Institute of Geodesy and Navigation

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Comparison of Multipath Mitigation Techniques with Consideration of Future Signal Structures

M. Irsigler, <u>B. Eissfeller</u>

Institute of Geodesy and Navigation

University FAF Munich

Germany

Overview

✓ **Performance analysis for several multipath mitigation techniques**
- **Narrow Correlator™**
- **Double Delta Correlator**
- **Early/Late Slope Technique (ELS)**
- **Early1/Early2 (E1/E2) Tracker**

✓ **Consideration of BPSK and BOC signals**
- **BPSK(1)** **representing the current GPS C/A code**
- **BOC(2,2)** **representing one Galileo signal option**

✓ **Background/Motivation:**
- **Multipath is dominating error source for many GNSS applications**
- **Different types of signals will be available in the future**

>> how do they perform in a multipath environment?

Introduction

Errors caused by multipath depend on a variety of signal and receiver parameters:

- ✓ **Signal type/modulation scheme**
- ✓ **Pre-correlation bandwidth**
- ✓ **Pre-correlation filter characteristics**
- ✓ **Chipping rate of code**
- ✓ **Type of discriminator**
- ✓ **Chip spacing d between correlators used for tracking**
- ✓ **Carrier frequency**
- ✓ **Multipath relative amplitude α**
- ✓ **Actual number of multipath signals**
- ✓ **Geometric path delay of multipath signal(s)**

Signal and Receiver Parameters

SIGNAL PARAMETERS	GPS C/A Code	Galileo Signal Option
Frequency Band	L1	E2-L1-E1
Center Frequency	1575.42 MHz	1575.42 MHz
Modulation Scheme	BPSK(1)	BOC(2,2)
Chipping Rate	1.023 MHz	2.046 MHz
Chip Length	293,05 m	146,53 m
Data Rate	50 bit/s	200 bit/s

RECEIVER PARAMETERS	
Pre-Corr. Bandwidth	32 MHz
Band Limiting Filter	Ideal Band Pass Filter
Discriminator	1-Chip Early minus Late

Further assumptions (multipath environment):

- ✓ Direct signal always available
- ✓ One multipath signal
- ✓ Multipath relative amplitude α=0.5
- ✓ Static environment

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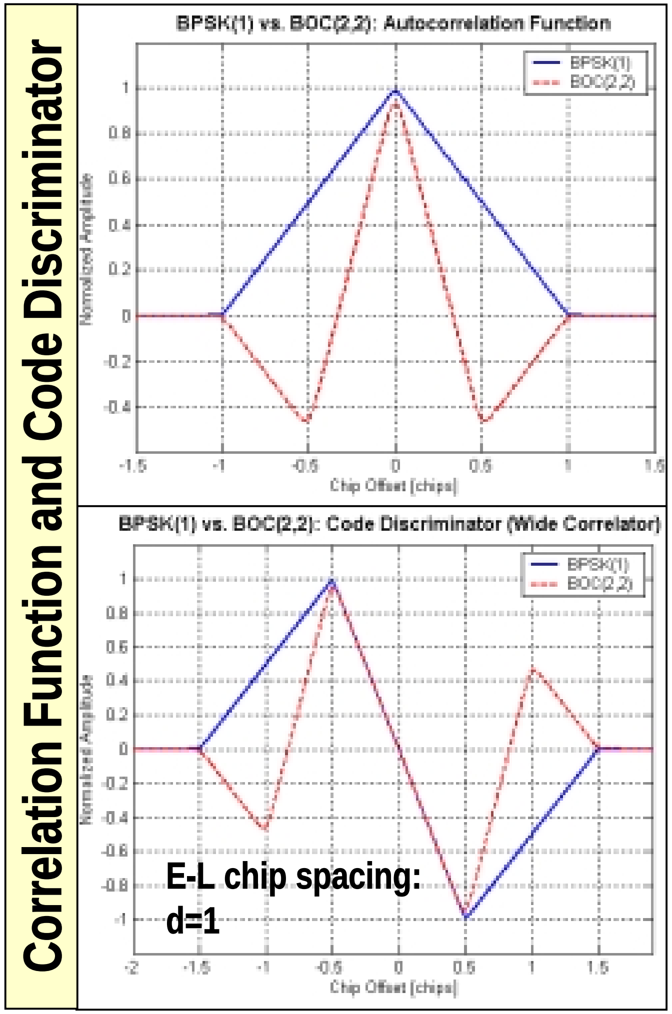
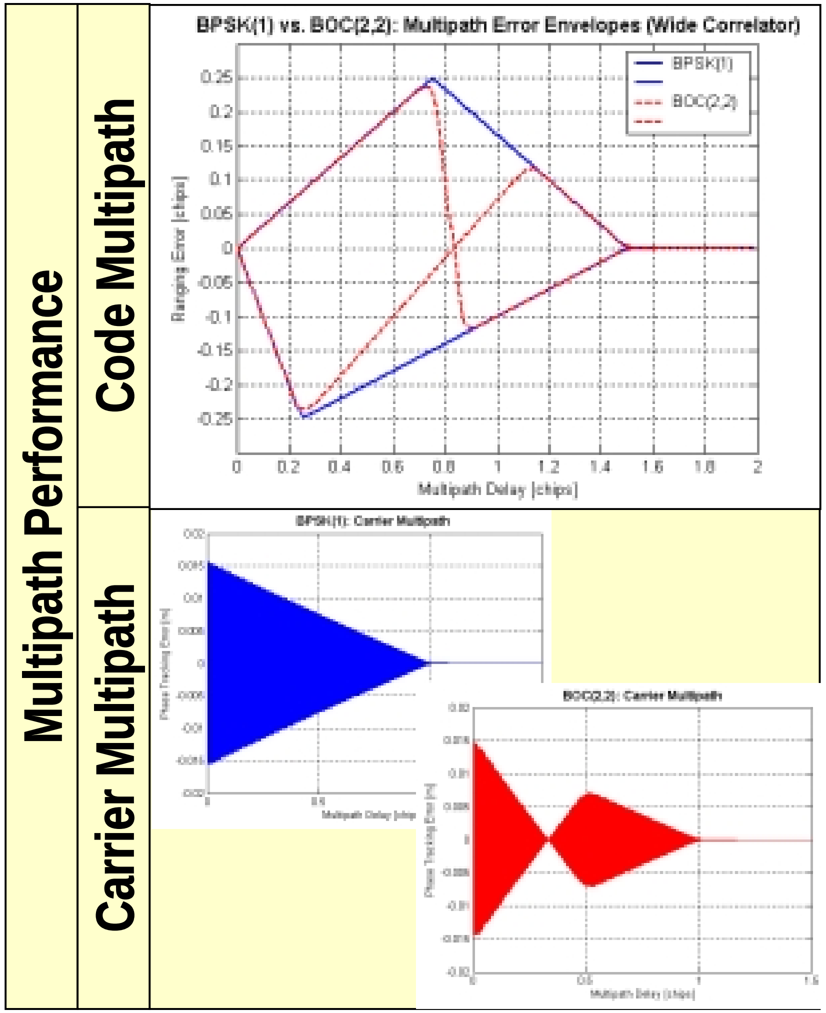
Wide (Standard) Correlator (d=1)





Results:

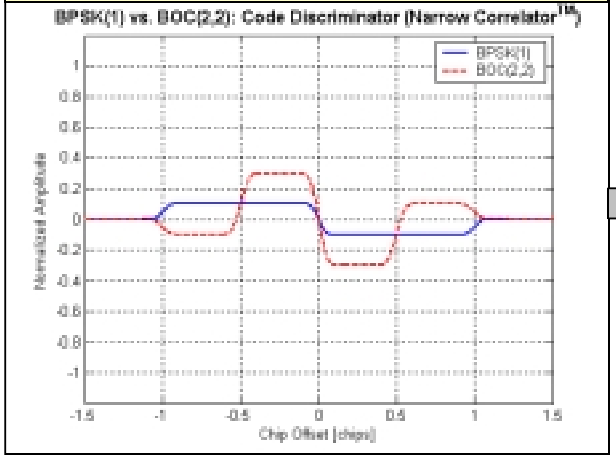
- **Maximum multipath error (nearly) identical for both signals**
- **BOC(2,2) less sensitive to medium-delay multipath**

Narrow Correlation Technique

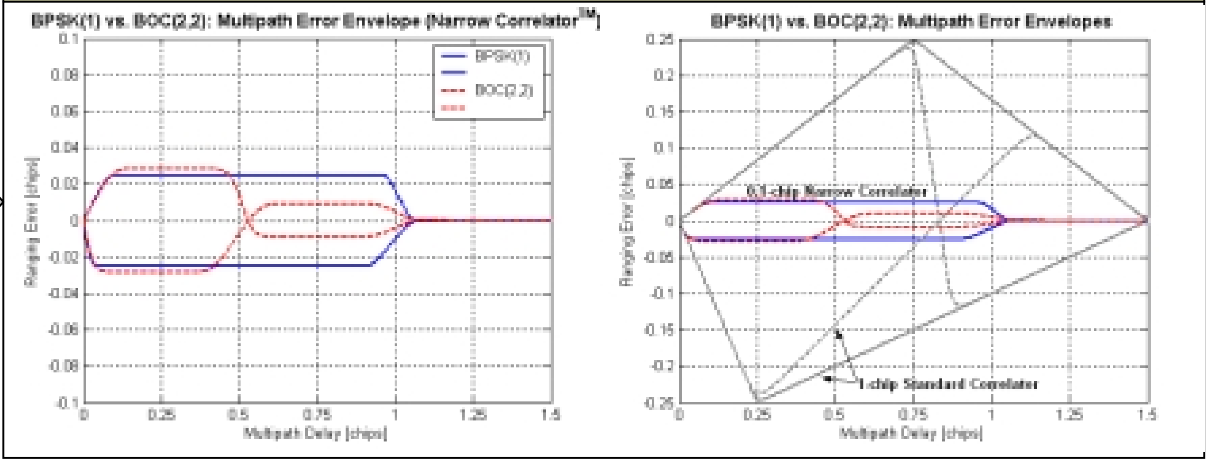
✓ **2 Correlators with small spacing between early and late code (d < 1)**

✓ **NovAtel's Narrow Correlator™: d = 0.1**

Discriminator Function



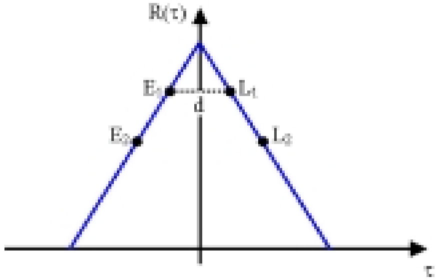
Multipath Performance



✓ **Results:**

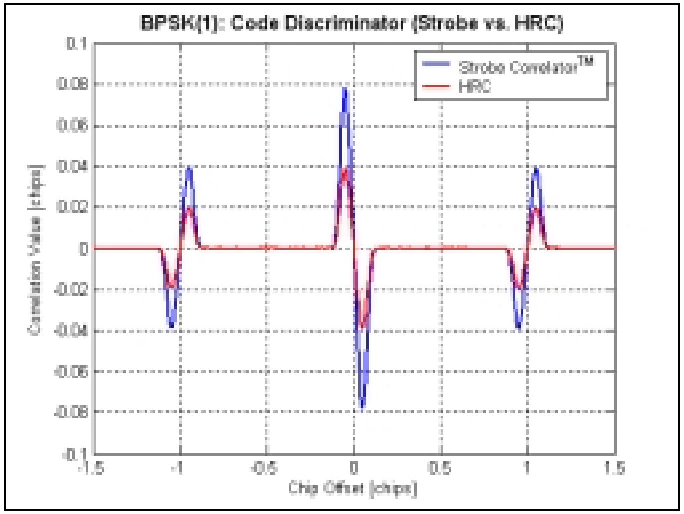
- **Maximum multipath error nearly identical for both signals**
- **BOC(2,2) less sensitive to long-delay multipath**

ΔΔ Correlator



- ✓ **Basic concept:**
  - **5 Correlators (E1,E2,P,L1,L2)**
  - **Discriminator function: D = a(E1 - L1) - b(E2 - L2)**
- ✓ **Several discriminator functions can be set up (variation of a and b)**
  - **Strobe Correlator™ (Ashtech):** **D = 2*(E1 - L1) - (E2 - L2)**
  - **High Resolution Correlator (HRC):** **D = (E1 - L1) - 0.5*(E2 - L2)**
- ✓ **Strobe vs. HRC:**
  - **Different amplitudes**
  - **Same shape**

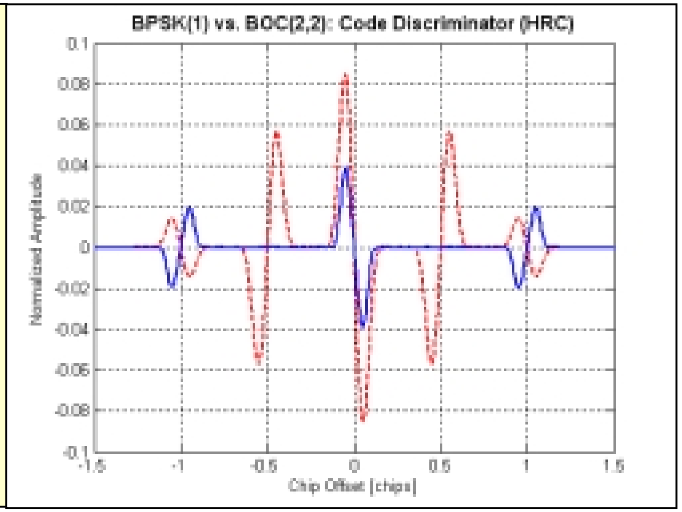
  >> Same multipath performance expected



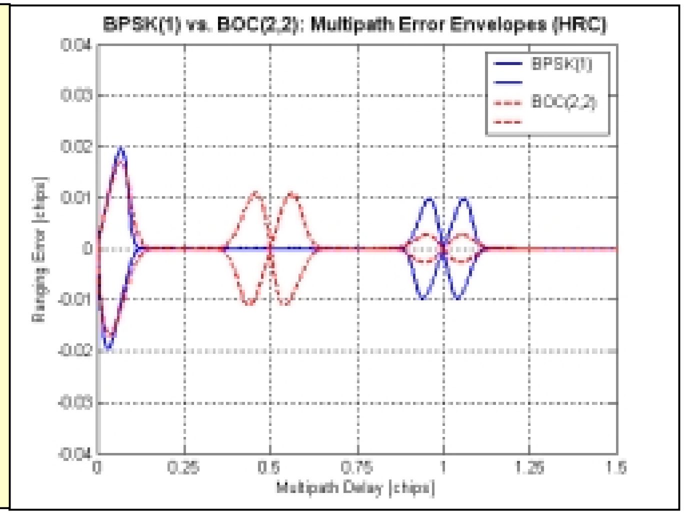
ΔΔ Correlator: Code Multipath

✓ **HRC discriminator function: D = (E1 - L1) - 0.5* (E2 - L2)**

Discriminator Function



Multipath Performance

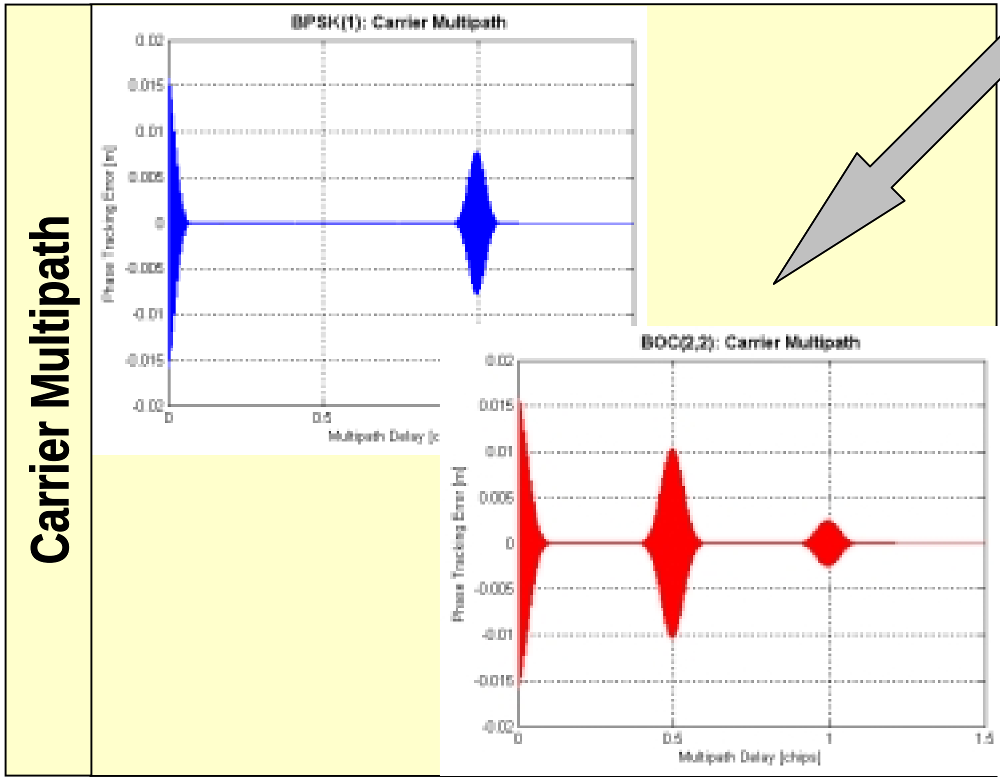


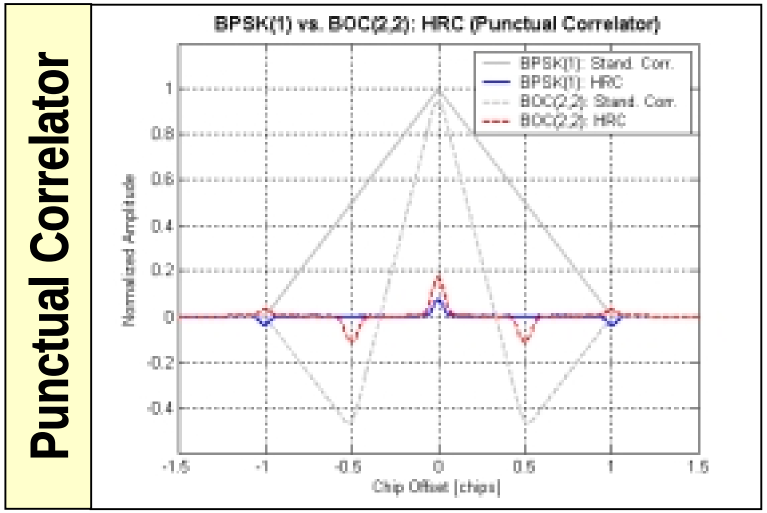
✓ **Results:**

- **Maximum multipath error nearly identical for both signals**
- **BOC(2,2) sensitive to medium-delay multipath**
- **BPSK(1) <u>not</u> sensitive to medium-delay multipath**
- **BOC(2,2) less sensitive to long-delay multipath**

ΔΔ Correlator: Carrier Multipath

- ✓ HRC concept proposes synthesized punctual correlator for carrier tracking
- ✓ $P_{HRC} = 2*P - (E1 + L1)$





Results:

- Maximum multipath error identical for both signals
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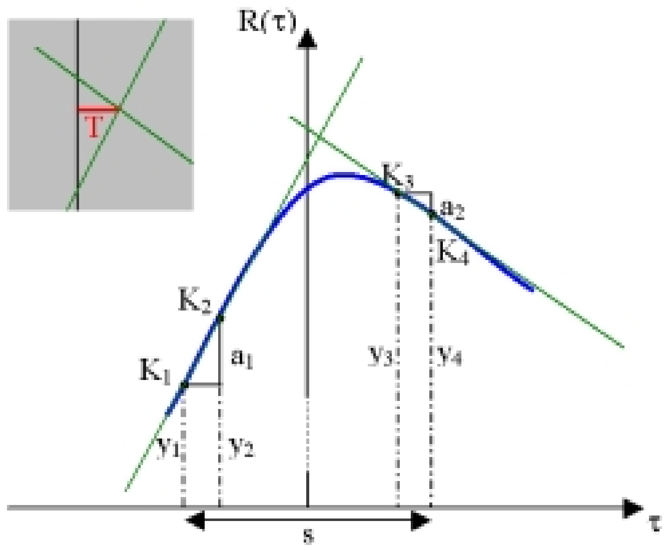
- BOC(2,2) less sensitive to long-delay multipath

Early/Late Slope Technique (ELS)

✓ **Basic concept:**

- **2 correlator pairs at both sides of the correlation function**
- **Determination of slopes a_1 and a_2**
- **Computation of pseudorange correction T by intersecting two first-order polynomials defined by (K_1,K_2) and (K_3,K_4)**

✓ **Introduced to GPS receivers by NovAtel as „Multipath Elimination Technology“ (MET)**



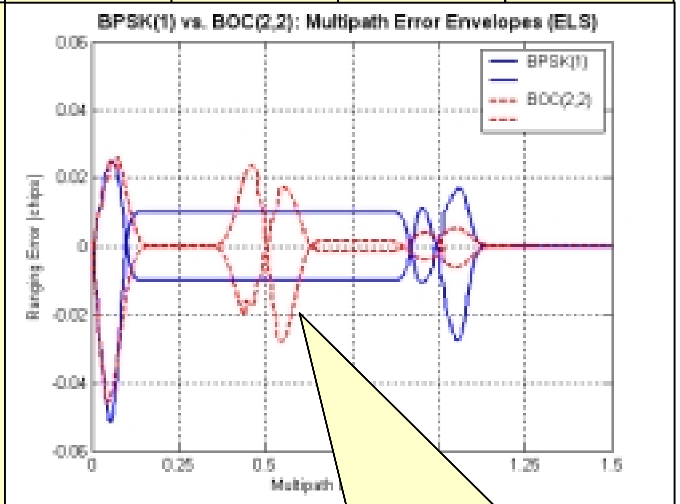
$$T = \frac{y_1 - y_2 + \frac{s}{2}(a_1 + a_2)}{a_1 - a_2}$$

Early/Late Slope Technique: Code Multipath

- ✓ **Computation of code error envelopes by comparing the pseudorange correction *T* with the actual peak location**

	τ_1=-0.1	τ_2 =-0.06	τ_3= 0.06	τ_4= 0.1

Multipath Performance



Multipath error envelopes only valid for given correlator configuration

- ✓ **Remarks:**
  - **Multipath performance strongly depends on actual correlator configuration**
  - **Slight changes of $\tau_1,\ldots,\tau_4$ result in fairly different error envelopes**
  - **impossible to make general statement whether the BPSK(1) or the BOC(2,2) performs better**

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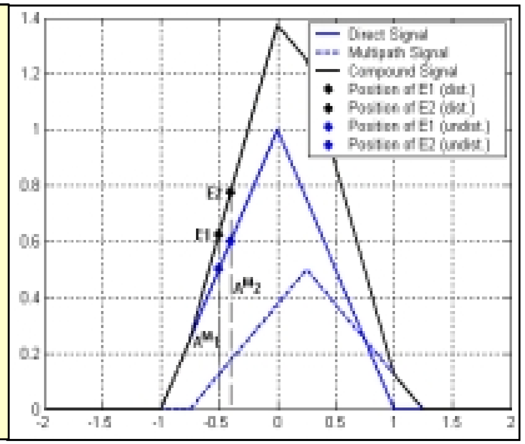
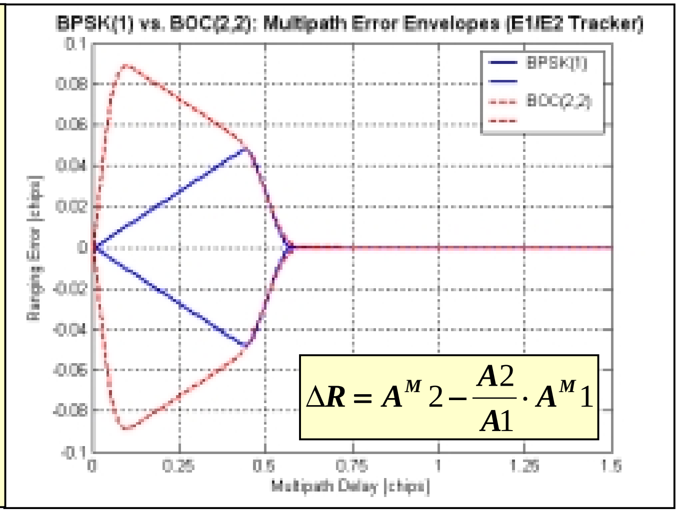
Early1/Early2 (E1/E2) Tracking

Distorted ACF



- ✓ 2 correlators (E1,E2) located on the early slope of the correlation function
- ✓ Amplitudes at E1,E2 are used to compute error function ΔR

Multipath Performance

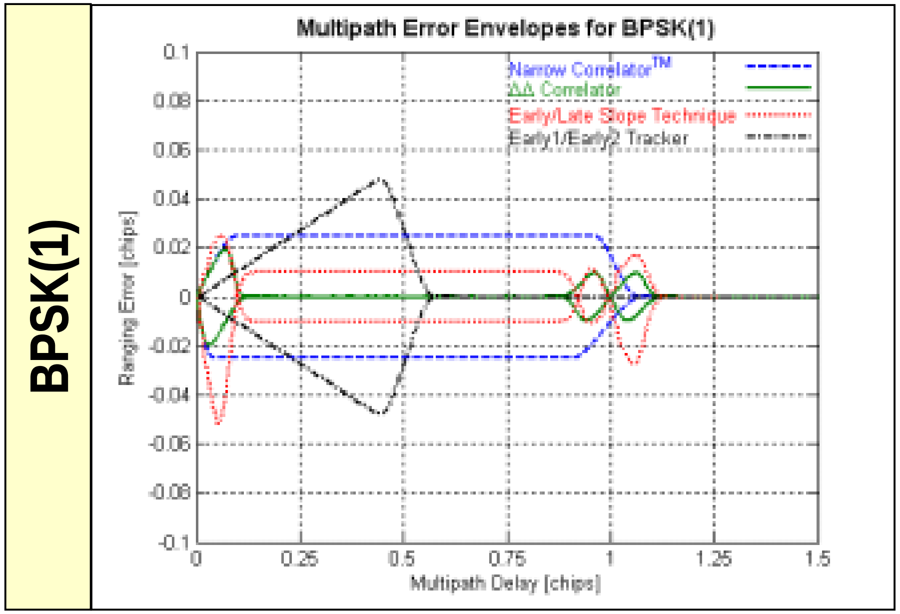


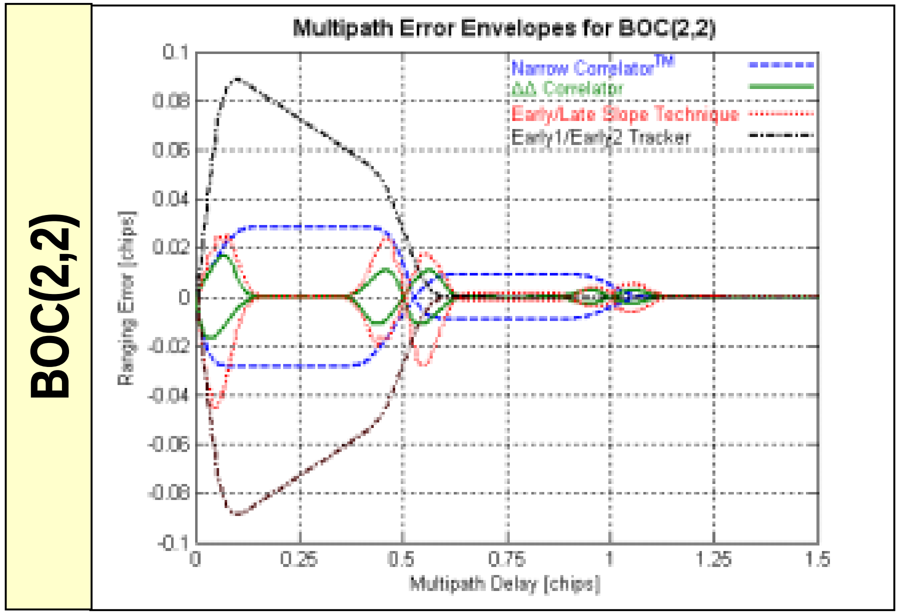
Results:

- Multipath errors are zero for path delays greater than (1+E2)
- maximum ranging error of BOC(2,2) much larger than that of BPSK(1)
- BPSK(1) less sensitive to short-delay multipath

- ✓ **Issues:**
  - Shape of undistorted correlation function must be known (R=A2/A1)
  - Degraded noise performance (reduced signal power at tracking point)

Summary





Results:

- **Double Delta shows the best overall code multipath performance**
- **E1/E2 Tracker produces large maximum multipath errors (worst multipath performance for short- and medium-delay multipath)**
- **BOC(2,2) outperforms BPSK(1) for long-delay multipath (path delays > 0.5 chips)**