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M/S 298
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Bendix Field Engineering Corporation
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FOREWORD

These Proceedings contain the papers presented at the Twentieth Annual Precise Time and Time Interval Applications and Planning Meeting. The meeting was held at the Sheraton Premiere Hotel in Tysons Corner, Virginia. A good attendance at the meetings and the banquet was an indication of the continuing interest in the field. We had a number of invited papers, some of which are included in these Proceedings. Some papers are missing because they were not received in time for publication. The question and answer periods following each talk are included, but they are marred this year by the lack of cooperation among the questioners in not speaking with the microphones.

There were 205 registered attendees (down from 225 last year). Of the attendees, 119 were from East of the Mississippi (67 last year), 62 were from West of the Mississippi (137 last year) as well as 24 from 11 foreign countries (17 from 9 last year).

The objective of these meetings is to provide an opportunity for program planners to meet those who are engaged in research and development and to keep abreast of the state-of-the-art and latest technological developments. At the same time, they provide an opportunity for engineers to meet program planners.

The success of these meetings depends on the efforts of the Program Chairman and the Individual Session Chairmen and the organization of the entire meeting by the Chairman of the Executive Committee. Without their unstinting labor, such meetings could not be held.

The purpose of the PTTI Applications and Planning Meeting is to give Managers, Systems Engineers, Program Planners, and Industry:

- A forum for presentation and discussion of current and future programs and requirements
- A general and in-depth review of plans and trends in PTTI applications
- An opportunity to discuss results, accomplishments, and problem areas in the application of PTTI technology
- A review of new developments which influence PTTI applications

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Chairman: James Wright
Computer Sciences Corporation and Raytheon Company

Aspects of Coordination (Management) of Precise Time and Time Interval (PTTI) Systems.

Gernot M. R. Winkler
U.S. Naval Observatory
Washington, DC. 20392–5100

Those who do not remember the past
are condemned to relive it.
Santayana

INTRODUCTION

Systems that use precise timing and/or precise frequency are generally electronic systems that operate over extended geographical areas and involve many different types of equipment. The concept development, implementation management, and operation of such systems present, of course, all the problems that arise if we deal with large, diversified systems. The only thing one can say in general terms is that in almost all such cases, with very few exceptions (the Polaris submarine system, or the U–2 projects were such exceptions), totally unforeseen problems arose that forced a scaling down, increasing costs, and delaying substantially, or even preventing, the completion of the system. In retrospect this is easy to see. What is very difficult is foresight, i.e., to find out at the very beginning of the project how improvements could be accomplished and costly pitfalls avoided. This is even more important in the case of systems that involve PTTI. The problems that are peculiar to PTTI are amenable or altogether avoidable with a relatively small effort if, from the very beginning, one is aware of past similar problems in other systems [1]. This contribution discusses broadly the specific PTTI problem areas as they arise in the R&D phase; it will also address questions of operations; finally it will touch upon questions that usually arise whenever we have to "coordinate" anything. (The quotation marks are to indicate that this is a popular euphemism for situations where you will be blamed without having had real authority.)

THE DENIAL PHASE

In almost all cases of PTTI systems R&D that I have observed over the last thirty years, the system managers denied that they were to be concerned with timing. "No, we only use precise frequency control, only relative synchronization is needed, we must remain completely independent". These are some of the comments one hears when the question of timing is raised by the consultant or observer who learns about the new system. It is, of course, an entirely natural attitude because why would any manager want to become involved with questions that do not seem germane to the task? It should be easy to inform people that experience shows that one will get involved with typical timing problems even if one can't see it yet. But unfortunately, the denial attitude is supported, strengthened, and advanced beyond a reasonable degree by the present management culture that insists on overly precise cost estimates and cost accounting from the beginning. It is always hard to explain in detail the reasons why one proposes to include in the estimated budget items that have no obvious connection with the task at hand. But this forces from the very beginning of the project an attitude of mind that is hostile to mental efforts over and beyond the absolutely necessary. I can only compare this with the constrictive effects of a cup of lemon juice taken as aperitif at the beginning of a dinner. The mind suffers constriction, too, in such a climate! In fact, we need the exact opposite effect. We need to enlarge our vision and expend a large part of the mental energy at the beginning of the project and not when we find that we are getting into trouble. This means that all possible scenarios must be envisioned and analyzed regarding their impact on the system under design. It is extremely difficult to convey to those who have not personally paid the price of past mistakes, the consequences of stopping too soon. I beseech you to envision, if you can, the full magnitude of our intellectual limitations. Following the eminent example set by Socrates 2400 years ago, it has always been seen as the highest achievement for the human mind to understand his own ignorance and to grasp the enormous difficulty in overcoming it, if only so slightly. There is no hope of gaining some insight unless this understanding is achieved first. I find no better way to illustrate this all important point then to give you in the appendix, with the author's permission for which I am most grateful, some personal reminiscences by "Jack" Pierce. His is the voice of many decades of experience, because he is the inventor of the Omega system and a truly eminent contributor to LORAN and other radio navigation and communications system technology.

It is true that the recommended extensive preparation may be costly. Possibly we have to call for help and advice ($500 to $1000 per day for an experienced consultant). But without doing this at the beginning, the chances are great that much more expensive problem– fixing will have to be done later or even towards the end of the development when these unforeseen problems will surface.

The best way to start is always with a pilot project that will allow the people who have to make decisions some familiarization with potential problems. The crucial questions that must be answered and clarified in the case of a PTTI system are the following: Why are precise clocks (or frequency standards) necessary, how often should they be re–calibrated to maintain system coherence, and in what environment must the equipment operate?

THE SPECIFIC TECHNICAL PTTI ASPECTS.

Suppose we find ourselves involved with such a project. Then we will examine the following details:

- 1. What clock (or frequency standard) performance is really needed? It is very important that we are realistic at this point. We must not specify much more than what is needed, including a margin of safety (as a rule of thumb, a factor of ten). I am a great believer in conservative designs, and the inclination to get the best available performers is natural and laudable, but we must remember that engineering is the art of finding a sound compromise between conflicting requirements. Price is the least important consideration compared with the other "payments" for excessively sophisticated choices. Super high performance clocks entail substantial problems such as shorter life, greater sensitivity to the environment, and expensive support.

- 2. What are the environmental conditions? This is also a very important subject. Lest we forget, high–precision timing and frequency control are applications of highly advanced technology. The environmental sensitivity of the devices used is a rather steep function of the performance expected. It may be more cost effective to increase environmental protection (such as shock and vibration absorbers, acoustic shielding, external temperature and humidity control) as compared with the use of specially hardened frequency standards. An obvious exception to this would be radiation hardening where the use of lead very quickly leads to unacceptable weights. In such cases, different system approaches may be required.

- 3. How often can we re-calibrate the frequency standards and clocks? This brings us back to item 1. Why do we use high-performance clocks in the first place? What we gain is independence, in most general terms. The more independence we need, the greater the requirements for clock performance at the points where independence is needed. This seems like a silly triviality, yet I have witnessed lengthy committee meetings where one agonized over possible savings by putting greater stability into the operational center of a PTTI system at the expense of a substantial relaxation (use of cheaper clocks) at the outlying parts of the system. The original idea, why clocks were needed in the first place, was lost after several years of development and frequent changes. Again, why are clocks to be used at all?

- 4. What do we mean when we talk of synchronization? We must specify an acceptable time error within the system. Of course, it is always perfectly possible to avoid the use of high-precision clocks or frequency standards by re-calibrating at very short intervals. A good example is color television. The receivers use extremely cheap quartz crystal oscillators for the generation of the color reference phase (the 3.5 MHz subcarrier). The necessary precision is secured by phase locking the crystal oscillator to the transmitted color burst reference every 16 milliseconds (ms). As one can see, it is necessary to refine our concepts of synchronization. We must specify not only the acceptable tolerance but also the time interval over which this tolerance is to be maintained. In addition, we must also specify the measurement or calibration accuracy that is necessary to achieve and maintain the tolerance over the specified time. This last point is usually forgotten, but a rule of thumb is that we want to measure with the highest precision that can be achieved economically (at reasonable expense). Today that means the use of 1 ns resolution for time interval meters. As an example, assume that a tolerance of 1 microsecond (us) is required with re-synchronization in intervals of 10 days. That implies a frequency (rate) calibration to better than 100 ns/day (about 1 part in ten to the 12th). In order to do this within one hour, we need a counter resolution of 1 ns and also signals that can give us a precision of a few nanoseconds. Therefore, the stated tolerance of 1 us over 10 days entails a requirement for a 1 ns calibration capability. One can say that the operational requirement over a certain time and the need to calibrate (check) the clock in a reasonably short time entails a magnification factor for the timing precision, 240 in our example. Please note that the setting of requirements is not as simple as it often seems to be taken. All this, of course, assumes that the clocks can maintain the required frequency stability over the time specified.

- 5. How will the logistics and support for the PTTI equipment be arranged and managed? Clocks from reputable sources have MTBF's in excess of 30,000 hours. Such a performance is not easy to achieve and, indeed, after model changes the number drops immediately and will remain lower than before the change, until a continuing feedback loop from customer back to the development team and production can flush out the new weaknesses. Of course, there is going to be a problem if the development team has been disbanded in the meantime. While repair is best arranged through replacement and vendor repair, each larger PTTI system should have a central office or person to supervise the performance of the system (especially the clocks) and for record keeping. The office that started with the pilot projects, worked out the specifications, and did the design, should also arrange training and operational supervision. Even though our systems today are being designed with as much automation as possible built into everything, one must not believe that this will reduce the need for supervision completely. Another possible pitfall is in the acceptance of "turnkey" systems. The special requirements for training, performance supervision, and logistics, after acceptance from the contractor, may not be fully recognized by the user who, up to this point, had no opportunity to develop sensitivities to problems peculiar to PTTI.

- 6. Primary and backup power for the PTTI instruments, particularly clocks, distribution amplifiers and time code generators, is also an important subject for study and concern. In the long run, this may well be the most important point to consider. In many locations it will be necessary to provide some form of backup generator to protect against longer outages. But public power may not only be unreliable, it is probably "dirty" as well. Therefore, it is highly recommended to operate all sensitive equipment from conditioned (no–break) power because experience has shown that equipment operating directly from public power has a significantly higher breakdown rate than equipment running from conditioned (e.g., no–break) power. This power source must never run motors, air conditioners, or anything that produces surges and voltage spikes; only the really critical equipment must be on this power source. In addition to AC backup, all critical equipment must have a DC backup. The use of small separate supplies is uneconomical and has a poor reliability record. There are large 24V (and 48V) supplies available that use large (automotive type size but high quality standby) batteries. These have a much longer life, do not need to be exercised, and cost relatively less than small batteries. It is imperative that a second, spare, or standby PTTI system, if available, must be operated from a second, independent power system to assure real standby capability. In other words, a "vertical" separation of the systems is required. It would even be desirable to schedule access and maintenance for this second system at times different from the main system because people are the source of the high correlation of "accidental" events (we tend to make a mistake thoroughly).

- 7. Operations. It is possible and inexpensive to automate, and control remotely, most of the regular operations such as measurements and adjustments. However, it would be a grave error to assume that this removes the need for careful selection and training of those who are in PTTI operations. Furthermore, all activities have a natural tendency to degenerate without continuous vigilance. Therefore, inspections or some form of quality control is mandatory. Unfortunately, when resources are cut, this is the first area that suffers because there are no immediate obvious effects. It is partially for this reason that performance specifications (such as measurement precision, clock tolerances, etc.) must be set to the highest level the system is capable of, whatever the system tolerance is. It is a most dangerous idea, but widely held, that a marginal performance is still acceptable, if it just meets the stated system tolerance. This almost amounts to permitting a time bomb in the system. It is the equivalent of a time bomb because by allowing slack in the system performance, one abandons the best and only way to discover immediately if something ill is developing, before the system operations are affected in dangerous ways. This is, after all, why mature designers will always use margins of safety to protect the system from the unforeseen small problems. In other words, we are recommending to operate in a way that maintains an operational margin of safety. One cannot press this point hard enough because a general spirit of permissiveness, once allowed entrance, will propagate rapidly and endanger the system before we know it. On the contrary, we must insist on a spirit of excellence and it would be beneficial if worker incentives could be provided for any consistent performance that is better than specified. Here, again, a superficial idea of cost savings may be a contributing factor. It is a mistaken idea because the costs of poor system performance or breakdowns are vastly in excess of the proposed incentives to excellence that would go a long way in prevention, or timely discovery, of serious problems.

- 8. The Benefits of Operating in Time Coordination with UTC Against Complete Independence. It is less expensive to use UTC as an external benchmark for a timed system as compared to a completely arbitrary rate and epoch, and it provides great operational benefits. The reason is simply that at negligible cost, the world's most advanced timing becomes available for calibration, stabilization, performance evaluation, and recovery after breakdowns [2]. A necessary condition for this is, of course, that interfaces with other PTTI systems have been designed into the system at key points. There is also no penalty in regards to an imagined dependency because, as we have seen above, one can make the "lifeline" arbitrarily long by simply setting tolerance and re-synchronization properly. There is also no penalty for classified systems to use UTC as benchmark because the progress of time, as such, is the most predictable thing we know and we can't and should not attempt to keep the time of day secret. It is the "when" that can be easily protected, if necessary. This understanding has been reached eventually by every timed system that I have observed, Omega, LORAN, Transit, DSCS, etc.; each one had to install more sophisticated PTTI capability as the operational experience dictated. The GPS is somewhat of an exception (but only in this respect) because it has been designed from the start with precision timing as the well understood central principle of operations [3]. A related question should also be mentioned. That concerns specifications of the interfaces for time codes and standard frequency. In this area, a new standard is being drafted by a working group involving NRL and others.

COORDINATION AND MANAGEMENT

It is not my intent to compete in these few comments with the flood of good advice that is available in print and in countless "How to Improve Your Managerial Performance" seminars. Of course, if you are a professional manager then you should stop right here, because you already know everything. Others, less professional, may want to avail themselves of some of the management bestsellers. Here, I wish only to make some remarks that reflect my own observations from having seen the fate of quite a few systems, from design to shutdown; and having worked in quite a few different environments.

There is no question that planning and control are essential for success. What I have observed, however, is that systems that were somehow protected from excessive management attention achieve a consistently superior performance compared to those that enjoy the full benefits of professional management. Here, I am offering my own explanation. Engineers and scientists have an instinctive respect for truth: they must find and understand the facts, unless they are phonies. (In this case they repeat the buzz words they hear from others). Engineers are also conservative and like to be careful. This is rather unique because everywhere else, the primary objective is not care and truth but expediency. This is particularly so in politics, in sales, and often in management. The higher up we go, the more urgent the call for expediency becomes. But one cannot serve two masters. Things look different if one's primary objective is expediency and not truth. It is much more difficult and requires much more doubt to see the facts as they are than most people realize.

I am not talking so much about the deliberate lie and distortion of truth. But, if you evaluate stated performance, an allowance for "optimism" must be made, particularly if the speaker is in the "sales" mode and not in the "objective" mode. Unfortunately, this bias is very different from case to case, making comparisons extremely difficult. In some cases I know, an extremely conservative attitude even goes the other way, claiming much less than is actually achieved routinely. The only way to resolve the problem is, again, to make inquiries and to rely on proven reputation. This is very difficult in the government procurement process which is still too occupied with the idea of least initial cost. I stress this point because our success will be exactly commensurate with the realism of our assumptions and designs. This seems to be unknown in certain quarters because otherwise why would they thrive on euphemisms? The deliberate distortion seems to be an indispensable tool in much of modern life. In fact, we have become accustomed to this. The punishment, however, comes quickly when the perpetrators of the lie start believing it themselves. If this happens in management, the results will be serious. It makes them blind to reality and then they fall into the ditch. Even if there is no willful distortion, an excessive optimism, or lack of self critique is almost equally dangerous.

There are other observations that worry me. The fantastic success in many areas of science and technology, combined with certain deficiencies in our education and great luxury in lifestyles, has created a blasé attitude on the part of many, often coupled with outright intellectual arrogance (we know it all, we can do everything with money). How are we going to communicate in such a climate? Effective communication always requires a certain match of the intellectual level and a willingness, nay, eagerness on the part of the listener to understand the message. This is where the personal style and energy of the "coordinator" has to come in. In brief, what I recommend is a synthesis of a realistic optimism with a tremendous respect for the problems, of understanding the technical details and pitfalls, the selling of the project to those we need as partners, and the motivation of a high quality work force. It is particularly in this last area where the classical scientific management has failed because it was too simplistic. Yet much of our industry, and most of the actual operation of the government, is still dominated by obsolete ideas, many of them in new appearances. The worst of them is the idea that there is such a thing as management as such, without a specific technical background. In any high–tech area, and PTTI is definitely high–tech, you will fail unless you obtain, and can keep, a substantial commitment from your co–workers for high quality work. This can't be done with management buzz words or gimmicks. Loyalty, both ways, example, honesty, and technical competence are indispensable.

I have mentioned deficiencies in our education. The point that is important for us here, and that goes beyond the main concern of the current public debate and the recent report of a presidential commission[1], is the insufficient preparation for the complex situations with which we have to deal in the modern world, especially in complex modern systems and their management [4]. We see the conspicuous results of poor and immature management all around us. Most have their roots in a failure to grasp the difficulties in their full dimensions, and in a lack of vision (even interest!) for the magnitude of the likely consequences of hasty actions. It is so much easier to act than to think, and so many managers have the silly idea that acting, as such, with only quick and superficial intellectual preparation is all that is needed! (And if we know nothing we still can re–organize and change the name of the organization to something more impressive!)

I have discussed one remedy before, the General Systems Approach as an educational discipline [5]. Some familiarity, gained possibly in self study, with the abstract ideas of complex general systems (including catastrophe theory and concepts such as chaos) will, at least in some way, assist with an accelerated gaining of some degree of genuine wisdom, i.e., a feeling for the right measure. Without right measure we will vacillate between extremes. This feeling for the measure, therefore, is indispensable for deciding, not what can be done, but what should be done.

NOTES AND LITERATURE

[1] A technical overview of PTTI with some references has been given in my article "What Is PTTI?" in the 17th Proceedings of the PTTI, p.33–44.

[2] A very good example for the gradual learning of the benefits of operating on UTC is described

[1]American Education: Making it Work, William Bennet, April 29, 1988

in Mr. Vannicola's paper on the Omega system, in this volume.

[3] The parenthetical exception refers to the fact that even in this case other problems arose that forced substantial and costly changes late during development. At least a part of these complications would have been avoided if greater use could have been made of the substantial practical experience that had been gained with the operation of the pilot project, NRL's TIMATION. But this is not so easy in the face of all kinds of difficulties that arise, and compromises that must be made, in the process of getting large systems contracts under way.

[4] There is no question that our education has become too narrow. It had to be, because the universities and the students wanted to maximize the immediate utility of the young professional. In my opinion, we have gone much too far because the technology changes so rapidly that the first thing can only be to be firm in the fundamental principles; the specific details must be learned on the job at any rate. In addition, as we progress and take on greater responsibilities, we not only need additional professional skills, but also need to develop much broader views and sound judgment because no effort stands isolated on its own but is embedded in the system of our country and in our culture. The present educational background is of little help because of the narrowness and short range outlook of the curricula, except, of course, in the liberal arts. On the other hand, a liberal arts university education by itself can be useless, or even harmful, unless a practical trade or profession has been mastered in addition. Otherwise, the young noble person has been prepared for great things but will feel as an outcast because he can't do and can't understand practical, useful things. Hence the mandatory need for continuing self development of all. More details along these lines are given in my lecture notes on Self Development, available on request. In the meantime one must continue with his lifelong professional education but should also sometimes start with Plato if one is an engineer, and with a course in science, electronics, or computers, if one is a liberal arts major. C.P. Snow was the first one to observe the dangerous communications gap between the "Two Cultures" and those who followed his advice have been able to enrich their lives greatly and avoid the terrible shallowness so typical of much of modern management and science.

[5] As a very brief and superficial start that can only give an overall impression, see my paper "Introduction to Systems Approach" in the 10th Proceedings of the PTTI (p.1–15). I recommend some of the literature cited, particularly references 4, 12, 13, 25, 26, and 33. In addition to these it would be useful to gain an understanding of the basics of catastrophe theory because, by gaining insight into the causes of system collapse, one will hesitate stressing a system more than necessary. As long as one keeps intellectually curious and active one will avoid a dangerous narrowing of his views. For those who are engaged in creative work, or have responsibilities in any way connected with such work, one should recommend a repeated reading (once per week) of the following appendix. I believe it conveys the essence of excellence.

APPENDIX

"NEVER STOP THINKING"

J. A. Pierce

My text is intended to warn against the danger of believing that one has finished. The feeling of triumph that he enjoys when he has reached the end of a difficult course may itself be enough to blind him to any further advance that might be possible. In

a foot race, or when killing an enemy, a clear end can be distinguished. But in most activities in life, every achievement is usually only a step on a long path.

An early violation of the truth I am claiming came when I was helping a few others in the design of the first LORAN receiver. We measured the difference in the time of arrival of two trains of pulses by triggering an oscilloscope sweep at their repetition frequency and then delayed one pulse until it could be visually made to coincide with one in the other train. In the presence of noise, the persistence of vision caused the display of several pulses of continuously–varying shapes, and it was difficult to judge which way to turn the knob of the delay control. Only when it was too late to be incorporated in the design, did it occur to me that we should have made one of the pulses appear in dotted lines while the other was continuous. The sense of an error in the matching would than have been conspicuous. I still blush a little to realize that a few minutes of thought at the right moment could have made possible this improvement, and have made the operation of seventy–five thousand receivers a little easier. Another case of the violation of my theme is easier to explain. I heard of it in 1960, when I was serving as a member of the Polaris Command Communications Committee of the U.S. Navy. The giant, very–low–frequency radio transmitter at Cutler, Maine had begun to operate at 14,000 hertz. The committee was astounded to be told that on the first voyage of the SSBN George Washington, when no more than half way across the Atlantic Ocean, the signals received from Cutler were lost the moment the ship submerged.

The trouble was found to be just a bad case of local interference. The Polaris vessels used several kilowatts of 400–hertz power. The antenna leads had thoughtlessly been led through the same conduits as the 400–hertz line, and the thirty–fifth harmonic of the power frequency was far louder than the Cutler signal from the submerged antenna.

This error was corrected, at least for the moment, by changing the frequency of Cutler to 14,700 hertz. I have never heard how the antenna leads are now arranged.

Another omission for which I feel personally guilty is connected with the choice of 10.2 kilohertz for the primary carrier frequency for Omega Navigation System. An earlier experimental system measured the phase difference between trains of 200–hertz modulation on signals received from pairs of stations. The Navy Electronics Laboratory, the Naval Research Laboratory, and I all had equipment for measuring the 200–hertz modulation. It therefore saved each of us a little effort to transmit pre–Omega signals at 10,200 hertz and beat them against ten–kilohertz frequency standards. The final decision to use 10.2 kilohertz in an operating system was not made until several years after I had heard about the difficulty with the Polaris signals. This knowledge notwithstanding, it did not occur to me that the 170th harmonic of the 60–hertz power frequency would ever rest very long in the narrow receiver pass–band.

I suppose, also, that it never occurred to me that a sine wave that was relatively pure could possibly have a measurable harmonic of such a high order. The cases of such interference, which are now occasionally reported, may arise from the extensive use of silicon– controlled voltage regulators. These do terrible things to 50 or 60 hertz waveforms, but fortunately, they are used to control only a tiny fraction of our electric power. From the beginning, it should have been clear to me that offsetting the Omega frequencies from coherence with any frequencies measured in the decimal system would have been a worth–while safety feature. Had we, say, adopted for the primary frequency five megahertz divided by 491 (yielding about 10183.3 hertz), it would have made no difference in the operation of Omega and would have forever protected the system from foreign signals or interference at frequencies measured in integral numbers of hertz.

I have recently found myself wondering whether the unfortunate destruction of an Iranian passenger aircraft by the U.S.S. Vincennes may not have been caused in part by such a premature termination of thought. Listening carefully to radio and television comments about the incident, I have at times heard "experts" remark that "the Aegis system is not designed to indicate the size of an attacking aircraft". Aegis is no more than a very sophisticated set of radars. Even a simple radar tells us the distance and direction of an object and whether the reflected signal is strong or weak. Because the distance is known, the strength of the reflected signal is an excellent measure of the size of the target.

It seems possible that the designers of Aegis may have become so hypnotized by their ability to track dozens or hundreds of objects and exhibit their positions and rates of closure, that they may have neglected to add to each indication a note that the target is large or small. If so, a valuable part of the original information is being thrown away. This may be an example of what worries me: the cessation of thought at a critical point in a design.

I should add to my argument the obvious fact that ideas come only to minds which are ready to receive them. This preparation may be the result of study, worry, prayer, dreams, or experience. It is, of course, the primary reason for education. Probably all of us have had an idea come "like a bolt from the blue". In thinking over a few of my own experiences of this kind, I have realized that the most dramatic and important instances had come at the end of the longest periods of contemplation and worry. This is exactly the converse of the threat that I am preaching against: the belief that the end has been reached. It is precisely at this point, after long study and much thought, that one's mind is best prepared to continue, offering the chance of attaining something better than what originally had been sought.

THE PROJECT BEGINS WITH:

- INVENTORY OF SCENARIOS
- SPECIFICATIONS FOR PILOT PROJECT
- PILOT PROJECT
- CRITIQUE OF PILOT PROJECT
  (Consultants)
- SYSTEMS SPECIFICATIONS

WHAT CLOCK PERFORMANCE IS REQUIRED?

- SET ACCEPTABLE TIME/FREQUENCY TOLERANCE
- APPLY A SAFETY MARGIN (less or equal to 10X)
- SELECT CLOCK TYPES
- CHECK ENVIRONMENTAL CONDITIONS
  Temperature, Magnetic Fields, Vibration,
  Pressure, Humidity, Accelerations

HOW OFTEN CAN WE RE-CALIBRATE THE CLOCKS?

- MORE INDEPENDENCE REQUIRES BETTER CLOCKS
- FROM COMPLETE INDEPENDENCE TO TIGHT PHASE LOCK LOOP
- WHY ARE GOOD CLOCKS IN THE SYSTEM?
  Ask this question at every design change.

TO MEET AN ACCEPTABLE TOLERANCE

WE MUST MEASURE AS ACCURATELY AS POSSIBLE.

EXAMPLE: TOLERANCE = 1 MICROSECOND OVER 10 DAYS

Measurement and setting of rate to within 100 ns/day

We need a capability to do this over 1 hour

Requires a resolution of <4 ns

Magnification Factor 240

EVERY PTTI SYSTEM NEEDS A PTTI OFFICE

for

- SUPERVISION OF PERFORMANCE
- LOGISTICS
- TRAINING
- RECORDS KEEPING

POWER SUPPORT

- PRIMARY POWER -- PUBLIC UTILITIES
- BACK-UP -- AC
- NO-BREAK -- AC
- BATTERIES -- DC

Maintain "vertical" separation of systems!

OPERATIONS

- INSIST ON EXCELLENCE
- GIVE INCENTIVES TO PROMOTE BETTER THAN MINIMAL PERFORMANCE
- MAINTAIN INDEPENDENT EVALUATION OF PERFORMANCE

DANGERS OF MANAGEMENT

- DEFICIENT MANAGEMENT
- OVER-MANAGEMENT
- COMMUNICATIONS GAPS
- WRONG PERSONNEL POLICIES
- EUPHEMISM - EXPEDIENCY
- INCOMPLETE ACCOUNTING
- LACK OF TECHNICAL COMPETENCE AND JUDGMENT

COORDINATORS SUCCEED BY:

- MANAGERIAL COMPETENCE
- PLEASING PERSONALITY - SKILLFUL COMMUNICATION
- TECHNICAL COMPETENCE
- WISDOM

WHAT IS THE ORDER OF IMPORTANCE?