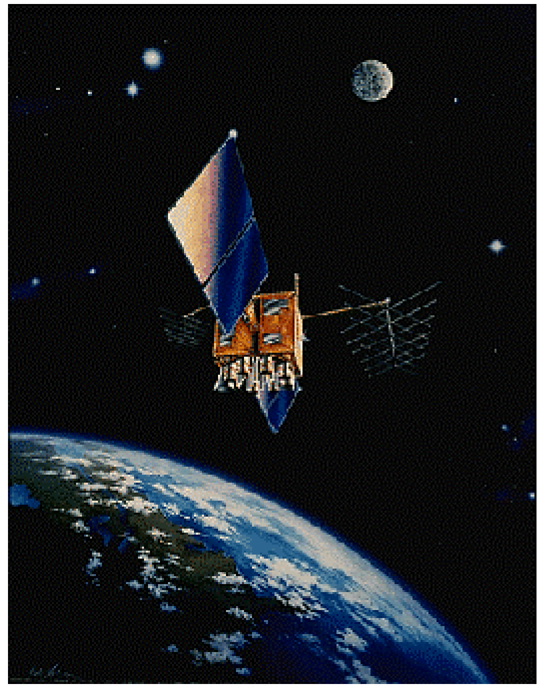
PICO Advanced Clock for Precision GPS Holdover Timekeeping



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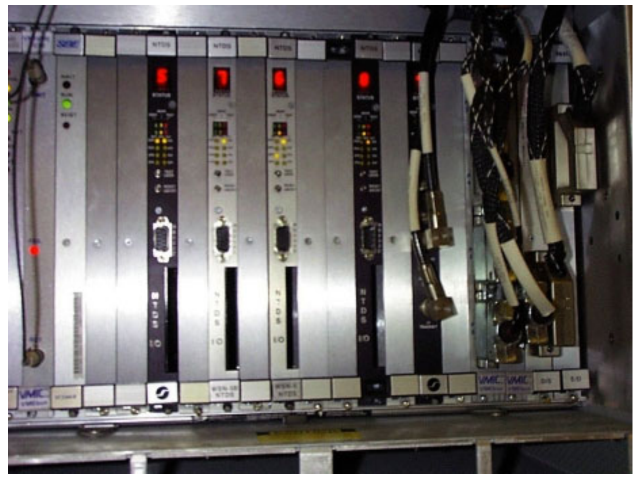
PROBLEM STATEMENT

The U.S. military requires precise timekeeping to support communications, sensors, targeting, and information distribution. In some applications, an atomic clock is used as a precision clock; more commonly, a precision oscillator disciplined by the Global Positioning Satellite (GPS) system is used. Over the past decade, the U.S. military has become increasingly dependent on GPS and this trend will continue. The advantage of GPS is that it provides a precise (sub-microsecond) common time reference for all branches of the service; the disadvantage is that GPS is vulnerable to outages caused by enemy threats (e.g., jamming) and unintentional malfunctions. This drives the need for a reliable, robust time and frequency source that sustains precise timekeeping even during GPS outages ("holdover timekeeping") – Syntonics' ***"PICO Advanced Clock".***

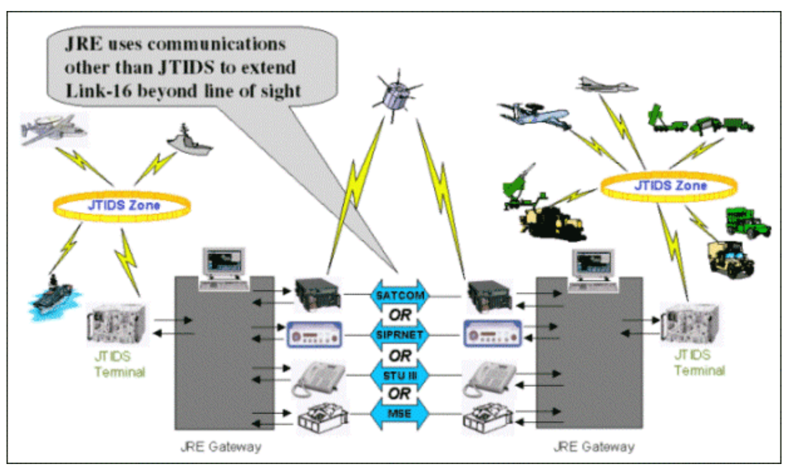
The U.S. Navy has taken the lead in pursuing a technology capable of providing GPS holdover timekeeping. Under a Phase I SBIR contract, the Space and Naval Warfare Systems Command (SPAWAR) selected Syntonics to demonstrate the feasibility of its PICO Advanced Clock concept – a timekeeping system using multiple oscillators that are measured while GPS is available and used to sustain reliable, robust sub-microsecond timekeeping when GPS is interrupted. After successfully completing Phase I, Syntonics was chosen to prototype the PICO Advanced Clock under a Phase II SBIR contract. During Phase II, Syntonics is developing a prototype advanced clock ensemble adaptable to both the Navy's Navigation Sensor System Interface (NAVSSI) and Link-16 terminal applications. Phase II began in May 2002 and is scheduled for completion in late 2003.

From there, Syntonics will identify and pursue the many applications for this technology within the U.S. military and commercial marketplaces.

In its 2001 Phase I solicitation, the Navy combined two program requirements for improved precision timekeeping – NAVSSI and Link-16 terminals. Each of their problem statements are individually addressed below:



NAVSSI. NAVSSI (AN/SSN-6) is a tactical navigation suite scheduled for installation on 169 combatants in the Fleet. It collects and distributes precise navigation and time data to shipboard users. The NAVSSI Real-Time Subsystem (RTS, shown at right) does not have a precision holdover timekeeping capability. The systems' clock is currently a single 10-MHz oven-controlled crystal oscillator disciplined by the GPS timing signal. The NAVSSI engineering staff at the SPAWAR Systems Center in San Diego reports the existing clock drifts noticeably (milliseconds over a few hours) when GPS is interrupted. They also anticipate the current clock will not adequately support future microsecond-level timing requirements for "hot starting" precision GPS-guided munitions (PGMs). "Hot starting" enables an immediate acquisition of GPS after firing the PGM. It is imperative the PGM acquires GPS as early in its flight as possible, to minimize its vulnerability to jamming. The requirement for precise "hot start" timing information will support GPS-guided munitions such as ERGM, Tomahawk, Standard Missile-3 (SM-3), and Land Attack Standard Missiles (LASM).



Link-16. Link-16 is a radio communications protocol that provides real time data communications, situational awareness and navigation, and in some cases digital voice, in a jam-resistant, crypto-secured manner. Joint Tactical Information Distribution System (JTIDS) and Multi-functional Information Distribution System (MIDS) terminals use the Link-16 protocol.

Link-16 terminals use an oven-controlled crystal oscillator as a frequency reference and separately perform minimal timekeeping functions in software; they do not currently have a precision holdover timekeeping capability. Link-16 terminals require a precise knowledge of time in order to support their time synchronous operation and a high accuracy Time of Arrival (TOA) measurement capability. When a terminal is turned on, time synchronization to the local

Link-16 network is achieved in two steps, coarse and fine synchronization. A Relative Navigation (RelNav) function can provide munitions-quality accuracy, but its performance is highly dependent on the ability to maintain a precise knowledge of system time. This requires very low time drift characteristics during clock and position measurement intervals. Unfortunately, the 10-MHz oven controlled crystal oscillator used to establish system time does not have drift characteristics sufficient to meet the requirements of many users. Minimizing the frequency drift error in Link-16 terminals to microsecond levels will allow the RelNav capability to be used in ICBM and other applications where long flight times are a critical mission requirement.

WHO CAN BENEFIT?

Any commercial or government organization with an application or platform that depends on GPS for precise timekeeping and/or requires highly accurate and coordinated knowledge of time. In addition to the U.S. Navy's NAVSSI and Link-16 applications, examples include:

Aviation. Air-traffic control; precise airfield and landing aid to airports; precision all-weather approaches (WAAS); tightly coupled aircraft GPS-inertial navigation systems.

Communications. Precise timing for network security protocols; wide-area synchronization of high-speed networks; precise timing and synchronization for wireless local loop systems; synchronization of power plant generators for electrical phase matching throughout power grids; validation of information transmission (precision time stamping); precise timing and synchronization for CDMA systems

Military. Precision-guided munitions; Airborne Warning and Control System (AWACS) platforms; Joint Surveillance Target Attack Radar System (Joint STARS); submarine atomic clock performance monitoring.

BASELINE TECHNOLOGY

Strengths and weaknesses of current time/frequency technology. A single free-running oscillator provides the holdover frequency and timekeeping capability in both the NAVSSI system and current Link-16 terminals.

NAVSSI timekeeping currently drifts noticeably when GPS is not available. This drift will not adequately support future timing requirements for “hot starting" precision GPS-guided munitions (PGMs). Also, the current NAVSSI system also cannot directly sense an oscillator malfunction, so a partial failure that degrades shipboard timekeeping can go unobserved.

Link-16 terminals cannot currently support Relative Navigation (RelNav) because their single oscillator drifts too much to meet the requirements of many users. Also, current

Link-16 terminals cannot sense an oscillator malfunction, so a partial failure that degrades network synchronization performance and local timekeeping can go unobserved.

PICO comparison to existing single-oscillator applications

Characteristic	Single Oscillator	PICO Advanced Clock
Precision	Can only maintain precise time when an external precise time reference is present	Maintains precise time for hours after an external precise time reference is removed
Time/frequency drift	Cannot compensate for oscillator drift	Compensates for drift in all connected local references, include customer-supplied clocks
Robustness	Partial or complete oscillator failure causes complete loss of time and frequency capability	Partial or complete oscillator failure, including in a customer-supplied clock signal, results in minimal loss of time/frequency capability
Reliability	No self-monitoring or reporting capability	Sophisticated self-monitoring and reporting
Flexibility	Single-purpose device	Can use clock signals from existing atomic clocks, if available, protecting current investments in time / frequency references

TECHNOLOGY DESCRIPTION

PICO features, advantages, and benefits. The PICO Advanced Clock technology provides precise, low-drift, robust, reliable and flexible holdover timekeeping, as well as providing stable precision frequency reference:

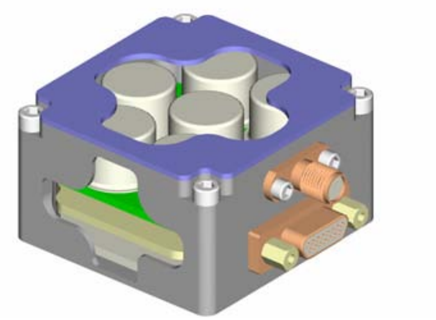
- **Precision** results from PICO's ability to synchronize within a few nanoseconds to an external time source, such as GPS or a Network Time Reference.
- **Low-Drift.** After synchronizing to an external reference such as GPS, PICO compensates mathematically for any drift in its clock ensemble (including customer-supplied clocks), sustaining precision timekeeping for extended periods if the external reference is interrupted.
- **Robustness** results from an architecture where any oscillator's partial or complete failure (including in signals from any customer-supplied clocks) only slightly degrades the performance of the unit.
- **Reliability** results from PICO's self-monitoring and reporting.
- **Flexibility** results from PICO's ability to include existing customer devices, such as atomic clocks, to participate in the ensemble timekeeping.

CURRENT STATE OF DEVELOPMENT

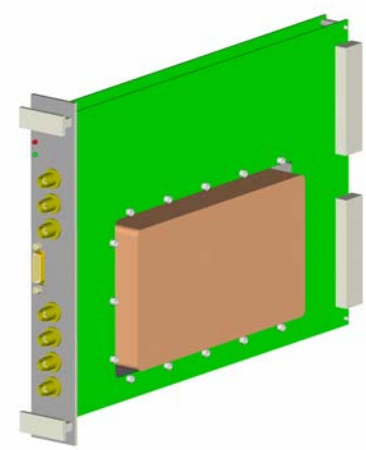
Phase I of the PICO Advanced Clock project was completed in September 2001. Syntonics proved the feasibility of an innovative approach to achieving minimum frequency drift and good holdover timekeeping for NAVSSI and Link-16 applications by using an ensemble of quartz oscillators and an adaptive Kalman filter controller.

In Phase II, Syntonics is developing and testing the a benchtop prototype and demonstrating real-time hold-over timekeeping with no operator intervention or data post-processing. The heart of the PICO prototype is the Time Measurement Unit (TMU) and Central Processor Unit (CPU) with its algorithm processing software. The TMU and CPU implement, in hardware and software, oscillator data gathering and adaptive Kalman filter operation. Clock testing will be completed in late 2003.

PICO—Link-16 Terminal Concept



PICO—NAVSSI Concept



Syntonics will require additional non-recurring engineering (NRE) funding to convert the PICO proto-type to the specific "form, fit and function" required by NAVSSI and Link-16. Conceptual designs are shown at right. Once funded, the NAVSSI NRE effort will take approximately nine (9) months. It is anticipated that SPAWAR will perform vibration and other rigorous testing on this unit at that time.

REFERENCES

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WHEN THE TECHNOLOGY WILL BE READY FOR USE

A production version of the PICO Advanced Clock technology in a customer-specific "form, fit and function" can be ready to use in 2004.

ABOUT THE COMPANY

Syntonics LLC is a "technology transfer spin-out" of the Space Department of The Johns Hopkins University Applied Physics Laboratory (JHU/APL). Founded in 1999 and operating as a fully independent commercial company, Syntonics is owned by its employees and The Johns Hopkins University. Syntonics is located in Columbia, Maryland, halfway between Washington, D.C. and Baltimore.

Syntonics is focused on research and development (R&D) of wireless and precision timing electronics for military and intelligence applications. Syntonics is continually improving its ability to perform as a DOD R&D contractor and has earned these credentials:

- DCAA-approved government accounting system
- ISO 9001:2000 registered Quality Management System
- DSS-approved SECRET security clearance.

The company's recent and current customers include the U.S. Special Operations Command (SOCOM), the Space and Naval Warfare Systems Command (SPAWAR), the Naval Surface Weapons Center—Carderock Division (NSWC-CD), NASA/Goddard Space Flight Center (GSFC), JHU/APL, the Institute for Defense Analysis (IDA) and the Maryland Procurement Office.