Development of the dual-channel frequency meter for measurements with hydrostatic pressure sensor

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Abstract. The paper describes the process and the results of development of the dual-channel frequency meter, which function is to measure the output frequency generated by bottom-mounted pressure sensors. The sensors are actively used to monitor the marine environment. AVR family microcontrollers were used as the computing core of the presented device. This solution allows to obtain far lower power consumption, which is especially important when operating with no industrial power supply system in the coastal zone. As a result, we can deploy a reliable monitoring equipment capable of long-term saving data and if necessary transmit it for further processing. The developed frequency-meter is able to continually record the ambient temperature, atmospheric pressure and dynamically varying output frequency, which depends on hydrostatic pressure (sea level). To obtain more accurate data, we implemented a frequency measure method called reciprocal counter with lower relative error not affected by value of the output frequency. A laboratory experiment has been conducted, which confirms the suitability of the developed frequency meter for field-oriented conditions.

1. Introduction
One of the scientific researches of the Institute of Marine Geology and Geophysics is a coastal wave monitoring for identifying dangerous marine phenomena. Long periodic wave registration is conducted with special wave recorders, which have sensitive elements constructed on the basis of crystal oscillators, which output vibrating frequency changes depending on hydrostatic pressure. The recorders are waterproof, which makes it possible to mount them on seafloor for continuous measurements. There are two monitoring methods: cable systems and autonomous wave registration. For the second method, we use the autonomous waves recorders (AWR) intended for long-term periodic registration of the absolute pressure of the sea. It is not connected to the coastal measuring construction and data is saved in non-volatile memory, which is read only after removing the AWR ashore [1]. The power supply is provided by internal battery enough for long periodic measurements.

The cable systems consist of the hydrostatic pressure sensor with a cable communication line connected to a coastal construction that measures the output values of the sensor. As a result, the system can record all the data in real time with further transmission of the information for analysis. In contrast to the AWR, the advantage of the cable system is no loss of the recorded data with losing the sensor, which may occur due to sea waves, ice and other reasons [2]. However, the cable system requires a communication line between the sensor and the coastal measuring construction and, considering the lack of the power supply system in coastlines, it must have a backup power source. In
order to make the measuring process less complicated, we should decrease the amount of cables used for communication and powering the sensors. To simplify the problem, it is recommended to use the frequency output sensors, which can be connected with one coaxial load-bearing cable [3]. Meteorological condition must be taken into account with wave registration, which results in using meteorological station, that also requires its own power supply making it more difficult to install the measuring equipment. Based on the above, when installing a cable monitoring equipment, we have not only to record meteorological condition and the output frequency with required discreetness within certain range, but also make its power consumption low enough for long-term measuring with powering by either a small-capacity battery or alternative source of energy like a solar panel with an energy accumulator.

In order to install the monitoring equipment and carry out the experiment, the standard solution is a complex of a personal computer, PCI timer/counters and digital meteorological station [4]. Computer parts and software must be modified to meet required conditions [5]. This method is not optimized since a PC has an excessive computational capability compared to its high power consumption for study of the wave processes.

The developed dual-channel frequency meter is the measuring coastal low-power device, which function is to record the output frequency of the hydrostatic pressure sensors, atmospheric pressure and temperature with data accumulation in non-volatile memory. The paper describes the developing process of the device, its block diagram and the implemented method of frequency measuring.

2. Development of the dual-channel frequency meter
2.1. Block diagram
The measuring device presented in this article is based on microcontrollers (MC) as the «intellectual» core, that decreased the power consumption of the scheme from several amps to milliamps. Its electrical characteristic makes it possible to operate with its own power source in any coastal zone with no industrial power supply system. It has an SD card as the data storage, real time clock module for saving data with time series and a barometer module for meteorological parameters.

The block diagram of the frequency meter is shown in figure 1. When conducting an experiment with several sensors, the equipment must provide the simultaneous measuring and recording of the values [6]. Usage of the personal or industrial computer could be the universal solution since modern processors have high frequency rate and software or hardware multithreading. Usage of the microcontroller can lead to a data loss or an asynchronous measurement of the frequency which is not valid for the experiment. Considering the fact, that it takes time to record the data packet to the SD and an error may occur when two events must be handled, we have taken a decision to use three separate MCs connected to the common I2C bus.

For frequency measurement two separate slave ATmega8-16PU MCs are used. The slave MCs have hardware timer-counters which are able to count the voltage impulses and the time between them that can be used for period measurement. It is more advantageous than the usage of mass-produced timer-counter for personal PCs characteristics of which don’t exceed the used ones.

A piezoresistive absolute pressure sensor LPS25HB is used for detecting the absolute pressure and the ambient temperature. It is a digital output MEMs barometer with communication through I2C bus. A real time clock module (RTC) is connected to the common bus in order to obtain time reference for the recorded values. It has its own power source (battery of CR2032 type), which makes it possible to count the time after the main power source shutoff. The RTC is used to make the frequency measurements simultaneous in order to obtain strongly identical discreetness for both sensors. The RTC has an integrated temperature-compensated crystal oscillator (accuracy of 2 ppm) which is used to configure the sample rate of the frequency meter. The frequency output of the oscillator can be selected by the I2C bus master. The synchronization signal is connected to the slave MCs, which perform the simultaneous frequency measurements with a sample rate chosen by a user for an experiment.

The central component of the scheme is the main ATmega32A-PU MC. It reads all the needed data from peripherals, forms a data packet with further transferring the information to the SD. According to the SD card specification, it can enter SPI bus mode, which makes it compatible with MCs of AVR
family through SPI bus regardless of SD manufacturer or its classification. When using an SD in the PC it requires a special program driver to identify it as a memory space for file recordings. The MC uses its own data structuring on the SD without a file system. Data placed in the storage is a large thread of bytes with no information where it begins or ends. Since the MC does not use a file system for data recording it results in no files on the SD when plugging it in a PC. If an SD falls into a wrong user, one cannot read the information. We created our own software desktop application to read the data from the storage and convert it into usual files for further analysis. It was not one of the technical requirements but it can be an additional feature. The main purpose of rejecting file systems is to increase the speed communication and make it reliable for long-term accumulation. An SD card of 8GB capacity is enough for more than a year of accumulating, which meets the requirements of instrumental experiment.

![Block Diagram of Dual-Channel Frequency Meter](image)

**Figure 1.** The block diagram of dual-channel frequency meter.

### 2.2 The method of frequency measurement

The frequency measuring method must cover the range and the resolution of the frequency generated by the hydrostatic sensors. The hydrostatic sensors produced by Russian company «SCTB ELPA» (Uglich, Yaroslavl region) were used to define the requirements to the frequency meter. The sensors have frequency range of 300─3000/42000─48000 Hz with error of ±0.06%.

The accuracy of the frequency measurement depends on the used frequency reference Fref (figure 2). Two crystal oscillators of 2-ppm accuracy have been used as the reference signal. There are many measurement methods, for instance, a gated counter where a timer-counter counts the frequency impulses (Fin) within a certain period. Counting the impulses per one second results in the Fin frequency of one-second discreteness. The disadvantage of the method is varying of the measurement resolution with the change in the input signal.

As it is shown in figure 2, the MC counts the input Fin signal within the Gate period. As we can see, using the gated counting leads to the MC missing the Tb and Te periods (figure 2). That is why special precaution must be taken, in particular, described in the source [7]. The resolution increases with the Fin frequency rising due to the Tb and Te periods decreasing. With low values of Fin frequency, it is recommended to measure the periods of the signal with further recalculation it into the actual frequency instead of impulse counting. Using this method makes it possible to consider the Tb and Te periods resulting in lower measurement error. In contrast to the first method, the measurement resolution decreases with the Fin frequency going up. The MC is able to switch to both programming methods with the Fin frequency going up or down and in consequence getting the maximum resolution not affected by Fin signal change. Implementation of this software solution is problematic when having dynamically changing Fin frequency from two hydrostatic sensors.
The software reciprocal counter has been implemented in the dual-channel frequency meter and the final resolution remains stable regardless of the Fin frequency (figure 3) [8]. In this method the Gate period is not the time within a timer counts the Fref impulses, but it is only a sign to start the measurement, so the Fref signal is counted by the signal. The real measurement period starts at the first input signal and ends with the final one. So, if the Gate period stops, the counting keeps going until the last impulse is over. It results in the stable resolution not affected by the change in the Fref input. As we can see in the figure 3, the influence of the Tb and the Te periods is minimal. The software also considers the emergency situations when the Fref input unexpectedly disappears or it is beyond the range of the expected frequency.

3. The results
The result is the developed low-power dual-channel frequency meter which synchronously measures two input frequencies generated by the hydrostatic pressure sensors, ambient temperature and absolute atmospheric pressure. It accumulates the data as long as the SD has enough memory size. The device can be used to observe the waves in coastal zones with no industrial power supply system. The design of the device is shown in figure 4. The scheme was mounted in the container case suitable for field-oriented conditions.

A laboratory testing and a functionality checking were carried out in order to set the parameters of the constructed device. A user can monitor the status of the scheme by the led indication mounted on the top of the case. A feeder on the front is used to connect the sensors.

The output data is text files in lines, one of which has the values for one measurement, for instance, for one second. The information can be easily imported in Microsoft Excel program or any other suitable one for operating with a large mass of data.
Figure 4. The design of the frequency meter with two connected sensors.

The completed instrumentation complex with the developed frequency meter and its mechanical and electrical characteristics is shown in figure 5. As we can see, there are two sensors placed on the sea bottom at a close distance from the shore where the frequency meter is set.

Figure 5. The instrumentation complex with dual-channel frequency meter.

4. Conclusion
We developed the dual-channel frequency meter for wave monitoring with its power consumption low compared to analogues. Usage of the microcontroller unit makes it possible to reject personal and industrial computers as a solution for instrumental observations. Due to the simple construction, it was possible to develop and construct the device directly in the research equipment sharing center of the Institute of Marine Geology and Geophysics. It is not only important to perform an experiment for estimating the waves characteristics but also to accumulate the experience of implementing the equipment similar to the one described in the paper.

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