PTTI AND ITS PP&T'S
(Problems, Pitfalls and Troubles)

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ABSTRACT

An overview will be given of the main problem areas in practical Time/Frequency (T/F) applications. Specifically the following will be briefly discussed:

Specifications versus realistic clock performances.

Operations - power, reliability, redundancy.

Training of operators.

Repair - maintenance.

Standards - conventions.

Utilization of assets (use all clocks available).

Path and equipment delays - variations.

Management understanding and approval versus decision delaying and decision avoidance techniques.

It appears to me that precise timing systems may be, at least initially, more subject to troubles than other systems of comparable complexity, even though modern precision clocks reach levels of reliability which are excellent. However, our clocks are parts of systems and it is in this overall context that I wish to discuss briefly some problems and pitfalls that I have seen and experienced myself. The two most important single problems stem from the fact that clocks must operate without any interruption; and from frequent misunderstandings and errors in the basic system design, i.e. in the overall balance of the engineering compromise. Fig. 1 is a summary of the main factors in such a balance. As so often in life, if we are too demanding, we will have to pay dearly, and not only with money, but also in terms of parameters which are usually underestimated at the time of system acquisition, e.g. maintenance, training etc.

We have seen a significant change in doctrine in the overall design of systems in the DoD in the last five years. It has not yet filtered down through the ranks. One used to specify optimum performance of the overall system. This entailed the need for many special developments of subsystems and components - a very costly process by the time everything was debugged and ready for production. A much quicker, less expensive, safer (no breakthroughs required), and operationally much more reliable strategy of systems acquisition is one where a survey of components and subsystems already in production precedes the overall system concept development including its final specification. In our terms of reference, this means that we first should look at what is currently available in the timing area.

Fig. 2 is a short list of what is practical and sufficient for the large majority of users at this time. On the other hand, Fig. 3 shows what I believe could be obtained with systems which exist, but which require a modest further development (several hundred thousand dollars).

An area of frequent misconceptions is the great difference in performance and environmental sensitivity of the various clock types. This is a large and important area which I present in Fig. 4.

In addition to other criteria which limit the choice of a clock type for a particular application, the system noise is often overlooked as a basic limitation of clock utility. Fig. 5 is possibly an oversimplification, but one can see very clearly that towards the right part of the Figure we gain a great margin of safety with less expensive, simpler and more reliable clocks.

I consider it as one of the great injustices in this world that those who select and purchase complex systems usually are not the ones who have to operate them. In fact, no other measure may be as effective in improving technological performance as keeping the noses of our specifiers and procurers on the grindstone of operations after the goods have been delivered. Fig. 6 lists only the most important sources of trouble, lack of redundancy and primary power.

Now let us move to the human side. Fig. 7 points to the need to adhere to standards in our terminology and Fig. 8 sketches my minimum ideas on training.

Maintenance of PTTI equipment (Fig. 9) in my opinion can only be organized with a view to the qualifications of the people on hand. In an environment of frequent transfers, a technician may never see a malfunctioning atomic clock (they have half-life times of 3 to 4 years), so why should we train him extensively in such a sophisticated piece of equipment? In such a case, replacement maintenance is the only economical approach. Many mini-computer users seem to have reached the same conclusion and that is also why the Naval Electronic Systems Command has established its atomic clock logistic support facility (within its Washington Division).

That one should use all assets (Fig. 10) is not a very frequently followed maxim and brings me to my last and most delicate point: Management (Fig. 11).

It is also the most important item because when things go wrong, who else is to be blamed but management? It is strange, however, that we don't do much better in this area, since most of us are managers as well as subordinates to higher management which should give us an excellent opportunity at least to see how not to do things! Since we can hardly tell our superiors how to run their ships, we can only do one thing to improve this world: Learn from the mistakes of others and do it better ourselves.

But there must be one word of caution. Our attention may be so out of focus from some particular examples of pseudo-management that we mistake it for something different. Management is not firefighting, or bookkeeping, or "politics" - it is thinking, planning and motivating. Nothing else will lead to success in science and technology.

Therefore, let us use the opportunities for constructive actions whenever it is up to us to move. In the PTTI area we depend on mutual cooperation if we want to obtain the best performance at least cost with greatest reliability. To make such cooperation work, it is essential to develop a positive attitude which looks at the goals rather than at the procedures and which is more after substance and less after form. To achieve this goal, we must communicate and inform each other of problems and possible solutions; that is the purpose of this conference.

What We Want	and	What We Pay
Stability Infrequent Synchronization		Cost Size Weight Power Consumption Maintenance Costs Reliability Operator Training

Fig. 1. Clocks are Parts of Systems. Engineering is a Compromise Betwixt.

By more than 95% of users
5 μs Time Accuracy
0.2 μs Time Precision
1×10^{-11} Frequency Accuracy
1×10^{-12} Frequency Precision

Fig. 2. Practical and Needed, Today

5 ns Accuracy, Locally (PC, TV, μ-Wave)
100 ns Time Accuracy Worldwide
5×10^{-14} Frequency Stability (1d)

Fig. 3. Possible Today

	Additive Noise	Perturbing Noise	Parameter Changes
Atomic Clocks (Rb, Cs)			
τ range	< 1s	1s to 1 week	> 1 week
Causes	Thermal	Shot noise of detector	Spontaneous systematic
Influenced by	Buffer amps.	Age	Environment
Quartz Clocks			
τ range	< 1s	--	> 10s
Causes	Thermal circuits	Acceleration	Spontaneous diffusion of defects
Influenced by	Amount of buffering	Vibration	Age, environment, radiation

Fig. 4. Noise Types and Oscillators

Phase Noise	500 ps	10 ns	200 ns	2µ	1 ms
Typical System	VLBI µ-Wave	Loc. TV Ph 3 DSCS Improved NAVSAT	DSCS Loran-C TV Network TRANSIT	VLF Noon OMEGA	HF VLF Ops
Clock of Choice	"H"	Cs 004	Cs	Rb	Xtal
Sigma (1d)	6×10^{-15}	3.5×10^{-14}	2.3×10^{-13}	2×10^{-13}	1×10^{-10}
Required	6×10^{-15}	1.2×10^{-13}	2.3×10^{-12}	2×10^{-11}	1.2×10^{-8}
Safety Margin	0	5 db	10 db	20 db	21 db

Fig. 5. System Noise and the Choice of Clocks. We assume daily re-synchronization.

Reliability Through Real Redundancy
Power, Standby, NO-Breaks
One DC Line Can Also Be Shorted
Project Books for Clocks

Fig. 6. Operations.

Discipline in Terminology
Clock Difference - Signs
Clock Rate, Fast - Slow
Frequency, High - Low

Fig. 7. Standards - Conventions.

Selection of "Metrology" Persons
Motivation - Pride in Accuracy
Continuity of Assignments
Pomona's TV Training Cassettes
Competent Leader - Teachers

Fig. 8. Training.

Batteries Need Care
Fuses in DC Supplies
Repair vs Exchange
Pitfall: Exchange for a Burned-Out Warning Light

Fig. 9. Maintenance.

Use Best People
Use All Clocks
Exchange or Repair of Faulty Equipment

Fig. 10. Use of Assets.

Today's Crisis - Management
Training - But no Touch With the Bench
Well Indoctrinated - But Does Not Know
If You Want Action - Don't Treat Them as Idiots
Follow Up With His Successor
Impress But Don't Snow

Fig. 11. Management.

REFERENCES

1. Hellwig, H., Frequency Standards and Clocks: A Tutorial Introduction, NBS Technical Note 616, March 1974.

2. Hellwig, H., A Review of Precision Oscillators, NBS Technical Note 662, February 1975.

QUESTION AND ANSWER PERIOD

DR. KLEPCZYNSKI:

Klepczynski, Naval Observatory.

Is today's crisis management or is it crisis management?

DR. WINKLER:

I think the fact that we have crisis management is already a problem. Because management has nothing to do with bookkeeping, and yet, I think that is what everybody thinks it is. It has nothing to do with side effects. I think it has to do with thinking and planning and with motivating, but how can you do that?

MR. LIEBERMAN:

Could we go back to that slide about the VLF? Are you saying synchronization for VLF operation versus VLF noon? Are you suggesting that we go to crystal oscillators for the 1 millisecond timing versus the 2 microseconds for VLF noon timing? Are you talking about the need for timing or are you talking about synchronization of the communications?

DR. WINKLER:

I am talking about the limitation of all your measurements if you use high frequency signals. You are limited to a precision of about 1 millisecond from day to day. If you lose time, you can pick up time, again to 1 millisecond, by listening to a time signal. If you have a daily operation like that, in a system where the 1 millisecond phase noise is your allowed performance limit, I think a quartz crystal oscillator is your oscillator of choice because it gives you a performance about 100 times better than what you need in order to stay within that 1 millisecond from day to day.

MR. LIEBERMAN:

Is that at the transmitter?

DR. WINKLER:

At the transmitter as well as the receiver. It is only that you want to use, in order to freely utilize the benefits of the time system, you will want to have less frequent re-synchronization than daily and then, of course, here you are immediately using your margin of safety.

And then you may decide you want to put in a higher performing clock, but that is caused by a less frequent than daily re-synchronization, given that phase noise. If you want to stay within 2 microseconds over a period of 100 days, I would even go to the same choice.

So, again, please, I have to apologize in the interest of making a point, somehow one has to start out with oversimplified charts. This is an oversimplification. But, I think it gives you the main ideas, what are the parameters and where can I have payoffs? It brings out another point, of course, and that is that any systems engineer ought to be really bargaining about these various performance parameters. That is a process which I don't think is really carried out.

I have never yet seen people who will turn around and say, look, that is simply asking for too much trouble. But, you can have this. Could you design your system around a great capability here? It is a kind of bargaining and maybe we are not salesmen enough to point out great advantages on the one hand and a high price on the other one. The design of a system, not by first dreaming up a gigantic thing which will do everything and then worrying about what components do we now have to develop. I think that is the wrong approach.

That is what is causing the very high expenditures which we are facing in our modern system. The right approach, I think, is to look around to have a general idea of what we want to do and to look around at what is available today and only use those components. But, I don't think we are doing that.

DR. COSTAIN:

Dr. Winkler, you mentioned for 100 nanosecond worldwide synchronization that it would take about $100,000 or $200,000. Are you referring for installation and are you including any maintenance costs in this?

DR. WINKLER:

I have mentioned several hundred thousand. I don't think you can do it with $100,000. There are two candidates which I think could do that. One is the improved transit satellites about which I hope to hear a little bit more again this session. We had a paper last year about it and what you need to do here is to get several hundred thousand dollars to develop receivers, and the other one is the navigation technology satellite or the navigation development satellite going into the global positioning system.

Here again, to get started with timing receivers will require that kind of funding but after we have started and really have some receivers on the market, I am sure the price will go down. I think such a receiver, in fact, I am reasonably confident, is already under development for the global positioning system.

So, I think that this is within the reach, a couple of hundred thousand dollars will give you, I am quite confident, 200 nanoseconds. In fact, I think last year there was a report by the NRL group, NRL mentioned by Dr. Clark. Some of these experiments which are being carried on, are exactly in that area, and I think they are achieving this kind of performance; 200 nanoseconds.

It is clear that a worldwide coverage can only be achieved by a satellite.