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QC Tests of GaAs Preamplifier Chips

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Abstract. For the Hadronic End-Cap calorimeter of ATLAS the full amount of GaAs preamplifier ASIC chips has been produced. All of them have been tested at room temperature and good chips are selected for the production of the preamplifying boards. The experimental setup and measuring procedure are described. The chip selection logic and results of tests are presented.

1. INTRODUCTION

For the ATLAS Hadronic End-Cap calorimeter, the GaAs preamplifiers, working in liquid argon, have been chosen [1]. Several prototypes of the preamplifier chips have been developed during years 1994-1996, initially in the framework of RD33 project [2] and later on for the HEC prototype and HEC module-0. The most recent version of the ASIC (that we refer to as "BB96" or "MPI96") has been studied in details, the results can be found in [3]. It was demonstrated that the characteristics are good enough and the preamplifier has been approved for the full-scale production.

Two hadronic end-cap wheels consist of 64 ϕ-wedges. In each wedge the signals from subsequent gaps are summed to form four longitudinal segments . These summation is made in preamplifying and summing boards (PSB), installed on the outer radius of the calorimeter. One wedge is equipped by a group of 5 PSBs, all together containing 67 GaAs chips. For 64 HEC wedges we plan to produce 75 groups of PSBs that gives ~20% spare boards. For this production volume we need **5025** chips.

In the beginning of 1997 the first pre-production batch of 800 chips has been ordered. That time no quality control has been done by the manufacturer. All chips have been tested at MPI and it was found that 68% of them are within the specification requirements. The full production volume has been estimated supposing that the final yield will be approximately the same.

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The production run of 20 GaAs wafers (570 chips per wafer) has been made in August – September of 1998. 16 wafers have been cut and packaged. Chips have been tested by the manufacturer and 6600 chips have been delivered to MPI by the end of 1998. The in-factory tests include the wafer parameters, the shorts and opens, the supply currents, the potentials on the inputs and outputs, and voltages on the floating pins.

The quality control (QC) procedure of the HEC cold electronics has been worked out for Production Readiness Review of GaAs preamplifiers [4]. It consists of 3 steps:

1. Before being soldered on the PSB, each chip has to be tested and qualified in order to decide either it can be used in PSB or not.

2. After the production, each PSB is measured at room temperature and then in liquid nitrogen. The goal of these tests (which we call "functional tests") is to be sure that all PSB components are alive and there is no need for repairing.

3. The last step is the final detailed measurements of the PSB characteristics both at room temperature and in liquid nitrogen. The boards passed this test are delivered to the modules assembling. The results of these measurements will be placed in the HEC production database.

By the date all chips have been tested (p.1), all PSBs produced. The functional tests (p.2) as well as final QC tests (p.3) are going on. In this note we describe the setup for the chip tests, measurements procedure, logic of the chips selection and the results of the data analysis. The other two QC steps will be described in the separate papers.

2. TEST PROCEDURE

One of the requirement to the cold electronics is to have no failure during cooling down and warming up cycles. In the QC tests it is foreseen the procedure of multiple temperature shocking of chips. All preamplifiers are dropped to liquid nitrogen, kept there 20 – 30 minutes and then taken out and dried by pressured air. This operation repeated five times. To study the effect of the temperature shocking, the chips from the pre-production batch have been measured twice – before and after the shocking. It was found that only 1% of the chips are damaged. In order not to double the amount measurements, for the final production batch we made all tests only after the temperature shocking.

The chip contains 8 identical preamplifiers and 2 line drivers. This architecture has been chosen because it gives the possibility to realize the summing schemes corresponding the physics requirements. In the HEC readout channels there are three summation configurations – to sum signals from 4 preamplifiers to one output, to sum 8 preamplifier signals and to sum 16 of them. The interconnections between preamplifiers and drivers are determined by the PSB design. The schematic diagram of the first two summing configurations is shown in figure 1. In the case of summing 16 inputs, the preamplifiers from 2 neighboring chips are connected to the driver of one of the chip.

According to the specification, all preamplifiers connected to one driver should have gain, equalized within ±1% [5]. In the QC tests the gains equality is characterized by the uniformity parameter, that is defined as follows:

$$U = \frac{\max(A) - \min(A)}{\text{mean}(A)} \cdot 100\% \qquad (1)$$

where A is 4 or 8 measured amplitudes.

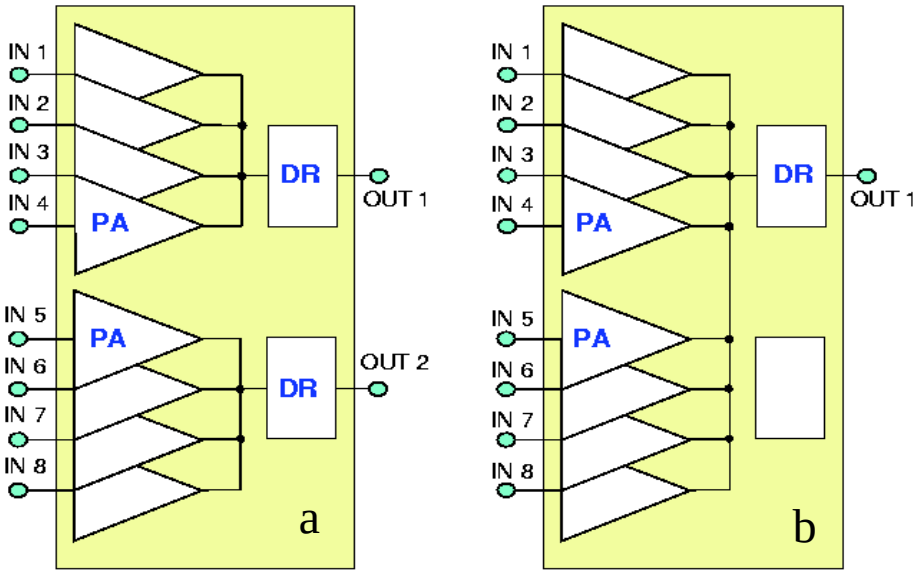

***Figure 1**: Different summing configurations used in the HEC readout channels.*

In the QC tests all parameters are measured in the configuration of summing 4 preamplifiers (fig.1a). But this scheme can not give evaluation of the uniformity in the case of summing 8 inputs since the contribution of preamplifiers 5 – 8 and driver 2 can not be separated. The direct measurements can be done only in the scheme of fig.1b. That is why we made second measurement for each chip on the separate test board (see next chapter) where the summing scheme of fig.1b is realized. In order to save time, only signal amplitudes were measured in this test.

Another characteristic that has to be compared with the specification requirements is the transfer function that is characterized by the absolute value of signal amplitude and it's rise time. It depends on many factors – bias voltages, detector capacitance, input cable length, driver feedback resistor (it is external component), shaper gain and time constant, and input signal shape and value. In the test setup we use conditions close to those expected in ATLAS:

- Values of low voltages are nominal for room temperature:
  $V_{EE} = -2.0V$; $V_{DD} = +7.0V$; $V_{DR} = +3.0V$;
- Detector capacitance $C_D = 220\ pF$, this value is in the middle of the HEC channels range;
- Input cable length $L = 1\ m$, this is also the typical value for the HEC;
- All passive components are the same as on PSB;
- The shaper is RC^2-CR with gain = *10* and time constant = *25 ns*;
- Input signal has exponential shape with decay time *360 ns*, that is close to the ATLAS calibration signal. The value of the input current is *50 μA*;

Noise on the shaper output was measured as RMS value when calibration signal is switched off. The typical equivalent noise current (ENI) of BB96 is *250 nA* for the conditions of the test setup. For the chip selection we apply a condition that ENI has not to exceed ***300 nA***, that corresponds to the output RMS voltage 1.5 mV. Unfortunately, the system noise, coming mainly from the scanner relay card has considerably high value, contributing *1.4 – 1.5 mV*. So the final requirement to the noise RMS value was ***2.0 mV***, chips with higher noise are considered as failed.

Crosstalk was measured as the ratio of the amplitude of the second driver on the same chip to the amplitude of the active channel. The specification requirements is ***1%***. We found that similar to the case of the noise measurements, there is a big contribution from the system, between 1 and 4% for different output channels. These values have been measured and then subtracted during the chip selection procedure. It has been found that the crosstalk in the chip is very small, systematically below 0.5%.

All measurements are performed at room temperature since the standard sockets are not designed to work at cryogenic temperatures. They are destroyed after a few cooling cycles and do not guarantee reliable contacts being placed in liquid nitrogen. The specification parameters are developed originally for the LAr temperature and can not be applied directly to the normal conditions. The parameters were recalculated to room temperature on the basis of laboratory measurements of the preamplifier characteristics made in cold and in warm.

3. EXPERIMENTAL SETUP AND MEASUREMENTS

The measuring setup is shown in Fig.2. Signal from rectangular pulse generator PM5193 carried through standard 50Ω cables to calibration box (CB) where the exponential current is formed by high precision 5.1 KΩ resistor and capacitor of 68 pF. The capacitor of 220 pF, simulating the detector capacity, is also placed in the CB. The CB is connected to preamplifier by coaxial cables of the same type as used in the HEC modules.

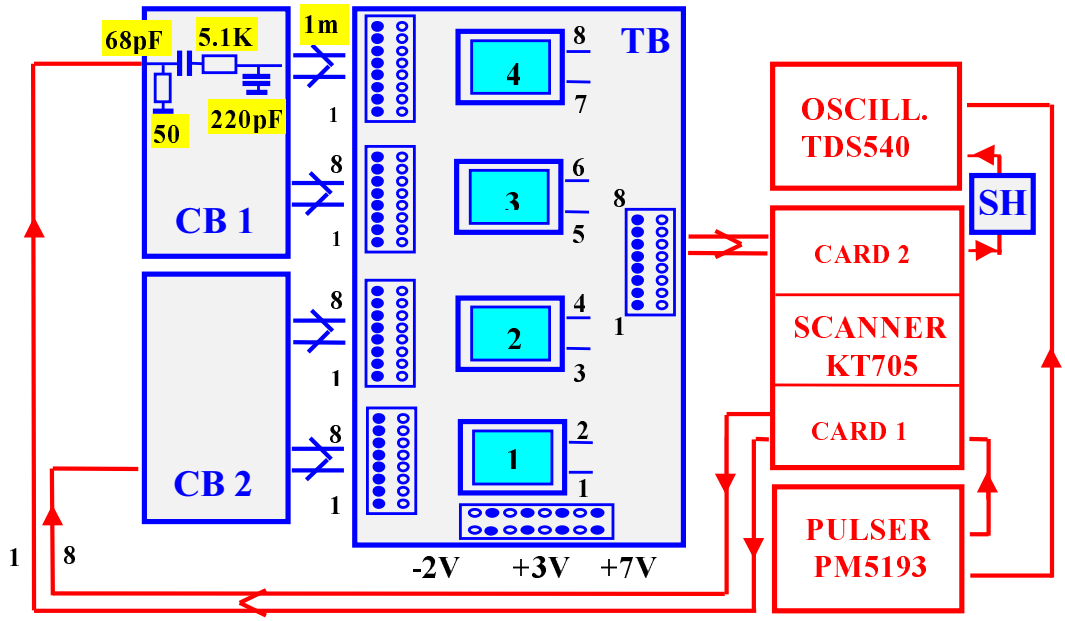

Figure 2: *Setup for the chip tests. CB – calibration box, TB – test board.*

To perform measurements, the chip is fixed in the socket. The test board (TB) contains 4 sockets, so 4 chips can be tested at ones. Two types of TB, corresponding to summing schemes of Fig.1a and 1b are especially designed and produced for the QC tests. All components of TB including input and output connectors are of the same type as used in the serial PSBs. The biased voltages have values, nominal for room temperature. The relay card of the Keithley Model 705 scanner is used to demultiplex the generator pulses. One signal line serves one preamplifier of each chip. The preamplifier output is connected with the shaper trough the second relay card of the scanner. The output signal waveform is digitized by the oscilloscope Tektronix Model TDS 540.

The measurements are automated by PC running under Windows NT system. The program to control instruments, read data and make the online analysis is written in TESTPOINT software [6]. The measuring procedure in the case of summing 4 preamplifiers consists of the following steps:

1. Initialization of measurements.

2. Noise RMS values are measured for each output channel. During this step the generator is disabled, all channels of CARD 1 are open. Noise is calculated and stored for the further analysis. Noise measurements take 4 minutes.

3. The calibration signals are applied sequentially to 8 calibration lines and output signals are read out only for active outputs. The amplitude and peak time values are evaluated for each preamplifier. This step takes 6 minutes.

4. Crosstalk is measured following the same way, but passive channels are read out. It takes also 6 minutes.

Data are saved in ascii file (one per chip), analysis is performed and characteristics are compared with the quality control parameters. Each chip is characterized as DEAD (D) if one or more channels are dead (amplitude is below 30 mV) and as GOOD (G) if all QC parameters are within a specified window. Otherwise it is characterized as FAIL (F). The result of qualification is saved separately in “summary” file (one per all chips from the same wafer). The QC parameters and window used to specify chips are presented in Tab.1.

Table 1: *Parameters used for the chip qualification*

QC parameter	QC passed when:
Amplitude (A)	All A> 170 mV
Uniformity (Eq.1)	U ≤ 2%
Peak time (PT)	All PT < 60 ns
Uniformity of PT	< 2 ns
Xtalk	< 2%
Noise RMS	< 2.0 mV

In the second tests with summing 8 preamplifiers, only amplitudes are measured and uniformity is calculated over 8 signals rather than over 4 in the previous case. Each chip is qualified again as DEAD, GOOD or FAIL depending on the results of the online analysis. This tests take 6 minutes per load of 4 chips.

When the measurements have been started, it was observed that the calibration lines are not identical (mainly due to the scanner relay card), that contributes directly to the uniformity

parameter. In order to remove the setup nonuniformity, it has been calibrated and corrections are applied on the level of online calculations.

4. RESULTS OF MEASUREMENTS

By the date all chips have been measured and data analyzed. Fig.3 illustrates the distribution of QC parameters obtained from tests with summing 4 preamplifiers for 395 chips produced from one wafer. The QC window is represented by not-dashed areas. It can be seen that the chips are rejected mainly due to uniformity of gains.

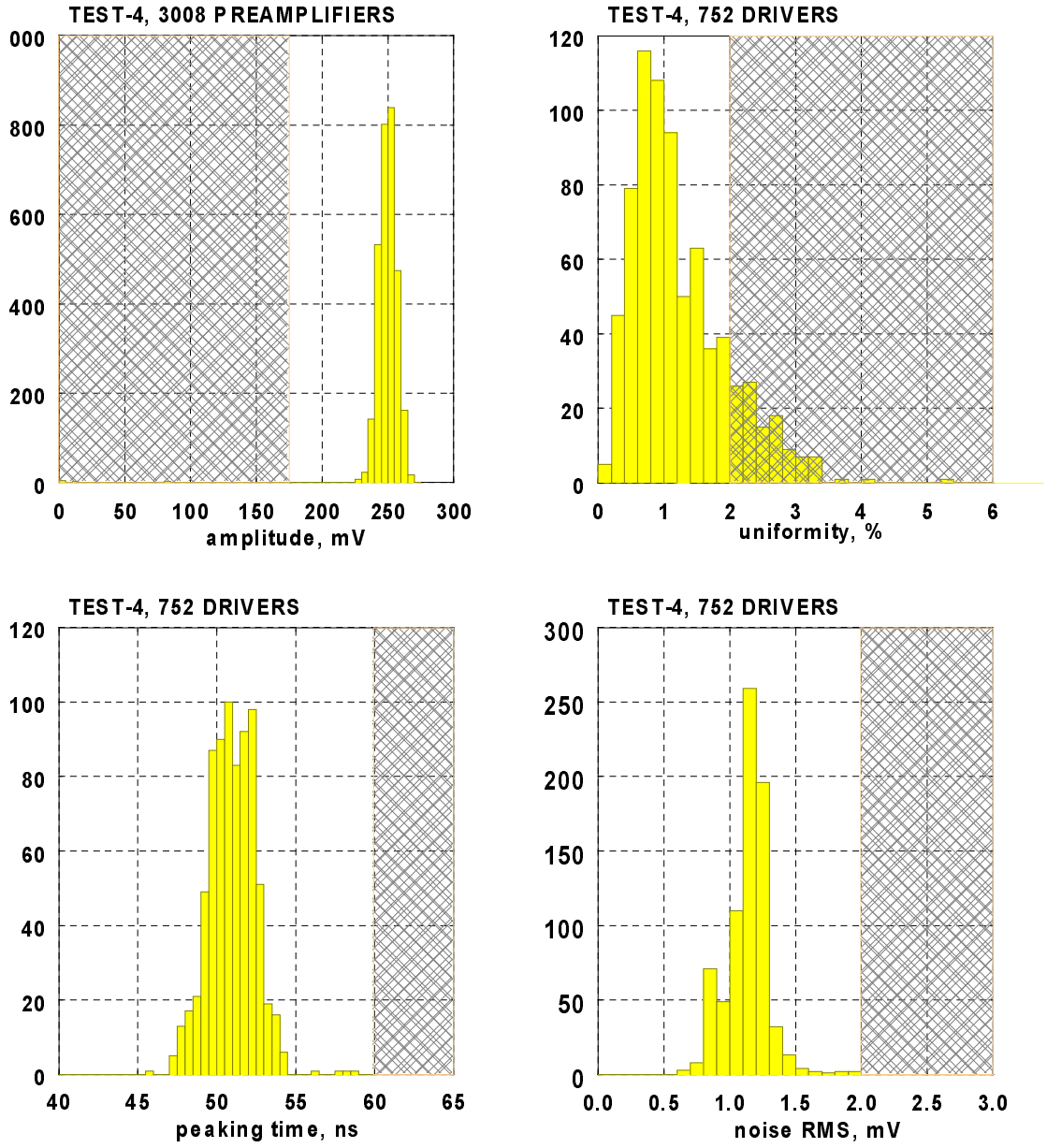

Figure 3: *Distribution of amplitude, uniformity, peaking time and noise for chips from wafer #600 in tests with summing 4 preamplifiers.*

The final qualification of each chip is done on the basis of tests in 2 summing schemes following the logic presented in Tab.2. There were a part of chips not measured in QC setup, they were used for other tests. Such chips are qualified as "N" in each of 2 tests. The chips with final qualification "NM" (not measured) are supposed to be not used for the PSB production. If necessary, they can be measured and qualified. If chip is failed in both measurements or dead in one of tests, it can not be used and qualified as "NU" (not use). Good chips can be used to sum 8 preamplifiers only if they passed the second test, they are qualified as "S8". Other chips will equip the PSB channels with summing 4 preamplifiers (qualification "S4").

***Table 2**: Qualification of chips based on results of two tests. See text for notations and comments.*

T8\T4	N	D	F	G
N	NM	NU	NM	S4
D	NU	NU	NU	NU
F	NM	NU	NU	S4
G	NM	NU	S8	S8

Tab.4 presents the result of qualification of all chips from 16 wafers. From 6600 delivered chips, **5508** can be used for the PSB production. There is quite sufficient amount of chips to be used to sum 8 preamplifier signals (4132 available while 2625 needed), a part of "S8" chips will be used for channels with 4 preamplifiers.

***Table 4**: Yield of tests for all wafers*

wafer #	deliv quant	TEST-8	TEST-4	S8	S4	NU	NM	Yield
074	402	03.99	02.99	219	112	32	39	82.33%
583	424	03.99	06.99	297	75	50	2	87.73%
589	411	03.99	06.99	231	113	63	4	83.70%
590	361	03.99	06.99	236	83	40	2	88.37%
591	400	05.99	12.98	239	75	82	4	78.50%
592	384	04.99	06.99	162	68	145	9	59.90%
593	306	04.99	06.99	170	95	40	1	86.60%
594	413	04.99	08.99	310	79	24	0	94.19%
595	418	04.99	12.99	266	62	56	34	78.47%
596	446	05.99	01.99	332	63	46	5	88.57%
597	395	04.99	08.99	260	92	41	2	89.11%
598	480	04.99	08.99	268	104	100	8	77.50%
599	454	04.99	09.99	280	95	73	6	82.60%
600	395	05.99	10.99	210	92	91	2	76.46%
601	477	05.99	10.99	332	99	44	2	90.36%
602	434	05.99	10.99	320	69	43	2	89.63%
SUM	**6600**	**05.99**	**10.99**	**4132**	**1376**	**970**	**122**	**83.45%**

There is a small number of HEC channels with summing 16 preamplifiers. Such type of channels require 2 chips with equivalent response functions. The pairs of chips for these channels have been selected from group "S8" by making off-line analysis of the uniformity of 16 amplitudes.

5. SUMMARY

The QC tests of GaAs preamplifier chips are successfully completed. From 6600 delivered chips, 5508 are selected for the PSB production. This amount of chips is 10% higher than required to produce 375 PSBs (320 for HEC and 55 spare).

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