UF
C7	22 PF	22 PF	22 PF
C8	1.0 UF	1.0 UF	1.0 UF

INDUCTORS:

L1	100 NH	47 NH	47 NH
L2	18 NH	8.2 NH	6.8 NH

TRANSISTORS:

Q1	NE856	NE856	NE856
Q2	NE856	NE856	NE856
Q3	NE856	NE856	NE856
Q4	BF660	BF660	BF660
Q5	NE856	NE856	NE856
Q6	BF660	BF660	BF660

DIODES:

D1	BAV99ZX	BAV99ZX	BAV99ZX
D2	BAV99ZX	BAV99ZX	BAV99ZX
D3	BAV70ZCT	BAV70ZCT	BAV70Z CT

ALL ABOVE COMPONENTS ARE 1 PER CHANNELS EXCEPT D3 WHICH IS 1 PER TWO CHANNELS.

CERAMIC SUBSTRATE

96% ALUMINA SUBSTRATE FOR THICK FILM FINISH ON TWO (2) SIDES.
EACH SUBSTRATE HAS 176 EACH VIA HOLES .010” DIA. +/- 0.002”.
THE BOARD OVERALL SIZE IS 2.580” x 3.600” x 0.040”
EACH SUBSTRATE HAS TO BE LASER SCRIBED AS INDICATED IN THE ATTACHED BNL DRAWING IO-804.

EDGE PIN CONNECTORS

P1-P20	DIP CONNECTORS	Die-Tech (LF-5104B-04-510)(*)

(*) The pin material must be Phosphor Bronze with selective or total Gold Plating for finish.

RESISTORS: 1 % tolerance

			Dimension	
R1	2K	1K PASTE	030/050	
R2	3.32K		(CHIP RESISTOR)	030/060(*)
	1K		(CHIP RESISTOR)	030/060(*)
	619 OHM		(CHIP RESISTOR)	030/060(*)
R3	30 OHM	10 OHM PASTE	025/060	
R4	30 OHM	10 OHM PASTE	025/060	
R5	100 OHM	100 OHM PASTE	040/030	
R6	4K	1K PASTE	030/095	
R7	10 OHM	10 OHM PASTE	040/030	
R8	200 OHM	100 OHM PASTE	025/040	
R9	2.4 OHM		(CHIP RESISTOR)	030/060(*)
R10	33 OHM	10 OHM PASTE	030/080	
R11	4K	1K PASTE	030/095	
R12	169 OHM		(CHIP RESISTOR)	030/060(*)
	107 OHM		(CHIP RESISTOR)	030/060(*)
	63.4 OHM		(CHIP RESISTOR)	030/060(*)
R13	30 OHM	10 OHM PASTE	025/060	
R14	51 OHM	10 OHM PASTE	025/100	
R15	100 OHM	100 OHM PASTE	040/030	
R16	10 OHM	10 OHM PASTE	040/030	
R17	1K	1K PASTE	040/030	
R18	51 OHM	10 OHM PASTE	025/100	

R19	200 OHM	100 OHM PASTE	025/040

(*) Manufacturer part numbers: Panasonic Precision resistors Series ERJ3EKFxxxxV
Where "xxxx" is the resistor value

CAPACITORS:

C1	100 NF	0603 SIZE	Johanson (250R14Y104ZV4T)
C2	100 NF	0603 SIZE	Johanson (250R14Y104ZV4T)
C3	2 PF	0603 SIZE	Johanson (250R14N2R0CV4T) +/- 0.25 pF
C4	100 NF	0603 SIZE	Johanson (250R14N2R0CV4T) +/- 0.25 pF
C5	1.0 UF	060/120 SIZE	Murata (GRM42-6Y5V105Z016AL) (*)
C6	1.0 UF	060/120 SIZE	Murata (GRM42-6Y5V105Z016AL) (*)
C7	22 PF	0603 SIZE	Johanson (250R14N220JV4) +/- 5%
C8	1.0 UF	060/120 SIZE	Murata (GRM42-6Y5V105Z016AL) (*)

(*) Equivalent component from other manufacturer: Nova Cap (1206Y105Z250NT)

INDUCTORS:

L1	100NH	0805 SIZE	Toko (LL2012-FR10J)
	47 NH	0805 SIZE	Toko (LL2012-F47N)
L2	18 NH	0805 SIZE	Toko (LL2012-F18K)
	8.2 NH	0805 SIZE	Toko (LL2012-F8N2)
	6.8 NH	0805 SIZE	Toko (LL2012-F6N8)

TRANSISTORS:

Q1	NE856	(SOT 323 SIZE)	Nec (NE85630-T1-R25)
Q2	NE856	(SOT 323 SIZE)	Nec (NE85630-T1-R25)
Q3	NE856	(SOT 323 SIZE)	Nec (NE85630-T1-R25)
Q4	BF660	(SOT 323 or 23 SIZE)	(Siemens, Temic) (*)
Q5	NE856	(SOT 323 SIZE)	Nec (NE85630-T1-R25)
Q6	BF660	(SOT 323 or 23 SIZE)	(Siemens, Temic) (*)

(*) Other transistors can replace them if necessary.
Possible alternatives are Siemens BF569 or Nec NE97833.

DIODES:

D1	BAV99ZX	(SOT 23 SIZE)	Zetex (BAV99ZXTR-ND)
D2	BAV99ZX	(SOT 23 SIZE)	Zetex (BAV99ZXTR-ND)
D3 (*)	BAV70ZCT	(SOT 23 SIZE)	Zetex (BAV70ZXTR-ND)

(*) Share 1 diode per 2 channels

5. Design Qualification

The hybrid preamplifier design has been tested and verified through the productions of prototypes and hybrids to equip Mod0. The information gathered during this preliminary phase would be used to optimize the final production.

5.2. Performances of prototype preamplifiers

5.1.1. First prototypes

In 1997 a prototype production of 200 hybrids of type A and B was conducted concurrently at BNL and Milan.
This preliminary series of hybrids has shown that the design and the technology adopted are able to meet the TDR requirements. A study of the statistical distribution of the circuit performances is summarized in Table 7. The measurements were taken after burn-in, on the BNL-produced hybrids.

TABLE 7.

	TDR requirements	Type A	Type B
Gain Uniformity	+/- 2 %	+/- 1.2 %	+/- 1.3 %
Peaking Time Uniformity	+/- 1 ns	+/- 0.4 ns	+/- 0.7 ns
Noise Uniformity	+/- 5 %	+/- 3 %	+/- 1.9 %
ENI(*) (typical)		50 nA	125 nA

(*) C_D = 400 pF, tp = 40 ns for Type A and C_D = 1500 pF, tp = 40 ns for Type B

Upon receiving, the hybrids were visually inspected, bar-coded for identification purposes and tested against a known template in a "Go No-Go" test. The criteria for rejecting a hybrid was based on the idea that a hybrid was considered acceptable if and only if all four channels were inside the template.
It is worthwhile to notice that NO TESTS were performed at the manufacturer prior to delivery. Such strategy was chosen to prevent fixes at the manufacturer and to understand possible problems related to component misplacement, etc.
After the inspection a yield of 96% was calculated. The units not in specifications were analyzed and was found that:

- one unit had a short between power supply and ground which was non detected during visual inspection,
- all other units had some components misplaced.

Those malfunctions were attributed to error in assembly.

5.1.2. Mod0 hybrids

In 1998 a production of 1600 hybrids of three hybrid types (A, B, D) was conducted concurrently at BNL and Milan. 1000 units were produced at BNL and 600 units were made in Milan. The hybrids will be used in the upcoming Mod0 test.

Inspection and measurements, similar to the one performed in the 1997 pre-production, were repeated on this new batch of preamplifiers. The results obtained on these hybrids confirmed the yield, uniformity distribution, performances and noise obtained on the first prototypes. These results were presented in November 1998 during a LAr week.

More research about possible assembly problems was also performed. In particular during visual inspection was noticed that some of the hybrid power pins (the four pins on the longest side of the hybrid) could be source of failure. Some of them were indeed not centered into the pad and they looked to be soldered to an angle in respect to the ceramic substrate.
Subjected to repetitive mechanical stress some of the pins lost contact with the substrate.
These pins are the last components to be assembled and need to be hand-soldered in place.
The input/output pins on the contrary are assembled through "dipping and flowing" in one step operation.
The pin assembly is the less automated part of the assembly and will require a very stringent inspection even in the final production.

5.3. Burn-in studies and results

The first series of hybrid produced (200 units) after being tested for electrical functionality was subjected to 168 hours of an environmental stress screening (or burn-in) at ambient temperature to identify and eliminate deficiencies and early failures. Moreover few hybrids (4 units, two each of type A and B) were also fully characterized in term of gain, peaking time and noise before and after burn-in to detect any possible variation of performances due to aging effects.

At the conclusion of the burn-in only one channel failed to meet specification.
The unit failed because a PNP transistor (Q4) in the white follower broke during burn-in. After replacing the transistor the channel was tested again and it met specification.
The hybrids that were fully characterized before burn-in did not show any performance variation due to the environmental stress.

The burn-in results brought to the conclusion that the environmental conditions adopted for the test were not sufficient to rule out all the early failure mechanisms.

A more extensive burn-in study was indeed adopted for the batch of hybrids produced for Mod0. Those tests were performed on the units manufactured at BNL, the result obtained are summarized in Table8.

TABLE 8.

Number of hybrids	Temperature	Hours	Failures
676	Room temperature ~ 27 C	168	2 (*)
24	Room temperature ~ 27 C	432	0
252	Elevated temperature ~ 70 C	168	1 (**)
48	Elevated temperature ~ 70 C	432	0

Explanation of failure: (*) on two different units, two transistor pins developed open. After re-soldering, the units were still funct ioning.

(**) One channel developed a short across an input diode through solder migration. After removing the excessive paste the channel was still functioning.

The combination of elevated temperature and/or extended time did not increase the number of failures. The performed study brings to conclude that the infant mortality of this product is extremely low and can not be easily estimated from burn-in.

Other hybrids designed and manufactured in large number at BNL in the past which have used a similar thick film technology have been proved to be extremely reliable on the field. The typical source of failures in these hybrids was almost exclusively a "cold solder joint".
Under the assumption that the same failure mechanism dominates even in the ATLAS hybrids, it could be concluded that a burn-in of 168 hours at an elevated temperature of 70-80 C, is enough to eliminate all causes of infant mortality.

A higher burn-in temperature/shorter time is not achievable because some of the components used in the preamplifiers are not rated for temperatures higher than 100 C, namely the inductors.

5.4. Reliability evaluation

The reliability of the hybrids has been evaluated based on the internationally recognized method of calculating electronic equipment reliability given in "Military Handbook MIL-HDBK-217" (published by the US Department of Defense).

This standard uses a series of models for various categories of electronic components to predict failure rates that are affected by environmental conditions, quality levels, stress conditions and various other parameters. These models are fully detailed in MIL-HDBK-217.

Most the models in MIL-HDBK-217 use some ten or more parameters for the calculation of the component failure rate. Commercially available programs, such as "Milstress" from ITEM software have been written to facilitate the calculation of failure rates. The calculation was performed using the Milstress software package.

The TDR specification for channel failure rate is "0.5 missing channel per year" or "868 missing channel per year".
If the worse case condition is taken, i.e. one channel missing means a full hybrid missing, the maximum tolerable failure rate per hybrid is "217 missing hybrid per year" or 0.57 frmh (where frmh stands for failure per million hours of operation) or $1.75\ 10^{6}$ hours MTBF.

The technology/component/design adopted for the hybrids has to be evaluated against this benchmark.

The reliability prediction presented in this section is for guidance only and shall not be cited as a requirement for the manufacturer. The purpose of this calculation is to establish, by means of a consistent and uniform method, the reliability of what has to be considered a "mature design".

The calculation is based on the two methods known as "Part Count" and "Part Stress Analysis" and the following assumptions have been made:

- Most of the details used in the project are known, in term of material and components
- In a hybrid package, resistors and inductors are considered to contribute insignificantly to the overall hybrid failure rate and for this reason are assumed to have a failure rate of zero
- The hybrid temperature has been assumed to be know and equal to 35 degree centigrade.
- The power dissipation of each hybrid component has been estimated from an actual hybrid sample and from design analysis. It has been compared

with the maximum power from the component data sheet to obtain the "stress factor" for each individual hybrid component. The stress factor has been always rounded up to the second figure.

- The hybrid quality has been chosen equal to "class B microelectronic" as defined in Mil883-C screening procedure method 5004.9
- The quality of the individual component used for the manufacturing has been set to "industrial grade, RE"
- The environment has been set to "ground benign"

Based on this information a failure rate of 0.48 frmh has been calculated. This result shows that the solution adopted has a predicted reliability similar to the one requested by ATLAS TDR.

Figure 4 shows the significant component failure rates for one hybrid. The transistor Q5 (the NPN NE856) transistor used in the white follower is the single largest contributor to the hybrid failure rate.

The failure rate is temperature dependent as shown in Table 9.

TABLE 9.

Temperature (degree centigrade)	FRMH
20	0.44
30	0.48
40	0.59
50	0.70
60	0.76
70	0.93

Moreover the contribution to the failure which is related to the edge pins is estimate to be less than 0.002 frmh.

The previous calculation is also dependent by the parameter chosen for the environment and for the microelectronic quality. It has also been proved that the reliabilities calculated with this methodology have to be considered the absolute WORSE CASE.

Other high-energy-physics experiments, for example D0, have used a similar tool to estimate reliability for various components of the experiment and have concluded that the results obtained in the field were better than the estimated values.

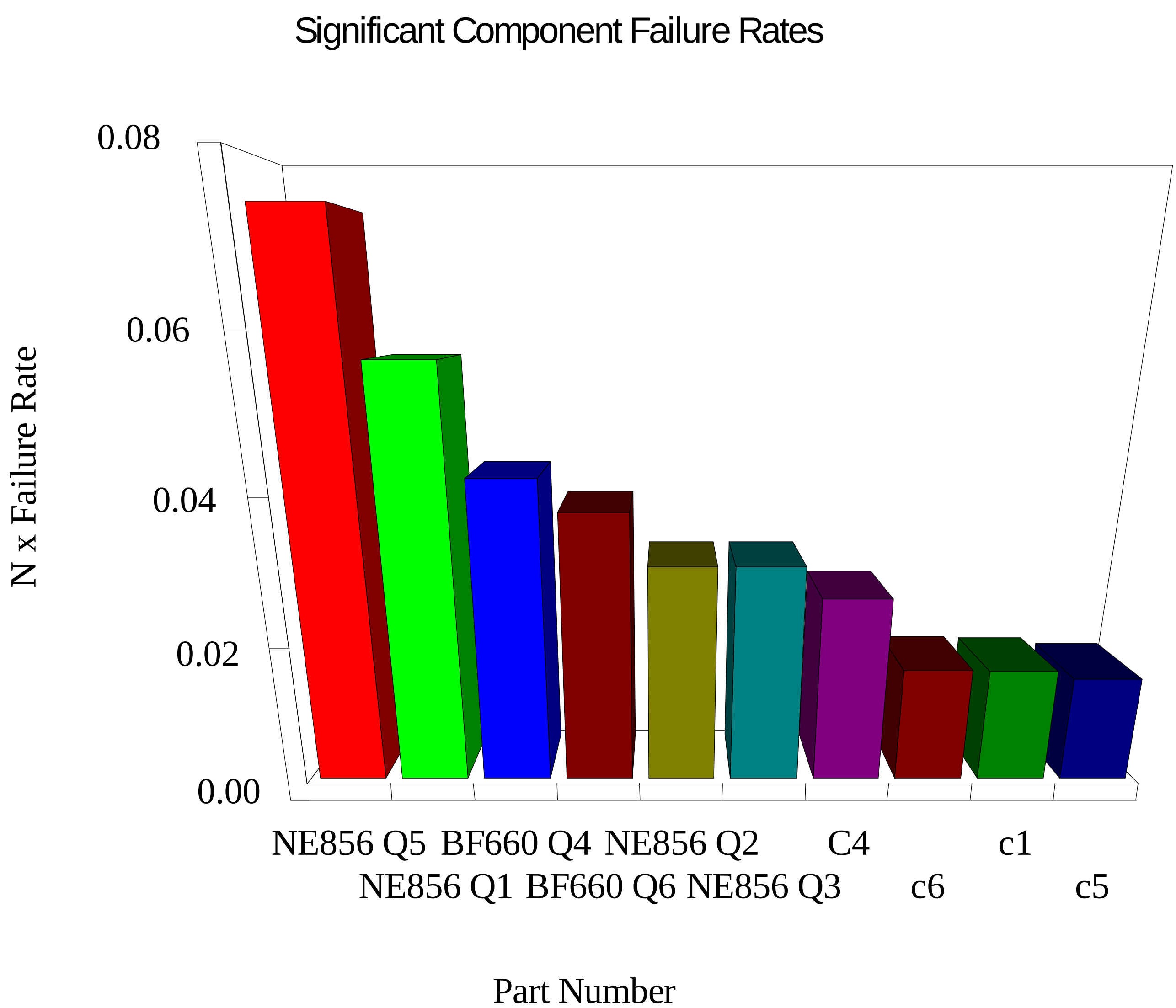


Figure 4. Failure rate results

5.5. Highly accelerated life tests

As an aid in testing the reliability and design limits of the ATLAS preamplifier design a Highly Accelerated Life Test (HALT) of a selected group of preamplifiers was performed at a Qualmark Corporation facility in Marlborough, Massachusetts. The purpose of this testing process is to induce failure in the tested product(s) in a nondestructive way so as to expose weaknesses in design or manufacture. This information then can be used to improve the devices and to select the manufacturing processes used in producing the devices.

5.5.1. Test Setup

The environmentally controlled chamber at the Qualmark facility resembles a large insulated stainless steel box containing a large flat “table.” Viewing windows permit visual inspection of the interior during the test. The table can be vibrated by simultaneous triaxial shakers in a frequency range of 0 to 2 kHz.

Twelve preamplifiers, six IO823 (50Ω/1mA) and six IO824 (25Ω/5mA) were selected. The preamplifiers were mounted on a board with power and signal input/output lines so that the response could be monitored during the test. The board with the mounted preamplifiers was tightly clamped to the table and at selected positions on the board thermocouples and, when appropriate, accelerometers were mounted to measure temperature and acceleration uniformity. All signal and power lines were passed out of the chamber to monitoring equipment.

5.5.2. Testing Procedure

The testing process is divided into 3 stages. The initial stage consists of varying the temperature of the preamplifiers, first gradually and then in rapid temperature cycling. The second stage involves accelerating the preamplifiers at a fixed temperature (30 °C) starting at 5 Grms (Gravities root mean square) and increasing the acceleration in steps of 5 Grms up to a maximum of 50 Grms. In the final stage, both acceleration and rapid thermal cycling are combined.

5.5.2.1. Stage 1

The board/devices are gradually cooled from room temperature to –100 °C in steps of 10 °C. After each step the temperature was maintained to let the preamplifiers thermally stabilize and to allow time to check the preamplifier response. After reaching –100 °C the preamplifiers were gradually returned to room temperature and the same process was repeated going from room temperature to 100 °C. Again, the devices were returned to room temperature. At this point the preamplifiers were rapidly cycled (heating rate was about 1 °C/sec) back and forth from –100 °C to +100 °C for 5 complete cycles. At each temperature extreme the temperature was maintained for about 10 minutes to achieve thermal stability and test the preamplifier response. No preamplifier failures occurred.

5.5.2.2. Stage 2

At 30 °C the devices were accelerated from 5 Grms to 50 Grms in steps of 5Grms. No preamplifier failures occurred.

5.5.2.3. Stage 3

The preamplifiers were rapidly cooled to –100 °C, subjected to 10 Grms, and then held for 10 minutes to test response of the preamplifiers and reach thermal stability. The temperature was rapidly cycled to +100 °C while maintaining the 10 Grms acceleration. The temperature was held for about 10 minutes (again to measure etc.) and then the devices were rapidly cooled to –100 °C. The acceleration was increased to 20 Grms, this state was held for 10 minutes and then the system was rapidly heated to 100 °C. This process continued until the devices were subjected to 50 Grms while being cycled between the temperature extremes. At a condition of –100 °C and 50 Grms all four channels of one hybrid became intermittent. This was the only significant preamplifier failure observed in the test.

The failure was caused by the failure of the +3 Volt power pin. The edge pin solder joint broke due to the "fatigue" accumulated in the test.
At the conclusion of the test the pin was replaced and the hybrid was found working in specifications.

This failure confirms, as already explained in section 5.1.2, the need of "high quality" workmanship in the pin assembly.

5.6. Radiation tolerance

5.6.1. Gamma Radiation Effects

Expected gamma doses over the life of the preamplifiers is estimated to be approximately 2 x 10^4 rad silicon. It is expected that the total possible dose would be no more than 5 x this number or 10^5 rad. Two hybrid preamplifiers under power were exposed to a total of 10^5 rad. One was part number IO823, a 50Ω impedance device and the other was an IO824, a 25Ω impedance device. Both hybrids were measured for gain, peaking time, ENI, and input impedance before irradiation and after total doses of 5 x 10^4 and 10^5 rad of ^{60}Co gamma radiation. Gain, peaking time, and ENI changed by less than the measuring error for both hybrids after 10^5 rad. Average input impedance (of 4 channels) at selected doses for the two devices is shown in Table 9.

TABLE 9. Input Impedance versus gamma dose

	unirradiated	5 x 10^4 rad ^{60}Co	10^5 rad ^{60}Co
IO823	51.3 Ω	50.1 Ω (2.3% change)	48.8 Ω (4.9% change)
IO824	25.4 Ω	25.3 Ω (0.4% change)	25.2 Ω (0.8% change)

5.6.2. Neutron Radiation Effects

Preamplifier hybrids were irradiated with fast neutrons at the SARA facility (Grenoble). G. Battistoni et al reports the results of this in the ATLAS internal Note LARG-NO-083. Here are reported only the conclusions of this note.

- There is no noise degradation of the NEC856 (NPN) transistors till a fluence of 5 x 10^{13} n/cm^2.
- The degradation of the forward-gain β follows the Messenger-Sprat relation and, at first order, is inversely proportional to f_T.
- The impact of the β degradation of transistors on the preamplifier gain is very small. The 25Ω hybrid preamplifier exhibits about 3% of gain loss after 1.1 x 10^{14} n/cm^2, while the 50Ω preamplifier, has about 7% gain loss after the same fluence.

- The measurement of input impedance of all irradiated preamplifiers indicated that there is no stability problem with irradiation. All of them have positive real part of input impedance in a frequency range 1-200 MHz.

6. Quality Assurance

The general guidelines on electronics quality assurance that the ATLAS experiment has decided to adopt are contained in the TDR (Sec. 10, 453-454). In those paragraphs, the warm preamplifiers have been taken as a case study. The quality assurance procedure reflects those guidelines.

6.1. Tests at the manufacturer

The first level of quality control will be performed at the manufacturer level.
The manufacturer will be required at least to perform a "Go No-Go" test after completing the assembly to verify that the units are working. Only the units that passed this electrical test will be delivered. BNL and Milan will supply the respective manufacturer with a test unit to be used for this purpose. The test unit must use a "zero insertion force" socket to avoid any damage during handling of the hybrids. The "Go No-Go" test will consist in comparing a pre-determined output signal against a good know template for each single channel of the hybrid under test.

6.2. Incoming Inspection

Each hybrid circuit is visually inspected when received from the manufacturer to check for conformity to design and process specifications (manufacturing deficiencies, work omissions, etc.), quality standards (concealed damage, improper workmanship, etc.) or any other condition which will indicate departure from the product requirements or adversely affect reliability. The units considered "non-acceptable" will be kept on hold to await evaluation for further disposition. Records of the discrepancies from the specifications will be retained for corrective actions and to prevent recurrences.

6.3. Bar-coding

The accepted units shall have evidence of the inspection status prior to engagement into the next qualification stage. Each hybrid will be identified through a bar-code label attached to the substrata. A database will be established for each hybrid. The records will contain information including the unit type, the date of manufacture, lot number and any other pertinent information.

6.4. Burn-in procedure

Prior to the burn-in procedure a fraction of the hybrids will be characterized using the same acceptance test procedures described in the next section. This will detect any significant changes in preamplifier properties induced by the burn-in procedure. Based on the information collected from the prototype and Mod0 phase, the burn-in process will last for 168 hour at 80 degree centigrade in custom designed burn-in cards. Zero insertion force cards must be used to minimize stress to the hybrid pins during handling operations.
Due to different procurement strategy between Milan and BNL, as explained in Section 7, the hybrids produced under BNL responsibility will be burnt-in at BNL, while the hybrid produced in Italy will be burnt-in at the manufacturer facility.

6.5. Acceptance Test Equipment and Procedures

6.5.1. Hybrids produced by BNL

The design requirements, as stated in the Technical Design Report, require that ALL preamplifiers must to be tested for gain, linearity, peaking time after standard shaping, and

noise characteristics and the results compared against the design specifications. This will be accomplished using a specially designed automatic test station.
On arrival from the manufacturer, each preamplifier will be uniquely identified with a bar-code label. All test data on a specific preamplifier will have this identifier as part of the data file. Before the acceptance tests the preamplifiers are taken through visual inspection and burn-in procedures as described in the previous sections. This is followed by a final acceptance test where each preamplifier channel is tested for gain, peaking time, linearity, and noise after standard shaping. The following specifications are used for each tested parameter.

Gain uniformity	±2%
Peaking Time Uniformity	±1 ns
Noise Uniformity	± 5 %
Linearity	± 1.5%

A selected group of preamplifiers (at least 400 channels) will be carefully measured to determine an average value for each of the parameters above.

6.5.1.1. Description of Test Station

Figure 5 shows a functional block diagram of the acceptance test station. All of the measurements are made using a semi-automatic computer controlled system. There are two major sections of the test station. One major section is a crate containing power supplies, a standard injection network, a relay board to distribute the test signal, a socket board to mount the preamplifiers under test, and a back-plane in which to mount the relay and socket boards. The other major section of the test station consists of a Dell controlling computer, pulse generator (BNL produced), shaper (L.A.L Orsay), track and hold (BNL), and a Tektronix TDS 540 oscilloscope. All the software used in control and data acquisition is written in LABVIEW. All communication from the computer to the instrumentation uses either a GPIB interface or a DAC/ADC card.

The signal path starts with the pulse generator sending a standard pulse through a standard injection network. This generates a current pulse of the same exponential shape (τ= 400 ns) used in the calorimeter calibration. This signal is directed into the relay board and on to one selected preamplifier channel. It then goes back through the relay board and out to a CR-RC^2 shaper. To avoid saturating the shaper the signal is reduced by a relay controlled 40 dB attenuator for the gain, peaking time, and linearity measurements. This attenuator is not used for noise measurements. After being shaped the signal then passes through another relay which directs the signal either to a track and hold module (for linearity measurements) or Tektronix oscilloscope (for gain, peaking time and noise measurements).

Two different injection networks are used which differ primarily in the simulated detector capacitance C_D. For a 25 ohm impedance preamplifier the value of C_D = 1.5 nF is used while for a 50 ohm device the value is C_D = 330 pF. For impedance matching the relay and socket boards are produced in both 25 ohm and 50 ohm impedance versions.

At the present time all hardware and software for the test station have been completed with the exception of the relay and socket boards. The relay board has passed through a first generation design and testing. Currently, a prototype second-generation four-channel relay board has been completed and is being tested. The full size second-generation relay board is in the design phase and will be completed by the end of fiscal year 1999.

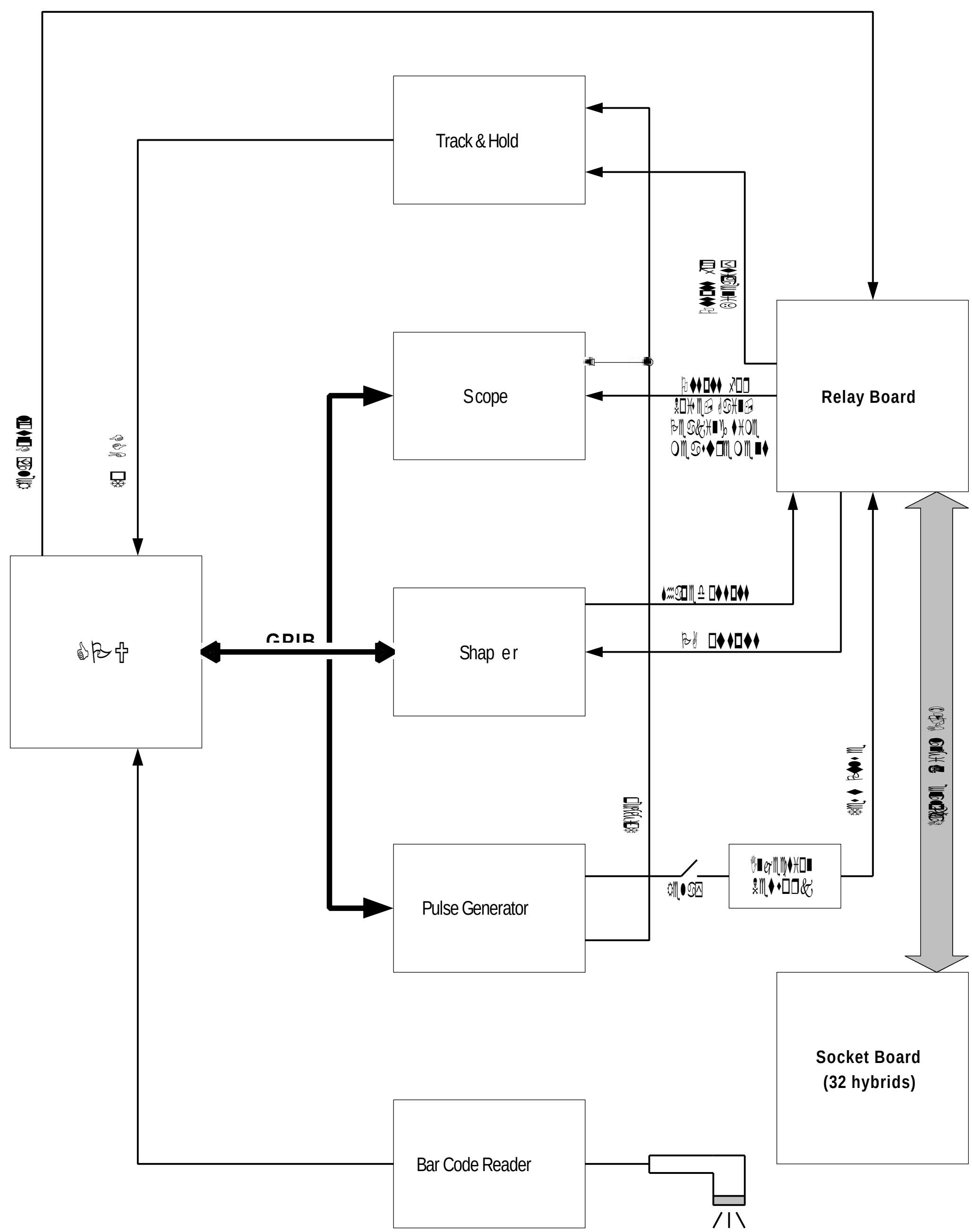


Figure 5. Automatic Test Station

6.5.1.2. Testing Schedule

The hybrids will be kept on the same socket board through the entire burn-in and acceptance test procedures. The burn-in procedure takes approximately 1 week. Assuming that the acceptance tests will take place in an 18-month period and that there are a total of 25,000 hybrids, this will require measuring at least 400 hybrids/week (assuming a 40-week work year including downtime). Allowing for enough extra testing capacity to assure completion, the design testing capacity should be about 500 hybrids per week. This requires 32 socket boards (sixteen 50 ohm impedance and sixteen 25 ohm impedance) for both burn-in and acceptance tests. The throughput rate of the acceptance test station is approximately 1 board every 2 hours or 20 boards in a 40-hour week for a total of 640 hybrids.

6.5.1.3. Testing Procedure

After visual inspection, each preamplifier is mounted on a socket board. Each socket board holds a group of 32 hybrid packages each with four channels. A filled socket board will be mounted in the test assembly. After entering identification information for the hybrids the test is started and no further attention is needed until the end of the test. At this point the measured socket board is removed from the test station, another socket board is inserted and the process repeats. The following techniques are used for each parameter.

6.5.1.3.1 Gain and Peaking Time

The parameters measured and stored in the database are the amplitude of the shaped signal obtained from a standard injection pulse and the peaking time defined as the time taken to go from 5% to 100% of the amplitude. The shaped signal is averaged on the TDS 540 oscilloscope at least 100 times and then transferred to the computer. A baseline is established by fitting a horizontal line to the portion of the average waveform preceding the shaped peak. A fourth order polynomial is fit to the 100 points around the peak of the waveform. This fit is used in determining the absolute amplitude and time position of the peak. The amplitude of the signal is then defined as the absolute amplitude minus the baseline value. The time of the 5% amplitude point is obtained simply by doing a linear interpolation between the times of the data points bracketing the 5% amplitude value. Based on measuring the same preamplifier channel multiple times the amplitude and peaking time can be measured with an error of less than $\pm$0.25% and $\pm$0.1 ns respectively.

6.5.1.3.2 Equivalent Noise Current

The ENI is measured using the same setup used in determining the gain with two differences. First, the pulser is disconnected from the input (using a relay) and second, the 40 dB attenuator is bypassed. When measured this way the noise from the preamplifier clearly dominates any contributions from the shaper, cable pickup, etc… Therefore, the primary noise is assumed to arise in the preamplifier. At least five oscilloscope waveforms are imported into the computer and used to construct a noise distribution. The rms noise voltage is determined from this distribution and with the previously determined amplitude the ENI is computed.

6.5.1.3.3 Linearity

The test station includes a module with an 8 bit DAC and an 8 bit ADC, which can be used to test the linearity of the preamplifiers. At least 3 points representing the range of the preamplifier are measured and fitted with a line to determine the slope, intercept and others desired parameters of the preamplifier response. This test uses the same modules as gain except that the amplitude of the pulse from the pulse generator is set by the DAC in the computer and the output from the preamplifier is directed to a track and hold rather than an oscilloscope. An ADC in the computer then digitizes the output from the track and hold.

6.5.1.4. Data

At a minimum the computer will store the hybrid bar code, and for each channel of a hybrid will store the gain, peaking time, ENI (or equivalent information) for at least the standard shaping time (τ = 30 ns which gives a peaking time of about 45 ns). Also, the linearity data for all measured points along with the fitted slope and intercept information is retained for each channel. This information is then sent to a database computer system described in the next section.

6.6. Database logging and retrieval procedures

A characterization of the preamplifiers before and after burn-in process described earlier is necessary to successfully complete the production of the hybrid circuits. The goal is to detect failures either in the assembling procedure or in the performances of the devices and/or components mounted on the ceramic substrate. This is vital, considering that the hybrids will be mounted on the Front-End-Boards where problems will be much harder to solve. Therefore it is necessary to perform extensive tests on the preamplifiers and retain the results of the testing in a production database.

The adopted procedure will fulfill a threefold purpose:

1) Track the production in any step of the testing process.
2) Define a standard strategy for all the items that BNL produces.
3) Allow other members of the collaboration to access BNL data to help them troubleshoot problems in their systems after the hybrids have been installed.

6.6.1. Requirements

6.6.1.1. Information to be stored

The information that will store in a database has been defined in previous sections. The minimum information stored will be records with supporting data demonstrating that each preamplifier was visually inspected, taken through the burn-in procedure and finally processed through the acceptance testing. One clear problem is tracking all the hybrids produced by BNL (30000 hybrids including spares and wastage) during each step of the validation tests. A solution to this is to label each hybrid with a unique identifier (barcode). This barcode will be used to trace the hybrid through each production step and label the test results in the database

6.6.1.2. Database requirements

6.6.1.2.1 Database access

A medium-sized database (about 50-60 MB) can contain all the information for the 30K hybrid produced by BNL. Main requirements are fast processing, robustness, expandability, portability, controlled and limited access. Fast processing and robustness is a general requirement that guarantee stability and a prompt reply after a user request. The test-station where the preamplifiers will be characterized will be in full operation for at least 2 years, so the system where the information will be stored has to be secure and stable. Paralleling some of the tests implies the necessity of having a system that allows multiple connections and a fast processing of the data. Expandability is necessary in case additional information has to be stored. The database must allow the user to update a table structure in an easy way (i.e. add new columns to a table). Portability is required to easily migrate to another server or another platform if the case requires it. Access has to be controlled and limited for different users and privileges. The database will allow some users to perform some operations (e.g. update or create new tables) while some others will be granted only to have a read access.

6.6.1.2.2. Data storage

The data have to be stored in a multi-level structured system. Different tables for different hybrid categories will contain a minimal set of information. This will allow faster access and shorter query processing times. A periodical backup of the database is necessary. A full backup of the database will be automatically performed on a magnetic tape. Also to keep full track of the tests the files with the raw data will be saved and stored in the database.

6.6.1.2.3. API and development

The database (DB) data will have to be accessed by a generic user with as many tools as possible. In particular the user has to be able to access the data through different programming languages on different platforms. The possibility of sending query and retrieving data through the Web may be also an advantage.

6.6.2. System Description

6.4.2.1. Database Choice

Based on the scope of the DB and the characteristics of the RDBMS databases have been preferred to OODBMS. They are solid, stable, well supported and for the dimensions considered fast enough.
After considering various available databases, in particular Oracle, MS Access, SyBase, miniSQL, the choice was made for MySQL, an SQL server by T.C.X DataKonsult AB BOX 6434 Stochkolm (SW).

6.4.2.1.1. What is MySQL?

MySQL is a true multi-user, multi-threaded SQL database server. It consists of a daemon (i.e. mysqld) and many different client programs and libraries. It is built as a set of routines that have been used in a highly demanding production environment for years; it is freely available for many Unix versions and is well supported and quite diffused, despite common opinion on freeware or shareable software.

6.6.2.1.2. MySQL features

The following list includes some MySQL features (see http://www.mysql.com and relative links for more details):

- It is fully multi-threaded using kernel threads and multi-user (i.e. many users can access and query the database at the same time)
- C, C++, Java, Perl, Python, TCL API clients are available.
- Libraries are provided for software development.
- Web interfaces through Perl drivers are also available.
- Many UNIX OS's are supported. These include Solaris 2.5,2.6,2.7 (with native threads on both sparc a x86 processors), SunOS 4.x and BSDI 2.x with MIT

threads, SGI IRIX 6.x, AIX 4.x, DEC UNIX 4.x, Linux 2.0+, FreeBSD, SCO, HP-UX 10.20, Win95 (NT) and OS/2.
- Many column types in tables: signed/unsigned integers 1,2,3,4,8 bytes long, float, double, char, text, blob, date, datetime, timestamp and many others types are included.
- Fast joins operations between tables.
- Fully ANSI SQL support in the SELECT and WHERE parts of queries
- Full support for SQL statements GROUP BY and ORDER BY.
- Mix of tables from different databases in the same query is allowed.
- ODBC for Windows 95 is available
- A privilege and password system, which is very flexible and secure with host, based verification. Password Encryption is done at the client site before connection to the server.
- 16 indexes per table are allowed.
- Variable and/or fixed length records are allowed.
- Fast thread-based memory allocation system.
- No memory leaks.
- Data saved and support for ISO-8859-1 Latin1 character set
- Clients connect to the MySQL server using a TCP/IP connection (Unix socket).

6.6.2.1.3. Why MySQL?

MySQL has been chosen for its performances, support and diffusion in large production environments and finally for its cost. The Web page http://www.mysql.com/info.html contains many links to benchmark tests and comparison of MySQL performances against other RDBMS databases for different systems.

6.6.2.2. Database Structure and Organization

The MySQL server will run on a dedicated Linux Box. The Linux Box will act also as a firewall to protect from external hacking.

6.6.2.2.1. Raw data handling.

The test station (Windows NT as OS) will take data through LabView (see Sect. 6.3). The raw data files will be saved on a local disk. A copy will be also saved on a public area available on the server where the MySQL daemon runs. This is made on purpose to have automatically a backup of the original data and to make the raw data available to generic users for checking purposes. This solution has been already implemented on our setup through the Samba protocol. The remote disk on the firewall is therefore seen as a local disk on the Windows client.

6.6.2.2.2. Database Organization

The database will be organized in a set of independent tables with indexes linking each other. Two main tables contain the measurement data.

6.6.2.2.2.1. INFO table

An INFO table will summarizes the history of the tests done on the hybrid. It is 1 table only for all the hybrids. These fields will specify the hybrid ID, the lot number, the bar-code string, the hybrid type, the manufacture date, the result of the visual inspection, the test operator, the date the inspection, the start and the end date of the burn-in, the date and the operator of the electrical test before and after the burn-in. The table includes also the delivery (shipment) date for mounting on the FEB and a link to an optional history file for more details on the hybrid itself.

6.6.2.2.2.2. DATA table

Three separate DATA tables (one per hybrid type) will contain all the necessary information on the electrical characteristics. The tables have been kept separate in order to speed-up the query process. The solution of a single table it's less functional because 50k hybrids would imply 450k entries in the table (~25MB). The fields of the table will include the preamplifier and lot IDs; the channel tested, the shaping time of the main amplifier used, the current injected. The measurements stored in the next seven fields are: the peaking time and the amplitude of the signal before the burn-in, the peaking time, the amplitude, the noise (as voltage RMS of the mean value of the baseline distribution and the noise calculated as ENI measured after the burn-in. A "Quality" Factor (QF) is also included in the table. The QF will give an indirect information on the linearity of the system on the full dynamical range of the preamplifier (see Sect. 6.5.1.3.3). Finally, two indexes are included to link to an array of measurement value corrections to compare the results obtained between different preamplifiers with the reference sample.

6.6.2.2.2.3. Support tables

A series of additional tables are inserted into the database with the aim to support the data stored and for seeking of completeness of the information. These tables are:
- LOT table which summarize the statistical information on the hybrids belonging to a particular lot (number of failures in the different test steps, number of hybrids delivered, no. of hybrids returned to BNL for subsequent failures...)
- AddDATA table. It's an optional table for inserting measurements of linearity if the case will require it. The table will include the gain, the integral and differential non linearity of the preamplifier, the number of points for the linearity measurements and the
- IDC table. A table with the DC currents monitored (each hybrid) during the tests (optional)
- RawFile table. A table to provide a link to the rawdata file
- CALibration CONstant table. It's a table mapping the corrections to apply to the data to take into account the test board and the position on the test board where the measurements have been performed.

6.6.3. Status and Development

A prototype version of the database system has been created. This includes the MySQL server, running on a Linux firewall, and the Windows client, which access the database and store the data on it.

6.6.3.1 Prototype Database

A prototype database with a fake DATA table has been generated.
The table included 10k preamplifier whose parameters have been simulated with a gaussian random generator. The goal was to test the speed of the system, its robustness, stability and some client program purposely developed.

6.6.3.2. LabView VI Interface

Some VI's have been developed in order to interface the LabView programs which actually make the measurements to the DB system The VI's use LabView drivers developed at BNL and based on MicroSoft Visual C++ 6.0 code. The drivers implement most of the SQL query to the DB (insert, retrieve, delete and create tables) The software is functional (alpha release) but still under test.

6.6.3.3. Web Interface

One of MySQL feature is the possibility to interface to the DBI-mySQL and to the DBD Perl drivers. This allows building applications to retrieve data from the DB through any Web browser. An Apache version 3.4 has been installed on the Linux firewall as web server. The application allows retrieving the data from the prototype database and displays the distribution of the measurement "on the fly" on the browser through the PGPLOT library and its associate Perl driver.

6.4.6.4. C++ sample program

A freeware C++ library allows any user to connect a remote MySQL server through a simple code.
The library is organized in such a way a simple class handles the access to the database, the query to be sent and the data retrieval. The library has been installed on our local workstations and tested. A simple C++ example program is available.

7. Procurement

The procurement strategy described in this section, apply to the hybrids that will be produced at BNL. The Milan procurement is described in a separate document.

7.1. Component acquisition

BNL will buy all components necessary for the production of the hybrid needed for the ATLAS experiment through qualified distributors. The component/material list is included in section 4.
Milan and BNL agreed that the presented component list has to be used for both production runs.
No components can be substituted without approval of both parties and CERN responsible personnel.

7.1.1. Component qualification

The components will be "out of the shelf" components. At the time of purchase, they will be inspected for quality and against manufacturer data sheet. The orders for each individual component will not necessary request that the components have a common batch identifier. However the batch identifier for each individual shipment may be requested for record keeping and for identification of malfunctioning.

7.1.2. Component storage

The components will be stored at BNL in dedicated containers for surface mount components. The storage containers must be at least "dry cabinets" with a monitoring of temperature and humidity.
All the components will be delivered to the hybrid manufacturer for production at the proper time.

7.2. Alumina substrate

BNL will purchase the alumina substrates necessary for the hybrid production through a qualified manufacturer. The substrate specification, the "via hole" positions and number as well as the laser scribing instruction will be contained in BNL drawing given to the manufacturer at the time of the order. Alumina backup plates will also be ordered.

All material will be qualified and stored as explained in paragraph 7.1.1. and 7.1.2.
All substrates and backup plates will be delivered to the hybrid manufacturer for production at the proper time.

7.3. Edge Pin

BNL will purchase the hybrid edge pins through a qualified manufacturer. BNL will specify the type and dimension of the pins, the height to which the pins will be "pre-coined" (if necessary), the pin material and the gold plating to be used for finishing. In particular the pins must be at least selectively plated in sulfamate nickel (MPS) and acid hard gold (AURUNA 7100 or equivalent). The nickel thickness must be 100 microinches and the gold thickness must be 30 microinches minimum. Pre-soldered pins, with solder on both side of the clip will be preferred. The solder type must be compatible with the hybrid manufacturer capability in term of reflow soldering and with the solder used to assembly the components on the hybrid.

The edge pins will be qualified and stored as explained in paragraph 7.1.1. and 7.1.2.
The pins will be delivered to the hybrid manufacturer for production at the proper time.

7.4. Hybrid production

The hybrid manufacturing will be contracted between BNL and a US based hybrid manufacturer that will produce the hybrid following BNL fabrication specifications.
The specifications will contain:

- the number of hybrids and types to be produced and delivered
- the alumina substrate dimensions and details
- the total number of masks to be used
- a description of each individual mask
- the specification for the soft glass
- the specification for the palladium silver metallization
- the specification for the dielectric glass and the number of layer to be applied to obtain uniformity
- the specification for the solder mask
- the specification for the resistive inks
- the specification for the solder type to be used
- the specification for the resistor trimming. In particular, the fact that:
  - the resistor trimming shall be done after the soft glass has been fired
  - the resistor trimming shall be done by laser using J or L type cuts
  - the trimming shall not be more than 30% max of the horizontal cut
  - the resistor shall be trimmed to +/- 1%
- the fabricator will be required to produce a "first article prototype lot" for testing and engineering approval at BNL. The "lot" definition could be discussed with the manufacturer at the time of purchase
- the fabricator will not be allowed to proceed until formal written approval is given by BNL to produce the remaining hybrids
- the fact that BNL will supply 1:1 artwork and all materials including substrates, chip capacitors, inductors, surface mount diodes/transistors and edge connector pins for fabrication.
- the rules to be adopted for shipping of material from BNL to the vendor facility and the rules to be adopted for shipping of the final products back to BNL.

The ATLAS hybrids will be produced through a qualified thick-film hybrid manufacturer to be selected between the companies that will respond to BNL bid package.
The manufacturer qualification will be reviewed based on the standard BNL procurement practices and in particular the companies that will be considered satisfactory will be inspected by BNL representatives to verify qualifications.

Due to the design rules adopted for this project, many hybrid manufacturers are expected to qualify. However the bid package must contain provisions to guarantee that the vendor is capable of performing automatic assembly of surface mount components in-house or through subcontracting. If the last case apply, the qualification of the subcontractor must be also inspected for quality.

The manufacturer will be required to perform electrical tests on the finished product as explained in section 6.1.

The manufacturer will be required to supply proves of the manufacturing process, of the electrical test performed and of the corrective actions taken in case of malfunctioning.

The qualification test procedure discussed on Section 6 will be applied to all hybrids received.

After qualification, the hybrids will be stored as explained in paragraph 7.1.1. and 7.1.2.
The hybrids will be shipped to the ATLAS responsible party for installation at the proper time.
All the hybrids delivered for installation will have a “data history” recorded in the database described in section 6.6. Those data will be accessible through a WEB interface by the ATLAS community.

7.5. Schedule

The hybrid production schedule will follow the schedule indicated on the TDR. At the present time, there are no indications that the schedule can not be met.

8. Appendix

8.1. Component data sheets

8.2. Hybrid masks and drawing

8.3. Gold plating specification

8.4. Manufacturing specifications