COLD ELECTRONICS FOR THE LIQUID ARGON
HADRONIC END-CAP CALORIMETER OF ATLAS

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For the ATLAS hadronic end-cap calorimeter a monolithic Gallium Arsenide front-end chip has been developed. Detailed investigations of many chips have been carried out both at room and at cryogenic temperatures. The dynamic behavior as well as the noise characteristics are presented. The full production (6600 chips) has been completed and quality control tests are going on. 15 preamplifier and summing boards have been produced and tested according to the ATLAS quality assurance procedure. The characteristics of coaxial cables used for analog signals transmission have been studied. The model of the signal distortion is derived and applied to predict the signal shape.

1 Introduction

The hadronic end-cap calorimeter (HEC) of ATLAS is a liquid argon (LAr) sampling calorimeter with copper plate absorbers and ionization gaps having a structure of electrostatic transformer. Signals from two consecutive gaps are fed into the input of one preamplifier, and signals from a number of preamplifiers (from 2 to 16 for different regions of the calorimeter) are actively summed in the preamplifier chips, forming one output signal. The HEC electronics chain is schematically shown in figure 1.

The preamplifiers are placed on the outer radius of the calorimeter wheel inside the cryostat. Five preamplifying and summing boards (PSB) process signals from two HEC modules (1/32 of the wheel), each PSB contains from 12 to 15 preamplifier chips. Signals from PSBs arrive via cold cables at the warm electronics, placed outside the cryostat. In the present paper we describe only cold electronics - preamplifiers and cables.

2 GaAs Preamplifiers

The preamplifier ASIC is made by GaAs TriQuint QED-A Process. This technology has been selected because it offers excellent high frequency perfor-

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mance, low noise, stable operation at cryogenic temperatures, and radiation hardness.

The chip contains 8 identical preamplifiers and 2 drivers that give the possibility to sum signals according to physics requirements. The summing resistor, the driver feedback loop, as well as input and output decoupling capacitors are external components, mounted on the PSB.

The preamplifier scheme is shown in fig. 2a. The input stage is a cascode $X_1, X_2$, biased by two current sources $X_3, X_4$ and $X_7, X_8$. The diodes $Xd_1 - Xd_3$ protect the input transistor against possible high voltage discharges in the LAr gaps. The first transistor has the effective width of 10 mm (100 gates of 100 $\mu$m in parallel) in order to optimize the signal to noise ratio. Its forward conductance $g_m$ can be adjusted by applying an additional current through resistor $R_1$. The feedback loop is formed by the combination $R_5 - C_1$. Together with the open-loop gain its value determines the input impedance, that is close to 50$\Omega$. The last stage $X_5, X_6$ has high output impedance, so current signals can be summed at a load resistor. The combination of three diodes $Xd_4 - Xd_6$ and resistor $R_5$ is introduced for the level shift and temperature stabilization.

The driver scheme, shown in fig. 2b, is similar to the preamplifier one but has the external feedback loop. By choosing the driver feedback components one can adjust the overall gain and timing. The chip has the dimensions of about 4x3 mm. It is housed in a standard 40-pin ceramic package.
Several chips were used for a detailed study of signal and noise characteristics both at room and cryogenic temperatures. Input impedance at liquid nitrogen temperature, in the working frequency range (5 - 20 MHz) varies from chip to chip between 48 and 53 $\Omega$.

The rise time of the output pulse defines the final pulse shape and transfer coefficient. It depends on the detector capacitance and intrinsic frequency band of the circuit. It was measured for the HEC range of capacitances and it was found that the shape is reasonably described by an integration time constant, determined by the input impedance and an offset rise time 5.83 $\text{ns}$.

The expected range of ionization signals in the HEC is up to 250 $\mu\text{A}$ per preamplifier and 1000 $\mu\text{A}$ per driver. The nonlinearity in these ranges was found to be less than 1.4 % for preamplifiers and 1.6 % for the complete channel, both values are within specifications.

The electronic noise has a strong impact on the energy resolution of the calorimeter and limits the possibility to detect minimum ionizing particles (muons). A wide set of measurements of the equivalent noise current (ENI) has been done for various shaping time constants ($RC^2 - CR$ shaper), input capacitance and length of input cable. Fig. 3 shows a typical dependence of ENI on the peaking time for a fixed cable length of 150 cm and for three values of detector capacitance. It can be seen that for working peaking time of 50 $\text{ns}$, ENI is below the expected muon signal even for channels with the maximal capacitance.
3 Quality Control

The HEC is designed to operate reliably with full precision over a period of at least 10 years. That implies a careful qualification of all items. The PSBs and their components (mainly preamplifiers) are submitted to an extensive test procedure before being mounted on the detector. The quality control procedure of the cold electronics consists of the following steps.

After the GaAs wafer fabrication, all chips are electrically tested and only good chips are bonded to package. All delivered chips are measured at room temperature and selected before being soldered to PSBs. During these measurements we quantify all relevant parameters: gain and peaking time of each preamplifier, uniformity of all 8 channels in the chip, noise of each output and crosstalk between channels. We found that a typical yield of these tests is about 80%.

The chips which are qualified as good in the previous step are going to PSB production. Immediately after production, each PSB is tested in liquid nitrogen. During this test we check the gain, peaking time and noise of each PSB channel. If all channels are good, the PSB goes to the final measurements.

In the final step, up to 6 PSBs are placed inside a cryostat, filled with liquid nitrogen. We measure and qualify: gain, peaking time and linearity of preamplifiers, as well as uniformity, noise and linearity of output (readout) channels. The qualified PSBs are delivered to the HEC modules assembling.

Up to date the full amount (6600) of chips has been produced and deliv-
Figure 4. Cold cables of the HEC chain. PP - patch panels, CFT - cold feedthrough, WF - warm feedthrough, CB - calibration board, FEB - front-end board.

ered. About 30% of chips and 10% of PSBs have been tested. 15 PSBs are currently used in the beam tests of the first 6 serial HEC modules. The most relevant characteristics will be prepared and saved in the database, which is currently being established.

4 Cold Cables

The shape of signals is an important characteristic of the electronics chain. It determines the signal to noise ratio, optimal data processing and calibration constants. The shape is partly determined by the signal distortion in cables. The HEC cabling is shown in fig. 4, the total cables length for ionization signal is 10 m and for the calibration one - almost 23 m.

The signal distortions in cables have been measured in liquid nitrogen for 18 cables of different length from 1 to 18 m. It was found that the cable impulse response is fitted very well by the simple function, containing (in Laplace domain) two poles and one zero:

\[ F_c(s) = a(l) \frac{1 + s\tau_z(l)}{(1 + s\tau_p(l))(1 + s\tau_o(l))} \] (1)

The following dependence of the fit parameters on the cable length \( l \) has been found:

\[ a(l) = \frac{1}{1 + l/420}, \tau_z(l) = 25.4 + 0.55l, \tau_p(l) = 25.4 + 1.08l, \tau_o(l) = 0.142l \] (2)

here \( l \) is measured in meters and all time constants are expressed in ns.
The effect of cold cables on the final signal shapes (both calibration and particle) is studied supposing that all parts of cables contribute to the final shape as one line with the length equal to the sum of partial lengths. The warm part of the HEC electronic chain consists of a preshaper, where the preamplifier rise time is compensated, and $RC^2 - CR$ shaper with 15 ns time constant.

In the case of no distortion in the cables, both calibration and ionization signals have identical amplitudes and shapes in the positive part of the signal. If the cables are taken into account, the difference between signals becomes quite significant. This effect is demonstrated in fig. 5.

The specified accuracy of the calibration system (1%) can be achieved only if the signals distortion in the cables is taken into account.

References