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VME-Real-Time Data Acquisition for the Ultracryogenic Gravitational Antenna of Third Generation

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Abstract

We describe a new design of the front-end electronics for the data acquisition of NAUTILUS, the first ultracryogenic resonant gravitational wave detector, operating in the INFN Laboratori Nazionali di Frascati. The improved sensitivity of this kind of detector poses new requirements on the data acquisition, as more speed, amplitude and timing accuracy are needed. In this work we discuss the results obtained with a new front-end configuration based on VME standard for a data acquisition rate of 5kHz (present rate 220Hz). We also describe the data acquisition system for the cosmic ray telescope assembled around NAUTILUS and the timing system of both the components.

1. Introduction

The Ultracryogenic Gravitational Wave (g.w.) Antenna NAUTILUS [1], located in the INFN Laboratori Nazionali di Frascati, and operated by a team of physicists from LNF and the Universities of Roma (the Rome group) is the first resonant detector operating at very low temperature. This implies a large improvement in sensitivity with respect to detectors of previous generations. This detector is taking data at a sensitivity of a few mK, that means the possibility to detect stellar collapses with dimensionless g.w. amplitude h of the order of 10^{-19}. In the near future we hope to improve such sensitivity, approaching the standard quantum limit for resonant detectors, i.e. about 10^{-22} in h [2], and to make more significant coincidences among resonant as well as interferometric detectors [3]. These considerations motivated us to improve the data acquisition system of NAUTILUS, redesigning a new hardware and software configuration, faster and with higher accuracy. In this paper, after briefly recalling the present data acquisition system, we describe the development done for a new, improved hardware configuration and the preliminary tests performed. The hardware consists of a dedicated CPU in a VME environment communicating data given by ADC board to the main acquisition machine via ETHERNET. It is also reported the data acquisition system for the cosmic ray detector [4], assembled around the NAUTILUS antenna, and the solution adopted for synchronization and timing between the two detectors and other experiments in the world, based on a GPS (Global Positioning System) device.

2. Front-End NAUTILUS Electronics & Acquisition Chain

The mechanical vibration of the gravitational detector is extracted by an electromechanical transducer [5], and this signal is amplified by a SQUID amplifier [6]. For the details we refer to numerous specific papers [7]. Here we want to address the issue of how the signal is processed before being recorded. The scheme of the electronics read-out and of the SQUID configuration of the Rome Group antennas NAUTILUS and EXPLORER is shown in fig 1.

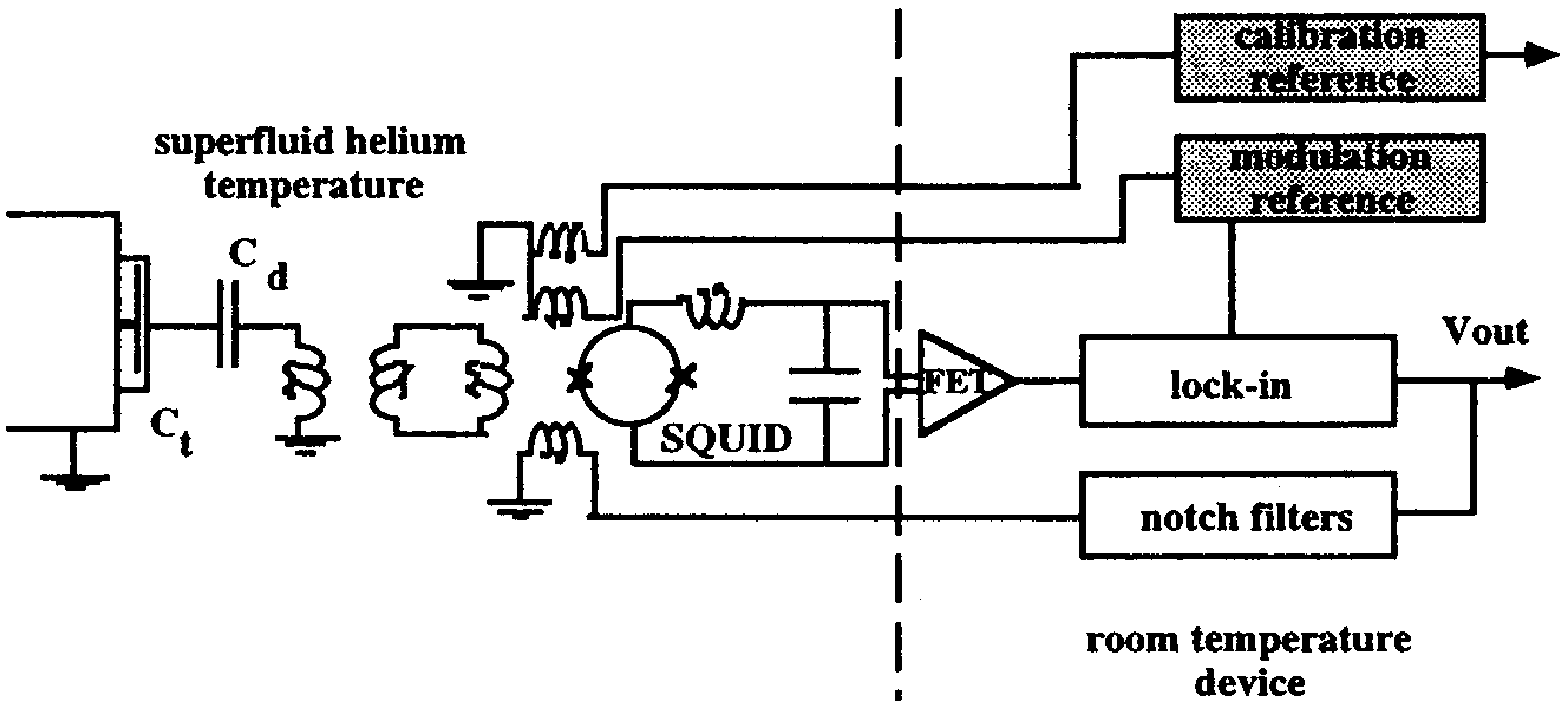

Fig 1. Read-out NAUTILUS configuration

The dc SQUID is a planar superconducting device that exhibit a very low intrinsic noise and a good coupling to external world. The SQUID is biased with a dc current (40-50 μA) and ac modulation flux ($\nu_m \simeq 80KHz$) applied through a coil. Its output pass through a cooled LC resonant circuit (tank circuit, $Q \simeq 70$) tuned at ν_m frequency and is amplified by a room temperature FET device. A lock-in amplifier (EG&G 5210) demodulates the signal from the modulation carrier, to the real frequency of the antenna (around 1 kHz). The output signal of the lock-in is split in two channels: the first one cleaned by notch filters at the antenna modes is sent again to the SQUID via a feedback coil. The second is passed trough a smooth bandpass amplifier (actually composed of two blocks: a preamplifier PAR 113 with a gain of 100 between 0.3-3 kHz, and selective amplifier PAR 189 with a Q of 10 at 1 kHz) and then divided again and fed to five conditioning chains. The signal, now, contains three main frequency components: the amplitude induced by the two normal modes (ν_- and ν_+) of the antenna-transducer mechanical system and the calibration peak, usually applied at a frequency between the two modes. This signal is sent from a synthesizer to the SQUID amplifier throughout a specific coil, in order to provide a known flux amplitude, and to give a real time measurement of the SQUID gain.

The five signals (see fig. 2) are collected by the ADC after being formatted by the following devices:

ν_- *lock-in amplifier* (EG&G 5210), driven by a reference oscillator at the frequency ν_- gives the X and Y (in-phase and quadrature) components of the first normal mode (channels 1 and 2).

ν_+ *lock-in amplifier* (EG&G 5210), driven by a reference oscillator at the frequency ν_+ gives the X and Y components of the second normal mode (channels 3 and 4).

calibration lock-in amplifier (EG&G 5206), driven by the same reference sent to the SQUID, gives the amplitude of the calibration signal. (channel 5).

direct acquisition block: this consists of a flat filter in the mode region (902-926 Hz), and a bandpass filter center at 900 Hz with a gain of 100 and a merit factor Q of 10 (channel 6).

wide band noise lock-in amplifier (EG&G 5210), driven by a frequency away from any resonance, measures the amplitude of the amplifier wide band noise (channel 7).

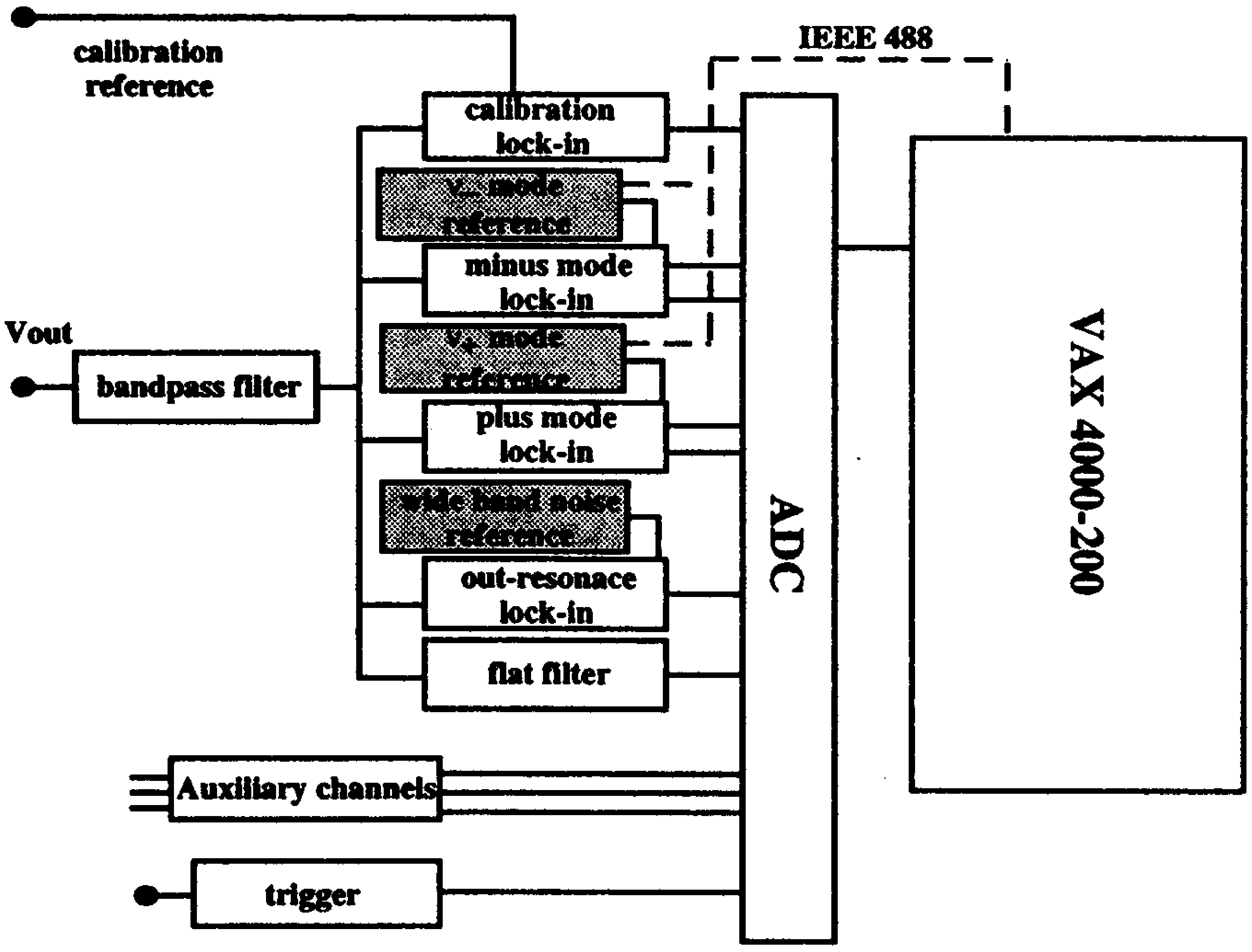

Fig 2. Front-end configuration

The ADC is triggered by a high stability signal at the chosen sampling rate (presently 220 Hz each channel), generated by digital division and forming of a 10 MHz sine wave from a quartz oscillator (Stanford Research system FS700) rephased by means of the LORAN-C radio signal. The same high stability 10 MHz signal is also used to phase lock all the HP 3325 synthetizers. Besides, the two mode and calibration synthesizers are controlled via IEEE-488. In such way a computer program supervising the data acquisition can perform an on-line re-adjustment of the frequencies of the signals collected.

Many other channels are acquired, 32 at present. Except for the so called direct channel (channel 6) they are all subsampled before processing and storage, either at 2.9 Hz or at 0.3 Hz. Two of them are called seismic channels. Each consists of an accelerometer signal, suitably amplified and filtered: lowpass below 3 Hz (low frequency seismic, channel 8), and bandpass in the mode range (seismic resonance , channel 9). Other two channels are used to monitor other diagnostic signals , like electromagnetic monitor, SQUID working point, other seismic channels. One channel acquires a pulse at the top of each seconds, and is very important in the timing of events (channel number 11, see *Data timing* section). The remaining channels are used to monitor the cryogenic parameters of the apparatus. Hence, on-line monitoring of the apparatus can be performed by remote access.

Up to now, the data acquisition is performed by a VAX 4000-200, operating under VMS system, equipped with an ADC card (DEC ADV11-D) and IEEE-488 card (DEC IEQ11). On this computer the DAGA2 (Data Acquisition for Gravitational Antenna) is running [8], a software system that manages all aspect of data acquisition, control, storage and analysis.

3. New read-out System Configuration

The VME standard has been chosen for the new system read-out hardware. This allows an easy reperibilty of boards with good performances. Hence, data acquisition is performed by DIGITAL Equipment KAV30-AD processor, an intelligent crate controller operating in the VME environment. The KAV30-AD runs the real-time DEC VAXELN operating system which is optimized for real time operations [9]. The acquisition reads data from a 32-channel, 16 bit ADC (Pentland MPV912), equipped with a FIFO (First-In-First-Out) system memory, that allows a maximum trigger frequency of 50 KHz. Data collected are sent to the main data acquisition machine Alpha Station 600 throughout ETHERNET in a local area network, where data are processed and stored by the DAGA2 system software. In the future we plan to replace the KAV30 board with a more modern CPU equipped with FDDI interface to link the VME to the main machine.

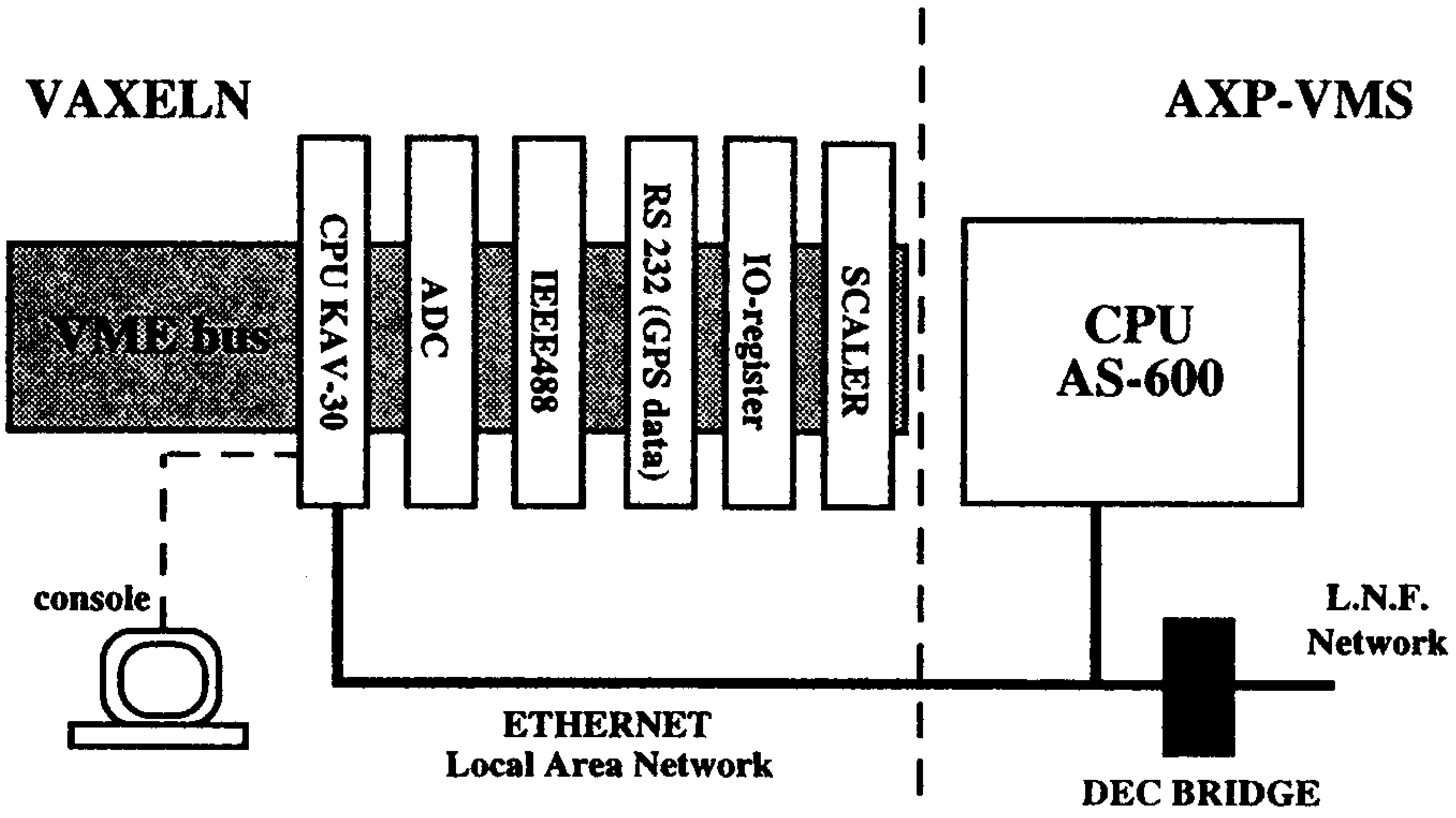

Fig 3. VME bus AXP-VMS system

The KAV30 running the VAXELN system becomes a machine dedicated to a particular application. The software system consists of many user jobs with different priority and same other system jobs (ETHERNET driver, console driver, ecc.). In each job many concurrent sub-processes can run with a different priority. All the software has been written in EPASCAL, the PASCAL native language of VAXELN.

The data flow is shown in figure 4. Data are exchanged between the jobs using the VAXELN structure called messages and ports. The communication with the VMS is done using different priority DECNET links. The data read out is performed by the ACQ job running at high priority that receives data from the ADC reading the FIFO buffer. The interrupt occurs when the FIFO is half full, typically about 700 Byte at a trigger frequency of 20kHz. Buffers are queued up to 20, and then sent by the job NET_SERVER to the main data acquisition machine. DECNET spy jobs may check data acquisition parameters and data quality via the SECONDARY_NET_SERVER job. The highest priority job is the ELN_VMS_SERVER that receives commands from VMS allowing the run control from the DAGA2 software system.

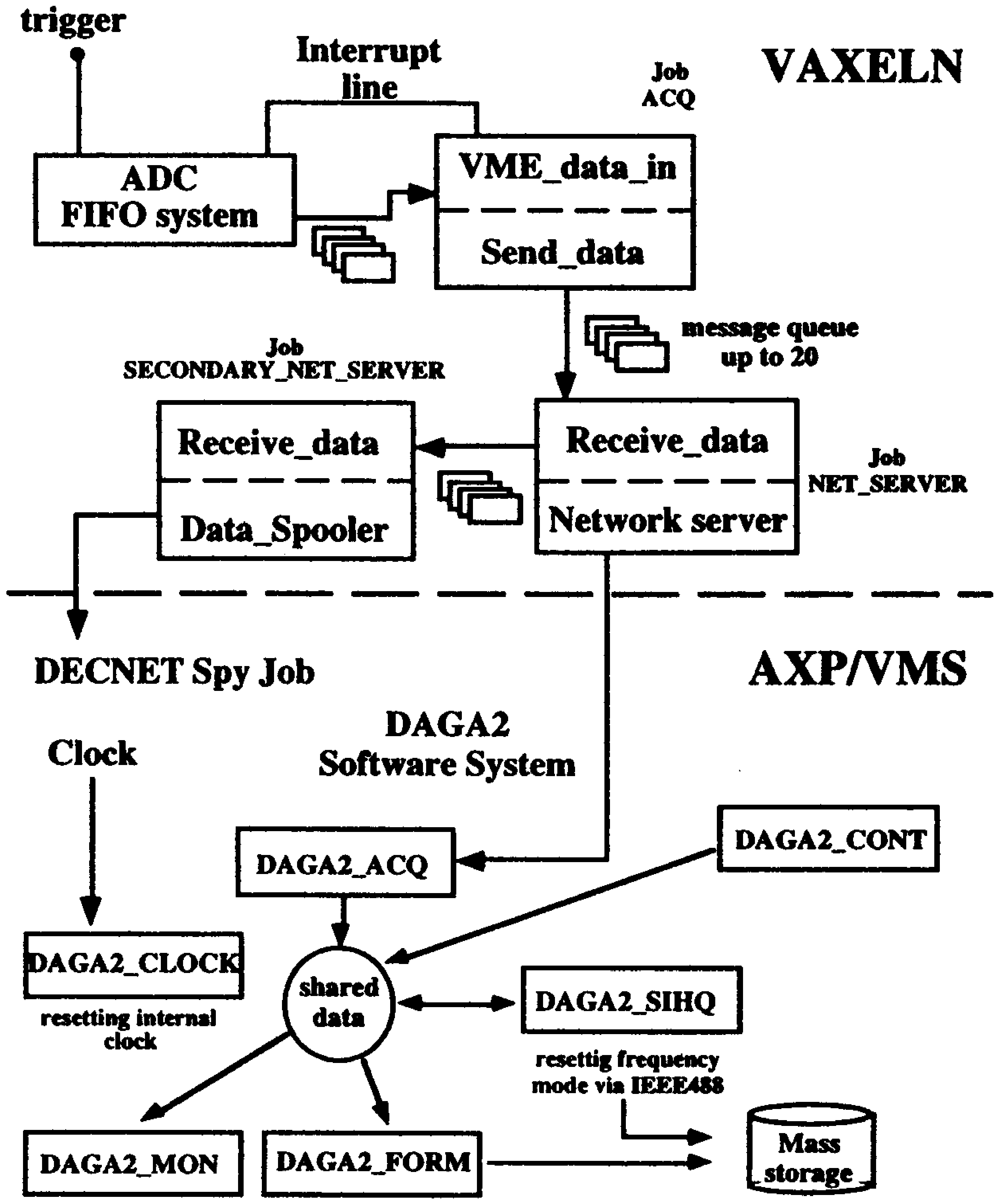

Fig 4. Event flow handling

The DAGA2 system is a software package that can be used in three different operating modes: acquisition, simulation, and analysis. For our propose the most important is the acquisition mode that consists essentially of six concurrent jobs. The first is DAGA2_ACQ, running at high priority; it reads data coming from VME and shares them with other jobs (RING structure). Data are then processed, analyzed and stored by the DAGA2_FORM. The DAGA2_SIHQ estimates some adaptive parameters, frequency spectra, and the resonance frequency settings the synthesizers via IEEE 488, while the DAGA2_CLOCK provides the setting of the VAX internal clock within a precision of 30 ms. The DAGA2_CONT permits to manage all acquisition run control, while supervisor batch checks all the data acquisition parameters. Moreover, DAGA2_MON allows all accounted users to have on-line monitor of raw and analyzed data, histograms, statistics and histories of last 30 hours.

In the following some performance of the system described above are shown.

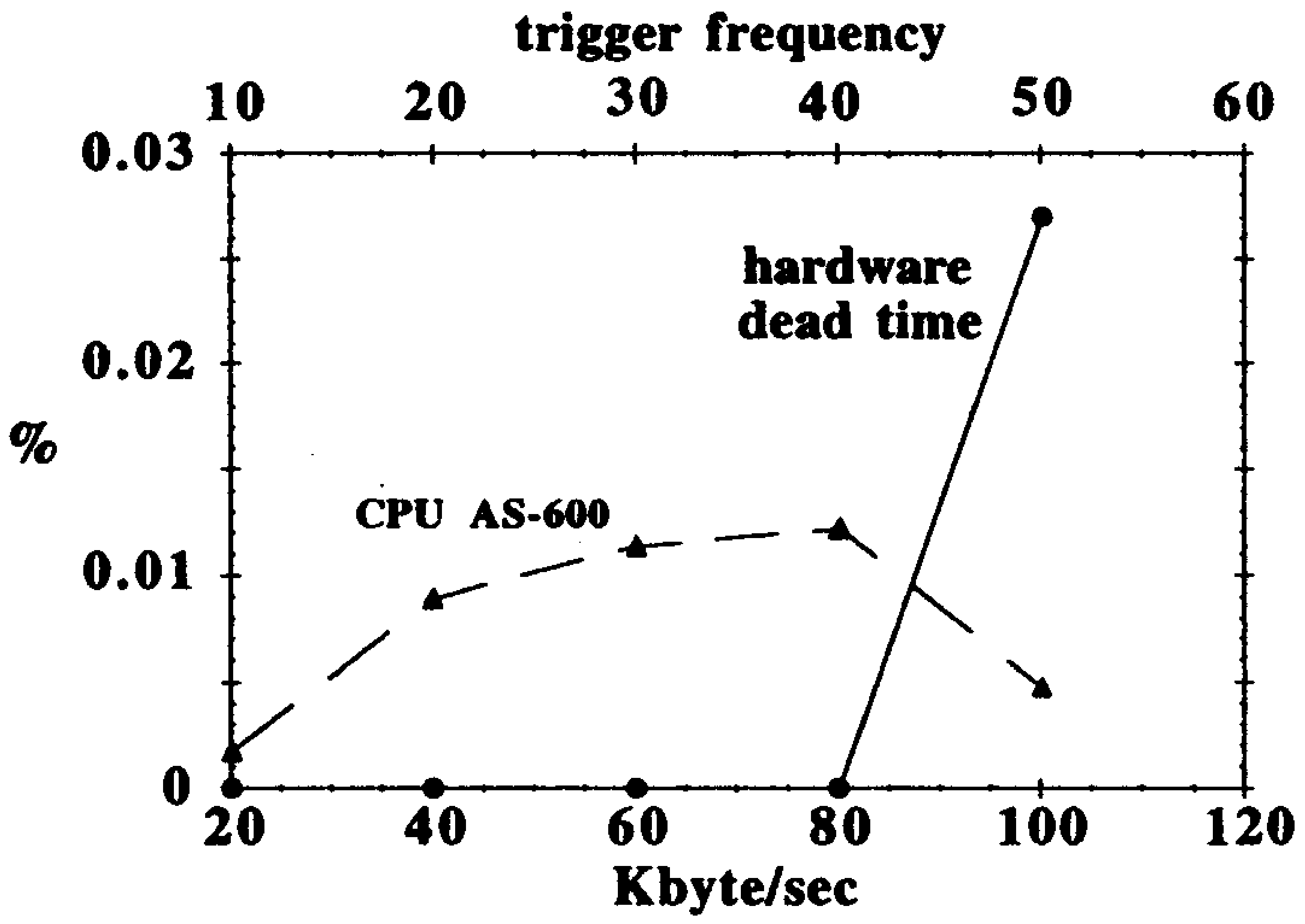

Fig 5. Percentage of dead time for VME system and remote CPU

The VME system runnig without the link with the remote host shows a maximum sampling rate of about 70 kHz (140 kByte/s). Hence, dead time immediately goes up to 50% at 80 kHz. With a DECNET connection to the remote AS-600 in the Local Area Network (LAN) of the Capannone Gran Sasso, where the NAUTILUS experiment is located, the system performances are lower but in agreament whith our requirement. The hardware dead time as a function of the kByte/s (or sampling rate) acquired by the remote machine, and the fraction of time lost by AS-600 CPU to get data in memory are shown in fig 5. The ADC board shows a throughput behaviour in agreament with the performances declared in the data sheet. The measured RMS error with a load of 50Ω is 6.6×10^{-4} V only when the load is closed on a capacity greater then 10nF showing that we have electromagnetic noise at frequency below 2 MHz.

4. Cosmic Ray Data Acquisition and Monitoring

The sensitivity of NAUTILUS is one order of magnitude better than that of other similar detectors. At the effective noise temperature T_{eff} of about 1 mK, we expect a few events per day originated by cosmic rays, which will give a detectable signal in the antenna. Hence the gravitational detector has been provided with a cosmic-ray veto system [4] consisting of layers of streamer tubes placed above and below the NAUTILUS cryostat.

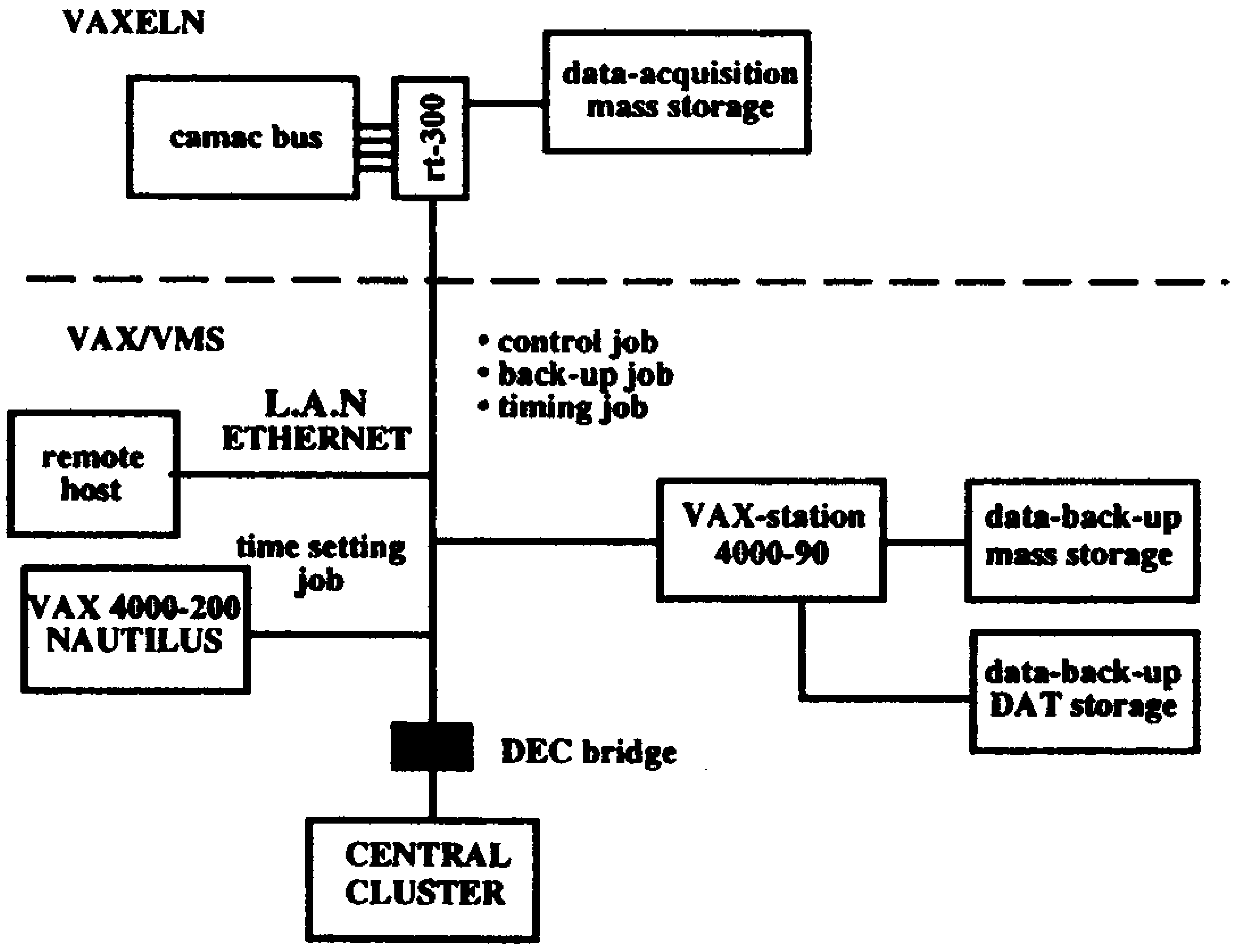

Fig 6. Cosmic ray LAN configuration

The cosmic ray detector data acquisition is performed by a Kinetic Systems VANTAGE 300 intelligent crate controller operating in the CAMAC environment and built around the Digital Equipment rtVAX 300 processor. VANTAGE 300 runs the real-time DEC VAXELN operating system which is optimized for real time [9] operations. A 16-channels-I/O REGISTER (CAEN C219) controls the ADC gates, and it is used for providing CLEAR signals and the veto logic. The programmable 7106 PHILLIPS module allows to chose the different trigger to be acquired.

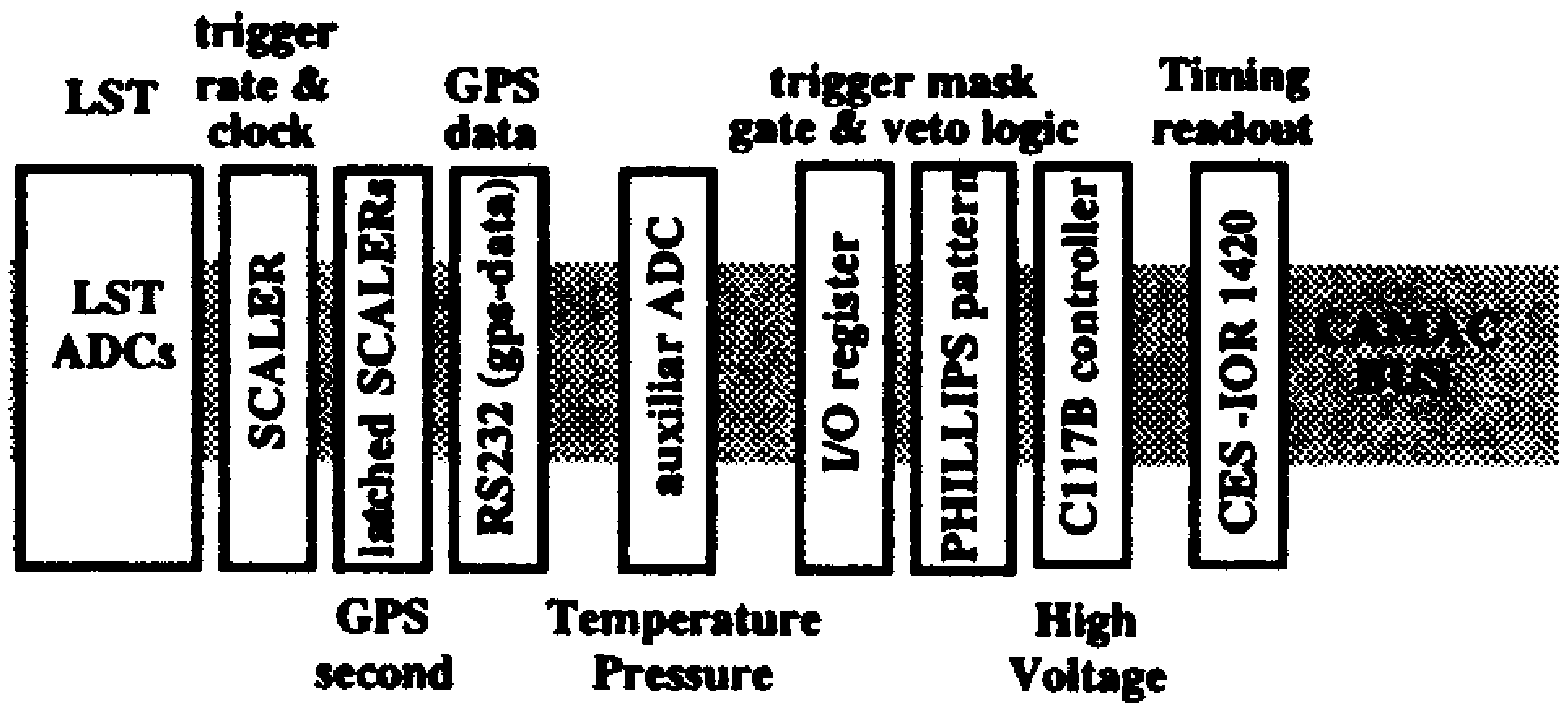

Fig 7. CAMAC read-out

The acquisition code running in the DEC VAXELN system stores data on two local mass storage of 1.2 GBytes. The acquisition throughput on mass storage is of the order of 50 MBytes/day with a average dead-time of about 4%. The system has been integrated in a ETHERNET/DECNET network in order to allow an easy access from remote locations. Hence, on-line control and monitoring of the apparatus can be performed.

The event and command flow handling is the same reported above for the new NAUTILUS data acquisition. A VAX-Station 4000-90 operating in VAX/VMS system has been dedicated to software development and debugging of the data acquisition system. A daily job allows to have the statistics on data collected and information on the status of the apparatus during the last-day data acquisition. All this information is shared and sent daily to all DECNET accounted user. Moreover, a daily job performs the back-up of the data collected from the local-data acquisition storage mass to the VAX-Station storage mass. In this way, about two months of data are available for analysis. Data are then automatically backed-up on DAT-cassettes and deleted. A supervisor job, throughout a secondary connection, continuosly checks the data acquisition status. Many other jobs, like histogram presenter, event display are available from remote location.

5. Data timing

It is essential, in order to correctly carry out coincidences among various g.w. detectors and between NAUTILUS and its cosmic ray veto system, to have a very accurate and reliable absolute timing of the data and the events [8][10], as well as an uniform spacing of sampling. The main concern in arranging a timing device is to guarantee long time stability and in reducing the chance of recording wrong time information. Indeed timing data provided by industrial standards are often affected by transmission errors. To overcome this problem we have adopted several timing devices, as described below, in order to have redundant information, and an on-line check of timing data.

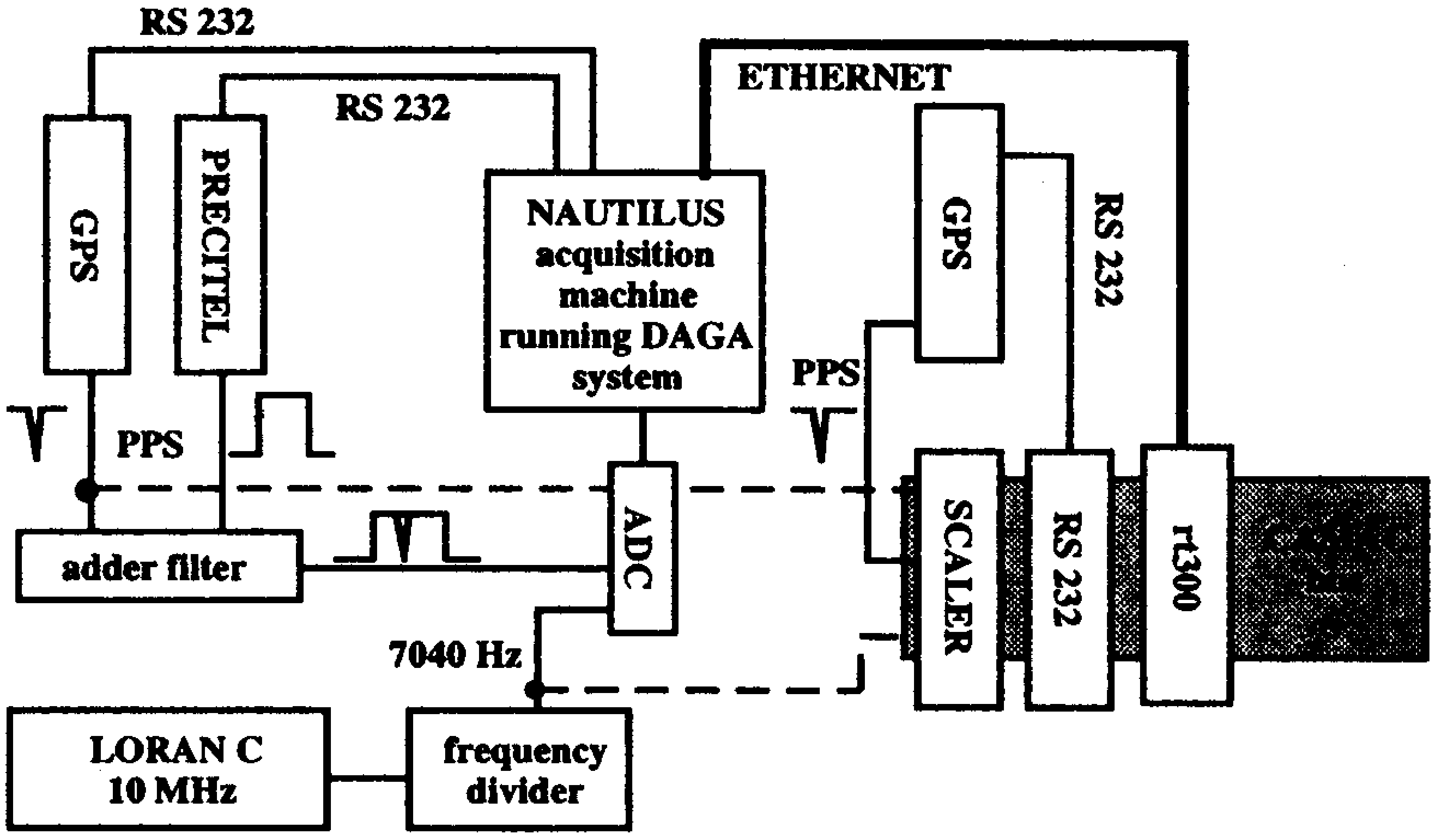

Fig 8. Timing system configuration

Both NAUTILUS and the cosmic-ray veto system have been equipped with two GPS (General Positioning System) Trimble Navigation SVeeSix boards.
The GPS receiver makes available, on RS232 interface, a lot of information of which we only use two substrings containing the timing information and the "health" status of the transmitters. An additional analog output provides a pulse per second (PPS) synchronized to UTC second. This signal can, if optimally set, achieve a synchronization within 1 μs to UTC. To have redundant time information, NAUTILUS has been also equipped with a radio controlled clock (using a Swiss time signal HBG). The PPS signal are summed and stored at the maximum sampling rate; this method permits, in principle, to have a precision comparable to the sampling time (4.5 ms at present). The DAGA2 software measures the differences between the internal VAX time and the time of the two receivers. All temporal differences and the possible actions taken are recorded in a log file. The VAX internal clock is reset by DAGA2 system only when the time difference is less of a given value, so that large and inappropriate corrections due to the above mentioned transmission errors are avoided. An on-line monitor gives information about the possible errors.

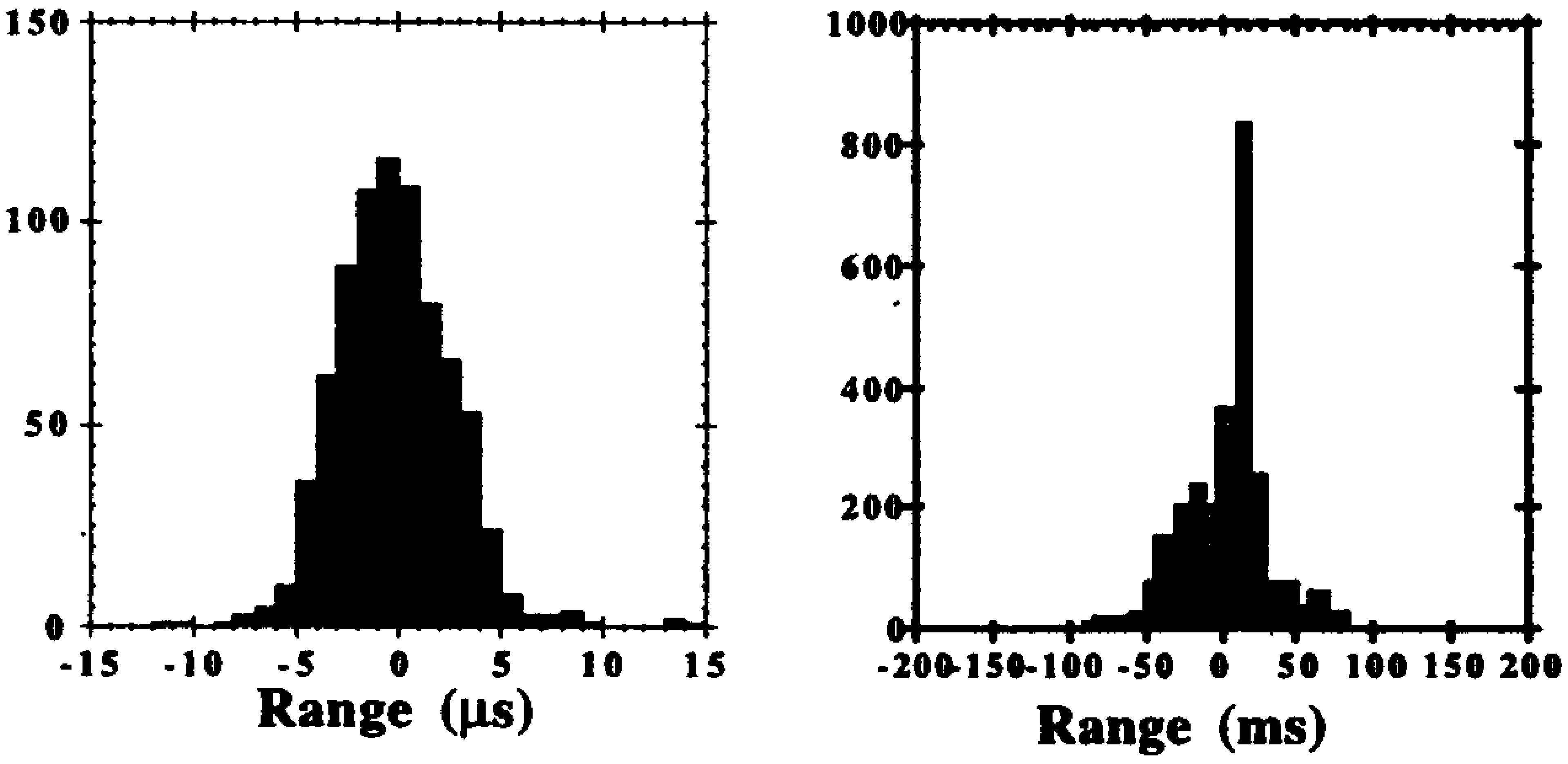

Fig 9. a) PPSs difference, b) Internal clock difference setted via ETHERNET

The cosmic-ray data acquisition stores timing data from a second GPS board. The times of arrival of the two PPS signals have been measured to coincide within a few μs as shown in figure 9.a. For increased redundancy of the time information, we also reset the internal clock of the microVAX rt300 to that of the NAUTILUS acquisition computer, with a DAGA2 batch job via ETHERNET. The precision achieved is of the order of a few ms as shown in figure 9.b.

In designing the new data acquisition hardware, we decided to improve the timing accuracy by using a new commercial integrated system [11] (ESAT GPS RAD100) that combines a GPS receiver with a Rb oscillator. In this way we can also replace the reference standard that is becoming unusable as the LORAN system is phased out. The logic is the same reported before, but the GPS board is replaced by a master-slave configuration that can serve both NAUTILUS and cosmic ray veto acquisition systems.

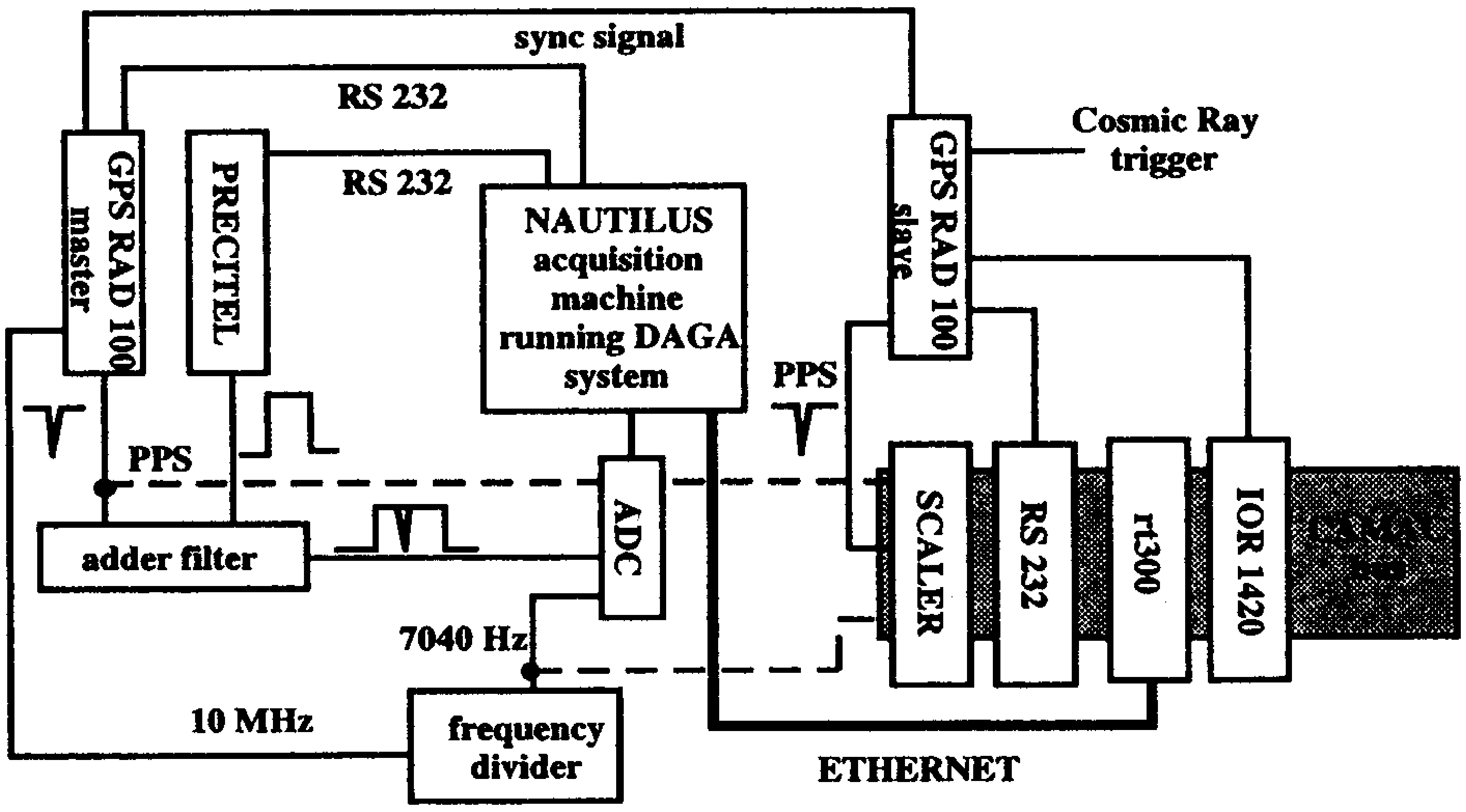

Fig 10. New timing system

The master clock is composed by a rubidium oscillator continuosly (every second) reset by a function calculated by fitting three hours of averaged GPS data. This time constant is chosen to minimize the effect of possible GPS errors. This configuration allows to have a precision of 100 ns on PPS synchronized to the UTC reference. The PPS signal is also sent to a slave device setting a quartz oscillator. The slave has also a parallel latched interface output. So, the cosmic ray trigger freezes the event time that is then read out by CES-IOR 1420 interface with the same precision of 100 ns.

6. Conclusions

The performances of the new data acquisition system for the Ultracryogenic Resonant Antenna NAUTILUS are in agreement with our requirement, anyway we plan to use a more modern dedicated CPU to control the VME bus equipped with FDDI interface. We are also testing a different ADC (Pentland MPX300) to reach an higher accuracy. The similar system for the cosmic ray telescope is running since two years with a duty cycle of 99% showing the high stability of the system. The new timing system for both NAUTILUS and cosmic ray telescope allows to have an events timing with a precision of 100 ns, and the Rb oscillator gives a very high stability of sampling.

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