Low Power and Easy to Use Ocean Bottom Seismometer (OBS) For Long Period Surveys

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***Abstract* – The OBS (Ocean Bottom Seismoemter) has been a key instrument for geophysical study of sea sub-bttom layers in the last decades. Now scientists are demanding highly relaible autonomous euipment capable of staying underwater for long periods of time and therefore handling large data storage.**

Power consumption of the acquisition system as well as a stable time base with temperature are the main issues in order to achieve high autnomoy together with a good data quality.

This paper presents a new Ocean Bottom Seismometer designed to be used in marine long term sureveys. To achieve our goals, a new datalogger based on Compactflash memories with high data transfer capacity is designed to enable continous data acquisition.

The equipment is now under evaluation where lab tests have been carried out and tests under real environmental conditions are programmed for second semester of 2005.

I. INTRODUCTION

The wide technological progress in marine sciences in the last ten years allows a better profit of natural resources, and risk and hazards assessment in the marine environment. Thus, the more developed countries have importantly invested in marine technological innovation, which allows continuous sampling and supervision of different events to a regional scale.

Among the different marine instruments, Ocean Bottom Seismometers (OBS) have deserved growing attention from the geoscientific community during the last twenty years. OBS sensors are sensitive to the motions of the ocean floor, which hold key information in order to study offshore seismicity and to explore the Earth's interior. In a seismic survey, a series of OBSs are placed on the seabed of the area under study, where they record either natural seismic activity or acoustic signals generated by compressed air-guns. Signal recordings are subsequently used to model both the earthquake locations and the crustal structure.

Useful seismic surveys require long term deployment of dense OBS networks. Increasing the autonomy of OBS by reducing its consumption is therefore one of the main technological aims. In addition, it must be taken into account that modern seismic experiments require fast deployment of several tens of OBSs, therefore another is goal to build small sized, light-weight and easy to use instruments. The purpose of this project, which integrates different scientific disciplines as electronics, mechanics, geophysics, acoustics, and communications, is to design a small and light autonomous OBS with large storage capacity and low power consumption capable of handling continuous recording for three months.

The instrument is equipped with a heavy anchor to sink it to up to 6000 meters depth. The OBS must be able to record continuously for about three months, allowing to do long term surveys as well as to plan different seismic experiments without recovering the equipment. The Lithium-ion power supply, acquisition system and burn-wire release electronics is placed inside a 43cm diameter glass sphere subjected to vacuum. Nitrogen gas is used to eliminate the existing humidity inside the sphere[1][3].

The equipment is recovered after sending an acoustic signal of a certain code from a telecommand deck unit placed on the surface, which starts the burn-wire process. After some time, which depends on water temperature and salinity, the anchor is released allowing the instrument to float to the surface. The tracking elements of the instrument on the surface are a radio beacon with a 4 miles range from the oceanographic vessel, a direction finding receiver on the vessel to locate the radio beacon and a xenon flasher, very useful in night recovery. Time release is also possible for bad communication situations.

Fig 1. Ocean Bottom Seismometer

II. INSTRUMENT SENSORS

A hydrophone based on a ceramic structure is used to collect the water vibrations and a tri-axial geophone is used to register the seabed vibrations. The geophone module (figure 2) is separated from the OBS structure by an arm which drops the sensor some time after the deployment and avoids the interfering signals caused by instrument vibrations to be collected. The geophoen is built of three 4.5Hz SM-6 geophones with a 28.8V/ms^{-1} sensitivity and a moving mass of 11.1g. The output is amplified using a low noise OP97 operational amplifier in a non-inverter configuration.

Fig. 2. Geophone coupling module

The geophone has been modeled and calibrated using an APS Air Bearing Horizontal Shaker 129 and a Beran 455 Calibrator. The shake table has presented accuracy limitations outside the 0.5Hz -50 Hz frequency band and the minimum inputs are 0.1mm/s^2 in acceleration and 0.15mm/s in velocity. The following figure show the calibration results using a PCB 393b31 accelerometer as the reference sensor.

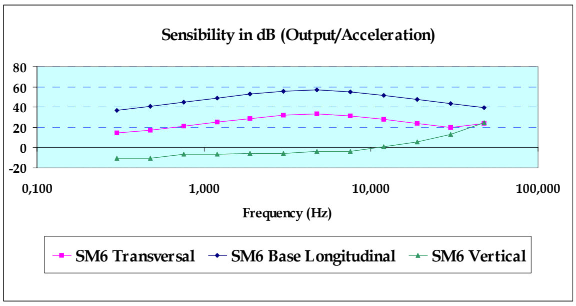

Fig 3. Frequency response of the three geophone channels

Figure 4 shows the frequency response of the geophone with a sand basement inside different boxes.

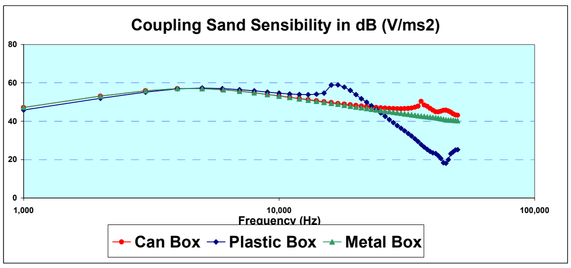

Fig 4. Frequency response with sand basement inside can, plastic and metal boxes.

The geophone presents a better response when coupled inside a metal box.

III. THE ACQUISITION SYSTEM

The acquisition system is based on a 4 channel 24 bits CS5372/76 analog to digital conversion together with input signal amplification. The CS5372 are two channel high dynamic range, fourth order Δ-Σ modulators designed for geophysical and sonar applications. Used in combination with CS5376 digital filter, a unique high resolution A/D measurement system results which all together provide higher dynamic range of 124 dB @ 411Hz bandwidth and lower total harmonic distortion than other industry modulators, while consuming significantly less power per channel. The modulators generate an oversampled serial bit stream at 512kbits per second when operated from clock frequency of 2.048 MHz.

In normal mode, that is when the clock frequency is 2.048 MHz and LPWR input signal is low, power consumption is 25mW per channel and in low power mode, that is when clock frequency is 1.024 MHz and LPWR is high, power consumption is 15 mW per channel. Each modulator can be independently powered down to 1 mW per channel and by halting the input clock; the modulators enter a micropower state using only 10 uW per channel.[5].

The CS5376 digital filter has decimation ratios that can support data output word rates between 62.5 sps and 4000 sps although the designed datalogger can achieve programmable sampling rates ranging from 125 Hz to 1 kHz, more than enough for any seismic application, while power consumption is rated below 6 mW per channel [6].

The Acquisition system communication is carried out through a QSPI bus by sending commands from a Motorola MC68332 microcontroller which works as master and initiates all data transfers configuring sampling frequency, digital filter output stage, storage capacity, digital filter read/write register, digital filter reset and self test, data read, etc. In order to build a distributed measurement network, data collection must occur with synchronous timing between measurement channels, therefore they are supplied with a synchronization signal (SYNC) with the same frequency as the sampling interval configured by the user. Each serial data transaction is composed of a series of 32 bit words, the first byte being status information and channel numbers and the last 24 bits of each output word are the conversion data for the indicated channel [6].

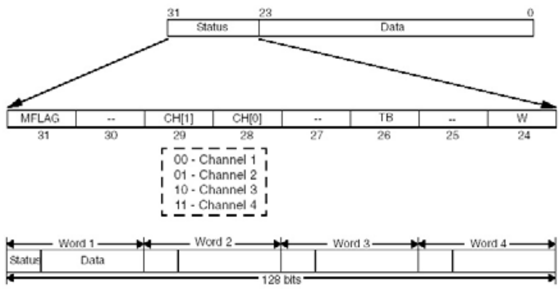

Fig 5. CS5372/76 data format

Finally data is separated in one second intervals and packed and stored in a 64 bytes format with a variable wordlength in a way that in every packet there are data present from one single channel,

the first 4 bytes being headers and the next 60 bytes are variable wordlength data which is the longest wordlength inside that second [2]. Figure 6 shows a simplified block diagram of the acquisition system:

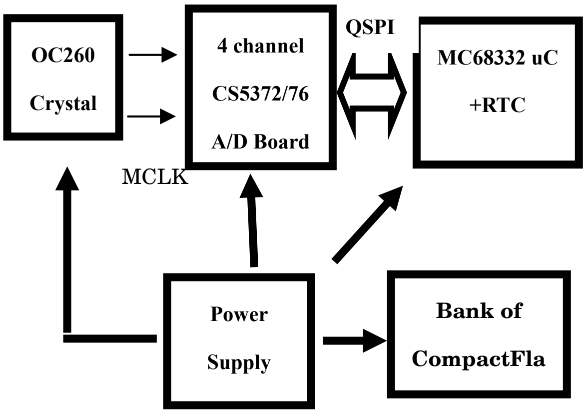

Fig 6. Acquisition system block diagram

IV. COMPACTFLASH INTERFACE

Aiming to satisfy the power requirements, two complementary strategies are followed: supply different parts of this module only when needed and read/write speed optimisation. This leads to supply only one Compactflash card at a time, activating the other ones as they are filled with data, using a partial power down technology whose 3.3V logical family is 5V input/output tolerant, making an easy connection with the uC module.

In order to maximize the low consumption time, it is necessary to increase the writing velocity to be limited only by the card, the system is designed to perform read/write operations in one bus cycle achieving transfer velocity of about 2 MB/s. The memory subsystem is organized in two main blocks: interface module and memory modules, the first one allows the connection with the uC module using 16 data lines and 8 address lines selecting only one memory card as well as configuring all the registers for True IDE mode transfer and satisfaying all timing specifications [5]. Each memory module supports one Compactflash memory card having an independent power supply.

The interface software consists of a single library organized in 3 layers which allows a transparent utilization of file system used by this kind of memories, the first one performing basic read/write and memory slot activation tasks, interacting directly with hardware, the second layer supporting all the required functions for a FAT16 file system implementation allowing long file names VFAT, and finally the third layer implements all the utilities needed to store the data samples coming from the A/D module in an efficient way. Figure 7 shows a picture of the Compactflash module and the microcontroller module:

Fig 7. CompactFlash modules connected
to the uC module

V. LABORATORY TESTS

The fact that the OBS has no access to a GPS signal during the experiment constitutes the need for a highly precision time base as in data processing of the collected data, generation and arrival times of acoustic wavefronts generated by compressed airguns on the surface has to be accurately known. Therefore two highly stable crystal oscillators with temperature and of different technologies have been tested in the laboratory.

The 32.768MHz OC-260 OCXO (Oven Controlled Crystal Oscillator) and a Vectron 4.194304MHz TCXO (temperature Compensated Crystal Oscillator) temperature stability and power consumption tests have been carried out using a Agilent 53132A frequency counter. These crystal boards were placed inside a VÖTSCH climate chamber and an automated measurement system was designed to take measurement samples every 5 seconds. The temperature was set to change in the following way to simulate the OBS deployment and recovery process: from +25ºC to –2ºC in one hour (OBS traveling to the seabed), at constant –2ºC for 2 days (OBS sitting on the sea), from –2ºC TO +25ºC in one hour (OBS traveling to the surface).

The following figures show the temperature stability of the OCXO and TCXO under study during the defined temperature profile. The OCXO and TCXO crystal frequencies show a temperature stability of 49ppb and 71ppb respectively.

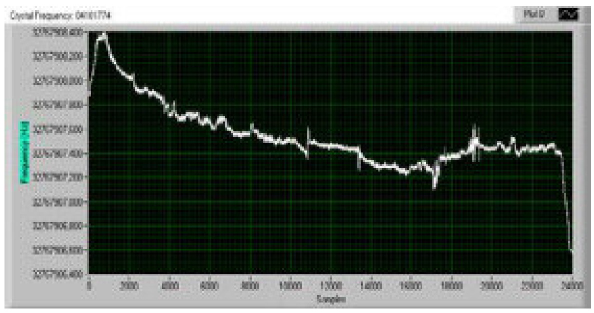

Fig 8. OCXO frequency temperature stability with a temperature profile of: from +25ºC to –2ºC in 1 hour, at –2ºC for 2 days, from –2ºC to +25ºC in 1 hour

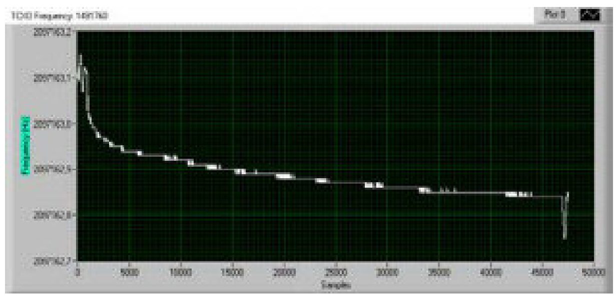

Fig 9. TCXO frequency temperature stability with a temperature profile of: from +25ºC to –2ºC in 1 hour, at –2ºC for 2 days, from –2ºC to +25ºC in 1 hour

The input current of the OCXO and TCXO crystal oscillators was measured using a HPE3631A power supply and when both crystals are powered at 5V, the OCXO presents a power consumption of 1.5W when the temperature is –2 ºC constant while TCXO's power consumption is 55mW at the same temperature. The following figures show the results of these tests:

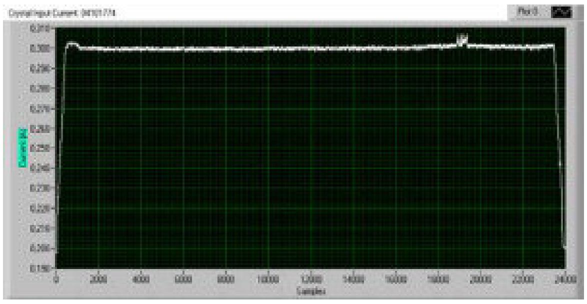

Fig 10. OCXO input current with a temperature profile of: from +25ºC to –2ºC in 1 hour, at –2ºC for 2 days, from –2ºC to +25ºC in 1 hour

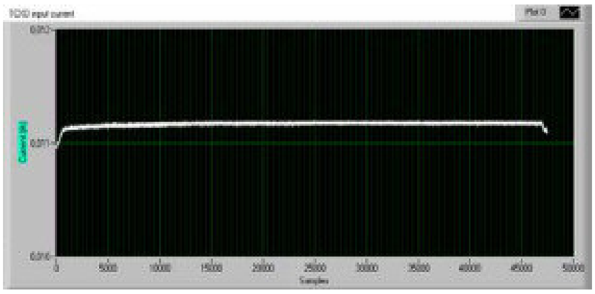

Fig 11. TCXO input current with a temperature profile of: from +25ºC to –2ºC in 1 hour, at –2ºC for 2 days, from –2ºC to +25ºC in 1 hour

The above tests show that the use of OCXO crystals as time base of the overall system would set major limit on the instrument autonomy even though presenting a better temperature stability than a TCXO crystal.

Further power consumption tests of the acquisition system have been carried out and the results are gathered in the following table:

Module	Power consumption (mW)
Microcontroller	150
ADC	200
Power supply	350
Storage (CF)	7

VI. RESULTS

In order to test the overall system, some data files are stored in the CompactFlash memory cards using the geophone and known signals as the input of the system and an application in Matlab is designed to read the data files from every channel and monitors the collected waveforms on a graph. The following figure shows a data file collected by the acquisition system with a hydrophone as the input signal.

Tests under real environmental conditions are programmed for the last semester of 2004 with the objective of making a new Ocean Bottom Seismometer (OBS) for the Spanish scientific community in 2005. Even though Instrument stability during deployment as well as burn wire release electronics will be the main issues of these tests, long term acquisition tests will take place in the second semester of 2005.

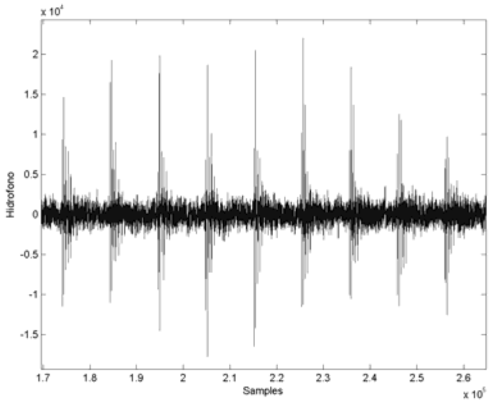

Fig 12. Datafile stored in CompactFlash memory with hydrophone as the input signal

VII. CONCLUSIONS

A new low power datalogger based on Compactflash memory cards has been developed for long term surveys to be used in the new Ocean Bottom Seismometers (OBS). The compact and reduced size of the complete offers more space for batteries. The 24 bits digitizers offer a great resolution and dynamic range necessary for marine seismic data acquisition. The Compactflash interface offers a high storage velocity as well as flexibility in increasing the overall capacity up to 14GB, small changes in the software driver can push up the capacity to the desired size.

However, lab tests have shown that the crystal OCXO frequency is highly stable with temperature but power consumption can be minimized by replacing the OCXO with a TCXO (Temperature Compensated Crystal Oscillator) with the same output frequency. Cirrus logic CS5378 digital filter with an integrated phase locked loop allows the use of timing modules with lower output frequency.

Acknowledgments

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