APPLICATIONS PANEL

Panel Chairman: Dr. Arthur O. McCoubrey, National Bureau of Standards

I'd like to welcome you to the panel discussion this morning. The panel this morning will focus upon the requirements for precise time and time interval technology from the viewpoint of the prospective users. Systems users and people who are responsible for the design of broad systems that depend on this technology.

As you recall, the panel discussion yesterday focused upon requirements from the perspective of planners. And I expect that there'll be a good deal of give and take between these two areas and the different perspectives.

As moderator, I'm not going to take any significant amount of time, what I would like to do is introduce the members of the panel and let them speak for themselves. We've asked each of them to speak for five or six minutes to identify their areas of interest as users, to identify the role or their corporations, or their organizations, and also to identify the areas of requirements as they see them from their perspectives.

I'll just introduce people now and I'll let each of them speak for themselves concerning the details of their involvement.

First, on my right is Bill Walker of Pan American Airways, and he represents that community of interests in the area of space vehicle test ranges.

Next is Ed Stein of Westinghouse in Baltimore. Ed's area of interest is communications. And on beyond Ed is David Clayton of Offshore Navigation, Incorporated. Ed's area of interest is navigation in a particular high frequency navigation. He'll have more to say about that.

Then next is Commander William May, the Commanding Officer of the United States Coast Guard, Omega Navigation Systems Operation Detail.

Next is John Illgen. John is a member of Kaman Sciences Corporation in Santa Barbara. John is also a member of the Board of Directors of the Wild Goose Association, an association of LORAN-C users.

Beyond John is Milton Boutte, also of Kaman Sciences, but in Albequerque, and Milton's area of interest is communications.

And on the end of the table, opposite me, is Dr. Mohan Ananda, Aerospace Corporation. And Dr. Ananda is going to bear the torch for the Global Positioning System, NAVSTAR, and will reflect the perspective of the three segments of NAVSTAR: the Space Segment, the Users' Segment, and the Control Segment.

I'll be a little bit arbitrary about starting this off, and I'm going to ask Commander May to give his summary of his interest and involvement first.

OMEGA NAVIGATION SYSTEM SYNCHRONIZATION

CDR William K. MAY, USCG

Commanding Officer,

OMEGA Navigation System Operations Detail

OMEGA

OMEGA is a long-range (10,000 nm), ground-based, very low frequency (VLF) navigation system which operates in the 10 to 14 kHz navigation band. Eight transmitting stations carefully sited throughout the world broadcast omni-directional, time-multiplexed 10 kW signals on 10.2, 11.05, 11.33, 13.6 kHz plus one frequency unique to each station. The timed transmissions allow easy identification of both station and phase. Phase measurements from three or more stations provide users with latitude and longitude to an accuracy of four nautical miles for 95% of the time. It is estimated that there are about 15,000 worldwide users of OMEGA. Early receivers were single-frequency, line of position (manual) instruments which required significant operator understanding and intervention in order to yield a position fix. However, today we have complex, multiple-frequency, state-of-the-art receivers (automatic) using microprocessors to convert OMEGA phase information directly into a latitude and longitude readout. Although marine user acceptance has been relatively slow due to early use of manual receivers coupled with an incomplete OMEGA system, the airborne community has dramatically increased its use of OMEGA within the last several years. Finally completed in August 1982 when Australia became operational, OMEGA is the most cost-effective, worldwide radionavigation system in existance today.

OMEGA STATIONS

Eight OMEGA transmitting stations are strategically located around the world. Each station has redundant timing and control equipment, two transmitters, and an antenna to ensure high operational availability. The antenna system is one of two types: A vertical tower approximately 1400 feet tall supporting 16 transmitting elements; or, a valley span antenna typically 10,000 feet in length. Each station radiates 10 kW on all transmitted frequencies. Station specifics are given in Table 1.

Table 1: OMEGA Transmitting Stations

Letter Designation	Location	Date Operational	Antenna Type
A	Aldra, Norway	DEC 1973	Valley Span
B	Monrovia, Liberia	FEB 1976	1400' gnd twr
C	Haiku, HI	JAN 1975	Valley Span
D	LaMoure, ND	OCT 1972	1400' hot twr
E	La Reunion Is. (FR)	MAR 1976	1400' gnd twr
F	Golfo Nuevo, Argentina	JUL 1976	1400' hot twr
G	Woodside, Australia	AUG 1982	1400' gnd twr
H	Tsushima Is., Japan	APR 1975	1500' hot twr

ONSOD

The OMEGA Navigation System Operations Detail (ONSOD) was established in 1971 in Washington, D.C. as a U.S. Coast Guard Headquarters Unit receiving technical direction from the Chief, Office of Navigation, U.S. Coast Guard. The mission of ONSOD is to provide worldwide coordination, day-to-day operation, and electronic maintenance support for the OMEGA System. The operational authority of ONSOD over OMEGA stations not on U.S. soil, but operated by partner nation agencies, is formalized in various Bilateral Agreements and supporting Technical Agreements between the governments of the partner nations and the United States.

ONSOD consists of 30 military and civilian personnel organized into three divisions. The Navigational Science Division is responsible for planning, organizing, directing and coordinating the acquisition and analysis of OMEGA data. It performs analytical investigation in such areas as semi-empirical signal modeling, improving propagation corrections, ionospheric modeling, and improving signal coverage diagrams. The Engineering side of the Engineering and Operations Division provides special maintenance and support of station electronics equipment, develops and installs field changes to station electronics equipment. Day-to-day control of station operations, navigational warning notices, and back-up synchronization control are the responsibility of the Operations side. The Comptroller Division performs the planning, programming and financial execution of ONSOD's annual $5 million budget.

OMEGA SYSTEM SYNCHRONIZATION

One of ONSOD's principal missions is to ensure the OMEGA system is maintained within established timing tolerances. All OMEGA stations transmissions are synchronized, so that one station's signals do not interfere with signals from another station. Futher, the accuracy of the system is dependent upon the stability at which phase-synchronized signals are transmitted. In order to ensure stability, the phase of each OMEGA transmission signal is controlled such that the phase relationship between signals from the eight stations does not deviate more than ± 2 us from the (estimated) system mean. The maintenance of this tolerance is called internal system synchronization.

Additionally, the OMEGA System is referenced to an external time standard: Coordinated Universal Time (UTC). To provide this synchronization, each station employs cesium frequency standards and considerable electronic circuitry within the Timing and Control Set. This circuitry provides and controls the proper timing signals to insure that each OMEGA station's synchronization (EPOCH) is correct relative to OMEGA standard time.

OMEGA standard time commenced on 1 January 1972 at 0000Z, when the phase of all OMEGA station transmissions were going through zero in the positive direction at all OMEGA transmitting antennas. At this instant OMEGA standard time was conincident with UTC. At present the OMEGA epoch leads UTC by intergral number of seconds. Approximately once every year, UTC is retarded one second to compensate as atomic time and astronomical time are not congruent and also because of the continuing slow down in the earth's rotation. The OMEGA epoch is not retarded as this would cause navigation receivers to lose synchronization. The OMEGA epoch and UTC were coincident at 0000Z, 1JAN72. Since then 11 leap seconds have occurred, the last being on 1JUL82.

OMEGA EPOCH is defined as the beginning of each and every thirty second period from when OMEGA standard time commenced. OMEGA EPOCH occurs at the beginning of every third signal format at seconds 00 and 30 (on OMEGA standard time). The ten second transmission pattern, the OMEGA Navigation System signal transmission format, is held to within ±5 us of UTC through comparison with LORAN-C signals (A, C, D & H), one-way OMEGA phase monitoring (OMEGA station D only), synchronized television signals (G), and perodic portable clock visits to the OMEGA Stations (OMSTAs). Future plans call for external time comparison with timing signals from the NAVSTAR Global Positioning System, with an anticipated accuracy of ± 1 us using a low-cost, C/A only receiver.

System synchronization is purely a technical function performed by the Japanese Maritime Safety Agency (MSA) (since 17OCT77), and duplicated by ONSOD to provide a back-up capability. Each OMEGA station monitors the signals id receives from other stations in accordance with the assigned Station Operations Bill. Every Monday, this, plus other data, is provided to MSA and ONSOD by each station in their Weekly Station Data Message. Each Tuesday, ONSOD prepares and sends to MSA a message which lists Delta OMEGA corrections gathered from the four nothern OMEGA stations (A, C, D, H) and four Loran-C chains plus one-way phase monitoring by U. S. Naval Observatory of Station D. Each Wednesday, ONSOD runs the SYNC2 Computer Program, compares results with the MSA Weekly Synchronization Message (also received Wednesday at ONSOD), investigates and resolves any discrepancies between the two SYNC2 results, and sends a message to MSA listing ONSOD SYNC2 results. Sending MSA the ONSOD SYNC2 results confirms to them our ability to function as a back-up, plus acts as a check to maintain system tolerance levels.

Further, each Wednesday MSA computes and sends each OMEGA station a Synchronization Directive listing ACCUM and CORRECTION values. This data is entered into the stations' cesium timing standards to maintain the transmitted phase to within ± 2 us of mean epoch of the OMEGA System.

THE FUTURE OF OMEGA

Since the OMEGA System presently provides worldwide coverage, no expansion in the number of transmitting stations is expected. However, an expanded transmission format has been implemented. This expanded format involves the addition of a fourth navigation frequency (11.05 kHz) to further help resolve lane ambiguity, and the addition of a frequency unique to each station to provide positive station identification.

Differential OMEGA, still in the development stage in the United States, could provide another opportunity for improved OMEGA service. France, Canada, and the U.S. have all investigated the degree to which this technique can improve the accuracy of an OMEGA position fix. In fact, France already has over 15 differential OMEGA stations in operation today.

The Department of Defense has adopted OMEGA as an enroute navigation system for aircraft and ships. However, assuming NAVSTAR GPS becomes operational in 1987, the Army and Air Force plan to phase out OMEGA use by 1992. The Navy is presently evaluating continued use of OMEGA as a back-up to NAVSTAR GPS.

It is likely that OMEGA will be in operation at least until the year 2000. Six of the eight station have been established on non-U.S. territory through Bilateral Agreements between the U.S. and partner nations. Because of the international character of the system and international user acceptance, operational decisions regarding the system must be coordinated with the partner nations. Thus, any disestablishment of the OMEGA system would be conditional upon international acceptance and in accordance with the applicable sections of the Bilateral Agreements.

APPLICATIONS PANEL

Panel Chairman: Dr. Arthur O. McCoubrey, National Bureau of Standards

Thanks very much Bill. I'll ask you to be thinking of the questions that you'll be wanting to ask these people after we've gone through the introductory statements, and I'm going to ask the panel for questions of each other, and then I'll be asking for questions from the audience, so, please make it clear to me when you have questions.

I'd like to call next on John Illgen to talk about the LORAN area.

APPLICATIONS PANEL

Panel Member: John D. Illgen, Kaman Science Corporation, Field Testing Technology Group

I work for Kaman Sciences Corporation, in the Field Testing and Technology group and we've been evaluating the potential accuracy of a number of navigation systems over the years. These have included both terrestrial and satellite systems.

I've been asked to focus on the LORAN-C system for this discussion today, and I'd like to discuss some of the improvements where we are with respect to LORAN-C.

Many of us have been using it for timing purposes. The potential of using LORAN-C for timing has been discussed in literature over the years. First of all, the LORAN-C system is a hyperbolic system. It certainly does have a textbook shape pulse. Any of you have ever monitored it know that when we monitor the 30 microseconds from the start to the first pulse, it's easily controlled.

The coverage for this particular system includes 20 million square miles. The CONUS is covered by approximately 80%, including Hawaii and Alaska, and the expansion of the system over the past few years has been enormous, and I've listed the countries that are either negotiating now, or have included LORAN-C over, just the past few years.

On the next view foil, I'd like to show what the present day coverage in fact looks like. The dark area on this particular view foil represents the ground wave coverage, and the outlining area represents the sky wave coverage, and, as we can see, a very large fraction of the earth's surface that is covered by this particular system.

A particular chain consists of a master and two or more secondaries. Over the years, the time synchronization, the system has been improved dramatically. Each, almost each, TRIAD has its own control monitor, which basically measures the time differences in real time from the master and secondary pairs, and compares those with established mean values at that monitor site.

The chains as we had found in tests and experiments is held to within 20-25-35 nanoseconds for the TD's. These are the RMS standard deviations that I am mentioning.

The cesium timer and transmitter variations are approximately 15-20 nanoseconds. That's a very quick rundown of where the LORAN-C system is now. I should mention that there have been some improvements as far as signal-to-noise ratio. The base lines of the system are shorter. Transmitters are going solid state. The geometry in many of the areas has been improved, there's been careful planning placed into these issues.

In recent years, we have discovered that 50 nanoseconds, or 50 foot accuracy, for this system is possible. And today, the system is being used in the Delaware Bay area for navigation purposes in some of the very tight channel areas just to give you a feel for the accuracy potential of the system.

And, there's a great deal of interest in the offshore industry with LORAN-C. I'm sure other gentlemen will be addressing that question.

APPLICATIONS PANEL

Panel Member: David A. Clayton, Offshore Navigation

I'm the key sea manager for Offshore Navigation. We've been in the radio positioning business for thirty-six years, so, we feel we do have a lot of experience. I feel it's a little humorous that we were not known in the PTTI community until someone discovered we had in excess of seventy cesium standards.

We presently have eighty-three.

Naturally, someone became a little curious as to what a company like ours was doing with all these cesiums. This lead to the outcome where we're beginning to become familiar with the PTTI community, and it familiar with us, and the purpose of the community. I think we'll both benefit from this get-together. And for those who are not familiar with us, I'll explain briefly some of the functions we have for cesiums.

One of our main systems, we take a simple 1/2 to 2 magahertz hyperbolic phase comparisons radio positioning CW system and use it in the range-range mode. This is similar to the Coast Guard's LORAN-C chain. However, we work with much shorter base lines, and shorter ranges. Approximately 100 miles, this allows us to produce greater accuracies for the offshore oil industry and other people who require these accuracies.

Unlike the Coast Guard, we do not have sophisticated automatic time correction systems. We have a sort of clumsy monitoring system which detects clock drifts as they occur. When they fall out of tolerance, we dispatch a technician to each site who makes a C field correction. This is one of the most important problems we are faced with: how to keep these base stations synchronized at the lowest possible cost.

We're experimenting at the moment with microprocessor controlled micro-stepper connected to a modem, which in turn is connected through our land line. This land line is connected to a microprocessing control central monitoring station. The problem becomes a little more complex when we have to correct our cesium control transmitters which are installed in offshore platforms, which don't have the convenience of land lines.

We presently have six offshore platforms and thirteen on-site sites (on-shore sites we should say). The mobile tracking vessels offshore are passive, and their drift is determined by an on-board navigation computer, which is computing the ship's position from four simultaneously tracked ranges. The tracking of four stations also allows us to compute and correct the on-board clock drift. This assumes that the four stations are synchronized.

At the risk of sounding repetitive, to previous discussions, I feel our future requirements are the most obvious: one, that is stability; two, lower costs; three, less sensitivity to temperature changes; four, smaller physical dimensions; five, greater reliability; six, lower power consumption;

seven is an area I'm going to be cautious on. I'd like to see cesiums with built in microsteppers, but I believe someone is already doing that; and eight, more economical costs for replacement of parts: tubes, etc. We've found in the last ten years that replacement parts have skyrocketed for cesiums and it's something that's causing us a lot of concern.

One point that does need addressing, I feel, is the question of why cesium standards do not follow the trend of other electronic equipment that is: becoming less costly and more efficient with mass production. As far as the cesiums are concerned, they generally become more expensive to purchase and maintain with time.

We're also looking at other methods of keeping our transmitter clock synchronized, such as GPS, meteorburst, and other systems.

I would also like to mention that not only the HF system that I referred to, we do have a very, very large interest in the LORAN-C community, hyperbolic long range-range applications. And we feel that the requirement of cesium is going to be a long one in both our range-range and our hyperbolic systems.

Hopefully by the inventors, manufacturers and users getting together, such as at this meeting, we can look forward to an ever improving technology in the PTTI world.

Thank you.

APPLICATIONS PANEL

Panel Member: Dr. Mohan Ananda, Aerospace Corporation

As you all know, the Global Positioning System is currently in the concept and engineering sytem evaluation phase. We have six satellites up there, out of which four are in good health, and of the other two satellites, one of the satellites' clock is really bad, the other one is marginal.

We may have another satellite which will be launched early April or May. Also, the next phase, which is the operation phase, hopefully will begin late '85 or early '86. The Air Force office is currently negotiating with Rockwell Internation for the clock buy. It's planning to buy 28 satellites for the operational phase.

Now, each of the block two satellites will have two rubidium and two cesium clocks. In the future we may fly one hydrogen maser as an experimental clock.

Now, the performance of the space rubidium and cesium clocks have been extremely good. I have a chart to show. I have two.

The chart shows the clock prediction error for both NAVSTAR VI and NAVSTAR V, and NAVSTAR V has a rubidium clock and NAVSTAR VI has cesium. The dotted line is geared to the performance of 10^{-13}, the specification for the rubidium is 5×10^{-13}, whereas the cesium is 2×10^{-13}.

The performance exceeds the spec in both rubidium and cesium, if you're looking at a thirty days prediction. In fact the NAVSTAR VI shows somewhere around a five to eight times 10^{-14}, which is beyond expectations.

If you look at the next chart, the same thing predicted over a longer period for the bottom scale is ninety days -- The NAVSTAR V kind of drifts after forty or fifty days. NAVSTAR VI, still doing very well. So the manufacturers have built clocks of this type that are really very good.

Of course, the hydrogen maser technology, when it comes should provide better accuracy for a much longer period of time. As far as the space segment is concerned, there is quite a lot of interest in getting satellite autonomy or autonomous navigation where the two error sources are clock errors and errors in the ephemeris determination. Certainly, the clock error dominates after a long period of time.

There are two concepts we are pursuing. One of course would be a better clock. If a reliable better clock is avialable, that will be approached. If not, we are apparently thinking what's known as a cross-line communication concept which seems to provide a similiar level of accuracy. We're still in an analysis phase.

What it consists of, there exists a cross-link capability for communication purposes, and we plan to modify the communications link to provide a ranging signal, and to generate range data between the satellites. Then if the clock synchronization can be achieved on board the satellite, the requirement for a long-term stable clock may not be that stringent.

Coming back to the clocks, the space segment is not the only user of the clock. We have two other segments, as you know. The control segment, which is responsible for computing the orbit parameters, as well as the clock parameters, which would be transferred to the satellite, and would be used by the user.

And obviously, we have to have a highly stable clock for the control segment monitor stations. And now their accuracy requirements are as stringent as the space vehicle clocks. However, there's really no weight or power limitation and the reliability requirement is not as stringent as in the cases of satellite clocks because we can always replace the parts or we can have redundant systems available to the ground stations.

There is a future set of users which may require stable clocks primarily because, from a naviagation accuracy point of view, we don't need to depend upon four in-view satellites, if four in-view satellites are not available, you can still get the same accuracy if you have a stable clock on board the user and only 3 in-view satellites.

The satellite users, specifically surveillance satellites, which may require highly stable oscillators because if you want high accuracy the GPS antenna being limited to the earth pointing direction, the satellites above GPS have to look from the other side. So, the possibility of seeing several satellites is limited and you want 10 to 20 meter level of accuracy, you may need a, in fact, you do need a highly stable oscillator on board the satellite.

Of course, if you can live with 100 meter level of accuracy, then you don't really need the highest stability in the clock.

So, those are the three specific requirements from user control end and the space vehicle point of view.

Now, the most concern we have is the reliability of the on board satellite on clocks. Of course, lately we have had pretty good luck so far. We don't have a lot of experience, because we haven't flown that many cesium and rubidium clocks, so, hopefully, one of the problems the PTTI can solve is how to guarantee the reliability for a long period of time.

APPLICATIONS PANEL

Panel Member: L. Edward Stein, Westinghouse Electric Corporation, Defense and Electronics Center

Good Morning. Our corporation is an original equipment manufacturer and system design and integration company, principally for the DoD and for the other government agencies.

Most of the applications that I've had experience with personally, have been in the military strategic communications area. The environment is the usual military environment for the airborne or for the ground type application.

The particular area of communications is the VLF-LF, to some extent MF digital communications. The systems that we deal with are broadcast type of systems with a very limited number of transmitters and a large number of receivers used for the dissemination of information to various operational elements in the military.

The particular programs that we have done, or which are users for this type of equipment, are the 6168487L survivable low frequency communication system, the ARC-96, which is the airborne version of this survivable low frequency systems, the VERDAN, which is the Navy equivalent, the TACAMO, which is the Navy airborne version.

And then, all of these things interconnect into what is known as the minimum essential emergency communications network for the DoD, commonly called MEECOM. The communications technique is synchronous-coherent detection and direct sequence pseudo-random modulation is used in these systems.

That leads to the need for accurate time at the transmitters and receivers for system synchronization. Now, we use basically a correlator technique and the requirements that we have are much less stringent in terms of absolute time than the navigation requirement that I've been hearing today, here, this morning.

We have a requirement to know time at all the terminals in the network to an area that ranges from a few milliseconds in some systems, to tens and small numbers of hundreds of millisceonds in other systems, so that, in terms of absolute time, we thought we, we were pretty precise until I sat here this morning and listened to some of the navigation requirements. Now I don't feel very precise at all.

However, we do use cesium standards and we use cesium standards for several reasons. One is that we do want to maintain a systems standard at our transmitters which then can be used as reference for the rest of the system.

Also, we have the requirement, or certainly the desire, to maintain an accurate knowledge of time over a long period of time. Let's say a year or more, and the cesium standards provide the kind of accuracy that they can do that independent of periodic calibration. Also, the cesium standards provide a quite reliable, but redundant backup we use at the transmitting stations. Redundant timekeeping as you would expect for reliability, so we use a crystal standard and a cesium standard independently but, while they're not independent, they can be independent. They're normally connected together and monitor one another so that we have a way of determining if there is a time fault locally.

The area where we get into, perhaps, the driving thing for our technology right now then, is not so much absolute accuracy, but the types of problems that we face have to do with maintenance: the insertion, initial insertion and then the maintenance of time in the system. And, in the area of portability, particularly for airborne terminals, there is a requirement to be able to set time on board an airplane very simply.

The environment we're dealing in is a military user, where the people who are using the equipment are not people that are particularly trained in the techniques of precise time management. They're operational people, and what they want is to have something they can take in their hand and plug into a slot, push a button, and their system is going to work.

So, we find that we need equipment that is light, that is low power, that is highly reliable, it is very user tolerant, very user friendly (as they say in the computer business these days). Equipment that can be -- that does not hassle a man who's got many important responsibilities in serving time into his system being only one of them.

We also are finding currently, looking into the future, that our precision requirements are actually relaxing a little bit. Not a great deal, but somewhat, because we look to take advantage of the greatly increased processing capability that's coming along in terms of arithmatic processors, and high-speed, high capacity arithmatic processors. A high density low power, low cost memory that allows us to substitute a certain measure of processing for precise knowledge of time.

Sort of to sum up then, we are driven at the present time in the direction of low power, for portability, high reliability in terms of specific equipment such as cesium standards and crystal clocks which we use a great deal of. All of our receive stations are crystal clock controlled.

The other side of the coin is to find equipment which can be readily maintained and find techniques which we presently don't have, and which are some of the other things that are being discussed here today are relevant to that for inserting time into our system, both from a routine maintenance point of view, and from the point of view of recovering time in the event that some remote site loses real time.

Those are the areas that right now we are most concerned about, and we'd appreciate your comments and suggestions on it.

Thank you.

APPLICATIONS PANEL

<u>Panel Member</u>: Milton Boutte, Kaman Sciences Corporation

I work for Command Sciences Corporation in the Albuquerque office. My area of expertise is electronic warfare, and it's totally different from what you have heard thus far. I work as an independent test and evaluator, if you will, of tactical data links and navigation systems for the C^3 environment.

As you all know, the heart of all data links and navigations system is precise time and timing intervals. That's how I'm getting involved. We do not actually look at the hardware in the way of precise timing from the standpoint of looking at the oscillator and cesium clock. We're more interested in being able to take and independently evaluate a particular data link or system in a battlefield environment with red forces, with blue forces, with all kinds of chad propagation from the electronic support countermeasure area, and be able to define to the user in the field what the capability of that data link navigation tactical system is, and what its limitations are.

From this standpoint, we do get involved in evaluating the timing requirement that the designer has put into the system. From the standpoint of the user in the field and what we've seen over the years, that the clock is not the problem that we're having.

The problem we're having is synchronization. And once we lose synch, we're having trouble locking back up, or the system's having trouble locking back up.

The other problem that is rapidly coming upon us is DoD's thrust towards GPS, where our systems are required to be compatible with the Global Positioning System. There's concern about the availability of GPS timing.

Thank you.

APPLICATIONS PANEL

Panel Member: William Walker, Pan American Airways

Pan American World Airways contracts with the Air Force for the operation and maintenance of the eastern test range. Responsibility includes the collection, reduction, analysis and publication of test data.

A directed responsibility also exist for PTTI engineering support to operations for planning, for specification, acquisition and installation and check out of new equipment as needed to meet changing program requirements.

The Eastern Test Range (ETR) is a 5,000 mile range extending from the launching facility at Cape Canaveral southeast, southeastward. The instrumentation and tracking platforms located on the Florida mainland sides, Grand Bahama, Grand Turk, Antigua and Ascension Islands, and on ships located in the Atlantic.

The range PTTI system provides services to both range users and range instrumentation systems, such as photo optics, range safety, command disrupt, communications, telemetry and radar.

The UTC time scale is employed and synchronization is maintained with respect to the DoD master clock located at the USNO. The interrange instrumentation group serial and parallel standard time group formats, are generated and distributed. Range count status information is also generated, distributed and displayed in the user areas.

The PTTI operating philosphy is to provide both range and range user systems, timing signals at the user site which are synchronized better than 50 microseconds.

In the past, this has been accomplished by direct synchronization to LORAN-C. The range is now in a modernization phase, which will upgrade synchronization to an accuracy of better than one microsecond with respect to the DoD master clock. Conversion will be accomplished sequentially by platform on an as needed basis. The Cape Canaveral master clock conversiton is now in progress with completion expected in about six to nine months.

The Antigua platform is now operating on an interim basis to an accuracy of about five microseconds; better than five microseconds.

Complete range conversion is anticipated to take about three to four years, but it's dependent on yearly funding.

The PTTI operation philosophy employed at the ETR is to use a hierarchy of clocks, consisting of the range master clock located in the vault at Cape Canaveral, and synchronized to the USNO master clock to about one to two hundred nanoseconds.

The master clock consists of an ensemble of four or more cesium standards. A USNO, IEEE-488 Bus monitor system extends from Washington, D.C. to Cape Canaveral to monitor and verify the range master clock's synch status. Simultaneous time difference measurements between the USNO master clock and LORAN-C, and between the range clock at Cape Canaveral and LORAN-C, are the basis for the monitor system.

The same technique is applied in turn between the range master clock and station clocks located on each of the instrumentation platforms. When users are not co-located, the station clocks, site clocks, are installed at user sites. These clocks consist of synchronized time code generators with our local oscillators, operating in a discipline mode with memory.

This method assures PTTI integrity in the event of communication link failure between the station and site clocks. Timing signal input to the site clocks will be a modified IRIG serial time code, transmitted by a twenty-two gauge, or wide metal wire circuit, or by a microwave.

Correlation accuracy will be dependent upon transmission method used and will range from about one microsecond, to ten to twenty nanoseconds.

An ensemble of three or more cesium standards, frequency standards, is maintained at each station clock. The ensembles are steered continuously through the use of microphase steppers, the next higher level clock, with information obtained by portable clocks, and continuously verified by the monitor system.

As this system matures, control commands will be introduced via the bus from the Cape master clock to all station clocks to achieve a totally automated system with operator/technicians being required only for repairs or emergency manual control during periods of bus failure.

This technique minimizes direct dependence upon external PTTI dissemination systems at the expense of frequent clock trips. The technique is, however, flexible to place greater emphasis on external transfer systems as they become operational, portable and reliable.

PTTI dissemination system now used at ETR include LORAN-C, TRANSIT, GOES and WWV. The GPS receiver is under procurement with delivery expected by the end of 1983. We have noticed that a subtle change in the requirements from users numerous recent discussions concerning the need for timing signals which are active elements in ranging systems, rather than the more conventional use as a passive scaler for data tagging.

Requirements for a network synchronization of three to five ranging sites in the order of twenty to fifty nanoseconds have been discussed. We feel that these can be achieved through the use of the systems that I've described here.

APPLICATIONS PANEL

Panel Chairman: Dr. Arthur O. McCoubrey, National Bureau of Standards

That completes the statements by each of the panel members, and now we come to a period of discussion. I'd like to take advantage of my position as moderator and ask one question of one of the panel members to start it off.

As I listened to each of the presentations, I got a pretty good idea of where the requirements are, and where the most urgent requirements are. Yet, I may not have been listening hard enough, but there's one case where I didn't get the picture straight, and I'd like to be sure that we get it out, so I'll ask John Illgen a question.

John, if you had one wish, with one string attached, the string is that you've got to spend it on PTTI technology, briefly, what would it be?

MR. ILLGEN: I think presently, as far as the users' requirement is concerned for in the LORAN-C area, we've been, we have, the Coast Guard has installed cesium standards at each of the transmitters, and additionally, the control monitor that I referred to that is used to control the synchronization of the chain, of each chain, does have its own clock.

The computations to date, as I mentioned before, include cesium variations on the order of cesium variations and also transmitter fluctuations mixed in that we have measured at about fifteen nanoseconds.

Now, our receivers, our user receivers, the receiver noise is about twenty to twenty-five nanoseconds typically for time difference receivers. So, to really answer that question today, -- to do any better as far as synchronizing the chain from a high accuracy harbor standpoint, we're fine. But once the receiver, the onus today is on the receiver manufacturers to drive to reduce the error in the receivers.

And I think realistically, from a user standpoint, maybe what we're saying is, for harbor navigation we're not in too bad a shape.

DR. MCCOUBREY: OK. Thanks John.

Let me ask other panel members if they have some questions to ask of each other, or of the members of the audience to start the discussion here. Questions among the panel members?

DR. ANANDA: I have one. There was a concern about the availability of GPS timing.

DR. MCCOUBREY: Yes.

DR. ANANDA: Maybe explain what the concerns are?

MR. BOUTTE: The basic concern is that DoD is becoming extremely dependent on new systems for GPS, and I guess our concern is that we're going to be out in the field, and we're hoping that GPS is going to be there. And that's the basic concern. We need to track GPS and make sure that it gets there, because our systems are currently on schedule and we're worried.

DR. MCCOUBREY: Provide some assurances?

DR. ANANDA: As far as we know, we are also pretty close to schedule, unless something more happens.

MR. BOUTTE: Well, we're highly dependent on GPS and that's our concern. Without GPS we don't work.

DR. MCCOUBREY: John, perhaps you have a question?

MR. ILLGEN: Yes. From a user standpoint, what is the accuracy that will be provided to the civil community?

DR. ANANDA: As for the navigation accuracy, we have two modes, as probably everybody knows. One is for the military, or the classified community, and the other one for civil uses. However, the accuracy, full accuracy may be available to everybody. A decision to --

MR. ILLGEN: You're saying the precision code will be provided to the civilian and defense communities? That's a --

DR. ANANDA: Unless, there is a provision under which the security panel may choose not to make the precision code available to the user. All users. If that's the case, the navigation accuracy which will be around 200 meters. As far as the timing accuracy is concerned, it would be much better than that: 100 nanoseconds, or 150 or 200 nanoseconds. Just the time, that's only 1 parameter.

But if you want the full navigation accuracy, would like a circular probability on dimensions, then it's about 200 meters if the full accuracy is denied. Otherwise, the accuracy will be around fifteen meters in navigation, or better than ten nanoseconds in time.

MR. ILLGEN: There are many people that are using the systems for LORAN-C for timing, and a recent report that was issued by GAO recommends that LORAN-C be phased out in favor of GPS. That's one of the reasons why people, I think, are asking questions regarding the GPS schedule, and I guess the real concern is, currently the GPS system is in the conceptual stage, design stage, and in fact, production of the operational space segments, that has not started yet.

Is that true or false?

DR. ANANDA: The Operational satellites, what we call block two satellites; the prototype, which is the satellite twelve, already being built; thirteen through twenty-eight satellites, which we are going to buy, are funded and the contract is being negotiated. It's funded, that's the key, funded, at least for the next fiscal year.

Since the block buy is funded, we can hope that the missions will be there. The current schedule is, we will have in the beginning of '86, that there will be six satellites of block one, and subsequently we will start launching block two satellites at the rate of seven satellites per year.

So, by the end of '87, or the middle of '88, we'll have an eighteen satellite constellation there out, to be a mix of block one and block two. The block one satellites are in 63° inclination and the block two are fifty-five. However, as the time goes, one of the block one satellites will be phased out, and we will replenish and maintain an eighteen satellite constellation. --That's the correct one.

DR. MCCOUBREY: Ed, do you have a question?

MR. EDWARD STEIN: I'd like to raise a question in that same context. In the communications systems which we service, as I said before, time acquisition and maintenance is a problem for us and some different sites go at this in different ways. Different maintenance organizations.

But, people have used, or thought about using LORAN-C quite a bit. Television, line ten television synchronization has been discussed. I don't know that anybody is using it. I heard Omega mentioned -- By the way, all the systems that we're talking about are sufficiently accurate for our application, so I'm wondering, looking ahead, say, fifteen years from today, which systems would provide the most economical long-term approach.

If you were setting up a maintenance facility say, and one that would be responsible for the maintenance of time for a number of receiver sites, what way would you go? I'm asking anybody that would have an opinion on that in terms of utilization of Omega or LORAN-C, or, looking ahead to GPS.

DR. MCCOUBREY: Who wants to handle that?

MR. EDWARD STEIN: Would anyone like to comment on it?

DR. MCCOUBREY: Lets, ask Bill May to tackle it first and then, Mohan Ananda.

CMDR. MAY: I'd like to address that from the viewpoint of what radio navigation systems we have, and what the Federal government's planning forecasts are for these systems.

The Department of Defense, of course, runs some navigation systems, they run TRANSIT, they will run GPS. They run a number of aeronautical systems. The Department of Transportation, the two operating agencies in the Department of Transportation, the FAA and the U.S. Coast Guard, run the remainder of the government provided radio navigations systems for general use: the VOR/DME, the microwave, the ILS, LORAN-C, and Omega.

A number of years ago, it became apparent that there was not adequate coordination between DoD systems and DOT systems. So, we formed working groups in each of the Departments.

A navigation working group in DoD, and a navigation working group in DOT. These two groups talk to one another at least once a quarter and usually more frequently, to tell one another what they're doing.

Under mandate by Congress, we came out with an animal called the Federal Radio Navigation Plan, which is available through NTIS in Springfield. Unfortunately, at a fairly high cost. I think, $30.00 to $40.00.

This plan, now in its second revision, the second being March of 1982, details the long-range outlook for Federally provided radio navigation systems.

I'm only familiar with the marine segment, and I'll summarize what I know of it for you. For LORAN-C DoD has said their requirement will cease approximately five years after GPS becomes operational, or in late 1992.

So, we, the Coast Guard, are operating overseas LORAN-C to meet a DoD requirement.

I'll address TRANSIT, and GPS, and then Omega.

For LORAN-C, the Coast Guard operates the overseas LORAN-C chains. The current plans are that DoD requirements for overseas LORAN-C will end when GPS becomes operational.

DR. MCCOUBREY: Yeah, Alright. OK.

CMDR. MAY: I'm sorry. That means in 1992, the overseas chains will no longer be required by the DoD, and current plans are to phase out Coast Guard operation of these overseas chains.

There might possibly be host nations agreeable to taking over the stations and running them, but it's pure speculation at this point.

We foresee the CONUS chains, east coast, west coast, Gulf of Alaska, Hawaiian Islands as remaining on the air, continued to be operated by the Coast Guard to meet the needs of the United States coastal confluence zone.

TRANSIT is a Navy system. Always has been, and will be until it ends. Projected to end, again, in 1992, because the DoD requirement will transfer from TRANSIT to GPS.

There has been a lot of talk about a civilian consortium taking over operation of TRANSIT. To the best of my knowledge, there has been no active putting up of funds to take this over.

So, that is a DoD system which they have announced will end in 1992, about five years after GPS is operational. Omega, the system I'm most concerned with, is operated by the United States and six other partner nations. We're entirely a civilian system. We have 15,000 civilian users, more or less. Only 1,500 DoD users. We enjoy a fairly high degree of support from commercial civil aviation; somewhat less from civil maritime users.

Because we have so many partner nations involved and so much international acceptance, and a relatively low operating cost, it costs the U.S. Government approximately $8,000,000.00 a year to operate Omega, and that's for a worldwide system. My personal feeling is that Omega will be around at least until the year 2,000.

The Federal radio navigation plan hedges on this. They say that the Navy is re-evaluating their requirement for Omega as a backup to GPS even if the Navy does not want GPS. I still project it will be required for many years to meet civilian needs.

DR. MCCOUBREY: Thanks, Bill.

I'd like to begin to ask for questions from the audience.

MR. SAMUEL WARD, JPL: My question is to Commander May. You presently have your Omega operation in Australia, and its traceability to UTC is being established, as you said through TV, to the Department of National Mapping, and to UTC by way of UTC Australia? Do you plan to furnish them with GPS receivers so that you lower that present uncertainty that you have by, maybe, an order of magnitude or two?

You stated the TV traceability was plus or minus half a microsecond. And with the GPS that could drop to fifty nanoseconds or less, and for the UTC traceability plus or minus five microseconds, that of course, that could drop two orders of magnitude.

CMDR. MAY: Right. The primary purpose of precise time for Omega is to synchronize our signals for navigational use. The larger the time error between the phase synchronized signals, the larger the navigational error. The traceability back to UTC is sort of a side light, an extra provided service.

Our requirement is to keep our signal, our signals from our eight stations to within two microseconds of the mean Omega system epoch. OK. In doing this, we -- Oh, by the way, -- tie this into UTC, the Australian horizontal TV synch pulse, which is directly traceable to USNO through tying our signal into the LORAN-C system at our four northern stations and through USNO monitoring of our North Dakota station, they monitor the signal here in Washington, D.C.

All these various inputs go into a fairly complex computer program that produces weekly corrections which are entered into our system to bring all signals to within two microseconds of our Omega epoch. And the Omega epoch is within five microseconds, usually better, but, almost always within five microseconds of UTC.

To directly answer your question, we are planning to procure, if we can get a reasonable cost, and I'll define that as somewhere in the area of 10 K, a standard accuracy (the old CA code accuracy), commercial grade GPS receiver when it eventually becomes available on the market.

I've budgeted funds in 1984 to procure one of these, for trial, and to procure a number of these in following years, depending on the results of the first one. We would put these GPS receivers first on the stations that are not tied to an external UTC reference. That being Argentina, Liberia and Reunion Island.

If we get the funding, yes, we do plan to put it on all the stations as an external timing source which would indeed improve the accuracy. It would improve the accuracy to roughly what we get from GPS, which, I'm told by some of the experts in the field, that using a low cost standard accuracy receiver, we should expect somewhere between a half a microsecond and a microsecond and a half accuracy from GPS.

This will be another external input because if Omega, in fact, is a backup to GPS, which is the current plans, we cannot rely entirely on GPS. We have to be independent. So it would be an extra link.

DR. MCCOUBREY: Others? Sam? Another question?

MR. WARD: My question had to do with tying your Omega station to, directly to National Mapping Service.

CMDR. MAY: I'm not familiar with that, sir.

MR. WARD: To use two receivers at the same time. One at the Omega location, and the second at the National Mapping facility in the Canberra district, and, --

CMDR. MAY: You're talking about a differential GPS time recover?

MR. WARD: What'd you say?

CMDR. MAY: Are you referring to a differential GPS time recover system?

MR. WARD: Yes. That doesn't have to rely on the GPS clock. It would essentially provide real time synchronization.

CMDR. MAY: Again, our primary purpose is to synchronize our Omega signals in phase with one another using a satellite that happens to be synchronized to UTC. It will do us no good, the way our current synchronization program runs, to take only one station, Austrialia, and tie it down very closely to UTC. Because the other stations, then, could drift up to five microseconds from UTC and my synchronization program as written would tend to pull Australia away from being tied down to UTC.

What you're suggesting would only work if I could tap all of my stations down to the GPS time. Perhaps we could discuss it later, after the discussion.

DR. MCCOUBREY: Are there other questions from the audience? I have one over here.

DR. KELLOGG: I'm a aerospace representative, working for Lockheed. I have a question about why you're so confident that you have ephemerides under control? When one looks at other data sources of the on board clock performance, specifcally from the U.S. Naval Observatory, I find it difficult to be as optimistic as you, if you know what the causes are.

DR. ANANDA: I'm not clear what you're referring to.

DR. KELLOGG: I'm mostly concerned about on board clocks' reliability, and I have a good feeling about the accuracy of ephemerides. I cannot agree with that statement. I'm wondering what your source of data is. Do you weight the U.S. Naval Observatory data very lowly? Do you include it, or what?

DR. ANANDA: No. Many predict the GPS orbits. The loss of accuracy if you do not receive the navigation message, daily, or whatever the time period is, there are two error sources existing; one is due to the stability of the onboard clock; the second is the inability to model the ephemeris to the required accuracy.

Now, if you compare these two error sources, the clock error dominates that. I'm not saying that the orbit errors are not there. Maybe I didn't quite understand what you're suggesting.

DR. KELLOGG: Before I predict anything, I'd like to know where I am. If I'm uncertain about that, I assert that influences my predictions since at the present moment, I will assert you have some difficulty in establishing or distinguishing between an ephemeris error and timing error with the way GPS is set up.

DR. ANANDA: We can estimate that orbit accuracy to a few meters which includes the clock, as far as the knowledge phase is concerned. Then you extrapolate and you predict. That's when the users start using. The current operational control segment, the concept is, we process the available data, and every eight hours, or every ten hours, we upload a NAV message which would be available to user, so the total time predicted is ten hours.

And, we maintain a user range error of six meters, which includes the clock, as well as the ephemeris part. We do not plan to separate, however, if you start predicting further down, the correlation between the clock and the ephemeris breaks down and the clock starts taking off, which becomes the dominant error source.

So when we're talking about clock synchronization, it applies to only, on an autonomous basis, or navigation over a long period of time. We do not absorb a clock error in say, for example, two months. Then, if you do not have some kind of clock synchronization capability, you certainly cannot achieve that. You have to absorb the clock information more frequently.

So the ephemeris error comes from two sources. One is what we call the wide bias error, which is the misalignment of the solar panel, looking at the sun, which introduces a torque, and that contributes a radiation pressure effect on the satellite which is hard to model at present.

However, the concept which we are pursuing, which referred to using cross link ranging measurements, and a single ground station ranging signal measurement, we can estimate all those parameters and we can predict for a long period of time that doesn't contribute to the same level as the clock stability error. That's what I was referring to.

DR. KELLOGG: I don't wish to pursue that subject even further. I would like to ask a different question, if I may, sir.

DR. ANANDA: OK.

DR. KELLOGG: One of the other items, I believe, as I understand it in the GPS system, is that a search for users of time precision failed to unearth anybody who would ask for a precision greater than 100 nanoseconds and, consequently, the system accepts the fact that that's the floor. Will this decision be reviewed sometime between now and some sort of operational date?

DR. ANANDA: The timing accuracy as it stands in the program is 100 nanoseconds between USNO and GPS system time. That is, the maximum off-set between UTC and GPS system time would be 100 nanoseconds.

As far as validating the GPS system itself, there is no such requirement as 100 nanoseconds. You can actually do the time transfer to a level of ten nanoseconds or better. So 100 nanoseconds comes to the relationship between USNO and the GPS system time.

I do not believe there's any plan to improve upon that requirement unless there is a community which forces upon the GPS program to improve the accuracy, of the offset between the USNO and the GPS system time.

DR. MCCOURBEY: OK. It's getting close to the time now to conclude the session, but, I'd like to ask, is there one more question from the audience? Mr. Allan?

MR. ALLAN: I'd like to pursue a little bit more, if I may, the questions raised by Dr. Kellogg with respect to the GPS, to the Aerospace representative. You referred in your discussion to the desirability of getting much more highly stable clocks on board the GPS in order to allow for the projection during an autonomous period.

I'd like to just suggest that what was discussed on the panel yesterday a little bit, and what we discussed at some of these meetings before. In order to have a basis for projection, you've got to be able to read out the clocks with sufficient accuracy so that you have a projection base on which to go. And it seems to me, in all the discussions I've heard, that the Kalman filter readouts that are currently used, and presumably would be incorporated in these cross links and so on, do not have sufficient precision to accomplish the kind of data base that the projections would need.

DR. MCCOUBREY: OK. Just in winding up, I would like to observe that from the viewpoint of all the users I'm very much impressed with the need, the requirements for synchronization technology.

I'm also very much impressed that various system users are depending upon other people's systems in connection with synchronization. And, it does raise the question as to whether or not that interdependence among the systems, of one set of users depending on LORAN-C, and another set on Omega, GPS and so on, dependence which goes beyond the original intent of the system, perhaps, whether or not those requirements are getting into the planning at high enough levels.

In other words, are the planners at the very highest levels really listening to the users in these areas? Perhaps Dr. Winkler could comment on that.

DR. WINKLER: I do not know what the highest levels are doing.

DR. MCCOUBREY: You'd better do something.

DR. WINKLER: And moreover, we have all the indications that they change course every three years.

And, I want to remind you that the comment which was made by one of your panel members about the recent report that LORAN-C be phased out comes only six years after a major push for more LORAN-C as being instituted by the Department of Transportation, in which it was declared one of the two operational and reference systems for the coastal regions of the United States.

So you must expect that turbulance to continue. It is simply a fact of life. And, in regard to your question, is that good or bad if different systems depend on each other. I think it is a strength. It is in fact a big thing which PTTI, a coordinated system, has to offer.

That also, every single synchronized system ought to, as a matter of policy, be able to resynchronize itself from within the system. By having additional interfaces to other coordinated systems you gain a tremendous amount of redundancy, of insensitivity to disturbances of all kinds.

So, the question that you have asked is extremely difficult to answer, I think one must realize we have very great turbulance. Remember last year, the GPS system about which we are all concerned, it was whacked out by one of the Congressional subcommittees. Completely. It was restored later on, but that is how that is. We are living in a turbulent state, and we cannot project, I think, for longer than a couple of years in the future for any individual system. That's why we have to be coordinated.

CMDR. MAY: Art, if I could, just one minor thing here?

DR. MCCOUBREY: Yes

CMDR. MAY: When the U.S. Coast Guard petitioned Congress, and Congress decided to phase out LORAN-A in favor of LORAN-C, this was for the coastal confluence zone of the United States.

The U.S. Coast Guard is planning on running LORAN-C even after GPS, within the United States coastal confluence zone. What I was talking about is the phasing out of our overseas LORAN-C chains which were initially established to meet the DoD requirements.

Once these requirements end, the U.S. Coast Guard has no statutory authority to maintain radio navigation systems outside of the use of the United States' fifty states.

The other thing is that you are very correct, the FRP (the Federal Radio Navigation Plan) is a long range planning document which projects the needs of U.S. radio navigation mix and needs to the year 2,000. Unfortunately, funding of all the systems, the operation of all systems, is on a year to year basis.

So what you have is: the FRP is revised yearly, and in some cases it doesn't make a whole heck of a lot of sense, in my personal opinion, to revise a twenty year plan document every year. Yet, that's the way our system is organized.

DR. MCCOUBREY: John Illgen, a short one?

MR. ILLGEN: I'll try and make this short.

But, one of the points that I would like to make, and I do, I think CMDR. May has partially answered the question that I'm about to raise, and that is for the LORAN-C system has been around since the late 1930's, and has taken many, many years to sort out and understand a lot of the error sources associated with the system.

And, what worries me when I hear dates like GPS being opertional in 1988, or '89, and then we turn the switch in 1992, because we now have an operational satellite system. That concerns me a lot.

And I just-- one of the questions I was going to ask is how concrete is this Federal Radio Navigation Plan?

And I believe CMDR. May partially answered that in saying that it is revised every year. But a lot of people are taking the GPS system very seriously in the military communication area. And, it's needed in Europe. It's needed outside of the United Staes, GPS or LORAN-C for timing purposes, and I sure hope that the high level authorities within our government understand that there had better be considerable overlap between the two systems until the problems are sorted out on GPS.

DR. WINKLER: We may not be able to depend on the understanding, but we can depend on the inertia.

DR. MCCOUBREY: Well, with that I'd like to thank each of the panel members for joining us this morning. It's been a very interesting session. I'll turn it back over to the session Chairman.