THE ALTERNATE MASTER CLOCK AND PRECISE TIME REQUIREMENTS; WHY AN ALTERNATE MASTER CLOCK?

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Abstract

The U.S. Naval Observatory (USNO) Alternate Master Clock (AMC) became fully operational on 23 July 1996. The AMC was relocated to Falcon Air Force Base (AFB) from Richmond, Florida, commencing 24 October 1995. By placing the AMC at Falcon AFB, the clock is co-located with the GPS Master Control Station and, thus, the primary means of global time dissemination. The AMC is in a key position to provide significant improvements to the various space systems operated by the Air Force from Falcon AFB. Efforts are underway to enhance the timing of GPS, the Air Force Satellite Control Network, and some TALON programs within the Space Warfare Center. The AMC will be able to provide a more reliable and robust timing source for all users at Falcon. This will eventually lead to reduced navigation errors, increased communications capability, and improvements in C4I. The areas in which the AMC will be used to enhance worldwide military operations are highlighted.

INTRODUCTION

The U.S. Naval Observatory (USNO) Alternate Master Clock (AMC) is the backup for the Master Clock maintained at USNO. The move of the AMC to Falcon Air Force Base (FAFB) occurred between October 1995 and July 1996. The AMC was previously located in Richmond, Florida. The clock was relocated for several reasons:

1. Richmond, Florida, was highly susceptible to natural occurring problems, such as hurricanes
2. Co-locate with the Global Positioning System (GPS)
3. Place in a more secure environment
4. Provide a greater, more robust backup capability.

The AMC is designed to provide precise time, on the order of 2-3 ns accuracy a day to the military commands located at FAFB. The primary user of AMC data is GPS. Additionally, the system provides timing reference signals to the 50th Space Wing communications squadron and the Air Force Technical Applications Center detachment. Plans are in place to provide precise timing reference signals to the Air Force Satellite Control Network, Space Warfare Center, and other satellite control systems.

This project was coordinated with the Air Force and serves to support the interest of both services. The AMC obtained initial operational capability in November 1995 and was made fully operational on 23 July 1996. The next major step in the development and operational use of this system occurred on 12 September 1996. On this date, the AMC provided a 5 MHz signal to the GPS Monitor Station located at the Master Control Station (MCS).

WHAT COMPRISES THE ALTERNATE MASTER CLOCK

The AMC primary equipment consists of 11 cesium atomic clocks, 2 hydrogen masers, 2 Auxiliary Output Generators (AOGs), data analysis equipment, two-way satellite time-transfer systems, and distribution systems. The two master clocks at the AMC are the AOGs, with each AOG referenced to a hydrogen maser. The master clocks are named AMC #1 and AMC #2.

Data on all AMC clocks are gathered using two separate data analysis systems: the Data Acquisition System (DAS) and the Timing Solutions Corporation Measurement System (TSCMS). The DAS compares all AMC and GPS clocks to AMC #1 and AMC #2 every 20 minutes, while the TSCMS compares the 5 MHz frequency of all AMC clocks to AMC #2 every 20 seconds. These data are used both in the time scale and for analysis of clock performance.

The AMC has three GPS receivers: two Precise Positioning Service (PPS) keyed and one Standard Positioning Service (SPS) unkeyed timing receiver. The PPS receivers are made by Stanford-Telecom and the SPS receiver is made by Allen Osborne Associates. The PPS receivers are used to monitor the GPS satellite clock performance and provide a steering reference to AMC. The SPS receiver is used to conduct common-view time transfer between the AMC and USNO in Washington, DC.

The AMC maintains the highest precision reference to UTC(USNO) using Two-Way Satellite Time Transfer (TWSTT). The means of distributing AMC to users is via a 5 MHz, 1 pps, or IRIG B distribution amplifier. Additionally, many outside users connect into the AMC using a fiber-optic cable. The AMC also has a redundant telephone voice announcing system. The phone number is (719) 567-6742. In the future, the AMC will have a computer modem capability.

The AMC #1 has maintained time to within two nanoseconds of the USNO Master Clock in Washington, DC. This is made possible using the TWSTT system. Hourly the AMC and USNO establish communications via a commercial Ku-band satellite to exchange timing data. AMC #1 is then steered towards the Master Clock using a steering algorithm developed by Paul Koppang (USNO). AMC #2 is steered to USNO(GPS) using the data provided by a keyed Stanford-Telecom receiver.

WHO NEEDS PRECISE TIME?

Many users rely heavily on precise time and precise time intervals. For instance, GPS uses time at the nanosecond level for precise navigation and positioning of military units and weapon systems. The military communication system needs precise time at this same level for the synchronization of secure communications.

Time is disseminated to Department of Defense (DoD) users by many means. USNO primary time dissemination means is using GPS, with over 95% of military users relying on this means of dissemination. GPS provides nanosecond level accuracy to users on a continuous global basis. Other methods of time dissemination and their accuracies include:

1. Two-way Satellite Time Transfer (TWSTT) (nanosecond)
2. IRIG-B (microsecond)
3. Internet (millisecond)
4. Computer modem (millisecond)
5. Voice (second)
6. PTTI Advisory Service (bulletins–postprocessed data).

BENEFITS OF THE ALTERNATE MASTER CLOCK

In the event of a loss of the USNO Master Clock, the AMC will be the time standard for DoD and will operate using an independent time scale. This time scale will be based on the 11 cesium atomic clocks and 2 hydrogen masers. The AMC time scale is automatically computed hourly and manually computed twice per week. Many of the functions of the USNO Master Clock will be performed by the AMC; however, some may be conducted at a reduced level of support.

The installation of the AMC has enabled the direct monitoring of the Falcon GPS Monitor Station cesium clock. The hydrogen masers located at the AMC allow for special testing with classified users. The hydrogen masers will maintain an accuracy of close to 80 picoseconds over a period of one week. Plans already exist to conduct a special timing test between the AMC and the Space Warfare Center. This testing should be completed within the next calendar year, with data available in 1998.

Eventually, USNO plans to establish a distributed master clock. This distributed master clock will consist of the AMC time scale integrated into the USNO Master Clock. This will result in a more robust system and should improve the overall stability of the Master Clock.

TIMING REQUIREMENTS

The discussion of requirements must be addressed when referring to precise time and its uses. The needs within the DoD include, at a minimum, the following:

1) Communications
   a) Secure and Crypto
   b) Increased bandwidth utilization

2) Geo-location
   a) Remote sensors
   b) Combat ID
   c) Cooperative Engagement Capability (CEC)

3) Navigation

4) Computers
   a) Data recording
   b) Network Time Protocol (NTP)
   c) ATM/SONET

The impact of improved timing for GPS in the future is significant. The integration of timing, from GPS, will significantly enhance the war fighters capability to meet the challenges faced by the increased operations tempo. GPS in the cockpit will allow the pilot to not only improve his navigation picture, but also improve the quality and accuracy of his intelligence picture. Improved timing on the battlefield will reduce the likelihood of friendly fire or collateral damage. Remote sensors will realize the ability to provide precise intelligence data and to communicate these data to the war fighter with greater speed and accuracy.

With the integration of good internal clocks for the GPS receivers, more reliable tracking during periodic loss of the GPS signal will be realized. These internal clocks will significantly improve the Y-code acquisition time for authorized users and require fewer satellites in view to maintain a good position.

THE PTTI MEETING AND ITS PURPOSE

Following this talk on the AMC, a significant discussion arose regarding the need for precise time and the focus of the PTTI Meeting in general. The requirement for precise time transcends many levels within DoD and the commercial market. The impact of computers on everyday life is well known; however, the need for precise time is not as well understood. For instance, the speed of a computer is directly tied to time. A 100 MHz computer will perform an internal operation every 10 nanoseconds. This is not as critical in a stand-alone mode as it is when operating within a distributed system or in a virtual engineering environment. Here remotely located computer systems must rely on accurate timing between the various systems in order to efficiently perform operations and transfer data. For commercial power companies, precise timing at the nanosecond level allows for the accurate location of a power line fault in times unimaginably short in the past.

For the military, more accurate timing translates into putting ordnance on target and minimizing or even preventing collateral damage. In order to make this a reality, time must be known and transferred at the nanosecond level. The fact that light travels at 186,000 miles per second means a nanosecond equates to about one foot in linear distance. Thus, if two or three remote sensors identify the precise time of the occurrence of a unique event, relative to their location, then the exact position of this event will be realized and effective countermeasures may be launched. This assumes the sensors are all referenced to the same time. In terms of mine warfare, precise timing and navigation will prevent the damage or destruction of an ship as it transits a mine field. Why? Because the exact location of the enemy mines will be precisely known and units will then be able to avoid this area.

In the case of ships at sea, timing is critical to communication and combat systems. For a given threat, the ship may have less then 30 seconds to detect the threat and provide the necessary response prior to suffering damage. The program manager responsible for developing this system provides the overall time line from detect to engagement to the contractors. But in many cases, the exact breakdown of the three major components in this scenario is not known or defined. Three major systems are key to the success and all rely on computers and distributed processing systems to operate properly: 1. Detection, 2. Command and Control,

3. Engagement. If each contractor designs their system to meet the overall time line (for instance, 30 seconds), then the ability of the system to counter the threat will not be realized. This problem, coupled with the additional ability to receive threat data from external sources, compounds the processing capabilities of today's computer systems. Therefore, as stated earlier, the ability of a ship to respond to the threat may very well depend on the timing accuracy of the entire detect to engage system down to the nanosecond level.

For the PTTI Meeting to be a success, the right people need to be in the audience. Today's state-of-the-art equipment and high-speed weapons demand the attention of program managers, engineers, and system designers, both in government and industry. These people are not present. After all, what is the purpose of the PTTI conference?

Questions and Answers

ROBERT VESSOT (SMITHSONIAN ASTROPHYSICAL OBSERVATORY): I share your concern about the program management; I've lived long enough to work with NASA for the last 30 years. And I find that the deterioration of program management has gone to a level now where there is more concern with the PERT and the GANTT charts and the budgets than any conceivable interest, even, or understanding technically what is going on. Program managers in the bad old days – or I should think the good old days – used to be engineers that were working in the lab. And they managed outside contractors, but they had a very clear perception of what the goals were and how to get there.

Now program management has been relegated to the MBA; and even though I'm at Harvard, I admire the school, but these are not the kind of people you want to manage technical programs. They have to be engineers at least somewhere along the line, or have access and appreciation for engineering.

WILLIAM BOLLWERK: That's correct. And that's one of the problems we do face. When I was a program manager, I had GS-13s, 14s, and 15s who had no knowledge of the engineering that they were dealing with, much less how to manage it.

JAMES CAMPARO (AEROSPACE CORP.): It seems we keep talking around this issue of a disconnect between high-level system requirements and lower-level PTTI requirements. And I guess one thought that came to me as you were speaking, would it be beneficial at future PTTI meetings to invite program managers and have a session on system requirements? Let them tell us what the overall system requirements are; and that would put us in a better position to try to translate those into lower-level PTTI requirements for them.

WILLIAM BOLLWERK: That would be ideal because then you would get the same people in the room to be able to communicate. It would have to be a classified session. But the other thing we would have to face is, what program managers do we need to invite? We need to know what systems are coming down the line. So we would need assistance from several sectors, because I know I've stood in the same spot Commander Atkinson has here and have tried to find out the requirements. I went through all these operational requirement documents, these joint operational requirement documents and none of them addressed timing. Timing was a given; it's going to be there; but none of them specifically stipulated that I have a timing requirement and I have a timing requirement in the nanosecond or picosecond or microsecond or millisecond level.

So I think if we do get the program managers in here and we get some sponsors from the Pentagon in here, then maybe we can see some of these things put into some of these documents; and then maybe we can start heading in the right direction.

LT. OMAR NAMOOS (USAF): I'll just be brief. I come from the program management community. The thing about putting requirements on timing is – somebody mentioned it earlier – timing is really a derived requirement. I as a program manager have users, war fighters who do a task in the field. And I build my requirements – at least we're trying to do it and we think it's a smarter way – is to say, "build me a box that does this." And that's specified at the performance level.

Timing is then the contractor's responsibility to say, "In order to perform this function for you, I have the following derived timing requirement." The military shouldn't be in the business of doing that.

CAPT. KENT FOSTER (USNO): As a career oceanographer and weather guesser, I'm used to being in a lot of places where people don't like me a lot because of what I have to say and the information I bring to them. That is true no place more so than it is in dealing with program managers that are building systems that are susceptible to the elements of weather in the ocean and combined effects. And after having dealt with these people for several years, I'm convinced that the big problem is that weather guessers don't make life easier for operators or for people who design systems; they make life more difficult for them because they bring them problems that they need to overcome.

And I think that's the problem that we're coming to grips with here with timing. We don't make life easier for program managers, and it's very, very easy and very desirable for them to ignore us to the extent that they possibly can and get away with it. And that's a mindset that you really have to come to grips with and to reconcile and overcome. And I think that's probably why there are not a lot of program managers here.

PHILLIP TALLEY (RETIRED, AEROSPACE CORP.): In 1992, I made a rather sustained effort to organize a session for this PTTI that would bring in various major contractors like G.E. and Lockheed and so forth to let them explain how they went about through their systems engineering to specify time and frequency, not necessarily by a specific systems, but as a corporation how they went about doing this. And I got some early indication of cooperation, but absolutely no one actually participated. And I tried rather hard.

WILLIAM BOLLWERK: It's not going to be easy to get the program managers or those type of people in here, but that doesn't mean that we should stop trying. We need to make it happen somehow.

GERNOT WINKLER (INNOVATIVE SOLUTIONS INT'L): I think the core problem is that timing is an embedded requirement. And as you said, it is left to the contractor; that means that every contractor is going to solve it in his own way. This is a very expensive procedure; duplication is a consequence of that. And that is the reason why there is a PTTI instruction – or has been – in order to take it out and make sure that there is some coordination between all these individual embedded requirements which otherwise would solve the problem of bringing time to Hawaii or Kwajalein or wherever. We have to have a concentrating, coordinating center for that.

CAPT. KENT FOSTER: I think the solution is embedded; there's no doubt about it. But I don't think that that's a reason why the stated requirement should stay embedded.

GERNOT WINKLER: No, no, I agree.

RICHARD GRIFFIN (TEXAS INSTRUMENTS): A couple comments. We're using the phrase "program managers." I think the working people who do what you're talking about are systems analysts, systems engineers. They're the ones that provide the actual working interface between requirements that come down from operational command and the technologies that exist. That's why I was asked to come to this program by my company, because that's the interface area that I work.

And the way we do it is with error budgets. As the Captain said, one of the biggest problems we face within companies and, frankly, with respect to the government, there is today a great horror about hearing about problems. If you go into a meeting and do an error budget and say, "We're going to have a problem with this," you're going to get hit hard and fast because they don't want to hear about problems; they don't want anything that they feel will jeopardize the budget cycle, will jeopardize the political acceptability of a program, they're not willing to listen to it. And, of course, it's complicated by the fact, as we pointed out, that many of them don't have the technical expertise, either because they are MBAs or they were engineers 30 years ago; and that's the technology they remember, they haven't kept up.

But I think the people you need to bring in would be for a session on systems engineering associated with time. Because in my work what I have to do is take the overall requirements, derive an error budget, and then look at what the technology capabilities are to meet that error budget and go back. But often what I go back with is bad news or poor news. And you need support from there.

RANDOLPH CLARKE (USNO): I have a thought on the idea of program managers here. I think any program managers we could get here probably don't need to come here because they've already got the idea. So we should turn it around and try to determine where the program managers are in the first place, where do they meet, and send our people to their meetings and start opening this up. Eventually, then, we will get program managers here. But we have to make an outreach to where they are. They must have meetings like this.

WILLIAM BOLLWERK: Actually, they don't. There's no central meeting of program managers. Program managers are enmeshed in their own programs to make sure that their programs are executable, as is pointed out, with the budgetary and other cycles.

And also there's the big picture of meeting with their sponsor in the Pentagon, who is the resource sponsor for their funds. And try to then coordinate meetings with the contractors in industry and the Fleet, in some cases, to make sure that everything kind of comes together.

Program managers, though you said they probably shouldn't be here – I tend to disagree with that because they're going to help come up with the solutions; they're going to force their people to come with the solutions one way or another. And if you don't include them, then they may not appreciate the detail to which people have to go through to derive some of these requirements; because, they all are derived. And if we don't derive them properly, a little nanosecond here, as you translate up into the big picture, gets lost, and pretty soon you don't meet your threat or your requirement.

HELMUT HELLWIG (USAF): Try to bridge this. I think I would ask this audience to listen to some of the comments, because if I look at the sequence of the discussion, it is as if one of the discussants hasn't listened to the previous discussant. And I wanted to endorse what you said, it's a systems engineering thing that we're talking about, not a program management thing. Let's have the definitions clear. There are meetings of program managers, and I'm participating in those; you don't talk about this kind of thing, whether it's time or any other technical detail. Time and frequency and clocks are tools of systems engineering, and in a big system they are, yes, an important tool, but one of many, many, many. And you need to get together a systems engineering forum, as you said, and try to bridge the gap between a tool of the systems engineer and the systems engineering community. Most of you are experts in the tool, and you need a link to the systems designer; that's not the program manager, a program manager is not the systems designer.

And in the future, by the way, as a consequence of acquisition from DoD, more and more of the requirements – in fact, the current goal is all requirements, as I think the Lieutenant pointed out – are performance requirements as seen by the war fighter. And it's up to the contractor and the systems engineer to translate those into their particular system. And we will not, and DoD will refrain from specifying, what clock, what time system, what interface, except if it's an interface that matters.

DARRELL ERNST (MITRE CORP.): I think I can only support what this gentleman just said. I've worked in this area for many, many years, and it's not the program managers. Program managers' eyes glaze over even when they're directly affiliated with the problem.

I feel that the problem is a lack of education at the engineering level. Many of the engineers that work these problems, these systems engineers, go to a catalog and they find a number of different off-the-shelf items that meet their requirements; if they don't, they call around until they find somebody who's willing to modify their equipment to make it work. And then they plug it together and they run their tests and they go on. And Joe White [NRL] can support me, I think he watched me try to fight a problem in the AFSCN back in the '80s when we were building Falcon Air Force Base. For years, they didn't know it, but they were operating at the half a millisecond error in their timing systems because they were transmitting their IRIG-B code upside down. Engineers looked at it almost every day and didn't know what they were looking at.

It's at the technical level that we have to solve this problem. Program managers are doing their job, they fight Congress and they fight all the different people that are forcing requirements creep on their projects; they don't have time to worry about something to them that's a tiny little part of a huge system. We did a requirements analysis on some comm protocols, and you go ask program managers, or even their systems engineers, and say, "What are your comm protocol requirements?" And they say, "What are you talking about, what's a protocol?"

And the same thing with time. We've got the problem here, not at the program manager level. You go to these contractors; the contractor is going to take a junior engineer and put him on this because we're talking about one rack of equipment; he goes to the TRAK microwave catalog and he picks out his timing equipment; and he's solved the problem, he thinks.

JOHN VIG (ARL): Maybe what we need is a product liability law for military systems. Because when General Motors builds a car and gas tanks start exploding five years later, General Motors is still responsible, and gets sued, and they know it gets very expensive if they design a defective product. Unfortunately, in military systems it doesn't work that way. After a system is delivered and things start going wrong, guess who pays? It's always the taxpayer who pays, not the contractor who delivered that system.

So, in an ideal world, I agree with Lt. Namoos that the government should not be specifying how a system should be implemented; they should be specifying only what the system should do. That's absolutely the correct way of doing things. But if you do it that way, then you also have to have much better specifications for the system; and that specification probably should include lifetime beyond delivery of the system and incentives for ...

CAPT. KENT FOSTER: Not being one to shy away from controversy, I'll add one comment to this. I hear all that about the systems engineers, and I don't disagree with it. But again, system engineers are the solvers of the problem.

In my mind, there clearly has to be some accountability maintained over the systems engineers. And the person who is going to stand up and explain why the end performance level doesn't match the requirement isn't going to be the systems engineer, it's going to be the program manager. And, therefore, the program manager needs to get more involved in addressing the requirement to the performance level.

WILLIAM BOLLWERK: And to complement what the Captain just said, I think a clear example of that is Block IIR and the satellite that's going up in a couple months. It's going up with one set of clocks on it; it was specified to have two different types of clocks: rubidium, cesium. And the fact is that it's going up with only rubidiums.

So if we have a problem with those clocks and that one set of system, then we've completely thrown away a satellite in space, it's completely useless for navigation if those clocks were to fail. And that's where if the program manager was probably more aware of the implications between rubidiums/cesiums and having two different types of clocks on one satellite so that you don't suffer a manufacturing defect failure or something else, then probably we wouldn't be in that situation. We'll have to see what happens when the satellite goes up, but that's a potential problem with doing something like that.