GPS Critical Infrastructure

Usage/Loss Impacts/Backups/Mitigation

Other CIKR Sectors

IT   Comms   Electric Power

GPS Timing

R. James Caverly
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Critical Infrastructure GPS Dependencies

- **GPS Supporting Power Grid Systems**
  - Energy Plants
  - Substations
  - Power Grids

- **GPS Supporting Banking Operations**
  - ATM Networks
  - Stock Exchanges
  - Internet Banking

- **GPS Supporting Transportation Systems**
  - Rail Yards
  - Switching Towers & Signals
  - C² Centers

- **GPS Supporting Communications Systems**
  - Ship Routing
  - Access GIS / Map
  - Comms Networks

**GPS Critical Infrastructure Timing Study: Usage/Loss Impacts/Backups/Mitigation**
Summary of CI GPS Timing Usage

• Of the 18 CIKR sectors, 15 use GPS timing
• Major uses of GPS timing are for:
  – Network and phase synchronization in wireline and wireless networks (Communications/IT Sectors) used in multiple critical infrastructures
  – Precise frequency generation and stabilization for single frequency wireless networks (LMR simulcast)
  – Phase synchronization in Electric Power, Nuclear Power, and Dams/Hydroelectric power sectors/subsectors
  – Process scheduling, control, and synchronization in Oil and Natural Gas/Chemical/Critical Manufacturing/DIB sectors
  – Precise time stamping of data, transactions/high-frequency trading in Banking & Finance/Postal and Shipping sectors
• In general, GPS timing used in distributed interconnected systems that require synchronization for monitoring, control, production, transaction tracking, and other functions
• Of the 15 GPS timing using CIKR sectors, GPS timing is deemed Essential in 11 of them
  – Essential in more than half of the Nation's CIKR Sectors
  – Dependence is growing over time
It is the TFS, not the GPS Receiver alone, that should be considered as the building block for timing, frequency, and time-of-day services.
## CIKR Sector Oscillators And Holdover Times

<table>
<thead>
<tr>
<th>GPS Timing Essential CIKR Sector</th>
<th>Timing Accuracy Requirements*</th>
<th>Oscillators Used**</th>
<th>Least Robust Oscillator</th>
<th>Osc. Holdover Time (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications Sector</td>
<td>~ Nanoseconds (SONET, CDMA)</td>
<td>X X</td>
<td>OCXO (HS)</td>
<td>24 *</td>
</tr>
<tr>
<td>Emergency Services Sector</td>
<td>~ Nanoseconds (CDMA E911, LMRs)</td>
<td>X</td>
<td>OCXO (HS)</td>
<td>24 *</td>
</tr>
<tr>
<td>Information Technology Sector</td>
<td>20 to 100 Nanoseconds (PTP)*</td>
<td>X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Banking and Finance Sector</td>
<td>Millisecond- Microsecond (HFT)^</td>
<td>X X X</td>
<td>TCXO</td>
<td>&lt; .24 -1.7</td>
</tr>
<tr>
<td>Energy/Electric Power Subsector</td>
<td>1-4.6 Microsecond (Synchro-Phasors; Fault Loc.)</td>
<td>X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Energy/Oil and Natural Gas Sector Subsector</td>
<td>Microsecond (exploration, SCADA)</td>
<td>X X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Nuclear Sector</td>
<td>1 Microsecond (Synchro-Phasors)</td>
<td>X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Dams Sector</td>
<td>1 Microsecond (Synchro-Phasors)</td>
<td>X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Chemical Sector</td>
<td>Sub Microsecond- Microsecond</td>
<td>X</td>
<td>OCXO (MS)</td>
<td>1</td>
</tr>
<tr>
<td>Critical Manufacturing Sector</td>
<td>Millisecond</td>
<td>X X</td>
<td>TCXO</td>
<td>1.7</td>
</tr>
<tr>
<td>Defense Industrial Base Sector</td>
<td>Millisecond</td>
<td>X X</td>
<td>TCXO</td>
<td>1.7</td>
</tr>
<tr>
<td>Transportation Sector</td>
<td>~ Nanoseconds (Wireless modal comms)</td>
<td>X X</td>
<td>OCXO (HS)</td>
<td>24 *</td>
</tr>
</tbody>
</table>

* GPS Critical Infrastructure Timing Study: Usage/Loss Impacts/Backups/Mitigation
# CIKR Impacts Under GPS Outage Scenarios

<table>
<thead>
<tr>
<th>GPS Timing Essential CIKR Sector</th>
<th>Least Robust Oscillator</th>
<th>Holdover Time (hours)</th>
<th>Unintentional Interference impact: 8 hours (Y or N)</th>
<th>Intentional Jamming impact: Multiple Days (Y or N)</th>
<th>Space Weather impact: 16 hours (Y or N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications Sector</td>
<td>OCXO (HS)</td>
<td>24 *</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Emergency Services Sector</td>
<td>OCXO (HS)</td>
<td>24 *</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Information Technology Sector*</td>
<td>OCXO (MS)</td>
<td>1#</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Banking and Finance Sector</td>
<td>TCXO</td>
<td>&lt; .24 -1.7 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Energy/Electric Power Subsector</td>
<td>OCXO (MS)</td>
<td>1 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>Energy/Oil and Natural Gas Sector Subsector</td>
<td>OCXO (MS)</td>
<td>1 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Nuclear Sector</td>
<td>OCXO (MS)</td>
<td>1 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>Dams Sector</td>
<td>OCXO (MS)</td>
<td>1 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>Chemical Sector</td>
<td>OCXO (MS)</td>
<td>1 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Critical Manufacturing Sector</td>
<td>TCXO</td>
<td>1.7 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Defense Industrial Base Sector</td>
<td>TCXO</td>
<td>1.7 #</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Transportation Sector</td>
<td>OCXO (HS)</td>
<td>24 *</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>
GPS Timing Impact Assessment Approach

Unintentional Interference

Result: Limited to Moderate Regional Impacts

Operational Impact Level | Definition | Score
--- | --- | ---
No impact | Full operational capability. | 100
No - Lim | | 90
Limited | Infrastructure: Infrastructure is mildly impacted. Efficiency of some operations is reduced, workarounds are available, and the consequences are not important. Any degradations or impacts in service, costs, and risks that occur are localized (less than a metropolitan area) and do not extend to the regional level (metropolitan area or greater). Minor, localized public safety impacts. | 80
Lim - Mod | Infrastructure: Timing from GPS is not adequate to meet infrastructure needs over a significant region and time. Important portions of the infrastructure experience significantly degraded or complete loss of functionality as a result. Resulting degradations in the quality of infrastructure services and/or service impacts, costs, and risks that occur are significant to the region (metropolitan area or greater). Public safety impacts at the regional level. | 65
Moderate | Infrastructure: Timing from GPS is not adequate to meet infrastructure requirements over a substantial region and time period. Important portions of the infrastructure are severely degraded and there may be cascading effects within the infrastructure possibly cascading to other infrastructure sectors as well. Resulting impacts, costs, losses, risks that occur are significant to the nation. Public safety impacts over multiple regions and extended time periods. | 50
Mod - Severe | | 40
Severe | | 25

Intentional Jamming

Result: Severe Regional/National Impacts

Result: Limited to Moderate Regional Impacts

Result: Moderate to Severe National Impacts

Severe Space Weather Event

Communication

Emergency Services

Information Technology

Energy/Electric Power

GPS Critical Infrastructure Timing Study: Usage/Loss Impacts/Backups/Mitigation
Space Weather Planning Scenario

DETECTION

Very large, complex sunspot emerges
• Solar activity Forecast: High
• Probability of ≥R4 events: 80%

Many R1-R3 events (flares) occur through 24 Feb

Powerful solar flare erupts
• R5 Radio Blackout Alert issued
• S4 Radiation Storm Warning issued
• G5 Geomagnetic Storm Watch issued (onset expected in 24 hours)

RESPONSE

Extreme Geomagnetic Storm begins
• G5 Warning and Alerts issued (G4–G5 levels expected for 24 hrs)

• Widespread power outages in N. America and Europe

• Widespread communication outage
• GPS degradation (1-2 days)

• Many Satellites damaged
• Aircraft rerouted – no polar air traffic
• Communications severely degraded

• Communication outages (HF & Satcom)
• GPS errors and loss of lock
• Radar systems degraded (impacts are short-lived: minutes to hours)
Impact on GPS and CI Feb 20 – 24

_ R4 Solar Event Scenario_

• An R4 event is caused by a disturbances of the ionosphere caused by X-ray emissions from the Sun.
  – A “Severe” (R4) High Frequency (HF) radio frequency event; HF radio communications blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time.

• GPS Impacts: Loss of signal due to:
  – Ionospheric plasma density irregularities
    • Refraction and diffraction of GPS signal propagating through the irregularity
    • Rapid amplitude and phase variations
  – Locations:
    • Night-time equatorial regions (severe, common)
    • Polar regions (usually mild, rare)
    • All latitudes during geomagnetic storms (severe, rare)
  – Time Duration of Event: 10s of minutes to multiple hours over multiple days

• Radar degradation due to similar causes as HF radio and GPS signal impacts described above
Impacts on GPS and CI from 25-26 FEB G5 Geomagnetic Storm Scenario

• Electric Power outages due to:
  – Geomagnetic Storm induces ground currents and Earth surface potentials
  – Geomagnetically Induced Currents (GIC) at substations ( DAMAGES equipment) and on power lines (causes faults\lines to trip out of service)
  – Loss of control caused by corrupted grid state estimation\situational awareness due to loss of GPS timing synchronization of data from SCADA and Synchrophasors

• Communications degradations consist of:
  – HF Blackouts
  – Satellite communications losses
  – CDMA Cellular and Land Mobile Radio Simulcast loss due to loss of GPS timing synchronization

• GPS Impacts

<table>
<thead>
<tr>
<th>Solar Storm Effect</th>
<th>Single Frequency GPS Timing Error (Range)</th>
<th>Single Frequency GPS Position Error (Range)</th>
<th>Time of Day</th>
<th>Duration of Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC increase in ionosphere</td>
<td>Less than 100 ns Typical 10-30 ns</td>
<td>Less than 100 m Typical 10-20 m</td>
<td>Day side of the earth</td>
<td>Hours to days</td>
</tr>
<tr>
<td>-scintillation</td>
<td>Less than 100 ns for individual satellites</td>
<td>Loss of precision due to loss or corruption of individual GPS satellites</td>
<td>Worse in early evening</td>
<td>Individual events minutes but can persist for hours to days (diurnal)</td>
</tr>
<tr>
<td>-solar radio bursts</td>
<td>Severe events can deny GPS reception</td>
<td>Severe events can deny GPS reception</td>
<td>Day side of the earth</td>
<td>Minutes to hours (duration of the solar burst)</td>
</tr>
</tbody>
</table>
Geomagnetic Storm Caused Regional Power Outages