Timing Skew Compensation Technique Using Digital Filter with Novel Linear Phase Condition

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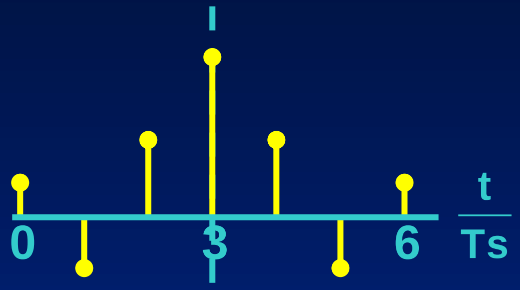
Purpose

- Fine skew adjustment using a digital filter while maintaining a linear phase condition in ATE
  - Timing accuracy is important to ATE
  - Various digital filters are used for testing analog LSIs
  - Linear phase condition is required of the digital filter to preserve the analog waveform

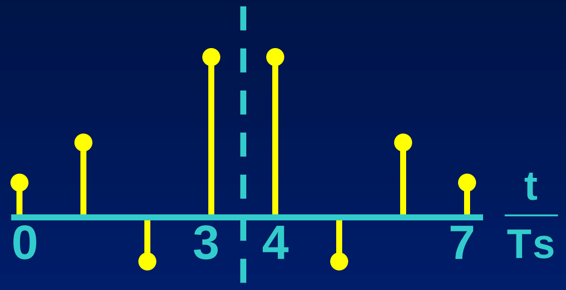
Outline

- Conventional linear phase FIR filter
- Time-shifted ideal filter
- Construction of linear phase filter
- Application examples
- Conclusion

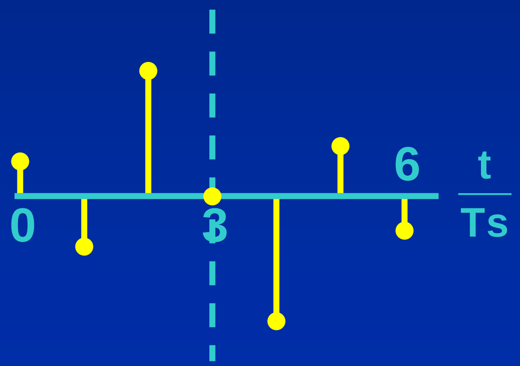
4 Types of Generalized Linear-Phase FIR Systems



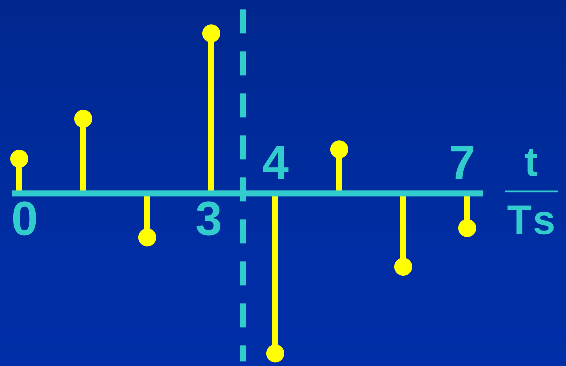
(1)Type I
symmetric
even-order



(2)Type II
symmetric
odd-order



(3)Type III
antisymmetric
even-order



(4)Type IV
antisymmetric
odd-order

Frequency Characteristics of 4 Types

h(nT)	$H(e^{j\omega T})$
Type I	$e^{-j\omega(N-1)T_S/2} \sum_{k=0}^{(N-1)/2} a_k \cos[\omega k T_S]$
Type II	$e^{-j\omega(N-1)T_S/2} \sum_{k=1}^{N/2} b_k \cos[\omega(k-1/2)T_S]$
Type III	$e^{-j(\omega(N-1)T_S/2-\pi/2)} \sum_{k=0}^{(N-1)/2} a_k \sin[\omega k T_S]$
Type IV	$e^{-j(\omega(N-1)T_S/2-\pi/2)} \sum_{k=1}^{N/2} b_k \sin[\omega(k-1/2)T_S]$

Phase : 1st order function of frequency
Delay : depends on number of Taps

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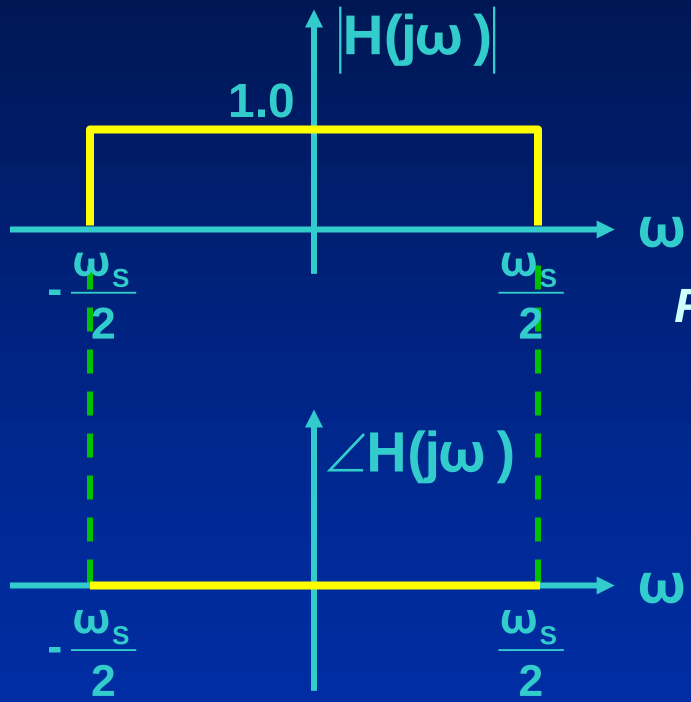
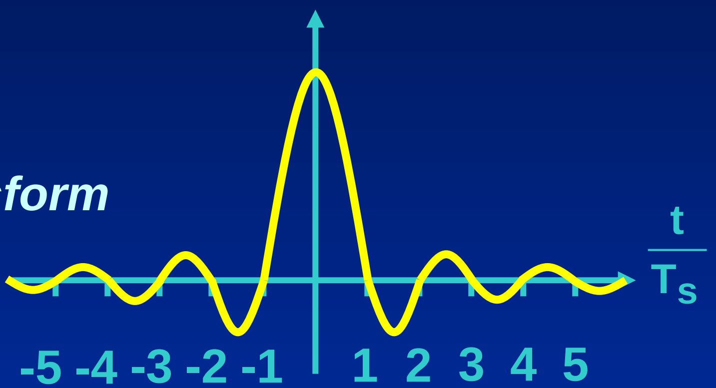
Ideal Filter Response

Frequency Response



Impulse Response

Fourier Transform

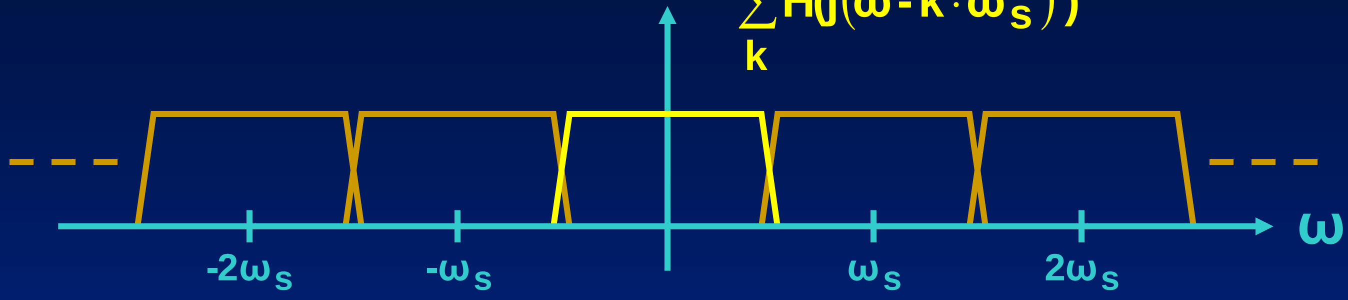


$$h(t) = \frac{1}{T_S} \cdot \mathrm{sinc}\left(\pi \frac{t}{T_S}\right)$$

$\omega_S = \frac{2\pi}{T_S}$ **: Sampling Rate**

Discrete-Time Expression

$$\sum_{k} H\left(j\left(\omega - k\cdot\omega_S\right)\right)$$

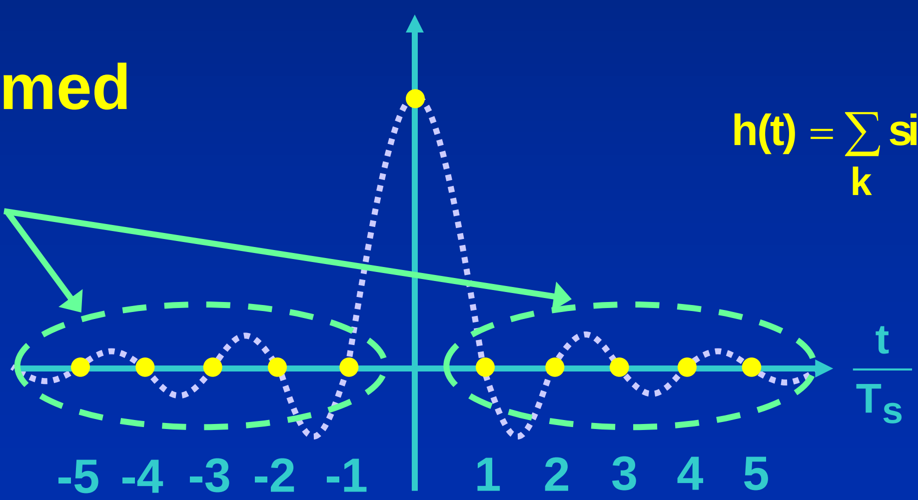


Fourier Transform

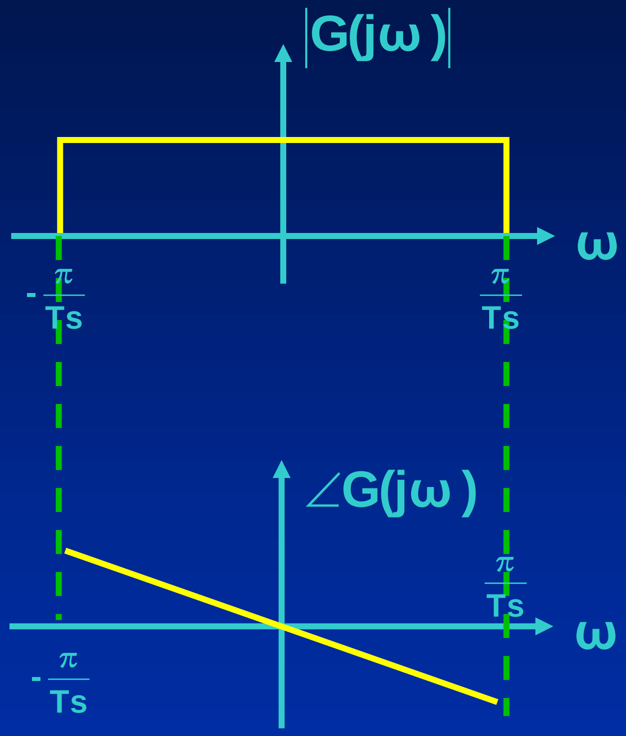
FIR is formed

$$h(t) = \sum_{k} \mathrm{sinc}\left(\pi \frac{k\cdot T_S}{T_S}\right)\delta\left(t - k\cdot T_S\right)$$

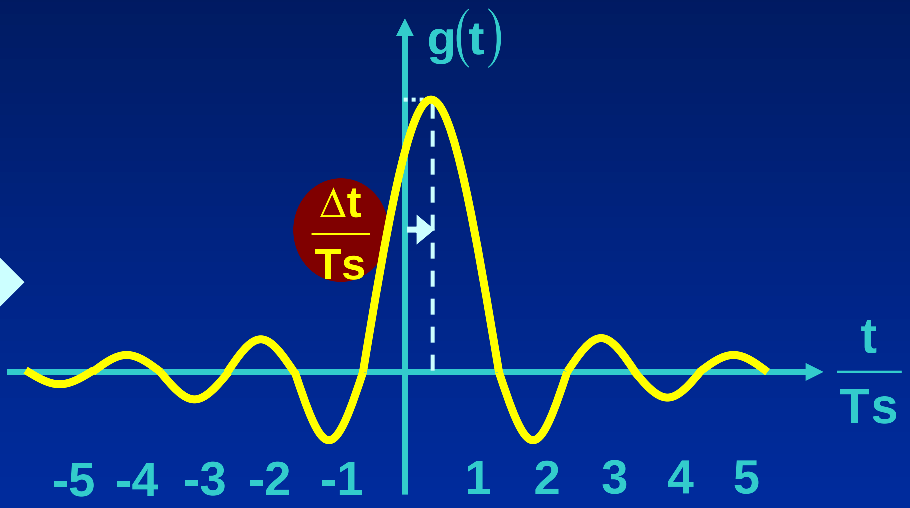
All zero



Time Shifted Impulse Response



$$\angle G(j\omega) = -\omega\,\Delta t$$



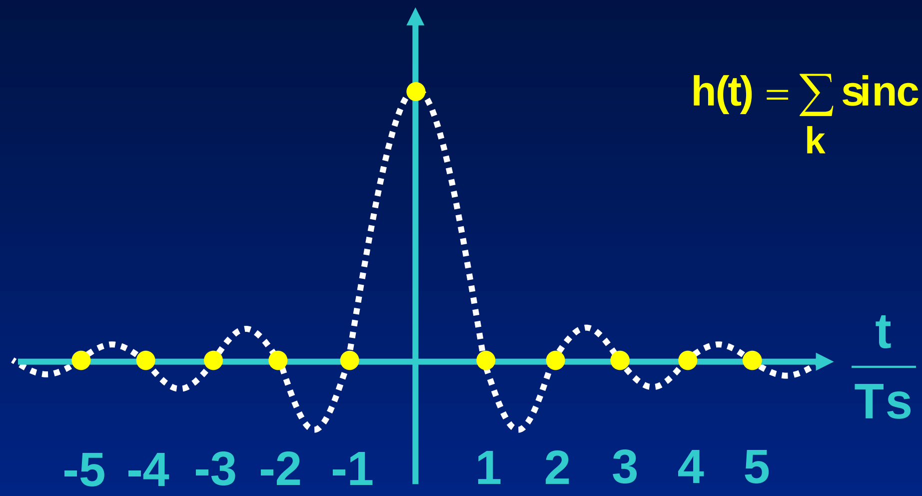
Only phase changed

Impulse response shifted Δt

Influence to Coefficients by Time Shift

FIR

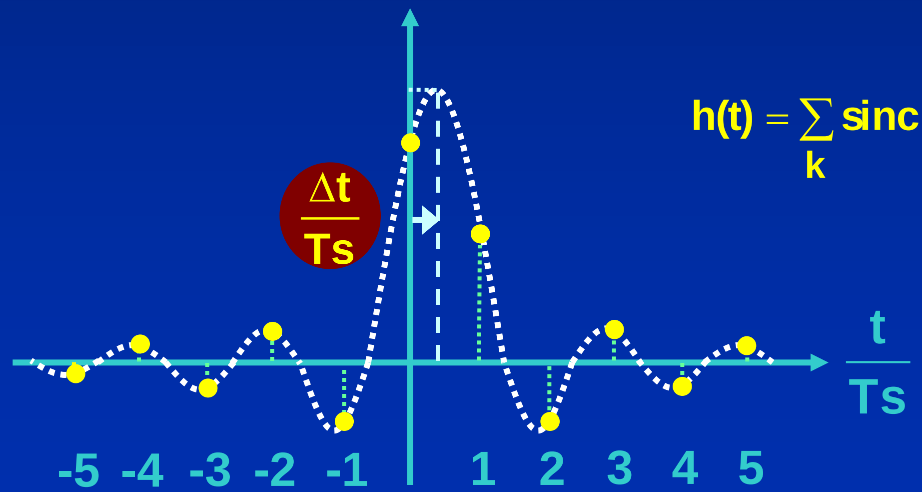
$$h(t) = \sum_k \mathrm{sinc}\left(\pi \frac{k \cdot T_S}{T_S}\right)\delta\left(t - k \cdot T_S\right)$$



Time shift

IIR

$$h(t) = \sum_k \mathrm{sinc}\left(\pi \frac{k \cdot T_S - \Delta t}{T_S}\right)\delta\left(t - k \cdot T_S\right)$$



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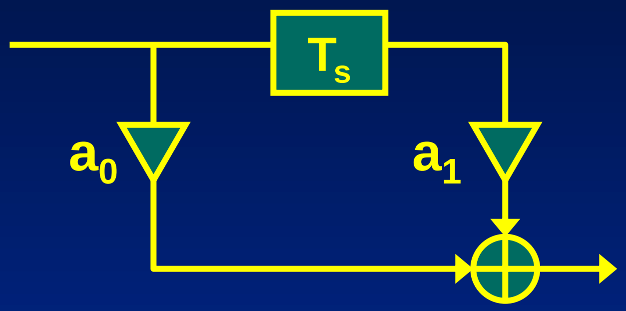
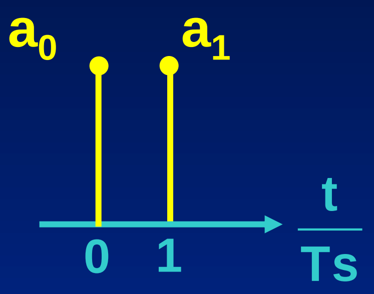
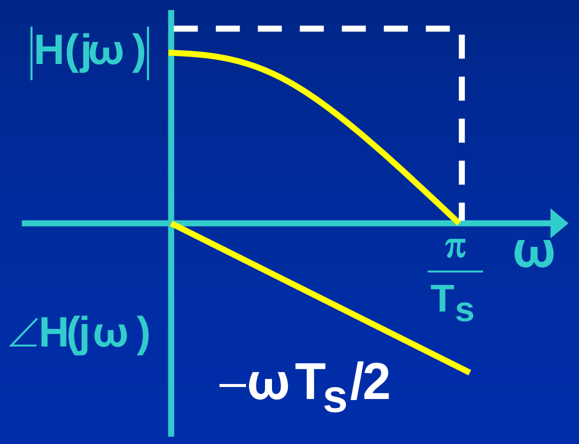
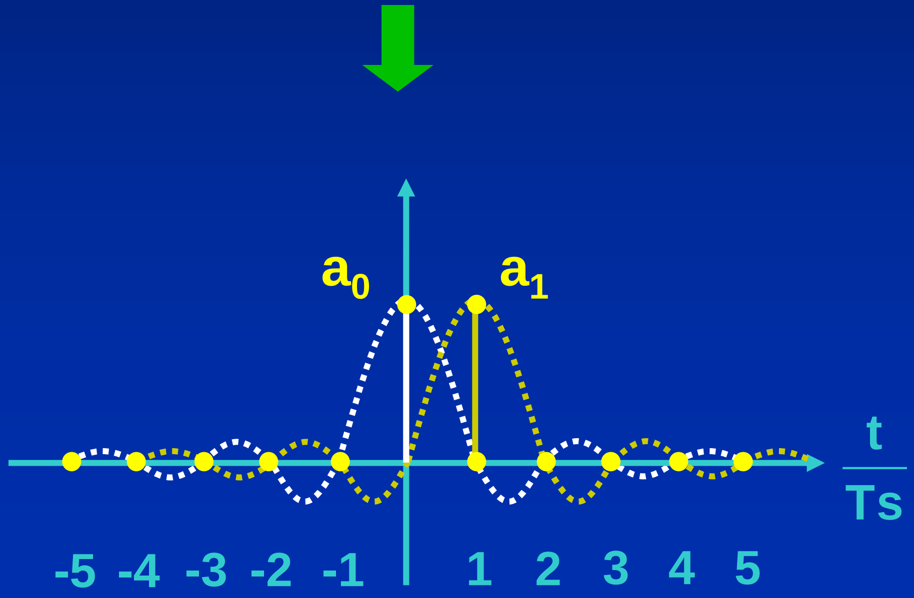
2 Tap FIR Model

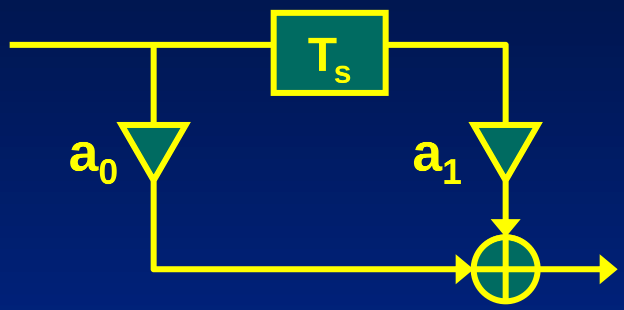


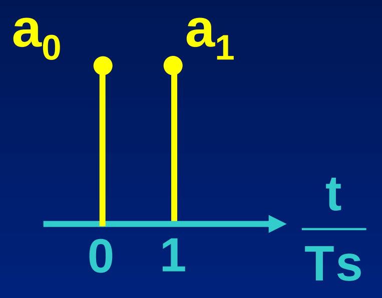


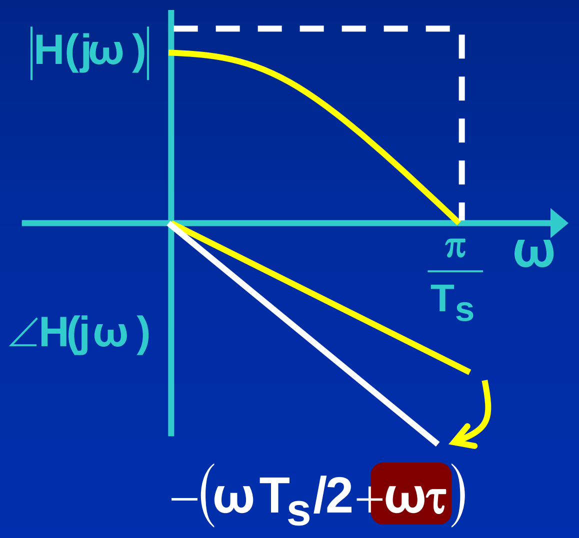


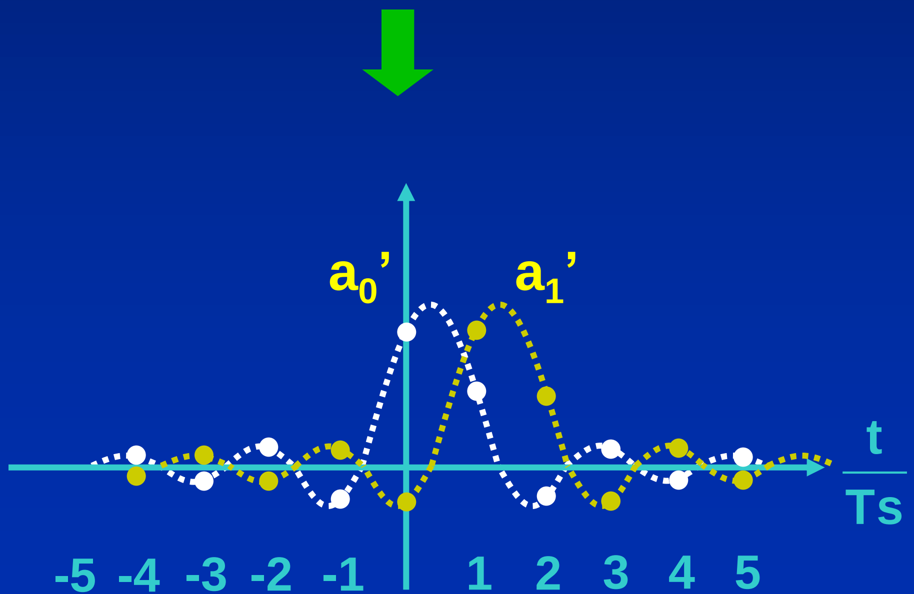


2 Tap Delayed FIR Model

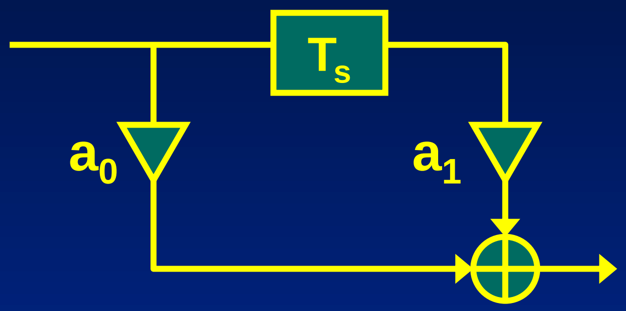


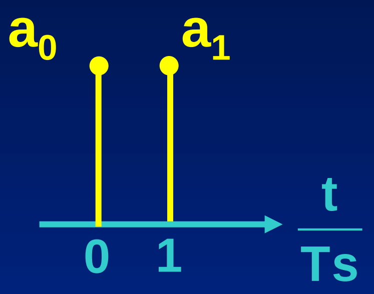


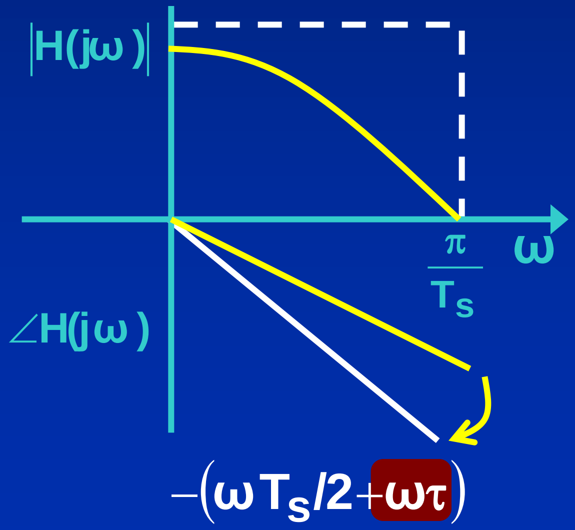


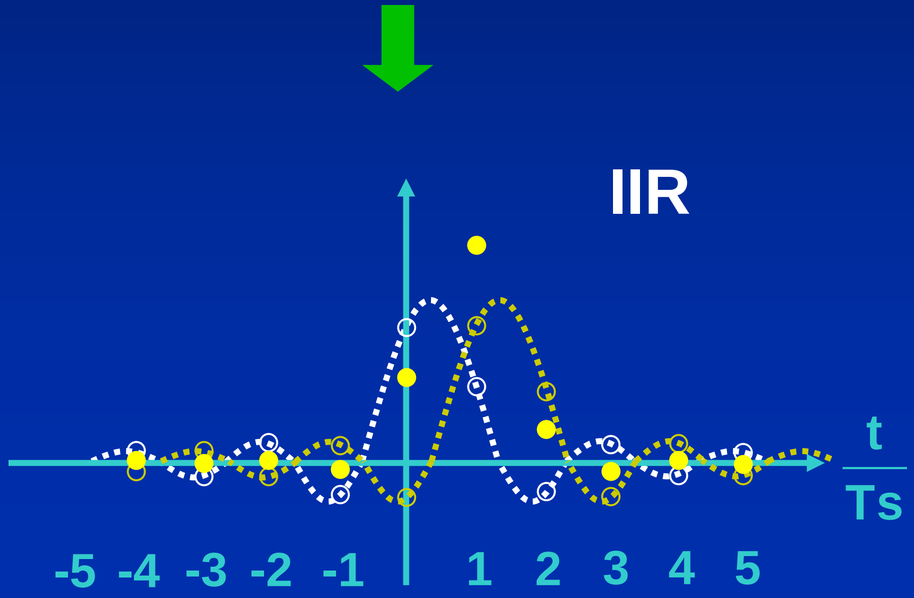


2 Tap Delayed FIR Model

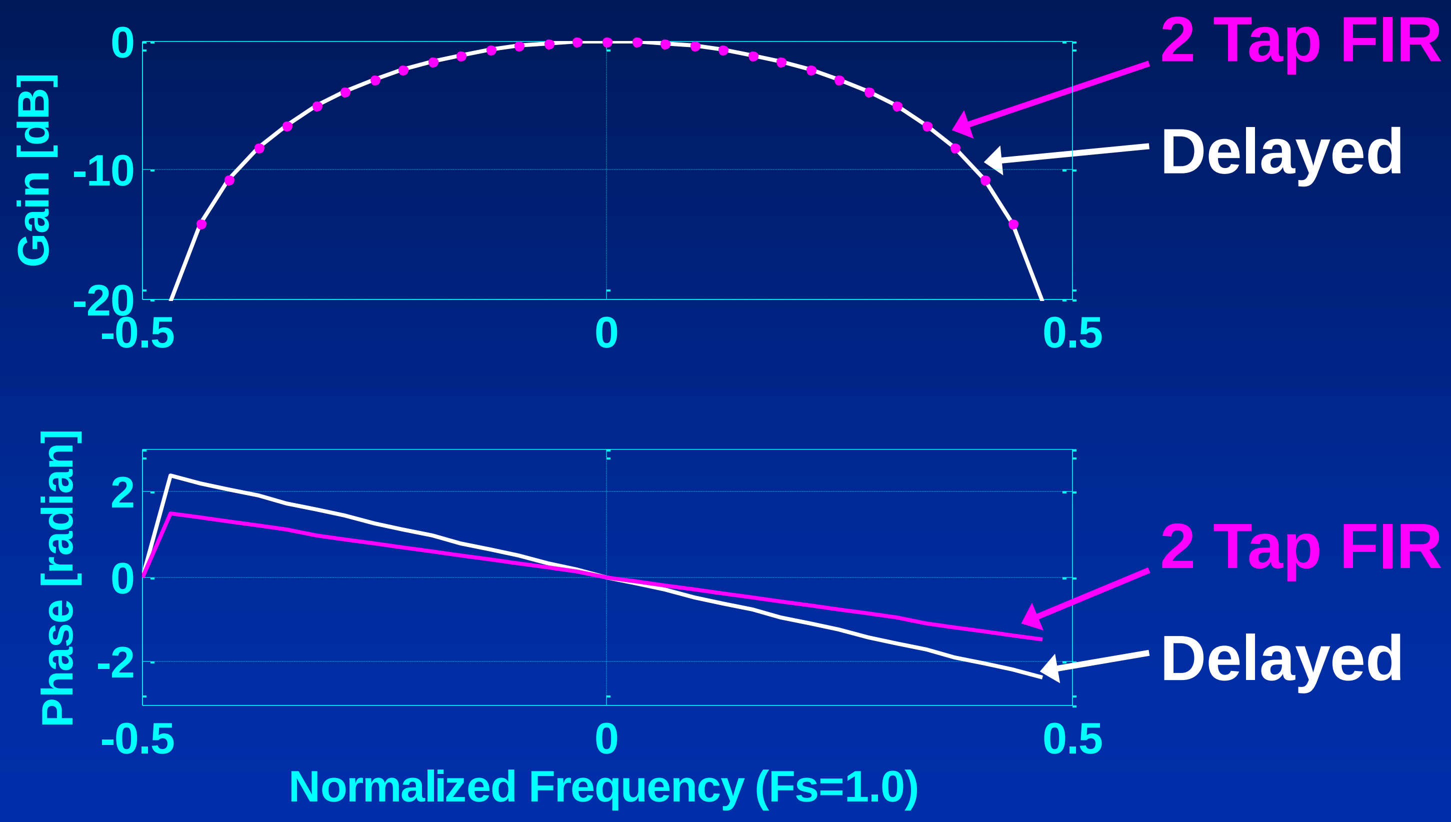








Comparison of Freq. Characteristic



Only slope of phase characteristic is changed

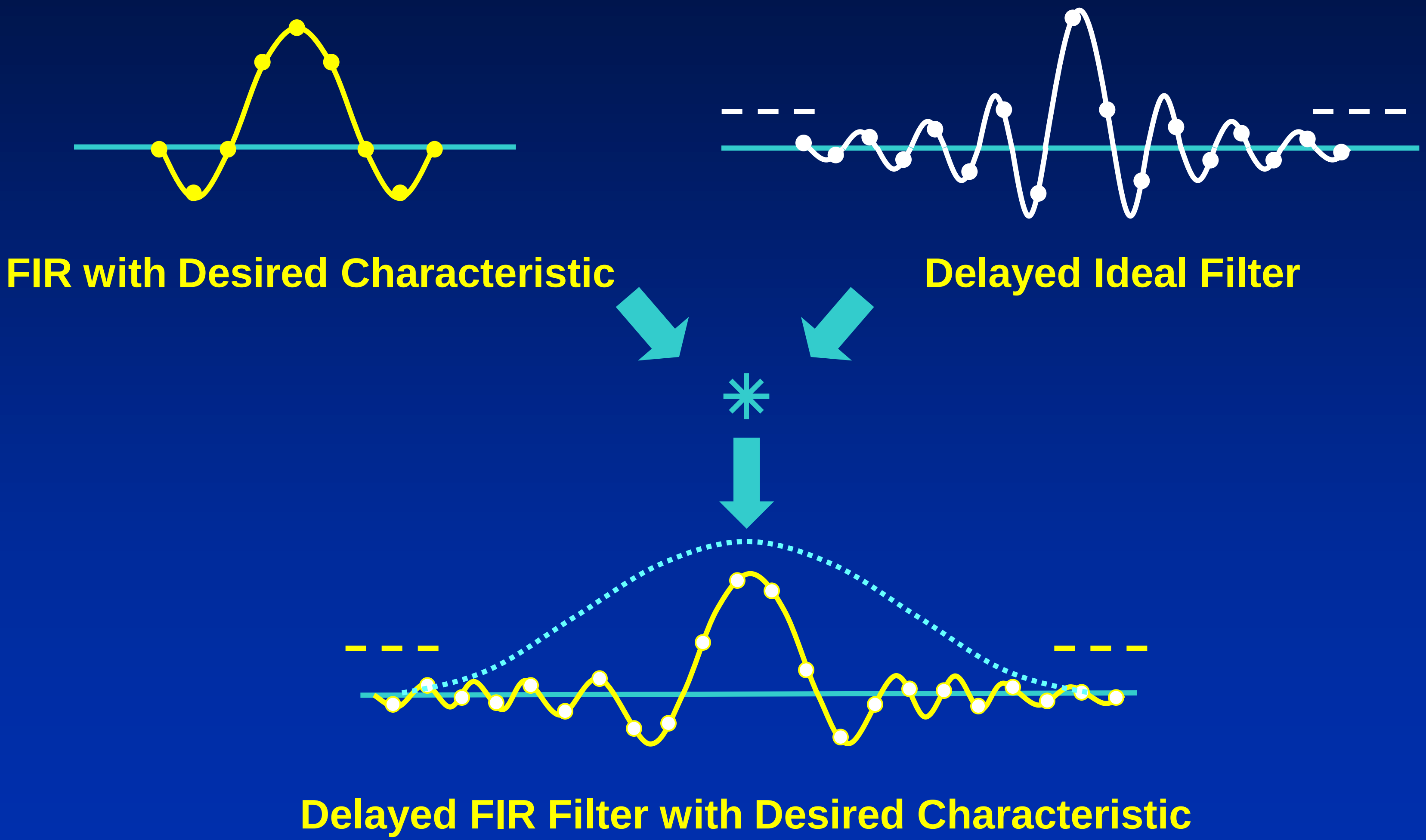
Frequency Characteristic of Proposed Filter

$g(nT)$	$G(e^{j\omega T})$
Type I	$e^{-j\left(\omega(N-1)T_S/2+\omega\tau\right)}\sum_{k=0}^{(N-1)/2} a_k \cos[\omega k T_S]$
Type II	$e^{-j\left(\omega(N-1)T_S/2+\omega\tau\right)}\sum_{k=1}^{N/2} b_k \cos[\omega (k-1/2) T_S]$
Type III	$e^{-j\left(\omega(N-1)T_S/2-\pi/2+\omega\tau\right)}\sum_{k=0}^{(N-1)/2} a_k \sin[\omega k T_S]$
Type IV	$e^{-j\left(\omega(N-1)T_S/2-\pi/2+\omega\tau\right)}\sum_{k=1}^{N/2} b_k \sin[\omega (k-1/2) T_S]$

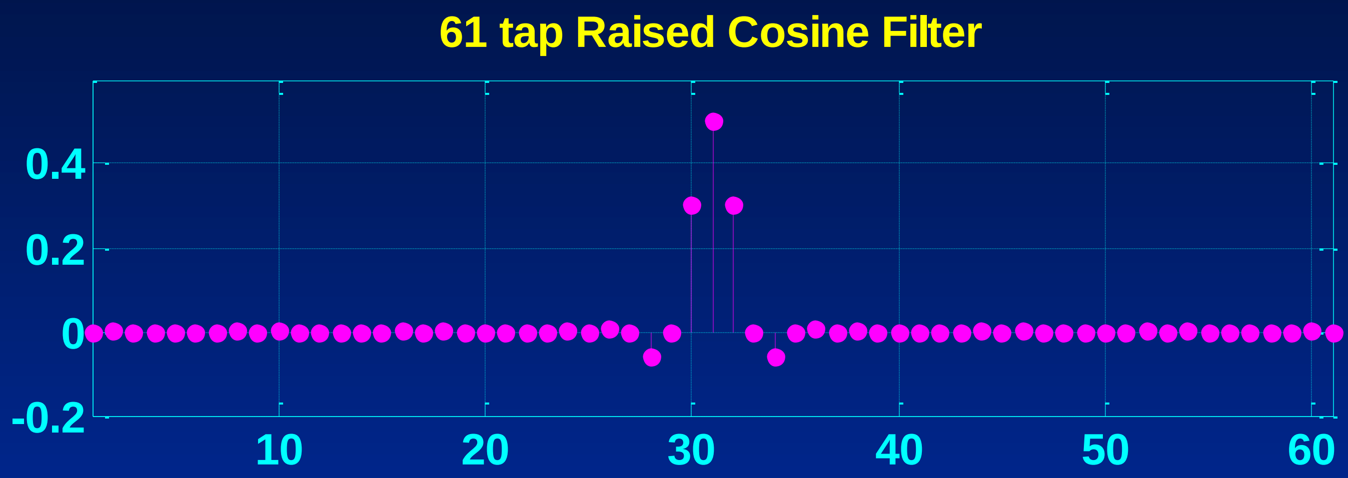
Phase : 1st order function of frequency

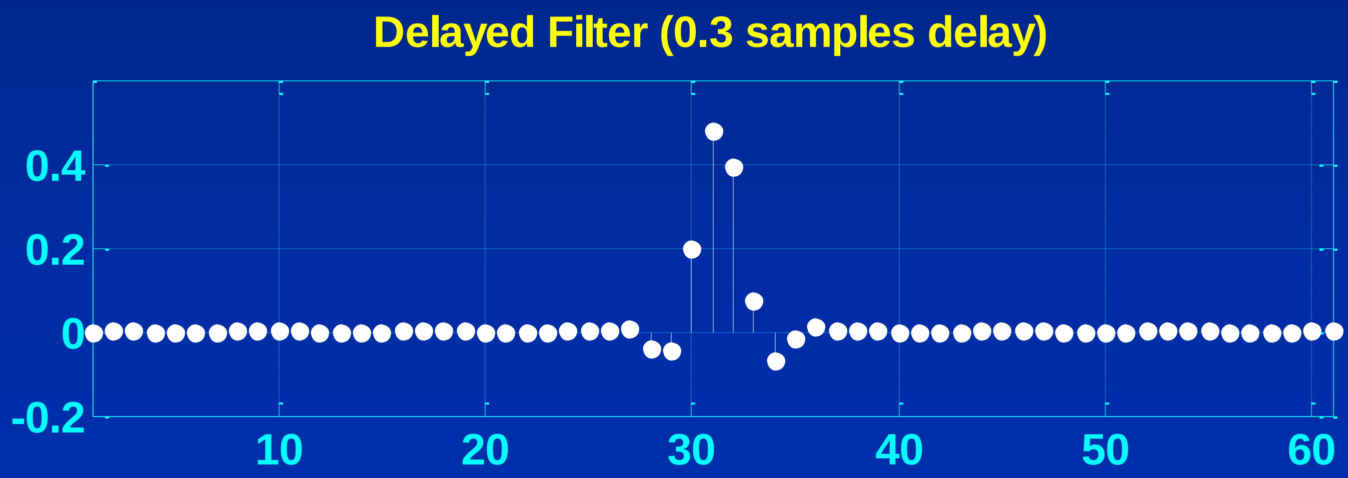
Delay : controllable with τ

Proposed Design Technique

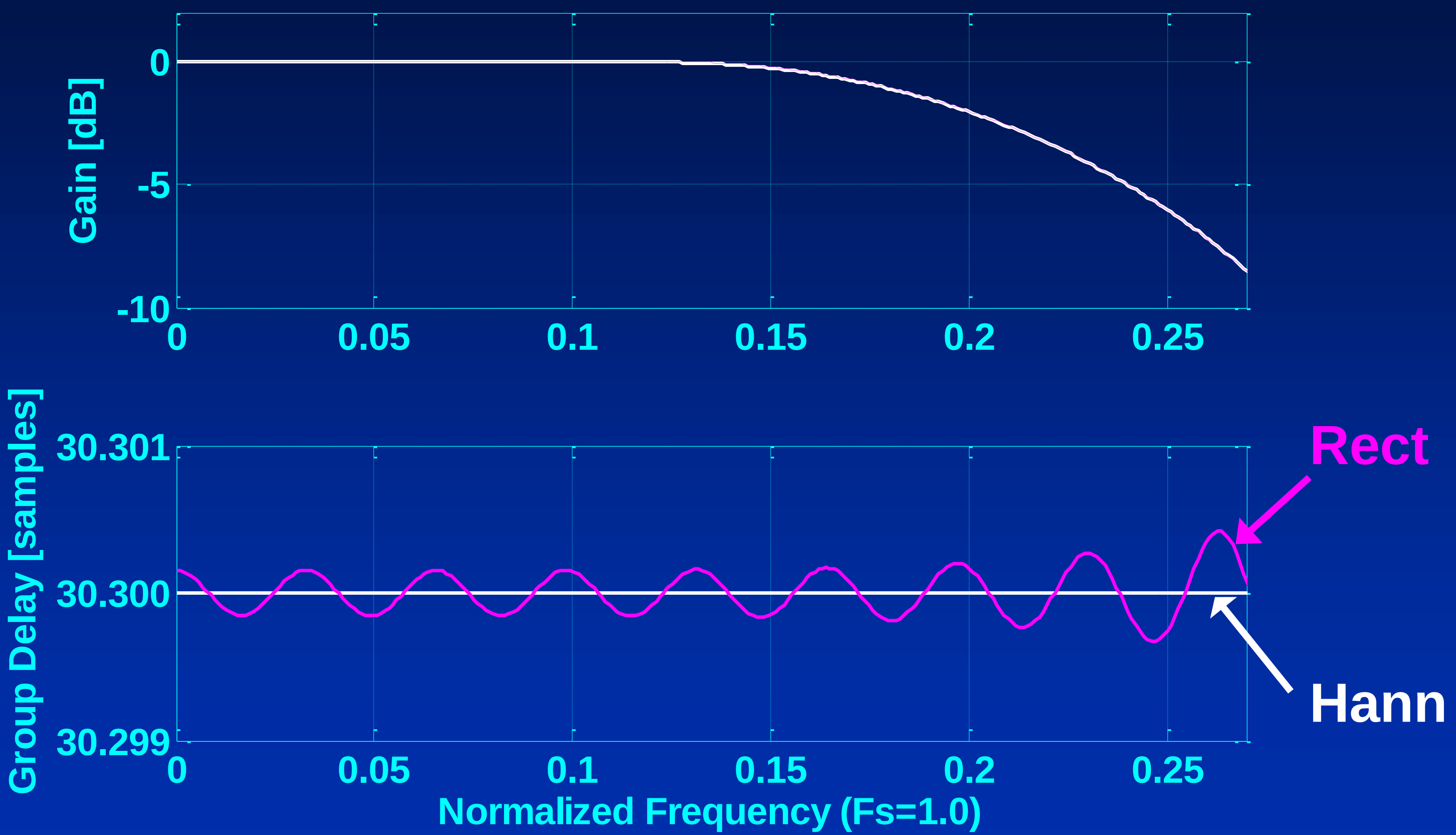


Example of Raised Cosine Filter





Effect of Window Function



Window function can reduce Gibbs phenomenon

Novel Linear Phase Condition of D.F.

- Original FIR filter has complete linear phase
- Original FIR filter is band-limited
- Bandwidth of signal is below Nyquist rate

⇓

Fine delay can be controlled using Ideal filter

- Delayed filter has infinite impulse response
- Window function can construct FIR effectively

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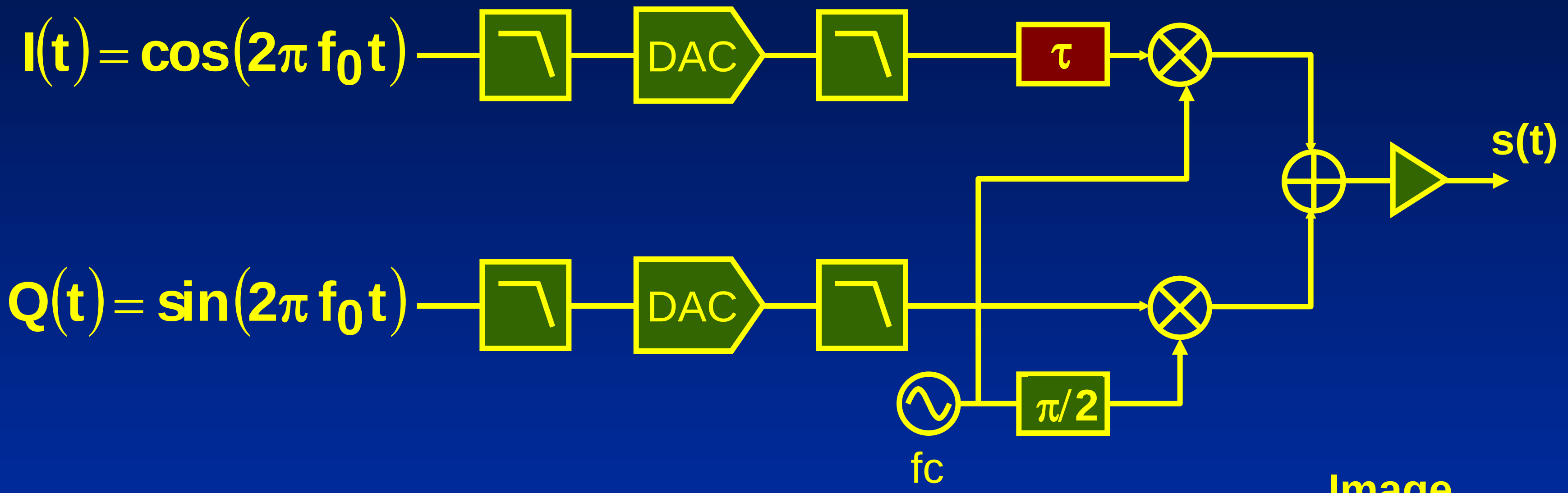
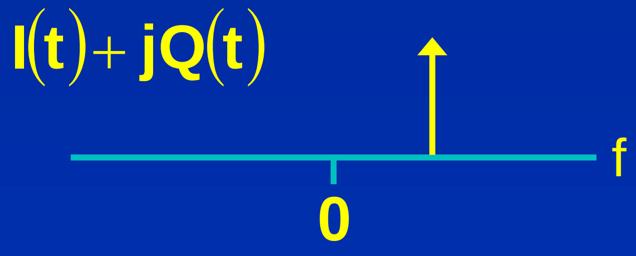
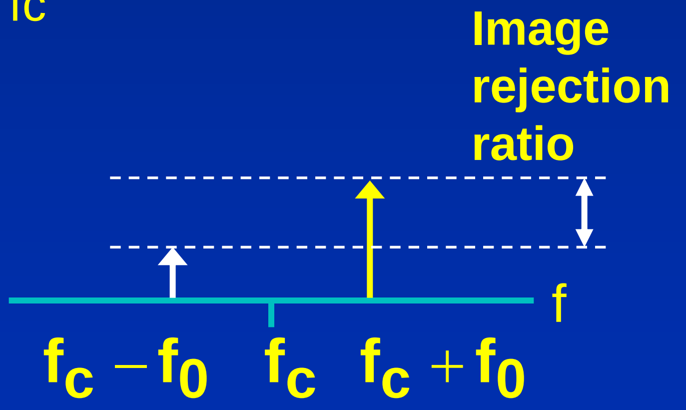
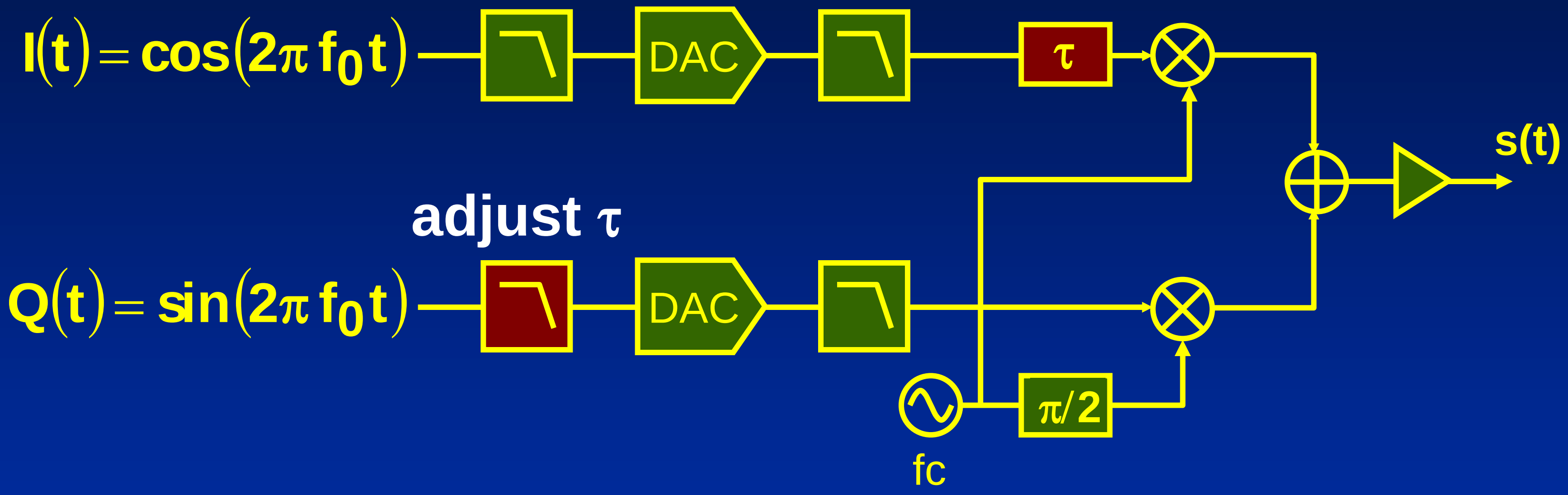
Application to Quadrature Modulator



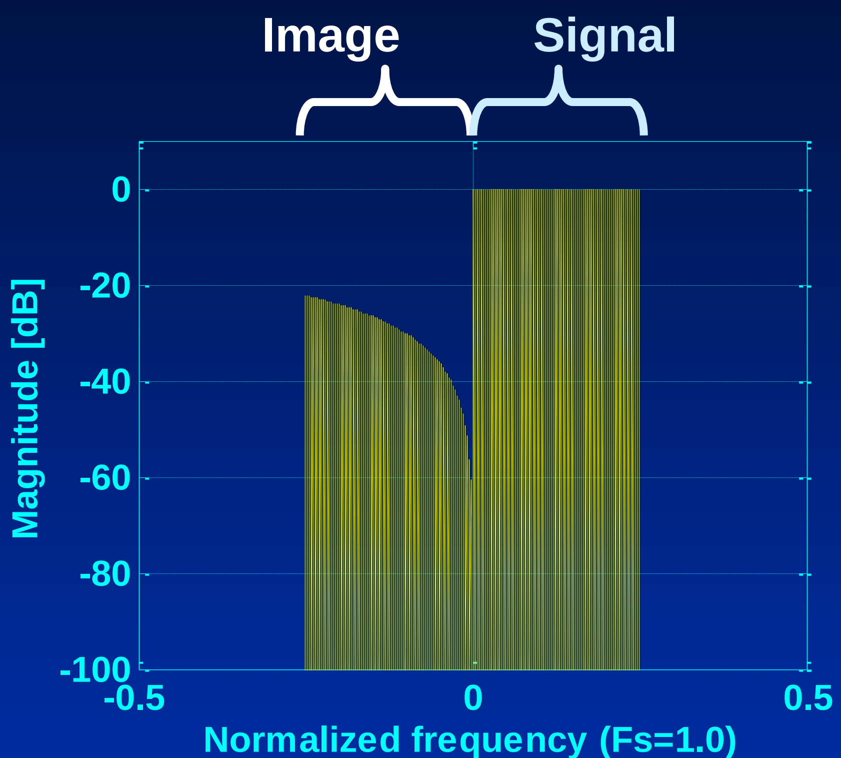




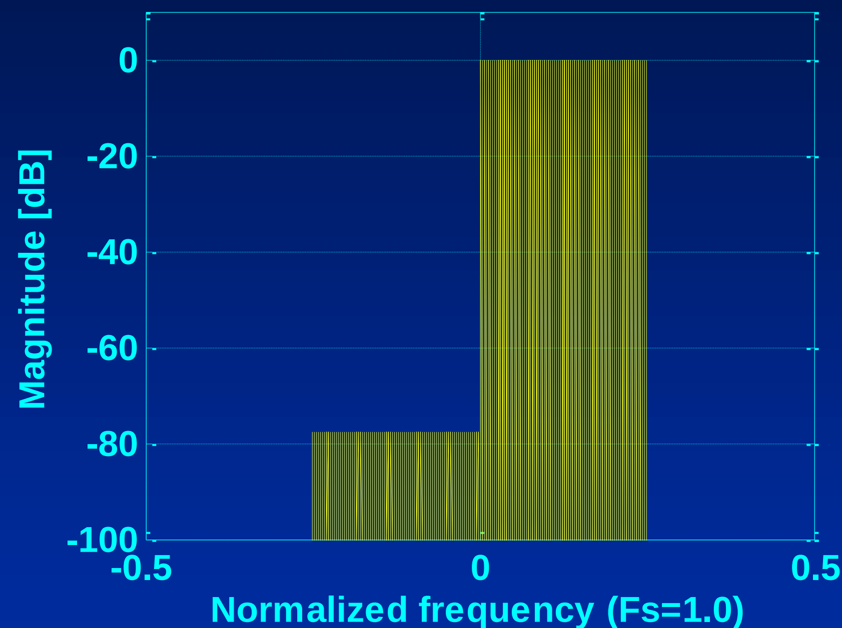
Adjustment of I/Q Skew



Simulation Results



(a) SSB signal with I/Q skew

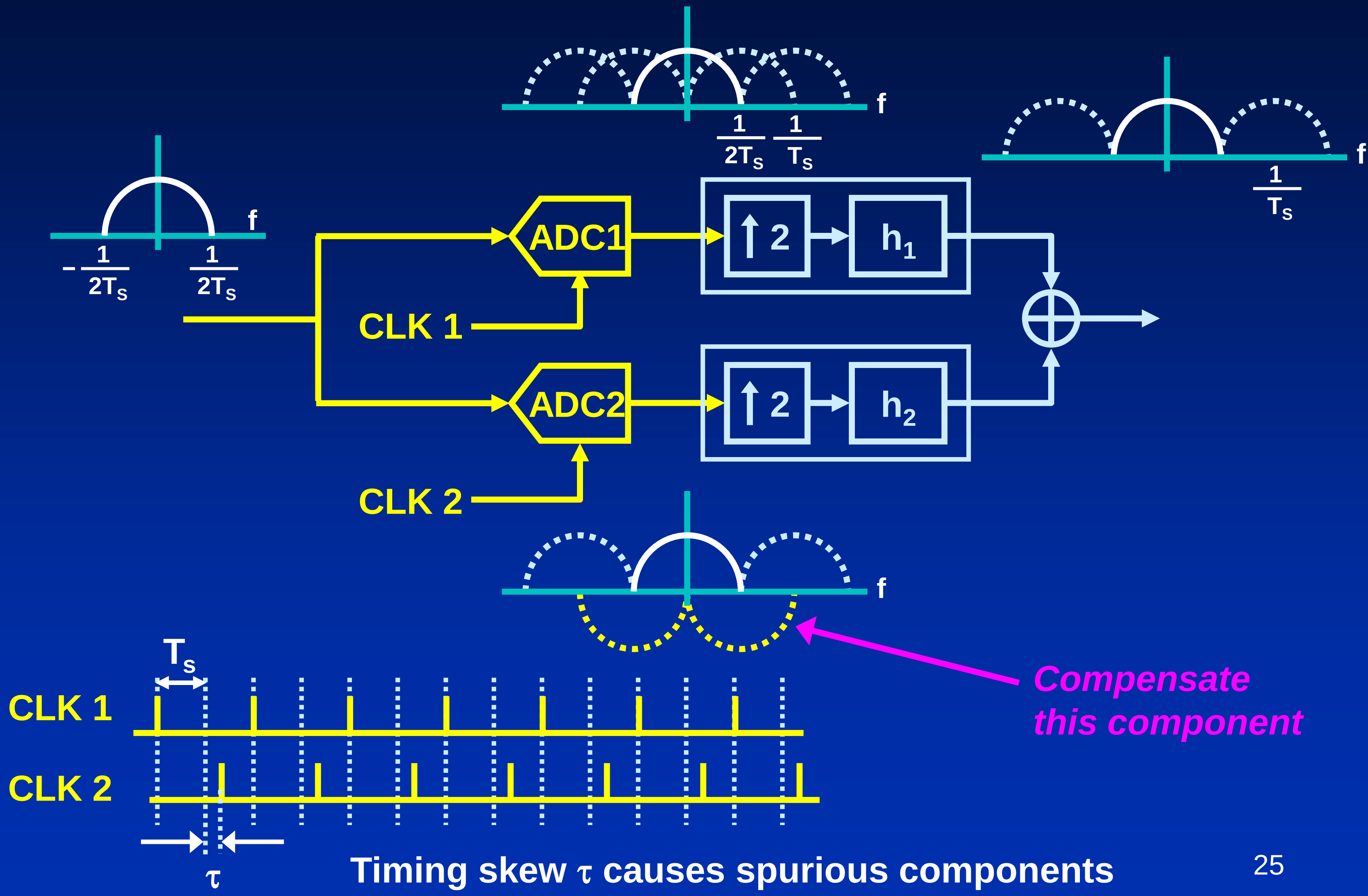


(b) SSB signal with compensation

Delay Compensation Filter

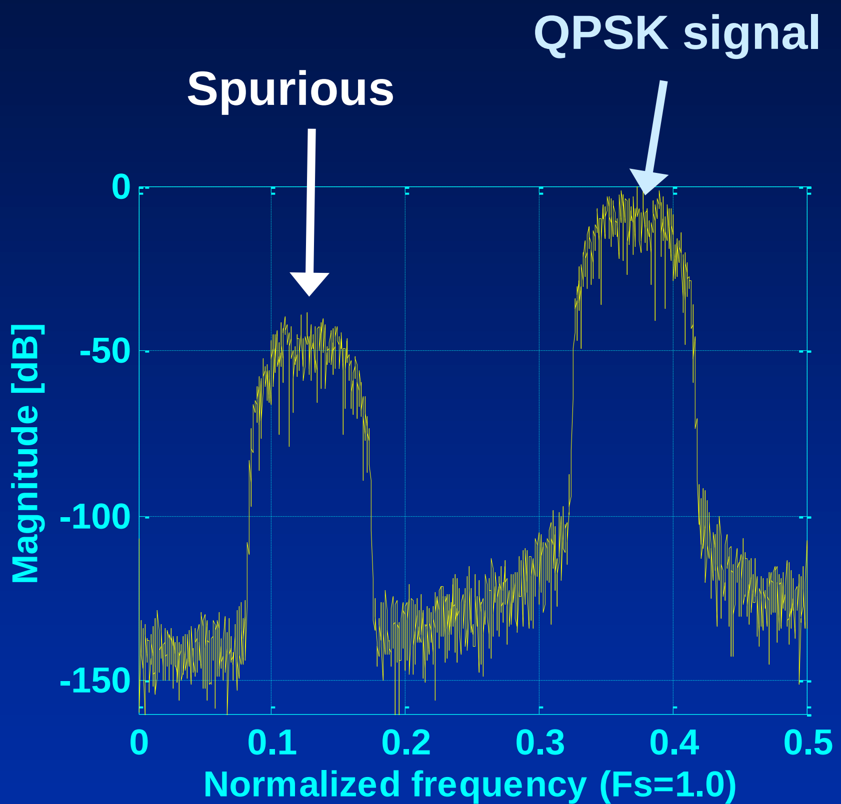
delay	0.1 sampling points
Taps	61 Taps
Window	Hann

Application to Time-Interleaved ADCs

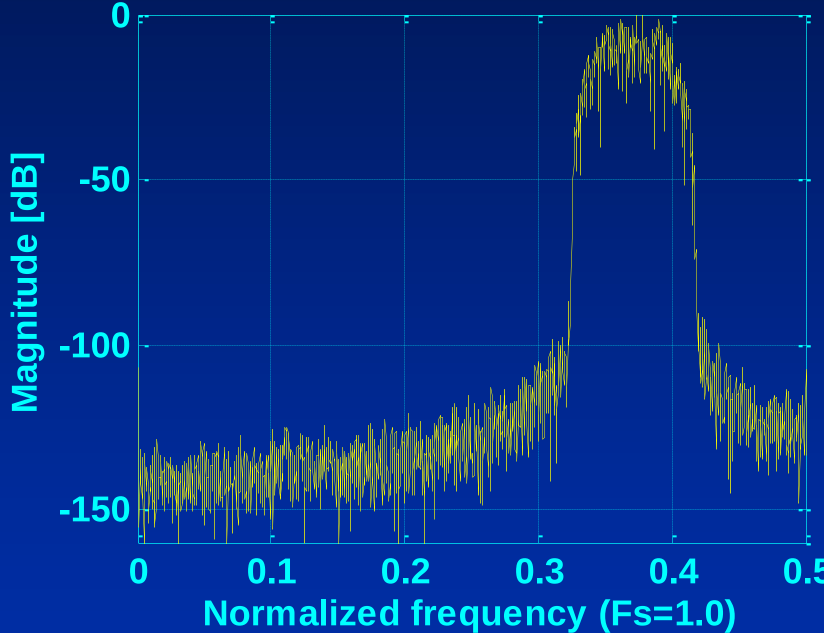


Timing skew τ causes spurious components

Simulation Results



(a) 2ch interleaved ADC with 0.01 samples skew



(b) Compensate the skew using 91 taps delay filter

Conclusion

- Fine delay controllable digital filter which maintains desired characteristics is proposed
- It is applicable not only to Low Pass Filters but also to Band Pass Filters
- It can compensate the timing skew of analog modules in ATE