ADVANCED CLOCKS FOR PTTI

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Abstract

Recent developments in clock technology have offered significant new capabilities for PTTI users. At the same time, PTTI users are seeking better clocks with smaller size, lower weight, and lower power. They are also looking for alternatives to GPS as a means of obtaining time of day. This paper describes the developing needs and responding technologies.

INTRODUCTION

Today's sessions of the PTTI Meeting describe new clocks and timing capabilities for PTTI technology. The purpose of this paper is to provide an overall perspective of where PTTI needs and technology are going.

USER NEEDS

Defining user requirements for timing in military systems has long been a challenge for government planners and technology providers. There are a number of reasons for this. One of the biggest has been that time use is often not obvious to the user. Systems level developers tend to treat time as a utility much like rack space and electrical power. As long as it is available, it is not flagged as a major developmental issue to the government sponsor. The fact that timing has not surfaced as a problem does not necessarily imply that the system has a low accuracy time requirement. In fact, time needs at the millisecond or higher are sometimes the ones that get the most attention.

Even though there always seems to be a lag in the accuracy requirements, factors such as size, weight, and power do surface quickly. Recent examples are the internal clocks used in battery powered Global Positioning System (GPS) receivers. In order to be able to acquire the Y (military) code directly and take advantage of its better anti-jam performance, the user needs time and position accurate enough to reduce the receiver's search space. These receivers need a clock that can maintain time to an accuracy of milliseconds for as much as several days in field conditions. While an ovenized crystal oscillator or small rubidium atomic standard can meet the time requirements, they are large and consume several watts of power. Similar problems drive the design of clocks for use in orbiting spacecraft **[1-3]**.

The remaining user need that drives clock choice and design is holdover performance. GPS has been used to great advantage to discipline clocks, allowing crystal oscillators to serve as Stratum one clocks in telecom systems. However, when GPS is not available, the user's clock may no longer be adequate. The user has two choices, install a better clock or find an alternative to GPS. The U.S. government has expended considerable effort in both directions **[4,5]**.

AVAILABLE TECHNOLOGY

There are many clocks available using technology already in production. It is possible that some of these are adequate to resolve many users' needs. The only thing missing is matching requirements to what's on the shelf. Crystal oscillators come in a broad range of size, power, weight, and performance. Vendors have continued to refine their offerings. Similarly, in the last several years, a number of new, small rubidium clocks have become available. These clocks seem strongly tailored to the telecom industry with small form factors, although operating power remains near previous levels. Commercial cesium and hydrogen maser clocks continue to be available. Cesium product lines now include new generation clocks and models designed specially for the telecom environment. Ion storage clocks are in use in the NASA/JPL Deep Space Network, but are not commercially available **[6]**.

Alternatives to GPS continue to receive attention and there have been efforts to make GPS and GPS receivers more robust. LORAN has been given additional longevity. Stein et al. **[7]** reported very good timing performance. Military receivers now typically contain technology that allows direct acquisition of the GPS Y-Code when position and time are available.

NEW INITIATIVES

One of the most widely reported new initiatives for clocks is the Defense Advanced Research Projects Agency (DARPA) Chip Scale Atomic Clock (CSAC) program **[8]**. CSAC has the ambitious goals of providing small atomic clock level stability at greatly reduced size, weight, and power. Virtually all of America's clock laboratories and manufacturers are involved. At the 35th Annual PTTI Meeting, papers on laser diodes for small clocks and three small rubidium cell clocks were presented. Additional reports were made at the Joint Meeting of the IEEE Frequency Control Symposium and the European Frequency and Time Forum meeting in June 2003.

The Office of Naval Research (ONR) began a University Research Initiative (MURI) on clocks using laser resonances in 2002 **[9]**. Until recently, laser clocks had shown great potential, but had limited practical application due to the difficulties of translating optical frequencies to the RF frequencies needed by most applications. The key development has been the laser comb **[10]**. The comb generates a set of laser frequencies referenced to a stable RF source. Beating the laser clock output with an adjacent frequency in the comb spectrum allows a direct comparison of the RF source to the laser clock **[11]**.

Work is continuing on an optically pumped cesium beam clock for future GPS applications at Symmetricom **[12]**. Optical pumping is particularly attractive in space applications because of the potential of trading weight for performance. Since the heavy state selection magnets in traditional cesium beam tubes are replaced by laser diodes, the designer can keep the same level of performance at reduced weight or lengthen the interaction region for improved stability at the same weight.

Another ONR initiative has resulted in a small, lower power rubidium clock by Kernco. In Figure 1, Dr. John Kim, ONR sponsor for the work, holds the new device, which is much smaller than any currently available rubidium clock. The difference in the clock that makes the reductions possible is the use of coherent population trapping, which they refer to as "dark line" technology. Traditional rubidium gas cell clocks use a bulb excited to a plasma state by an RF discharge. When interrogated by microwave energy at the proper frequency, the transmission of light from the bulb at specific wavelengths is attenuated. The Kernco clock replaces the discharge lamp with diode lasers, does not require an RF cavity, and uses an entirely different interrogation scheme **[13]**. The net result is smaller, lower power clock with performance comparable to a simple gas cell clock.

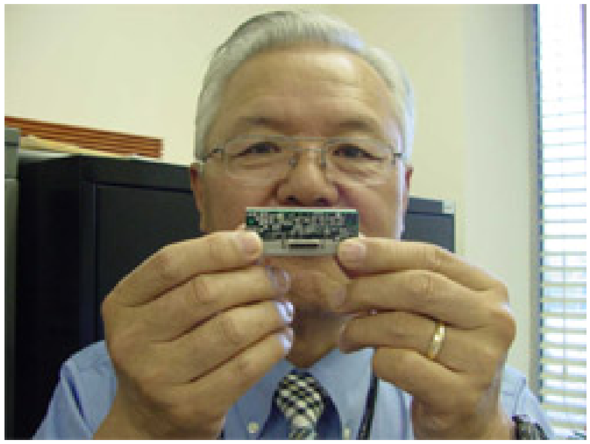

Figure 1. Kernco CPT Rb Clock.

The Space and Naval Warfare Systems Command has funded a Small Business Innovative Research (SBIR) program with Syntonics to develop a clock created from an ensemble of small, low-power crystal oscillators. The Pico Clock engineering unit shown in Figure 2 has four small crystal oscillators and a measurement capability to determine their relative offsets with respect to each other and any available external reference. It also contains a processor that ensembles the individual oscillators to produce an optimized output. Initial performance data has shown the ability to hold time to within 2 microseconds over 23 hours after a 12-hour disciplining period **[14]**. More work remains to complete the effort.

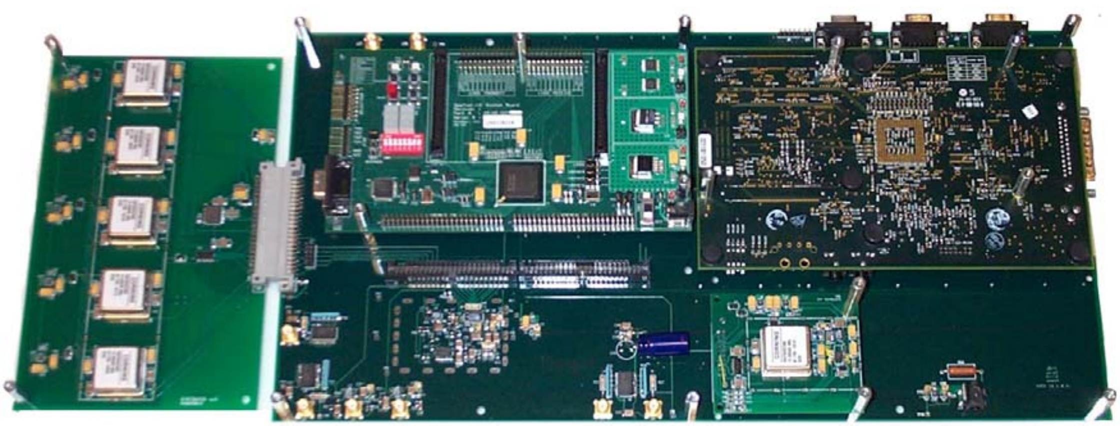

Figure 2. Engineering Model Pico Clock.

The use of laser-cooled atoms is yet another growing clock technology area. These clocks have the advantage of much longer interrogation times and very low Doppler shifts compared to uncooled designs. Cesium fountains have been built and put into operation at many of the world's primary standards laboratories and play an important part in their times scales **[15-17]**.

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