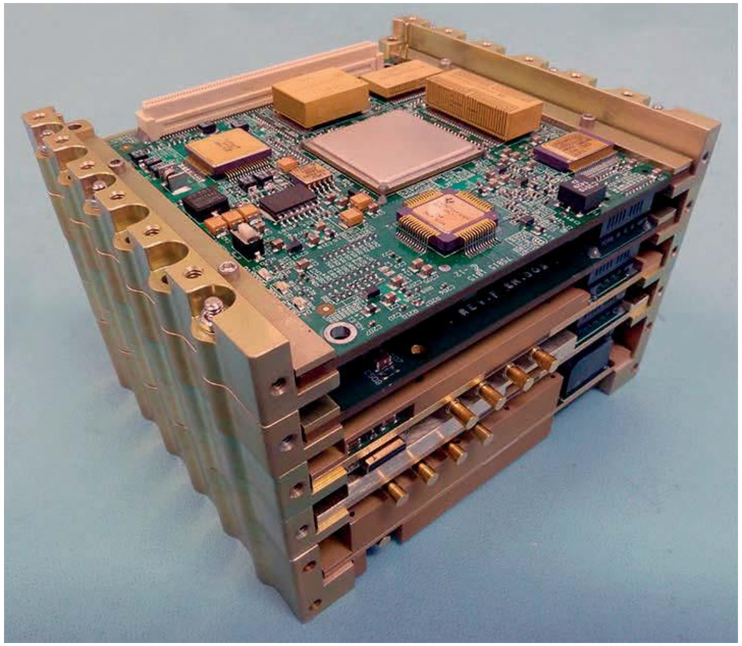
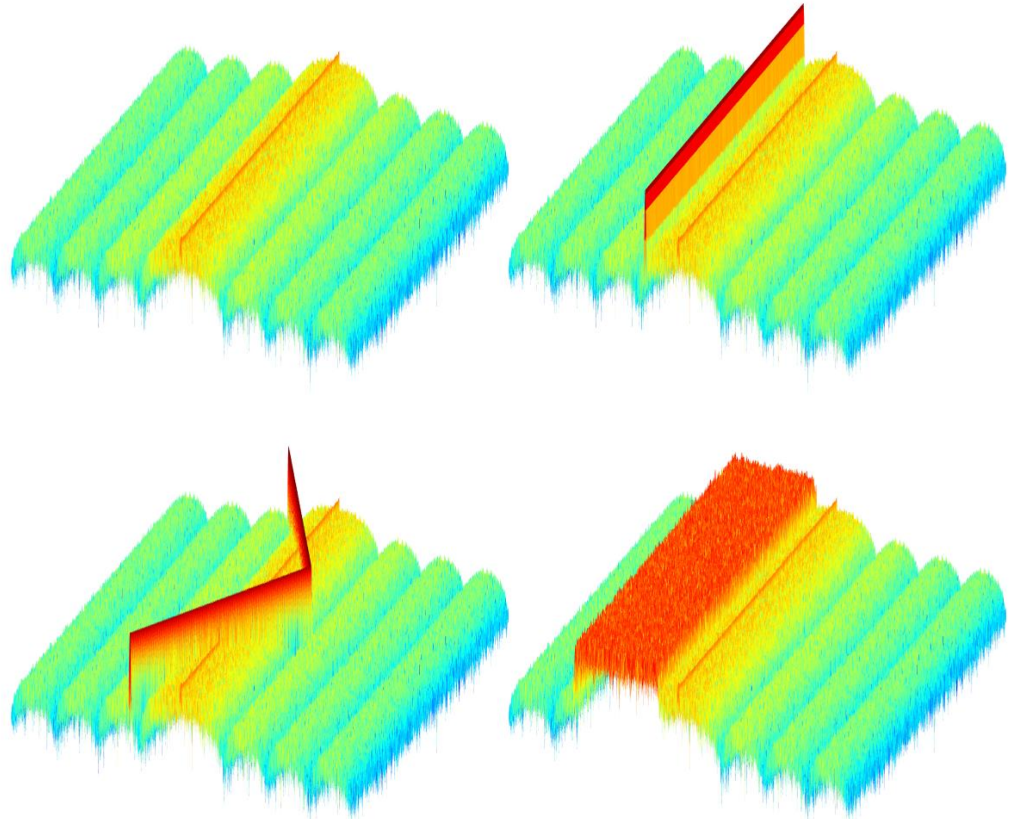




Anomaly and Interference Detection for Space Radios and Iris

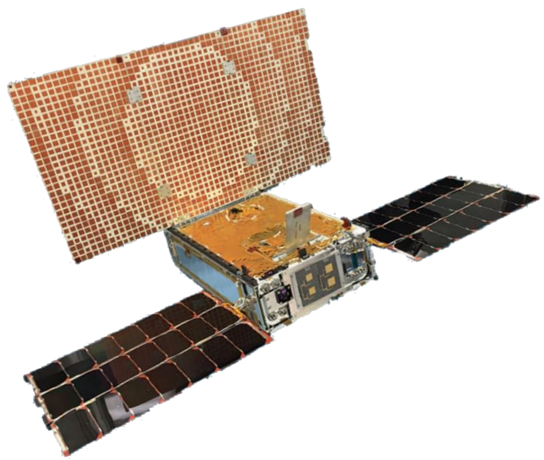
2022 Interplanetary Small Satellite Conference (ISSC)
California Polytechnic University, San Luis Obispo
May 2, 2022

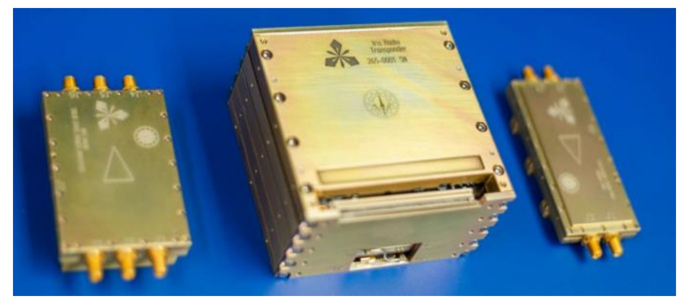
Presented by: Dennis Ogbe
Authors: D. Ogbe*, M. Chase*, Z. Towfic*
*Jet Propulsion Laboratory, California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

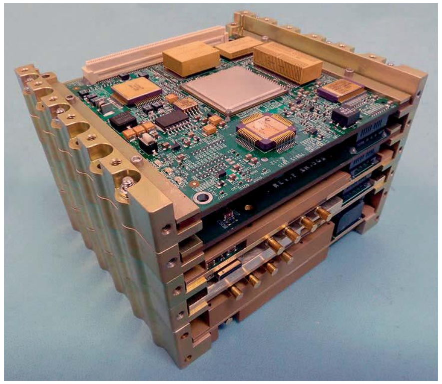
Overview

- Recent updates to the Iris Deep Space Transponder
- NASA STD-1006
- Iris I/Q recording capability
- Anomaly and interference detection method & evaluation





The Iris Transponder



- Iris is a CubeSat/SmallSat compatible transponder developed by the National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL) as a low volume and mass, lower power and cost, software/ firmware defined telecommunications subsystem for deep space. Iris is manufactured and fabricated by Space Dynamics Laboratory.

- Iris is a deep-space transponder targeted for NPR 7120.8 technology demonstrations and Class-D space flight projects, utilizing COTS-grade components.

- Iris' features include ~0.5 U volume, 0.86 kg mass, 35 W DC power consumption when fully transponding at 3.8 W radio frequency output (12.6 W DC input for receive only), and interoperability with NASA's Deep Space Network (DSN) at X-Band frequencies (7.2 GHz uplink, 8.4 GHz downlink) for command, telemetry, and navigation.

- Iris V2.1 is designed with an environmentally robust architecture including radiation tolerant parts needed for deep space missions with durations of a few years and thermal management needed for navigation tracking sessions of several hours.

- MarCO (May 2018)
- LICIACube (November 2021)
- Artemis-1 (June 2022)
    - Bio Sentinel
    - CuSP
    - NEAScout
    - Lunar ICECube
    - LunaH-Map
    - ArgoMoon
- CAPSTONE (May 2022)
- Lunar Flashlight (NET 2022)
- Janus (August 2022)
- D2S2 (NET 2022)
- Lunar Trailblazer (NET 2023)
- ispace lunar lander (2024)
- Solar Cruiser (2025)
- LEMS

Recent Updates to Iris

- One-way ranging capability with Chip Scale Atomic Clock (CSAC)

- Carrier acquisition improvements
  - FFT-based carrier acquisition
    - Acquisition of carriers > 150KHz away from best lock frequency
  - Multi-stage carrier acquisition
    - Large carrier tracking loop BW followed by narrow carrier tracking loop BW
  - Carrier can be acquired in < 1 second generally
    - Extremely useful during testing due to not requiring DSN and GSE to perform sweep

- CCSDS SDLS authenticated uplink encryption
  - AES256 Decryption capability

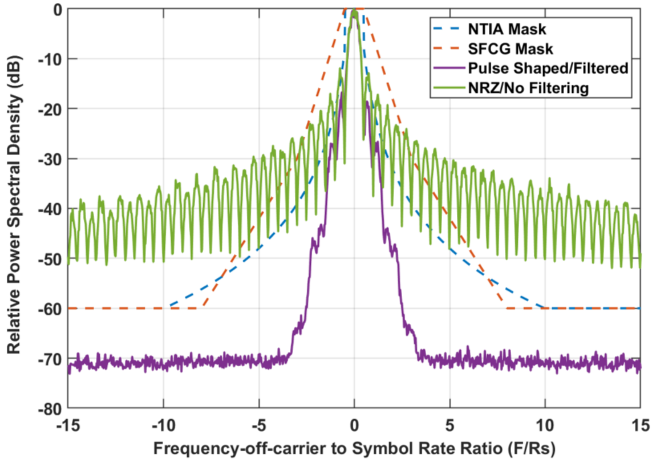

CCSDS
The Consultative Committee for Space Data Systems
Recommendation for Space Data System Standards
SPACE DATA LINK SECURITY PROTOCOL
RECOMMENDED STANDARD
CCSDS 355.0-B-1
BLUE BOOK
September 2015

- SpaceWire C&DH interface implementation

- LDPC Coding on Downlink (1/2, 2/3, 4/5, 7/8)

- Pulse Shaping for meeting NTIA and SFCG Spectrum Masks
  - GMSK coming soon.

- Many improvements to the demodulation chain
  - Implementation loss down to ~0.5dB.

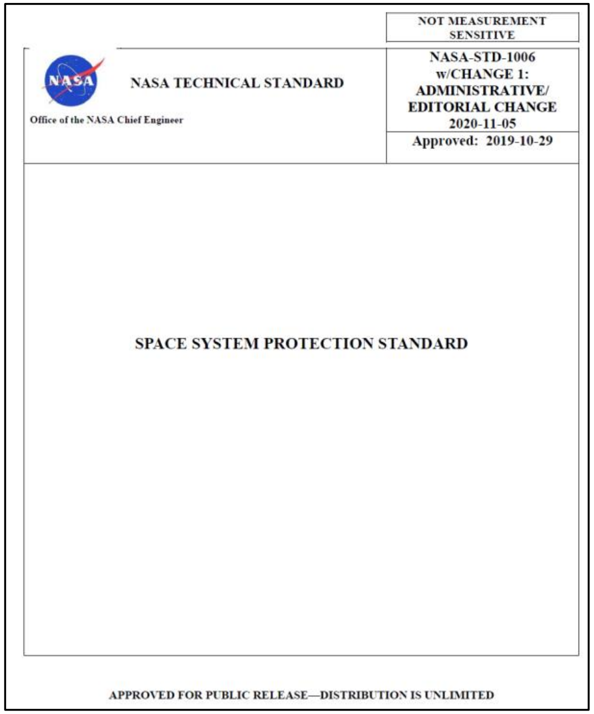


NASA STD-1006 “Space System Protection Standard”

- All projects established after February 2019 are required to comply

- Intended to ensure NASA missions are resilient to threats
  - Command link jamming/intrusion
  - GPS jamming/spoofing
  - Cyber exploitation

- Describes 6 Space System Protection Requirements (SSPRs)
  1. Command stack encryption
  2. Backup command link protection
  3. Command link critical project information (CPI) protection
  4. Positioning, Navigation, and Timing (PNT) Resilience
  5. ***Interference Reporting***
  6. Interference Reporting Training



NOT MEASUREMENT SENSITIVE

NASA TECHNICAL STANDARD

Office of the NASA Chief Engineer

NASA-STD-1006 w/CHANGE 1: ADMINISTRATIVE/ EDITORIAL CHANGE 2020-11-05

Approved: 2019-10-29

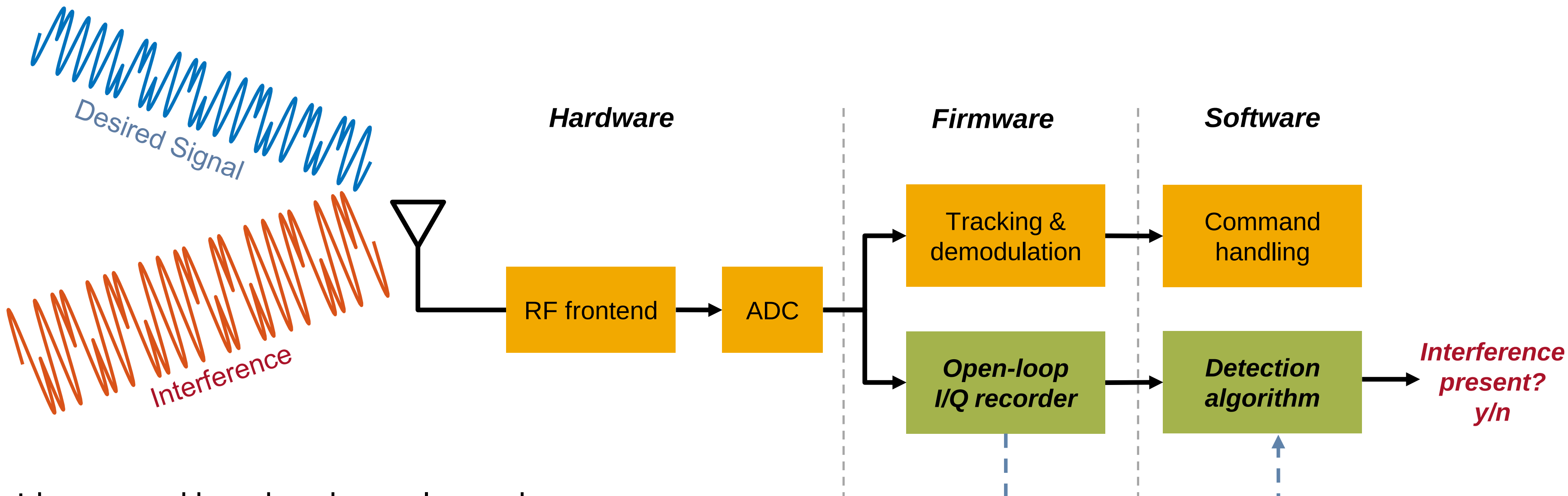
SPACE SYSTEM PROTECTION STANDARD

APPROVED FOR PUBLIC RELEASE—DISTRIBUTION IS UNLIMITED

https://standards.nasa.gov/standard/oce/nasa-std-1006-wchange-1

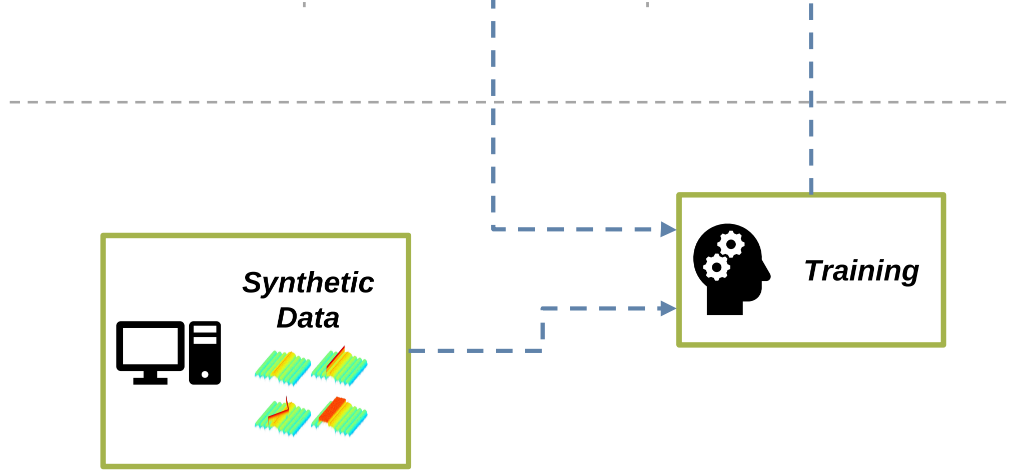
“Missions should incorporate autonomous telemetry monitoring to support operational teams in the detection of unexpected command link energy, unexpected loss of GPS satellite solutions, and other unexplained interference events.”

Anomaly and interference detection



- Idea: record baseband samples and implement interference detection in software
- Detection algorithm can be trained offline on either synthetic or real data

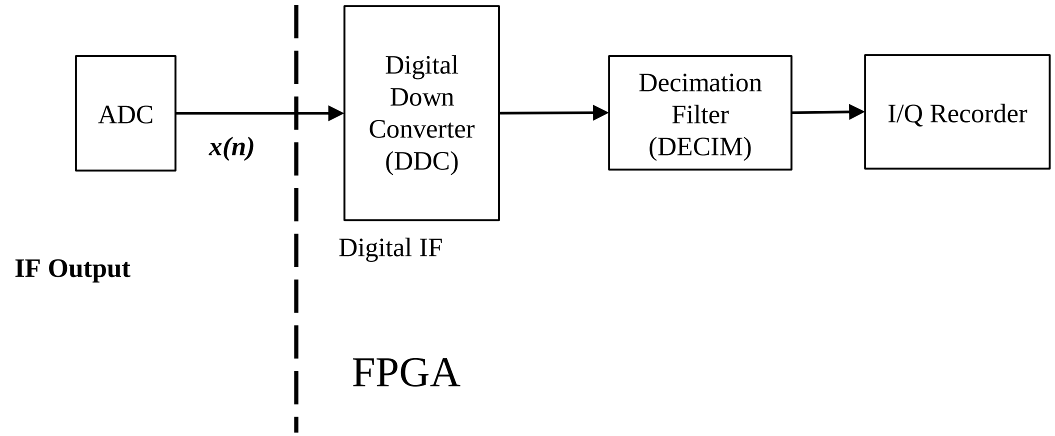
Desired signal only	**No Anomaly**
Desired signal + interference	**Anomaly**

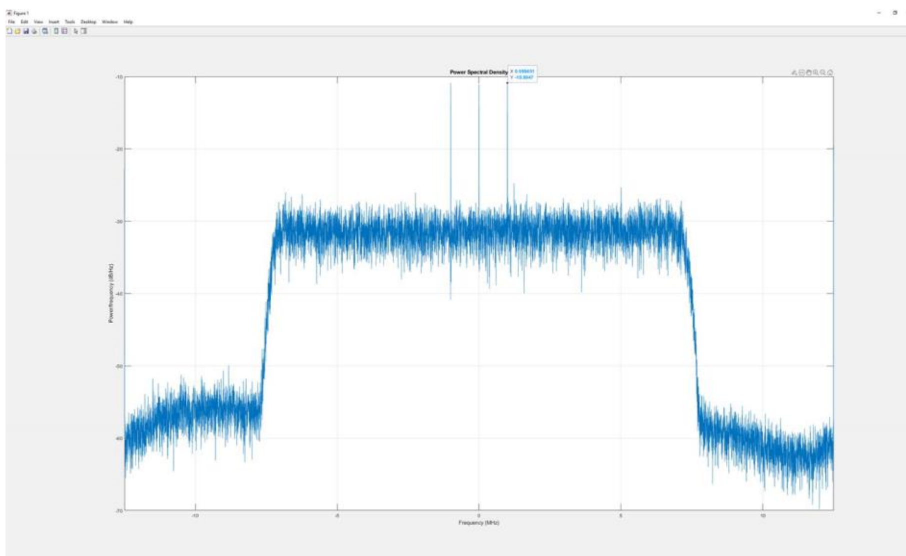


Iris I/Q Recorder

- This task added open-loop I/Q recording capability to the Iris firmware

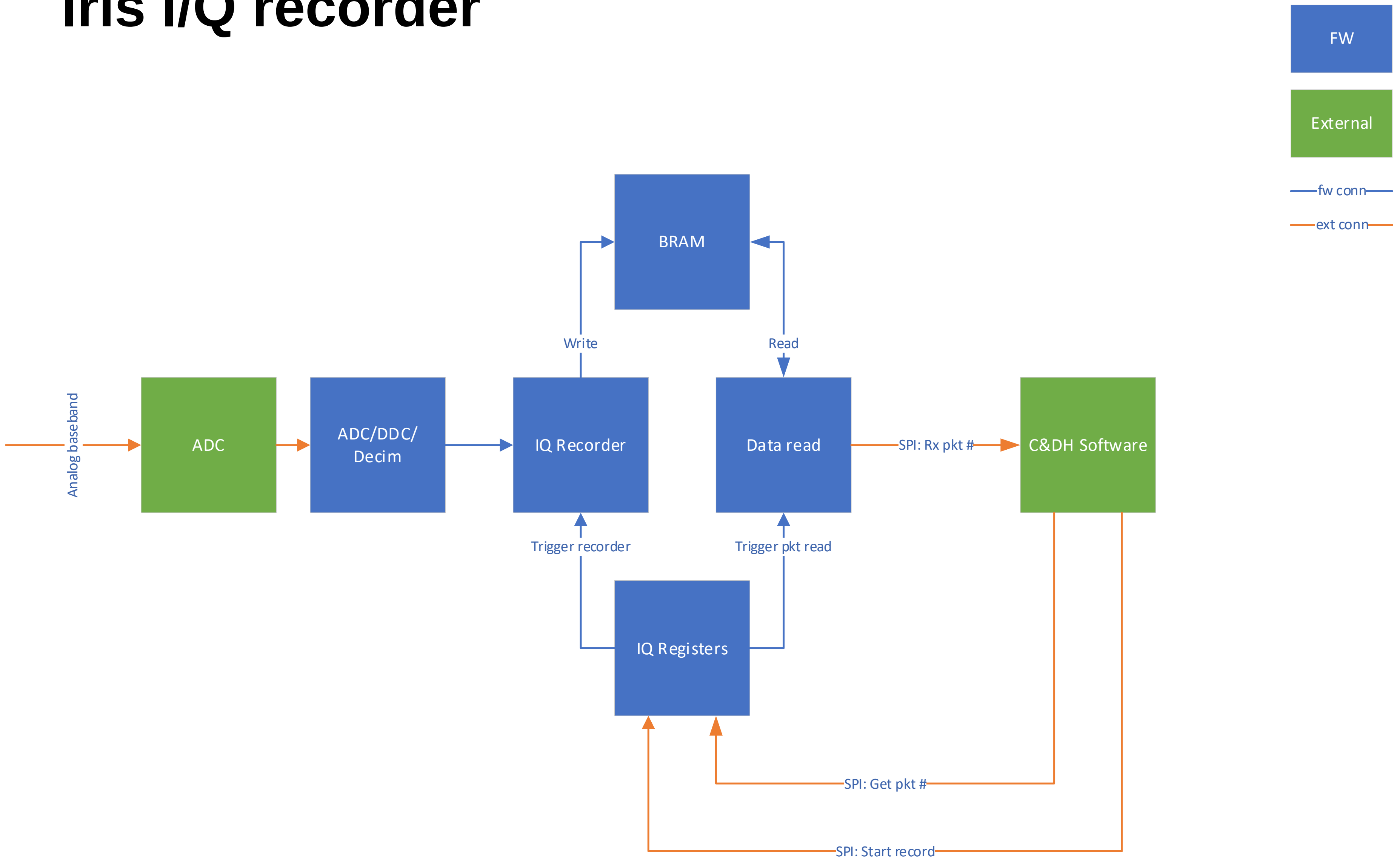
- Firmware appears to be ready, software component to transfer samples to C&DH is WIP





Recording of 1 MHz ranging signal + carrier.

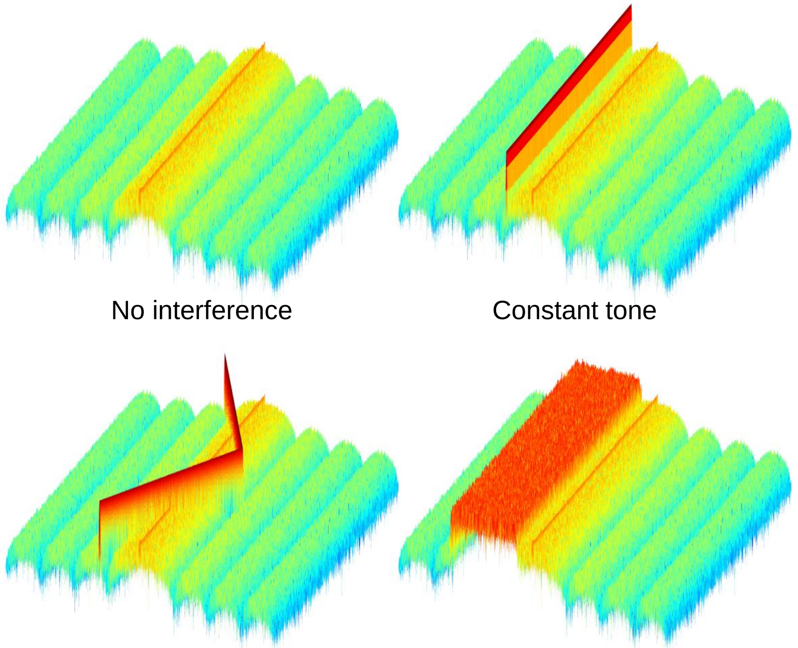
Iris I/Q recorder



Anomaly and interference detection method

This task evaluated an anomaly detection technique in simulation for three different interferers:

- **Constant tone:**
  - This can be benign interference (self-interference from instruments and switching power supplies).
  - Perhaps easiest for an adversary to make (constant modulus, etc.).
- **Linear chirp:**
  - Power supplies change tone patterns as load changes and as they age.
  - Covers wider BW while still being simple to produce
- **Band-limited (colored) noise:**
  - Less structured, difficult to mitigate, but possibly harder to make (requires back-off from PA of jammer)



No interference | Constant tone | Linear chirp | Band-limited noise

Anomaly and interference detection method

- **Main idea:**
  - Training: Learn the covariance matrix of non-anomalous data, $\boldsymbol{R}_c$
  - Inference: Whiten the observation with $\boldsymbol{R}_c$, compute power of whitened sequence, apply threshold

- **Training:**
  - Obtain N vectors of non-anomalous data

$$\boldsymbol{x}_c^{(n)} = \left[x_c^{(n)}[1], x_c^{(n)}[2], \dots, x_c^{(n)}[M]\right]^T, n \in \{1, \dots, N\}$$

  - Compute estimate of the covariance matrix

$$\boldsymbol{R}_c = \frac{1}{N} \sum_{n=1}^{N} \boldsymbol{x}_c^{(n)} \left(\boldsymbol{x}_c^{(n)}\right)^*$$

- **Inference:**
  - Compute power of whitened observation:

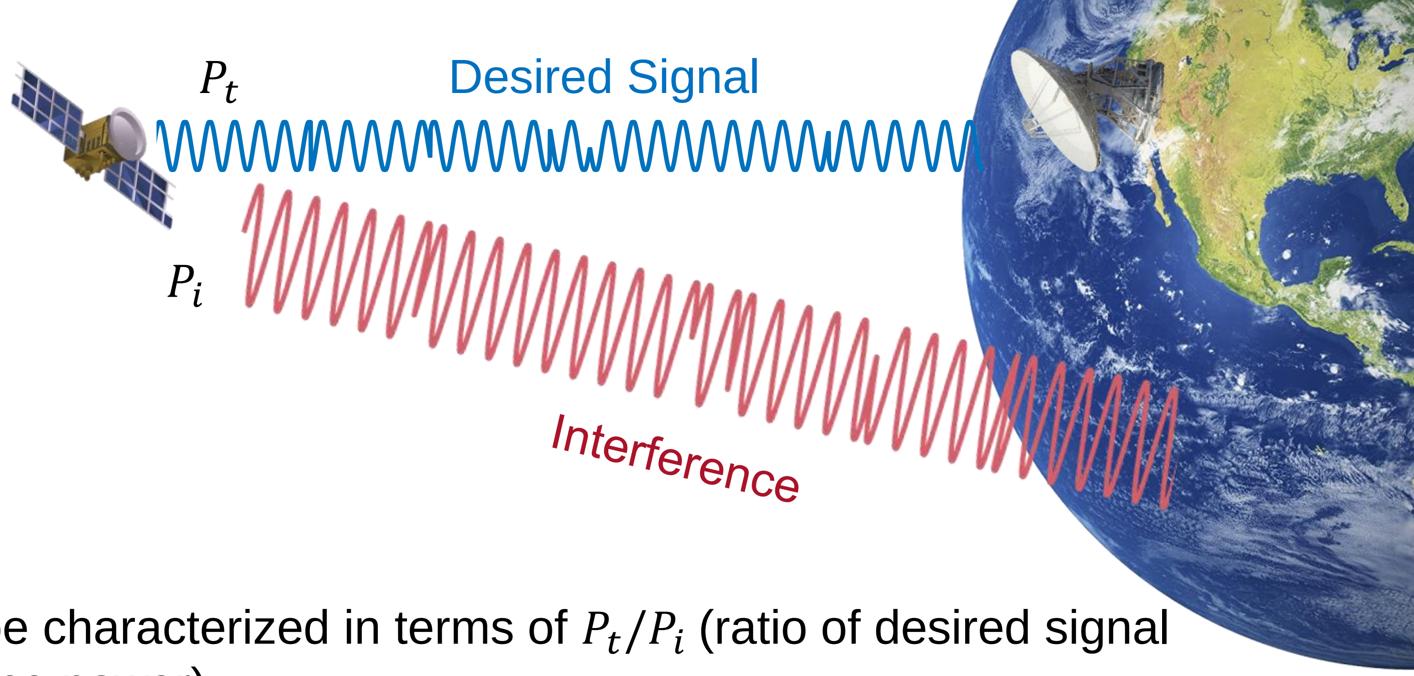
$$p_w = \left\| \boldsymbol{R}_c^{-1/2} \boldsymbol{x} \right\|_2^2$$

where $\boldsymbol{x} = \left[x[1], x[2], \dots, x[M]\right]^T$ is the vector of recorded I/Q samples

  - Apply threshold

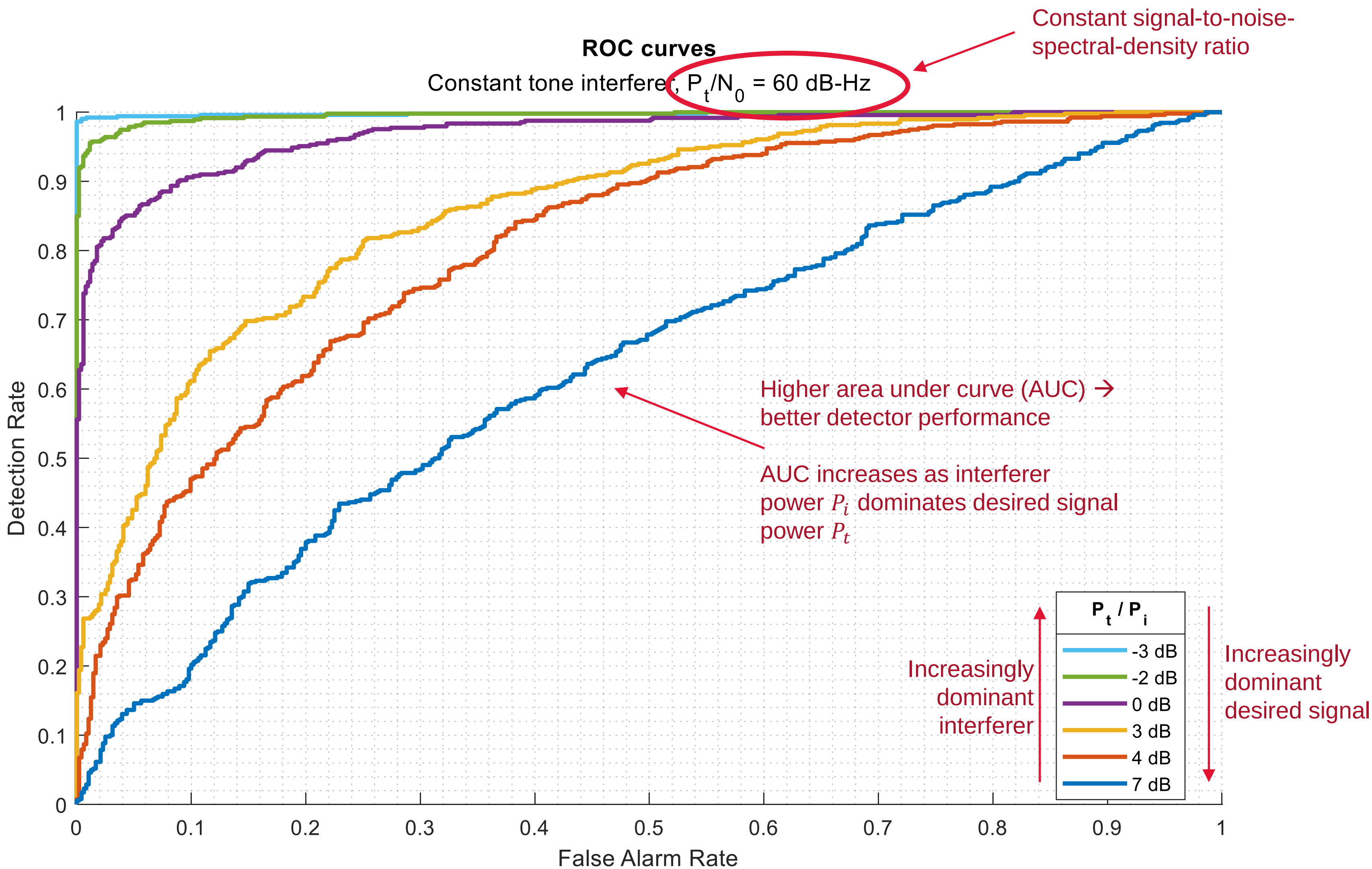
$$p_w \underset{>}{\overset{\leq}{}} \gamma \quad \begin{array}{c} \text{no anomaly} \\ \text{anomaly present} \end{array}$$

Assessment of Performance: P_t/P_i ratio

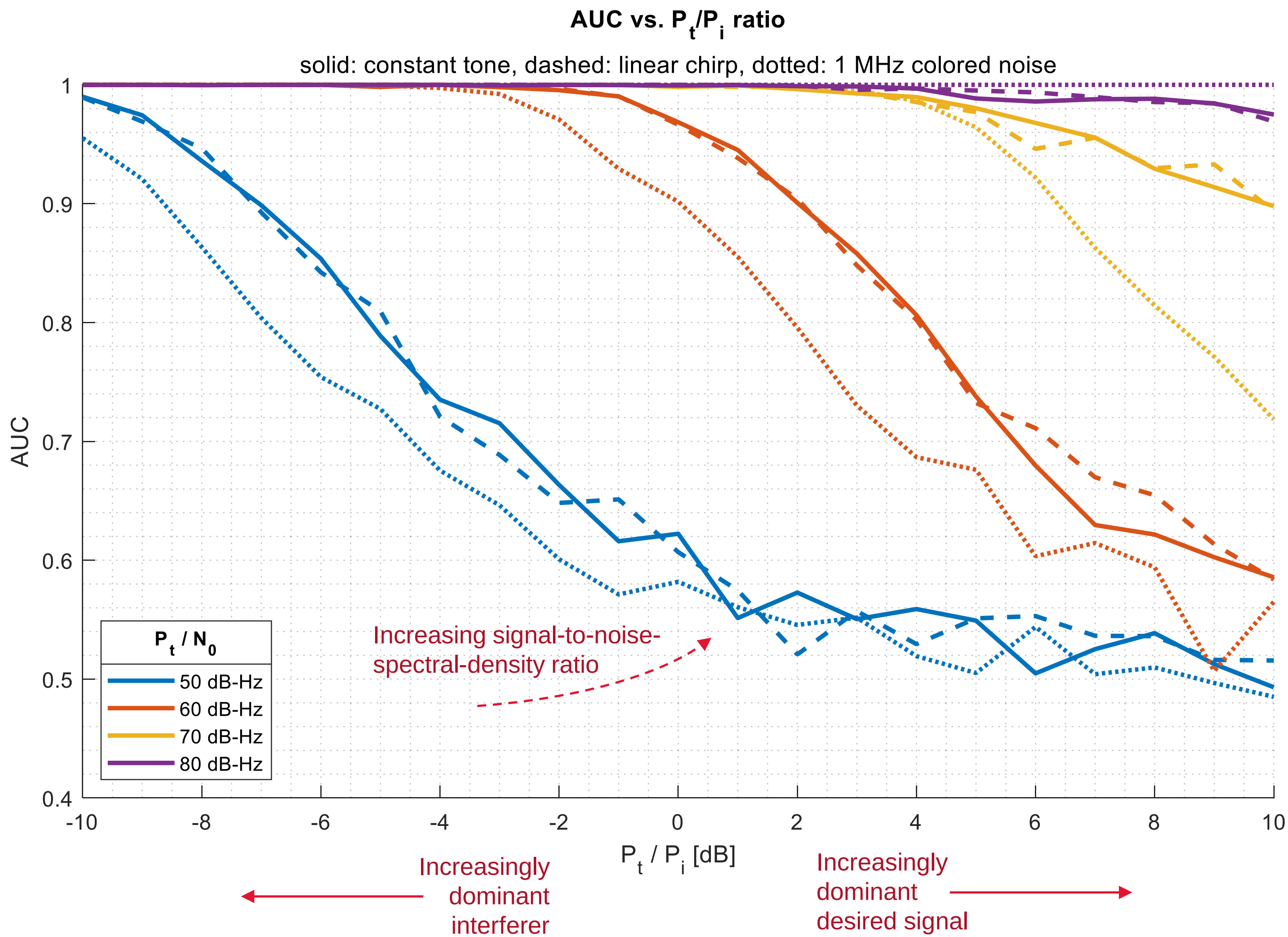


- Performance can be characterized in terms of P_t/P_i (ratio of desired signal power to interference power).
- We can assess (it is helpful to make such assessments per interferer waveform):
  - The probability of being able to detect an interferer for various P_t/P_i ratios (Using ROC curves)
  - The BER/damage to the communication link for various P_t/P_i values
- No assumptions are made regarding the location/source of the interferer or its actual absolute power level

Assessment of Performance: ROC curves



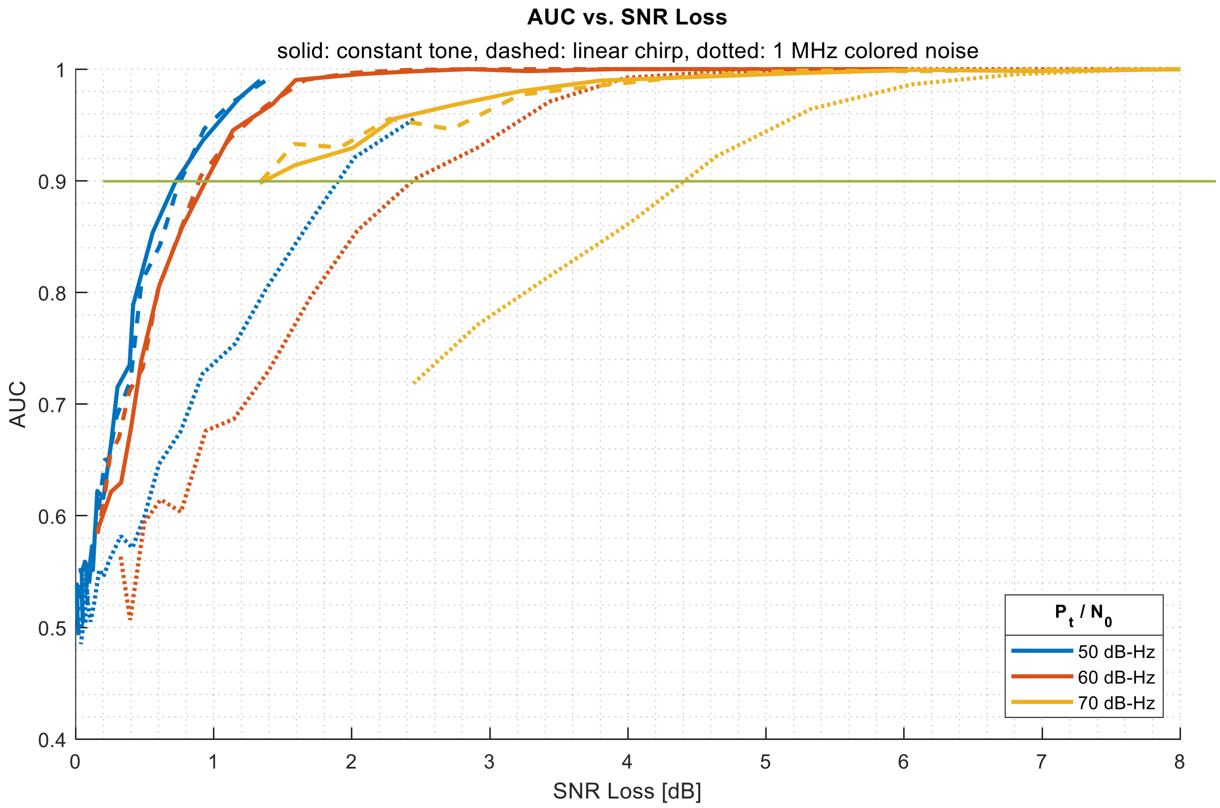
Assessment of Performance: AUC



Assessment of Performance: SNR Loss

- Can use theory to predict BER for given SNR P_t/N_0
- Can estimate BER using Monte-Carlo simulation for a given interferer & P_t/P_i
- Define

  SNR Loss = (theoretical SNR at P_t/N_0) – (theoretical SNR for estimated BER)
- Intuition: *How much will the interferer hurt our communication system's performance before we can accurately detect it?*



Example:

- Define AUC = 0.9 as sufficiently accurate detection performance
- At $\frac{P_t}{N_0} = 60$ dB-Hz, the tone and chirp interferer cause an SNR loss of approx. 1 dB before achieving AUC = 0.9
- The noise interferer causes an SNR loss of approx. 2.5 dB

Conclusion

- Overview of recent features added to the Iris transponder
- On-board anomaly and interference detection can aid in NASA STD-1006 SSPR 5 compliance
- Two major goals
  - Incorporation of I/Q recorder into Iris firmware
  - Characterization of training-based anomaly detection method to detect tone, chirp, and noise interferers
- I/Q recorder Firmware is ready for Iris
- Proposed anomaly detection method was simulated
- Detector performance is a function of base SNR P_t/N_0 and signal-to-interference power ratio P_t/P_i

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov