Figure 1: SV19 Spectrum Measured by the Univ. of Leeds

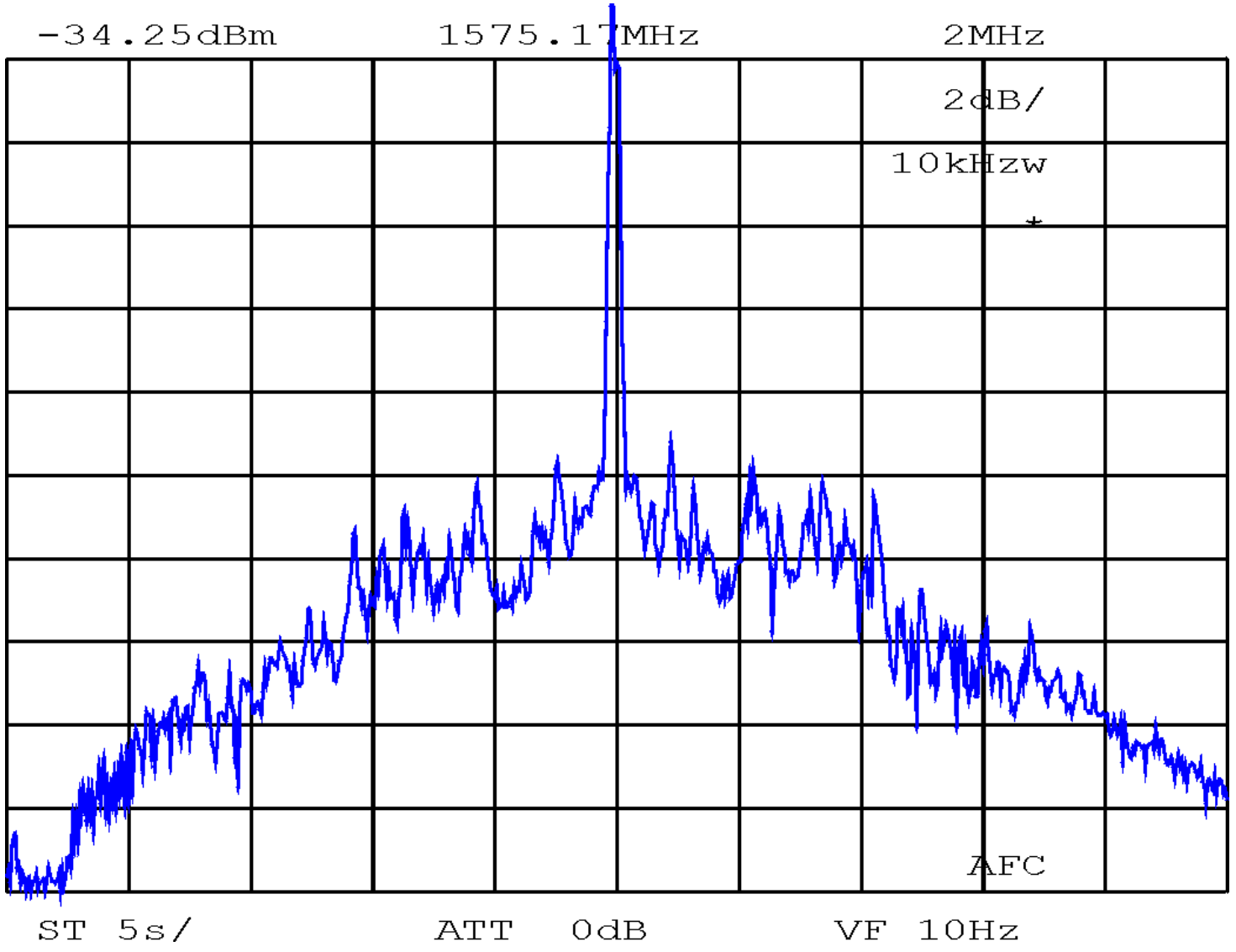

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Figure 2: Anomalous Signal With Lead & Correlation Function Showing Dead Zone

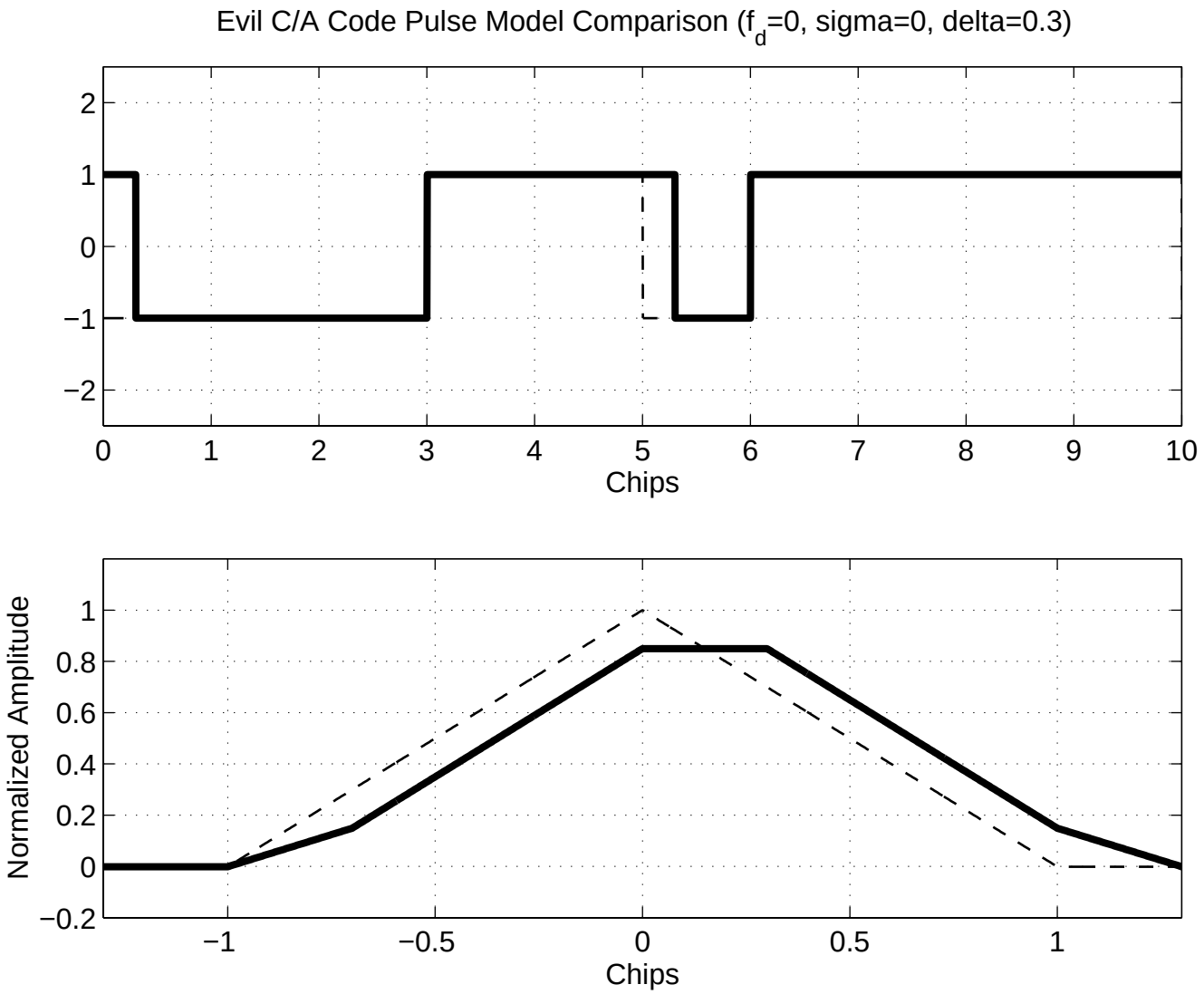

Figure 3: Second Order Anomalous Waveform & Associated Correlation Function Showing False Peaks

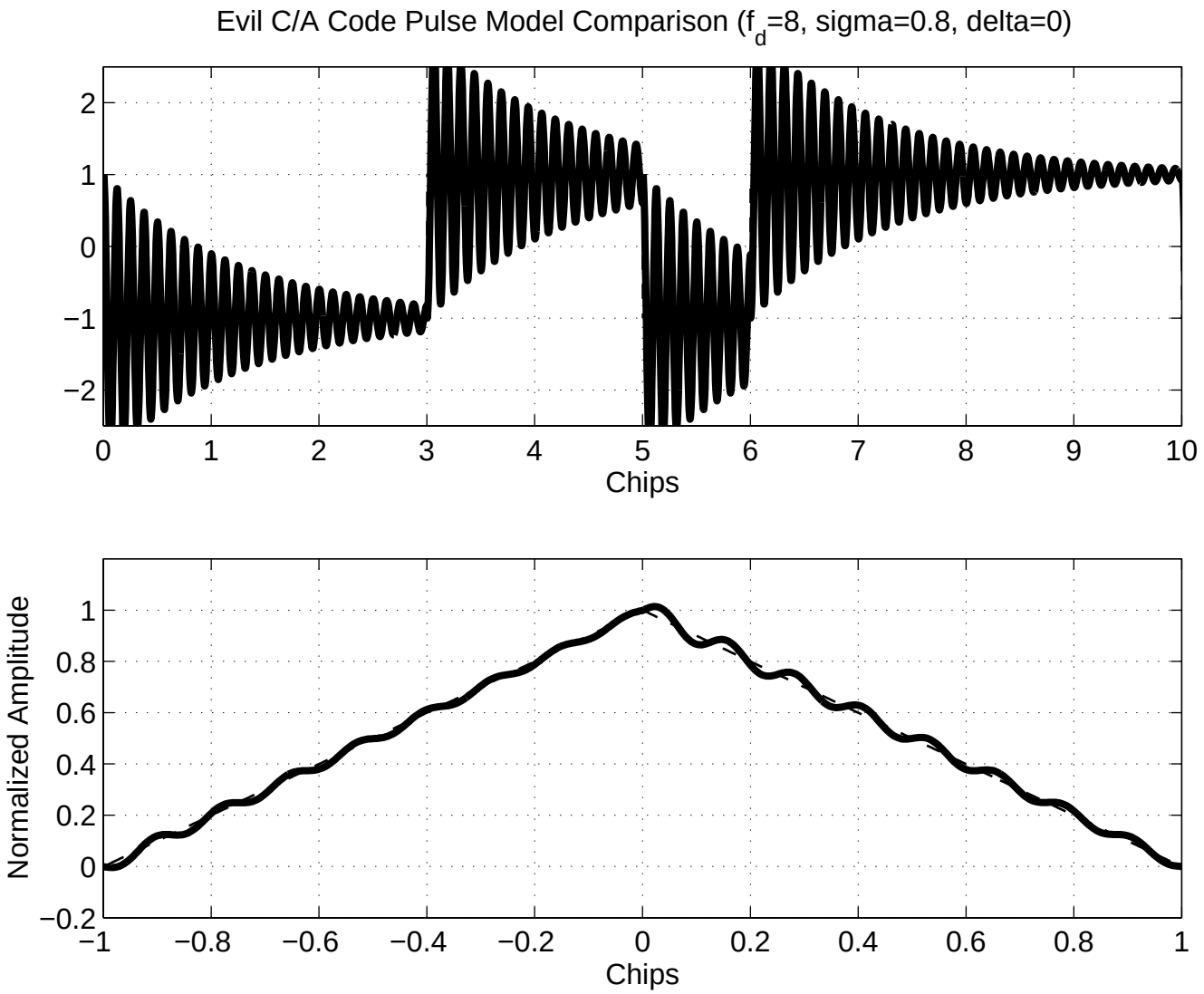

Figure 4: Second Order Anomalous Waveform & Associated Correlation Function Showing Distortion

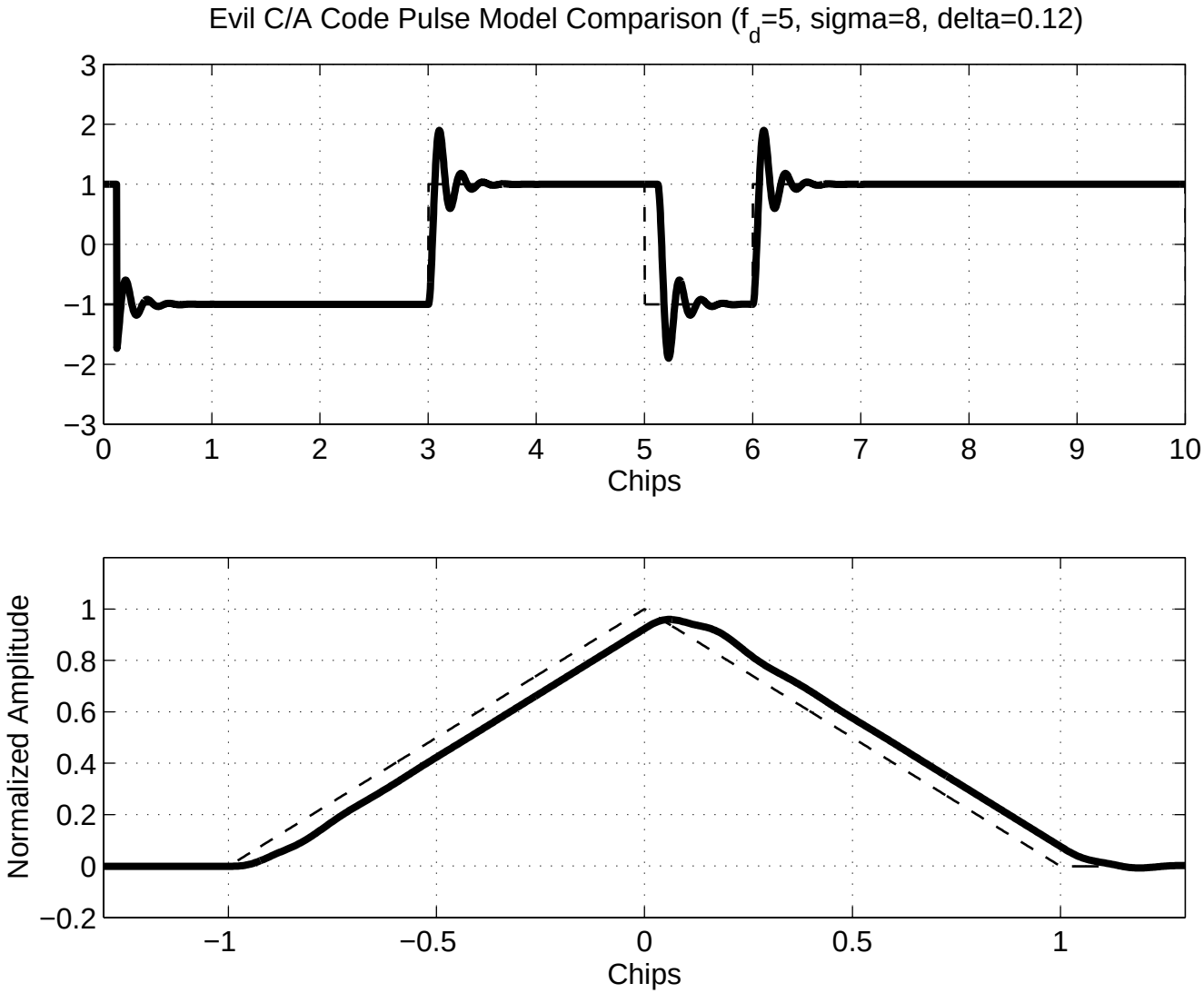

Figure 5: A Most Evil Waveform

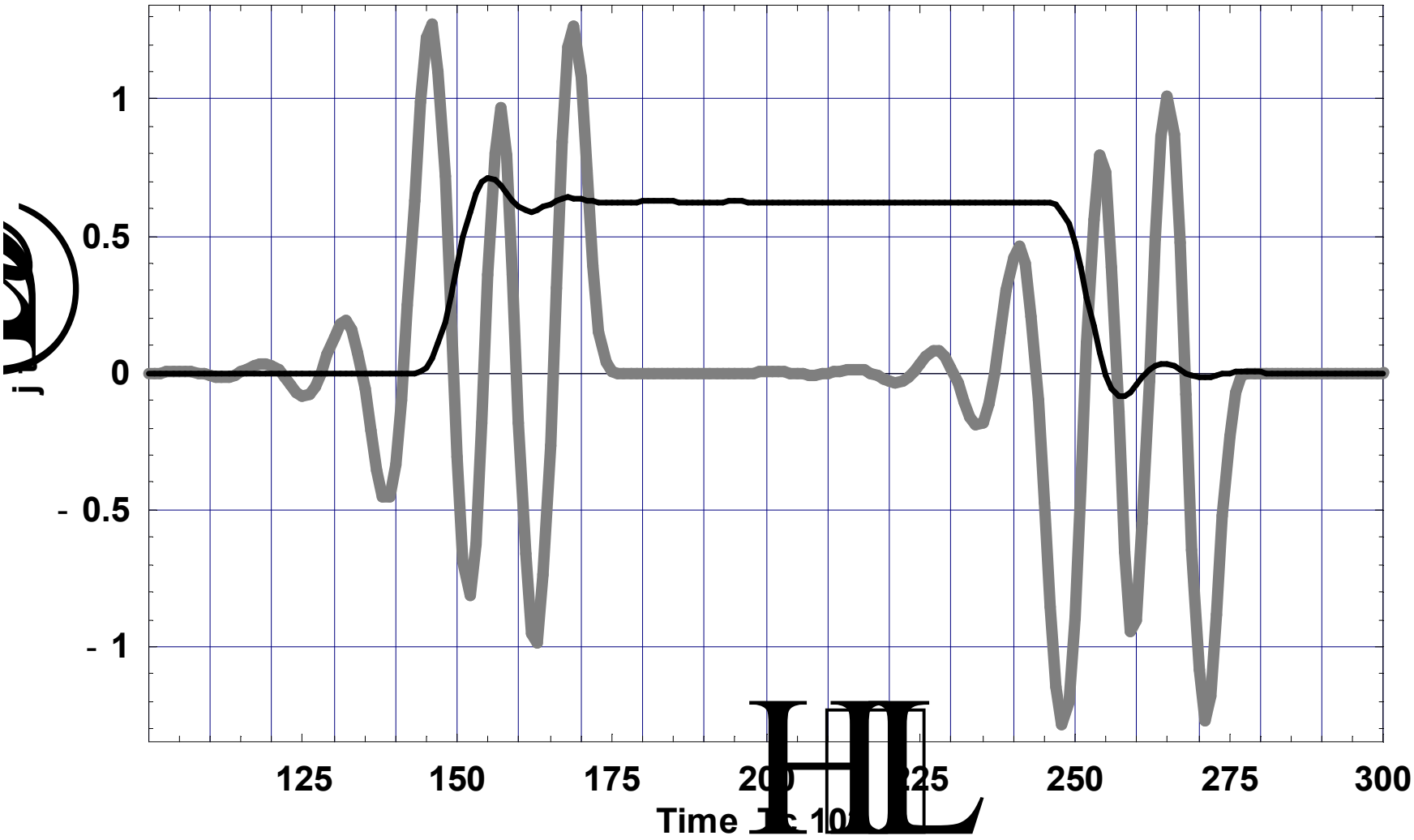

Figure 6: Correlations for Various Ratios of the Power in the Nominal Signal to the Power in the Disturbed Signal

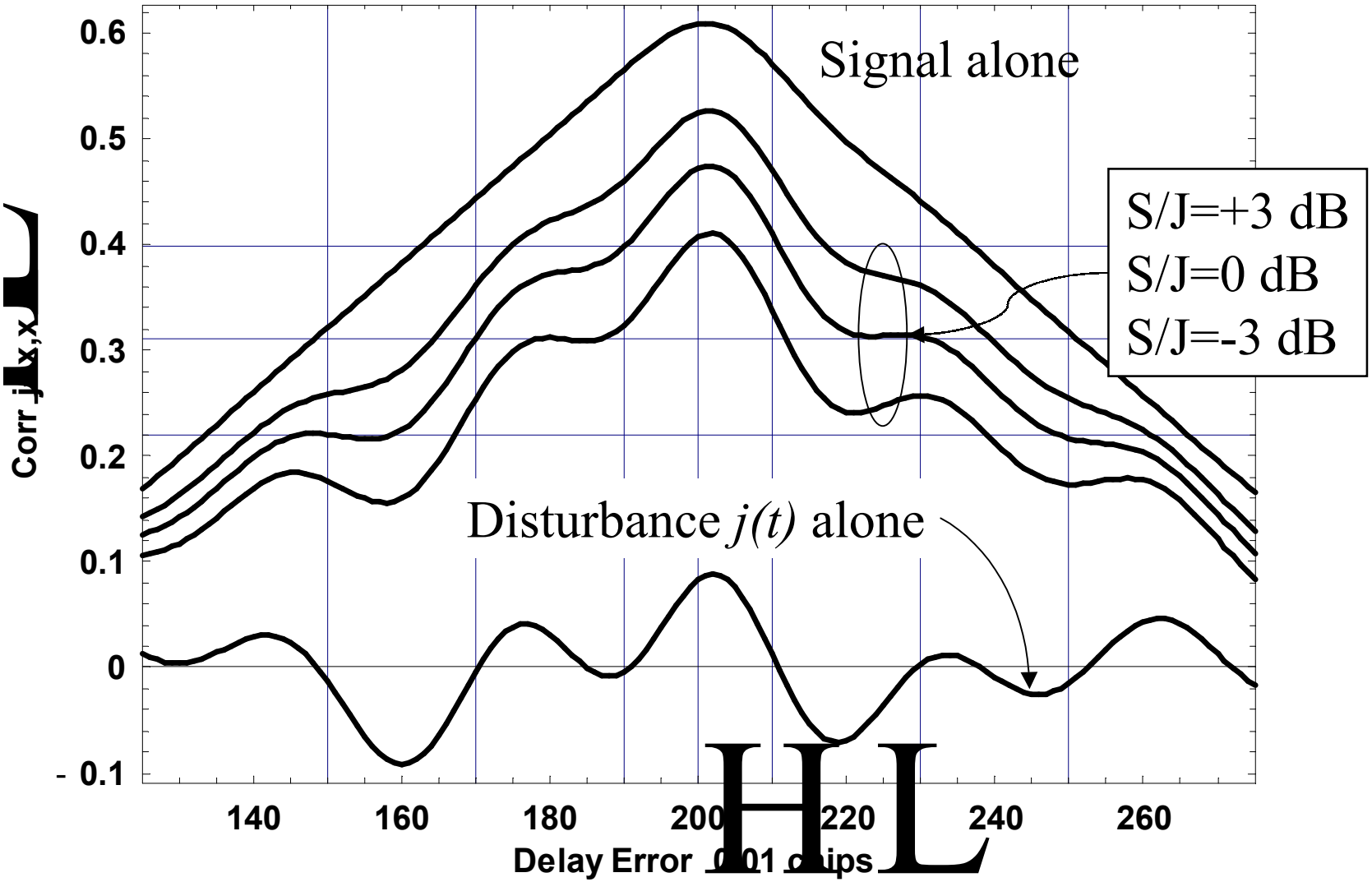

Figure 7: Summary of the Preferred Threat Model

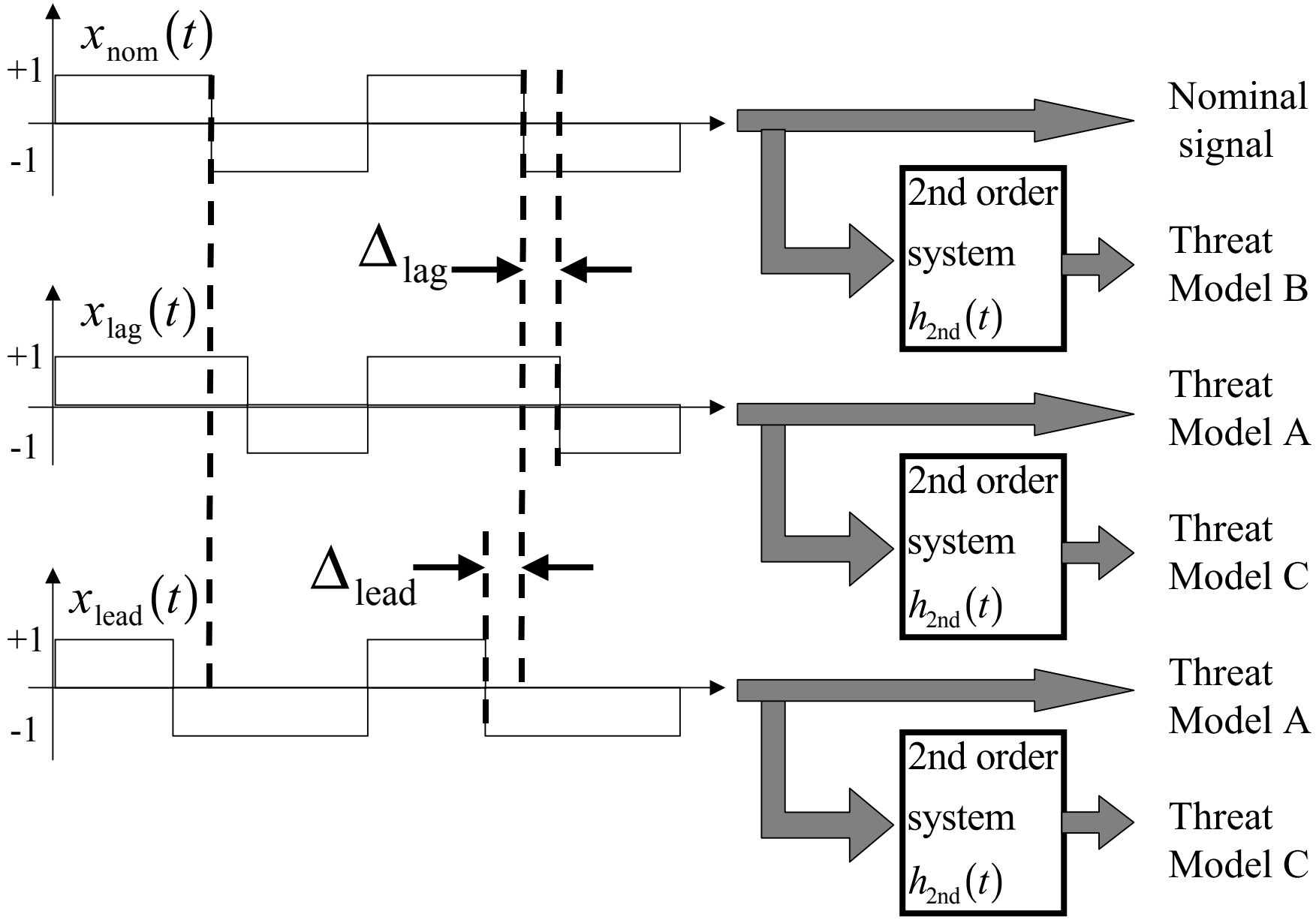

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Figure 8: Difference Between Nominal Signal and Signals with Lead and Lag

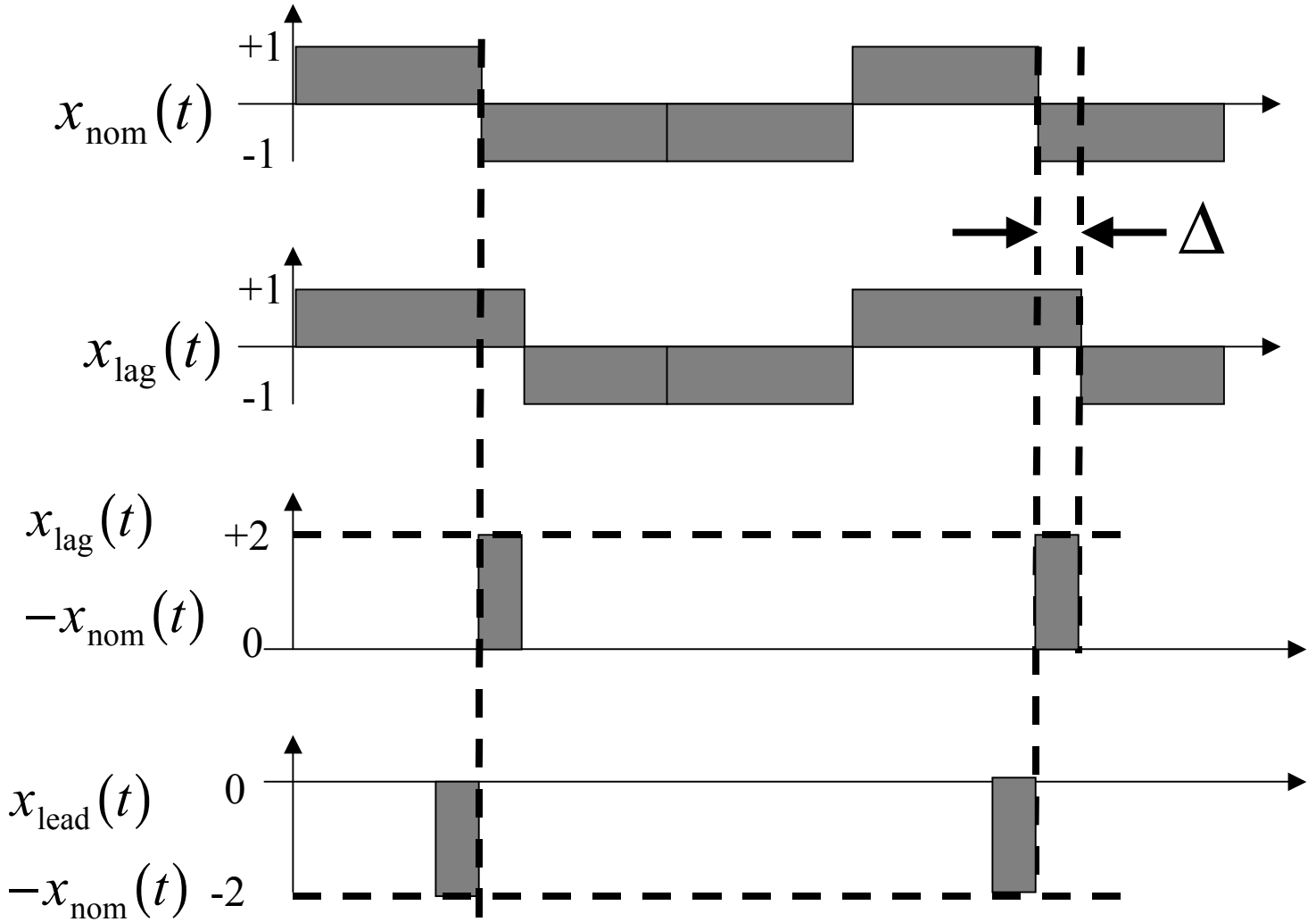

Figure 9: Correlation Between Nominal Signal and Lag Difference Signal

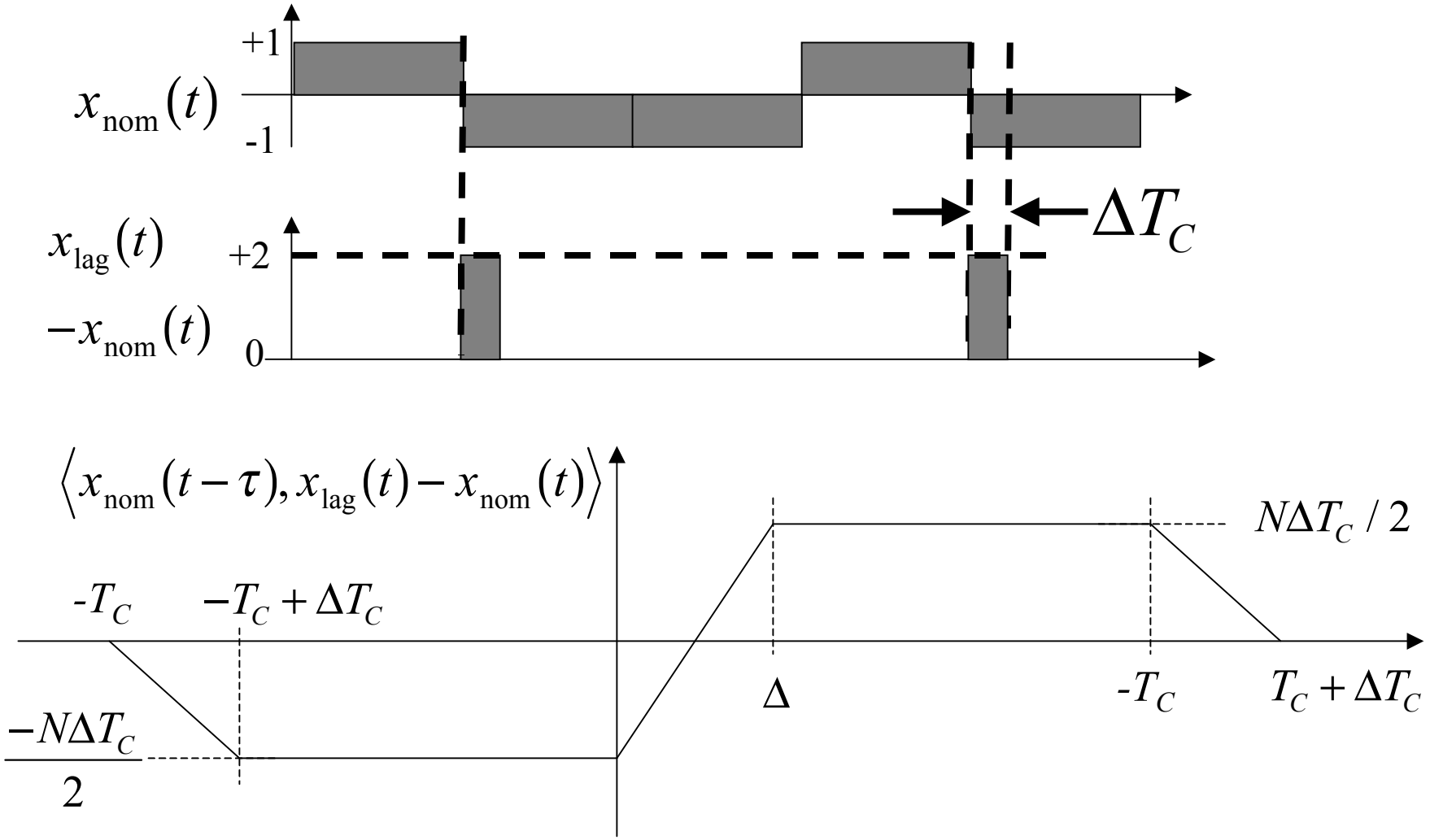

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Figure 10: Correlation of Nominal Signal With Lagging Signal and Its Derivative

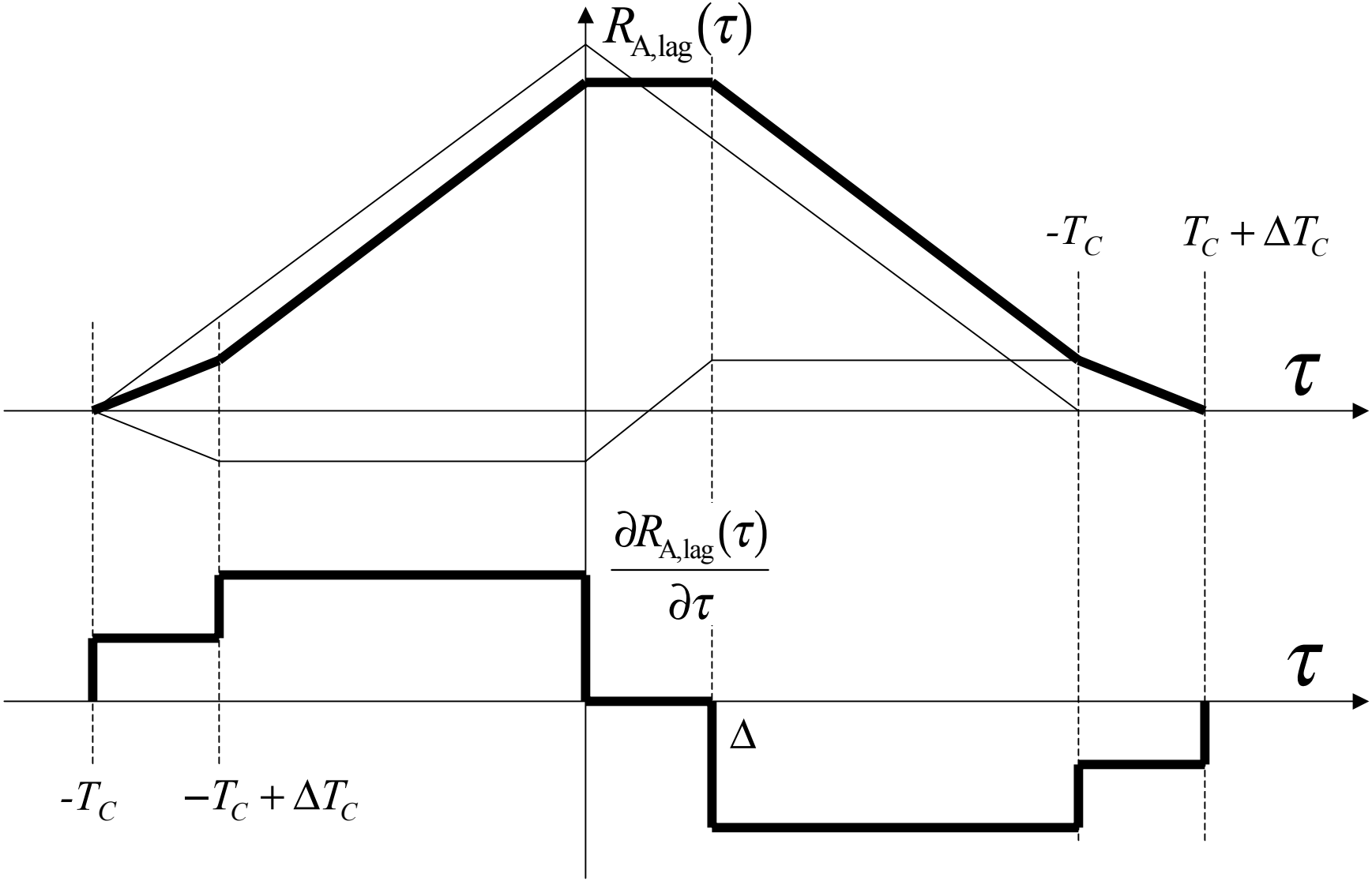

Figure 11: Exchanging the Order of Linear Operations

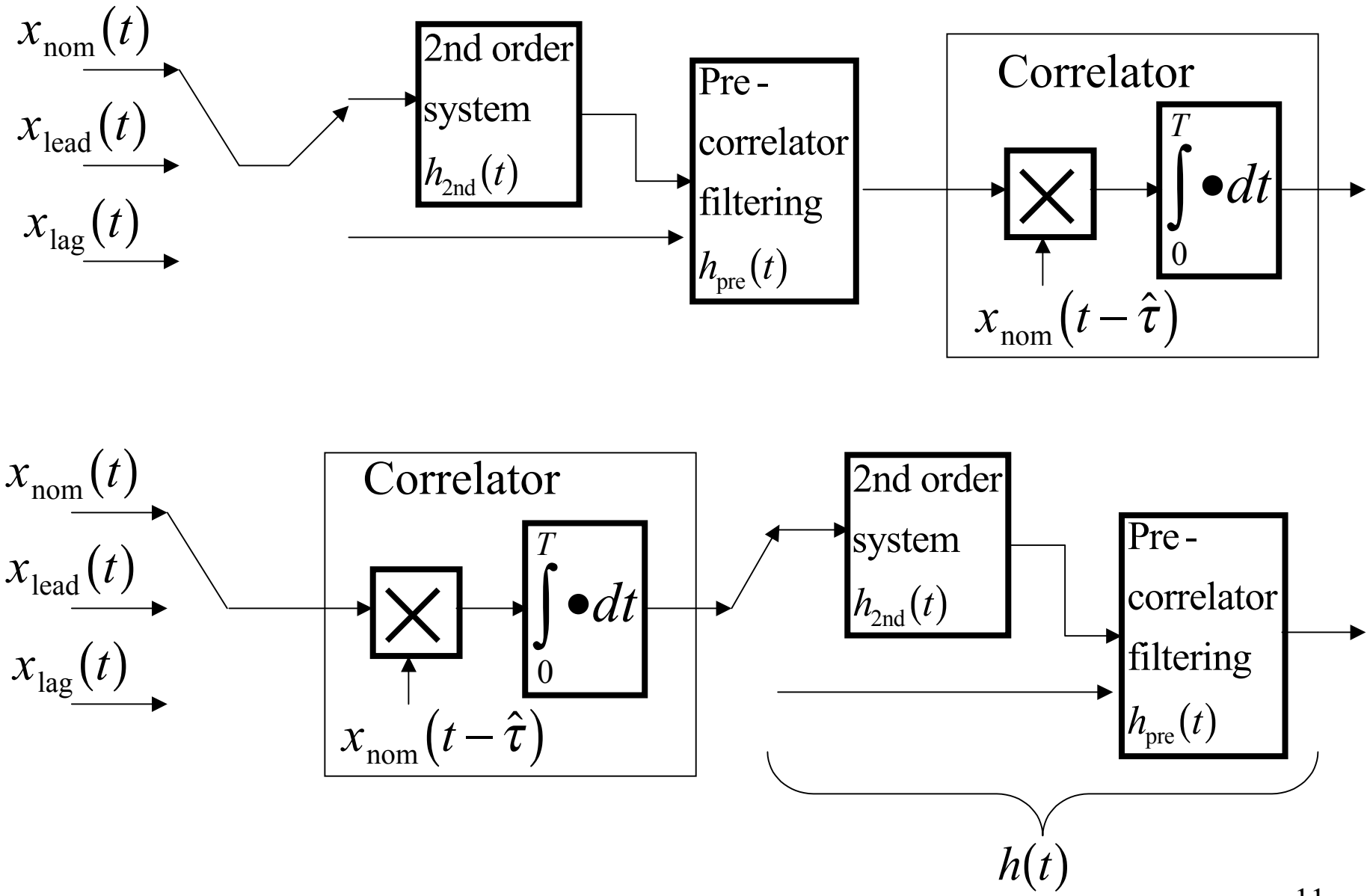

Figure 12: Nominal Correlation Peak and Its Derivative

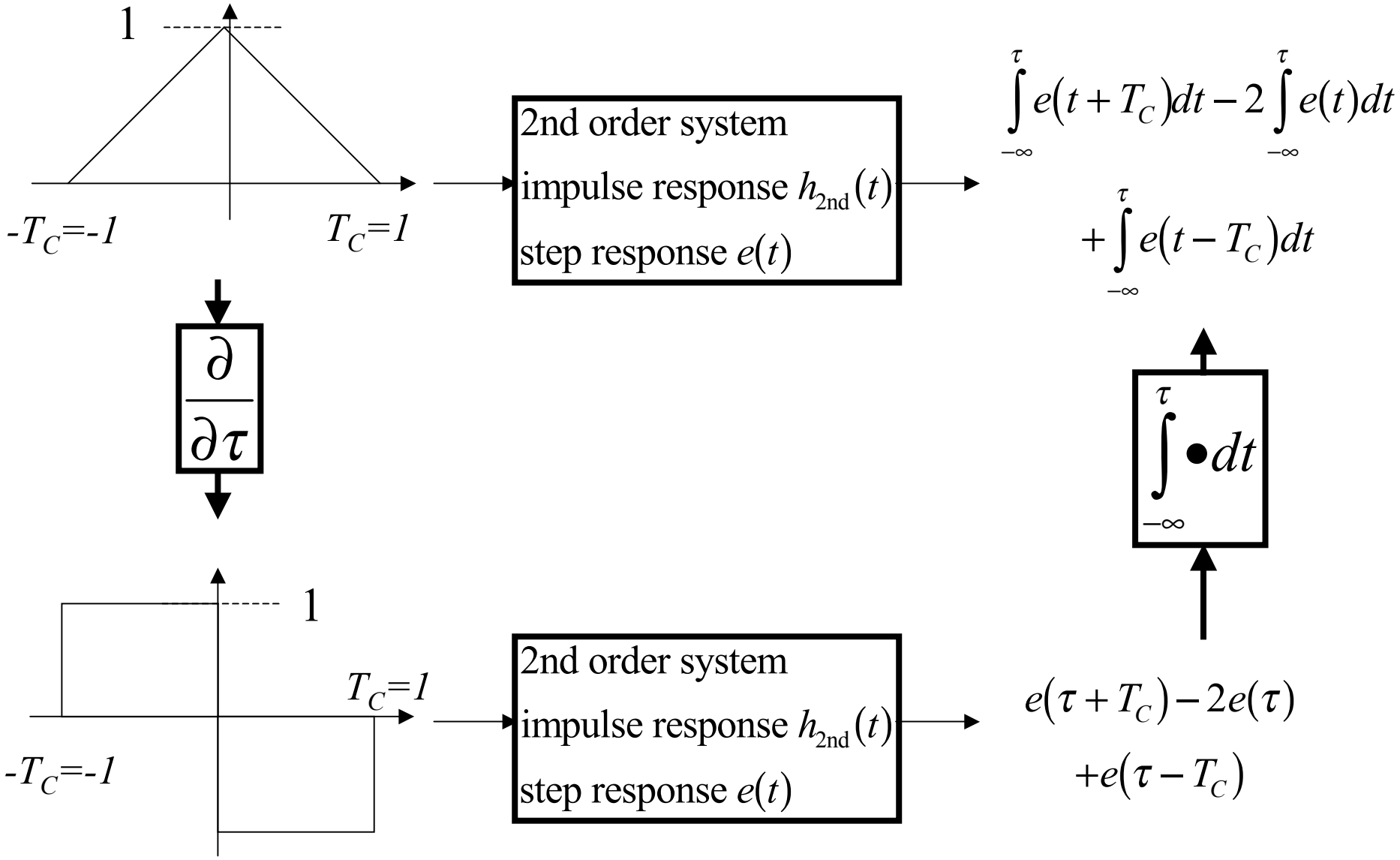

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Figure 13: Falling Edge Lead/Lag & 2nd Order Step Response

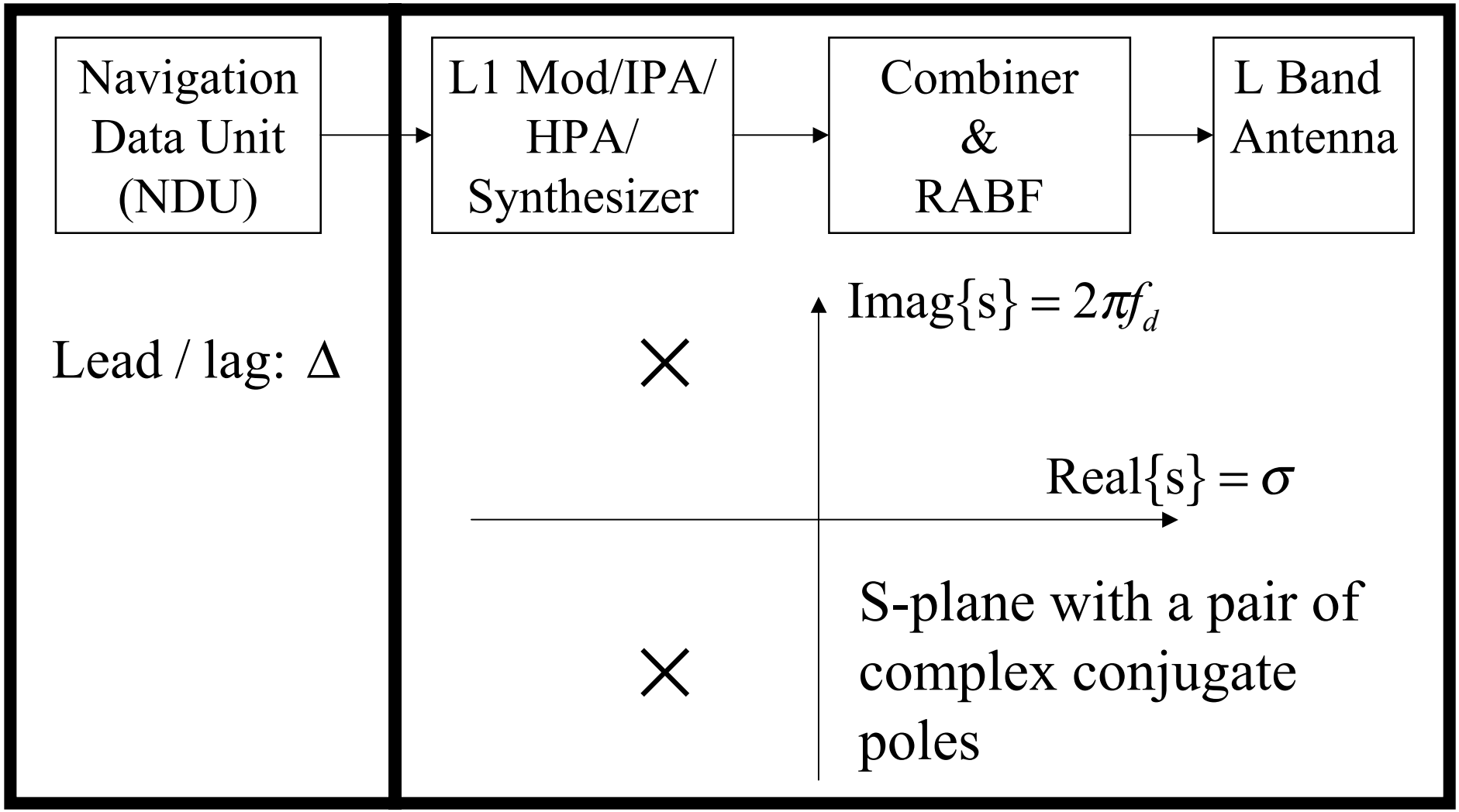

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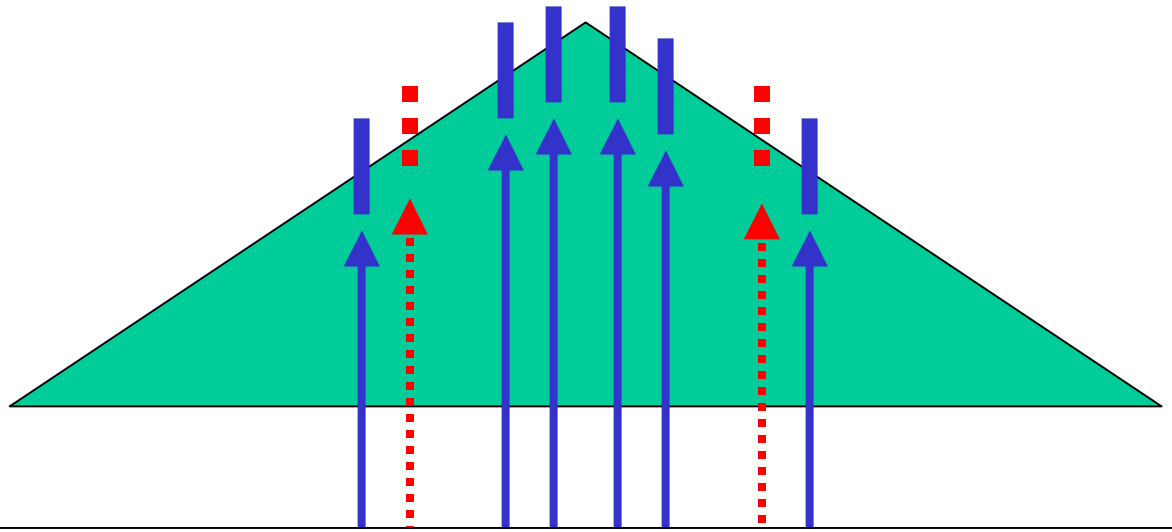
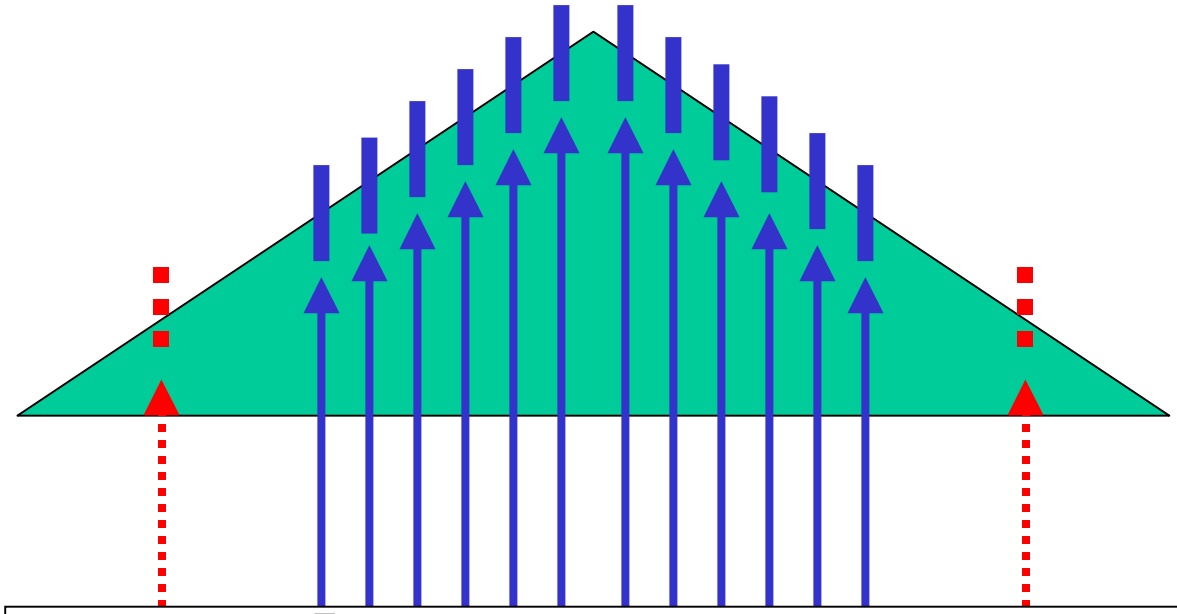
Figure 14: Sparse Sampling - Also known as Option B or Modified Option B



$$\beta_{\text{Sparse}} = \text{Max}\left[\frac{\tau_{0.3} - \tau_{0.1}}{MDE_{0.3,0.1}}, \frac{\tau_{0.05} - \tau_{0.1}}{MDE_{0.05,0.1}}, \left\{\frac{\tau_{0.25} - \tau_{0.1}}{MDE_{0.25,0.1}}\right\}\right]$$

Figure 15: Dense Sampling - Also known as Option C or a picket fences.



$$\beta_{\text{Dense}} = \text{Max}\left[\frac{\tau_{0.3}-\tau_{0.1}}{MDE_{0.3,0.1}}, \frac{\tau_{0.25}-\tau_{0.1}}{MDE_{0.25,0.1}}, \frac{\tau_{0.2}-\tau_{0.1}}{MDE_{0.2,0.1}}, \frac{\tau_{0.15}-\tau_{0.1}}{MDE_{0.15,0.1}}, \frac{\tau_{0.05}-\tau_{0.1}}{MDE_{0.05,0.1}}, \left\{\frac{\tau_{1.0}-\tau_{0.1}}{MDE_{1.0,0.1}}\right\}\right]$$

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Figure 16: Undetected Points for Threat Model A: Lead/Lag Only

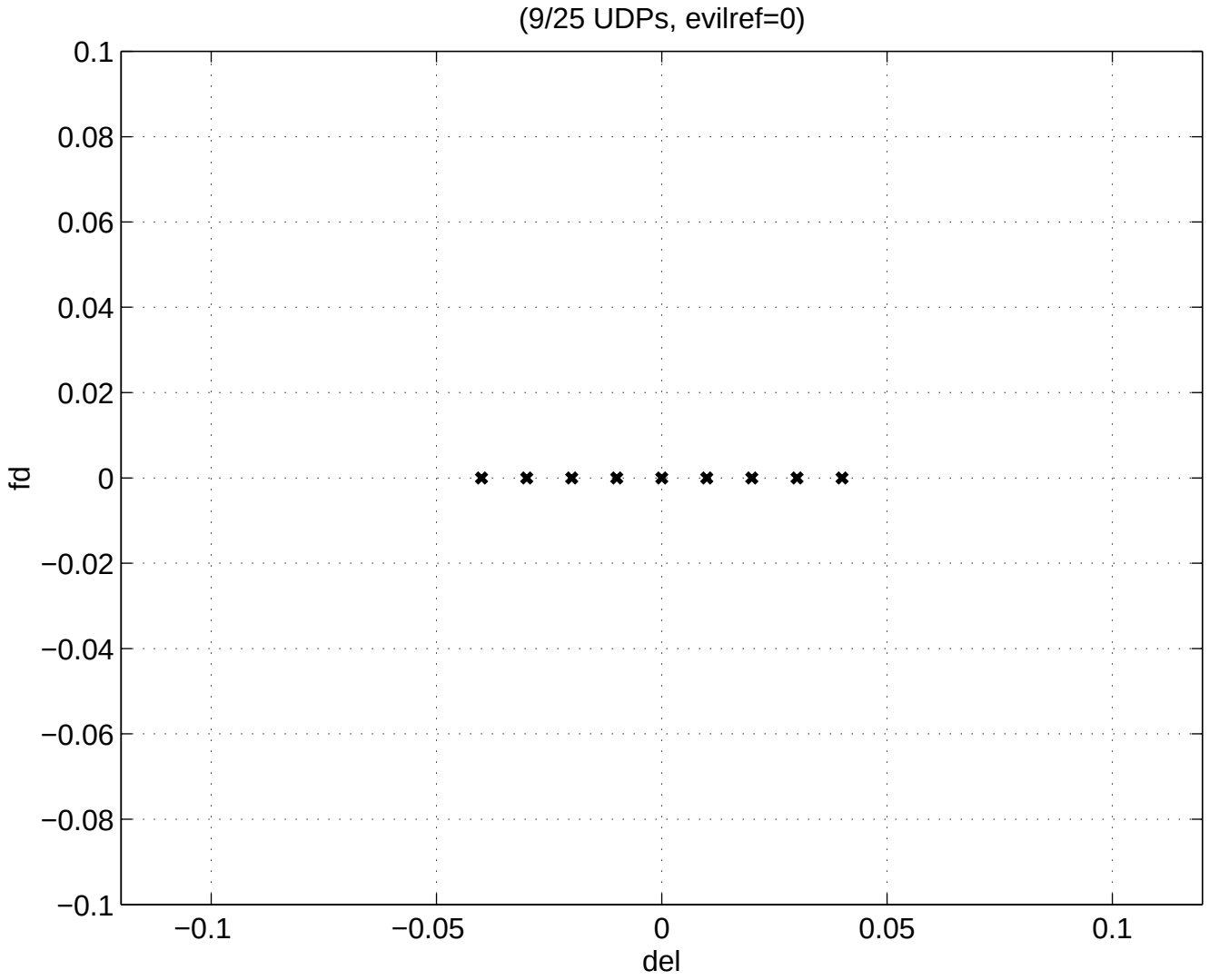

Figure 17: Airborne Pseudorange Errors for Sparse Ground Sampling & Threat Model A: Lead/Lag Only

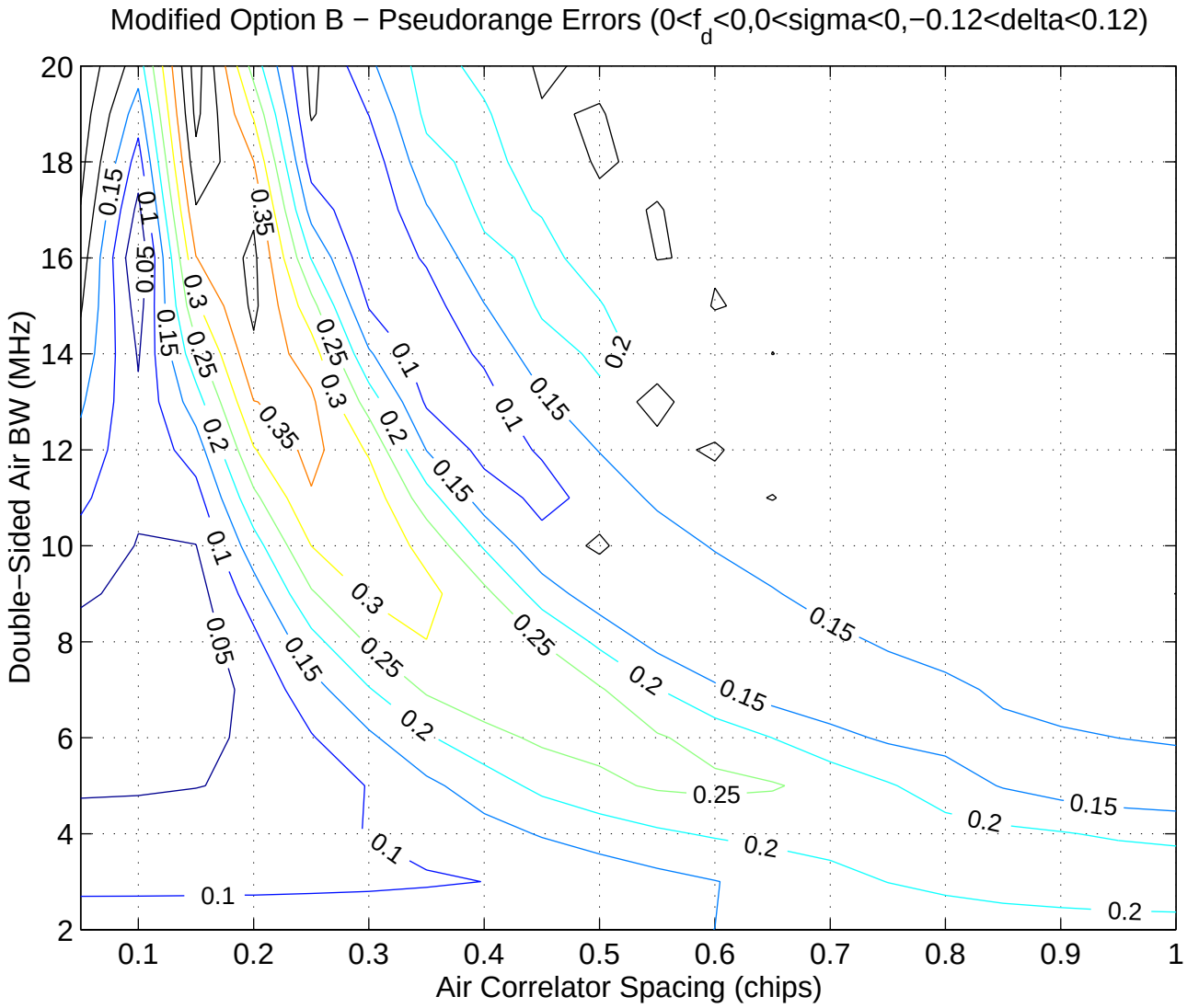

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Figure 18: Undetected Points for Sparse Ground Sampling Threat Model B: Second Order With 4 MHz<fd<17 MHz

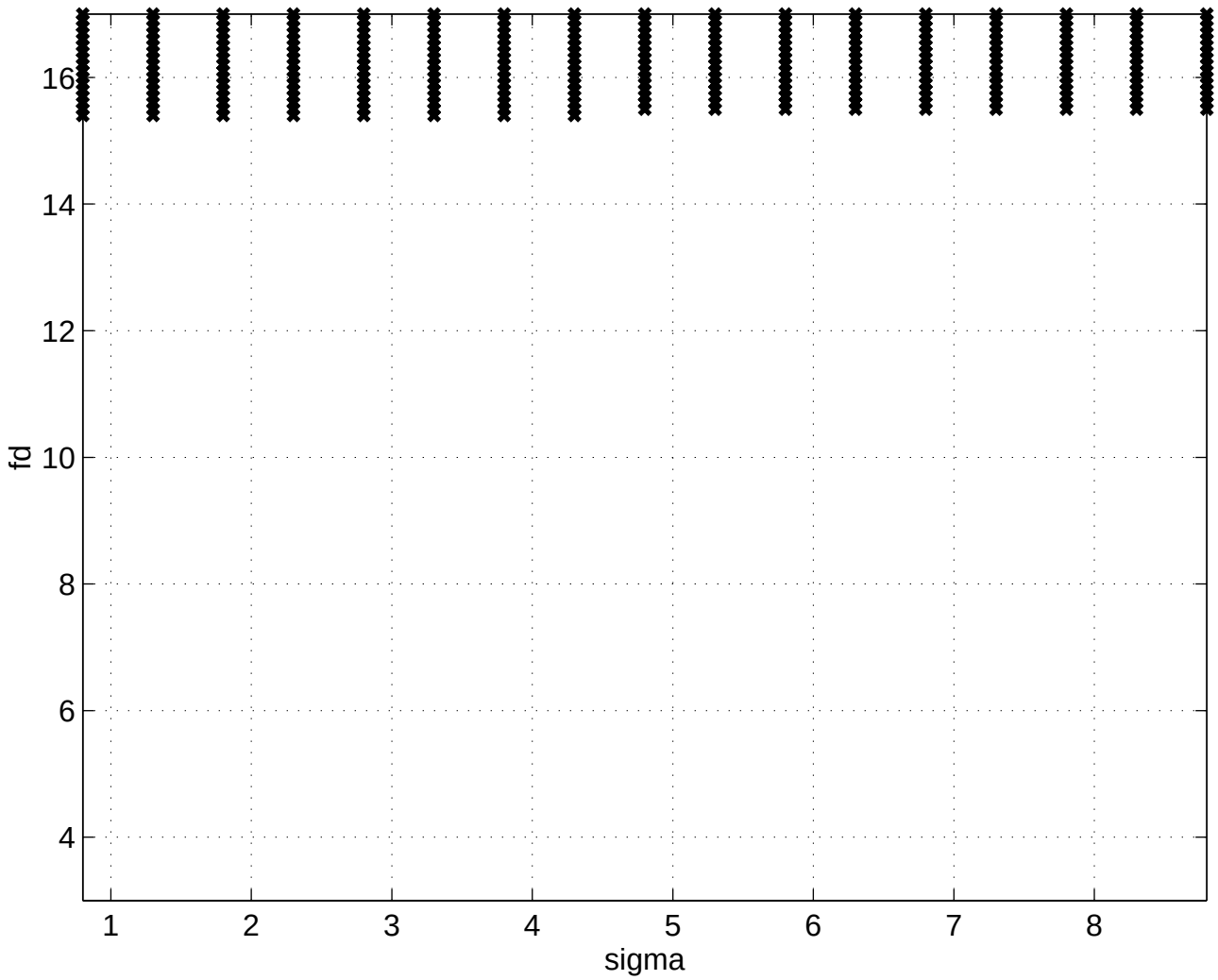

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Figure 19: Air PR Errors for Sparse Ground Sampling Threat Model B: Second Order With 4 MHz<fd<17 MHz

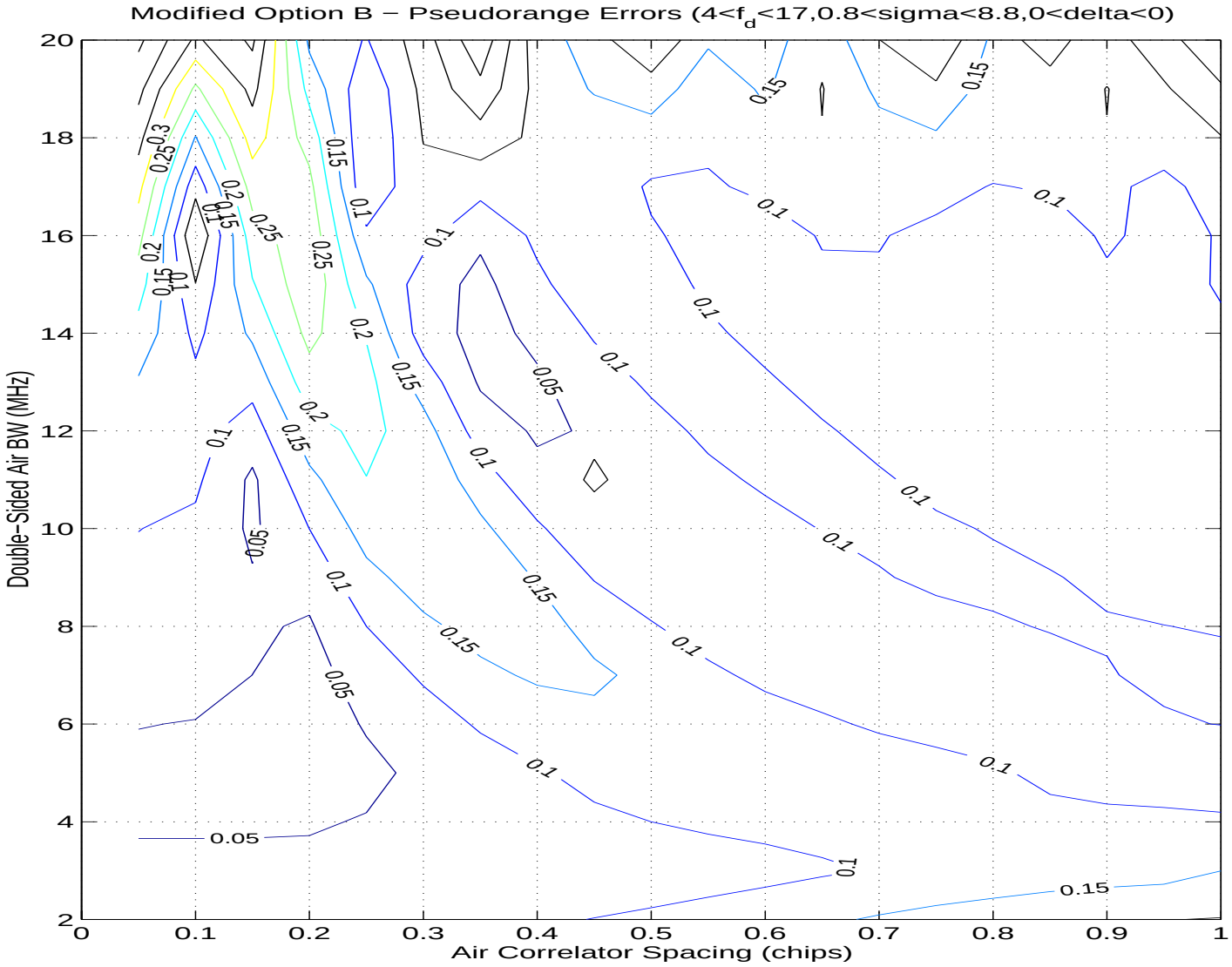


Figure 20: Undetected Points for Sparse Ground Sampling Threat Model C: Lead/Lag & Second Order With 7.3 MHz<fd<17.0 MHz

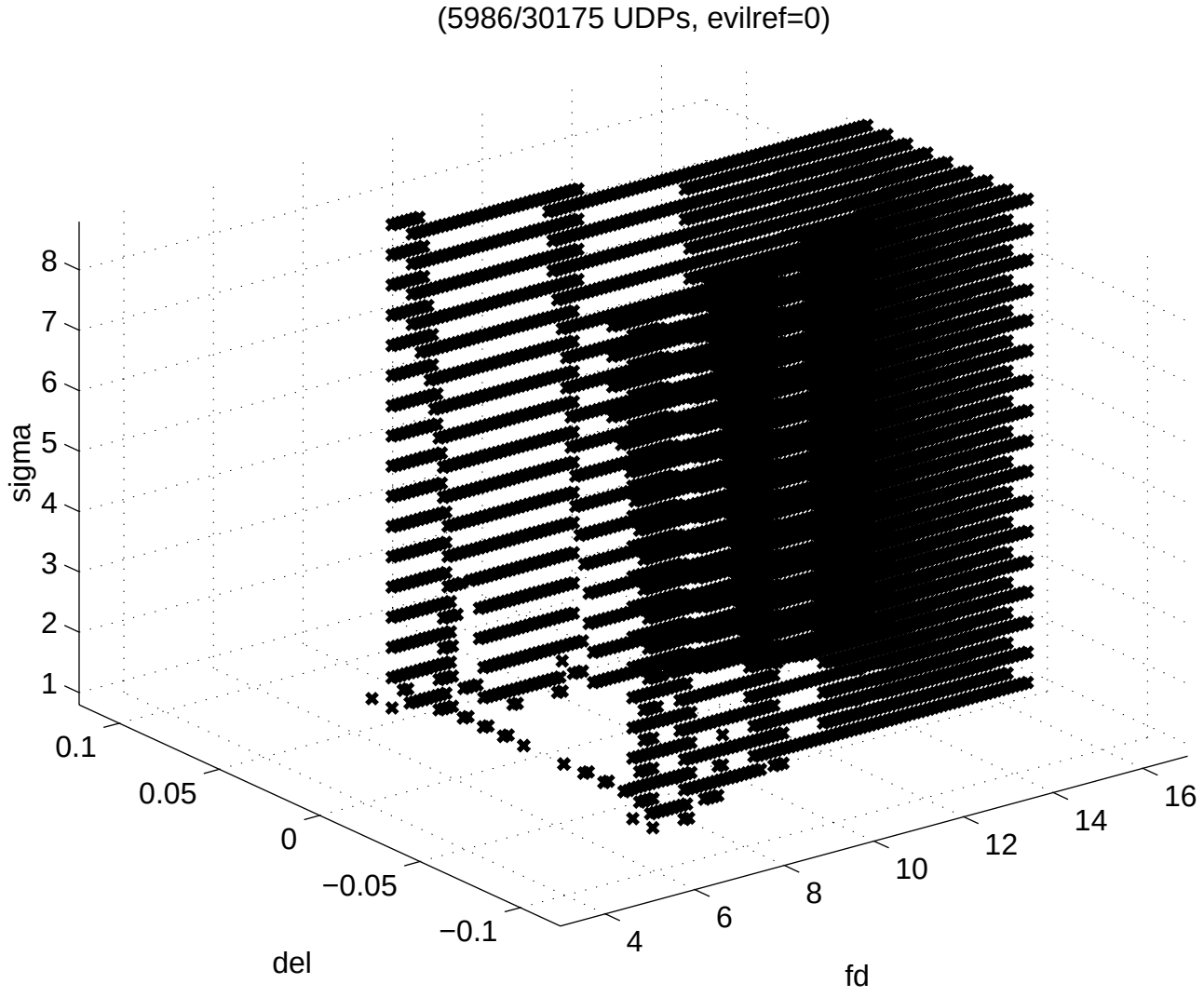


Figure 21 : Air PR Errors for Sparse Ground Sampling Threat Model C: Lead/Lag & Second Order Threats With 7.3 MHz<fd<17.0 MHz

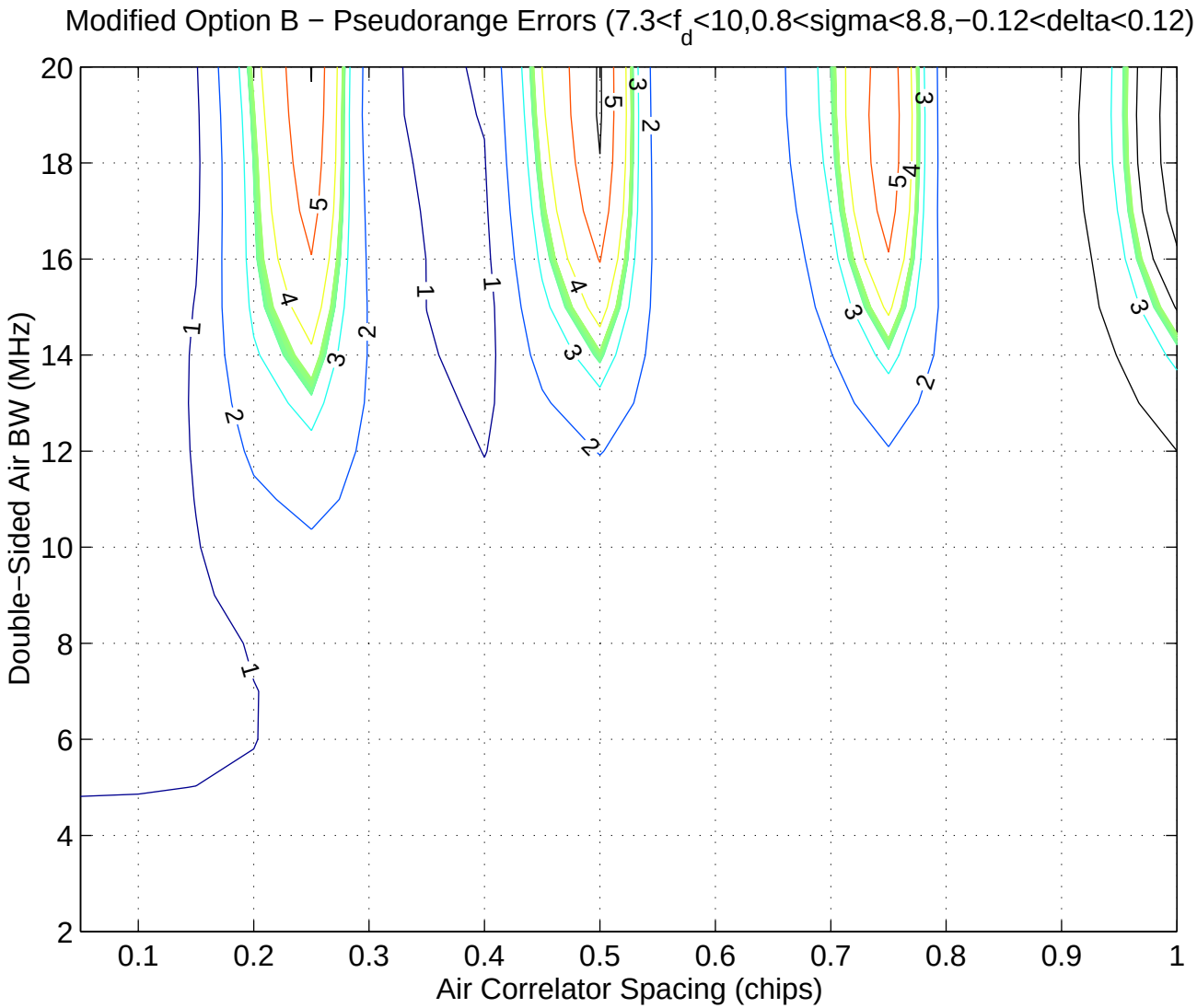


Figure 22: Impact of Differential Group Delay of the Aircraft Bandpass Filter

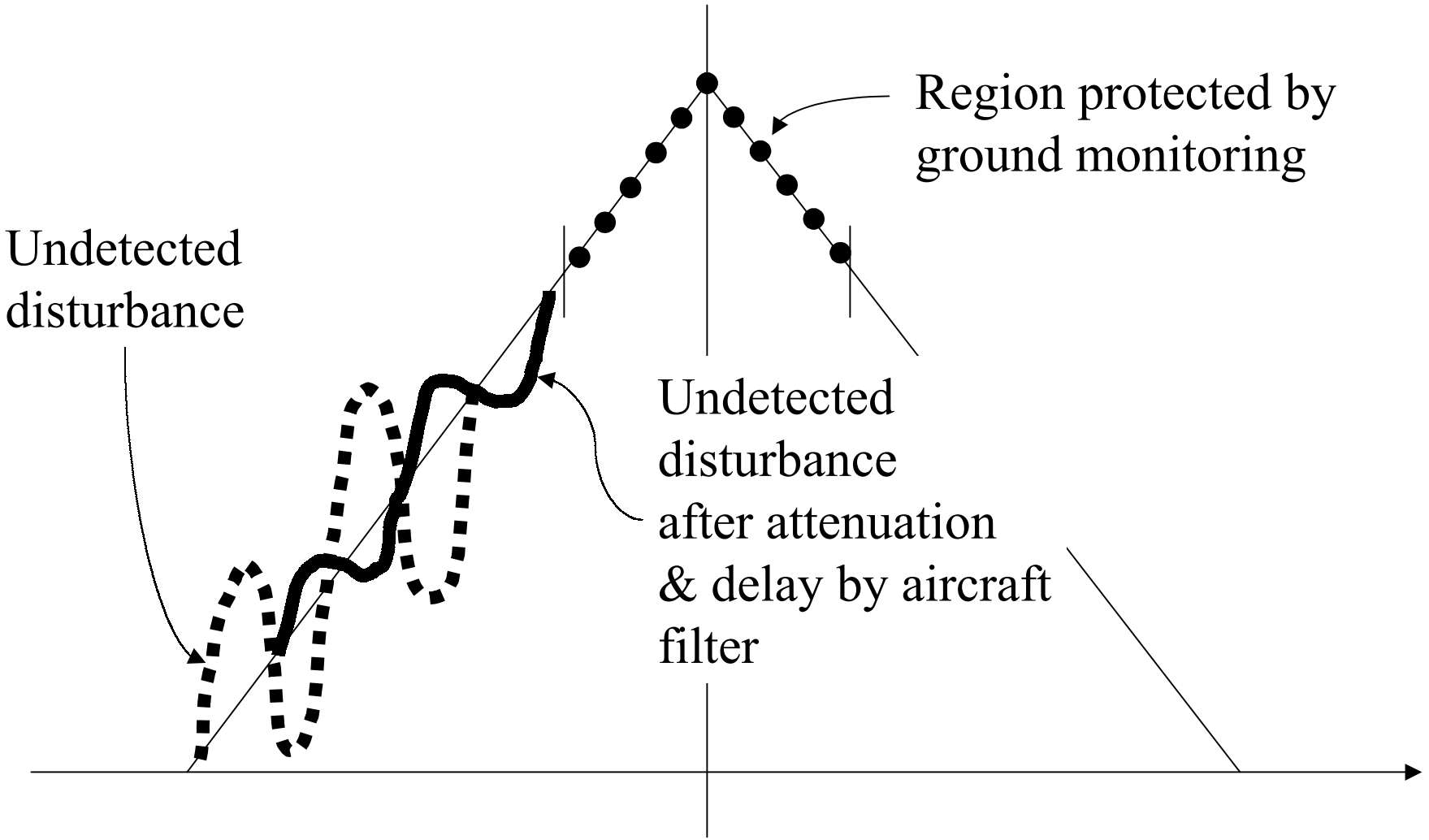


Figure A.1: GPS User Equipment: Time of Arrival Measurements

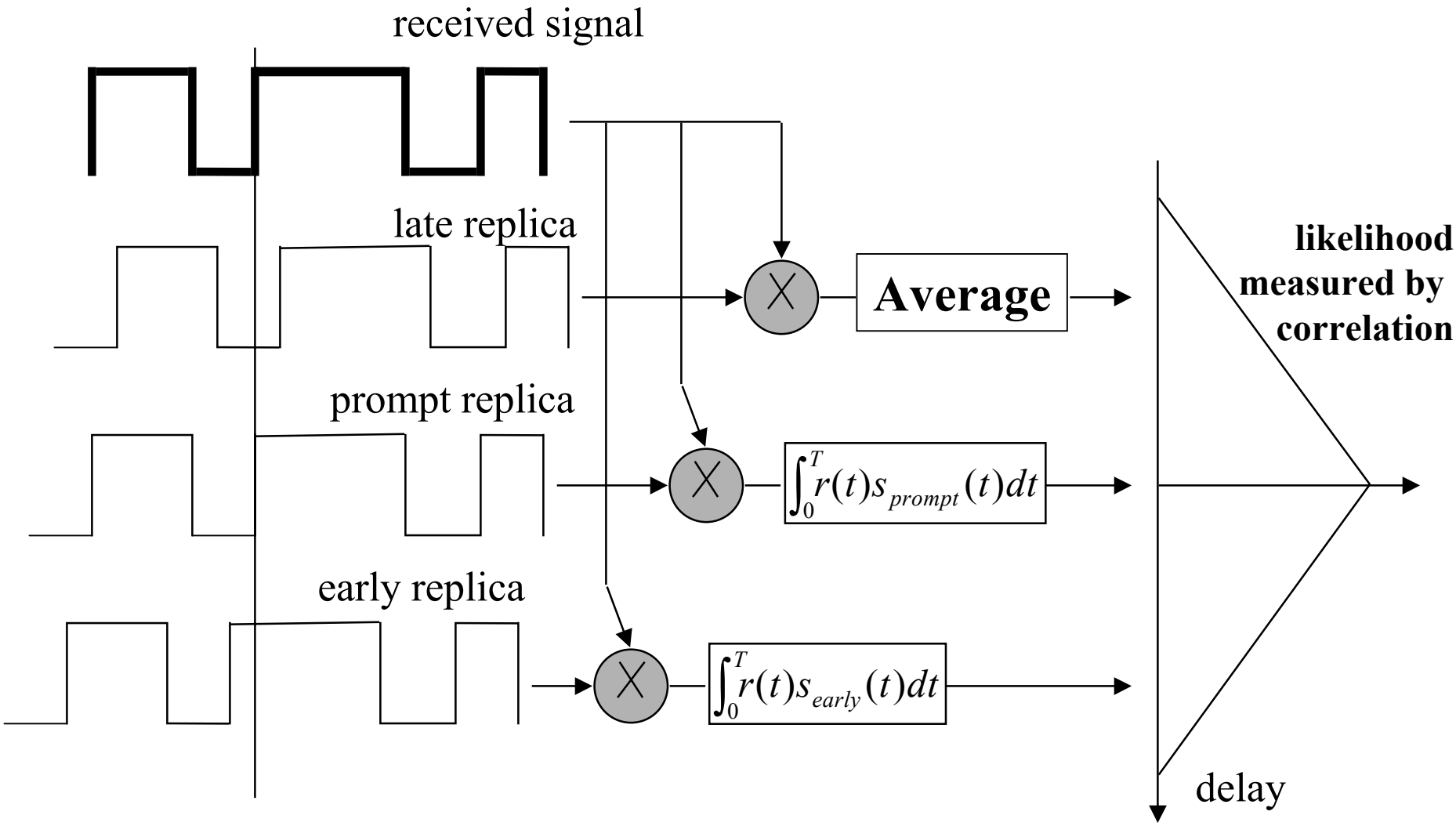


Figure A.2: Spread Spectrum for Ranging

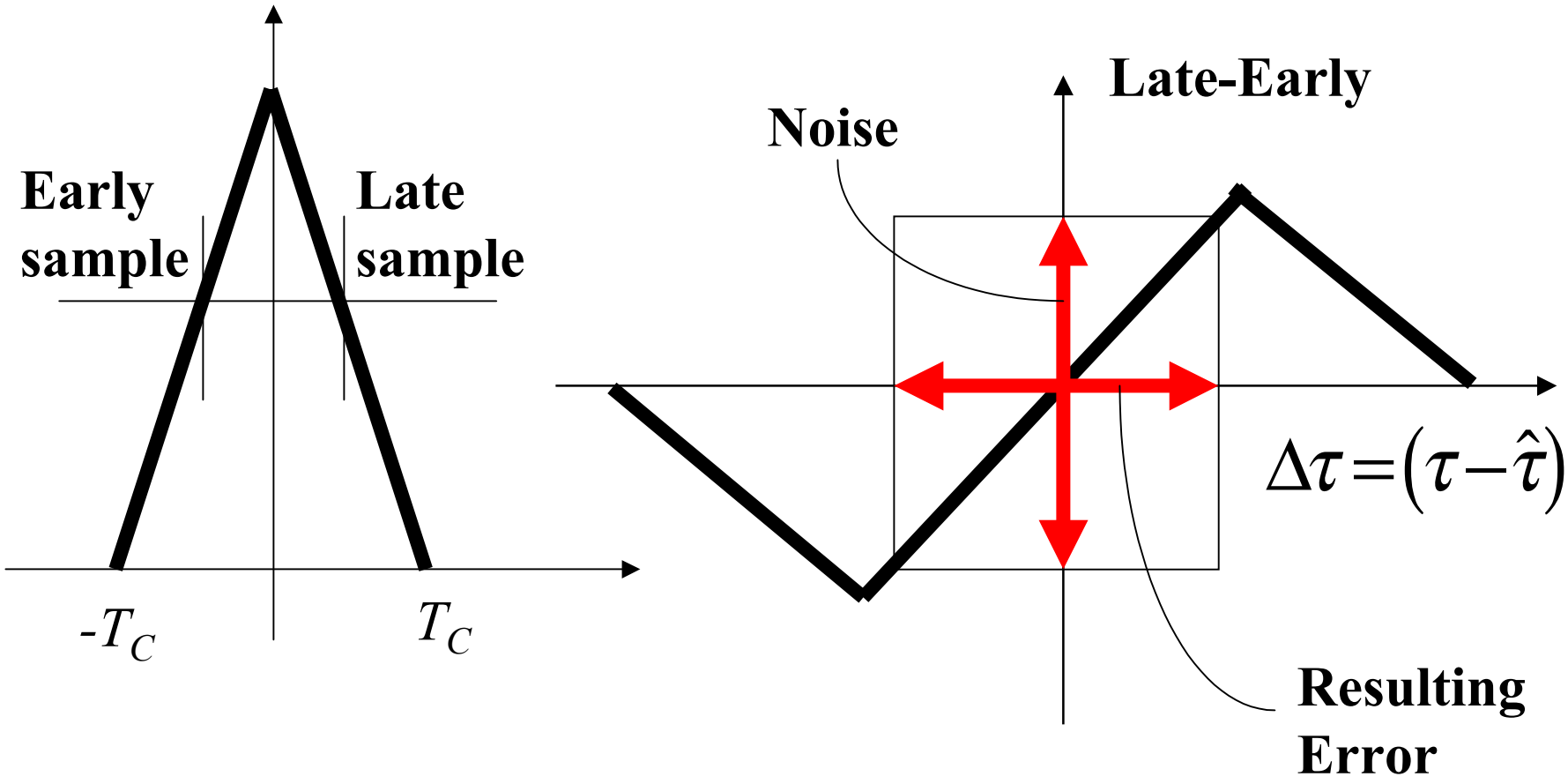
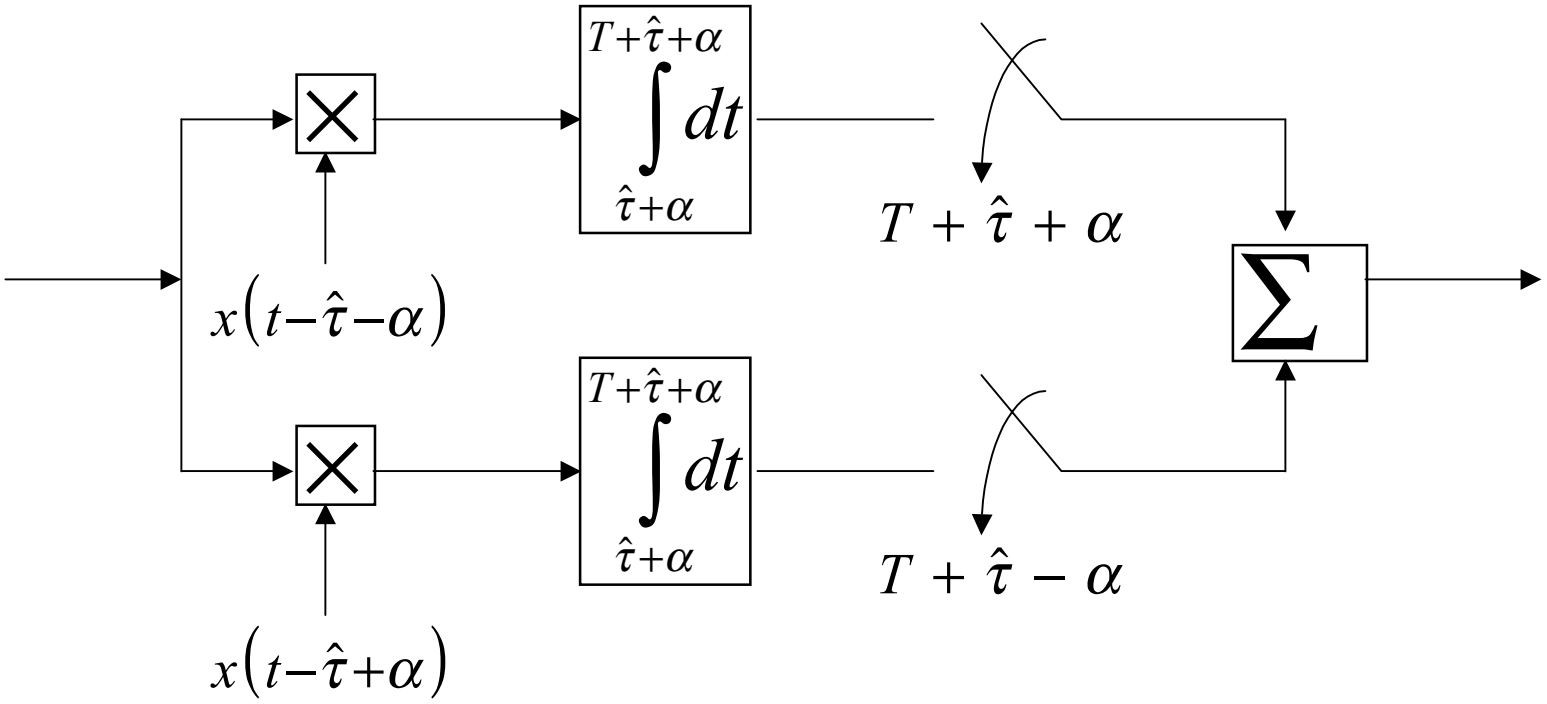


Figure B.1: Code Phase Threat Theory
A Most Evil Waveform



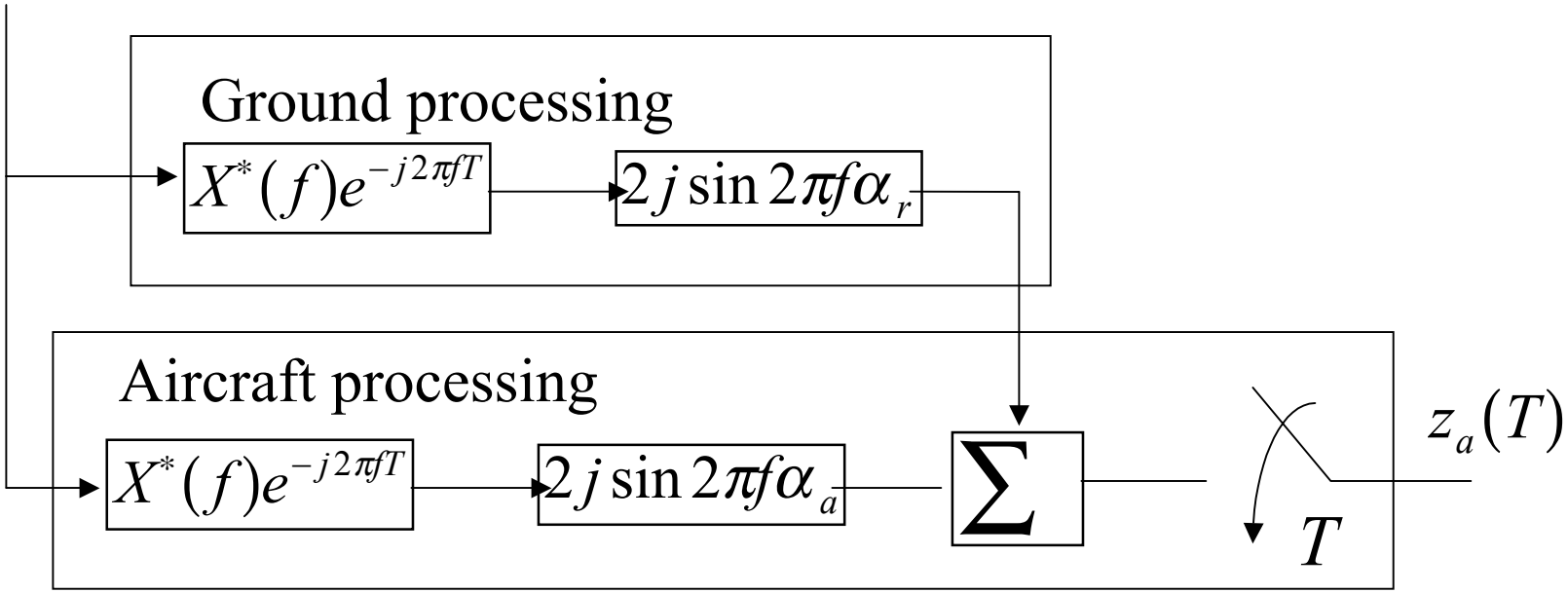
$$H(f) = X^*(f)e^{-j2\pi fT}$$
$$h(t) = x(T-t)$$

$$e^{j2\pi f\alpha} - e^{-j2\pi f\alpha} = 2j\sin 2\pi f\alpha$$

$$T+\hat{\tau}$$

Figure B.2: Most Evil Waveform With No Monitor (M=0)

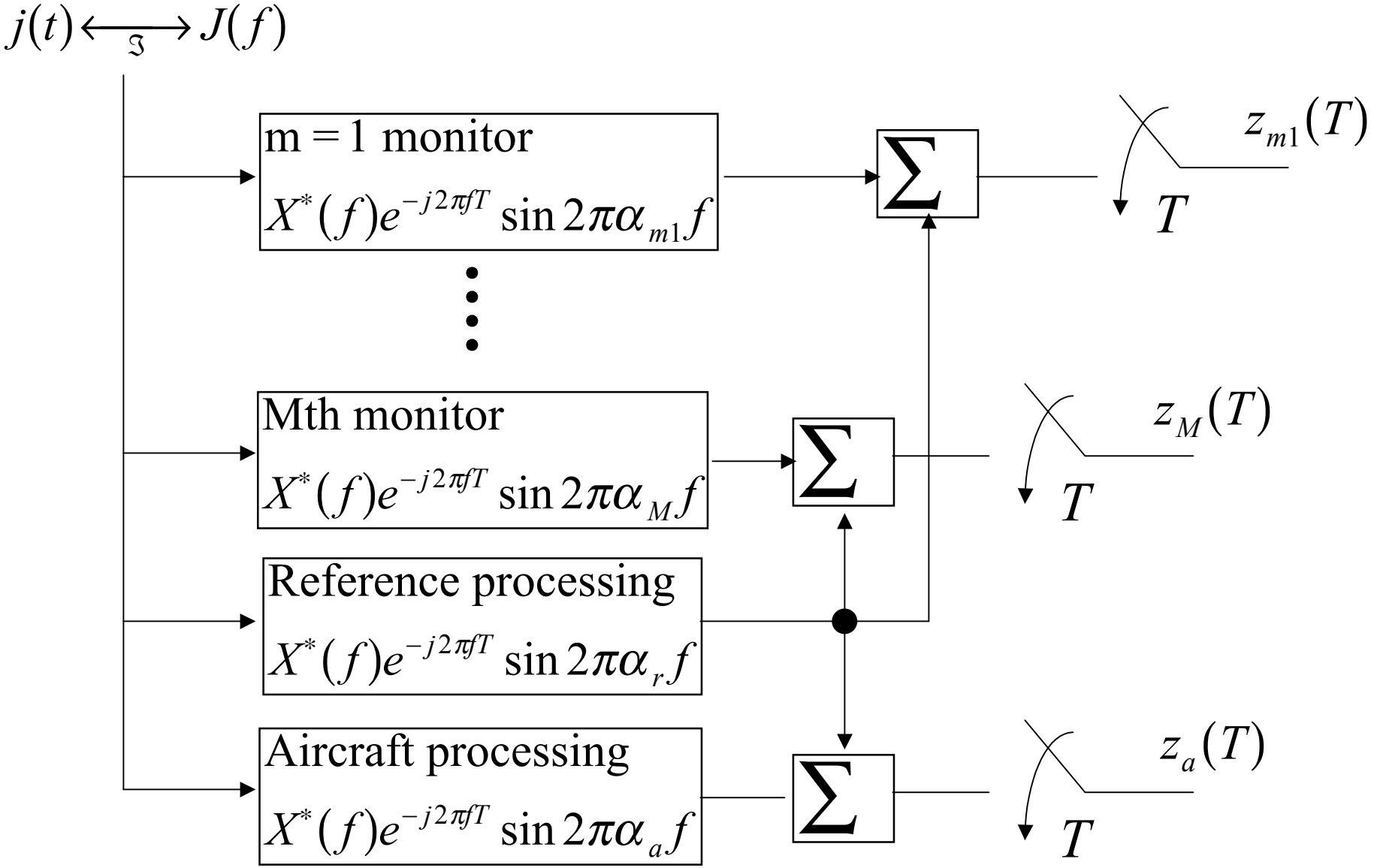
$$j(t) \underset{\Im}{\longleftrightarrow} J(f)$$



$$j_0(t) = \arg\max_{j(t)} z_0(T) \underset{\Im}{\longleftrightarrow} J_0(f)$$

$$J_0(f) = X(f)\left(\sin 2\pi\alpha_a f - \sin 2\pi\alpha_r f\right)$$

Figure B.3: Most Evil Waveform With M Monitors



Threat Model Summary

Model A: lead / lag anomalies only

$$-0.12 \le \Delta \le 0.12 \Leftrightarrow 0.0 \le \Delta \le 0.12$$

Model B: 2nd order anomalies only

$$\Delta = 0$$

$$4 \le f_d \le 17$$

$$0.8 \le \sigma \le 8.8$$

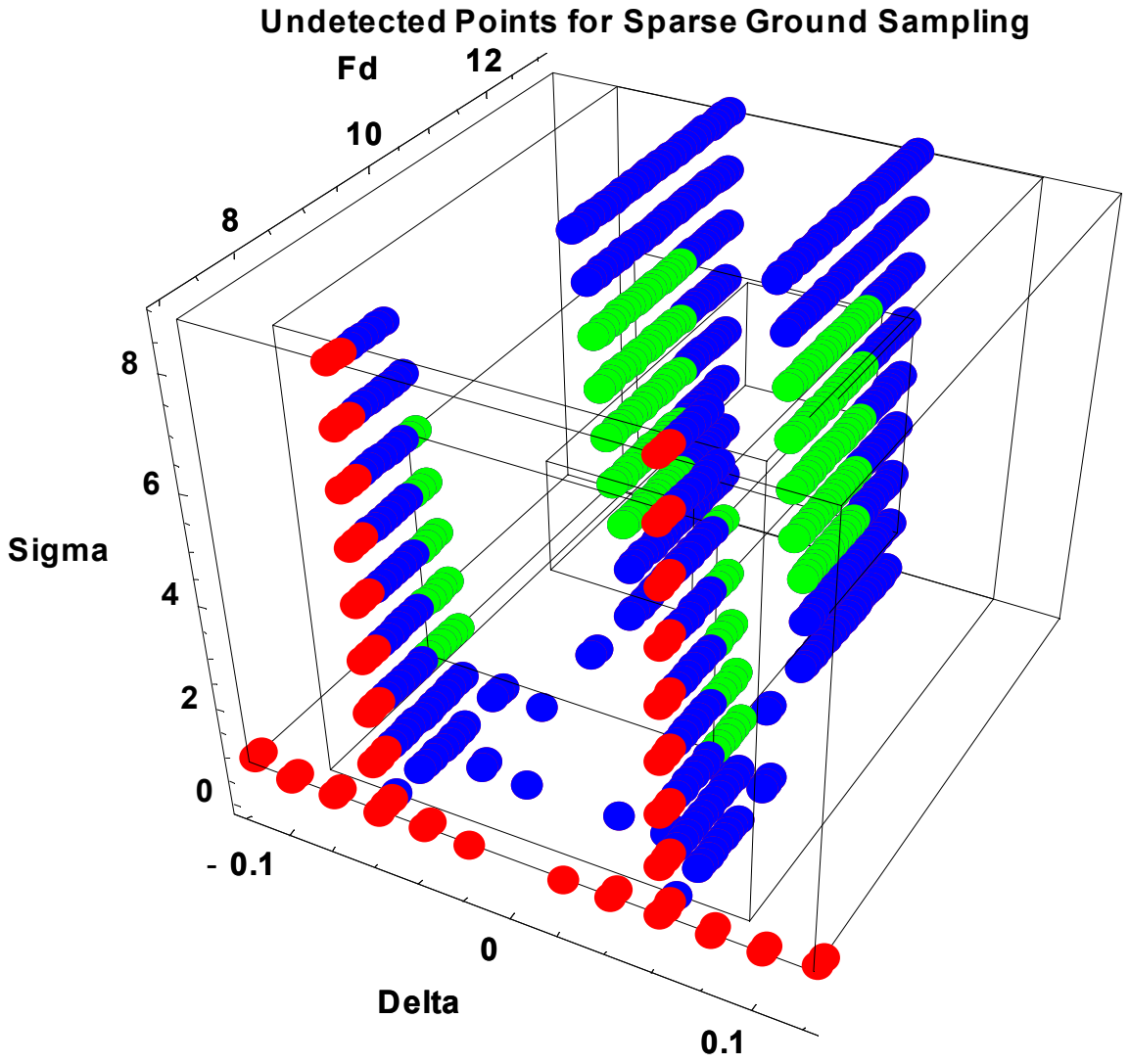
Model C: both lead / lag and 2nd order anomalies

$$-0.12 \le \Delta \le 0.12 \Leftrightarrow 0.0 \le \Delta \le 0.12$$

$$7.3 \le f_d \le 17$$

$$0.8 \le \sigma \le 8.8$$

Undetected Points for Sparse Ground Sampling
Threat Model C: $7<f_d<13$ MHz



Air PR Errors for Sparse Ground Sampling Threat Model C: With 7.3 MHz<fd<17.0 MHz N=12 Butterworth

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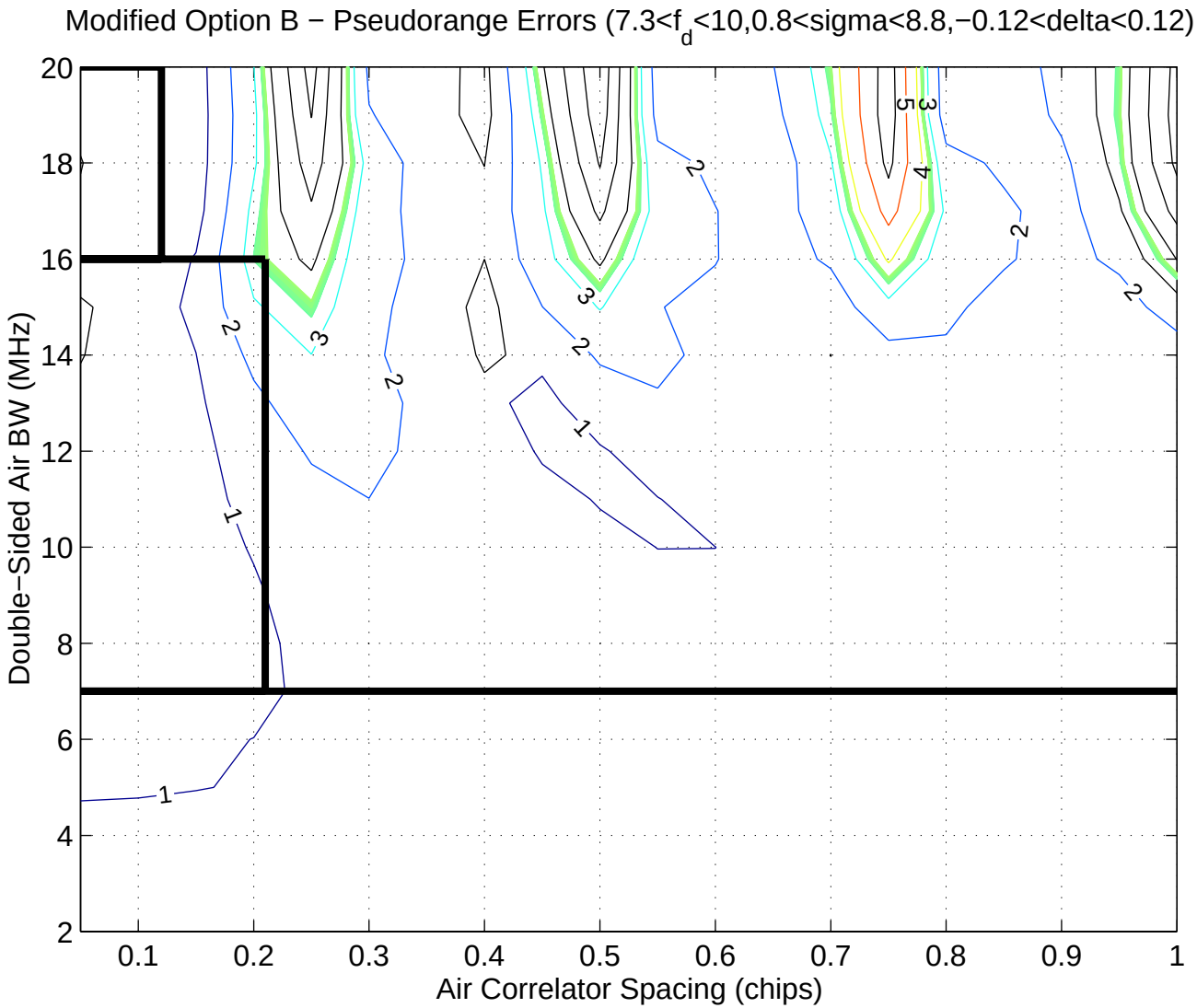

Air PR Errors for Sparse Ground Sampling Threat Model C: With 7.3 MHz<fd<17.0 MHz N=12 Tchebyshev

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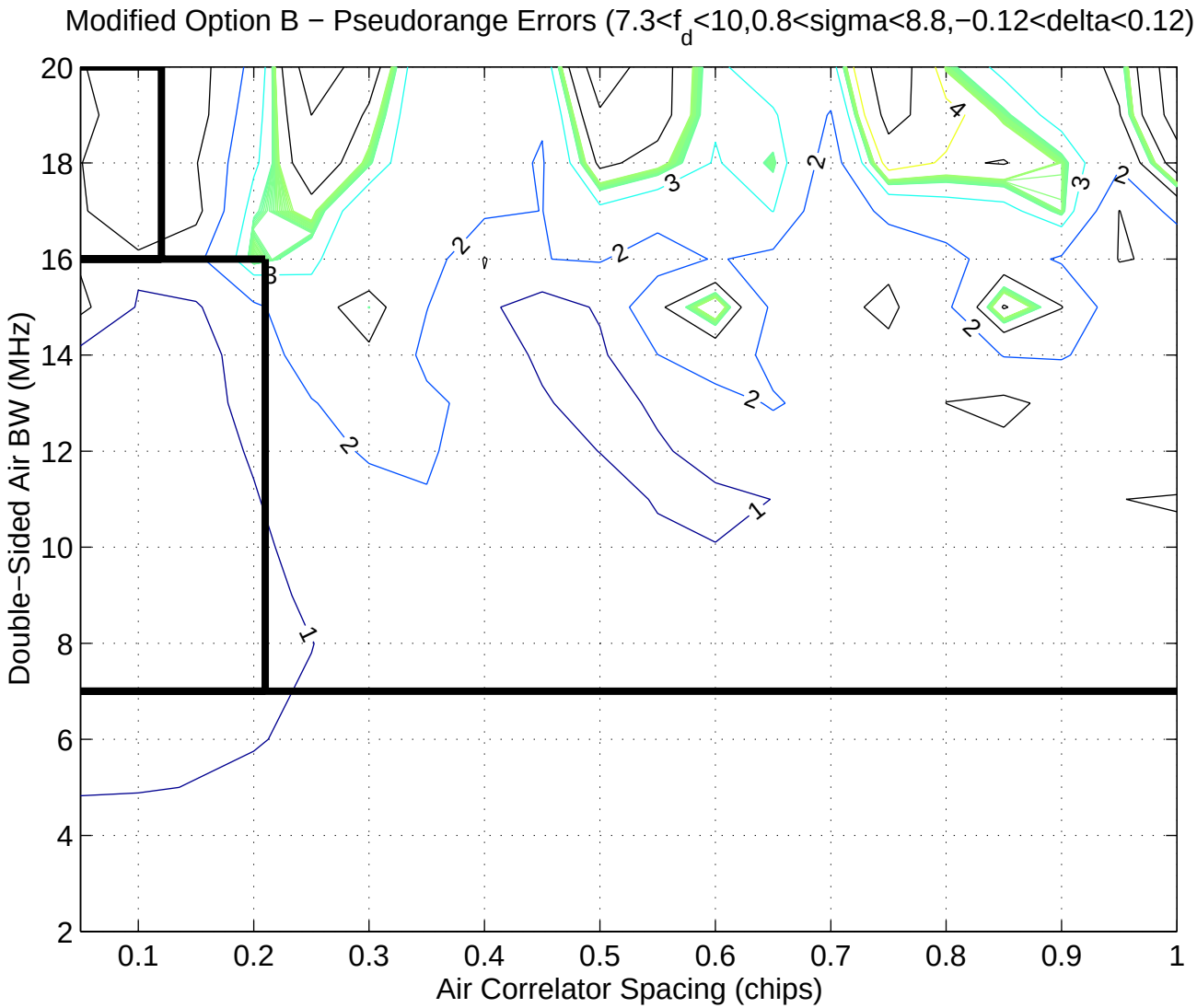

Air PR Errors for Sparse Ground Sampling Threat Model C: With 7.3 MHz<fd<17.0 MHz N=20 FIR Filter

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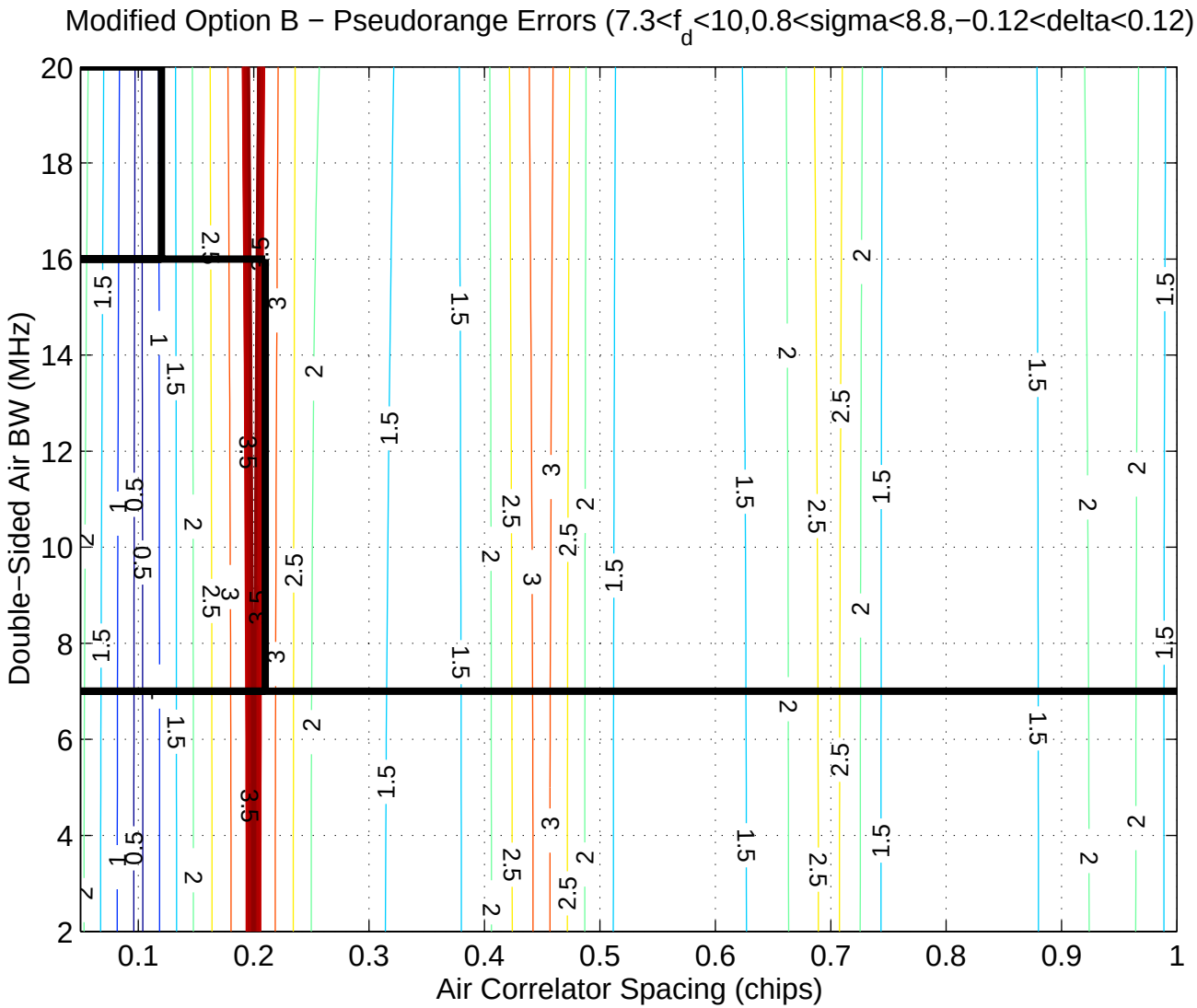
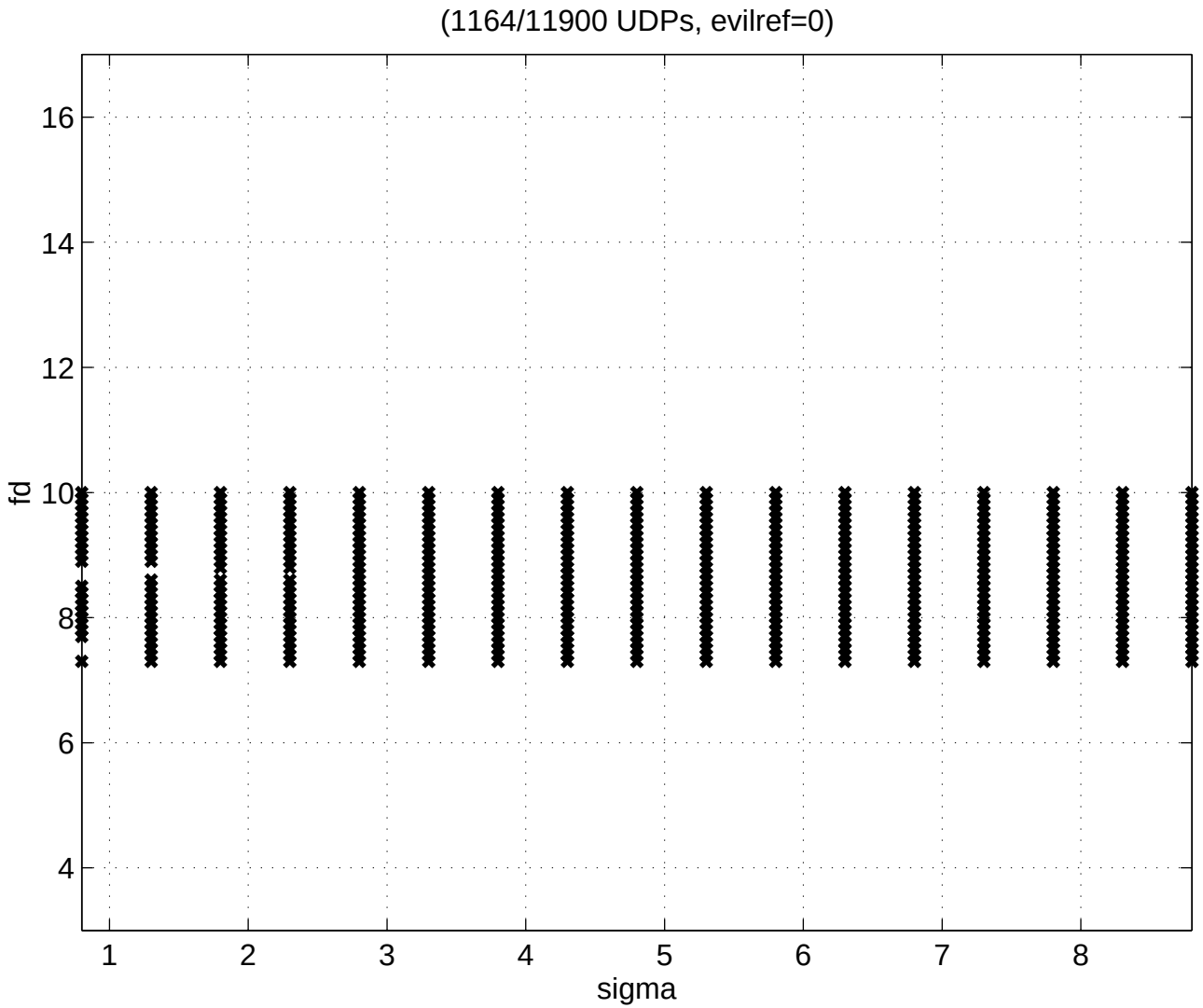
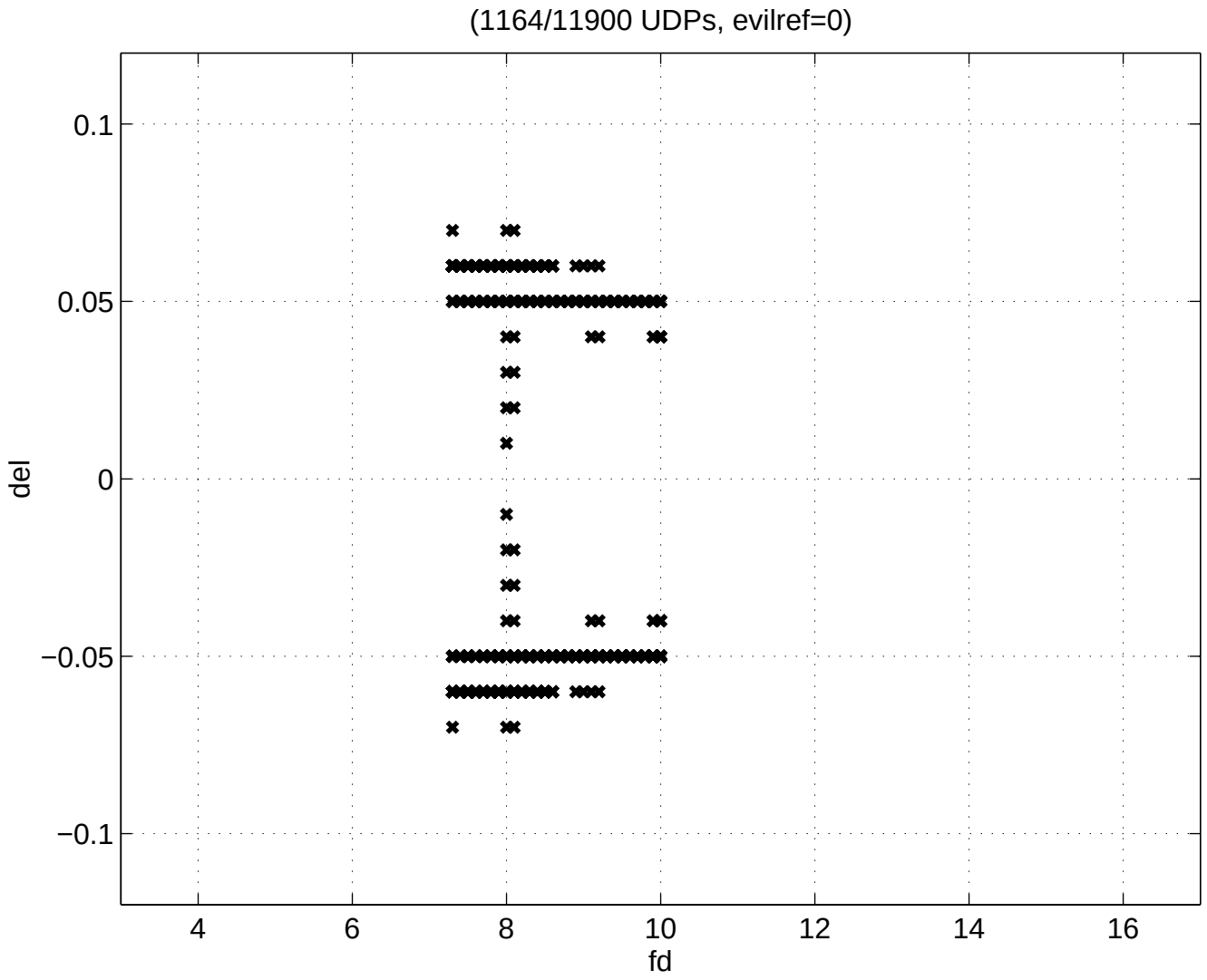
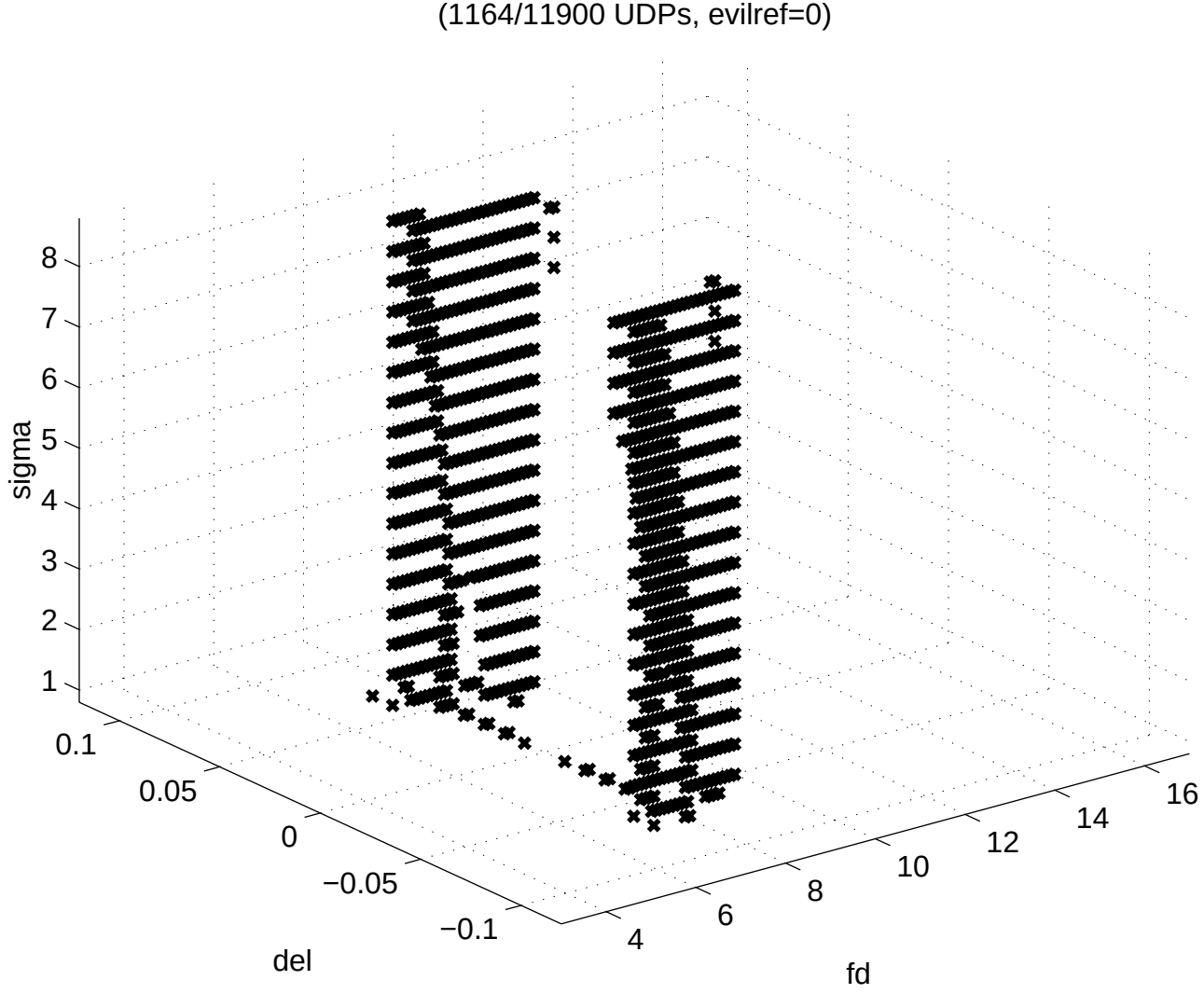



(1164/11900 UDPs, evilref=0)
fd
sigma
16
14
12
10
8
6
4
1
2
3
4
5
6
7
8


(1164/11900 UDPs, evilref=0)
0.1
0.05
0
−0.05
−0.1
del
4
6
8
10
12
14
16
fd


(1164/11900 UDPs, evilref=0)
sigma
8
7
6
5
4
3
2
1
0.1
0.05
0
−0.05
−0.1
del
4
6
8
10
12
14
16
fd