

THE PERVASIVE SOCIETAL IMPACT OF TIME AND FREQUENCY

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Abstract

This talk will paint a picture of these changes that were enabled by time and frequency technology, and provide examples ranging from clocks in the home, to hiking/driving in uncharted areas, to the reduction of the threat of weapons of mass destruction.

The motto of this year's PTTI Meeting is "31 years of progress." In a certain sense, there has been astonishingly little progress, namely in the areas of practical clocks and the basic ideas about their use. Although much scientific advance has been reported in regard to novel quartz crystals, trapped ion and atom configurations, and lasers, the practical clocks in use are still the cesium, rubidium, hydrogen, and crystal clocks already in use 31 years ago, albeit better engineered. Furthermore, the ideas of digital communication and time/frequency-based global navigation had been well developed 31 years ago. However, the combination of what was known and largely dreamed about 31 years ago with the advances in microelectronics and computing of recent times has catapulted time and frequency into a sweepingly pervasive role in today's communication and positioning (navigation) systems.

The T&F Revolution (selected areas)

SCIENCE	COMMUNI CATION	NAVIGA TION	INFORMA TION
trapped ions and atoms	digital networks	global positioning	search and rescue
geophysical data	high data rates	locating and mapping	situational awareness
space exploration	secure data links	precision attack	assured targeting

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True then – still true now

➤ Clocks

- Quartz Crystal
- Cesium Beam, Rubidium Gas Cell, Hydrogen Maser

➤ Applications

- Science and Metrology
- Communication and Information Networks
- Navigation and Position Determination (local, global, space)

What a revolution it has been! Our daily lives have become richer and more convenient; local, regional, and global information, flowing at incredible speeds, is now routine; political decisions and military threats, and even war itself have fundamentally changed.

Quotations from the Past

- “When mainframe or minicomputers cost a million dollars apiece 25 years ago, anyone with one would have shot you if you’d wanted to use it to write a letter!” Jack S. Kilby, inventor of monolithic IC.
- Being asked to assess the future 25 years ago: “GPS receivers may come down in price to \$40,000 and thus become feasible for major platforms” Gernot M.R. Winkler, T&F guru

Even 25 years ago or less, nobody was able to guess at the revolution that was going to hit all of us: the joining of IC technology, computer technology, and networks to cheaply disseminate, store, and process large large amounts of data.

Time and Frequency was swept into the Information Revolution

☐ What was NOT

- New atomic clocks
- Mostly autonomous systems
- Miniature atomic clocks
- Platform-specific hardware

☐ What DID happen

- Digital global networks
- Universal interfacing
- Data processing on a chip
- Custom adaptation by software

RESULT:

Cost and sophistication is in the network, NOT the user.

Affordable –Reliable - Expansive

Time and frequency became one of the components of the technical architecture of large, networked communication and navigation systems; not a stand-alone system, but an enabling component in a much larger system. This was made possible through the “computer revolution” (huge memories, very fast processing — all small and cheap). This allowed the manufacture of small, smart receivers and, more importantly, of large area (and global) networks of considerable sophistication and redundancy. This development made network design and investment in networks the governing principle; as has happened before (telephone, electric power, etc.), this allows large-scale user participation at low cost. This is what moved time-frequency-based technology into everyday life.

Examples from our daily life

Alarm Clocks

Wristwatches

Hand-held Navigators

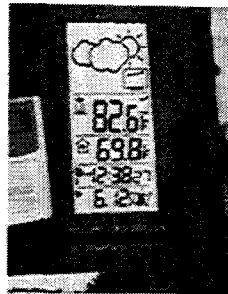
Automobile Map Systems

What happened is that, given the tools of the integrated circuit micro-technology and computing technology, systems engineers built communication networks and navigation networks. And being good systems engineers, they did what systems engineers have done since the last century when that term did not exist. They put the cost and the sophistication into the system. This allows the user to buy into the system at the lowest possible cost and sometimes sophistication. Think about systems we know: the telephone; turn of the century sophistication. One did not have the equivalent of an atomic clock in one's telephone. You were not the communication center at home. Electric network, power distribution networks, the Internet: sophistication in the system. This approach allows systems to have cheap buy-in — and the last word here is very important: “expansive,” not “expensive.” It allows a system to start with a thousand users and at hardly at any additional costs grow to serve a million users. That is the key to time and frequency proliferation.

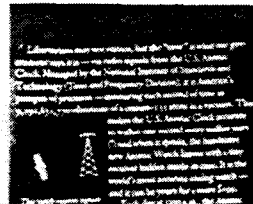
I took some pictures from catalogs like Front Gate and Brookstone. The time of day you can get cheaply now. In fact, the one at upper left I have at home and it works wonderfully. It gets not only the temperature and the weather, but sets itself at the transition to daylight saving time. The alarm clock is priced at all of a \$100; the wristwatch is still expensive (\$500); the last item is all of \$30-50. You all know that you can afford GPS for yourself and for your offspring. It's below \$100, not \$40,000. You can even buy it in a wristwatch.

I believe in 1982, when we did some product promotion at Rockford Collins in Cedar Rapids, I was invited to join them on a trip to the city in van, which was equipped with a GPS system that connected to a map of the area. They needed a van because the system didn't fit in a normal car. And it was -10 degrees and snowy, so we drove through the city and I was very impressed by being able to look at the readout of where we were — the corner of whatever street with whatever street; and then we reached a long building and you could tell whether you were at this end of the building or that end of the building. And I thought that we were getting somewhere, but it was too big and too expensive. Well, as you know, you can buy it now, or you can rent it with your rental car at rather low rates. I just picked two examples. One is a map device on the left, which interfaces with a small GPS receiver or any GPS receiver, and the other one is an integrated map with GPS. Again, you are talking here a couple of hundred dollars, the price for typical options on cars. And they really work.

Time of Day



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Locating on Maps

Navigate your way into the next millennium

With a home computer and their maps to use map-making programs, all it takes is 300Kb. *Delorme's* *MasterMap* is a wealth of a button, and by combining it with the permanent access to your GPS, you can download all those great hunting, fishing, and hiking spots to create a map that's loaded just for you. Thousands of popular recreational destinations are available online on www.delorme.com and there's more to come. So toss out

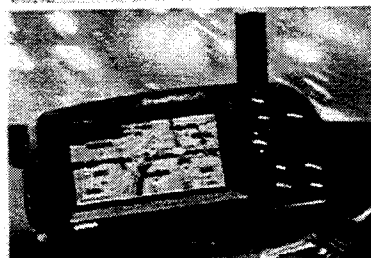
35, 40, 45, 45X
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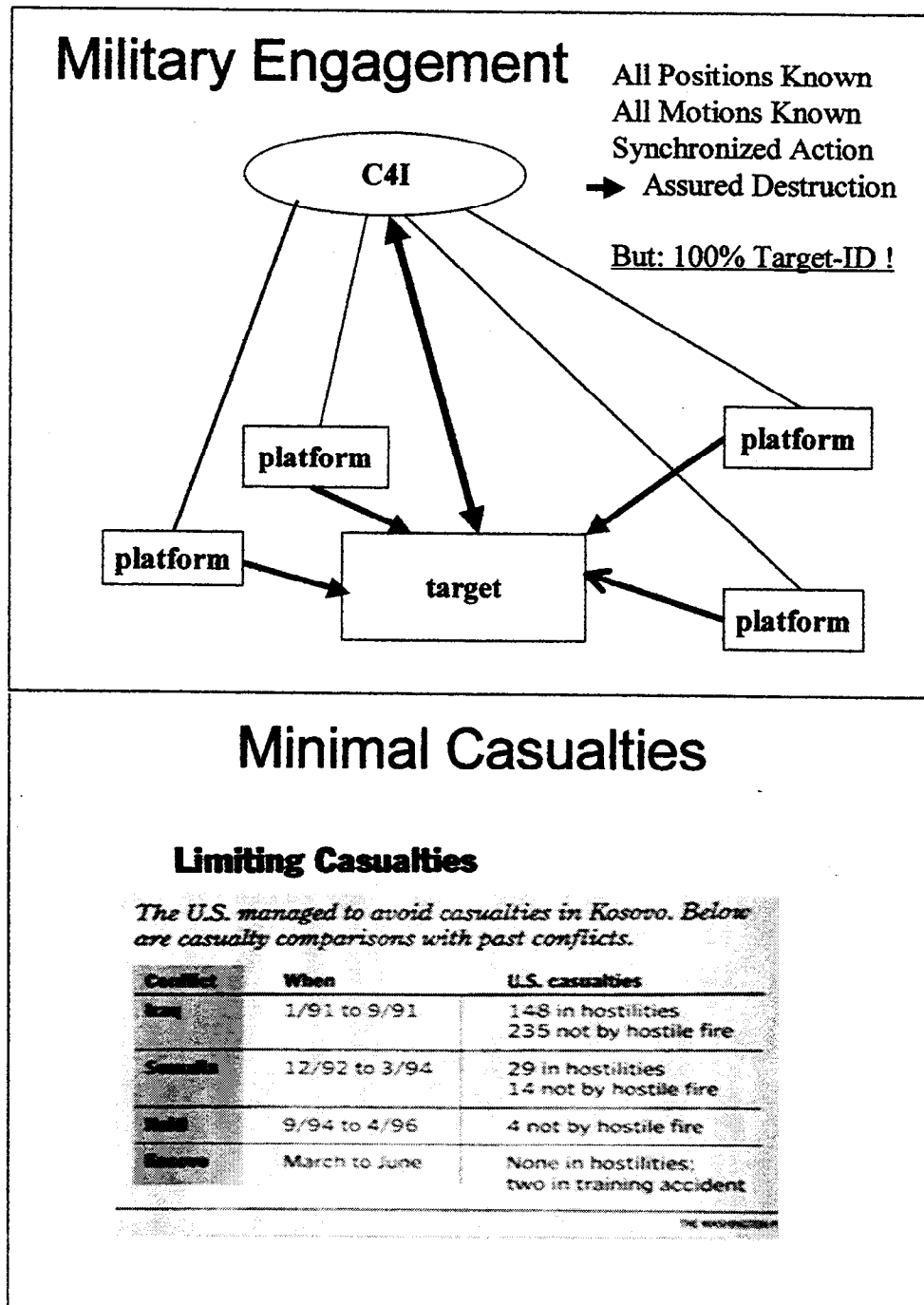
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The Military Revolution

History showed a steady escalation of mass-destruction capability:
bow&arrow; firearms; cannon;
machine gun; bombs; bigger bombs;
carpet bombing; nuclear weapons.

**Major driver: Lack of targeting
PRECISION**

Since David and Goliath, who settled the conflict with minimal destruction, the history of human conflict and warfare is characterized by continuing escalation in the capacity to destroy larger and larger target areas. This culminated in our century with the threat of global nuclear annihilation. A principal driver for the development of ever increasing means of mass destruction was the lack of precision in taking out critical military targets. If one is unable to ensure the elimination of the military target, then one is inclined to resort to taking out the "area" containing the military target; since the dawn of recorded history and until well beyond World War II, this approach has caused the escalation in collateral damage. The Gulf War of 1990/91 used for the first time precision-guided munitions in a major way: collateral damage was minimal, as were U.S. casualties. GPS for the first time became a major military asset.



Using GPS and other technologies (e.g. INS, laser, SAR), all positions and velocity vectors are known. Synchronized action is initiated, eliminating the target at a preset time with minimal expenditure of resources. In principle, collateral damage and casualties are zero, and all assets are optimally used and quickly available to engage other targets.

The public, especially in the USA, has come to expect very few casualties. Military action is now planned with the knowledge that judicious use of precision targeting will yield near-zero casualties. This has already changed (as in Bosnia and Kosovo), and will continue to change, the way military engagements are planned and carried out.

The New Challenge

- GPS with other technologies: No need for large area destruction; precision assures target-only engagement & elimination
- However, assured target destruction puts a premium on target identification

1999 Kosovo War: Considerable collateral damage caused by erroneous target ID

A NEW MORAL DILEMMA

The new precision capabilities allow for assured target destruction with zero collateral damage. However, if the target is wrongly identified, it will be nevertheless assuredly destroyed. Thus, an increasingly high attention must be placed on error-free target ID, or the enormous benefits from precision engagement ("ethical warfare") become a boomerang.

On the light side, I have a last viewgraph, which I think is sort of funny. The title can be read in two ways: "USNO Drops the Ball." It's again from *The Washington Post*. The article says that instead of running a line from the timing devices at the USNO to trigger this, they are using a GPS receiver because it is cheaper than running a cable. We have come a long way.

GPS helps USNO drop the Ball to start the new Millennium

So on the observatory's roof, at 12:00:00 a.m., Washington's ball will drop with peerless precision.

To make things interesting, and to symbolize global time, instead of simply running an orange extension cord from the hydrogen maser "master clock" up to the ball, one of the observatory's time technicians on the roof will determine midnight from a portable Global Positioning System

receiver, then drop the ball.

It's all the same, because the 24 Air Force GPS satellites set their watches by the observatory's atomic clock.

Washington will be a link in an earth-encircling chain of time-ball drops to mark the beginning of the new year as it sweeps westward from the international date line, with balls dropping at observatories on five continents. The Naval Ob-

