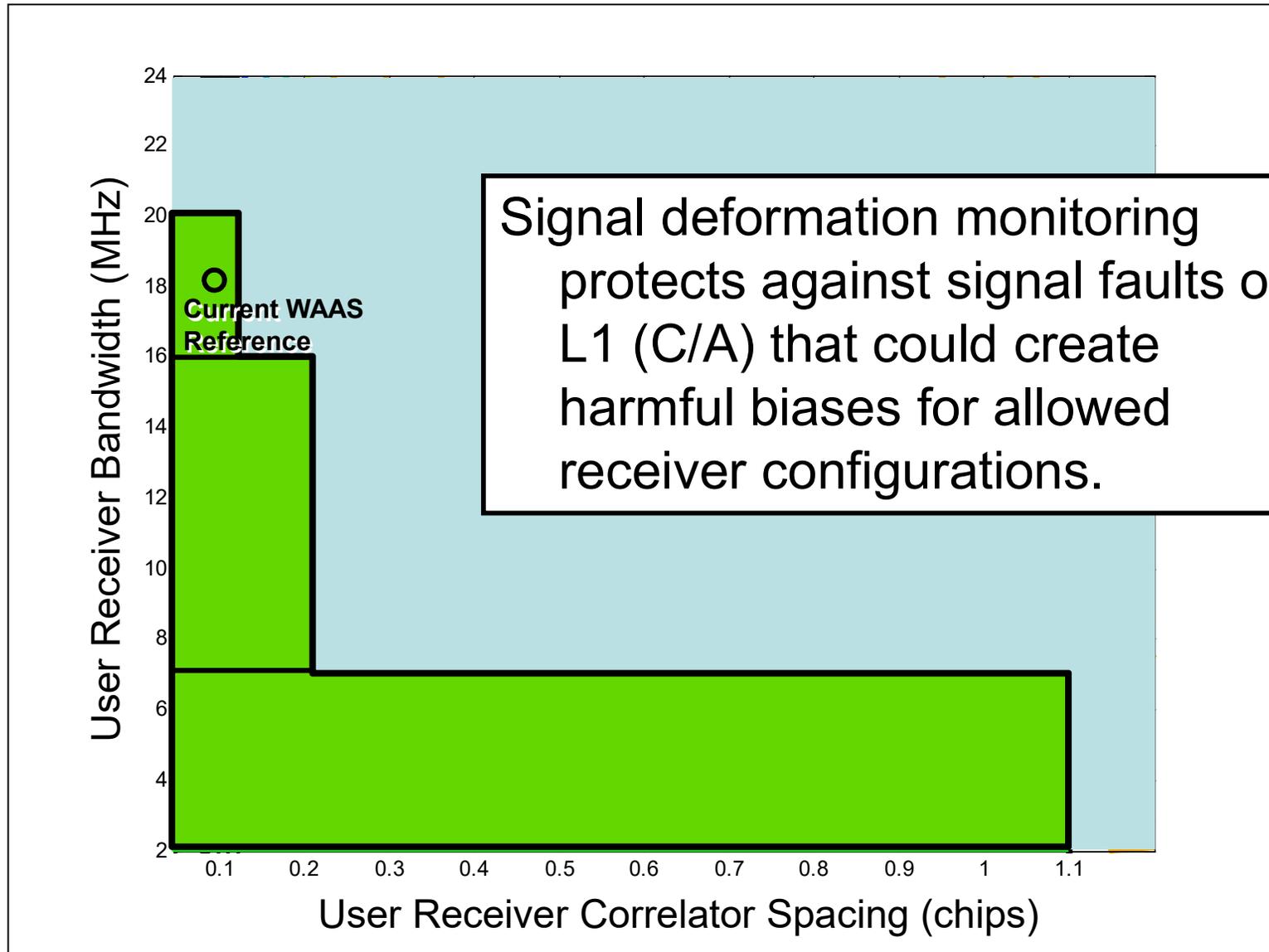


Signal Deformation Monitoring for Dual-Frequency WAAS

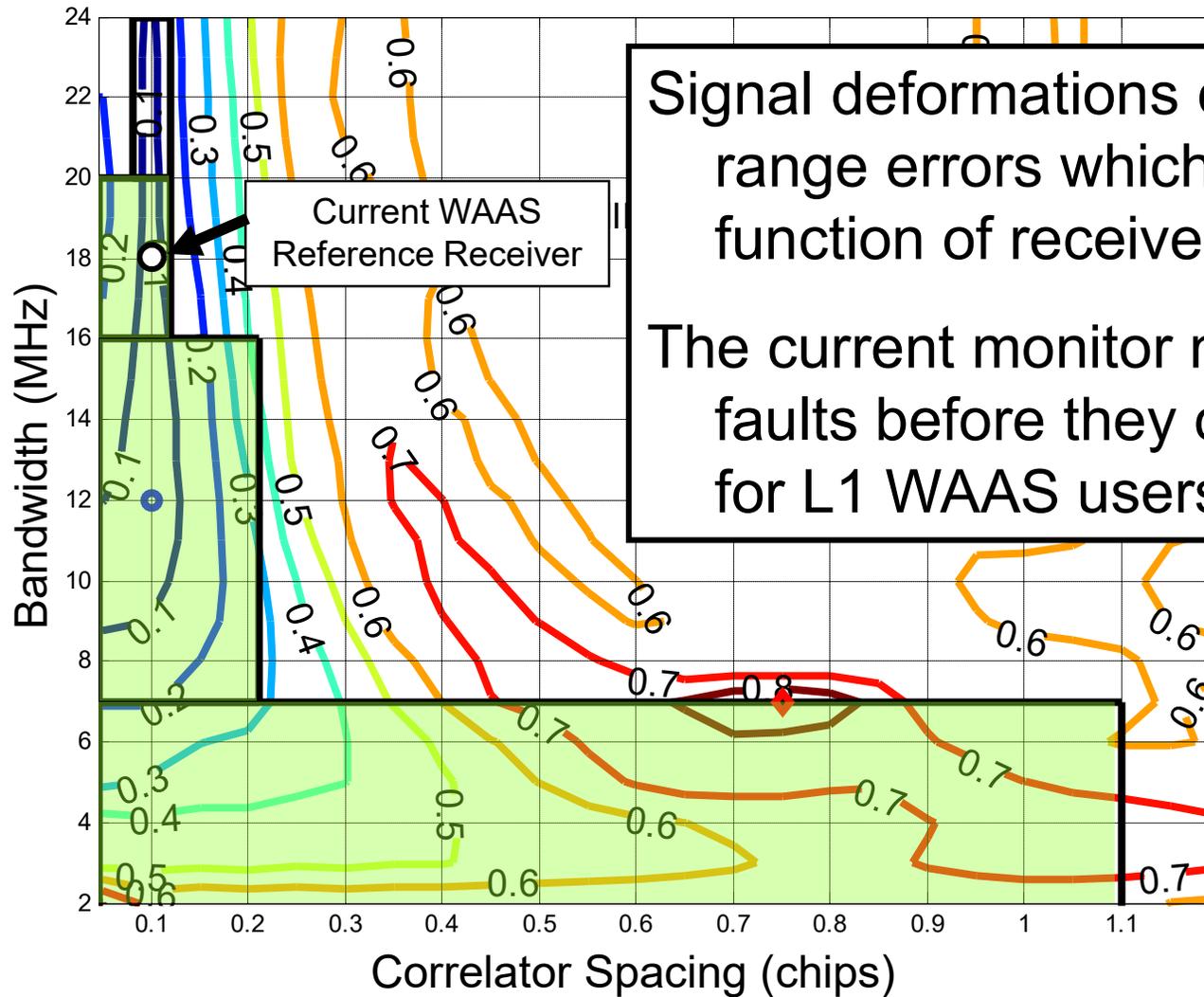
R. Eric Phelts, Gabriel Wong, Todd Walter, Per Enge
Stanford University

ION International Technical Meeting
San Diego, CA
January 28-30, 2013

The Challenge of L1-only SDM



The Challenge of L1-only SDM



Signal deformations can induce range errors which vary as a function of receiver configuration.

The current monitor mitigates these faults before they can create HMI for L1 WAAS users.

Challenges for the Dual-frequency WAAS Signal Deformation Monitor

- Ionosphere-free combination eliminates ionospheric errors but amplifies range biases
 - *Faults will need to be detected faster, with more margin*

Single Frequency SDM

$$\rho_{L1}$$

Dual-frequency SDM

$$\begin{aligned}\rho_{DF} &= 2.26\rho_{L1} - 1.26\rho_{L5} \\ &2.26\rho_{L1} \\ &1.26\rho_{L5}\end{aligned}$$

Challenges for the Dual-frequency WAAS Signal Deformation Monitor

- Smaller range error limits (UDREs) are desired
 - *More faults will have to be mitigated*

Single Frequency WAAS

Minimum Error Limit
(current):
6.08m

Dual-frequency WAAS

Minimum Error Limit
(desired):
1.21m

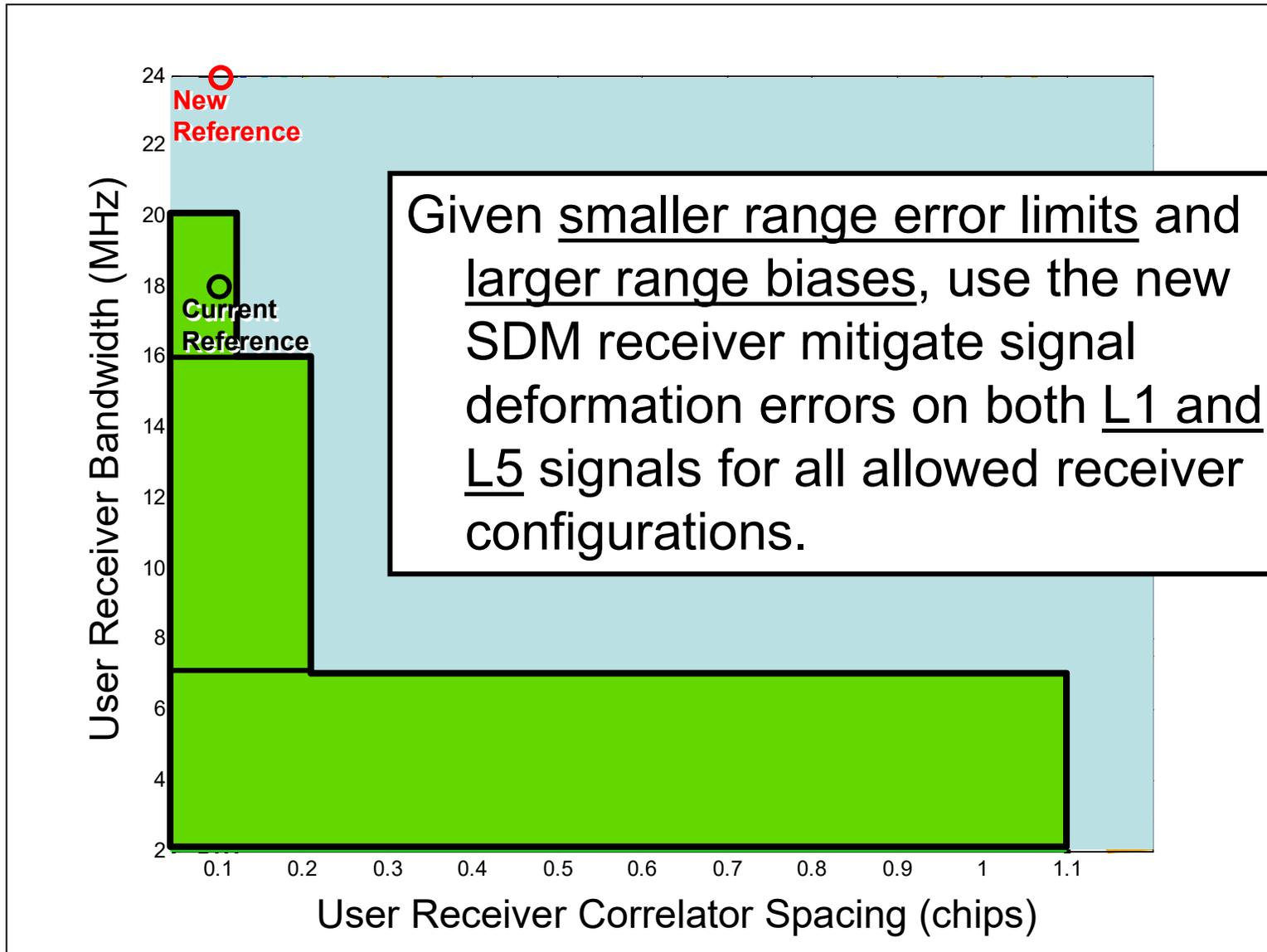
Challenges for the Dual-frequency WAAS Signal Deformation Monitor

- Smaller range error limits (UDREs) are desired
 - *More faults will have to be mitigated*
- Fault biases are larger: $\rho_{DF} = 2.26\rho_{L1} - 1.26\rho_{L5}$
 - *Faults will need to be detected faster, with more margin*
- Current detection approach has limitations
 - *L1 algorithm is near its performance limit*
 - *L1 algorithm not easily adapted to L5 signal*

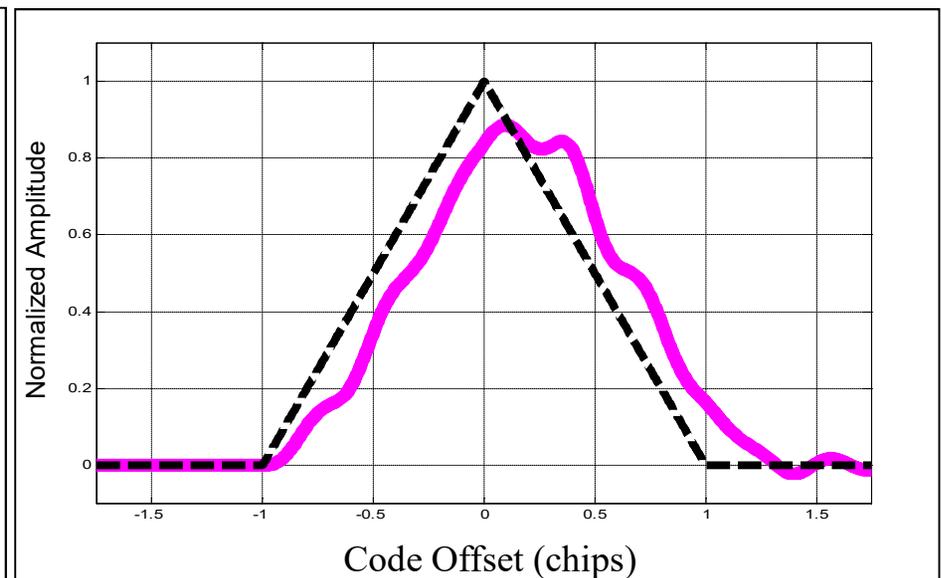
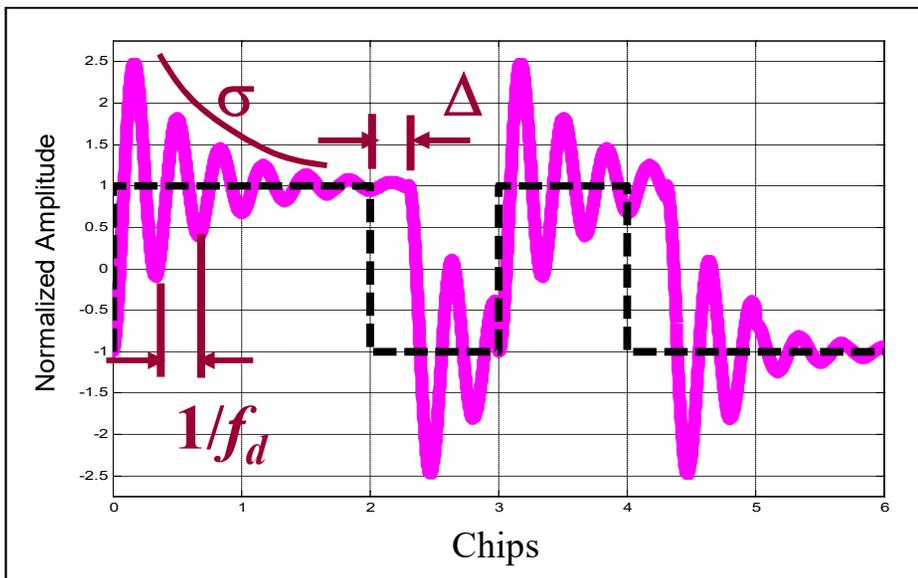
WAAS Hardware Upgrade: New SDM Receiver (Novatel G-III)

- L5 capable
- Wider bandwidth (24MHz)
 - Improves monitor detection capability, but increases user receiver error
- Chip shape-based correlator outputs available
 - Improves monitor sensitivity

Objective



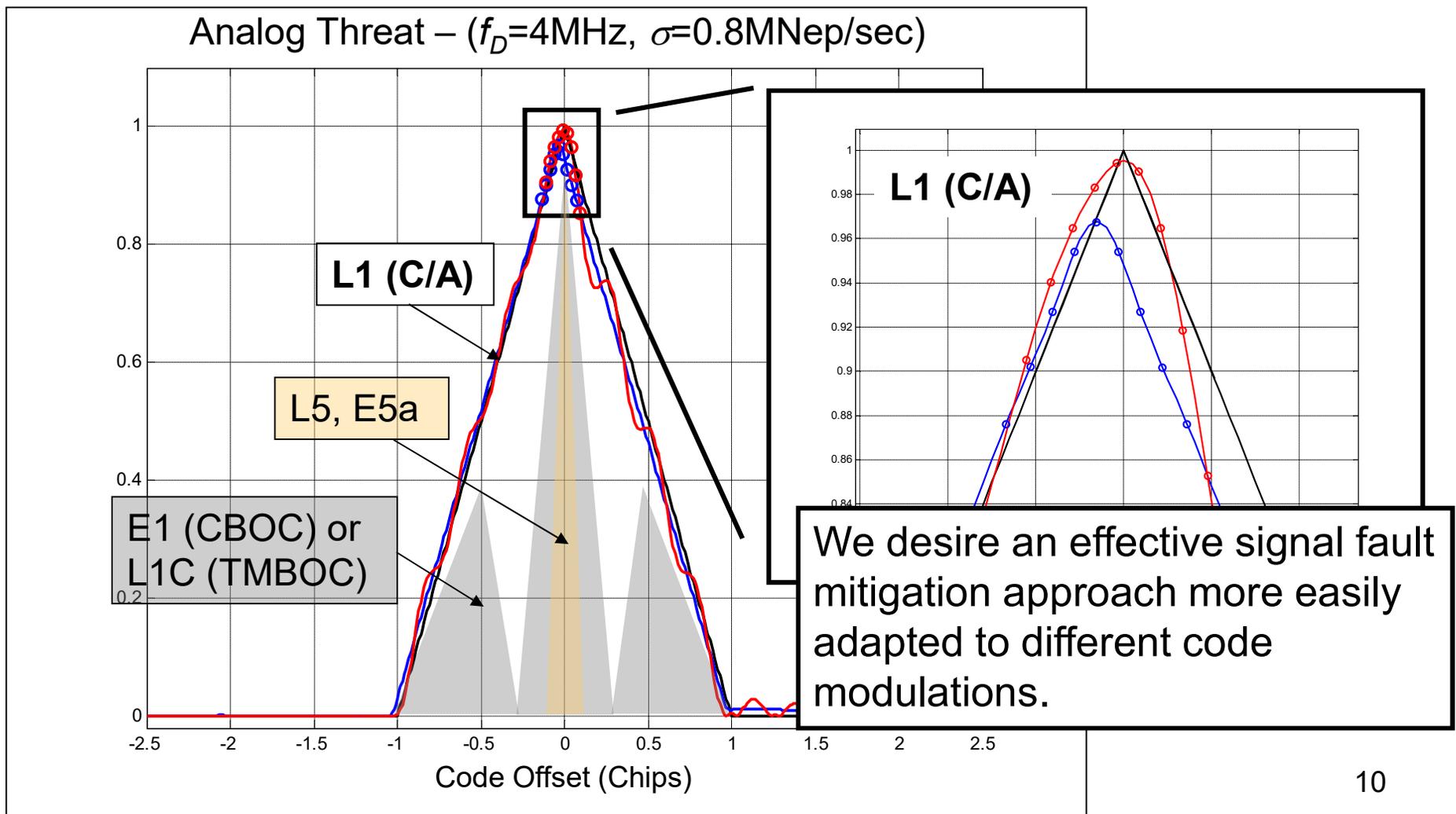
Signal Deformation Threat Model



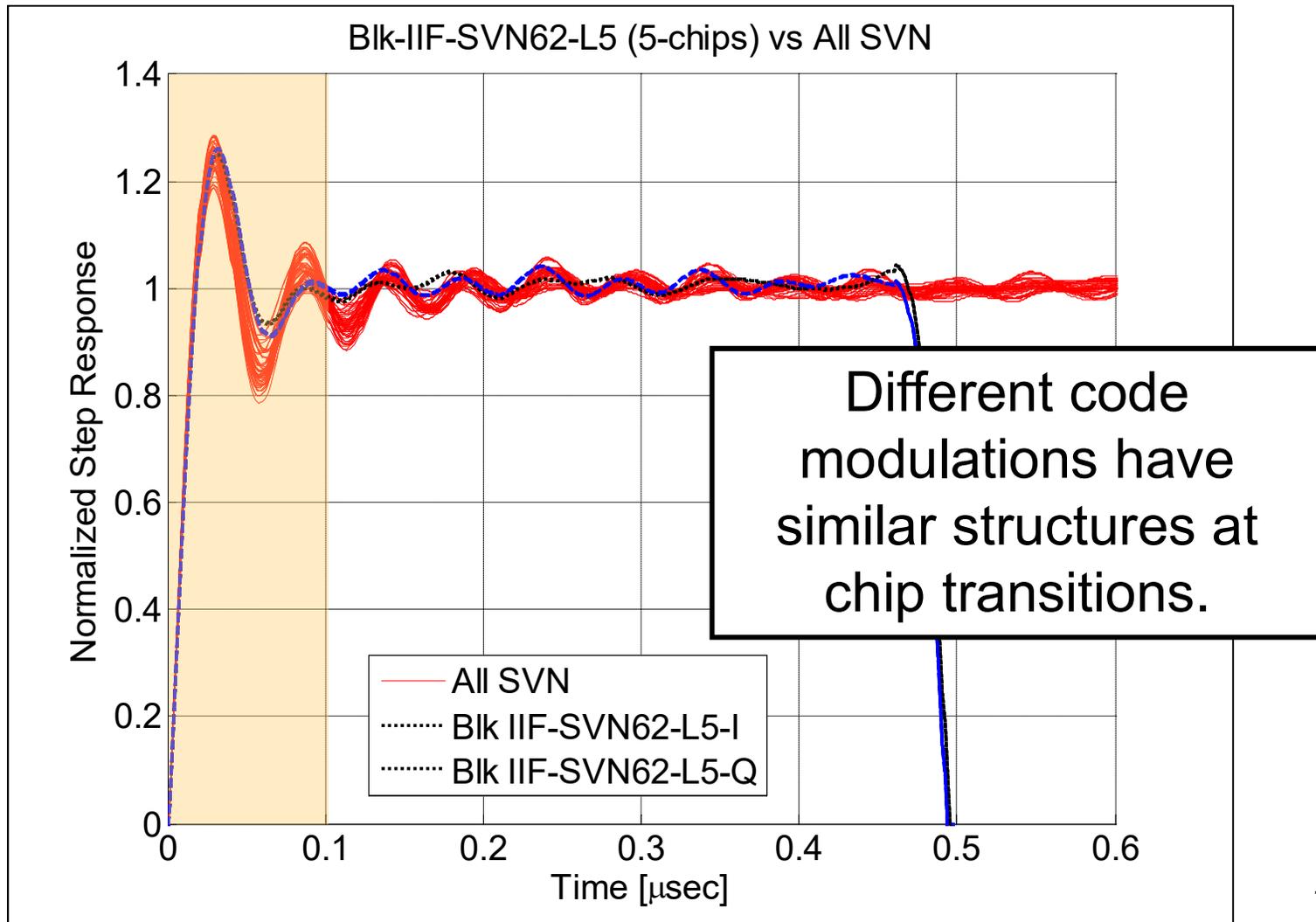
Assertions

- Threat model adequately captures all classes of anomalous peak distortions of concern to aviation users
- Fault onset is instantaneous
- Fault persists on signal until WAAS detects it and alerts the user

WAAS Signal Deformation Monitoring: Current Approach

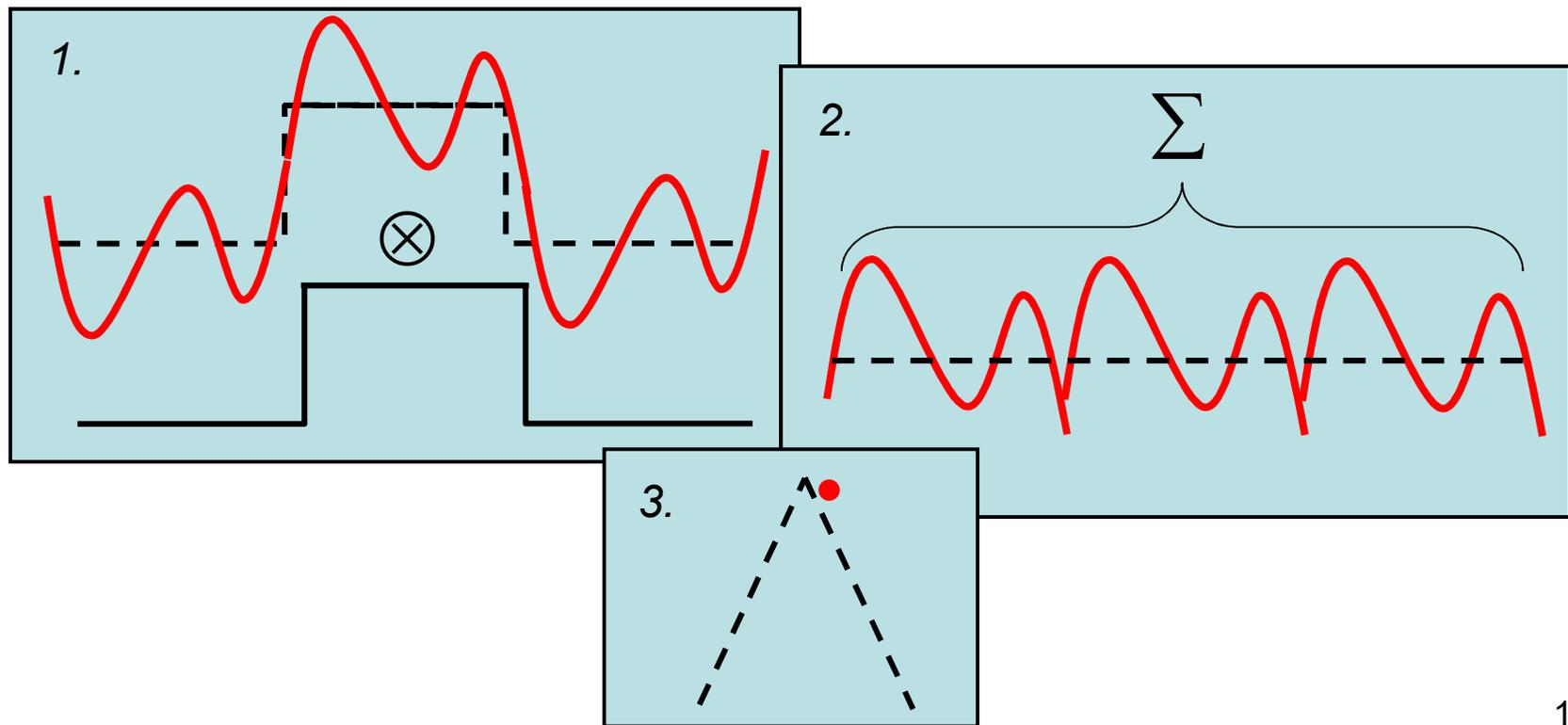


Nominal Signal Deformations on L1 and L5



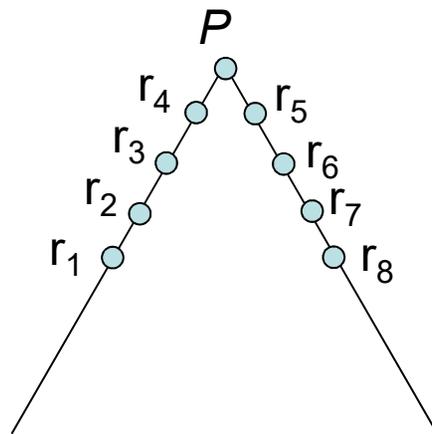
Advantage of a Chip Shape-Based Deformation Detection Metric

- Correlation filter has not been applied
 - Correlation process averages out signal deformation peaks and valleys



Current WAAS SDM Metric Design

The signal deformation metric for SV i is a **linear combination of the correlator outputs** normalized by the Prompt, P .



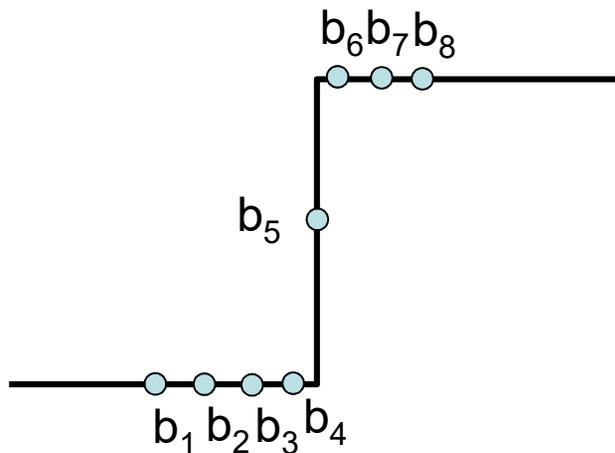
$$d^i = \frac{1}{P} \sum_{x=1}^8 \alpha_x r_x^i$$

The detection test D^i is formed by differencing each metric from the median metric across all SVs and normalizing by the threshold.

$$D^i = \frac{\left| d^i - \text{median}_i(d^i) \right|}{\text{Threshold}}$$

Proposed Chip Shape-based Metric

The signal deformation metrics for SV i are the **amplitudes of the individual chip shape outputs** normalized by the scaled prompt P' .



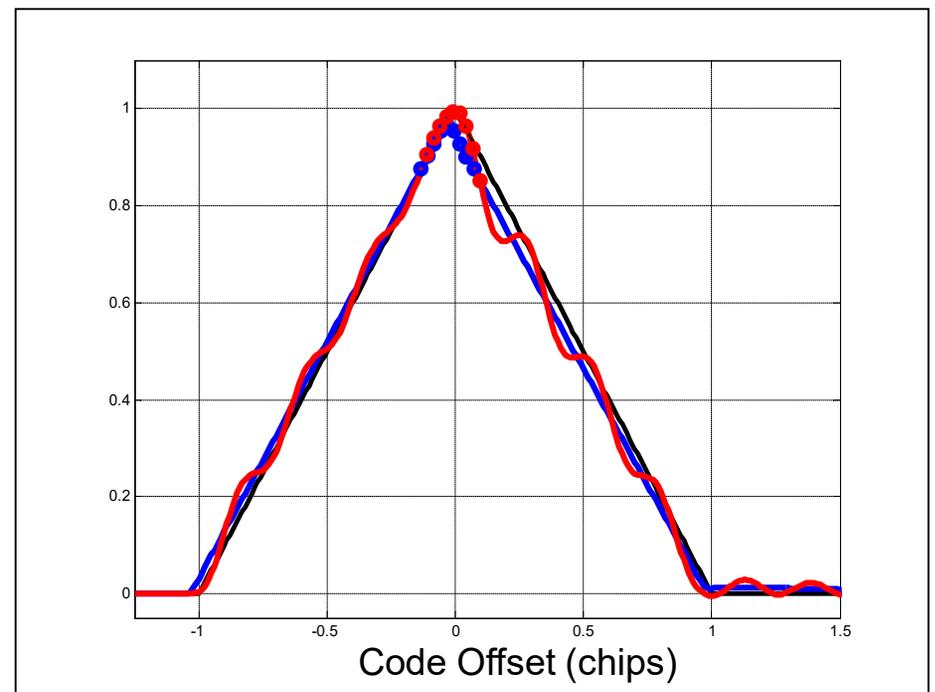
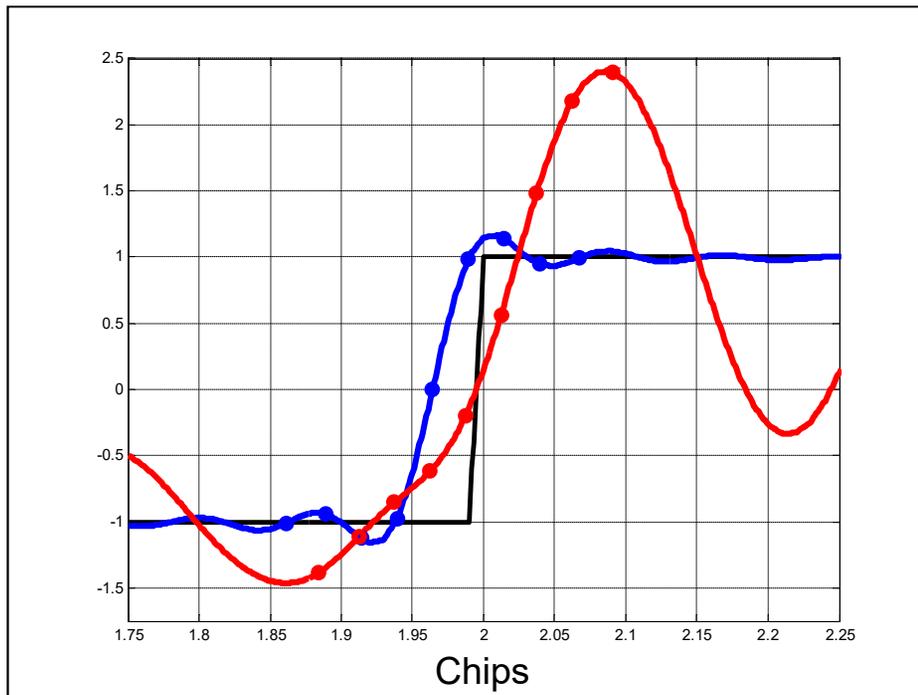
$$d_x^i = \frac{1}{P'} b_x$$

The detection test D is formed by differencing each metric from the median metric across all SVs and normalizing by the threshold.

$$D^i = \frac{\max_x \left| d_x^i - \text{median}_i(d_x^i) \right|}{\text{Threshold}}$$

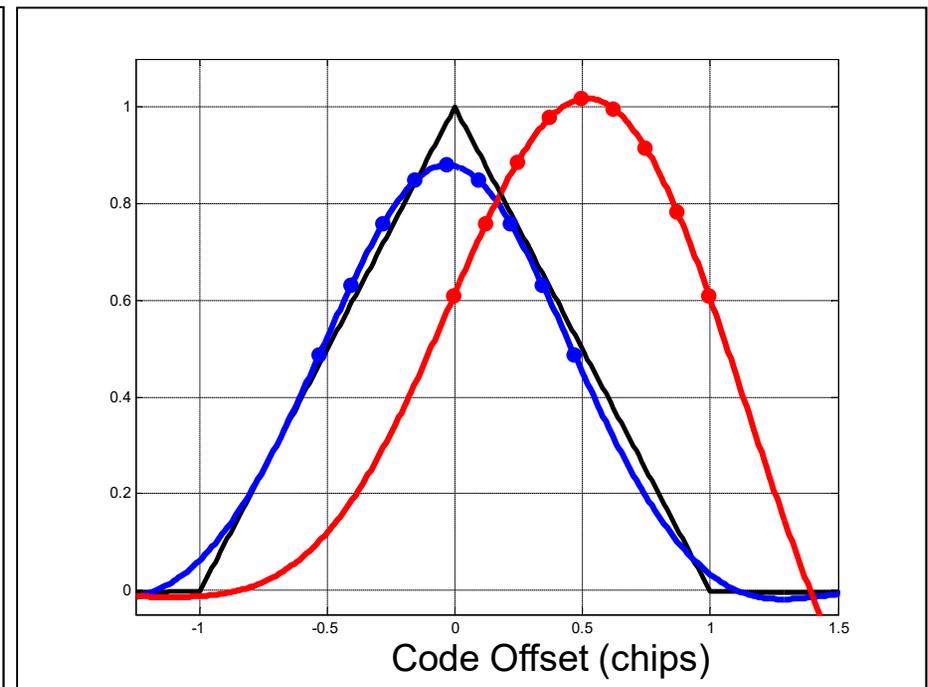
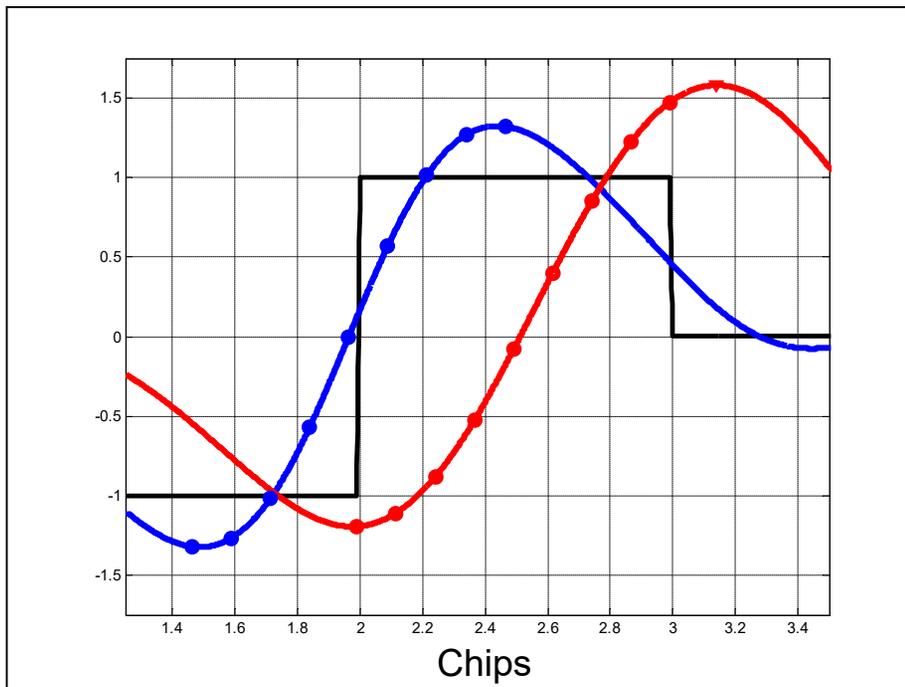
Chip-Based Monitoring vs. Correlation Peak Monitoring (L1)

Analog Threat – ($f_D=4\text{MHz}$, $\sigma=0.8\text{MNep/sec}$)



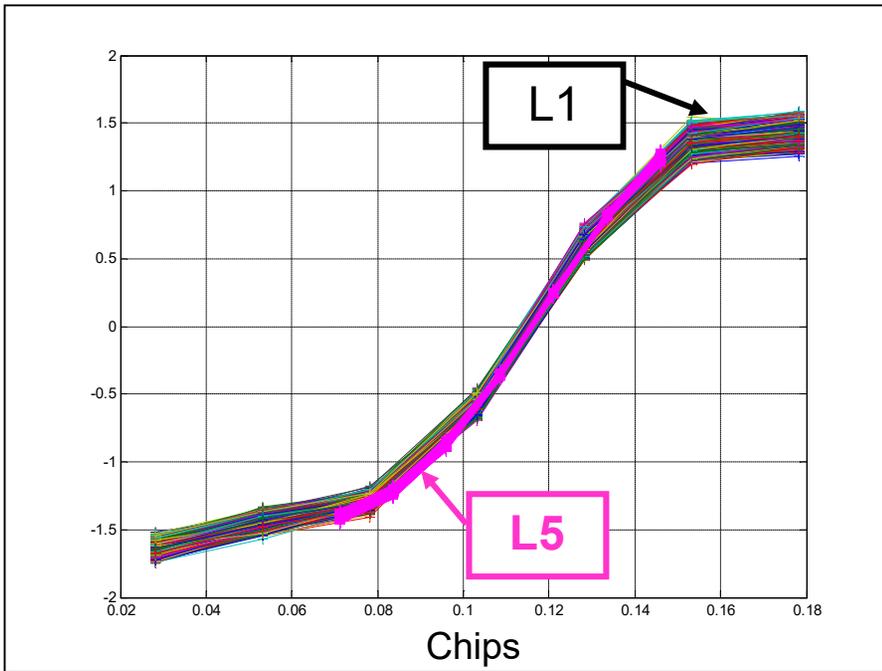
Chip-Based Monitoring vs. Correlation Peak Monitoring (L5)

Analog Threat – ($f_D=4\text{MHz}$, $\sigma=0.8\text{MNep/sec}$)

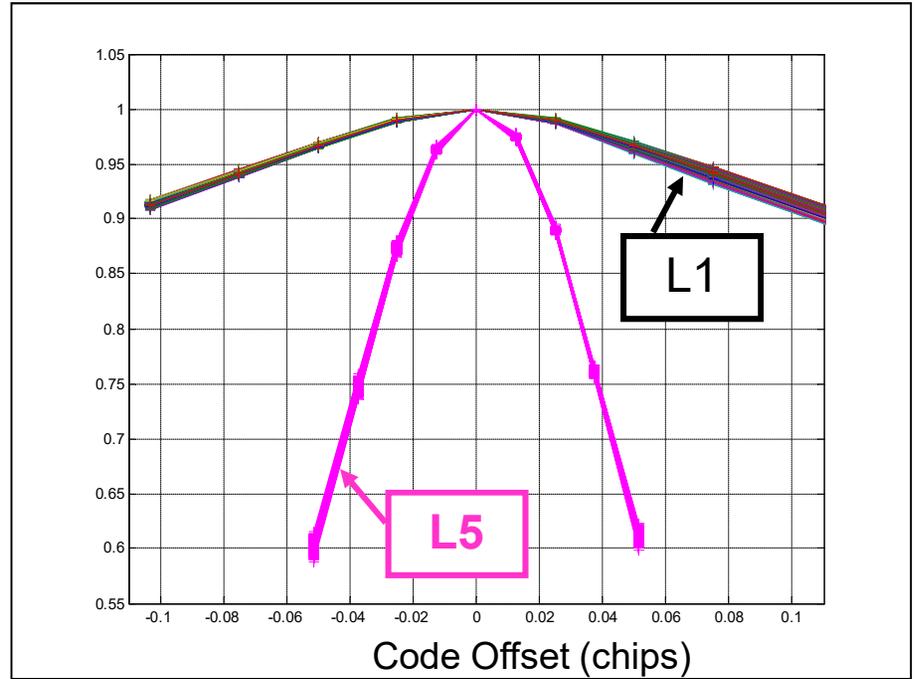


Nominal Monitor Measurements

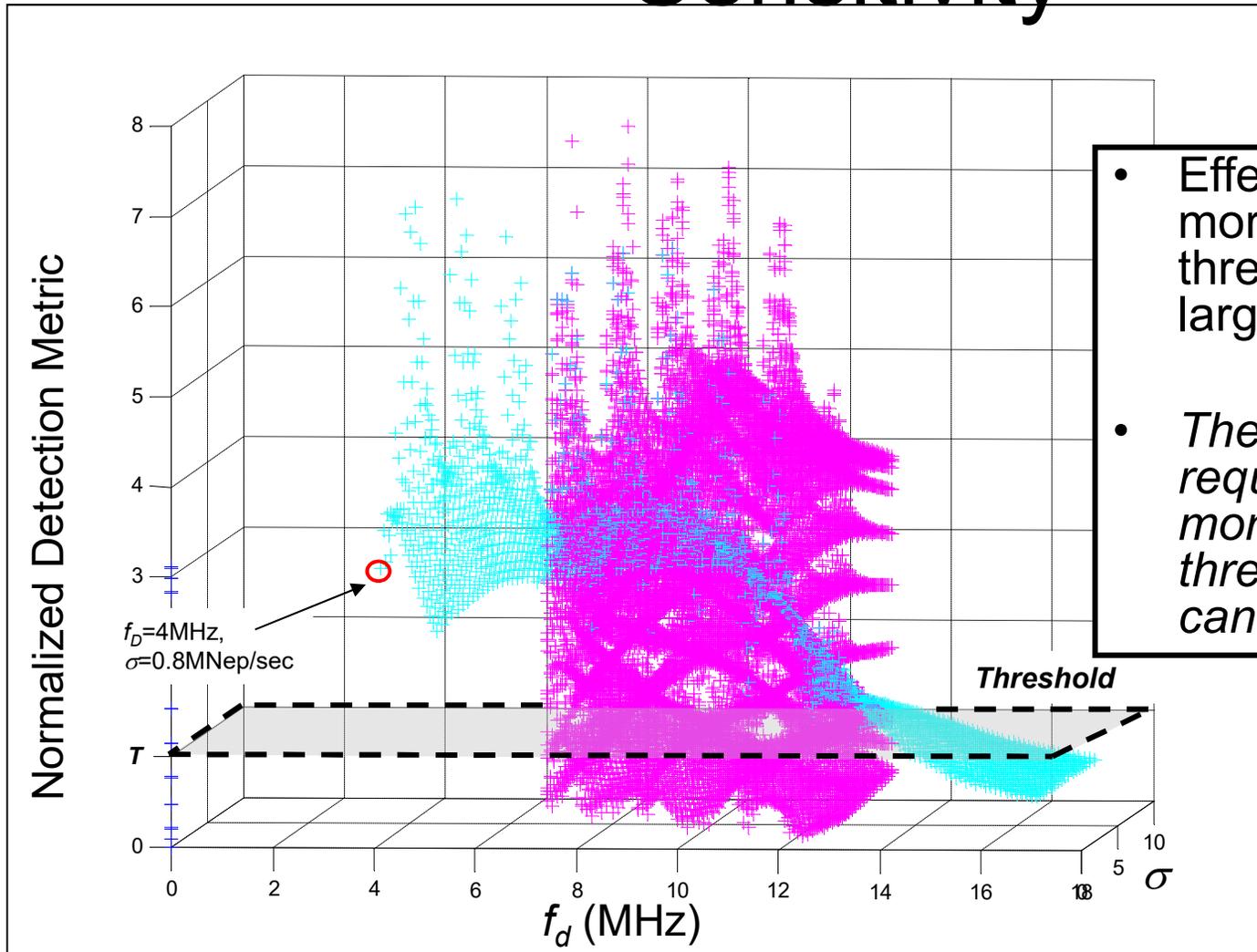
Code Chip Outputs



Correlator Outputs

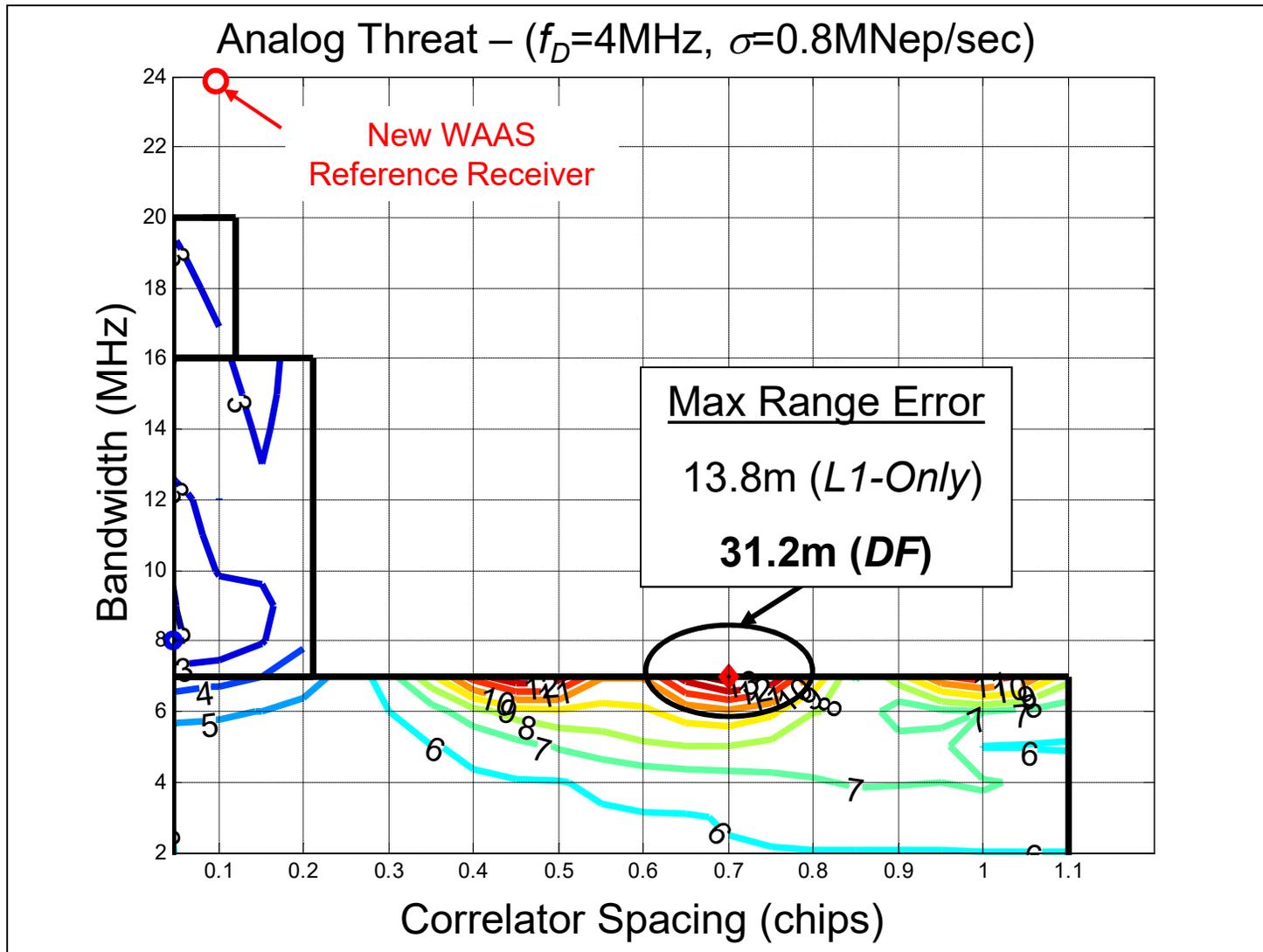


Signal Deformation Monitor Sensitivity

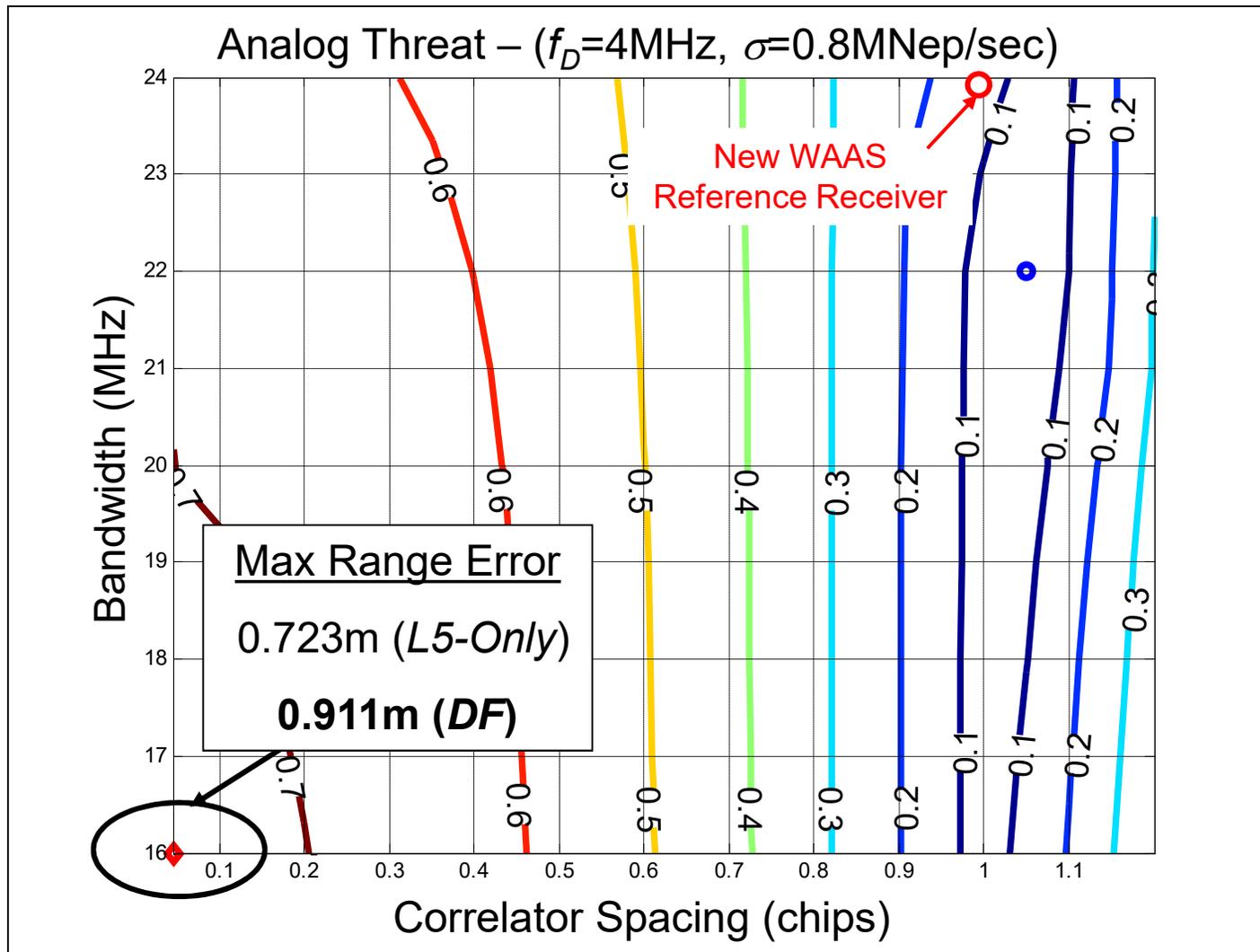


- Effective monitoring is more sensitive to threats that cause larger user errors.
- *The time-to-alert requires that the monitor detects threats before they can harm the user.*

Range Errors for Allowed L1 Receiver Configurations – Single Threat Case

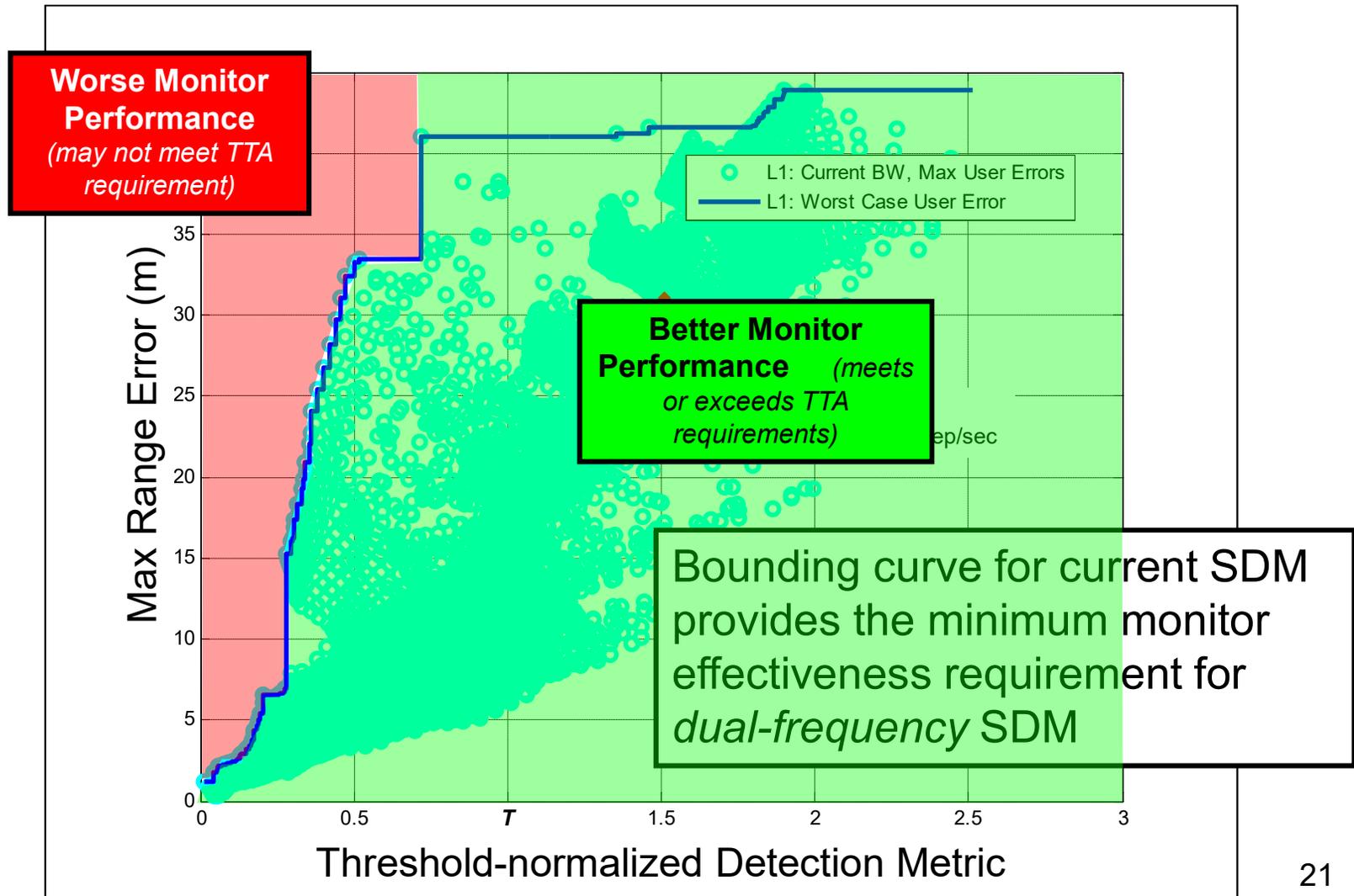


Range Errors for L5 Receiver Configurations – Single Threat Case

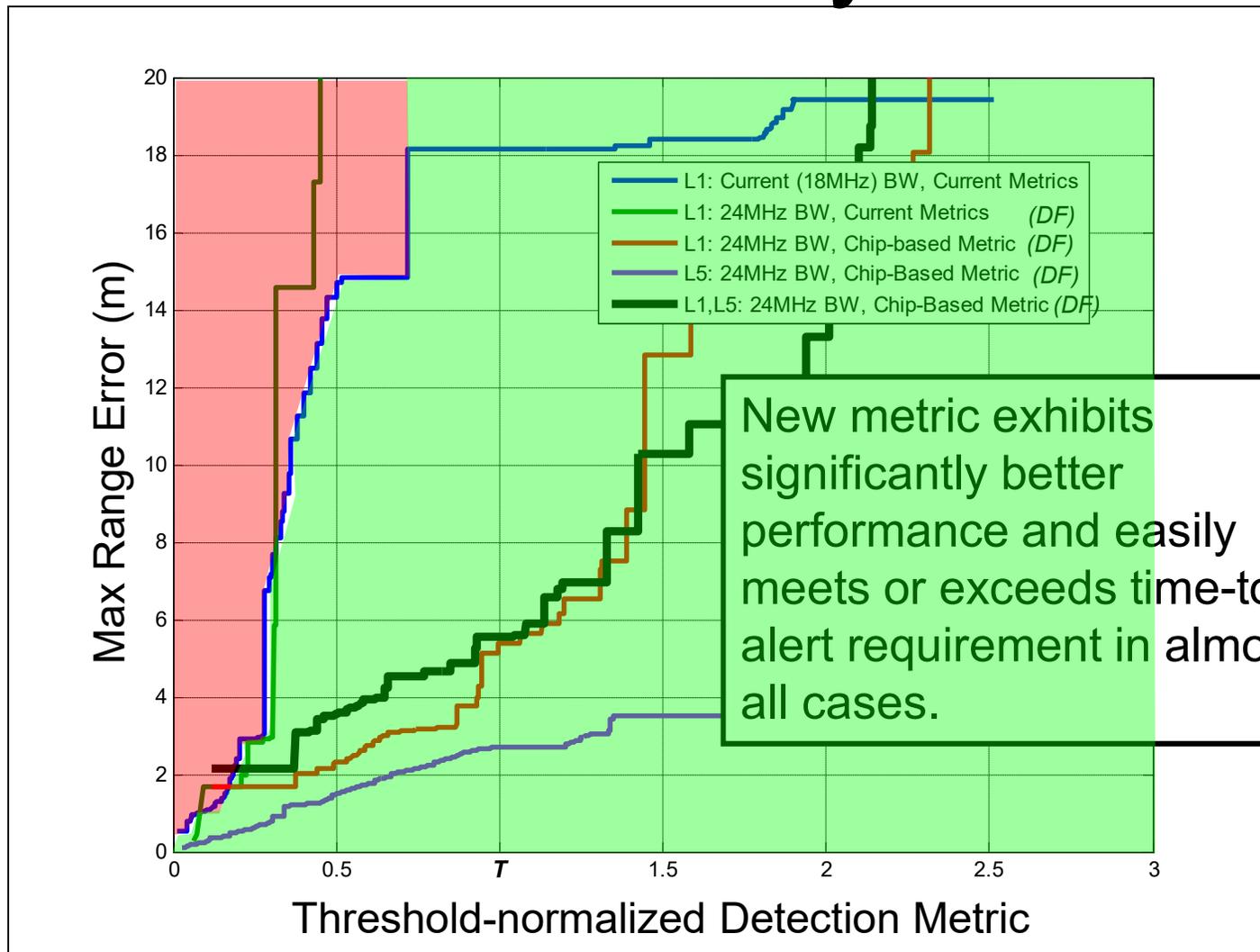


L1-Only SDM Effectiveness

(Current Receiver, Current Metrics, *Test Thresholds*)

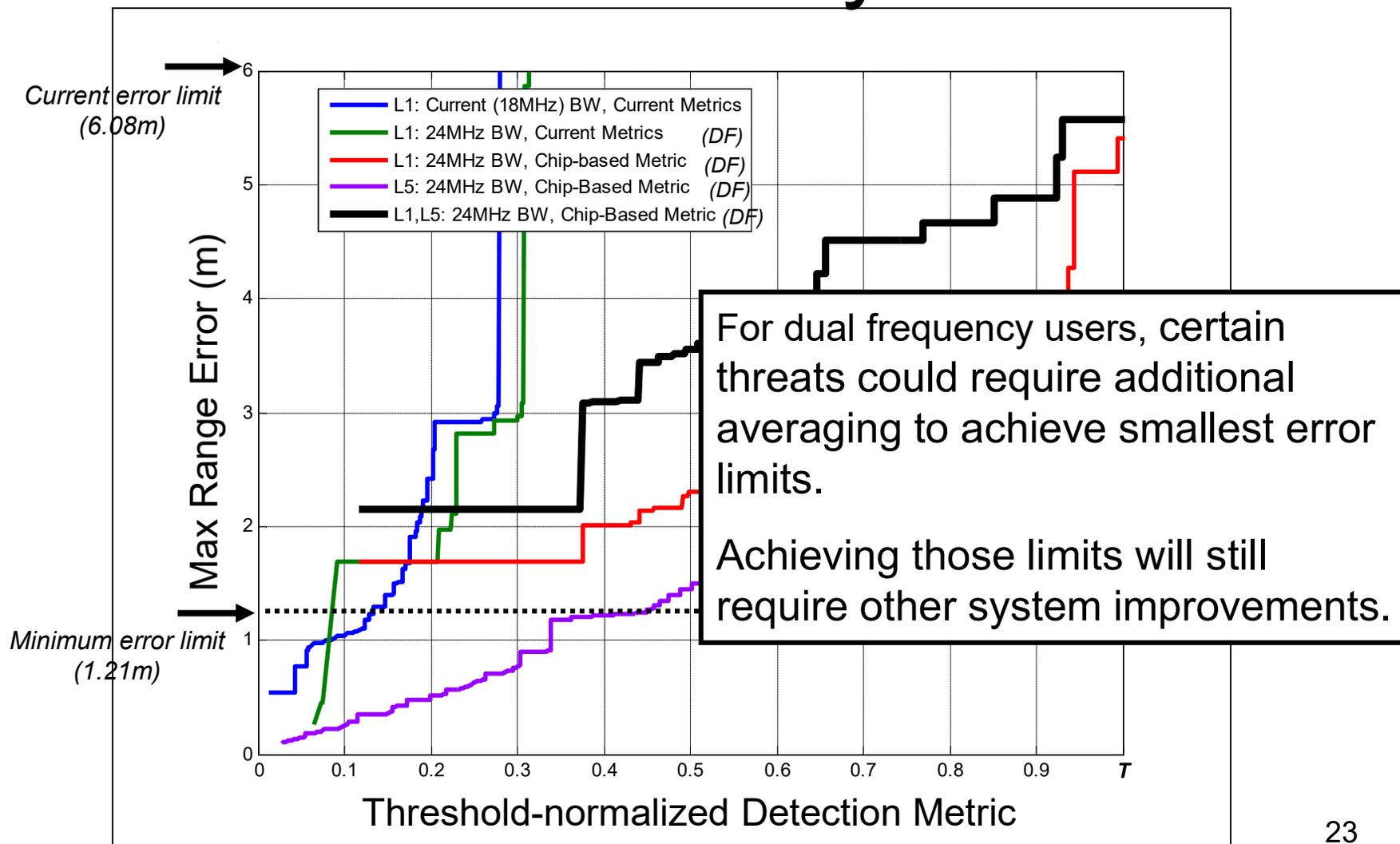


Relative Monitor Effectiveness: Summary

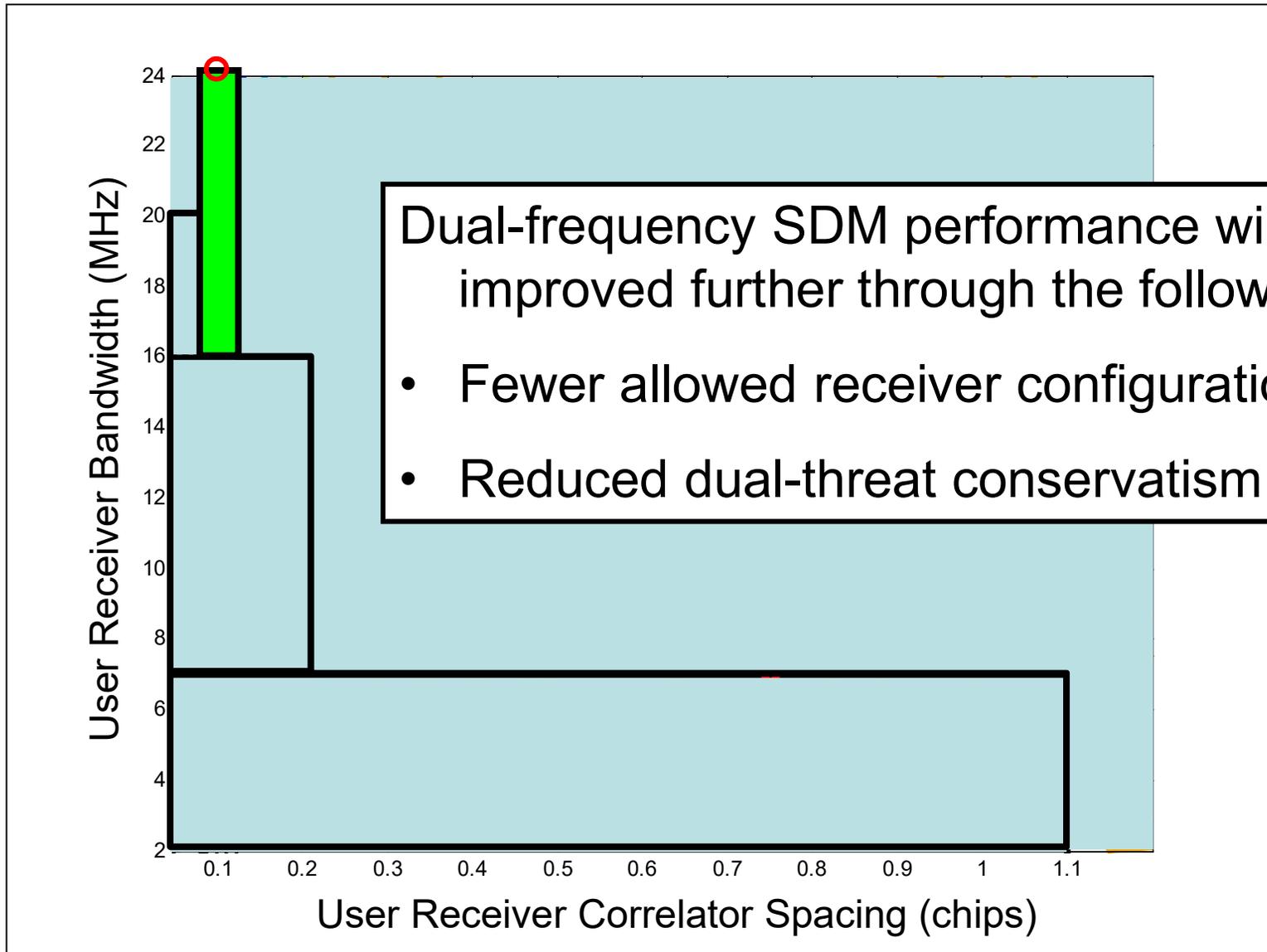


New metric exhibits significantly better performance and easily meets or exceeds time-to-alert requirement in almost all cases.

Relative Monitor Effectiveness Summary



Additional Mitigations



Conclusions

- The new G-III receiver is capable of mitigating the signal deformation threats for dual-frequency users
 - *Wider bandwidth*
 - *Chip-shape outputs*
- The chip shape-based detection metric is simple to implement and is significantly more effective than the current WAAS correlation-based detection metrics.
- The new metric is easily applied to other GNSS codes of various modulations