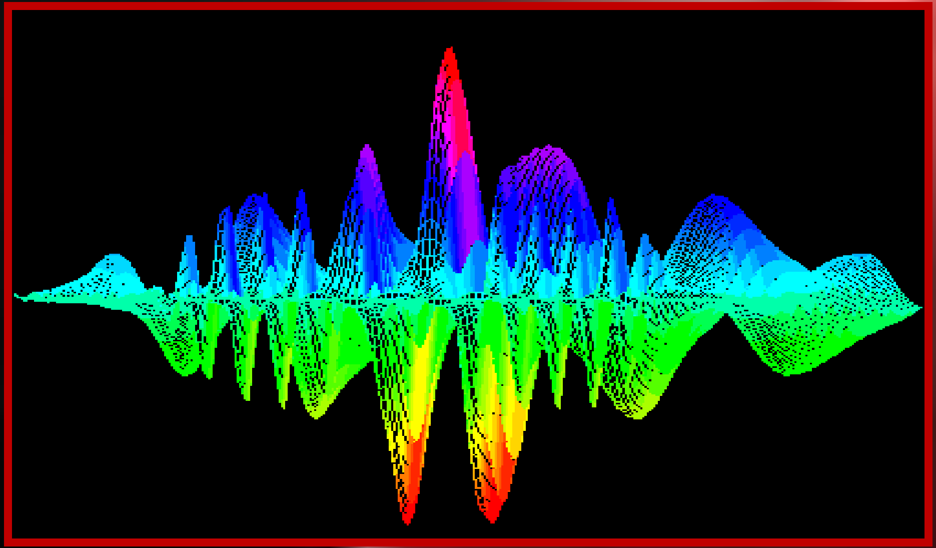
Using Telemetry Science, an Adaption of Prognostic Algorithms for Predicting Normal Space Vehicle Telemetry Behavior from Space for Earth, Planetary and Lunar Orbiting Satellites and Interplanetary Spacecraft

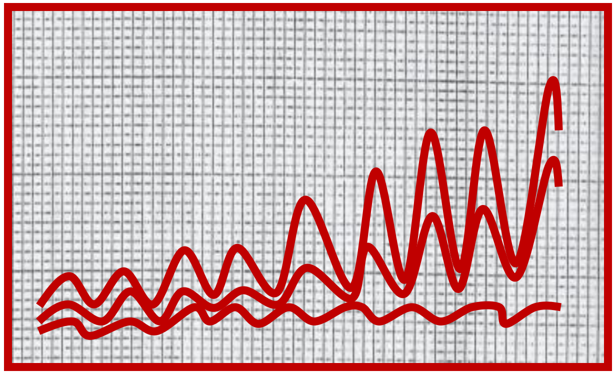


By

Failure Analysis

Telemetry Science

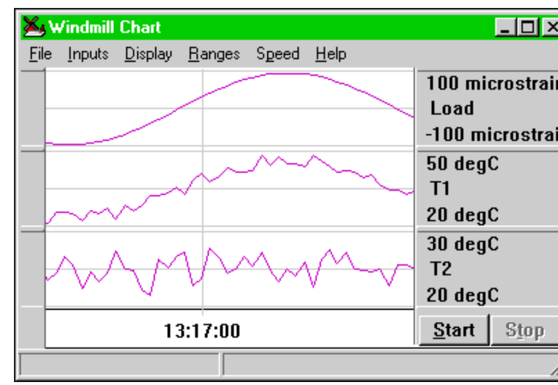
- **Telemetry Science Quantifies the Intelligence in Planetary and Lunar Satellite and Interplanetary Spacecraft Analog Telemetry Behavior**
  - Uses the same principles as RF and digital signal theory
    - » Signal intelligence
    - » Carrier signal
    - » Subcarrier
    - » Modulation
    - » Demodulation
  - – Technically justify the full use of telemetry



A Telemetry Measurement Min/Avg/Max Orbital Values

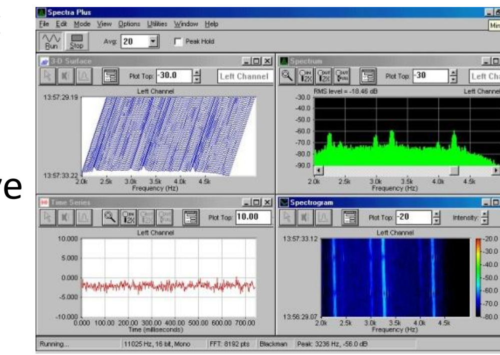
Telemetry Science

- **Why is Telemetry Science Important?**
  - Satellite/spacecraft owners/customers such as Air Force/NASA/INTELSAT do not require builders to provide predicts for normal analog equipment telemetry behavior
  - During spacecraft factory test, the actual in-orbit sun angles/body orientations are not duplicated so that normal space vehicle telemetry behavior is not obtained
    - Spacecraft are launched without means of predicting/understanding equipment analog telemetry behavior prior to launch
    - Engineers must wait to obtain actual satellite/spacecraft telemetry
    - Satellite control engineers often use factory test qualification (-10 to +50°C)/acceptance (+10 to +40°C)/red/yellow/green limits to compare actual data with
      - Most equipment/vehicle failures occur well within limits



Telemetry Science

- **Origin of Telemetry Science**
  - Prognostic analysis for in-orbit satellites and spacecraft
    - Used to produce equipment/products/vehicles with near perfect reliability
      - Uses forensic science to understand equipment/product failures that occur immediately after testing, i.e. infant mortality failures
      - Answers the why/how, after exhaustive & comprehensive factory testing, equipment/products fail when used
        - » Prognostic analysis after failure identifies when the early signs of premature aging/failure began
        - » Completed during manufacturing/production identifies the units that will fail within 1 year of use



    - Measure reliability invasively
  - Prognostic analysis is in prognostic technology

Telemetry Science

- **Prognostic/Diagnostic Comparison**

Prognostics	Diagnostics
Identifies equipment that has failed and will fail	Identifies equipment that has failed or changed performance
Uses active reasoning	Used for passively monitoring information
Illustrates the information used by prognosticians to predict equipment that will fail	Developed from ground test environment which is not real-time
Actively monitor data to provide knowledge of whether a failure has occurred, is occurring or when a failure is likely to occur	Record data and look at it later, after the fact response
All events are failure information until ruled out	Events are recognized but no action is taken
Prognostician doesn’t just stand by and watch failures occur, they stop them from occurring	Diagnostician waits for predefined error message before taking action
Requires high skilled personnel – with in-depth knowledge of what is being actively monitored	Allows lower skilled personnel - since data is evaluated post event
Identifies system readiness for successful deployment	Inadequate for meeting today’s customer expectations

Telemetry Science

Active/Passive Reasoning Comparison

Active Reasoning	Passive Reasoning
Evaluate symptoms continuously	Evaluates symptoms after the fact
Uses fault reasoning	Spurious symptoms misleads fault localization analysis.
Uses fidelity evaluation “how accurate are we?”	Spurious symptoms are regarded as observational noise
Uses action selection “what should we do next?”	Depends on monitoring agents to detect and report abnormality using alarms or symptom events
Takes passively observed symptoms as input and returns fault hypothesis as output.	After the fact search for root faults based on the observed symptoms
Searching for the best fault explanation of the observed symptoms.	
Event-driven fault reasoning technique improves the robustness of fault localization system by analyzing lost, positive and spurious symptoms.	
Assumes each event is a failure until ruled out	

Telemetry Science

- **Data-Driven Prognostic Algorithms Used in an Inference Engine**

ALGORITHM	PURPOSE OF ALGORITHM
BASELINE ANALYSIS	Identifies short and long term normal data behavior
CHANGE ANALYSIS	Determines change from normal behavior.
COMPARISON ANALYSIS	Determines when a change in normal behavior is occurring
DATA INTEGRATION	Collects and display all the data available to begin the process of illustrating failure
DATA MINING	Search large data sets for common behavior during the same time
DIGITAL PROCESSING	Replace values that are outliers improving image resolution
DISCRIMINATION ANALYSIS	Identify behavior that has changed from normal behavior
FAILURE PATTERN RECOGNITION	Illustrates data prognosticians use to predict behavior
MATHEMATICAL MODELING	For Generating mathematical equation to generate normal behavior
MULTI-VARIANT LIMIT ANALYSIS	Compare behavior from several telemetry measurements simultaneously
RATE CHANGE ANALYSIS	Identifies data to be investigated at a deeper level
REMAINING USABLE LIFE	Determines when equipment will fail
STATISTICAL SAMPLING	Reduces large data set before evaluating
STATE CHANGE ANALYSIS	Identifies data to be analyzed further for failure signature
SUPER IMPOSITIONING	Creates continuous data behavior when little data is available
SUPER PRECISION	Improves prognostic analysis image resolution
DATA AUTHENTICATION	Eliminates corrupted data
VIRTUAL DATA	Creates normal data behavior when none is available
DATASET GENERATOR	Creates data set when access to the full data set is not available or using data set is impractical

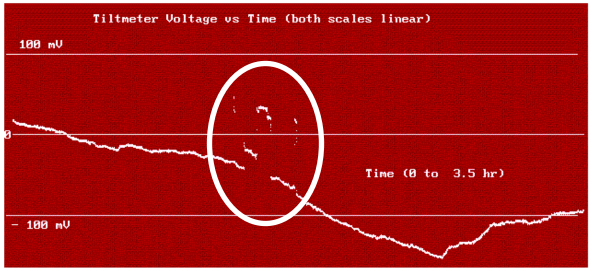
Telemetry Science

- **Prognostic Algorithms and their use**

Tool Box of Prognostic Algorithms	Equipment Factory	Satellite Factory	LV Factory	Launch Pad	Mission Control	Mission Control (CCSDS)
Data Integration	X	X	X	X	X	X
Baseline Analysis	X	X	X	X	X	X
Change Analysis		X	X	X	X	X
Comparison Analysis	X					
Data Mining		X	X	X	X	X
Day of Failure	X	X	X	X	X	X
Digital Processing					X	
Discrimination Analysis	X	X	X	X	X	X
Mathematical Modeling	X	X	X	X	X	X
Multi-variant Limit Analysis	X	X	X	X	X	X
Rate Change Analysis		X	X	X	X	X
Remaining Usable Life	X	X	X	X	X	X
Statistical Sampling		X	X	X	X	X
State Change Analysis		X	X	X	X	X
Super Impositioning		X	X	X	X	X
Data Integration	X	X	X	X	X	X
Super Precision					X	X
Telemetry Authentication					X	
Virtual Telemetry	X	X	X	X	X	X
Data Base Creation					X	

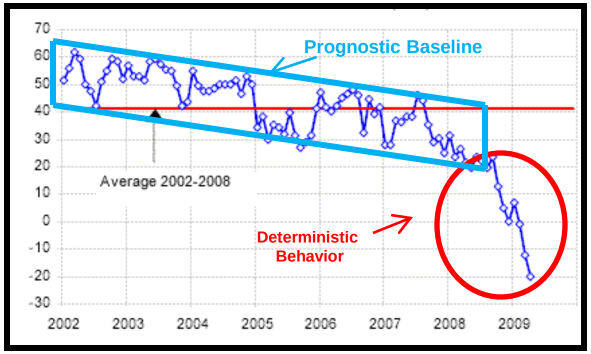
Telemetry Science

- **Prognostic Analysis**
  - Uses algorithms for illustrating and identifying the early signs of premature aging/failure (failure precursors/deterministic behavior/cannot duplicates (CND)/no failure found (NFF)/no failure identified (NFI), retest OK (RTOK)
  - Discriminate them from other normal appearing behavior, in completely normal appearing data from fully functional equipment/products, algorithms must:
    - Filter noise, corrupted data, excess data
    - Allow data reconstruction, virtual data
    - Identify normal behavior (baseline)
      - Kalman filter
      - Neural networks
      - Four analysis/transforms
        - » Fast Fourier Transforms
        - » Wavelets



Telemetry Science

- **Baseline Behavior Generation**
  - For earth/lunar/planetary satellites, equipment telemetry behavior is related to the shape and period of orbit (harmonics related to the body orbited)



Baseline Generation

  - For interplanetary missions, telemetry behavior is directly related to the trajectory (harmonics are related to the sun/interplanetary/planetary trajectory)
  - Requires education and training in illustrating and identifying/discriminating deterministic behavior from normal behavior

Telemetry Science

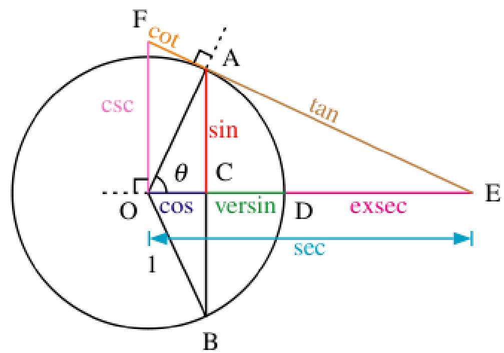
- **Communications Science**
  - Fourier analysis

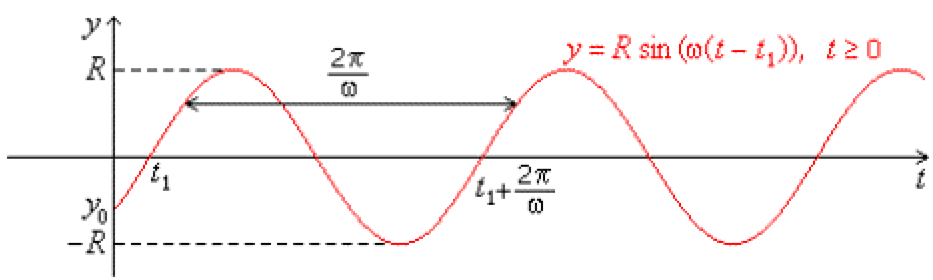
$$x(t) = R\sin(\omega t + \phi)$$

$$\int x(t) = f_{\omega}(\omega)$$

$$\int f_{\omega(}(\omega) = f_{\phi}(\phi)$$

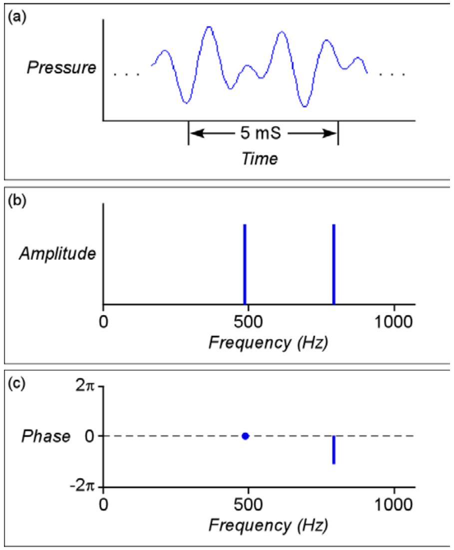
$$\int f_{\phi}(\phi) = f_{\acute{r}}(\acute{r})$$





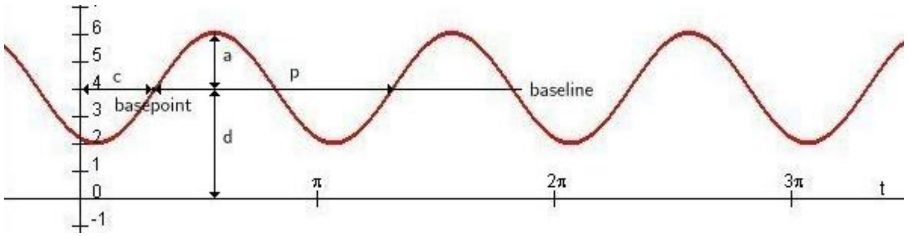
Telemetry Science

- **History**
  - – Created and used to predict rubidium and cesium atomic frequency standard performance behavior on Boeing/Air Force Global Positioning System satellites (circa 1978-1988)
    - Expanded for use across all satellite equipment behavior



Telemetry Science

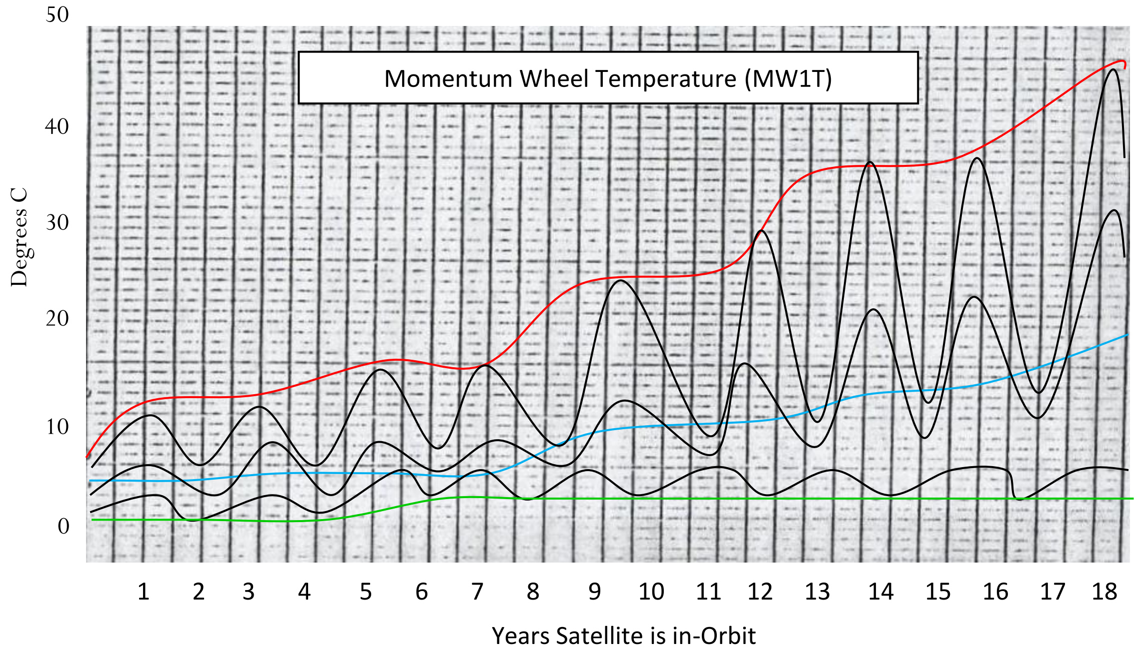
- **Purpose**
  - To understand the origin/source of intelligence in satellite and spacecraft analog telemetry behavior
    - Satellite engineers search for understanding and quantifying on-board equipment telemetry behavior to leverage the large quantity of telemetry recorded and stored
      - External spacecraft influences
        - Harmonic
        - Non-harmonics
        - Polynomial
      - Internal source influences
        - Local equipment cycling
        - Failure behavior



Telemetry Behavior from Orbiting Spacecraft

Telemetry Science

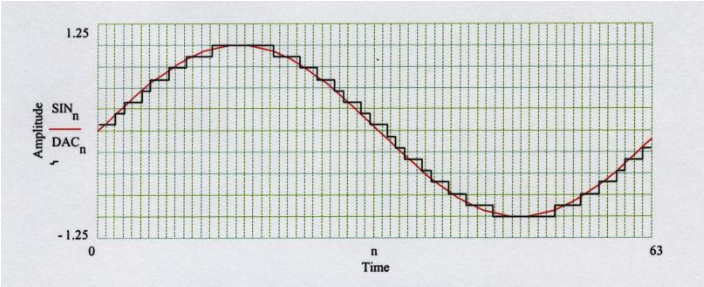
- **Satellite and Spacecraft Telemetry Behavior from Harmonic and Non-Harmonic Influences**



Peak values envelope – Red
Minimum values envelope – Green
Average values of the envelope – Blue
Minimum/average/maximum values- Black

Telemetry Science

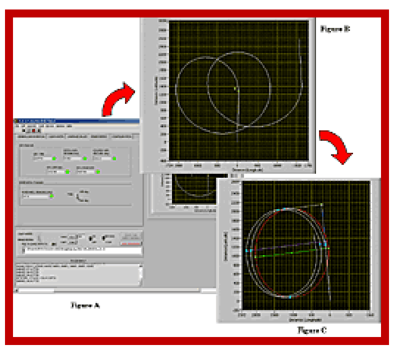
- **A Virtual Analog Telemetry Signal**
  - A telemetry analog signal is a reconstruction of an electrical analog signal
    - An approximation
    - Sampling frequency
    - Recording rate
    - Engineering unit conversion
    - Processing and display limitations
  - Can be analyzed using RF and digital communications theory

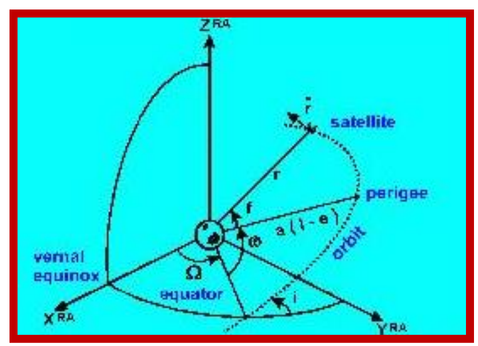


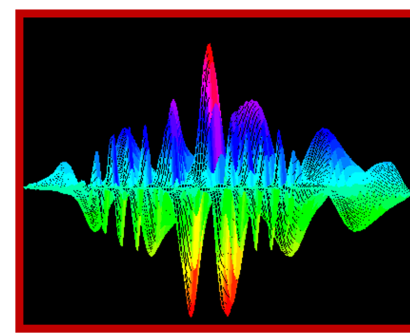
Reconstructed Analog Signal

Telemetry Science

- **Recommended Technical Background**
  - Orbital mechanics
  - RF and digital communications theory
  - Spacecraft system design
  - Telemetry system design







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