U.S. ARMY PTTI/FREQUENCY-CONTROL ACTIVITIES AND PLANS

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ABSTRACT

The primary mission of the Frequency Control and Timing Branch, ETD Laboratory, is to develop the oscillators and clocks needed by evolving Army communications, navigation, surveillance, identification-friend-or-foe (IFF) and electronic warfare (EW) systems. The main emphasis is on the development of small, low-power, high-precision quartz crystal oscillators.

This paper summarizes the current (1986) in-house and contractual programs and the directions that future programs are expected to take.

Army Needs:

Surveillance, C^3, navigation, IFF and EW systems currently under development require high-stability quartz crystal and atomic oscillators for use as (spread spectrum) system clocks and frequency standards. For many evolving systems, the commercially available oscillators lack the required long-term stability, vibration resistance, radiation hardness, small size, low power consumption, and fast warmup capabilities.

Without high-stability clocks, tactical radios and other C^3 systems will not be able to employ fast frequency hopping and/or high-speed pseudonoise sequencing for electronic-counter-countermeasures (ECCM) and will have inadequate autonomy (i.e., radio silence) capabilities.

Without vibration-resistant, low-phase-noise oscillators, aircraft, tank, and other tactical radars will have inadequate capability in their intended (vibrating) environments; navigation systems will have inadequate capability in the projected jamming environments; and strategic C^3 systems will suffer from high-bit error rates, long acquisition times, and high logistics (recalibration) costs.

Army generic requirements are summarized in Figure 1.

REQUIREMENTS

Oscillators/clocks for Army systems that are:

- **Stable over a wide range of environmental parameters (temperature, acceleration, radiation, etc.)**
- **Small size**
- **Low power**
- **Fast warmup**
- **Low life-cycle cost**

Frequency accuracy requirements currently being addressed range from ppm/yr (TCXO) to pp10^9/yr (RbXO).

Figure 1 - Army requirements.

Army Programs:

Army R&D programs are aimed primarily at the three oscillator types shown in Figure 2. Numerous technologies are being explored (see Figure 3) in order to improve the performance of the three oscillators. The crystal resonator, a ceramic flatpack-enclosed SC-cut resonator, is the main frequency-determining element in the crystal oscillators.

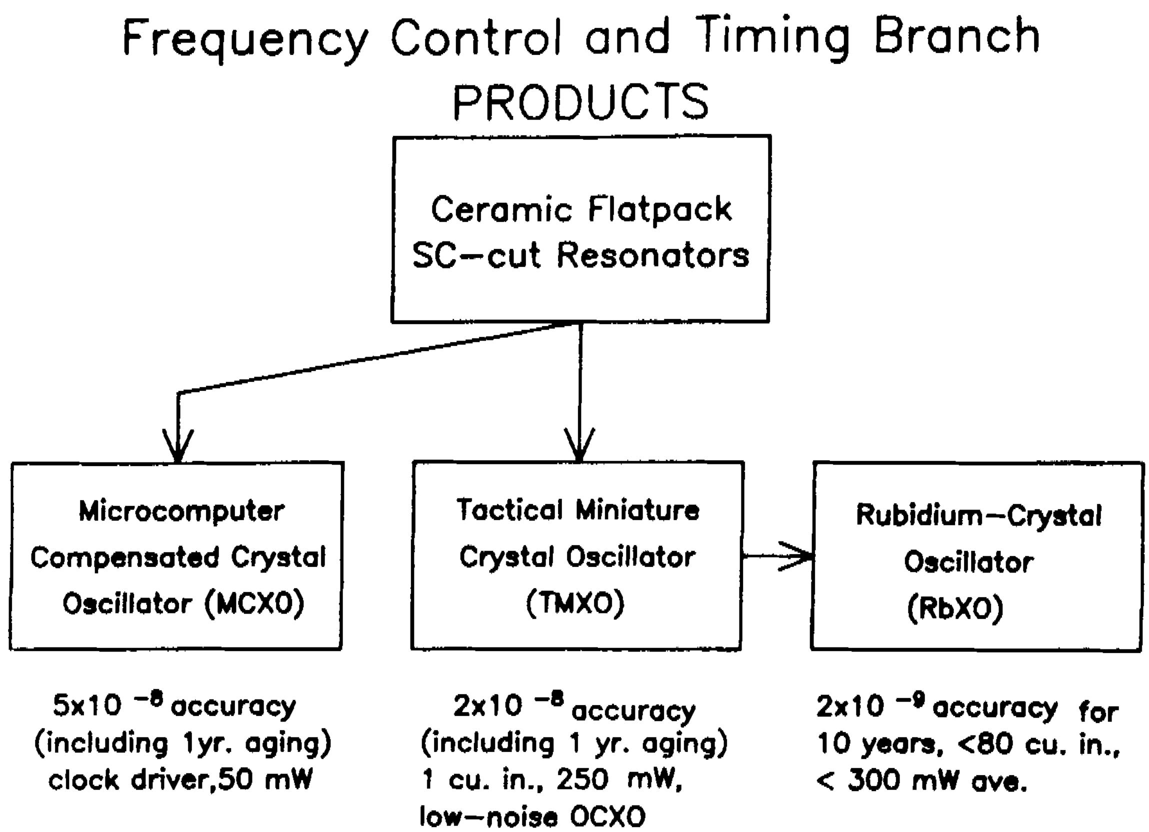

Figure 2 - Army R&D program's hardware products.

The microcomputer compensated crystal oscillator (MCXO) consists primarily of a dual-mode oscillator that employs a high-precision SC-cut resonator and digital circuitry. Currently, the MCXO is a clock driver; future models will be both clock drivers

High-Stability Resonator Development

- Acceleration Resistant Resonators, 6.2, In-house/GEND*, FEI**
- Low-Hysteresis MCXO Resonators, 6.2, In-house/GEND
- High-Stability OCXO Resonators, 6.2, In-house/GEND
- Aging Studies at High and Low Temperatures, 6.2, In-house
- Lateral Field SC-Cut Resonator Development, 6.2, FEI
- High-Stability Ceramic Flatpack Resonators, MM&T***, FEI/In-house
- Etching Studies and UHF Resonators, 6.2, PTI****, In-house
- Ultrahigh-Purity Quartz & Radiation Hardening, 6.2, Sawyer Res. Prod/ In-house
- Finite Element Calculations on Acceleration Resistant Resonators, 6.1 (ARO), Princeton University
- Ultrastable "Maxi" Resonators, 6.2, FEI/In-house
- Resonator Test Beds (vibration, aging, hysteresis, noise, etc.), In-house
- MIL-C-3098 Revision

*General Electric Neutron Devices Dept.
**Frequency Electronics, Inc.
***Manufacturing Methods and Technology Program
****Piezo Technology, Inc.

Figure 3-1 - High-stability resonator development programs.

High-Stability Oscillator Development

- Dual-Mode Oscillators, 6.2, In-house, SGC*
- Microcomputer-Compensated Crystal Oscillator (MCXO), 6.2, FEI and Brightline Corp.
- Tactical Miniature Crystal Oscillator (TMXO), 6.2, PTI
- CAD of Crystal Oscillators, 6.2, SGC
- Low Phase Noise Crystal Oscillator, 6.2, Frequency & Time Systems
- Vibration/Acoustic Effects Suppression, 6.2, In-house
- Oscillator Test Beds, 6.2, In-house
- Oscillator Evaluations, 6.3 & 6.4, In-house
- Rubidium-Crystal Oscillator (RbXO), 6.2, Efratom & EG&G/In-house
- Moderate Precision TCXO, 6.7 (MACI), PTI
- MILWATCH, SBIR Contract, Mayflower Communications Co.
- Active Vibration Isolation, SBIR, Manatech Assoc.
- MIL-0-55310 Revision

*Systematics General Corp.

Figure 3-2 - High-stability oscillator development programs.

and frequency sources. The MCXO has major advantages over conventional temperature compensated crystal oscillators (TCXO's) for the following reasons:

- The MCXO circumvents the need for pulling the crystal frequency and, therefore, permits the use of stiffer SC-cut crystal units that have superior thermal hysteresis characteristics.

- The MCXO allows resonator self-temperature sensing, using a dual-mode oscillator. A thermometry signal is generated and processed with the precision required for high-accuracy compensation.

- The trim effect, i.e., the degradation in temperature compensation due to frequency adjustment, is eliminated.

- Automatic recalibration features can be designed into the MCXO algorithm. An offset can be stored in nonvolatile memory following simple injection of an external higher-accuracy reference signal.

Whereas TCXO accuracies have been limited to about 1 ppm per year over the $-55^{o}C$ to $+85^{o}C$ temperature range, the MCXO has achieved 5×10^{-8}; 1×10^{-8} accuracy, with 5 mW power consumption, appears to be possible in the foreseeable future.

The tactical miniature crystal oscillator (TMXO) is a small (~$20 cm^3$) oven-controlled crystal oscillator. It consumes 250 mW of power at -55°C, about 140 mW at 20°C, and correspondingly less at higher temperatures. Its warmup time is 3 minutes to within 1×10^{-8} of final frequency. The TMXO's size, power, and warmup represents an order-of-magnitude improvement over conventional oven-controlled crystal oscillators. The TMXO's feasibility has been proven. Over 100 have been produced and tested to date. Current programs are aimed primarily at improving the TMXO's phase noise, especially under vibration, and at reducing production costs.

The rubidium-crystal oscillator (RbXO) is a rubidium frequency standard-crystal oscillator hybrid. Whereas in most atomic frequency standards the crystal oscillator is an integral part of the atomic standard, in the RbXO the crystal oscillator is external to, and separable from, the atomic standard. The crystal oscillator is kept running continually; the rubidium standard is turned on periodically but infrequently, just long enough to stabilize and adjust the crystal oscillator's frequency. The RbXO can have the long-term stability of the rubidium standard with the low power consumption of the crystal oscillator. It is intended primarily for applications where the energy consumption of the standard must be minimized (e.g., in battery operated equipment).

A listing of specific tasks in effect during 1986, including names of contractors where applicable, can be found in Figures 3-1 and 3-2. (Several of the contracts include multiple tasks.)

Strategic Plan:

A hierarchy of frequency standards/clocks, with a minimum number of types, will be established in order to satisfy the needs of the whole range of Army users (C^3, radar, position location, navigation, IFF, EW). It is anticipated that a class of six standard oscillators, ranging in accuracies from parts in 10^6 per year to parts in 10^{12} per year, will be able to satisfy nearly all future Army needs. These six oscillators are enumerated in Table I in order of increasing frequency accuracy. It is not feasible to reduce the number of types to fewer than six in the forseeable future because, as the frequency accuracies increase, power consumption, size, and cost also increase. For example, at the two extremes, a typical analog TCXO consumes 50 mW of power, is 0.5 in^3 in size, and costs \$50 vs. a cesium frequency standard's 50 W, 2000 in^3 and \$40,000. The frequency accuracies indicated are those of production models, not developmental models.

Planned Army programs are aimed at improving the accuracies of oscillator types 1 to 5, while reducing size, weight, power consumption, and warmup time and at the same time increasing short-term and long-term stability, vibration resistance, and radiation hardness. Army program plans do not include high performance atomic standards (type 6 in Figure 4), since such standards are being addressed by Air Force and Navy programs.

Large numbers of inexpensive clock oscillators, with accuracies in the 10^{-5} to 10^{-4} range, will also be required. Since industry is well-equipped to provide such oscillators, the only Army activity aimed at these oscillators is standardization.

TABLE I. HIERARCHY OF OSCILLATORS.

OSCILLATOR TYPE	ACCURACY* PER YEAR (1990-1995)	TYPICAL APPLICATIONS
1. Analog TCXO	$\sim 10^{-6}$	Frequency control in tactical radios
2. Microcomputer Compensated Crystal Oscillator (MCXO)	$\sim 10^{-7}$	Spread spectrum (ECCM) system clock
3. Tactical Miniature Crystal Oscillator (TMXO)	$\sim 10^{-8}$	Navigation system clock/frequency standard
4. Low Phase Noise, Acceleration Compensated TMXO	$\sim 10^{-9}$ (with 10^{-11} per g)	MTI radar
5. TMXO/Atomic f Standard (Rb) Hybrid	$\sim 10^{-10}$	Bistatic/multistatic radar, satellite terminals
6. High Performance Atomic Standard (Rb or Cs)	$\sim 10^{-12}$ to 10^{-11}	Strategic C^3, EW

*Includes environmental effects plus one year's aging.

QUESTIONS AND ANSWERS

GERNOT WINKLER, UNITED STATES NAVAL OBSERVATORY: Am I correct in understanding that, in your view, the greatest technical problem is in the reduction of phase noise in an operational environment?

MR. VIG: Currently that seems to be the most pressing problem. Unfortunately that is also the area where there is the least knowledge among system designers. We run into the situation continuously where we talk to people who do not understand the effect of vibration on phase noise. It is an educational problem. Perhaps the new MIL standard will help because that will force them to consider phase noise since we have several sub-paragraphs under phase noise; phase noise at rest, phase noise under vibration, phase noise under static acceleration, phase noise under acoustic levels, an important problem because people use vibration isolation systems and the acoustic noise goes right through, the vibration from the tables goes right through. Vibration isolation is the least preferred method of getting rid of the problem.