

PRECISE TIME TECHNOLOGY FOR SELECTED  
AIR FORCE SYSTEMS: PRESENT STATUS AND  
FUTURE REQUIREMENTS

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ABSTRACT

Precise time and time interval (PTTI) technology is becoming increasingly significant to Air Force operations as digital techniques find expanded utility in military missions. Timing has a key role in the functions of communication and identification as well as in navigation. A survey of the PTTI needs of several Air Force systems will be presented. Current technology supporting these needs will be reviewed and new requirements will be emphasized for systems as they transfer from initial development to final operational deployment. The PTTI program activity in the Signal Processing and Timing Devices Section of the RADC Solid State Sciences Division is reviewed, and a survey is presented of areas of mutual interest to Government and industry in planning and execution of PTTI research and development programs.

INTRODUCTION

This paper reviews the status of selected systems requiring Precise Time and Time Interval (PTTI) technology: systems in which the Air Force has either sole sponsorship or participates jointly with the Army and Navy. They include PTTI applications in space, in aircraft and on ground-based platforms. Future needs in these programs are addressed in terms of generic performance improvements, the need for which has been produced by operational constraints such as the time interval for which a specific communication code key is to be used, the allowable period between resynchronization, or the logistics of the platform carrying the system of interest. The opportunity is taken to describe the evolution of the time and frequency

activity at the Solid State Sciences Division of the Rome Air Development Center (RADC) and to review the scope of the current PTTI activity from the technology-base/system-support viewpoint. Finally we address areas of common interest, and occasional concern, to the PTTI community which detail some of the factors which control our ability to provide, in a timely way, the PTTI technology required for Air Force programs.

#### CURRENT PROGRAMS

Several acquisition divisions of the Air Force Systems Command: - the Electronic Systems Division (ESD), Aeronautical Systems Division (ASD), and the Space Division (SD) are involved with acquisition programs requiring precision timing devices.

The space segment of the Global Positioning System (GPS) program office at SD has completed the launching of the first six satellites of the total constellation. These satellites carry redundant rubidium and/or cesium frequency standards. The clock status of the GPS space segment is to be described elsewhere<sup>(1)</sup> in these proceedings and therefore a detailed discussion is unnecessary in this paper. The user segment equipment is based on quartz oscillator technology which employs a common module for placement in aircraft avionics packages, in rack-mounted equipment in submarine and surface vessels, and in compact electronic units for backpack and mobile ground equipment. In comparison with the relatively benign environment of the space segment, the oscillators for the user segment will be subject to the vibration, humidity, temperature and g-force extremes of the high-performance aircraft or rough-terrain vehicle platform. Dual contractors are now involved in full scale development programs which should deliver about 100 units. Production of the user equipment will require many thousands of oscillators.<sup>(2)</sup>

The Joint Tactical Information Distribution System (JTIDS) is a secure, jam-resistant, high-capacity, flexible digital communications systems under joint development of the military services. It provides for position location, communication and identification functions via a time-division multiple access architecture. Timing requirements for this system can be satisfied with quartz technology.<sup>(3,4)</sup> The JTIDS acquisition process is divided into three classes of terminals. The Class 1 terminal is for use in ground command and control centers and in long-

range surveillance aircraft. This terminal is now in production. Acquisition of the Class 2 terminal, which is scheduled for fighter aircraft deployment, is in the source selection process for full-scale engineering development. The Class 3 terminal, not yet initiated for acquisition, is intended for surface-based mobile users.

The United States Identification System (USIS, formerly the NATO Identification System, NIS), a tri-service effort, is in the first stages of the acquisition process. The USIS program involves both improvement of the Mark 12 IFF system now in use and the development of an entirely new IFF system designed to be secure, jam-resistant and interoperable within the NATO community.(5) The system will require clocks for ground control centers and AWACS aircraft, for tactical aircraft and helicopters, and for mobile ground-based users such as tanks, trucks and surface-to-air missile crews. For the timing system, the objective is to procure the highest quality clock commensurate with system economics. The goal is to minimize the code validity interval, thus reducing the interference options available to a jammer. The frequency stability to be specified forms part of a NATO agreement scheduled for completion by the end of the year. As is the case for the GPS user segment, the number of oscillators required will run to many thousands. Therefore it is highly probable that quartz technology will play the major role in surface based and, perhaps, airborne platforms. Several studies of the clock problem for USIS have been completed and development work on several aspects of oscillator technology are planned for this fiscal year.

The 616A program is the Air Force support to the Minimum Emergency Essential Communications Network (MEECN) and is a survivable very low frequency communication system for use by the Strategic Air Command. The principal clock application is for synchronized communications between the command structure, launch control centers, and SAC aircraft. Current status of the clock is a cesium-based unit which was developed with Air Force funding. The latest design is a portable (1 hour battery capacity), radiation-hardened device which is used to carry and insert system time into the communications hardware of network participants.

The SEEK TALK program is a secure anti-jam voice communication capability for Tactical Air Force use. The system is presently in full-scale engineering development under a dual contract award. The SEEK TALK scenario includes

timing performance which requires frequency stability at the high technology end of quartz capability. Both rubidium and advanced quartz technology are considered to be candidates for the SEEK TALK oscillator. The near-term solution to the SEEK TALK requirement is vested in the HAVE QUICK program. The latter system is an ECCM modification to certain ground-based and airborne radios which gives them a frequency-hopping capability.<sup>(8)</sup> A randomized channel selection sequence which is changed rapidly inhibits an enemy interceptor or jammer from joining the communication system because of the very short residence time of the system in any one channel. The HAVE QUICK program is based on Coordinated Universal Time in order to be able to take advantage of the TRANSIT satellite system as a means of obtaining time. Reference frequency for ground-based units is supplied by rubidium oscillators and almost all of the clocks in the HAVE QUICK system are required to hold correct time to within 3 milliseconds for mission duration. An analysis<sup>(6)</sup> of possible errors in initial setting accuracy coupled with ageing of the unit indicates that frequency recalibration would not be required over a period of five years in order to hold to the 3 millisecond specification.

#### FUTURE NEEDS

We address this topic less from the viewpoint of individual program office requirements but rather from developments which would benefit across-the-board users of PTTI technology. The importance of reviewing these topics becomes clear when we consider the 1980's as a decade when industry will be called upon to provide reliable oscillator hardware by the tens of thousands of units. When acquisition is discussed in these terms, our ability to deploy quality systems will depend to a large extent on economies of scale associated with continuing, large-quantity purchases, and the development of innovative manufacturing processes which will produce the desired equipment at prices which the acquisition divisions can afford. It is important, therefore, that substantial, serious process engineering development work be completed by the early 1980's. We believe that any plant or equipment modification plans must be finished and evaluated in pilot plant operation early enough to respond to the acquisition milestones of the programs with PTTI needs. The plant capacity topic will be addressed further in the last section of this paper.

For many systems using quartz oscillator technology, a fundamental operational choice usually emerges: whether or not to turn the unit off. If constant power is maintained, we avoid the problems associated with frequency retrace and warmup time. We pay for these benefits through providing battery backup in the case of line power failure and enough battery capacity for the stand-alone unit to maintain operation for mission lifetime. For most of the programs involving man-portable clocks, it is unlikely that continuous power will be available except for missions of rather short duration. Therefore it is important to note that improvement in the warmup time would benefit several programs which will enter the procurement phase in the 1980's. Given fast warmup, say less than 60 seconds to some narrow band around nominal frequency, the capability for tuning would complete the process of clock initialization. Without the tuning capability, the retrace of the unit must be good enough, early enough, so that the oscillator can stay within the required specification for the necessary mission period. The last few years have witnessed exciting new strides in quartz material and resonator research which are still to be fully exploited. Improved packaging and thermal controls, plus the SC-cut technology, have shown improved performance levels in terms of power consumption and warmup. Continued research and engineering effort will be needed to transfer new technologies into the small, rugged unit which will meet the military specifications of several programs.

The rubidium oscillator provides the stabilities associated with an intrinsic atomic phenomenon. Although the optical pumping system and other aspects of the physics package limit rubidium to secondary standard status, it is essentially free from the perturbations which are common with a mechanically vibrating device. We would like to see an expanded role for rubidium as a candidate in large-quantity acquisitions. This will be possible only if the price for rubidium oscillators, even in quantity procurement, is substantially reduced from current costs for military quality units. This is possibly achievable by radical design departures from state-of-the-art technology which could reduce fabrication costs. More likely to succeed are new developments in electronic configuration and physics package design which can lead to savings in the manufacturing process. Size reductions in the physics package will lead to smaller power requirements for maintaining operating temperatures: - an important factor since steady-state power requirements under temperate conditions for rubidium oscillators are five to ten times

greater than those of precision quartz oscillators. Improvements in manufacturing technology must be seriously considered as a viable avenue to substantial reductions in unit costs in large-quantity procurements.

There are now commercially available at least four, rugged, portable cesium clocks which could meet at least some of the requirements of systems needing timekeeping accuracy associated with primary standards. Given the complexity of the beam-tube design and the necessary electronics to provide a standard frequency, these devices are outstanding engineering achievements today. As with rubidium, a major driving force for broader use of cesium standards is the price factor. As demand for cesium stability becomes documented, it is in the examination and improvement of the manufacturing process where we seek the cost reductions that will permit expanded use of cesium clocks with the benefits of system performance inherent to cesium technology.

#### PROGRAMS

As part of this paper, we include a brief summary of program efforts conducted by the Signal Processing and Timing Devices group at RADC. The laboratory's involvement in this field began in the mid-1960's with fundamental solid state physics research programs in radiation-induced changes in the structure and properties of quartz. By the mid-1970's, RADC had been assigned as an Air Force Systems Command laboratory dedicated to support of the mission of the Electronic Systems Division (ESD). As C<sup>3</sup>I became the principal focus of the ESD program offices, it was natural that RADC take advantage of past work in quartz material research to assume an active role in quartz oscillator R&D. As the needs of system program offices diversified, the RADC activity extended into R&D on many aspects of quartz oscillators and atomic frequency standards. In 1977, RADC was designated as the lead laboratory for Air Force R&D in PTTI technology.

RADC now operates research, exploratory development, and advanced development programs both in-house and via contracts with industry, university and non-profit organizations. The in-house activity includes sophisticated research autoclave systems for quartz material improvement through advanced, closely-controlled growth processes. Complete facilities for characterization of quartz material and resonator evaluation are coupled with contract programs for material and resonator development. Advanced

quartz oscillator technology is supported at all levels from research to the development of hardware responding to specific system needs.

RADC has active programs in hydrogen, rubidium and cesium technology. Atomic clocks for use by the 616A and SEEK TALK programs are presently under development, as well as a program for fabrication of a prototype small hydrogen maser for master-station timekeeping applications. A joint in-house/NBS/University effort is evaluating several new approaches to the use of optical pumping techniques in cesium, rubidium and other potential atomic standards.

RADC operates a Frequency-Time Test Facility (FTTF) equipped to evaluate oscillator performance at standard atmosphere conditions, and at extremes of Mil-Spec parameters of temperature, humidity and aircraft altitudes. Measurements can also be made under Mil-Spec conditions of vibration and in a comprehensive radiation test facility which forms part of the RADC Solid State Sciences Division. The FTTF is being used to evaluate and qualify oscillators for several program offices and is considered an R&D test facility for Air Force-wide needs in time and frequency hardware.

The Electromagnetic Sciences Division of RADC includes a diversified program for research and development on SAW correlators/convolvers for signal processing applications and research efforts on high frequency oscillators.

#### AREAS OF COMMON INTEREST

In this section we address several issues which affect the ability of the Air Force to carry out the acquisition of system hardware in a timely and efficient manner. Several of these issues play a significant role in the capability of industry to respond rapidly to Air Force needs.

Program continuity is of primary importance in establishing a smooth flow of technology from the early R&D stages, through the development model sequence, to final production. Abrupt changes in fund flows, particularly at high levels in the appropriation chain, cause disruption in the work flow and interfere seriously with our ability to meet the milestones scheduled at program inception. We acknowledge that we do not have the overall view of the priorities which is available to higher organizational levels, but unexpected shifts in program support lead to deferred activity and diminished regard for program

importance. In some cases, we can blame ourselves for our inability to provide decision-makers with adequate information to allow intelligent conclusions based on complete data. Such events often lead to program deferrals and perturbations in the industrial process from which recovery is difficult and slow. It is incumbent on planners within the Government structure to ensure that adequate, significant program documentation is available both for intelligent review and to facilitate the decision-making process.

The Air Force Systems Command does not usually advocate forward-financing activity. That is, funds which are budgeted for FY80 cannot be expended in FY81. Although this is strong motivation to operate a fiscally responsive program, an unavoidable consequence is the pressure to utilize authorized funds in a rush at fiscal year end. The situation is caused frequently by the unavailability of funds for expenditure until well into the fiscal year. Even when budgeted funds are on time, the procurement process for an R&D contract can take from three to six months with the same result. The situation is frustrating to the government agency, causes serious fluctuations in flow of funds to contractual efforts, and leads to public misrepresentations in the press of what is actually taking place.

Air Force managers are keenly aware of the forces of supply and demand in the marketplace and the cost/performance benefits resulting from competition among suppliers. That is one of the reasons for multiple source development programs. HQ AFSC has exerted heavy pressure to promote competitive contracting and the fostering of multiple-sources for needed equipment. The rationale is not only to assure that more than one vendor is capable of supplying the hardware, but this policy also promotes efficiency and tight program control in the industrial community. The end result is generally a superior acquisition program for the funds expended.

The higher technology of modern C<sup>3</sup>I systems usually means higher costs per unit deployed. The impending proliferation of timing systems has been noted at the level of the Secretary of the Air Force as well as in the R&D laboratories and the acquisition divisions. RADC is involved in an attempt to consolidate program office requirements so that one or two standardized oscillators of each technology type can be used with only slight modification for a number of different programs. This activity has been stimulated by the USIS program office and participating

with RADC in this effort are the Aerospace Guidance and Metrology Center (AGMC), ERADCOM, several Navy organizations and various military program offices. We consider that an aircraft with three different systems requiring PTTI service will have higher reliability at lower costs if all the oscillators are interchangeable rather than if three independent, incompatible units are used. For those programs where many thousands of oscillators will be required, large savings can be realized by adherence to a commonality principle, and by applying extensive engineering activity to developing some entirely new and cost-efficient manufacturing processes as suggested earlier.

Finally, the US policy of government-industry-university relationships has worked somewhat adversely in the United States for certain technology areas. We consider that PTTI activity is one such area. European and far Eastern governments finance the entire birth and development of high-technology entities which finally mature enough to become stand-alone corporations in the private sector. Similarly, foreign governments have taken an active role in the sponsorship of their national academic programs and institutions devoted to precise time R&D. Such academic support provides a small but steady flow of highly-trained professionals who can enter government or industry laboratories and produce meaningful results without an extensive and time-consuming period of on-the-job training. We believe that the trend of frequency/time technology will require a formalized government effort to meet projected manpower needs efficiently. RADC, as part of its PTTI activity, is exploring the desirability and feasibility of establishing small but significant formal training programs for time and frequency R&D within the academic environment.

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