Imperial College London

# MODULE 4 CLASS

Aidan Hogg - 7 November 2019
ELEC96010 (EE3-07): Digital Signal Processing
Department of Electrical and Electronic Engineering

Method:

o .đĊÔÞĝĪİÇă ğİÞĤĪñđĊ ĝđĤÞÚ ŕ ĤĪİÚÞĊĪĤ ĪîñĊĀ ğİñÞĪăł đĊ ĪîÞñĠ đ ļ Ċ ÇĊÚ ĠÞĝđĠĪ ñĊñĪñÇă ÇĊĤ ļ ÞĠĤ đĊ ` ÞĊĪñ ĉ ÞĪÞĠ (3 mins)

π zĪİÚÞĊĪĤ ÚñĤÔİĤĤ ĪîÞñĠ ÇĊĤ ļ ÞĠĤ ñĊ Ĥ ĉ Çăă éĠđİĝĤ (2 mins)

ρ 8ŁĝăÇĊÇĪñđĊдÚñĤÔİĤĤñđĊ đè ÔđĠĠÞÔĪ ÇĊĤ ļ ÞĠ (3 mins)

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. đĊĤñÚÞĠ ī î Þ èđăăđ ļ ñĊé ļ ñĊÚđ ļ Ĥ

vÞÔīÇĊé İ ăÇĠ HÇ ĉ ĉ ñĊé -ăÇÔĀ ĉ ÇĊŕHÇĠĠñĤ

If we were to design a filter using the windowing method, which window should be selected if you only care about the transition bandwidth being short?

! vÞÔīÇĊé İ ăÇĠ

- HÇ ĉ ĉ ñĊé

. -ăÇÔĀ ĉ ÇĊŕHÇĠĠñĤ

# ANSWER

Consider the following windows:

Rectangular Hamming Blackman-Harris

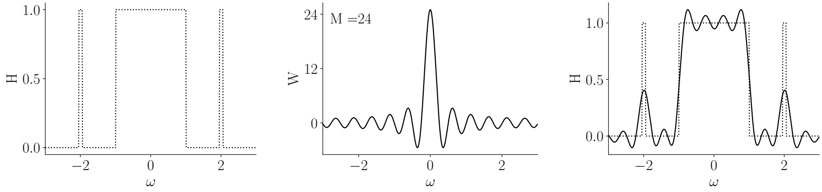
If we were to design a filter using the windowing method, which window should be selected if you only care about the transition bandwidth being short?

A. Rectangular
B. Hamming
C. Blackman-Harris

## Window Relationships

vÞăÇīñđĊĤîñĝ ļ îÞĊ łđİ ĉ İăīñĝăł ÇĊ ñ ĉ ĝ İăĤÞ ĠÞĤĝđĊĤÞ קŸ”[ Ół Ç
ļ ñĊÚđ ļ ÐŸ”[ īîÇī ñĤ đè ăÞĊéīî ז

. k &פv ' ; / 0 . &פv ' ک ڵ &פv '




¡ĠÇĊĤñīñđĊ ÓÇĊÚ ļ ñÚīî ; ļ ñÚīî đè īîÞ ĉ ÇñĊ ăđÓÞ

vÞÔīÇĊé İăÇĠ ļ ñĊÚđ ļ ; 2 k

vÞÔÇăă ĪîÇĪ Ç ÚñéñĪÇă ĤłĤĪÞ ĉ ñĊ éÞĊÞĠÇă ñĤ ÚÞĤÔĠñÓÞÚ Ół Ç ÚñèèÞĠÞĊÔÞ Þğ İÇĪñđĊ ļ îÞĠÞ Ç ĠÞÔ İĠĤñĻÞ ÚñèèÞĠÞĊÔÞ Þğ İÇĪñđĊ İĤÞĤ ĝÇĤĪ đ İĪĝ İĪĤ ļ îñăÞ Ç ĊđĊ ĠÞÔ İĠĤñĻÞ ÚñèèÞĠÞĊÔÞ Þğ İÇĪñđĊ ÚđÞĤ Ċđī

Consider the following statements:

o BKv ŒăĪÞĠĤ ÔÇĊ đĊăł ÓÞ ñ ĉ ĝăÞ ĉ ÞĊĪÞÚ ĊđĊ ĠÞÔ İĠĤñĻÞăł ñĊ ĝĠÇÔĪñÔÞ

π KKv ŒăĪÞĠĤ ÔÇĊ đĊăł ÓÞ ñ ĉ ĝăÞ ĉ ÞĊĪÞÚ ĠÞÔ İĠĤñĻÞăł ñĊ ĝĠÇÔĪñÔÞ

Which of these statements are true?

! o

- π

. -đĪî o ÇĊÚ π

## ANSWER

vÞÔÇăă ĪîÇī Ç ÚñéñīÇă ĤłĤīÞ ĉ ñĊ éÞĊÞĠÇă ñĤ ÚÞĤÔĠñÓÞÚ Ół Ç ÚñèèÞĠÞĊÔÞ Þğ İÇīñđĊ ļ îÞĠÞ Ç ĠÞÔİĠĤñĻÞ ÚñèèÞĠÞĊÔÞ Þğ İÇīñđĊ İĤÞĤ ĝÇĤī đİīĝİīĤ ļ îñăÞ Ç ĊđĊ ĠÞÔİĠĤñĻÞ ÚñèèÞĠÞĊÔÞ Þğ İÇīñđĊ ÚđÞĤ Ċđī

Consider the following statements:

o BKv ŒăīÞĠĤ ÔÇĊ đĊăł ÓÞ ñ ĉ ĝăÞ ĉ ÞĊīÞÚ ĊđĊ ĠÞÔİĠĤñĻÞăł ñĊ ĝĠÇÔīñÔÞ

π KKv ŒăīÞĠĤ ÔÇĊ đĊăł ÓÞ ñ ĉ ĝăÞ ĉ ÞĊīÞÚ ĠÞÔİĠĤñĻÞăł ñĊ ĝĠÇÔīñÔÞ

Which of these statements are true?

! o

- 2

. -đīî o ÇĊÚ π

# EXPLANATION

. đĊĤñÚÞĠ ī î ñĤ BĸV ŒăīÞĠ ÚÞĤÔĠñÓÞÚ Ół Ç ĊđĊ ĠÞÔ İ ĠĤñĻÞ ÚñèèÞĠÞĊÔÞ
Þğ İ ÇīñđĊ

| | |
|---|---|
| 3Ÿ"[ ; EŸ"[ ) EŸ" L /[ ) U ) EŸ" L 3.[ | cÇT |
| 3Ÿ" L /[ ; EŸ" L /[ ) EŸ" L 0[ ) U ) EŸ" L 3/[ | cÓT |
| 3Ÿ"[ L 3Ÿ" L /[ ; EŸ"[ L EŸ" L 3/[ | cÇT ŕ cÓT |
| 3Ÿ"[ ; 3Ÿ" L /[ ) EŸ"[ L EŸ" L 3/[ | Recursive |

cÇT BĸV ŒăīÞĠĤ ÇĠÞ ĊđĠ ĉ Çăăł ñ ĉ ĝăÞ ĉ ÞĊīÞÚ ĊđĊ ĠÞÔ İ ĠĤñĻÞăł Ó İ ī ÔÇĊ ÓÞ ñ ĉ ĝăÞ ĉ ÞĊīÞÚ ĠÞÔ İ ĠĤñĻÞăł

cÓT ĸĸV ŒăīÞĠĤ ÔÇĊ đĊăł ÓÞ ñ ĉ ĝăÞ ĉ ÞĊīÞÚ ĠÞÔ İ ĠĤñĻÞăł ñĊ ĝĠÇÔīñÔÞ ÓÞÔÇ İ ĤÞ ÇĊ ñĊŒĊñīÞ Ċ İ ĉ ÓÞĠ đè ÔđÞèŒÔñÞĊīĤ ļ đ İ ăÚ ÓÞ ĠÞğ İ ñĠÞÚ īđ ĠÞÇăñŇÞ ī î Þ ĉ ĊđĊ ĠÞÔ İ ĠĤñĻÞăł cĠÞÔÇăă 3Ÿ"[ ; ꭓ Ü β ; L Ü EŸת[קŸ" L ת[T

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The group delay $_e$ is measured in what units?

!⃞ zÞÔđĊÚĤ

-⃞ vÇÚñÇĊĤ

.⃞ vÇÚñÇĊĤ ĝÞĠ ĤÞÔđĊÚ

The group delay $_{e}$ is measured in what units?

! Seconds

- vÇÚñÇĊĤ

. vÇÚñÇĊĤ ĝÞĠ ĤÞÔđĊÚ

# EXPLANATION

. đĊĤñÚÞĠ īîÞ ĝđăÞŕŇÞĠđ ĝăđī đè īîÞĤÞ īîĠÞÞ ĤłĤīÞ ĉ Ĥ

! - .

Which system has most of its energy in קYײ[ concentrated towards
” ; .?

# ANSWER

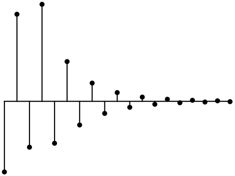
. đĊĤñÚÞĠ ī î Þ ĝđăÞŕŇÞĠđ ĝăđī đè ī î ÞĤÞ ī îĠÞÞ ĤłĤīÞ ĉ Ĥ

A - .

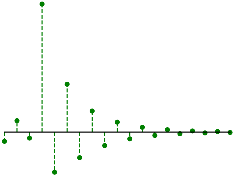
Which system has most of its energy in קẎ”[ concentrated towards ” ; .?

# EXPLANATION

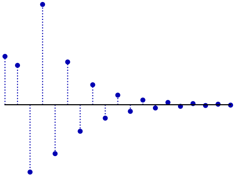
Impulse responses:



A (Minimum Phase)



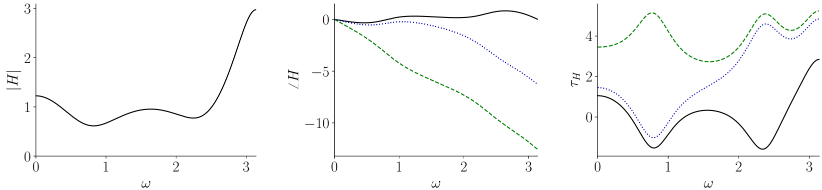
B (Maximum Phase)



.

## Minimum Phase

!ĻÞĠÇéÞ éĠđİĝ ÚÞăÇł đĻÞĠ ÞğİÇăĤ īîÞ cЭĝđăÞĤ ŕ ЭŇÞĠđĤт ļñīîñĊ īîÞ İĊñī ÔñĠÔăÞ ļ îÞĠÞ ŇÞĠđĤ đĊ īîÞ İĊñī ÔñĠÔăÞ ÔđİĊī èđĠ $\frac{E}{\phi}$




! ŒăīÞĠ ļñī î Çăă ñīĤ ŇÞĠđĤ ñĊĤñÚÞ īîÞ İĊñī ÔñĠÔăÞ ñĤ Ç ĉñĊñĉ İ ĉ ĝîÇĤÞ ŒăīÞĠ

o ¡îÞ ăđ ļÞĤī ĝđĤĤñÓăÞ éĠđİĝ ÚÞăÇł èđĠ Ç éñĻÞĊ ĉÇéĊñīİÚÞ ĠÞĤĝđĊĤÞ
π The energy in קΥ״[ is concentrated towards ״ ; .

! BñĊñīÞ Ꝁ ĉ ĝ İ ăĤÞ vÞĤĝđĊĤÞ cBꝀvт ŒăīÞĠ ñĤ đĊÞ ļ î ÞĠÞ מ &ị ' ; ¯ &ị ' ם &ị '

Consider four filters with the following coefficients:

o ʊ_E ʏ" [ ; y /* .* /* .* .* /* .* /{

π ʊ_ф ʏ" [ ; y /* /* /* .* .* L /* L /* L /{

ρ ʊ_o ʏ" [ ; y /* /* .* /* /* /* /* .* /{

ς ʊ_ʔ ʏ" [ ; y .* /* .* /* .* .* L /* .* L /{

Which of these filters will have linear phase?

! ʊ_E ʏ" [

- -đīî ʊ_E ʏ" [ ÇĊÚ ʊ_ф ʏ" [

. -đīî ʊ_o ʏ" [ ÇĊÚ ʊ_ʔ ʏ" [

# ANSWER

! BñĊñīÞ Ꝁ ĉ ĝ İ ăĤÞ vÞĤĝđĊĤÞ cBꝀvт ŒăīÞĠ ñĤ đĊÞ ļ îÞĠÞ מ &ı' ; ¯ &ı'ם&ı'

Consider four filters with the following coefficients:

o ꝺ_E Ỵ"[ ; y/* .* /* .* .* /* .* /{

π ꝺ_ф Ỵ"[ ; y/* /* /* .* .* L/* L/* L/{

ρ ꝺ_o Ỵ"[ ; y/* /* .* /* /* /* /* .* /{

ς ꝺ_ƻ Ỵ"[ ; y.* /* .* /* .* .* L/* .* L/{

Which of these filters will have linear phase?

! ꝺ_E Ỵ"[

- Both ꝺ_E Ỵ"[ and ꝺ_ф Ỵ"[

. -đīî ꝺ_ф Ỵ"[ ÇĊÚ ꝺ_o Ỵ"[

## Linear Phase Filters

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

**Important:** [illegible]

[illegible]

Ķī ňĤ ĝđĤĤňÓăÞ īđ īĠÇĊĤèđĠ ĉ Ç ÔđĊīňĊİđİĤ īň ĉ Þ ŒăīÞĠ ňĊīđ Ç ÚňĤÔĠÞīÞ īň ĉ Þ ŒăīÞĠ İĤňĊé ĶĶv ŒăīÞĠ īĠÇĊĤèđĠ ĉ ÇīňđĊĤ

Which transformation would be most appropriate to transform this continuous time bandpass filter into a discrete time filter?

- ! -ňăňĊÞÇĠ ĉ Çĝĝ ňĊé
- - Ķ ĉ ĝ İăĤÞ ňĊĻÇĠňÇĊÔÞ
- . -đīî ÓňăňĊÞÇĠ ĉ Çĝĝ ňĊé ÇĊÚ ň ĉ ĝ İăĤÞ ňĊĻÇĠňÇĊÔÞ ļ đ İ ăÚ ÓÞ Çĝĝ ĠđĝĠňÇīÞ

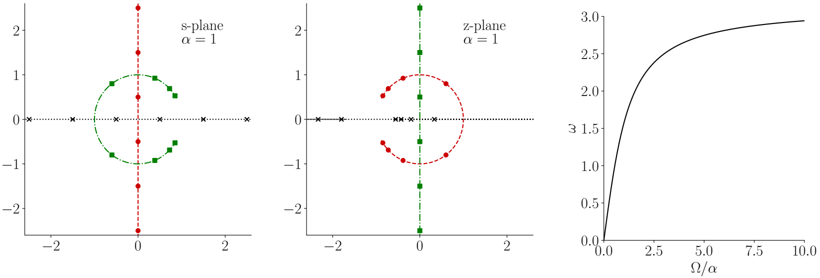
# ANSWER

[illegible]

Which transformation would be most appropriate to transform this continuous time bandpass filter into a discrete time filter?

- [illegible]
- Impulse invariance
- [illegible]

## Bilinear Mapping



## Impulse Invariance

-ñăñĊÞÇĠ ĪĠÇĊĤèđĠ ĉ ļ đĠĀĤ ļ Þăă èđĠ Ç ăđ ļ ŕĝÇĤĤ ŒăĪÞĠ ÓİĪ ĪîÞ ĊđĊŕăñĊÞÇĠ Ôđ ĉ ĝĠÞĤĤñđĊ đè ĪîÞ èĠÞğİÞĊÔł ÚñĤĪđĠĪĤ ÇĊł đĪîÞĠ ĠÞĤĝđĊĤÞ ¡îÞ ñ ĉ ĝ İăĤÞ ñĊĻÇĠñÇĊÔÞ ĪĠÇĊĤèđĠ ĉ ÇĪñđĊ ñĤ ÇĊ ÇăĪÞĠĊÇĪñĻÞ ĉ ÞĪîđÚ ĪîÇĪ đÓĪÇñĊĤ ĪîÞ ÚñĤÔĠÞĪÞŕĪñ ĉ Þ ŒăĪÞĠ Ół ĤÇ ĉ ĝăñĊé ĪîÞ ñ ĉ ĝ İăĤÞ ĠÞĤĝđĊĤÞ đè ĪîÞ ÔđĊĪñĊİđİĤŕĪñ ĉ Þ ŒăĪÞĠ

&æ' ĻĻΩ ק&в' ĻĻĻΩ קŸ"[ ; ' Φ ק&" ' ' ĮΩ &į '