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Data Compression For Multi- Platform Emitter Location

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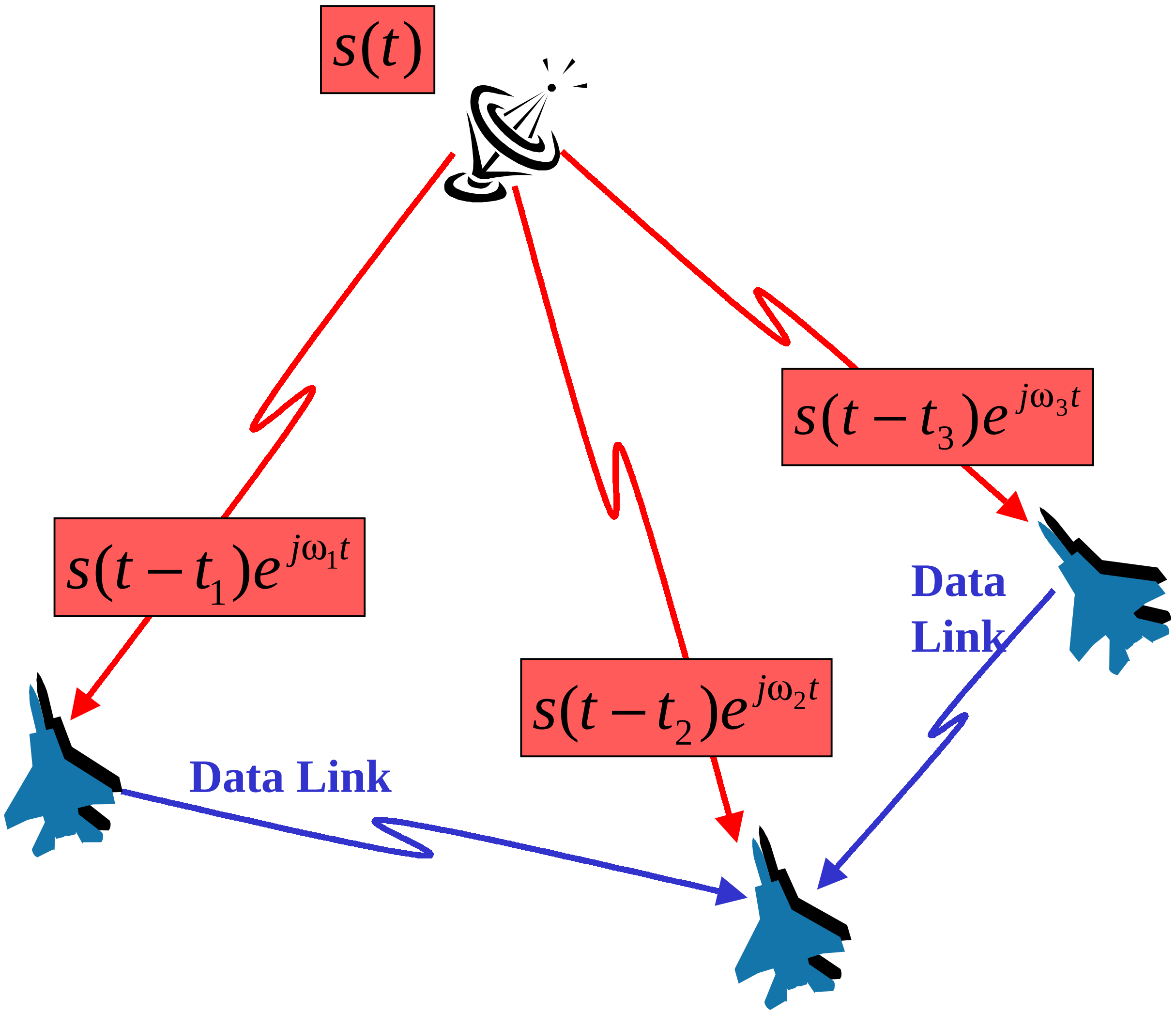
EMITTER LOCATION PROBLEM



TDOA Location

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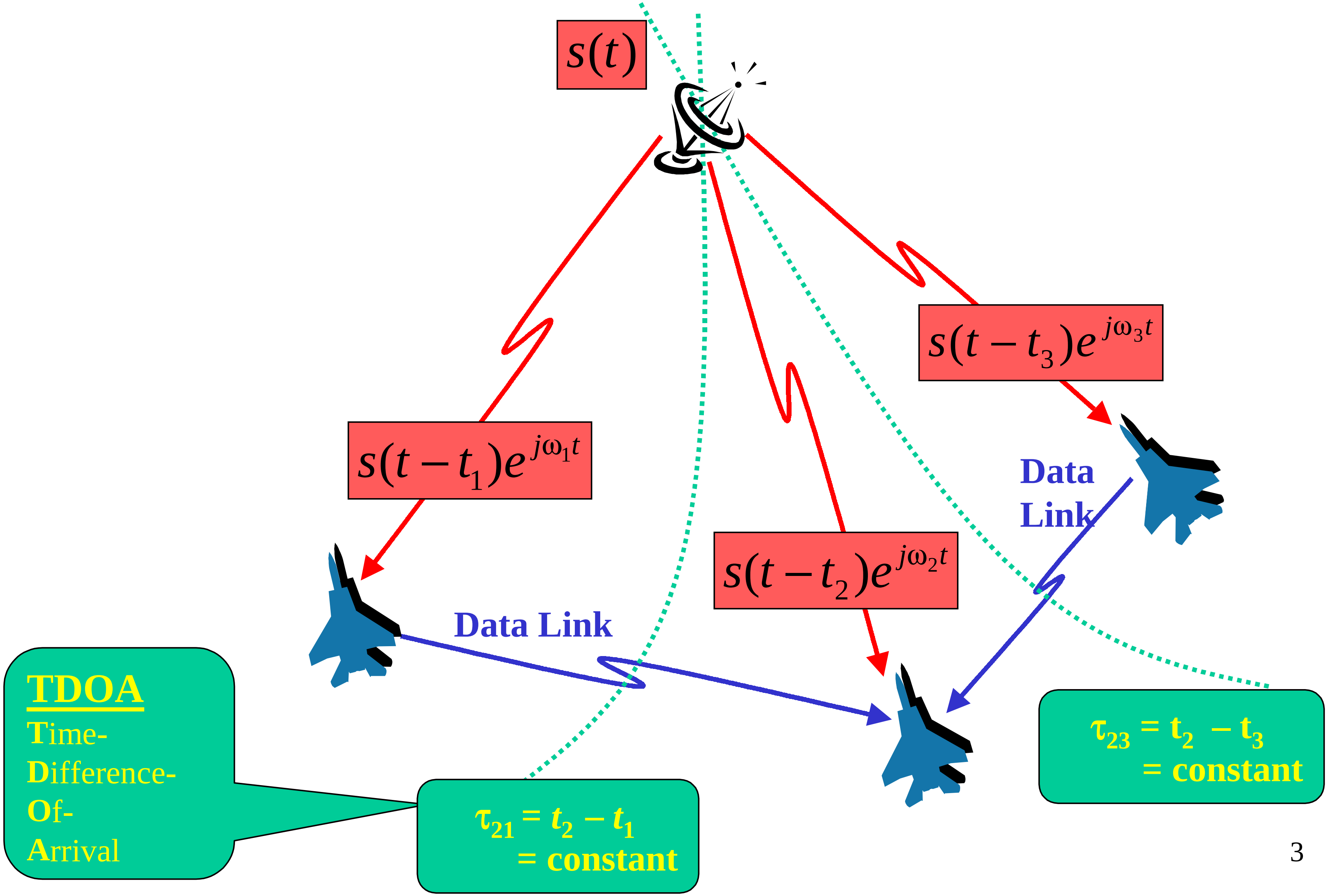
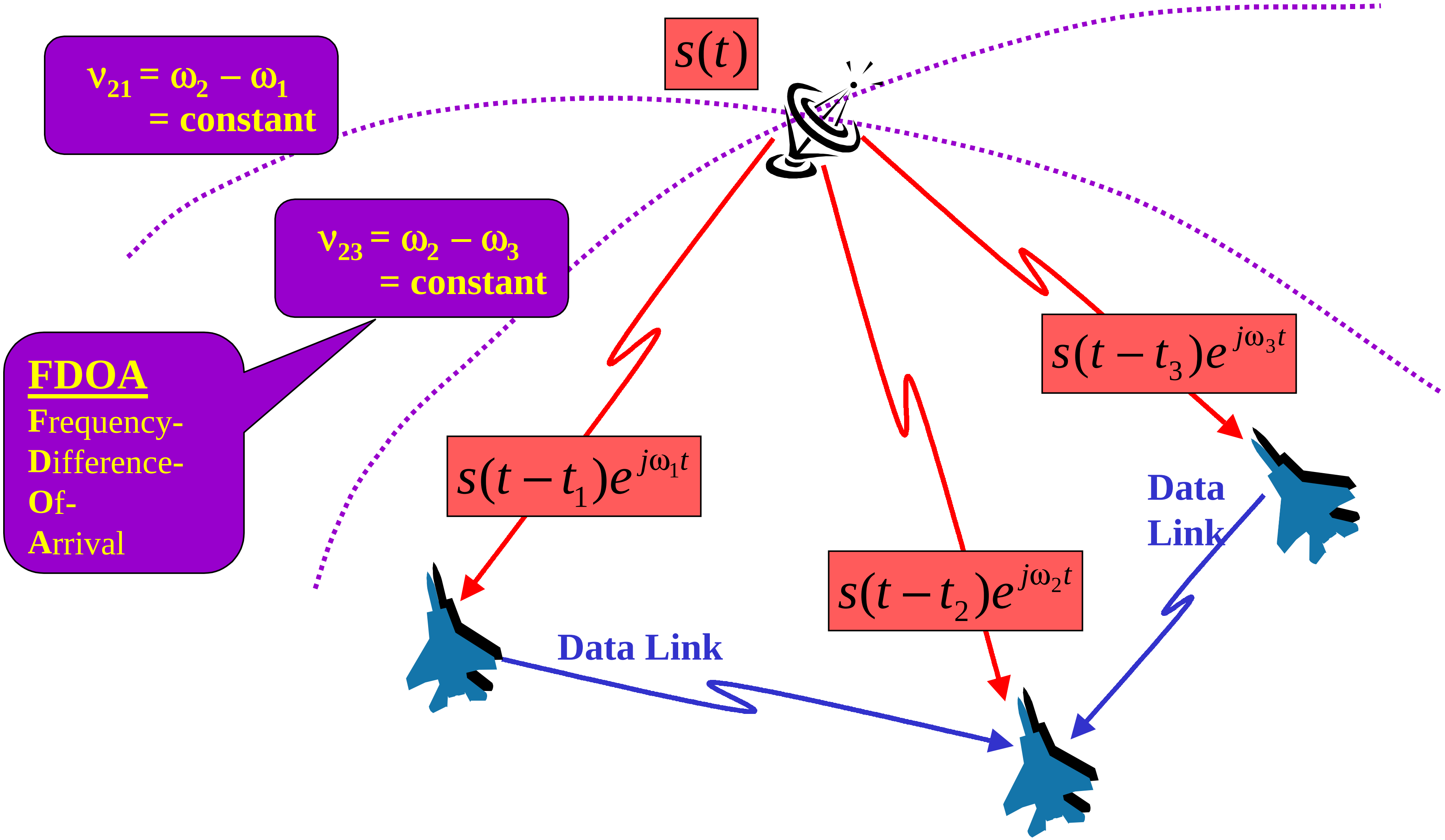
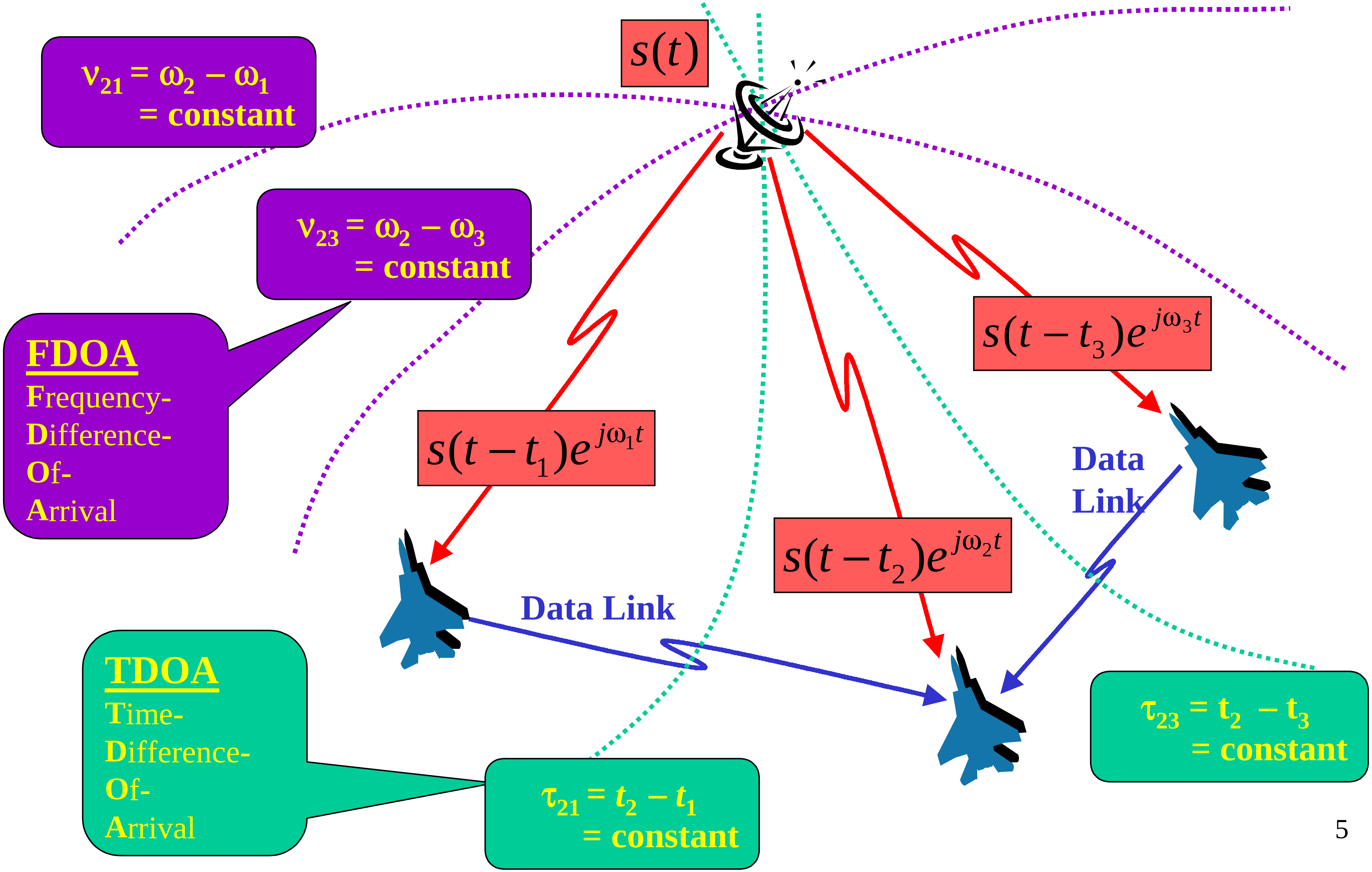


FDOA LOCATION



TDOA/FDOA LOCATION



CROSS-CORRELATION FOR TDOA

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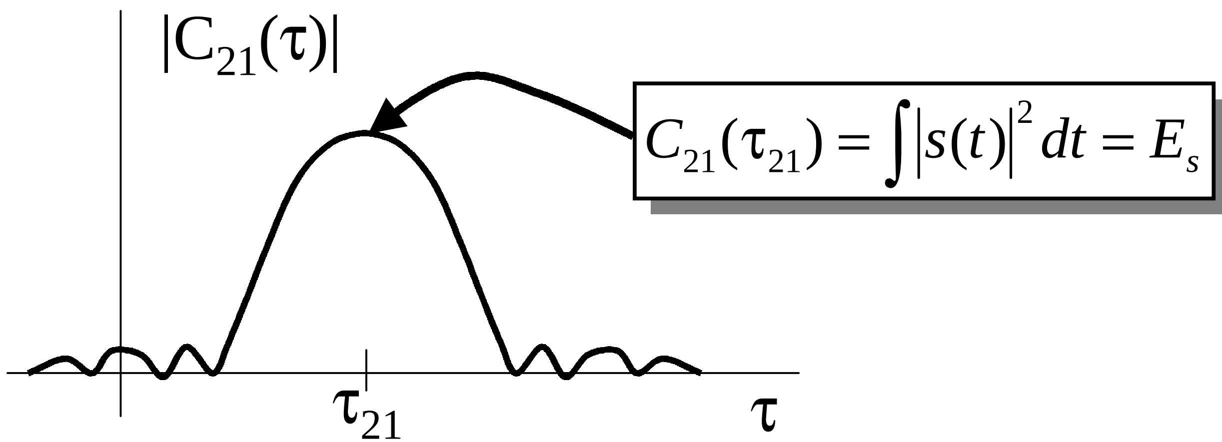
- Estimate τ_{21} Using Cross-Correlation:

$$
\begin{aligned}
C_{21}(\tau) &= \int s_2(t)s_1^*(t-\tau)dt \\
&= \int s(t-t_2)s^*(t-t_1-\tau)dt \\
&= \int s(t)s^*(t+\underbrace{(t_2-t_1)}_{\tau_{21}}-\tau)dt
\end{aligned}
$$



TDOA ACCURACY

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- After correlation:

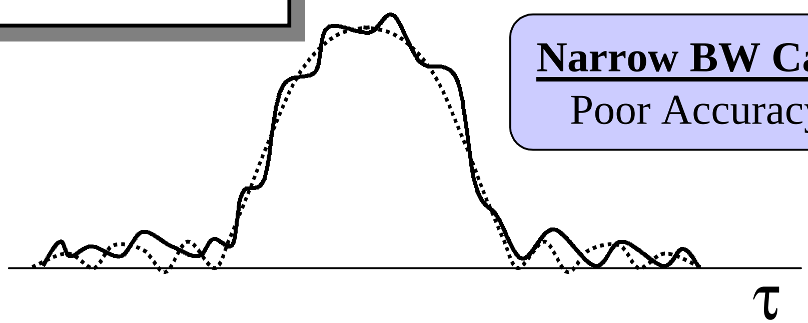
$$SNR_{cc} = \frac{WT}{\frac{1}{SNR_1} + \frac{1}{SNR_2} + \frac{1}{SNR_1 SNR_2}} = WT\, SNR_{eff}$$

WT = Time-BW Product
SNR_1: signal-to-noise ratio #1
SNR_2: signal-to-noise ratio #2

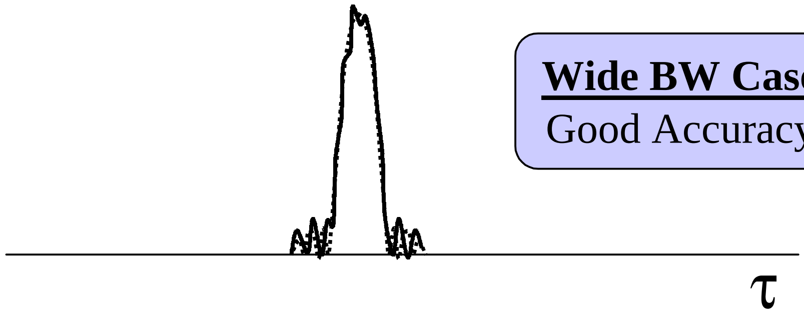
- TDOA accuracy:

$$\sigma_{TDOA} \geq \frac{1}{2\pi B_{rms} \sqrt{SNR_{cc}}}$$

$$B_{rms}^2 = \frac{\int f^2 |S(f)| df}{\int |S(f)| df}$$



Narrow BW Case
Poor Accuracy



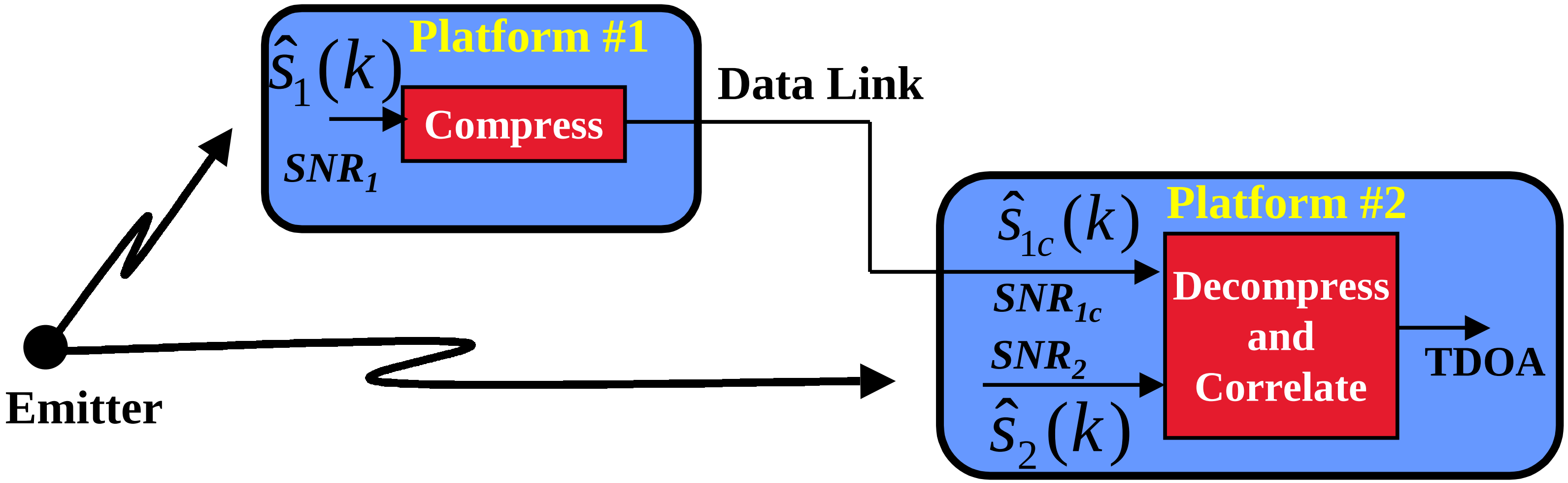
Wide BW Case
Good Accuracy

DATA COMPRESSION

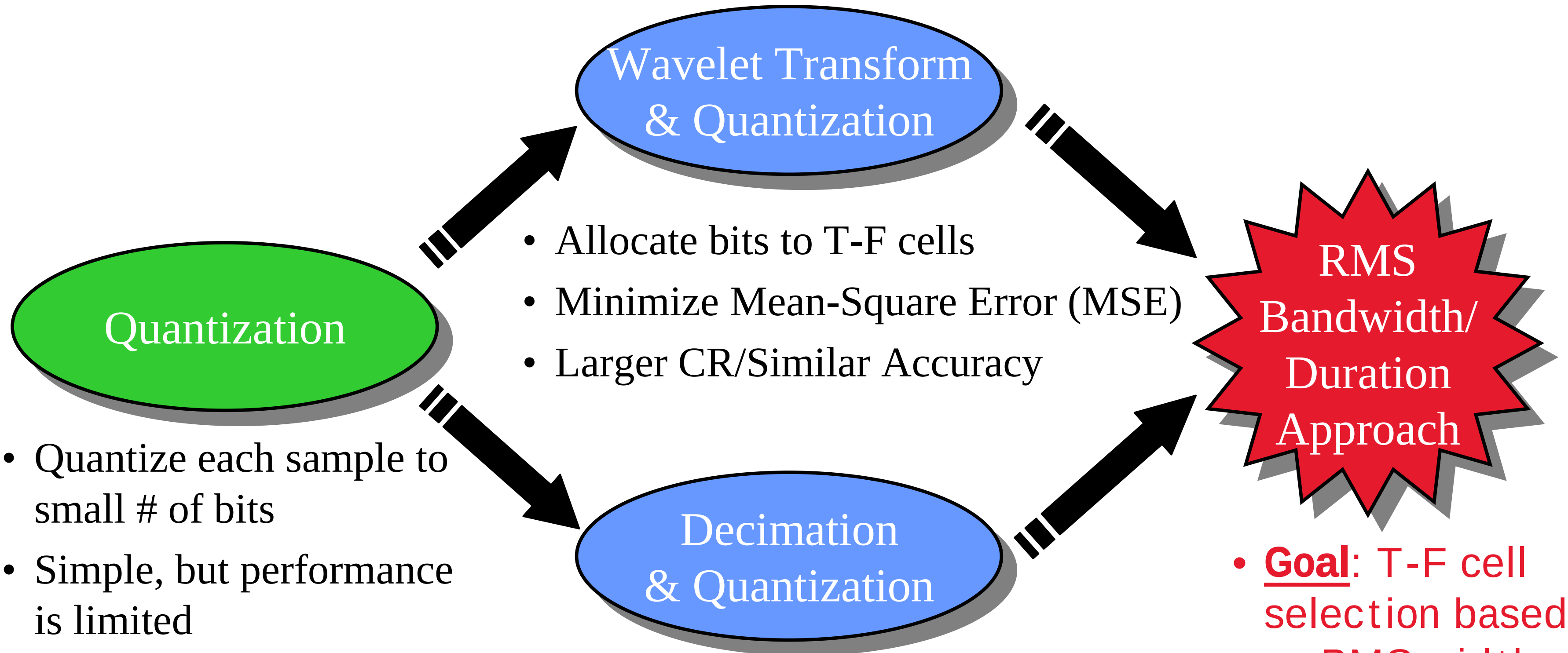
- Intercept several signal pairs received at separate sites
  - » Estimate Time-Difference-of-Arrival (**TDOA**) via **Cross-Correlation**
  - » Emitter location found by fusing several TDOA estimates
- Requires transferring signal data between sites
- Link **rate often insufficient** to transfer within **time limit**

➔ **Use Compression to meet link requirements**

➔ **Assess via Rate-Distortion Analysis**



THREE NEW APPROACHES



- Quantize each sample to small # of bits
- Simple, but performance is limited

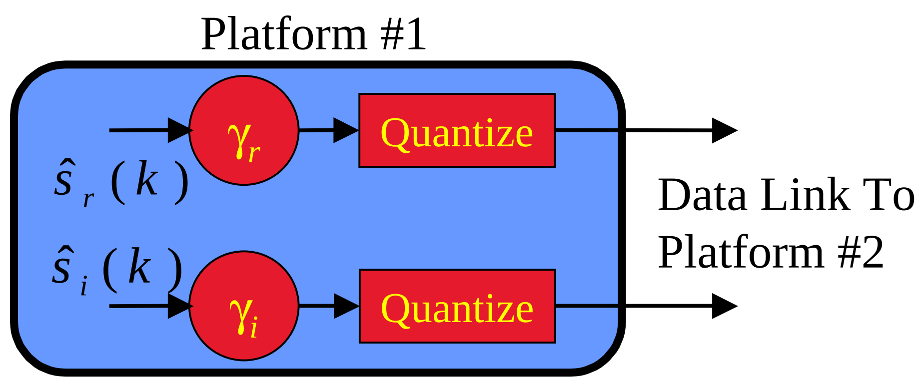
- Allocate bits to T-F cells
- Minimize Mean-Square Error (MSE)
- Larger CR/Similar Accuracy

- Optimally trades dec. & quant.
- Non-MSE Approach
- Outperforms quantization only

- **Goal**: T-F cell selection based on RMS widths

R/I QUANTIZATION

- For each block, apply to real and imaginary parts:
  - » Scale samples
  - » Quantize



- Performance measured by SNR after compression

$$SNR_{1c} = \frac{SNR_1}{1 + \alpha^2 SNR_1 \left(\frac{2^{-2b}}{3} \right)}$$

See **M. L. Fowler**, "Coarse Quantization for Data Compression in Coherent Location Systems," in *IEEE Transactions on Aerospace and Electronic Systems*, Oct. 2000.

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COMBINED QUANTIZATION & DECIMATION

M. L. Fowler, "Decimation vs. Quantization for Data Compression in TDOA Systems," Conference on Mathematics and Applications of Data/Image Coding, Compression, and Encryption III, San Diego, July 30 – August 4, 2000 .

SIGNAL MODEL

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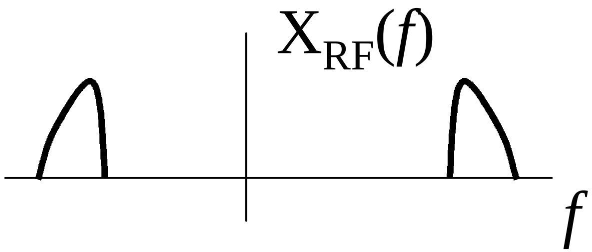
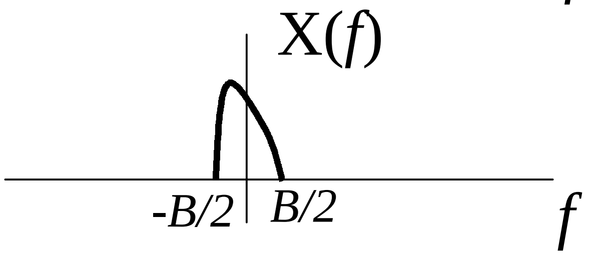
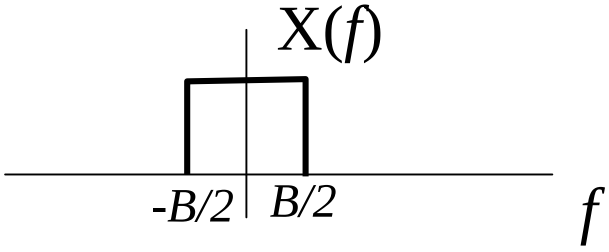
- Complex Equivalent Lowpass signal, **BW = *B* Hz**
  - » Representing RF signal with RF BW = B Hz
- Sampled at **Fs=B** *complex* samples/sec
- Quantized to **2*b* bits**/complex sample
  - » *b* for real part
  - » *b* for imaginary part
- Fixed **Collection Time *T*** sec
- **Total Bits: 2*bBT***
- **Simplifying Assumption: Flat Spectrum –B/2 to B/2**
  - » Simplifies analysis, yet allows insight
  - » $2\pi B_{rms} = 1.8B$







NON-MSE DISTORTION CRITERION

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- Past efforts have focused on MSE Distortion
  - » Control impact of compression on SNR_q and hence SNR_{cc} and hence σ_{TDOA}

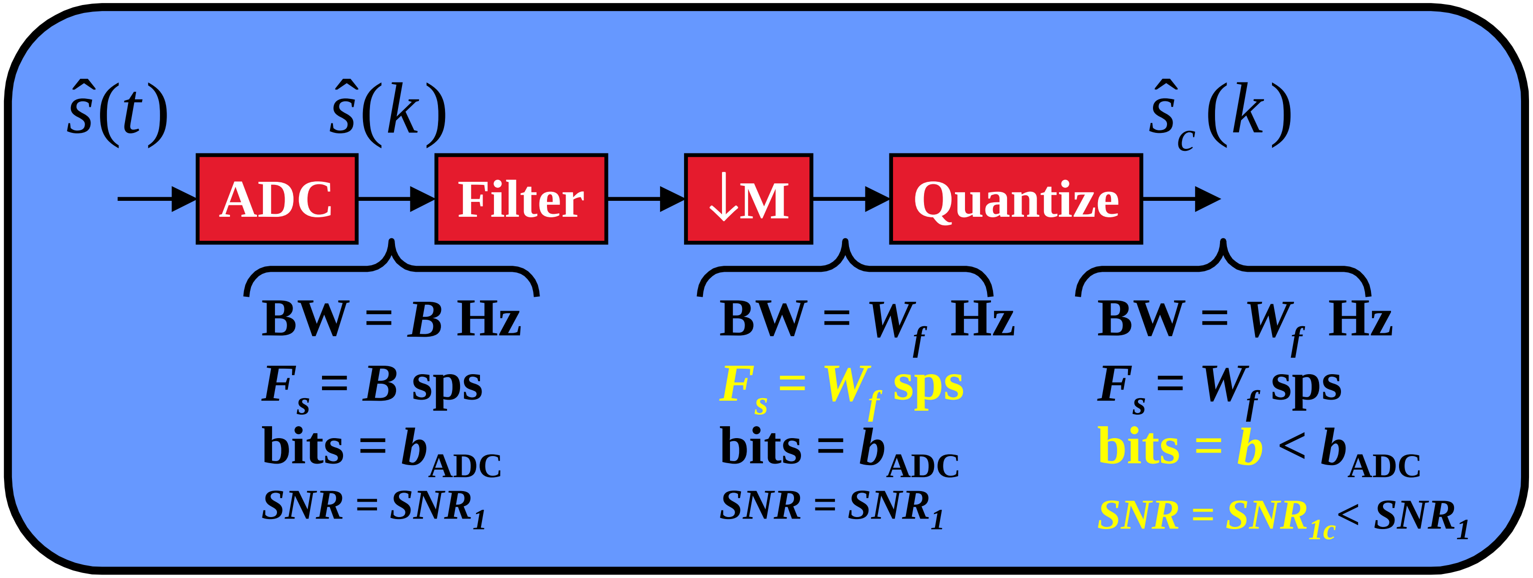
$$SNR_{cc} = \frac{WT}{\frac{1}{SNR_{1c}} + \frac{1}{SNR_2} + \frac{1}{SNR_{1c}\,SNR_2}} = WT\,SNR_{eff}$$

- This ignores exploitable structure of signal
  - » Namely, B_{rms} also impacts σ_{TDOA}
  - » How can we exploit this for compression in TDOA Systems?
    - – **Simple Way: Quantize (SNR_{cc}) *and* Decimate (B_{rms})**

$$\sigma_{TDOA} \geq \frac{1}{2\pi\, B_{rms}\sqrt{SNR_{cc}}}$$

PROCESSING MODEL

- Combine Quantization & Decimation
- Optimize Under Rate Constraint



RATE CONSTRAINT

- Goal: Minimize σ_{TDOA} for fixed Effective Link Rate

- Requirements: Fixed **link time T_l**
  Available **link rate of R_l**
  Fixed **signal collection time T**

Effective Rate
$R = R_l (T_l / T)$

- ➔ **Rate Constraint:**

$$2bBT \leq R_l T_l$$

or

$$2bB = R$$

Fully Utilize Link

QUANTIZATION *AND* DECIMATION

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- Goals: 1. Find optimal trade-off for Dec vs. Quant
  2. Compute R-D Curves
- Optimally Choose: **2*b* bits**/complex sample
  Filtered BW W_f Hz
  Decimated $F_s = W_f$ complex sps

$$\sigma_{TDOA}(W_f) \geq \frac{1}{1.8 W_f^{3/2} \sqrt{TSNR_{eff}(b)}}$$

Rate Constraint

$$W_f = R/2b$$

$$\sigma_{TDOA}(R) \geq \frac{2^{3/2}}{1.8\, R^{3/2} \sqrt{T}} \left[\frac{b^{3/2}}{\sqrt{SNR_{eff}(b)}} \right]$$

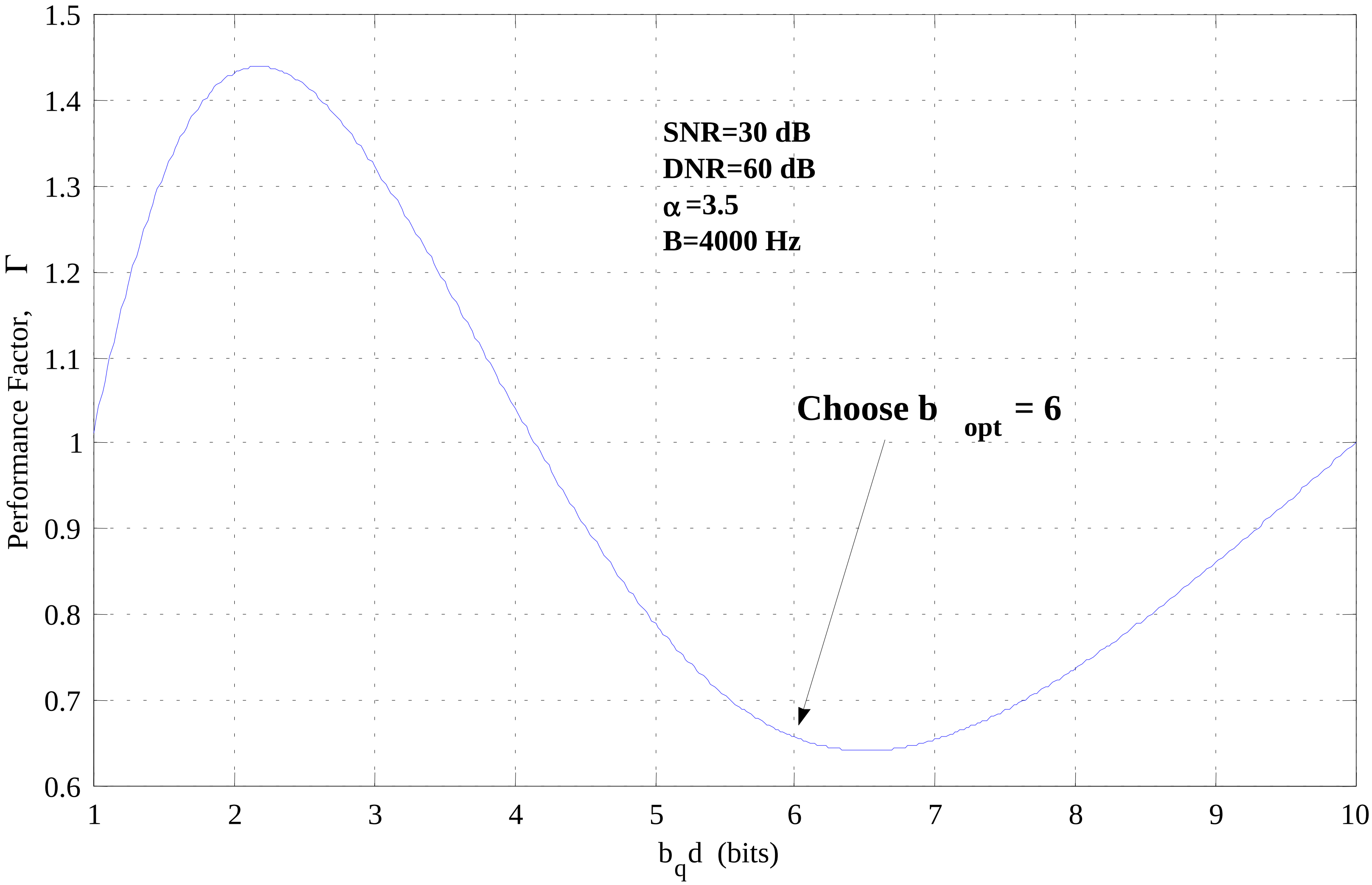
Depends on α, SNR & DNR

Fixed by System Parms

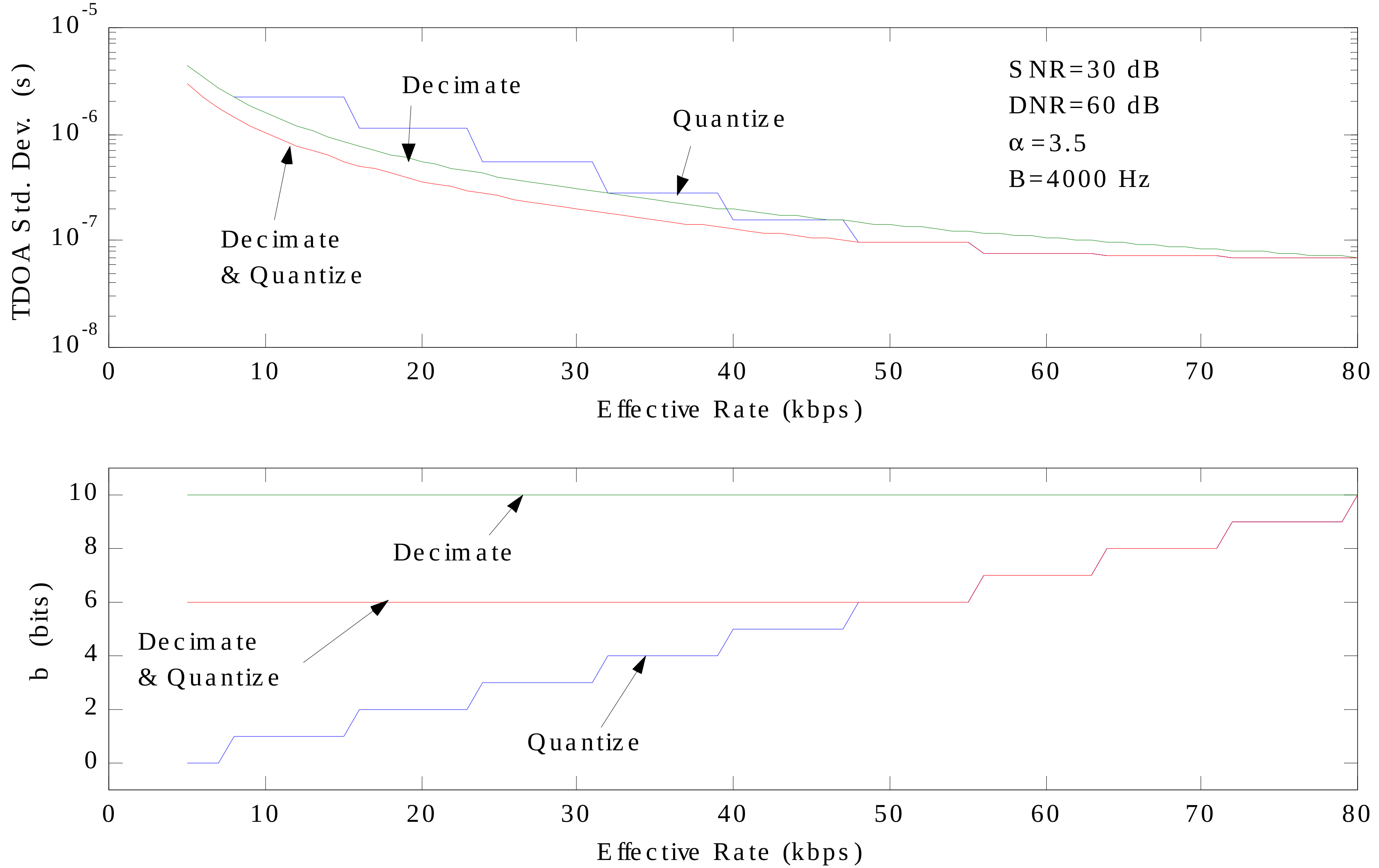
$\Gamma(b)$ Perf. Factor

Minimize vs. *b*

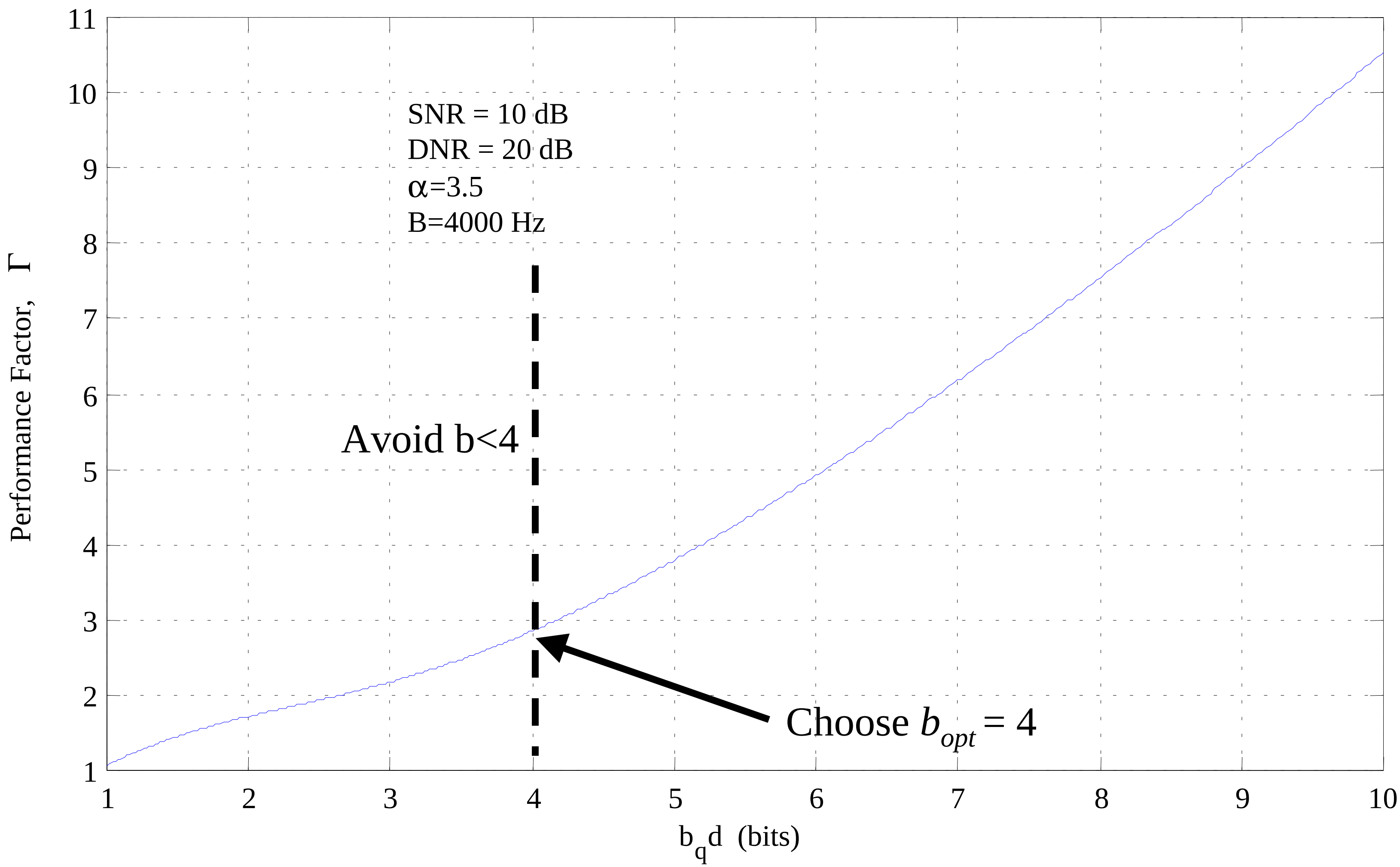
HIGH SNR: PERFORMANCE FACTOR



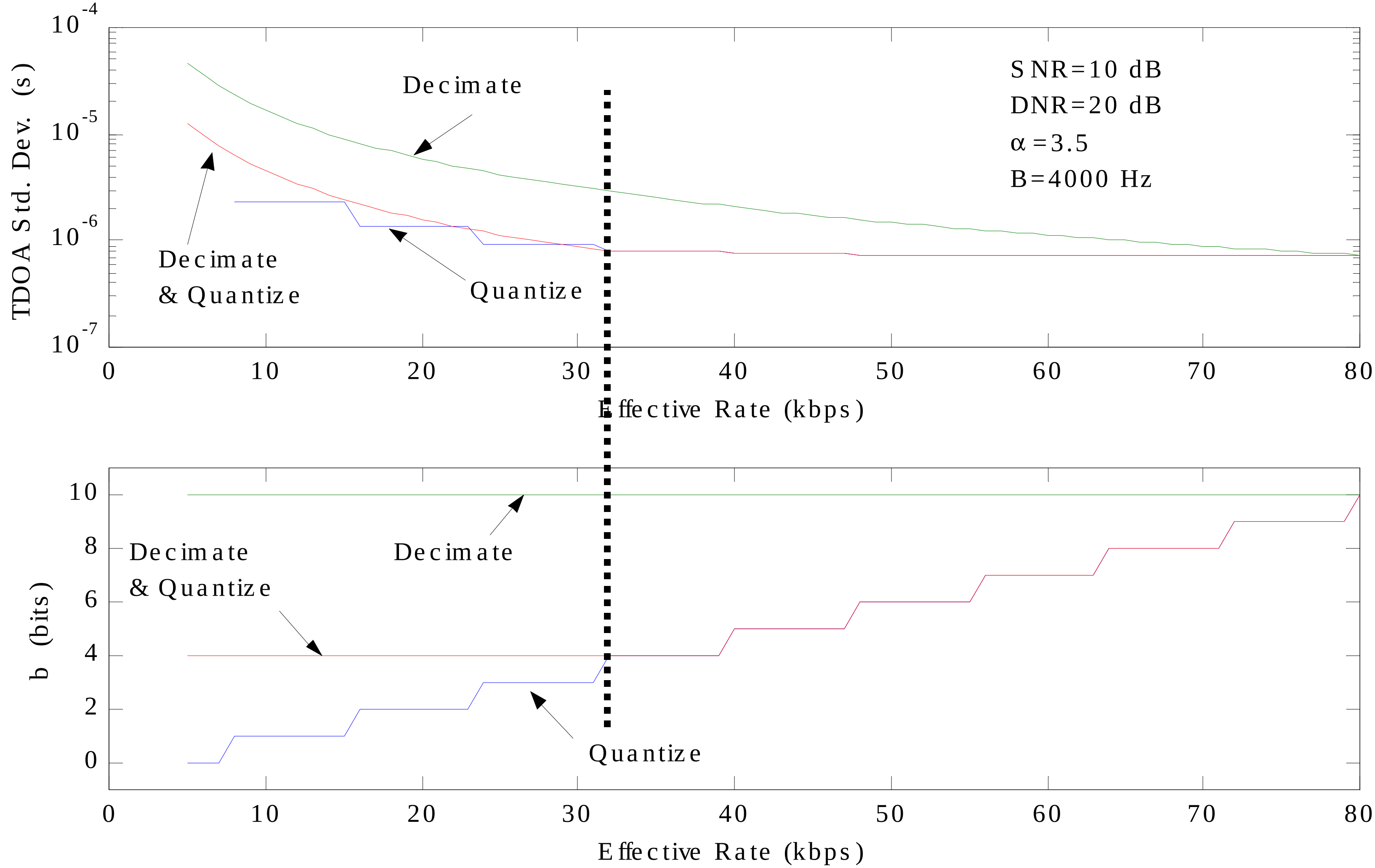
HIGH SNR: R-D CURVE



LOW SNR: PERFORMANCE FACTOR



Low SNR: R-D Curve



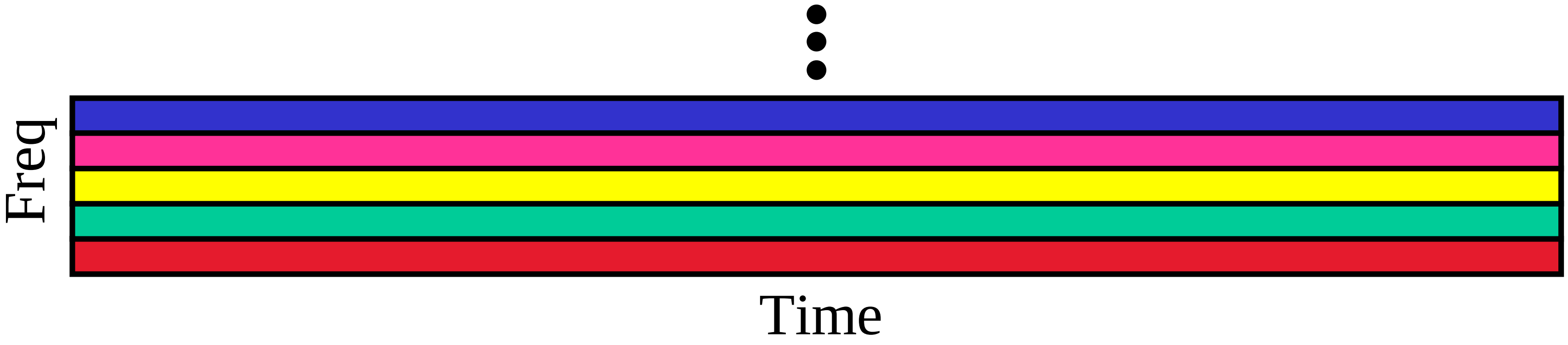
WAVELET METHODS

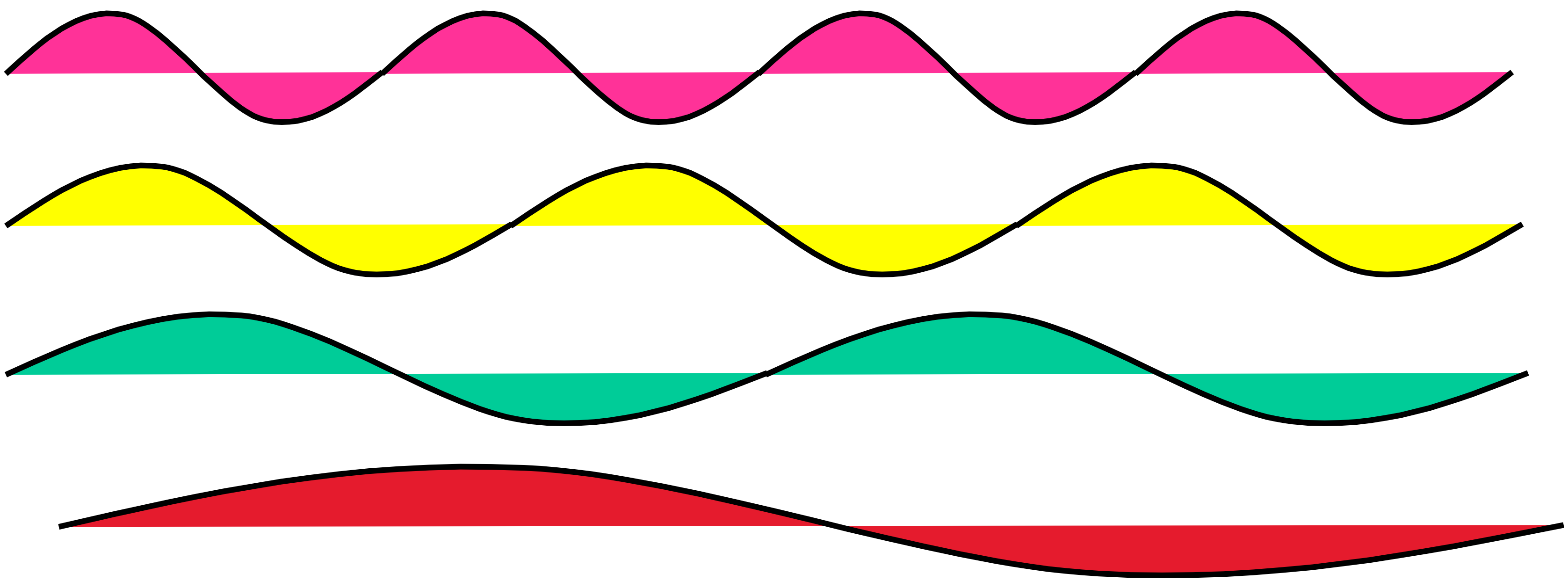
- MSE-Based Method
- Non-MSE Method

M. L. Fowler, “Data Compression for Emitter Location,” Conference on Information Sciences and Systems, Princeton University, March 15-17, 2000.

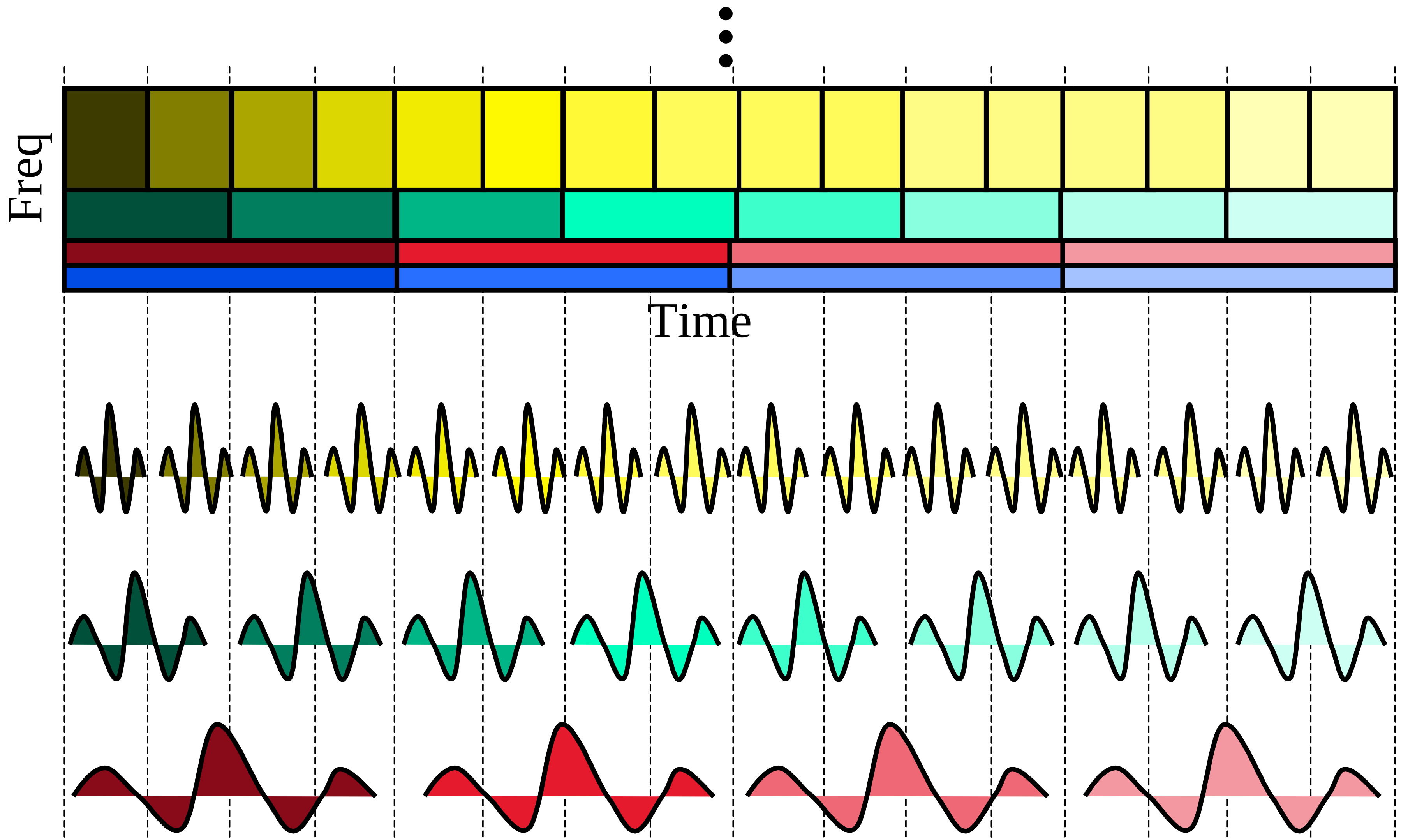
M. L. Fowler, “Exploiting RMS Time-frequency Structure For Data Compression In Emitter Location Systems,” National Aerospace & Electronics Conference, Dayton, Ohio, October 10-12, 2000.

DISCRETE FOURIER TRANSFORM

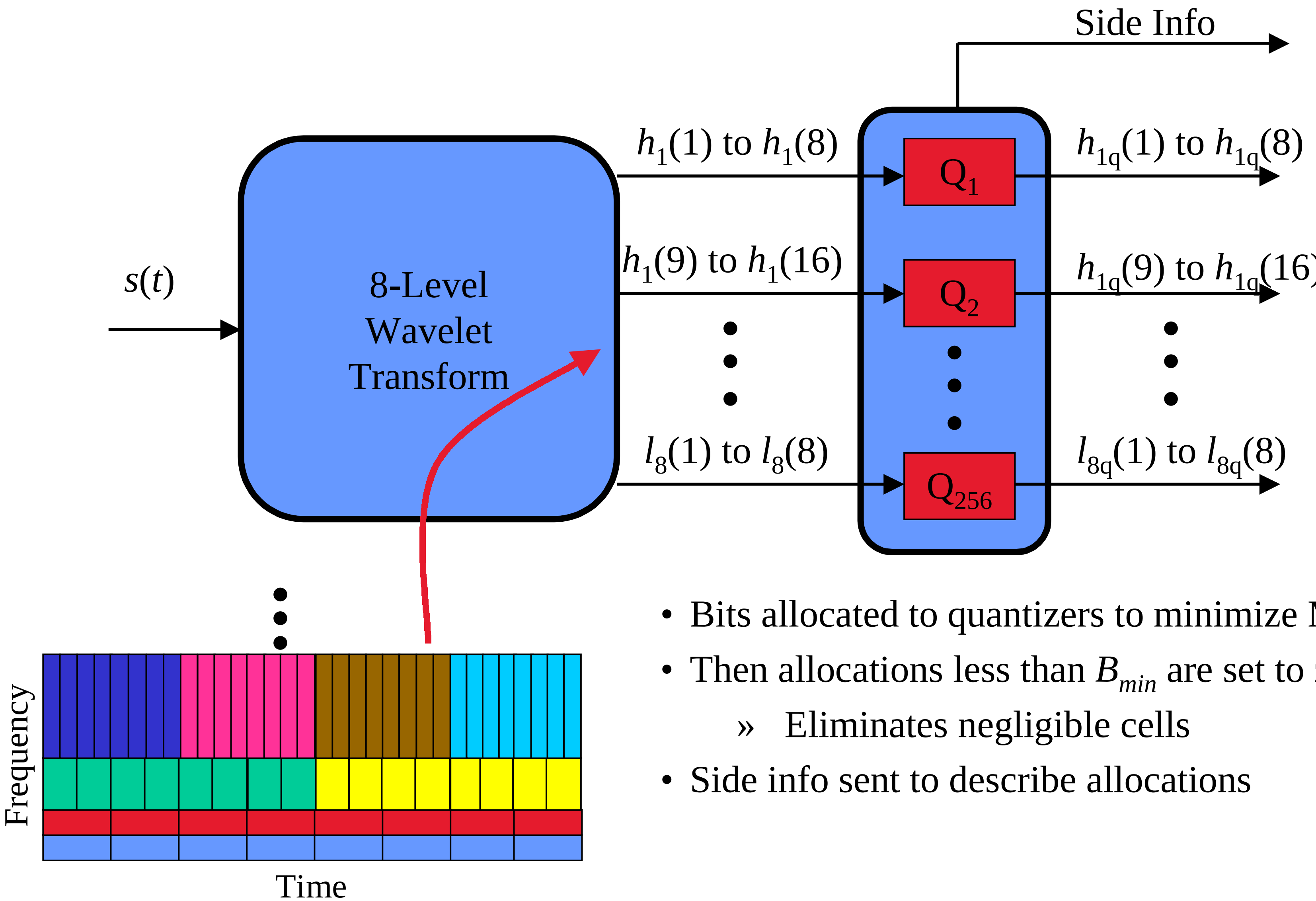




Wavelet Transform



WT-BASED COMPRESSION



- Bits allocated to quantizers to minimize MSE
- Then allocations less than B_{min} are set to zero
  - » Eliminates negligible cells
- Side info sent to describe allocations

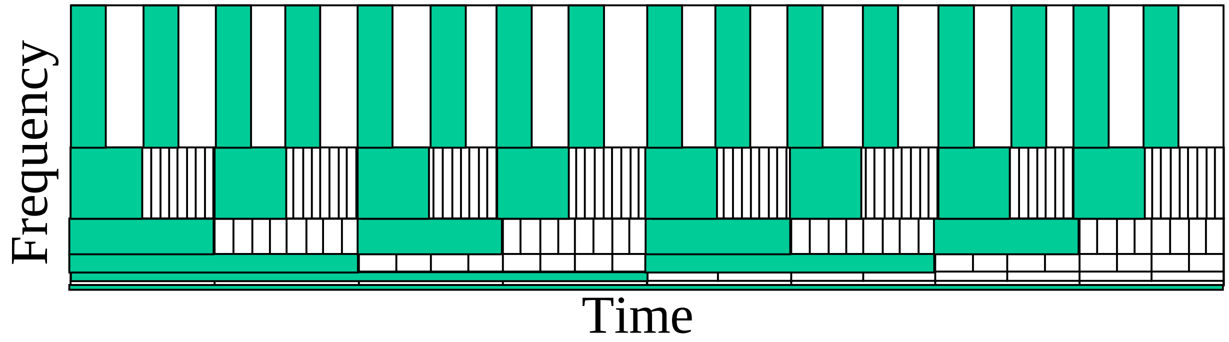
WT METHODS: MSE VS. NON-MSE

MSE Approach

- Allocate bits to quantizers to minimize MSE
- Then allocations less than B_{min} are set to zero
  - » Eliminates negligible cells

Non-MSE Approach Experiment

- First Perform MSE-Based Allocation (w/ B_{min})
- Then throw away "white cells" on checkerboard
  - » Effective at preserving RMS Widths
  - » Increases Compression Ratio



WT SIMULATION RESULTS

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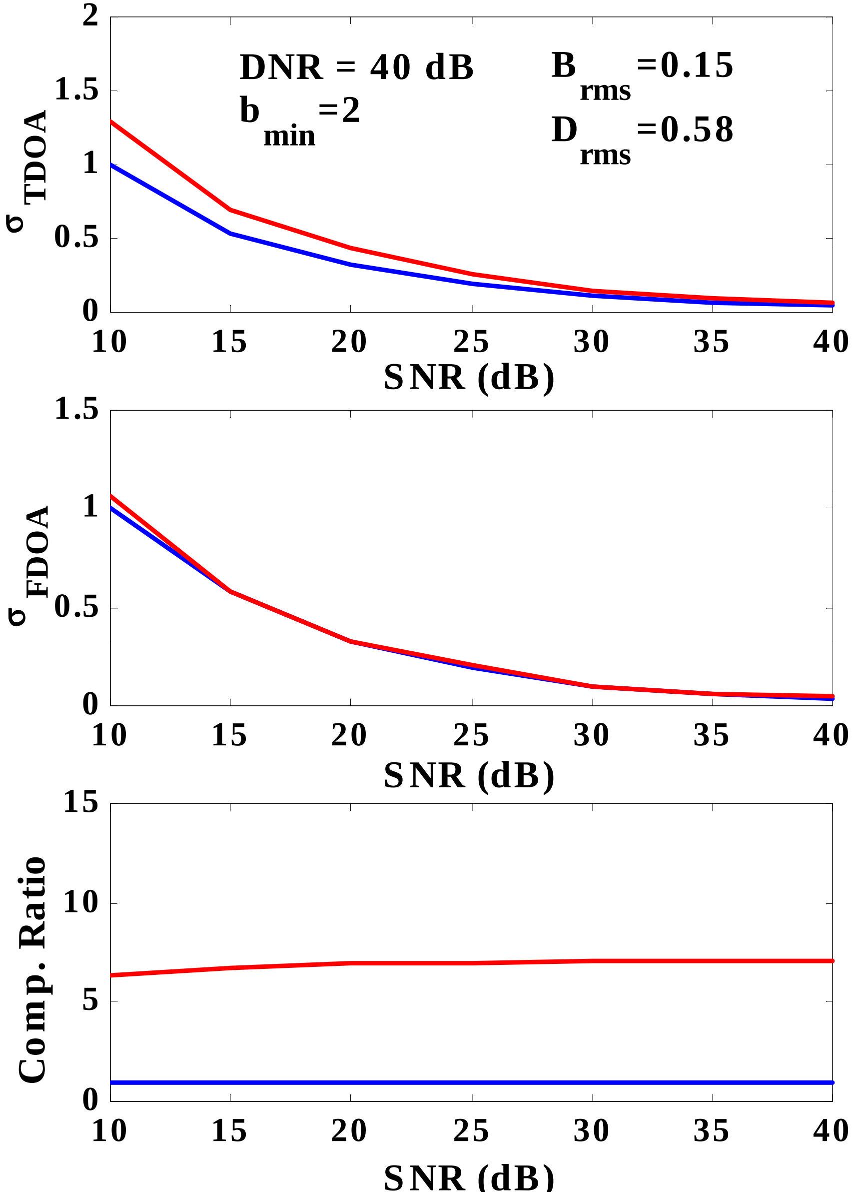
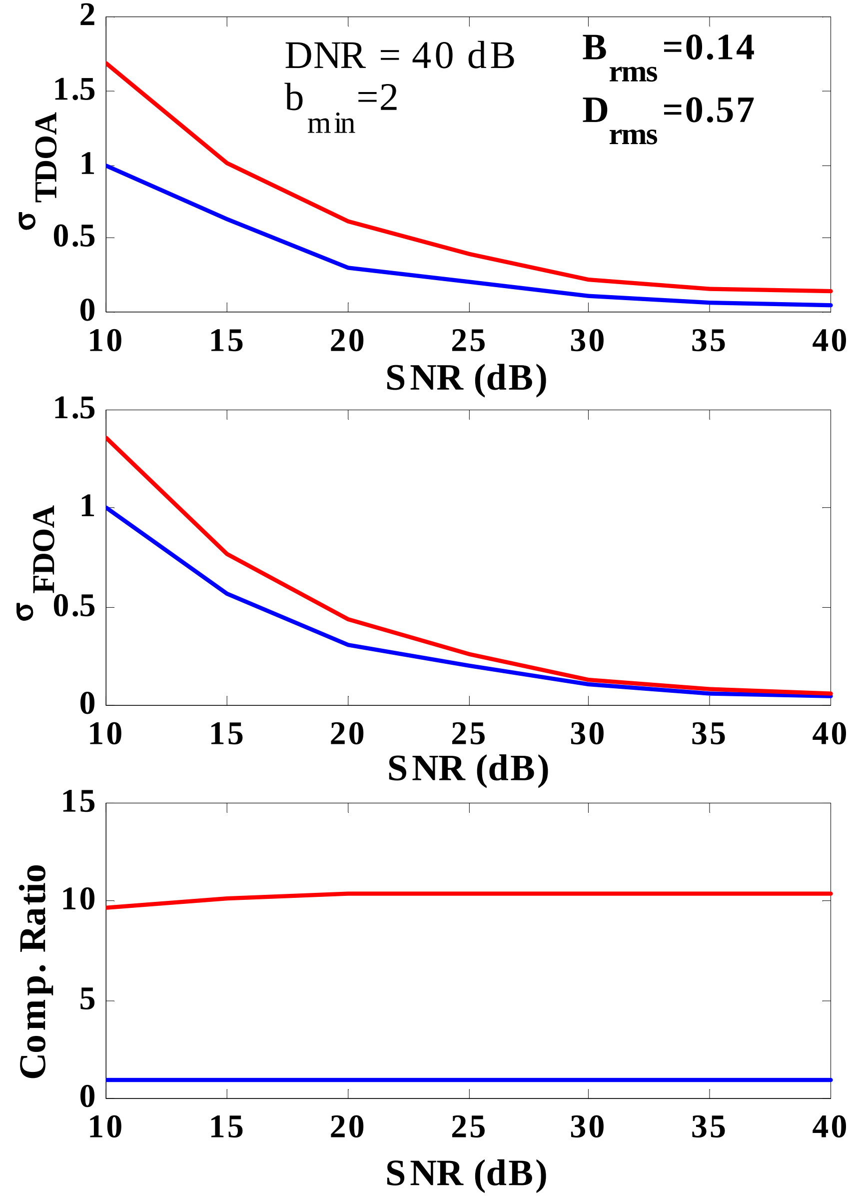
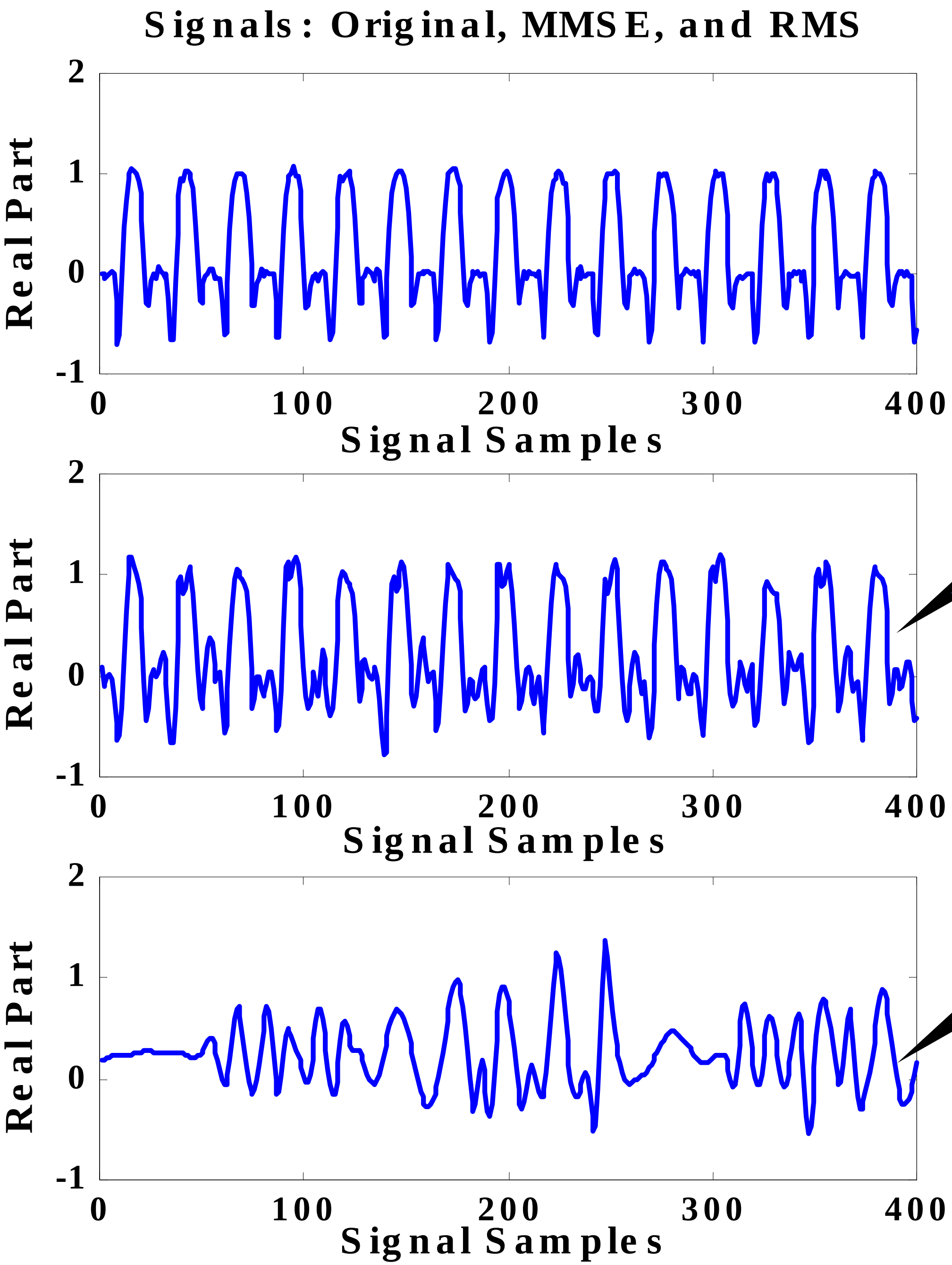
MMSE Approach | Blue = No Compression | **RMS-Width Approach**







MSE Approach gives **Good** Reconstruction

RMS Approach gives **Terrible** Reconstruction

BUT, Still Decent Accuracy**!!**

SUMMARY

- Pointed out Importance of Non-MSE Criteria
- Optimal trade-off between decimation vs. quantization
  - » **Outperforms Quantization-Only & Decimation-Only**
  - » Points out usefulness of non-MSE Distortion approach
- Proposed MSE-Based Wavelet Approach
  - » Allocates bits across T-F cells to minimize MSE
  - » **Outperforms Time-Domain (Quantization) MSE-Based Approach**
- Explored non-MSE Wavelet Approach
  - » **Simple Experiment Shows Potential**
    - → Can discard WT coefficients with negligible effect on RMS widths
    - → Improved CR by 67%
    - → However, did degrade accuracy
    - → But, not as much as one would expect by looking at reconstructed signal
- What Next?
  - » **Optimal method for discarding WT Coefficients**