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Institute of **Geodesy and Navigation**
Institut für **Erdmessung und Navigation**

MULTIPATH DETECTION AND MITIGATION

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MULTIPATH DETECTION AND MITIGATION BY MEANS OF MULTI-CORRELATORS

- **A multi-correlator approach can be followed in order to realize**
  - Multipath Detection and Monitoring
  - Multipath Mitigation

- **By using the same basic principle (linear combination of the correlators' outputs) one can obtain:**
  - Multi-correlator-based real-time multipath monitoring system
    - Provide user with instant information regarding multipath affection of signals
    - **Implemented** in Matlab as RTMM (Real-Time Multipath Monitor)
  - Optimum S-Curve Shaping, by means of a coherent code phase discriminator defined as linear combination of the correlators output
    - Determine optimum S-Curve to mitigate multipath
    - **Implemented** for various GNSS signals in a real-time software receiver

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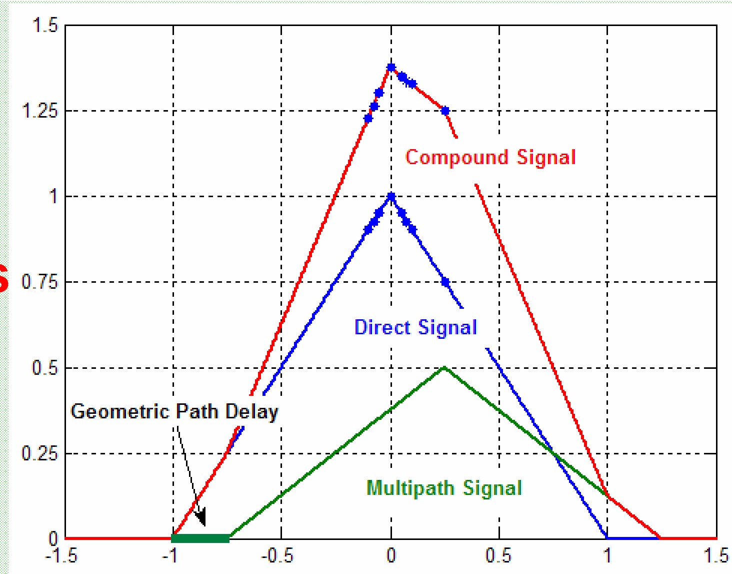
REAL-TIME MULTIPATH MONITOR - 1

- ✓ **Real time multipath monitor based on multi-correlator observations**
- ✓ **Allows instant detection of multipath signals and thus to**
  - ✓ **Exclude the observations**
  - ✓ **De-weigh the affected observations**
- ✓ **Determining optimum metric (i.e. a suitable combination of correlator peak observations), the monitor can be made very sensitive**
  - ✓ **Extremely weak multipath signals can be detected**

REAL-TIME MULTIPATH MONITOR - 2

- ✓ **Presence of multipath signals**
  - **→ Distortion of correlation function**
- ✓ **Use combination of multi-correlator outputs to set up a variety of test metrics**
- ✓ **Multipath distorts correlation function**
  - **→ Correlation values for indicated correlator positions are distorted**
  - **→ Test metrics itself are affected**



- ✓ **Idea of RTMM: Constantly monitor set of test metrics and compare to threshold**
- ✓ **Test metric exceeds corresponding noise level → multipath present**

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REAL-TIME MULTIPATH MONITOR - 3

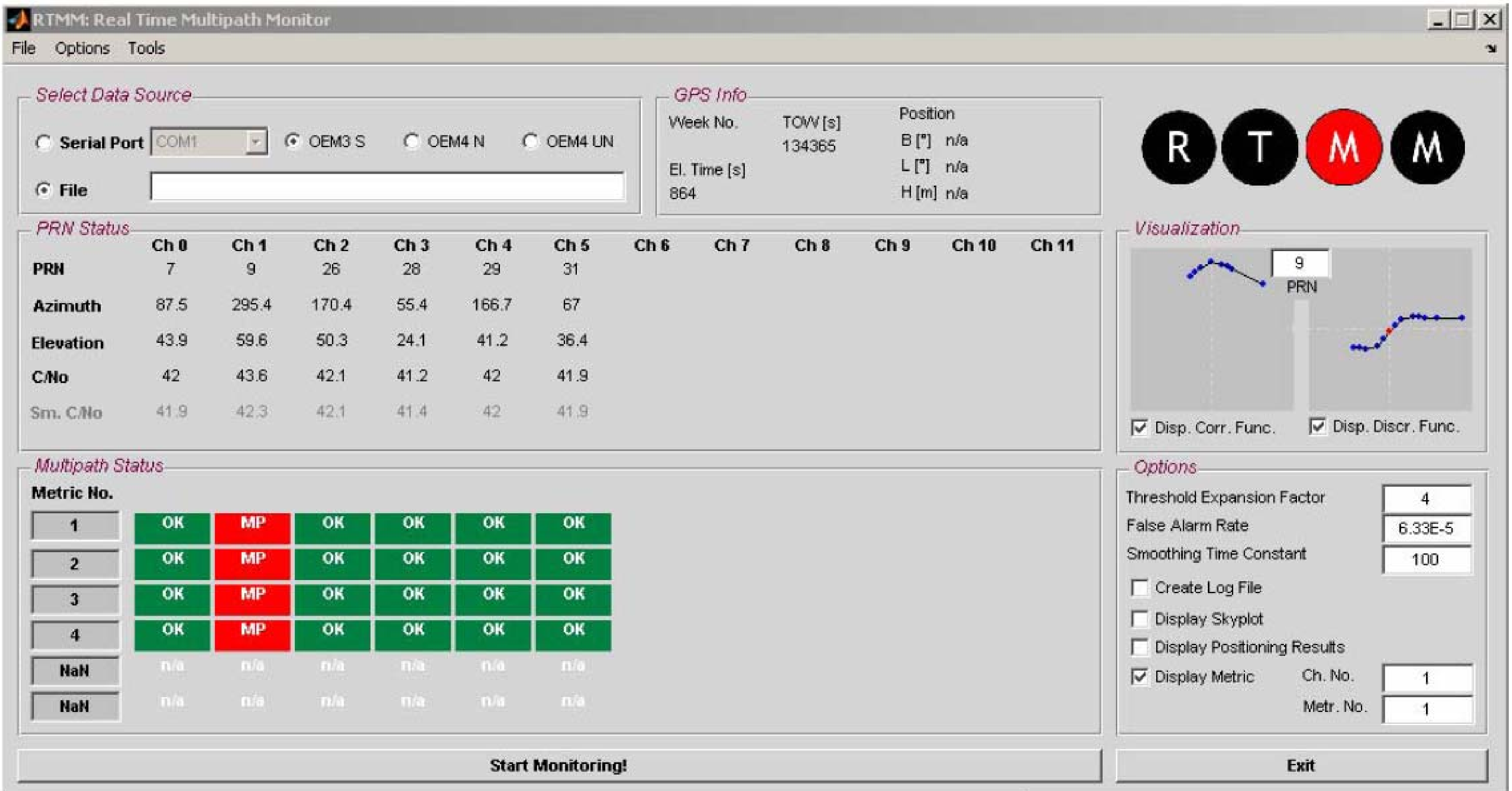
- **Huge variety of test metrics can be defined**
- **Examples**

Type of Test Metric	Formation	Example(s)
Delta-Tests	$\frac{(I_{-X}-I_{+X})-(I_{-Y}-I_{+Y})}{I_Z}$	$\frac{I_{-0.075}-I_{+0.075}}{I_{+0.1}}-\frac{I_{-0.05}-I_{+0.05}}{I_{+0.1}}$
Symmetric Ratio Tests	$\frac{(I_{-X}-I_{+X})}{I_Y}$	$\frac{I_{-0.05}-I_{+0.05}}{I_{-0.075}}$
Simple Ratio Tests	$\frac{I_X}{I_Y}$ and $\frac{I_Y}{I_X}$	$\frac{I_{+0.25}}{I_{-0.1}}$ or $\frac{I_0}{I_{-0.075}}$
Differential Ratio Tests	$\frac{(I_X-I_Y)}{I_Z}$	$\frac{(I_{-0.1}-I_{+0.25})}{I_{+0.05}}$

- **Set of test metrics needs to be condensed in order to**
  - **Eliminate mutually depending metrics**
  - **Provide metrics sensitive to**
    - **Short/long delay multipath**
    - **Weak/strong multipath signals**

REAL-TIME MULTIPATH MONITOR - 4

✓ RTMM implementation



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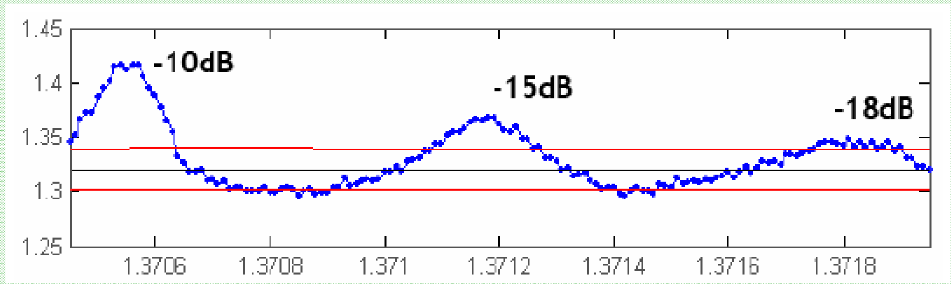
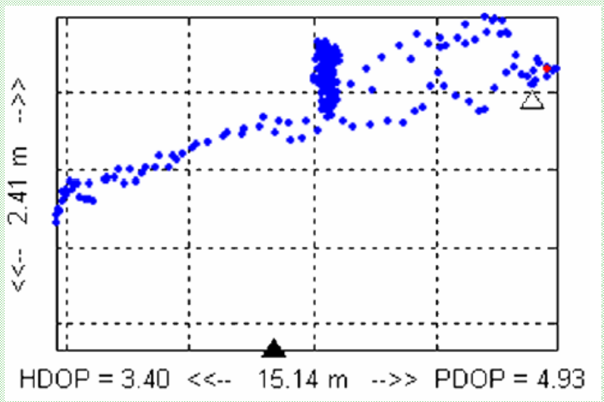
REAL-TIME MULTIPATH MONITOR - 5

✓ Performance

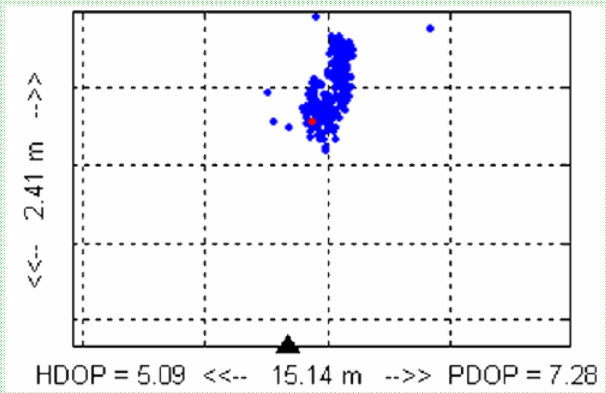
- ✓ **Detection of multipath signals with extremely low SMR**



- ✓ **Exclusion or de-weighthing of multipath-affected signals**



No countermeasures



Signal exclusion based on RTMM

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REAL-TIME MULTIPATH MONITOR - 6

- **Benefits**
  - **Real-time capable, thus instant multipath monitoring**
  - **Unambiguous identification of multipath affected signals possible**
  - **Monitoring scheme easy to be implemented**
  - **Detection of weak multipath signals possible**

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OPTIMUM S-CURVE SHAPING FOR MULTIPATH MITIGATION

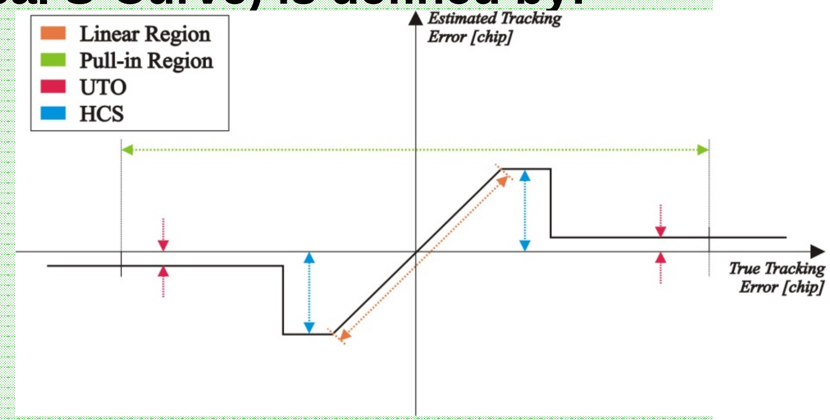
- **Multi-correlator approach can be applied to a conventional tracking loop structure to define an optimum coherent code phase discriminator aiming at mitigation of error introduced by multipath**
- **Coherent code phase discriminator defined as linear combination of correlators output**

$$\tilde{D}(\Delta\tau) = \sum_{i=1}^{N} \alpha_i R_i(\Delta\tau)$$

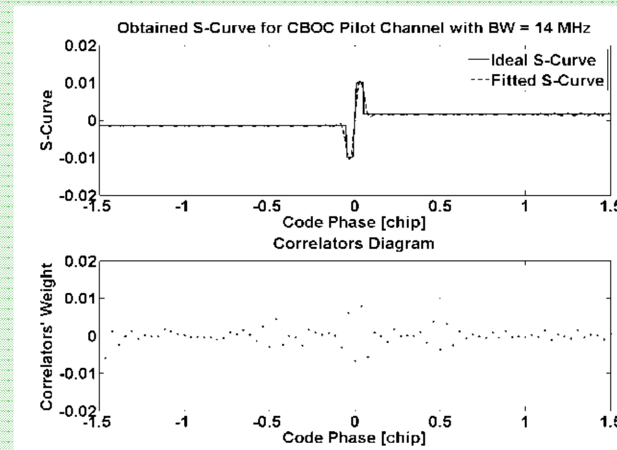
- **Basic idea:**
  - **Determination of Optimum S-Curve as goal of an optimization process**
  - **Choice of signal and pre-correlation bandwidth**
  - **Fitting of the optimum S-Curve**

SHAPE AND FITTING OF THE OPTIMUM S-CURVE

- ✓ **The ideal coherent code discriminator (Ideal S-Curve) is defined by:**
  - **Linearity around tracking point**
  - **Zero value outside pull-in region**
- ✓ **To enhance performance characteristics are introduced**
  - **Unambiguous Tracking Offset (UTO)**
  - **High-Cut of the S-Curve (HCS)**



- ✓ **The fitting of the Optimum S-Curve is obtained by means of:**
  - **Definition of a fitting range**
  - **Resolution of the correlators**
  - **Derivation of the weights of the correlators**



COST FUNCTION

$$\sum\left[\tilde{D}(\Delta\tau)-\tilde{D}_{ID}(\Delta\tau)\right]^2$$

→ ***Linear combination of shifted replicas of the autocorrelation function***

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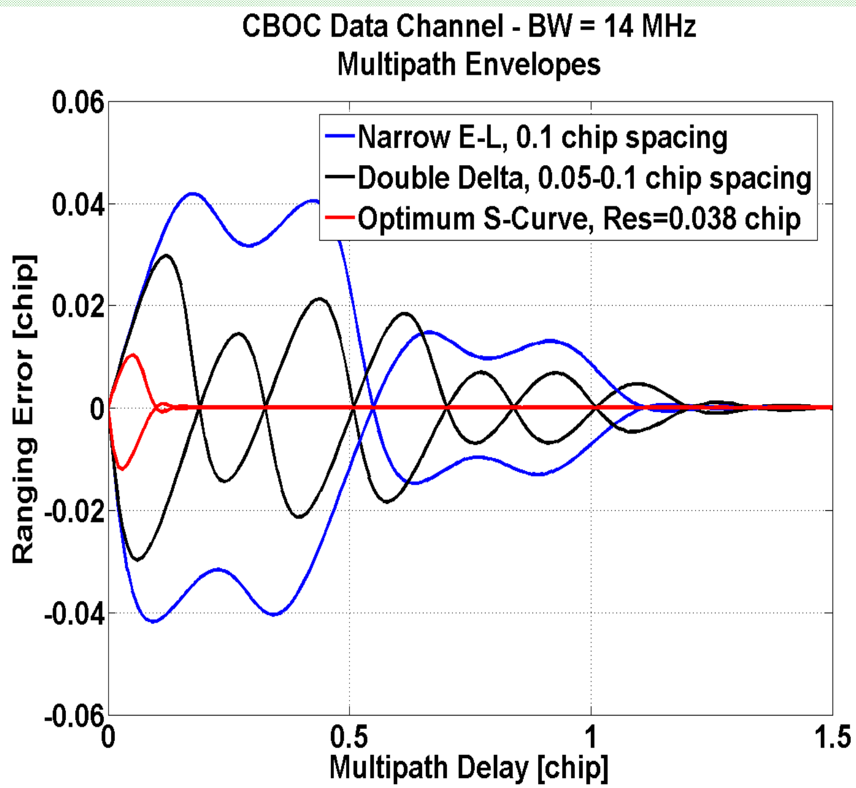
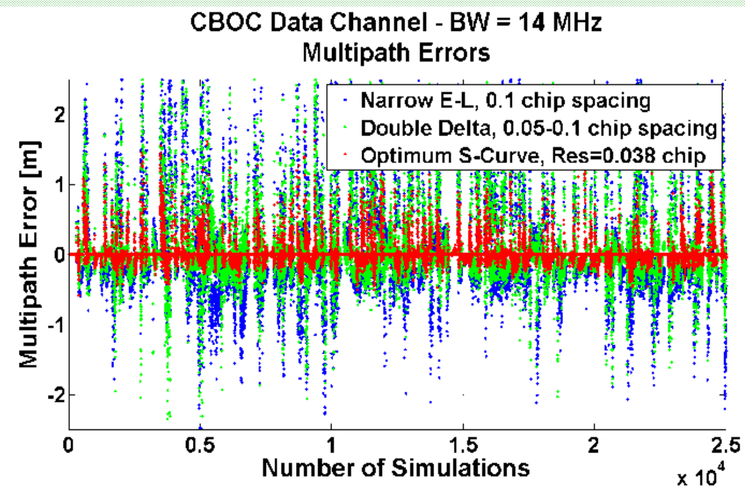
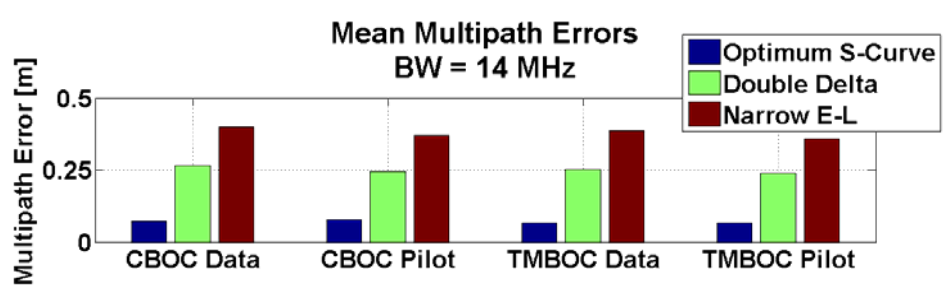
OPTIMUM S-CURVE SHAPING
ASSESSMENT OF THE PERFORMANCE

Example of optimization for the tracking of the data channel of the Galileo E1-OS signal







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SUMMARY

- Instant multipath monitoring approach has been presented
  - Identification of weak multipath signals possible
  - Easy implementation at low-end receivers
  - Unambiguous identification of multipath-affected signals
- Optimization of S-Curve for minimum multipath error has been presented
  - Significant reduction of multipath error possible
  - Determination required only once depending on desired signal and receiver characteristics

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THANKS FOR YOUR ATTENTION!