PANEL DISCUSSION

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DR. WINKLER:

And now, while we are preparing for the panel discussion, for which we will have this morning's speakers present, I would like to invite comments on the last paper.

DR. REDER:

There is a disadvantage to using centicycles instead of microseconds. That is, if you have a rapid onset of a distrubance, you may get a cycle jump and, as was pointed out, you won't know it. And you think you don't care. The only trouble is when the distrubance slowly recedes and the previous level is reestablished, then you will introduce new cyclic advance or delay, and you won't know when it was caused previously.

I also think the notion that microseconds are completely arbitrary is very objectionable because the microsecond scale is just derived from the cycle scale by dividing phase by circular frequencies. So it's not arbitrary, and if you want to argue about that then I can give you an argument on that, too, because you can define phase propagation time, and in that case it's very useful to talk about microseconds.

DR. WINKLER:

I think the last point is also where I have strong feelings. I think for any combined use, which I envision for OMEGA stations, the measurement of propagation time in microseconds is better because it is frequency independent in the first approximation. But I propose that unless there are very strong feelings now for equal time on the other side, to go on to a different subject.

MR. WARD:

The arrival phase of F-1 and F-2 is unique for all points on a common great circle. But if you take the phase difference between these two, you now have media information because this is unique. And this changes only when the medium, when the effective path length changes. So you therefore can tell if you have cycle-slip information, and you'll also have propagation path information - everything is right there by simply taking the phase difference of the arrival phase. And as long as, for instance, the beat is 250 cycles, well within a path equivalent to the wavelength, it is unique.

MR. BRITT:

Yes, I think as Mr. Chi said, there are two ways of using this kind of system. You either have to know propagation, what to expect in the way of propagation quite well, and to be able to correct for it; or else you must start by knowing time quite well.

Now in the case of our demonstration in the back of the auditorium, we probably could have just come in, since we had very, very precise time, and we could sit at our receiver site and take data -- and this is something I failed to mention in the paper -- and then based on this phase data that you are talking about, we could manufacture our own propagation correction. So you could play it either way: You could make your own correction at the site, if you had good time to start with; or, if you didn't have good time, then you would need a good number to put in the receiver.

DR. WINKLER:

I'm sorry that it has not been possible to have a paper on LORAN-C. However, there is a development which is quite significant, which I would like you to know about.

We have tentative approval from various agencies to set the LORAN-D chain, which is presently operating in the western United States, on precise time. These stations are near Las Vegas and Reno, in Utah, and very close to Los Angeles. I think that the coverage is excellent and the signals can be received with a standard timing receiver.

The difference between LORAN-C and LORAN-D is mainly that LORAN-D, in order to compensate for the lesser power radiated from a smaller and more-mobile antenna, utilizes more pulses, the pulses following one-half millisecond intervals instead of one-millisecond intervals, but the one-millisecond interval pulses follow the same phase code as LORAN-C standard. And this I think will be a very significant improvement in our capability to disseminate time in the western part of the United States.

Indeed, I hope that these timing transmissions, which at this time we must consider experimental or test transmissions, nevertheless, can be continued until a more permanent LORAN-C arrangement can be developed in that area.

Now, going back into the subject of the discussions, I would like to ask, first, a very general question of our speakers here, who have been active in time and frequency applications and research. I would like them to summarize what they think is a major problem, or problems, which should be addressed in the dissemination of time or measurement of precise frequency, or the use of precision frequency and time standards.

MR. CHI:

As you know, the application of time depends on the need. In the past the requirement has always been for very coarse time, which is a problem, but not of interest to people who work at R&D activities in frequency and time.

Now, the application requirement is increasing to the order of a microsecond or below. The question is how can one be sure the time he gets is within that requirement? That is, how can one be sure that the time is correct. Furthermore, once one does have the time – I assume that he gets the time – he needs a way to verify that his time is correct. Now the next question: How can he get coarse time? Very often we work within microseconds or nanoseconds, and we lose in hours, minutes, or seconds.

So the problem is to be able to disseminate the time to the users to the point that the user can be sure that he meets his requirements. It does not require too much analysis, but if you want precise time you must exercise a certain amount of wisdom. Now the wisdom doesn't come with the users who are not in this particular field, so that some of these problems are involved in the designing of a system in a manner that people outside the field will understand exactly what they need to do.

DR. REDER:

I'm just referring to some problems which we have in VLF. I think we have learned a lot in this area during the last couple of years, but there are still some very puzzling things.

For instance, we do see antipodal interference on some paths where by all rights there shouldn't be any, and vice versa. The particular area of trouble is in the western Pacific, for instance on paths from Hawaii to Australia, as is now well known, and I think that the prediction in this area is still rather poor. So more work is needed. And I believe it could be extremely helpful if OMEGA could temporarily transmit a higher frequency on one of the segments, so that we would have three different frequencies reasonably spaced in order to get a handle on the main problems.

We have 10.2 and 13.6 kHz – if they could give us anything between, let's say 15 and 18 kHz, it would be helpful. It wouldn't have to be for a very long period of time, but as long as the segments aren't completely used anyway, and if they can do it technically, it would be very desirable.

MR. SWANSON:

May I comment on that? I believe that a signal structure question, say in the Australian area, is not really that germane to the timing problem.

The reasoning here is principally that in timing you have the choice; you can choose whatever time of day is best for you. Ordinarily, this turns out to be daytime. And actually both the 10.2- and 13.6-kilohertz signals have been monitored at the University of Queensland by Dr. Crouchley, who is here today. And the time was in fact checked by a flying-clock arrangement; it was not exactly done specifically for the experiment, so that there was an uncertainty of some microseconds. But nonetheless, the predictions at both frequencies, from Hawaii down to the University of Queensland, agreed with the clock by about five microseconds, I believe.

MR. WILSON:

Could I add just one comment on possible experiments added to OMEGA stations? As you may or may not know, the OMEGA navigation system is in the process of becoming an operational system, and while I wouldn't say that adding experiments is impossible, I would say that it's getting harder and harder as time goes along. There is a greater and greater reluctance to take the stations off the air for any amount of time to make changes and do experiments.

MR. SWANSON:

In fact, the last series of modifications for experimental purposes I can think of occurred prior to 1966.

DR. WINKLER:

We undoubtedly move now into an era of increased application of precise time and frequency standards. I think this year's conference and last year's conference indicate that there are many systems which will eventually use precise time and frequency standards in larger numbers. Conceivably, most of these standards will be better quartz crystals, because they are still the most reliable, and probably the least expensive, precision frequency oscillators. But I do foresee a significant number of atomic frequency standards.

In this respect, I consider the equipment which we see on display here to be quite a significant accomplishment of the last two years. And the question is now: What problems can be anticipated, or where do you, as systems engineers and managers, think that problems in that critical phase may arise? I'm thinking about calibration needs. I'm thinking about training arrangements which should be made. Things along these lines. And I am wondering whether there are any comments from the audience or from the panel?

MR. SWANSON:

I'd like to express a comment on one problem that I see and have always seen, and it seems to continue. This is the confusion, I believe, between frequency and perhaps epoch or date.

A frequency standard, no matter how good — and I do think there are some superb ones available — is not in itself going to provide permanent synchronization with anything else. It necessarily will vary slightly. There will be a random walk. And sooner or later, whatever one needs in the area of synchronization, will no longer exist.

How one balances this depends on a lot of things: how good the time dissemination is; how good the standards are; what these methods cost; and how laborious they may be. But it's necessary always to balance. There's nothing wrong with buying a cesium standard simply because you don't want to bother fiddling around with adjustments for the next year, and assume that you can leave it there for a year and then adjust. This is the economic thing to do; that's perfectly reasonable.

But to buy one without recognizing the fact that you must also have a dissemination or control procedure of some kind, if you really need synchronization, is a terrible mistake. Too often one winds up with nearly impossible frequency requirements, driving one to a standard which costs at least $10,000, when perhaps dissemination methods would solve the whole thing for very much less money. But again, this is always a tradeoff. As long as it's done properly it's all one can hope for.

Another quite unrelated minor practical thing I have forgotten to mention, but John Hannah pointed out that the Naval Oceanographic Office does not exist – they are now the Defense Mapping Agency. So if you wish to get any corrections, you had better get them from the only existing agency: the DMA.

DR. ROHDE:

There is minimum awareness in the Department of the Army of the need for precise positioning. And we in the topographic laboratories have a responsibility to provide the means, and we feel that substantial research and development should be performed in the area of providing precise timing devices such as clocks or atomic devices. But you have to realize that these equipments have to work in a dirty environment, and also they should be sufficiently cheap so that large numbers could be procured.

So there is an area where more research and development should be done, and we cannot do this in our agency. I guess it has to be done in other agencies or by industry.

Another area which causes considerable problems is the area of propagation. I indicated this morning that the ionosphere is not as simple as one may expect. In addition to ionospheric propagation, which is essentially a problem with satellite systems, there is also ground wave propagation with its attenuation problems. If one tries to get information about phase delays or time delays over ground, there is also very little material available, at least to my knowledge.

DR. WINKLER:

I think, however, that for precise time application itself, now considering the main interest of this conference, the detailed applications in navigation should be left aside.

So far as I see, the purpose of this conference is to discuss applications of technology to precise time and frequency generators, to measurements, and to certain fundamental difficulties. Well, in that respect, the propagation question is an important one, although I think of it with less seriousness because as we mentioned repeatedly, if you have to bring precision time, or to calibrate a user's clock, you can do that in a way which takes the most advantage from the fact that he has a good clock. You can do that at the best moment, which for a satellite dissemination would be probably 4:00 o'clock in the morning local time. And for VLF or OMEGA, probably around noon.

However, there is another point in the question of systems applications, and it is the following: I think it would be a mistake if large systems which propose to use precision time technology, or TF technology, depended solely upon external systems for synchronization. I think a time and frequency autosystem should have provisions for internal synchronization. On the other hand, it must also have an interface in case of trouble. That is the main purpose of having coordinated time; in case of trouble, you must be able to get time from a variety of other sources. I think these two principles are entirely compatible and, as we discussed yesterday, that is the difference between coordination and synchronization, or immediate synchronization. It is something which is very dear to my heart, because I find that it is a most frequent cause of misunderstanding, and misunderstanding produces wrong decisions, which can be exceedingly expensive. Duplication of effort, for instance, duplication of clocks within very small application centers such as vessels or aircraft or communications centers, can be avoided or at least reduced if the whole systems aspect is kept in mind. And that is a point which maybe we have not emphasized sufficiently at this conference.

This brings me to my last concern, which is that we do depend upon feedback from you, the users. I think the conference can only be beneficial if there is substantial feedback, and criticism if available, and suggestions of what should be covered, and where the problem areas exist.

Since our discussions have to end soon, I would not like to let that end arrive without giving credit to those people who have kept the ideals of this conference alive, and who have helped to accomplish this extremely desirable coordination of our efforts, and combination of sponsorship.

And I would like to really express my gratitude to Mr. Nick Acrivos of the U.S. Naval Observatory, and Mr. Clark Wardrip from the NASA/Goddard Space Flight Center. Without these two gentlemen there would be no conference today, I can assure you.

Are there any comments in regards to what we have discussed this morning, or what may be on your mind?

DR. SONKA:

I would like to ask the panel if they would briefly discuss limitations of using VLF in our RO-RO world navigations system when you have a clock on-board.

MR. SWANSON:

I think the main limitation is the one right off the top: How do you set your clock? In essence, when you ask, "How do you set up the clock?" by the time you've answered that you're back into a hyperbolic situation.

DR. SONKA:

Well, assume you have a clock.

MR. SWANSON:

Now, to do any good in a range-to-range sense, you must have the absolute epoch, or your ticking, or whatever.

DR. SONKA:

I know. Assume you have that; you've come to the Naval Observatory and synched your clock and carried it away with you, a cesium clock, or whatever. But now all the things we have talked about this morning, all of the errors in propagation, and everything, how are these things going to limit the navigation? In other words, what will be your navigational error? It appears to me it will be several nautical miles.

MR. SWANSON:

Again it would depend on how many stations you were using. For example, the OMEGA receiver error is one specific example. In this case there is an attempt made to set the clock, at least within the epoch dealt with by the normal frequency you happen to be working with. This is not of any great use for timing because of the scales involved, but that is how the receiver is set up.

And one could, I suppose, inject, that the receiver does operate with redundant range-range lines of position. The mere fact that they're redundant is sort of getting you back more or less to some of the advantages of the hyperbolic system. In any event, its nominal accuracy, at least in the OMEGA range, would tend to be on the order of a mile, which would be that of the OMEGA system itself. This would depend on time and whatnot.

DR. WINKLER:

I would like to make a comment here. I think with all due respect for the capabilities of the OMEGA system, that from my point of view it would be advisable not to overlook capabilities which we may have entirely for free.

What Mr. Stone has described, the timing of the VLF stations, enables a user, if his equipment is sufficiently flexible, to use any combination of signals.

Also, the bit timing, which I hope will be implemented soon on the VLF stations, will provide at least a starting point. You will be able to set your clock to within probably a fraction of a millisecond in respect to that signal.

Provided one has a small computer on-board, which is entirely possible -- I have seen aircraft VLF navigation systems demonstrated which utilize a small computer – the moment one has such a computer on-board, one can use a bootstrap method and a refinement in improving the synchronization of the clock by looking at several stations, exactly the same way as has been described for LORAN-C, in which by improving the fit of the circles one can update one's clock as well as refine one's position estimation. And I see no essential difference in the case of VLF or OMEGA application except that it is harder to account for the propagation anomalies and dispersion effects.

MR. SWANSON:

I agree. I think the only reason that people have ever bothered to invent a hyperbolic navigation system in the first place is because they don't know what time it is. Had the time been known, range-range is clearly preferable. But depending on the constraints of adjusting the clock, you may work out to identically the same situation, addressing it as range-range and trying to set the clock as if you had a hyperbolic system in the first place. You can't, in essence, get something for nothing, especially if you are dealing with only three stations and an unknown clock.

DR. SONKA:

In spite of the fact that you continually refine your position and your time, aren't there fundamental limitations just because of the propagation anomalies that we've talked about this morning?

DR. WINKLER:

Yes, there are, and maybe the most serious one is if you are moving. If you yourself are moving at high speeds there are additional complications. They are the same as if you use the satellite navigation system or time dissemination system. In these applications really time and location are almost equivalent terms.

It is true, there are limitations. But I think they will essentially be comparable to the noise level which we discussed earlier in the case of VLF and OMEGA systems. That seems to be around one microsecond for very quiet periods in the polar cycle. Short-term (precision) limits of noise seem to be in the 0.1-μs range, according to the numbers which we have seen this morning in Dr. Reder's paper. Would you agree with that, Dr. Reder?

DR. REDER:

We made some experiments using a better crystal, actually an atomic clock. And then we found that we could reduce the equipment noise. I would say we could reach 0.1-μs for integration periods of about 10 s.

DR. WINKLER:

The essential principle is exactly the same in all of these applications. You have redundant data; you look at several stations, or you look at a moving satellite, and the redundancy provides a capability to update and improve your location as well as your clock. But you have to have a starting point someplace, and in practice that may mean that for many of these applications you may want to leave your clock running, even if the aircraft is on the ground or the vessel is in the harbor.

MR. SWANSON:

I'd like to make a comment that Dr. Winkler has already made twice. But I think maybe I could just second it and agree to it. And that is the little matter of differences between time scales, for example, between NBS, USNO, OMEGA, and several others. The tradeoff here is one of how often do you want to adjust and try to keep together on the basis of a rather noisy intercomparison between sources? I think this is the sort of thing where feedback is very helpful to those who have to worry about this type of problem.

You can have a nice frequency stability by simply ignoring the rest of the world. This way you don't make any epoch changes, thereby inducing discontinuities in what you are doing, and it's very nice. I believe this is undoubtedly the concern of users who said to Dr. Winkler: "Please, don't fiddle with the scale," This is what they want. They don't want these horrible changes.

At the same time, you buy this continuity of scale at the expense of the divergence between different systems. So this is, in essence, the control problem that is faced by anybody running this sort of a system. The users are those who can say, let it go hands-off and then finally adjust it by a very large amount. So do you keep making small adjustments all the time? What is really best for the application?

DR. WINKLER:

I think that is an excellent comment. And there is another application which we should mention, and that is the SATCOM ground stations. As you know, these 28 stations are being equipped with cesium beam standards. Since the satellite link provides a synchronization capability to one-tenth of a microsecond, these stations automatically become precise time reference stations.

But what are the requirements to actually step these clocks? At the present time I think we have adopted a more-or-less experimental procedure to stay within 25 microseconds for all of these. We know, of course, the time difference to a tenth of a microsecond or so. But I can foresee that as one gains experience, and as the operators become more used to the new procedures, that one can reduce that tolerance to something like one microsecond without any difficulty. And I think that's just another example for this operational question which was raised by Mr. Swanson.

MR. LIEBERMAN:

I would like to leave this conference with just one thought. We've demonstrated here, and over the years, that we have disseminated precise time and time interval over satellite stations, LORAN-C, VLF, and now OMEGA, and also TV. I think we should begin to look for applied research in using this time and time interval information, which will be available almost throughout the world. We can now talk about getting comparatively inexpensive receiving equipment to make use of the time that's available. And I disagree that systems in the future necessarily have to have internal references, if there are sufficient sources, just like our power sources now, to keep them on time and frequency.

DR. WINKLER:

I think you will find the greatest amount of resistance for any military system to have to rely exclusively on something which is outside, because one should keep the systems separate in their operational capability. That capability should not be endangered by any failure outside of the system.

Ladies and gentlemen, I think we have come to the end of our allocated time. I would like to thank the speakers, and turn the meeting back to Mr. Clark Wardrip.

MR. WARDRIP:

It has been Goddard's pleasure to host the Fourth PTTI Conference; and on behalf of the U.S. Naval Observatory, the Naval Research Laboratory, and the Naval Electronic Systems Command, I thank you all for coming and for your participation.

Thank you very much.