GPS Civil Applications

GPS Integrity Failure Modes and Effects Analysis (IFMEA)

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Overview

- What is IFMEA?
- What Capability Does it Provide?
- Why is it Important?
- How Should This Capability Be Used?
- Does Your Organization Need This Capability?

Introduction

- **Desire to rely on GPS for safety of life applications worldwide**
- **Service meets specified levels**
  - **Accuracy, availability, continuity, and integrity**
- **Standalone GPS cannot meet integrity requirements**
  - **Augmented GPS required (RAIM/FDE, Differential-Based Systems)**
- **Knowledge of GPS Failure Modes Required to Design Integrity Monitoring Systems**

What is IFMEA?

- Integrity Failure Modes and Effects Analysis (IFMEA) project established by IGEB
  - 3-year project started in April 2002
  - Follow on to work done by JPO in 1990's
  - Interagency initiative
  - Team consists of DOT, JPO, and contractors
- Based on previous GPS failure studies, SV and OCS system design descriptions, and operational procedures

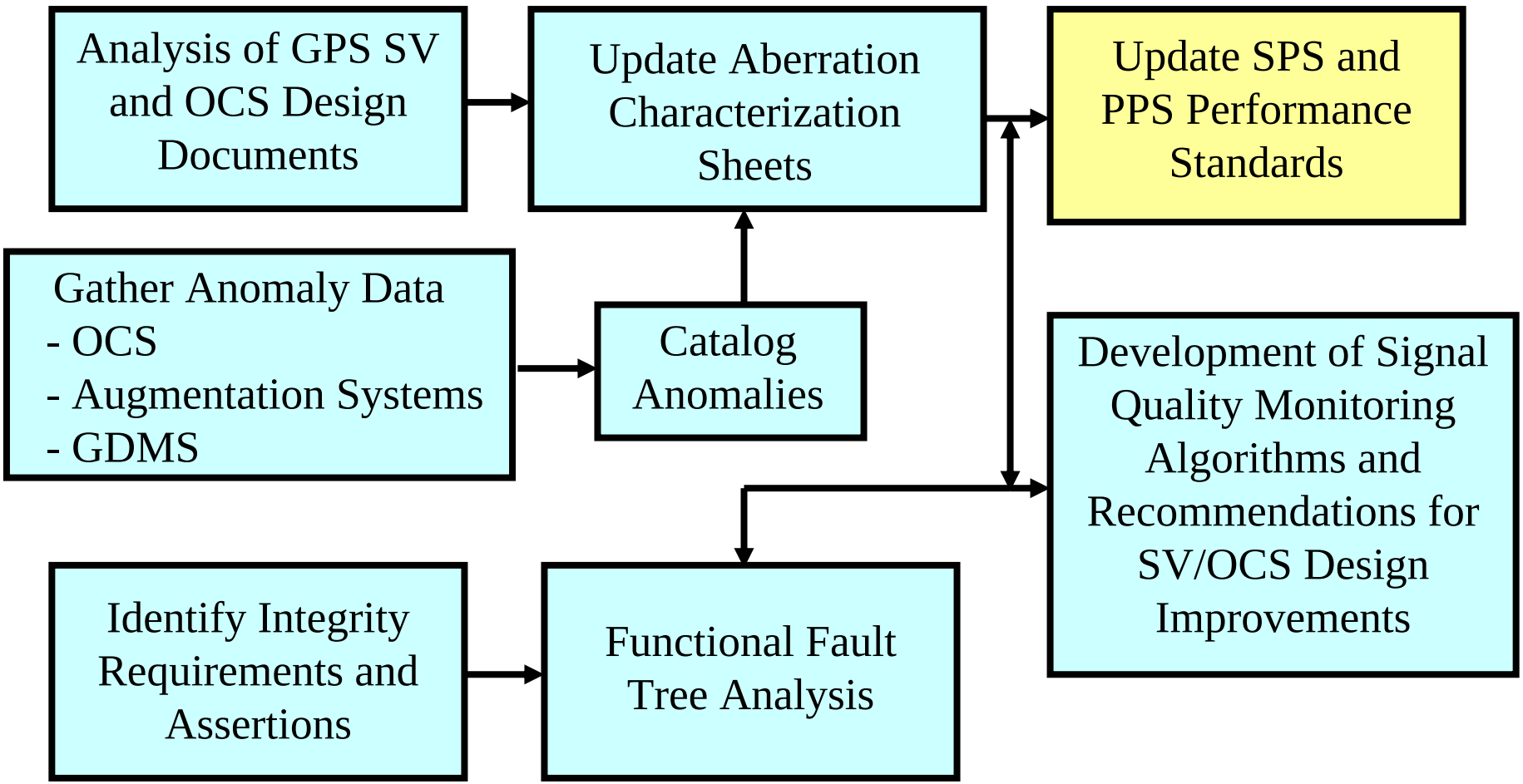
Background to IGEB IFMEA Project

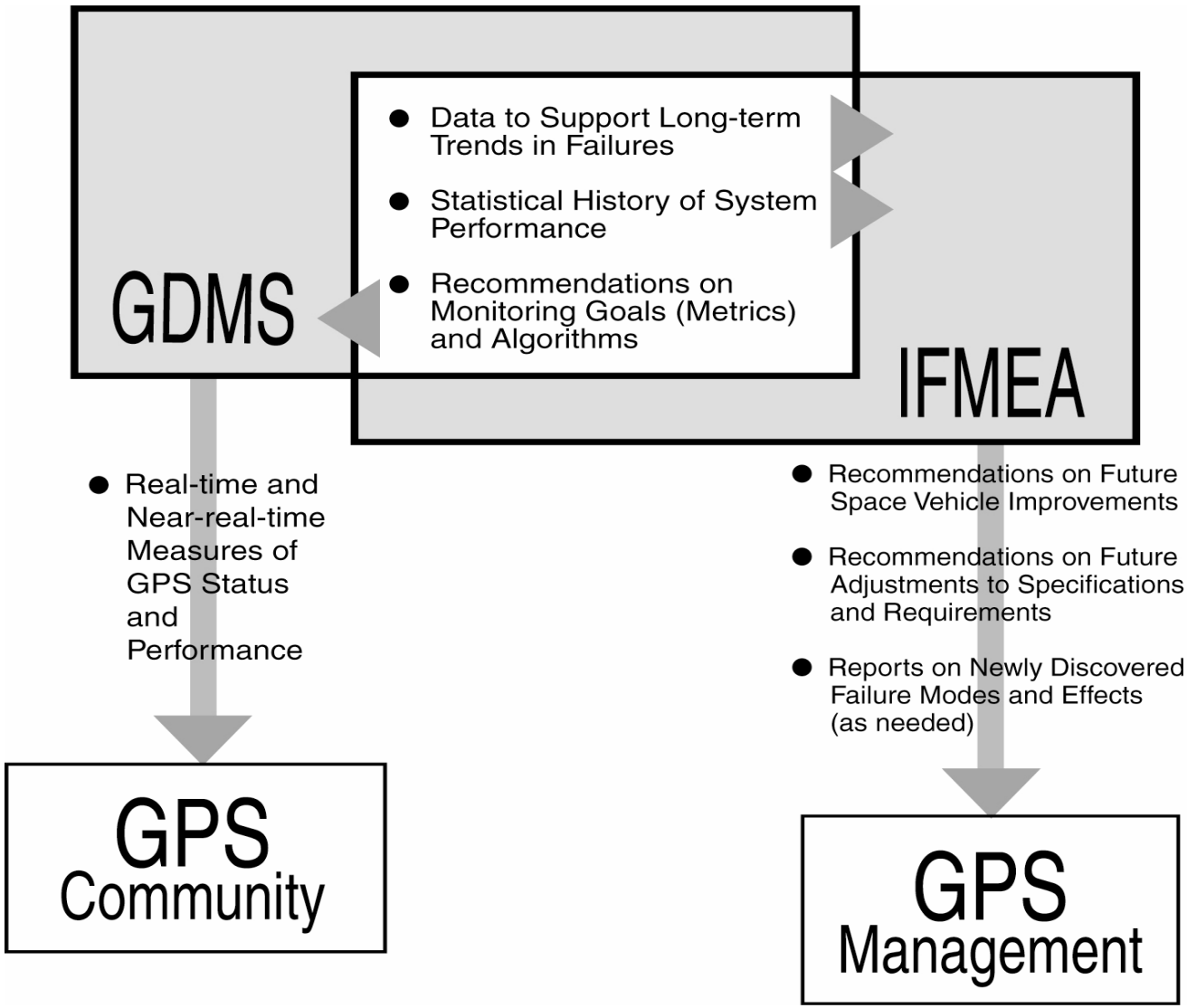
- Block I/II/IIA SV and OCS Integrity Aberrations Identified, Catalogued, and Updated By GPS JPO and Support Contractors From 1988 Through 1998
- GPC Recognition That Similar Work Had Not Been Conducted for Block IIR, IIRM, IIF, and AEP
- IGEB IFMEA Project Initiated to Develop Aberration and Update Block II/IIA Work and Provide Recommendations for GPS III
- Process Required to Sustain ACS Process After IGEB Stewardship Funds

IFMEA Objective and Benefits

- Identify GPS integrity anomalies (SV and OCS), potential causes and operational impacts of failures
  - Determine probability of individual failure modes (theoretical and observed)
- Develop interagency definition of GPS integrity parameters to perform effects analysis
- Improve the reliability of GPS in the future by providing recommendations of
  - GPS SV and OCS design modifications
  - Integrity monitoring provided by civil/military augmentation systems and monitoring networks
- Increase user confidence in the ability of GPS satellites and OCS to satisfy requirements stated in performance standards

IFMEA Process Flow Diagram




GDMS
IFMEA
Data to Support Long-term Trends in Failures
Statistical History of System Performance
Recommendations on Monitoring Goals (Metrics) and Algorithms
Real-time and Near-real-time Measures of GPS Status and Performance
Recommendations on Future Space Vehicle Improvements
Recommendations on Future Adjustments to Specifications and Requirements
Reports on Newly Discovered Failure Modes and Effects (as needed)
GPS Community
GPS Management

Aberration Characterization Sheet (ACS)

- Identifies failure points that could affect integrity
- Uses failure studies (e.g., FMECA) and system descriptions (e.g., wiring and block diagrams) provided by manufacturer
- ACSs previously developed for Block I, Block II, Block IIA, and Legacy OCS
- Project is developing ACSs for Block II-R, Block IIRM, Block IIF, and Architecture Evolution Plan (AEP) OCS and Updating Block II/IIA and Legacy OCS

Aberration Characterization Sheet (ACS)

ABERRATION NAME: Name Assigned to Aberration	
SEGMENT ALLOCATION: System, Space, Control, User	
SHORT DESCRIPTION: What is the aberration?	
PROXIMATE CAUSE(S): What most directly causes the aberration?	
PRECIPITATING EVENT(S): What is the ultimate source of the aberration?	
PROBABILITY OF OCCURRENCE: **Per day, per year, per SV, per constellation, per upload**	**EFFECT/MAGNITUDE:** **Effect on signal: Off, nil, ramp, step, noise, sinusoid, m, m/sec, m/sec squared**
DETECT RESPONSIBILITY: **System, Space, Control, User, mix, none** **When an aberration occurs, who is responsible for determining that it happened?**	**UNDETECTED PROBABILITY: Per day, per year, per SV, per constellation, per upload** **Probability that the aberration goes undetected.**
POST-DETECT EFFECT/MAGNITUDE: **Off, nil, ramp, step, noise, sinusoid, m, m/sec, m/sec squared** **What happens after the aberration has been detected?**	**UNDETECTED DURATION:** **Time until aberration is detected and user notified.**
REPRESENTATIVE OCCURRENCES (IF ANY): **Based on observed data obtained through IFMEA data collection effort**	

Development/Update of Aberration Characterization Sheets

- Team developed ground rules for preparing, maintaining and updating ACS sheets.
- Ten books written by Lockheed Martin on Block IIR Failure Modes And Effects Criticality Analysis Report (FMECA) were reviewed by the team members.
  - Aberration Characterization Sheets (ACSs) were written by team members on the failure modes listed in the IIR FMECA to identify integrity anomalies.
  - 53 anomalies identified and incorporated into the existing ACS Book.
  - Updates to the ACS Book included integrating Block II/IIA material with Block IIR.
- On-orbit Block IIR SV Incident Reports (SVIRs) incorporated into the ACS Book.

Focus of Recent IFMEA Activity

- Documentation Identification for Block IIRM, IIF, and AEP ACS Development
- Development of Block IIF ACSs
- Functional Fault Tree Analysis
- Review of Legacy OCS Procedures
- WAAS ACS Effects Analysis
- SQM Analysis
- Development of GPS Integrity Anomaly Database
- Recommendations for GPS III
- Development of IFMEA Transition Plan

2004-2005 IGEB IFMEA Project

- Prepare for Transition of IFMEA Processes Over to GPS JPO for Long-Term Updating and Maintainability
  - Update Aberration Characterization Sheets Through Block IIF SVs and AEP
  - Integrity Anomaly Database Available for Use (Public and Secure Versions)
  - Finalize Recommendations for Integrity Monitoring and SV/OCS Design Constraints or Improvements
  - Develop Processes, Procedures, and Training for Continuation of IFMEA Work Without Stewardship Funds

Block IIR Time Keeping System

- IIR/IIR-M Satellites Do Not Have Clock Run Off Errors
  - Run two clocks concurrently
    - Atomic (Rubidium)
    - VCXO (Quartz)
  - Monitor short-term difference between the clocks
    - If difference greater than a threshold (~5 m)
      - Immediately switch to non-standard code

Nominal Signal Deformation – Code Domain

Possible Explanation for Measured Signal Distortion Observed By Honeywell and Stanford

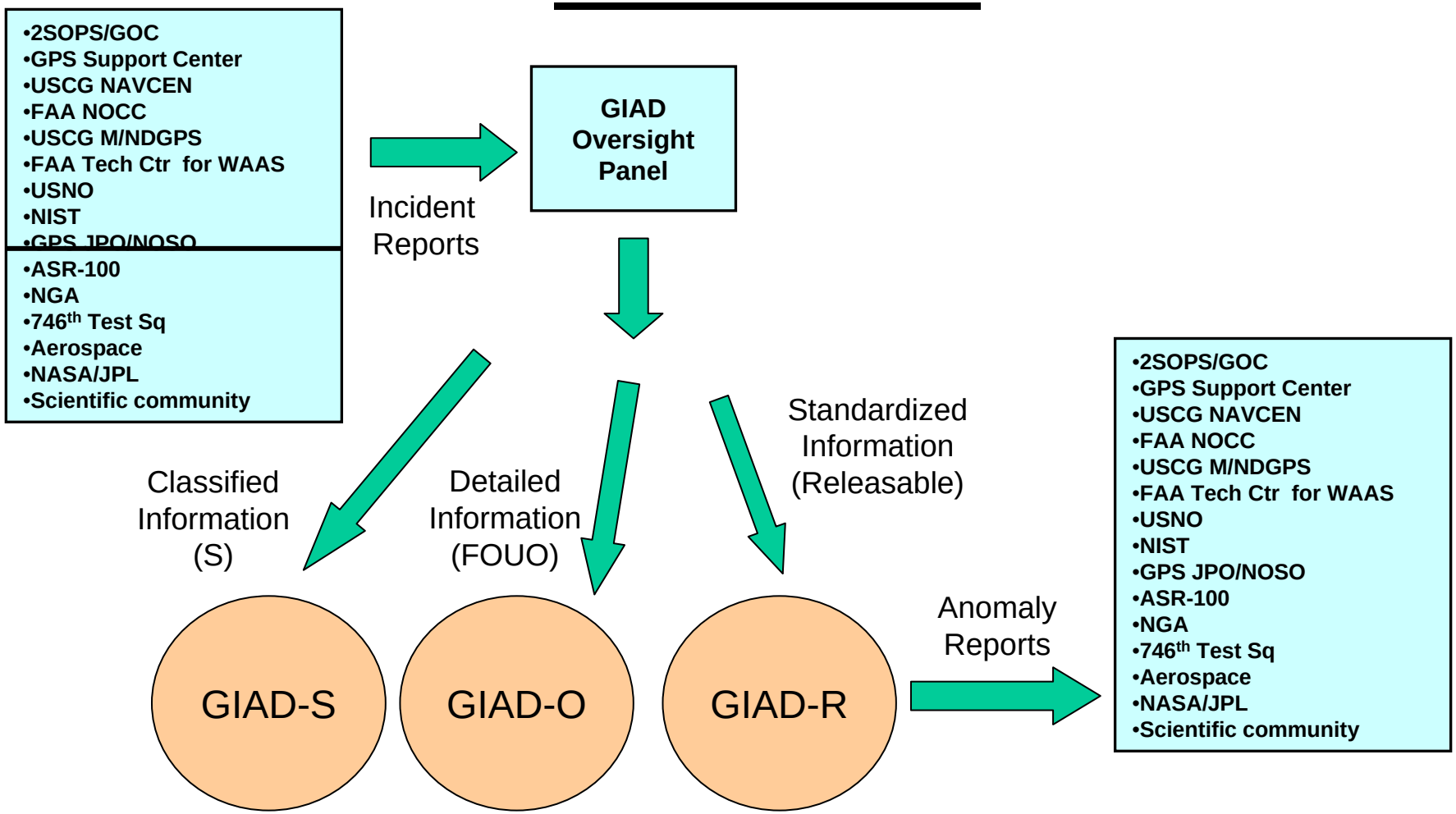
- Suspected that lead/lag distortion caused by asymmetries in rise/fall times of switching logic onboard the satellites
- ITT* confirmed that this is the likely cause
  - No current requirement for symmetry (they do not control this parameter)
  - Attempt to keep difference within 1% (~10ns)
  - Surprised by large asymmetry on IIRs
  - Modulator on IIAs and IIRs use the same technology
- Suggested pre-launch SV testing of SVs to characterize biases

*ITT is responsible for building some of this signal generating hardware for Block IIAs, IIRs

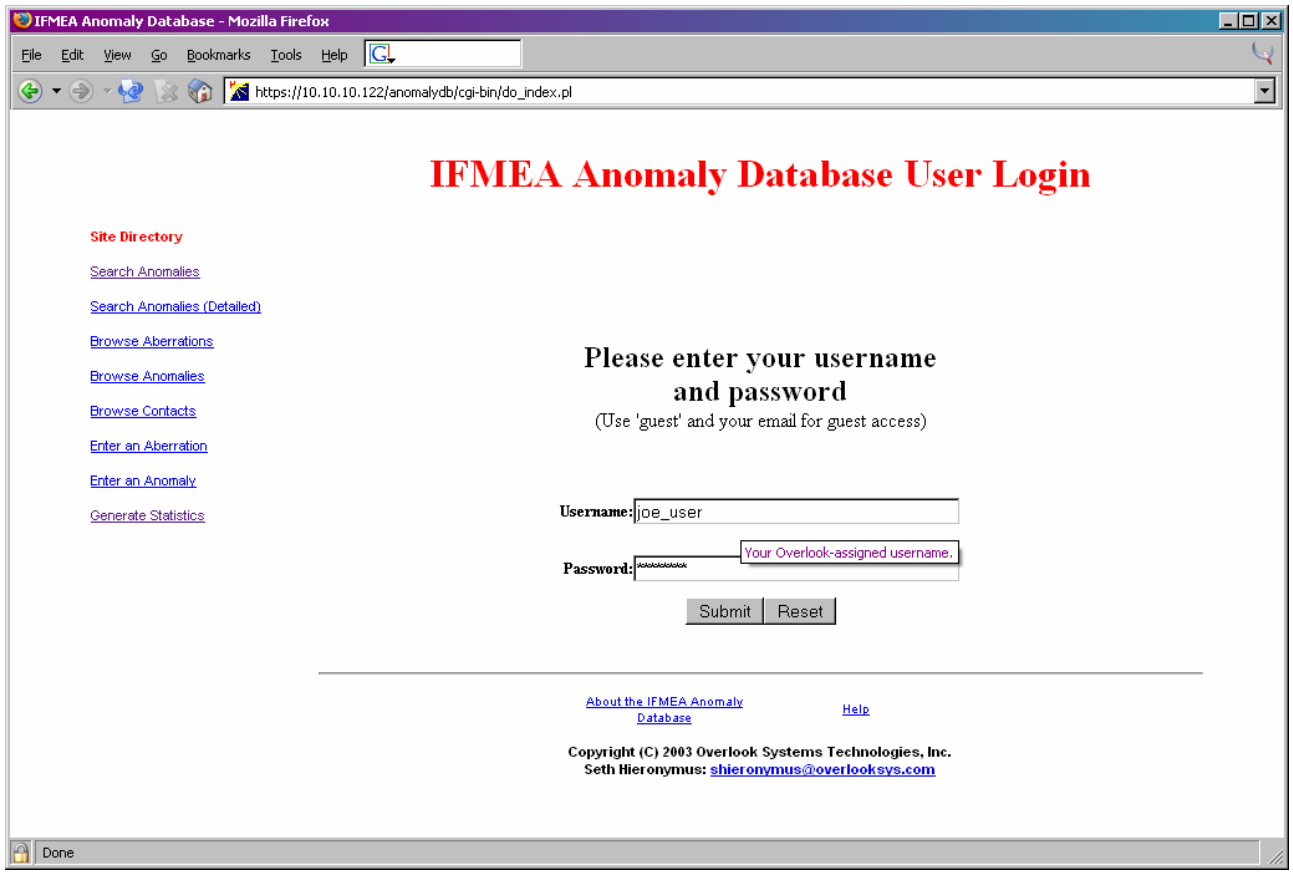
GPS Integrity Anomaly Database (GIAD)

- Key features
  - Includes both anomaly and aberration databases
    - Anomaly database stores anomaly type, satellite number, satellite block affected, magnitude of error, and duration
    - Aberration database stores aberration data per ACS
  - Anomaly database tied to Aberration database for updating
  - Web-based
  - Easy lookup features
    - Synonyms – wider searches without having to enter all keywords

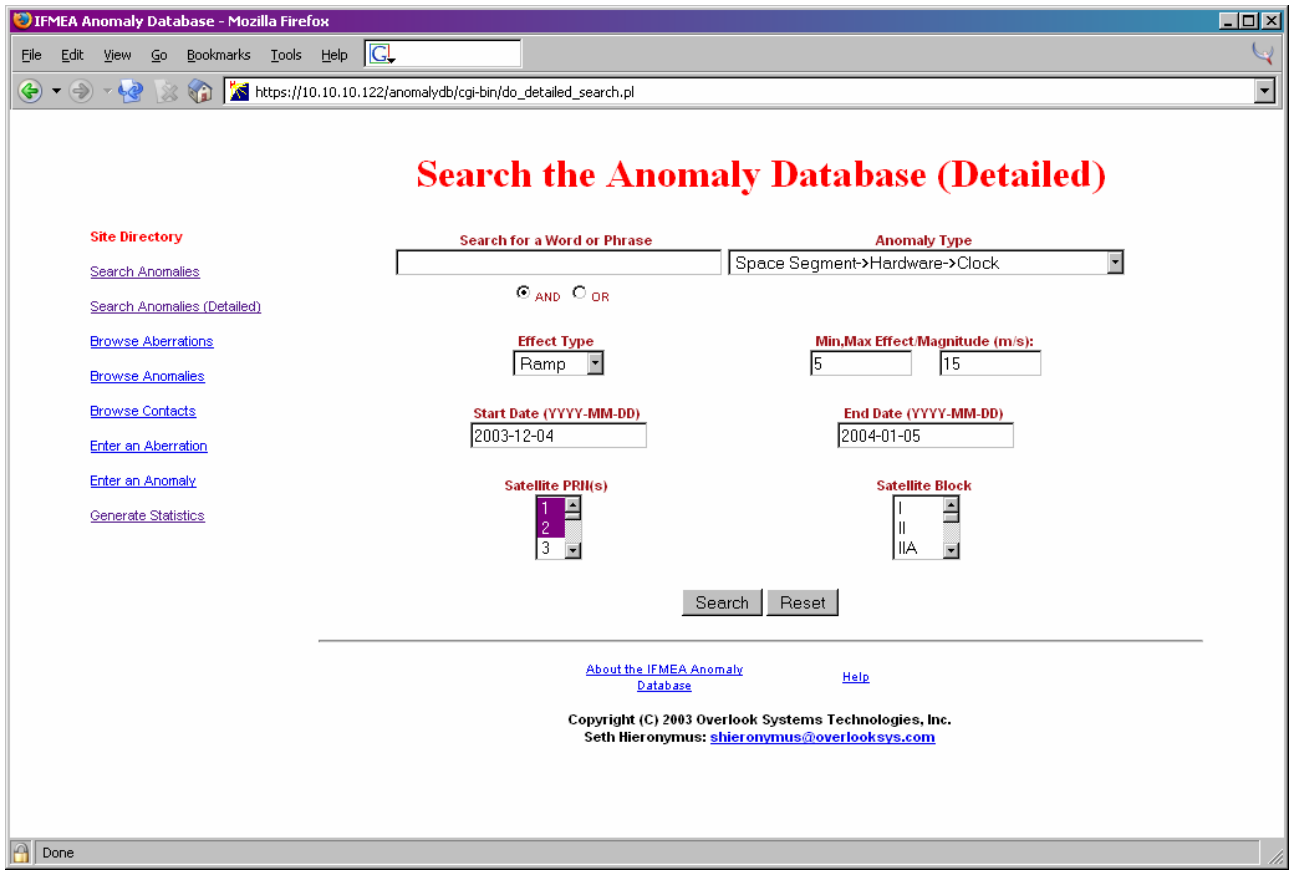
GIAD Process



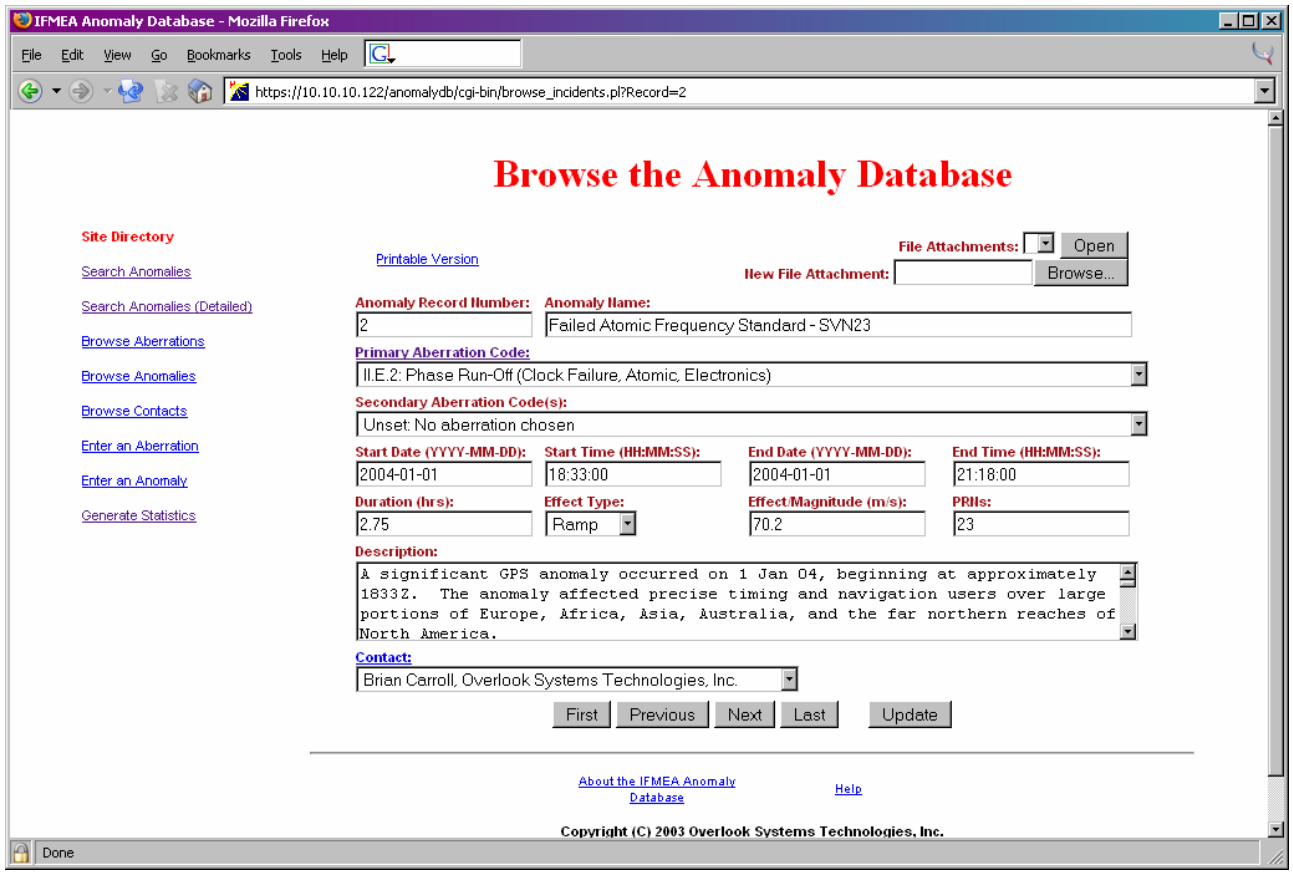
Login Screen



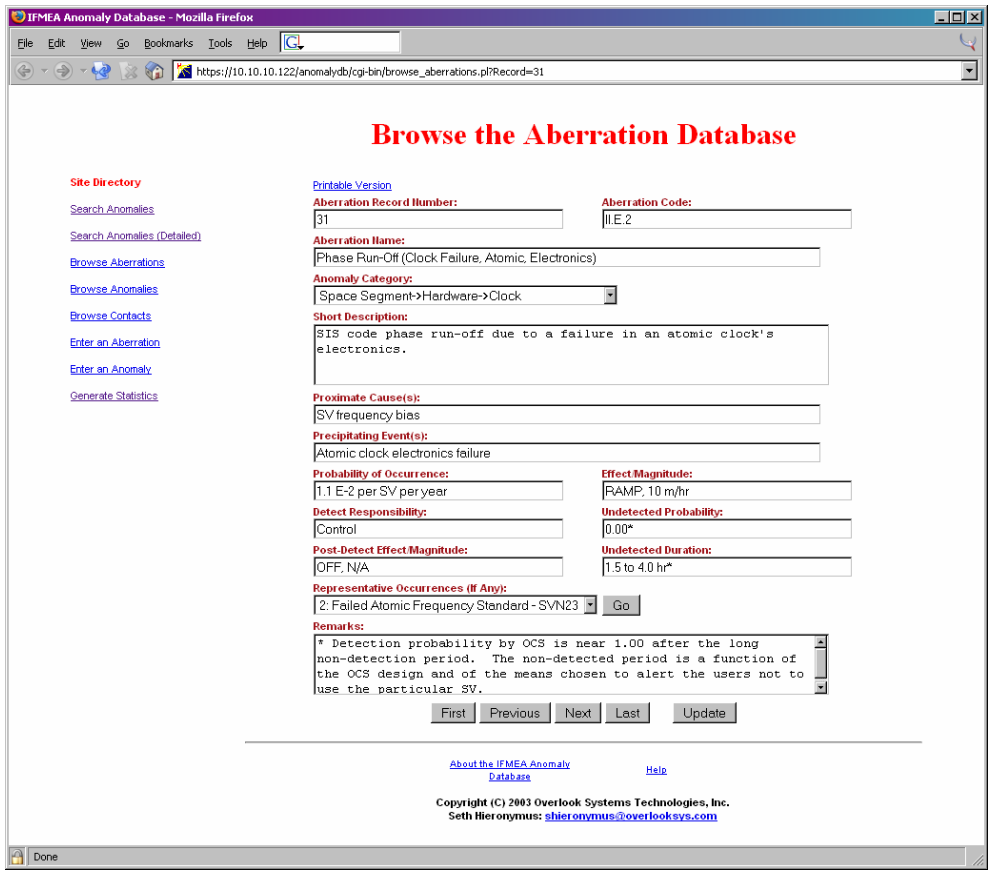
Detailed Search Screen



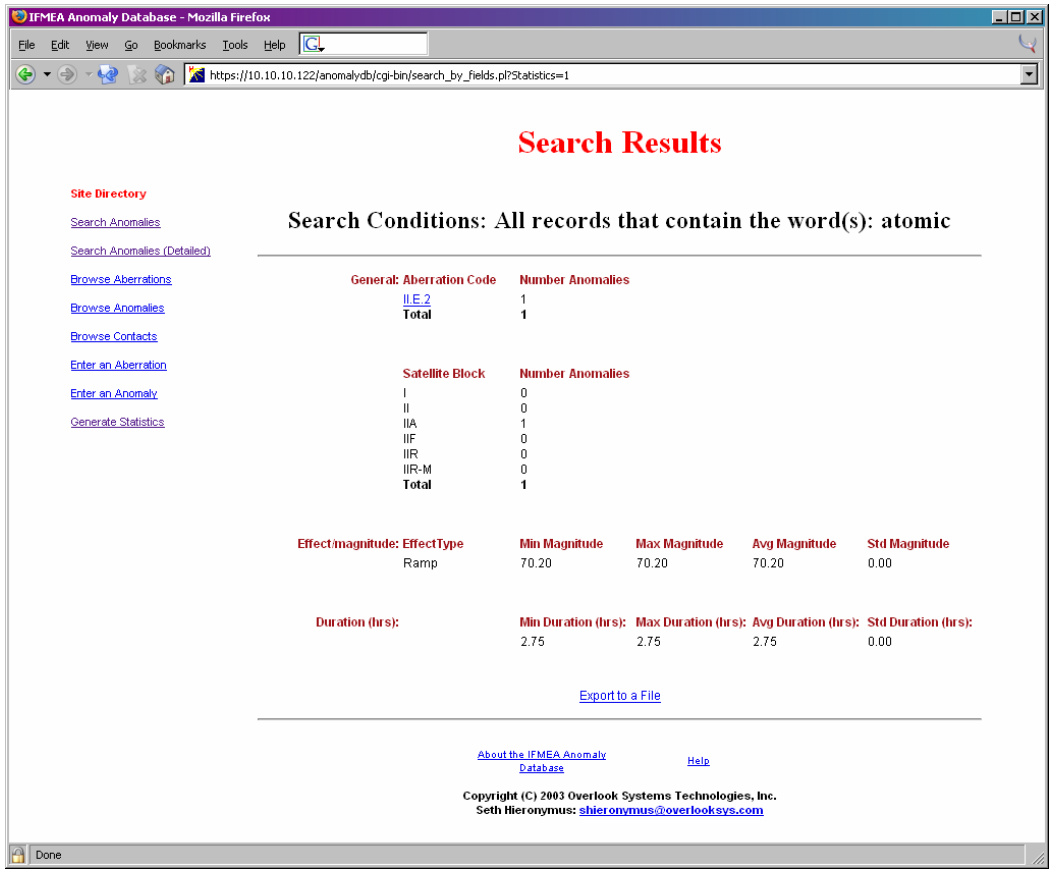
Browse Anomaly Screen



Browse ACS Screen



Search Results Screen



Access to Database Prototype

- URL: https://216.150.201.34
- Username/password: betatest/ifmea
- Username/password: guest/<email>
- Project contact: John Lavrakas, jlavrakas@overlooksys.com
- Technical contact: Seth Hieronymus, shieronymus@overlooksys.com
- Database Administrator: Brian Carroll, bcarroll@overlooksys.com

WAAS Effects Analysis

- IFMEA team requested to validate the WAAS assertions against the Aberration Characterization Sheets (ACSs)
- The team has focused on the following:
  - WAAS Assertions
  - RAIM and WAAS/RAIM Assertions
  - GPS/Inertial Assertions

WAAS Effects Analysis

- **Current analysis performed with the "Block II" version of the ACS**
- **Results must be updated when the Block IIR update is complete**
- **WAAS assumptions affected by not aberrations not monitored by Control Segment**
- **Statistics**
  - 82 ACSs
  - 25 ACSs affect at least one assertion
  - 11 WAAS Assertions
  - 3 RAIM Assertions
  - 3 GPS/Inertial Assertions

ABERRATION CHARACTERIZATION SHEET (ACS)
III.C.4

ABERRATION NAME: Bad SV Tracking Data: Noisey 50 Hz Data (NAV Message)	
SEGMENT ALLOCATION: Control Segment (MS)	
SHORT DESCRIPTION: An MS's SV tracking data for the 50 Hz NAV message can be noisy in a manner exactly analogous to the UE. Erroneously received settings for bit 18 of the HOW can cause unexpected reactions. Other bits produce no resulting effect.	
PROXIMATE CAUSE(S): Erroneously decoded bit 18 of the HOW	
PRECIPITATING EVENT(S): SIS path environment, noisey DEMOD hardware, low C/No	
PROBABILITY OF OCCURRENCE: 1.00 per SV per year	**EFFECT/MAGNITUDE:** OTHER, OTHER
DETECT RESPONSIBILITY: Control (MCS)*	**UNDETECTED PROBABILITY:** 4.2 E-16
POST-DETECT EFFECT/MAGNITUDE: OTHER, OTHER**	**UNDETECTED DURATION:** 1.5 to 4.0 hr
REPRESENTATIVE OCCURRENCES (IF ANY): SVN 13 (Block II, PRN-13), September 1989; two occurrences only	
REMARKS: * Detection is by Hamming parity and by operator visual monitoring. ** Post-detect effect/magnitude details not releasable.	

Summary

- IFMEA Project Provides Better Understanding of Integrity Anomalies and Probability of Occurrence

  - Development of Improved Integrity Monitoring Algorithms

  - Recommendations for Improved Future GPS SV and OCS Design

  - GIAD will Support Analysis of Anomalies

- Need to Have Smooth Transition of IFMEA Project/Process to GPS JPO with Continued Civil Participation