Portable compact cold atoms clock topology

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Abstract. The compact frequency standard under development at USP São Carlos is a cold atoms system that works with a distributed hardware system principle and temporal configuration of the interrogation method of the atomic sample, in which the different operation steps happen in one place: inside the microwave cavity. This type of operation allows us to design a standard much more compact than a conventional one, where different interactions occur in the same region of the apparatus. In this sense, it is necessary to redefine all the instrumentation associated with the experiment. This work gives an overview of the topology we are adopting for the new system.

1. Introduction
The use of cold atoms results in a significant improvement in the stability and accuracy of atomic frequency standards by reducing the effects inherent to the atoms velocity [1-3]. However, the size of the atomic fountains is incompatible with some applications, like industry and space, which require a compromise between size and performance. Because of this demand, we decided, in the context of embedded systems, to develop a compact clock with Cs cold atoms.

Our research group has been working intensively to establish various experiments of frequency standards and to consolidate partnerships for the development of national references in Brazil [4]. This is crucial for a country aiming stronger influence worldwide and that needs to reinforce strategic areas, such as defense and national industry. The project of the compact frequency standard was divided in three main stages. The first two have already been completed and in this work we will describe towards the third stage.

2. New apparatus – reducing instrumentation volume
The compactness of this kind of frequency standard is achieved by an operational mode purely temporal, instead of having different regions like atomic fountains (preparation, interrogation, detection). Indeed, during each cycle Cs manipulated in a single area: the microwave cavity.

A portable atomic standard is being developed with an instrumentation designed specifically for this role. Each part should play with minimal complexity and use hardware resources in order to allow compactness. It is then necessary to reduce the volume of sub-systems, such as laser drivers, microwave synthesizer, small-sized vacuum system and data acquisition.
3. General system topology

Our standard works with a cyclic process, where the atoms are trapped, cooled, interrogated and detected, successively. All the sequence process is realized using digital and analog signals that control acousto-optical modulators, microwave pulses, fluorescence detection and microwave signal corrections. A computational platform is used to process data, setup the sequential steps and user interface, working directly on the control of the closed loop operation.

In order to achieve robustness we decided to operate independent subsystems that have individual processing and are monitored by a supervisory interface. This defines a distributed architecture for control, monitoring and interface subsystems as diode lasers and microwave synthesizers.

Figure 1 is a general illustration of the topology for the portable standard in which the components operate independently, supervised by an embedded computer platform and connected using a data communication.

![Figure 1. Overview of the system topology, with the supervisory action performed by the embedded computer platform and the subsystems operating with some degree of independence.](image)

We adopted the LPC1768 microcontroller (NXP) [5] as a base processing unit because of some of this features. It has CANBUS native communication port, that allows the implementation of a robust communication network [6]. This microcontroller is being used in the laser systems, generation of control signals and acquisition.

The supervisory system is responsible for graphical user interface, setting parameters and microprocessor systems management, recording and analysis of the data obtained. Consists of an embedded computing platform able to communicate with a remote computer by universal serial bus (USB), also communicates with the microcontrollers in each module using CANBUS network.
The choice of an industrial communication protocol (CANBUS) is due to the fact that it has reduced cabling, real time support for data transmission rates, possibility of use of various network points and multi-master approach.

CANBUS network has been tested and validated for LPC1768 microcontrollers using the MBED development platform [7]. We are now developing the proprietary message protocol, specifically for use in our experiment.

The acquisition of analog data makes the voltage reading of the atomic fluorescence and sends to the processing unit the data obtained in synchronism with the remaining clock operating procedure. This data is set by the supervisory system and assigns the frequency correction for the microwave synthesizer.

4. Sample clock distribution
The internal clock system has the function of generating reliable signal updates for the subsystems. They must share the same sample rate signal, avoiding temporal differences between the phases of the operating cycle.

We therefore based on an 100 MHz oscillator, which is already part of the microwave synthesis, i.e. our sampling clock for the microcontrollers are intrinsically coherent with the atoms interrogation signal. Figure 2 shows in a block diagram how such system is composed.

The use of an oscillator belonging to the microwave synthesizer provides a very reliable signal. It is an OCXO (oven controlled crystal oscillator - Wenzel) with +13 dBm output level at 50 Ω impedance, stability of 0.1 parts per billion per day after 30 days of continuous operation [8].

The 100 MHz signal is then divided by a power splitter with 10 outputs (Minicircuits PSC-10-1) and amplifiers (Minicircuits MAV11). We obtain thus 10 outputs at 100MHz with +10dBm. One of these outputs is derived for the input sampling signal of a direct digital synthesizer (DDS - AD9912 Analog Devices) which provides 12 MHz signal which is also split and amplified, feeding the sampling clock of the LCP1768 microcontrollers.

We use a 12 MHz clock for the LPC1768, since all libraries are prepared for this rate, which is internally multiplied and provides a frequency of 96 MHz. Figure 3 shows the preliminary phase noise measurement of the splitter and amplifiers, working at 100 MHz.
5. Conclusion
We have been developing a compact system to be used as a portable reference for frequency signals. The core idea is the use of cold atoms as a high performance and reliable clock source. We are developing various embedded distributed systems, aiming that the apparatus has the flexibility of modular systems, allowing to make changes in hardware configurations.

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