



# BSM307

## İşaretler ve Sistemler

Dr. Seçkin Arı

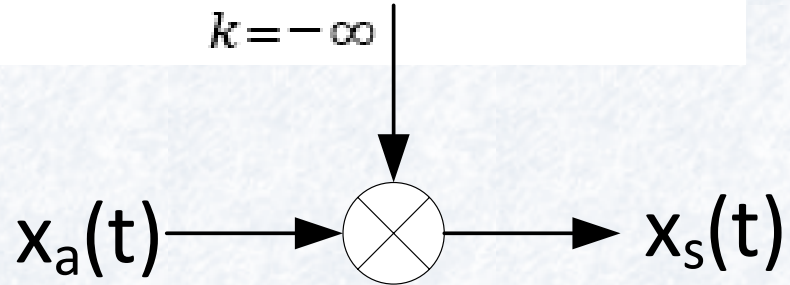
Örnekleme

- Örneklenmiş Sürekli Zaman İşaret
- Örneklenmiş İşaretin Frekans Spektrumu
- Nyquist Kriteri
- Örneklenmiş Ayırık Zaman İşaret

# Örneklenmiş Sürekli Zaman İşaret

- İdeal örnekleme: Zamanda çarpma işlemi
  - ♦  $s(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT_s)$  : Darbe dizisi
  - ♦  $T_s$ : Örnekleme Periyodu
- $x_s(t) = x_a(t)s(t)$

$$s(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT_s)$$



# Örneklenmiş Sürekli Zaman İşaret

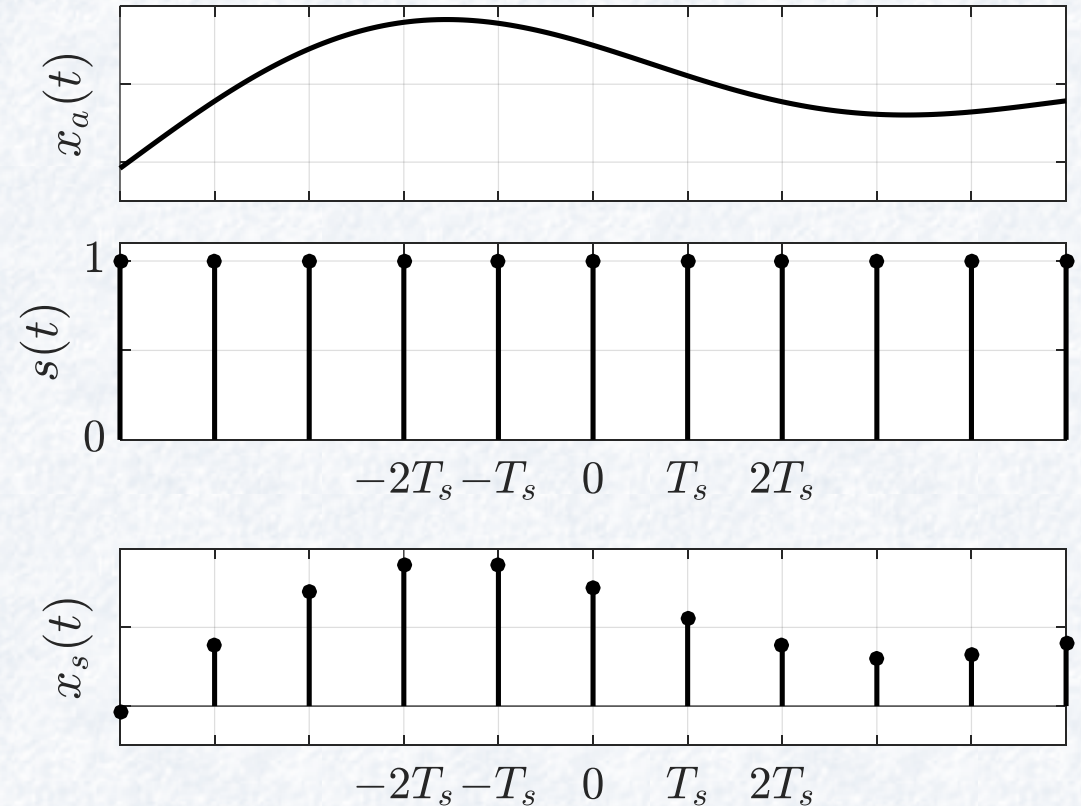
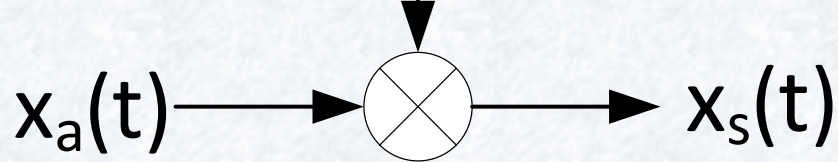
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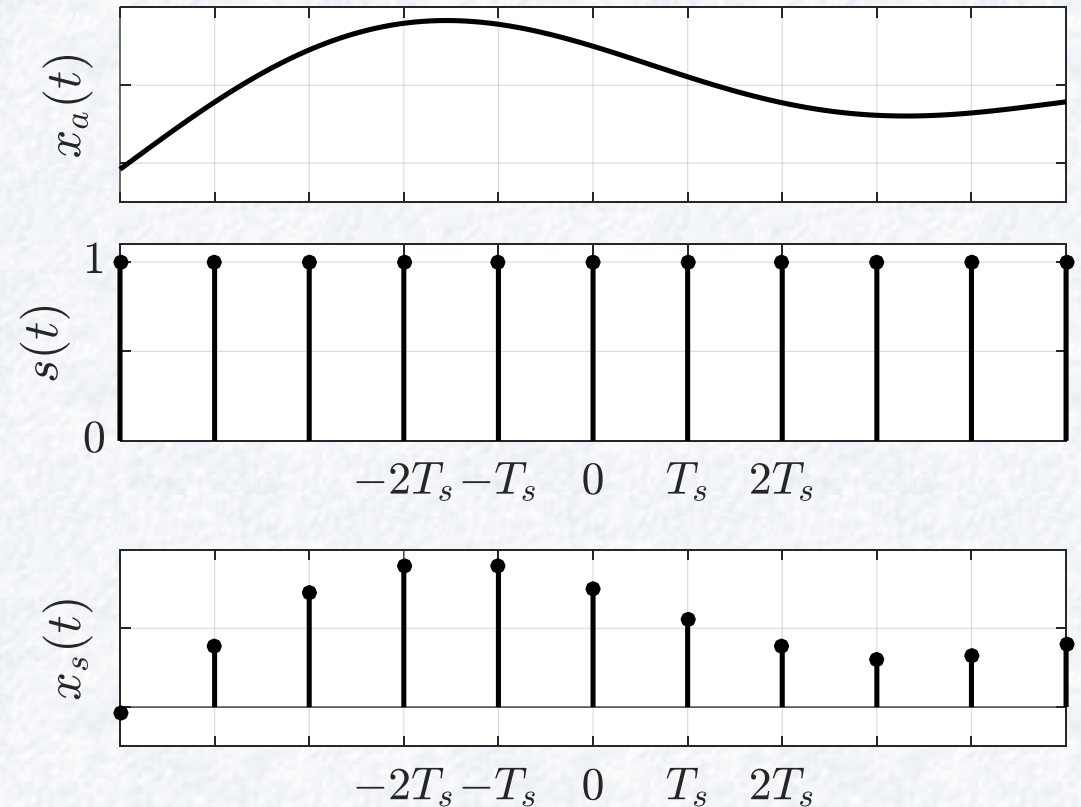
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- $X_s(\omega) =$





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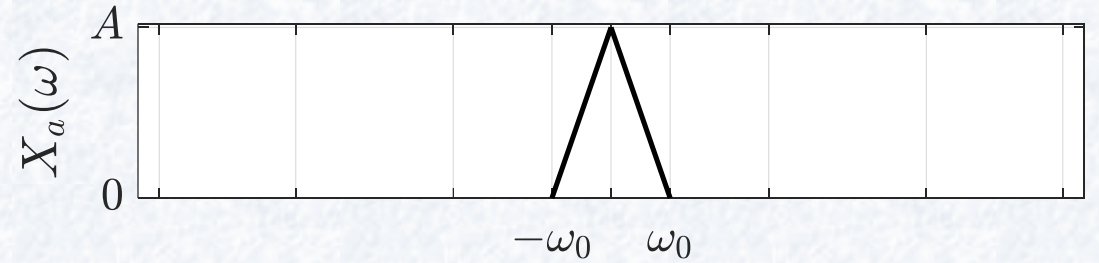
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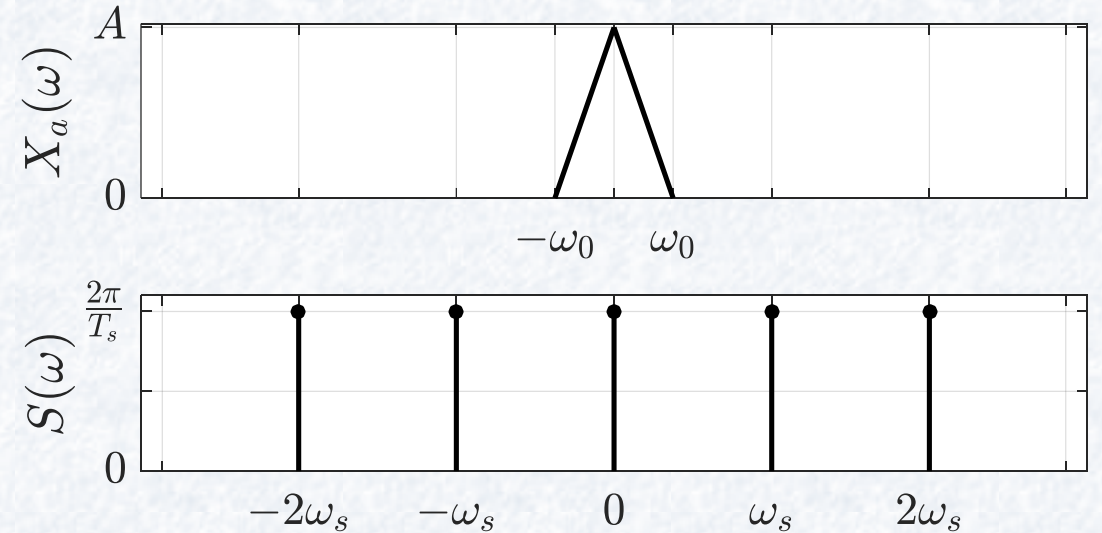
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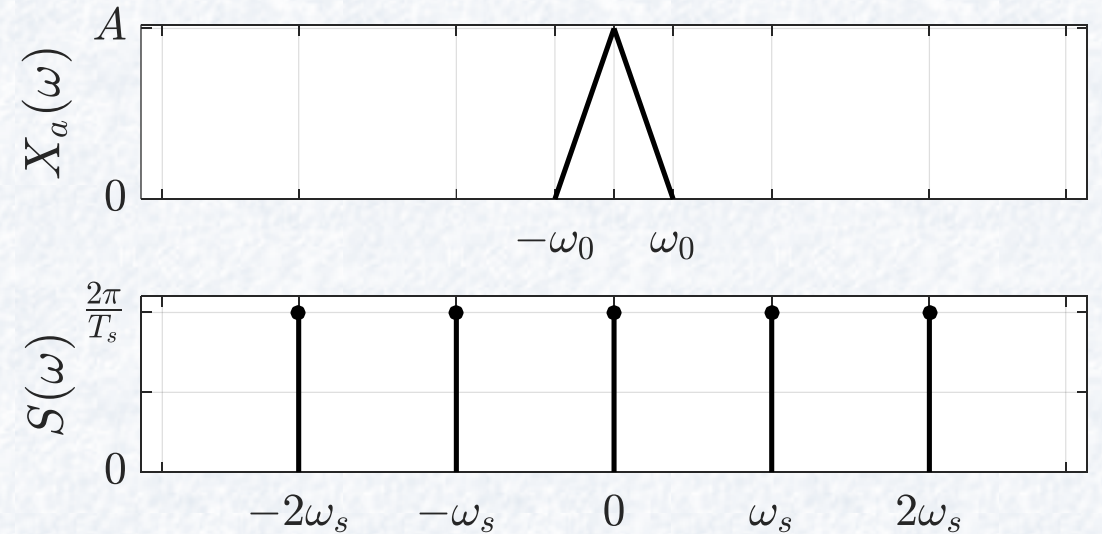
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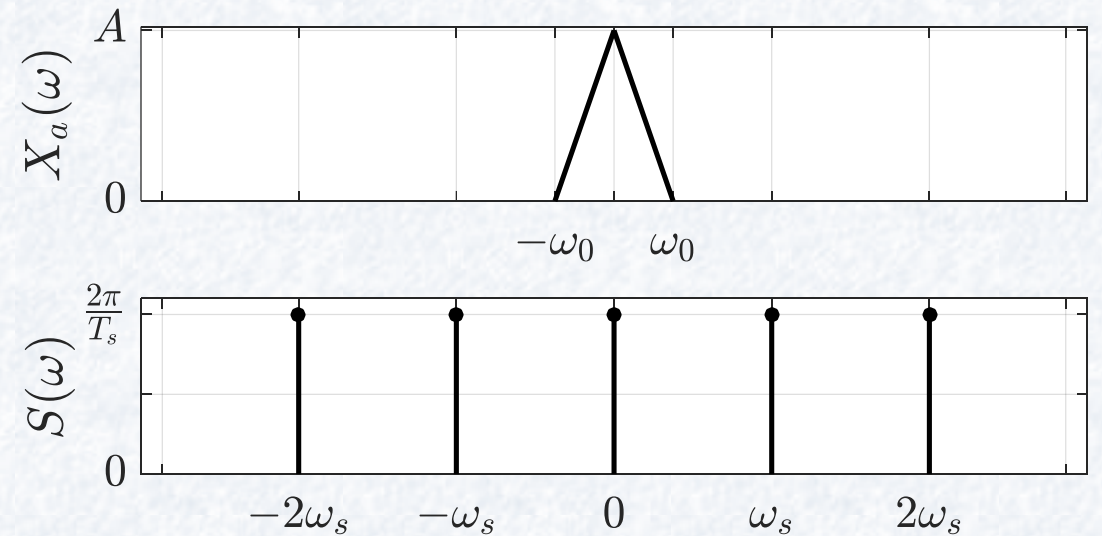
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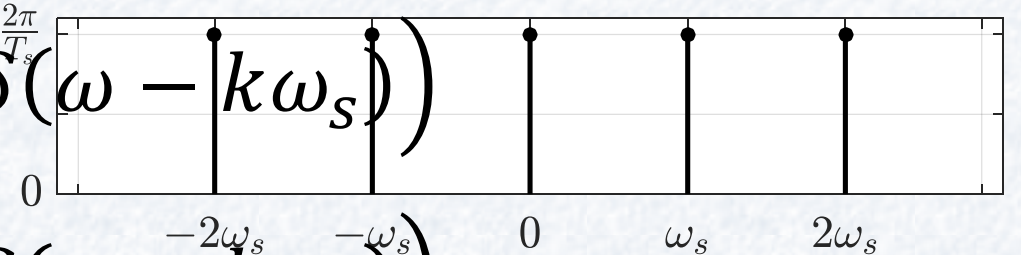
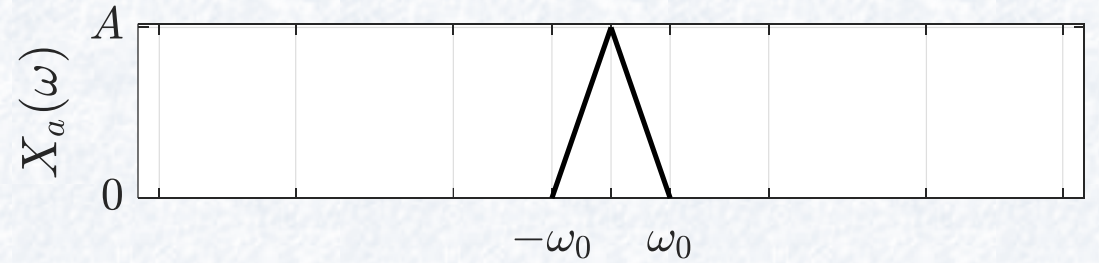
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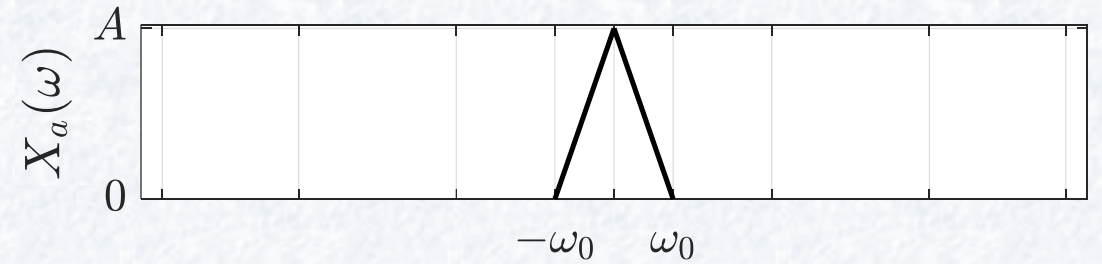
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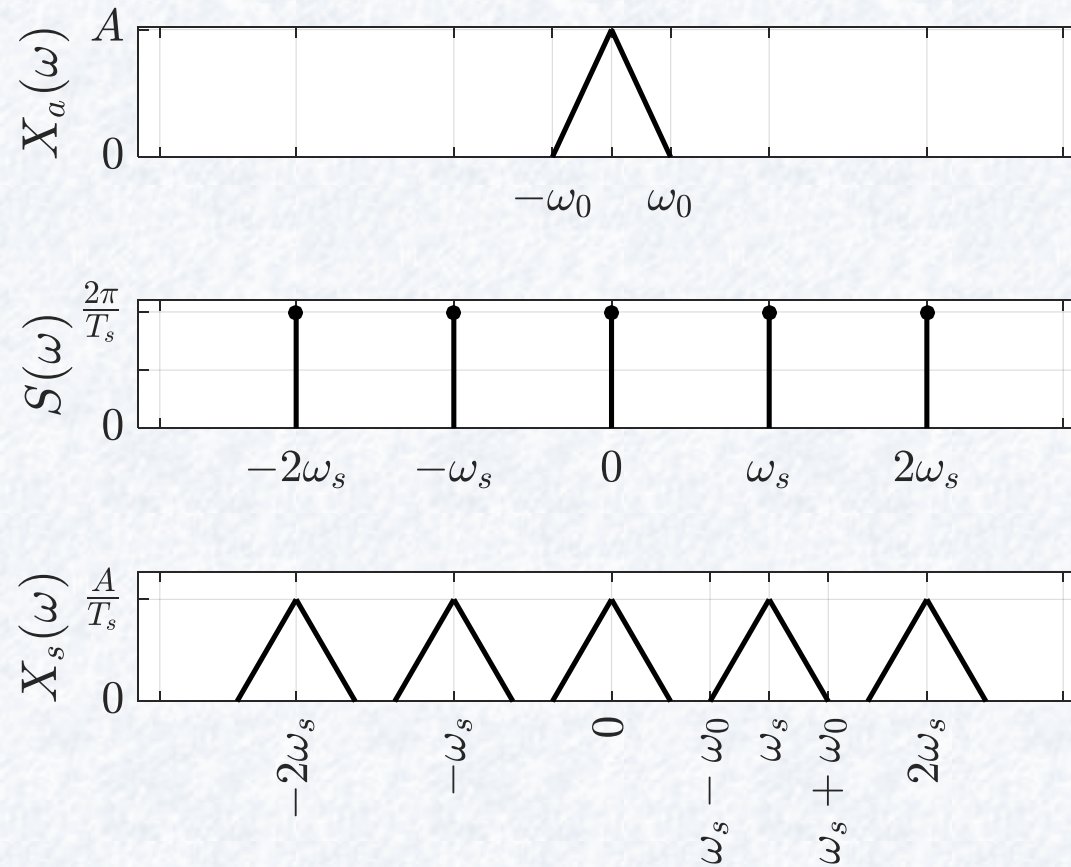
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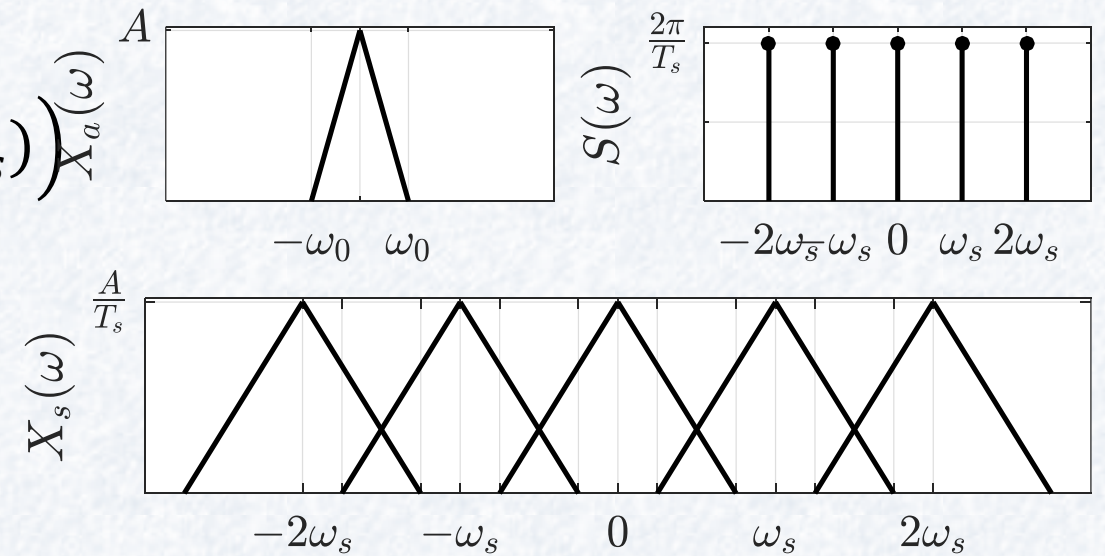
# Örneklenmiş Sürekli Zaman İşaret

- $$X_s(\omega) = \frac{1}{T_s} \left( \sum_{k=-\infty}^{\infty} X_a(\omega - k\omega_s) \right)$$



# Nyquist Kriteri

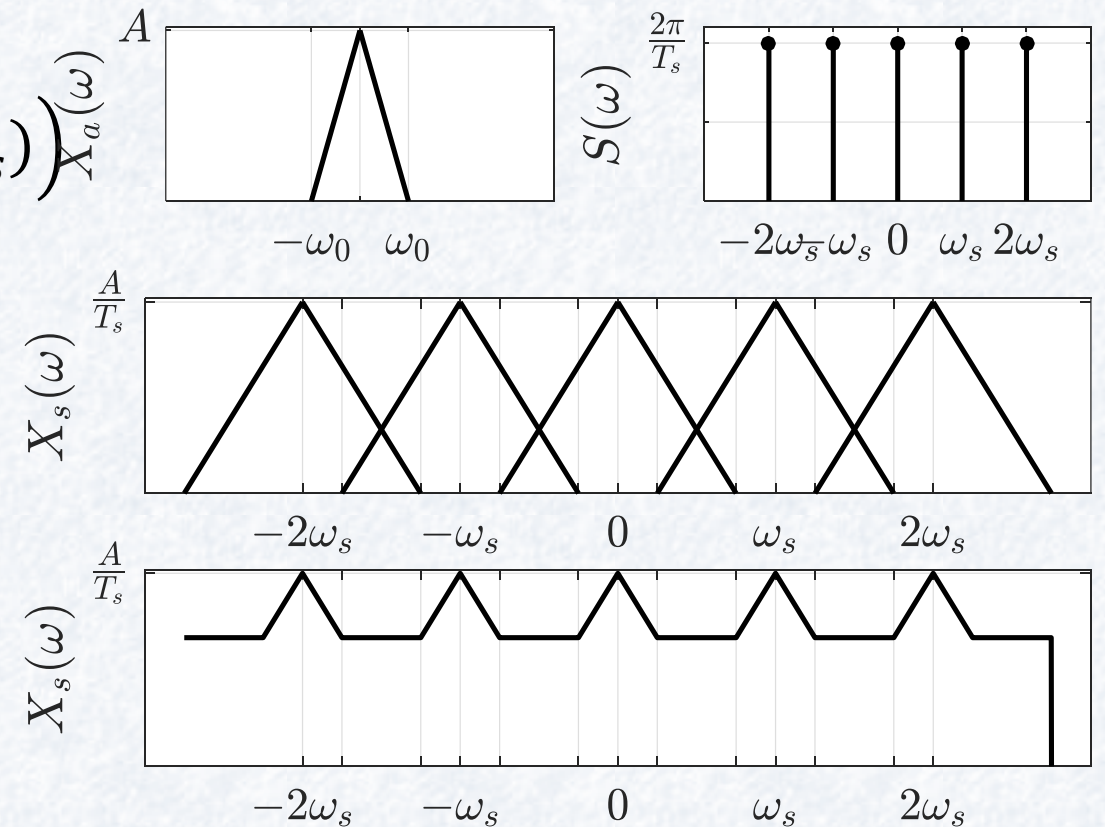
- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$
- $S(\omega) = \sum_{k=-\infty}^{\infty} \frac{2\pi}{T_s} \delta(\omega - k\omega_s)$
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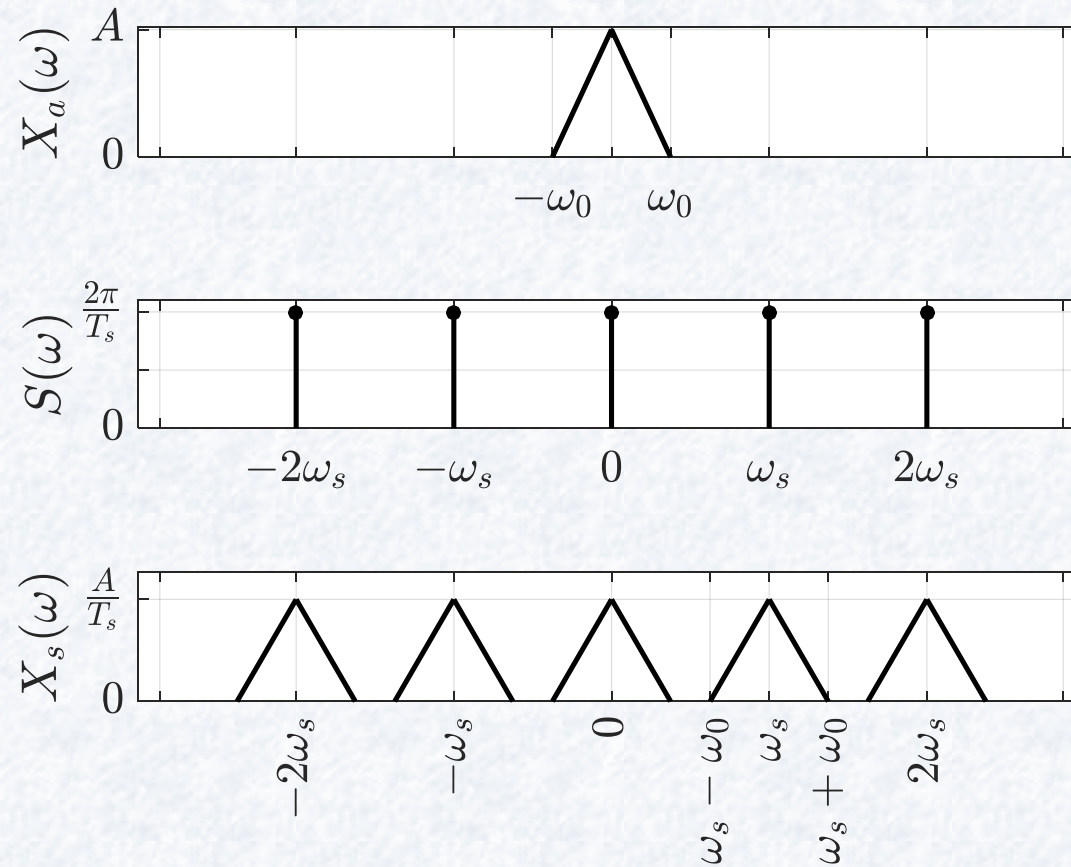
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- $X_s(\omega) = \frac{1}{2\pi} \left( X_a(\omega) * \sum_{k=-\infty}^{\infty} \frac{2\pi}{T_s} \delta(\omega - k\omega_s) \right)$
- $X_s(\omega) = \frac{1}{T_s} (\sum_{k=-\infty}^{\infty} X_a(\omega - k\omega_s))$
- Orijinal işaret geri dönülmez bir şekilde bozulmuştur.



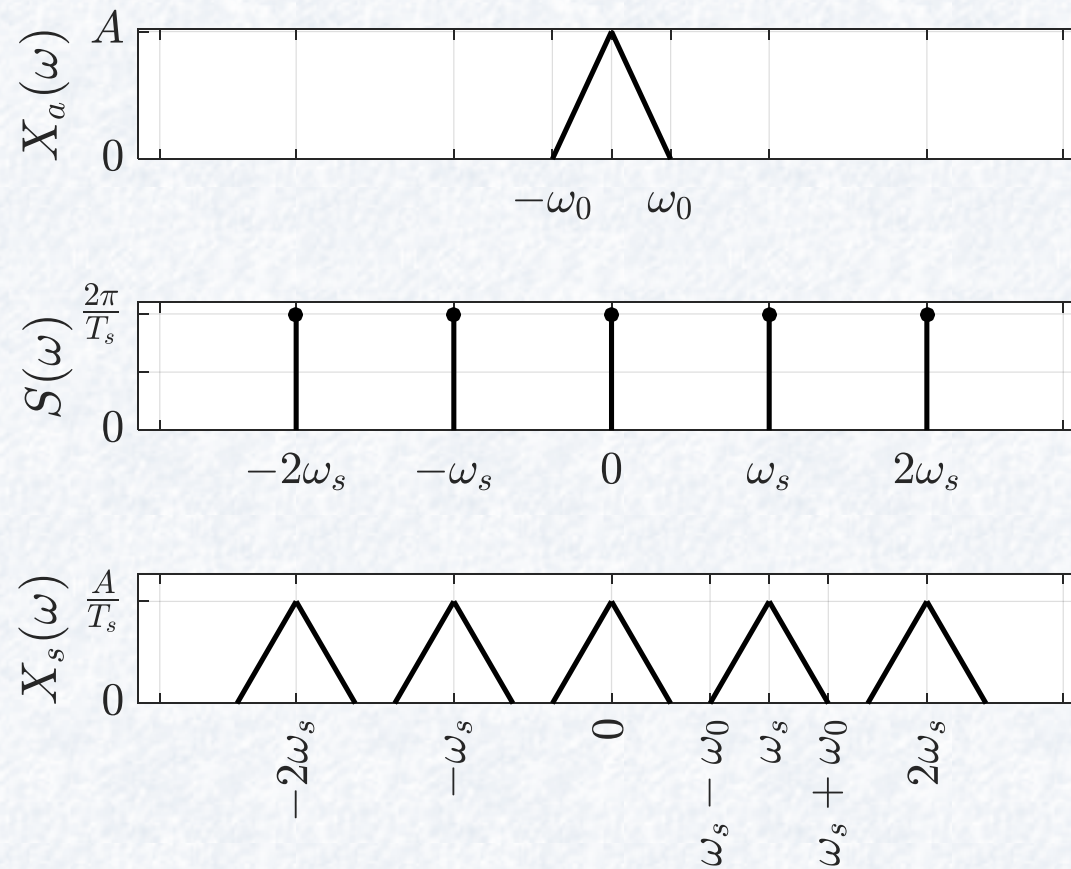
# Nyquist Kriteri

- $\omega_s - \omega_0 > \omega_0$



# Nyquist Kriteri

- $\omega_s - \omega_0 > \omega_0 \rightarrow \omega_s > 2\omega_0$



# Ayrık Zaman İşaret

- $x(n) = x_a(nT_s)$

# Örnek 1

- $x_a(t) = e^{j\omega_0 t} T_s$  periyodla örnekleniyor ise  $x(n) = ?$



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- $x(n)$ , periyodik midir?

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- $x(n) = x(n + N)$

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- $x(n) = x(n + N)$
- $e^{j\omega_0 nT_s} =$



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- $e^{j2\pi k} = e^{j\omega_0 NT_s}$

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- $2\pi k = \omega_0 NT_s$



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- $1 = e^{j\omega_0 NT_s}$
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- $2\pi k = \omega_0 NT_s = \frac{2\pi}{T_0} NT_s$

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- $1 = e^{j\omega_0 NT_s}$
- $e^{j2\pi k} = e^{j\omega_0 NT_s}$
- $2\pi k = \omega_0 NT_s = \frac{2\pi}{T_0} NT_s \rightarrow N = \frac{T_0}{T_s} k$

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- $x_a(t) = \cos(15t)$   $T_s = \frac{\pi}{10}$  sn. periyodla örnekleniyor ise  $x(n) = ?$

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- $N =$



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- $N = \frac{T_0}{T_s} k$ 
  - ♦  $T_0 =$

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  - ♦  $T_0 = \frac{2\pi}{\omega_0} =$

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- $N = \frac{T_0}{T_s} k = \frac{2\pi/15}{\pi/10} k$ 
  - ♦  $T_0 = \frac{2\pi}{\omega_0} = \frac{2\pi}{15}$

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- $N = \frac{T_0}{T_s} k = \frac{2\pi/15}{\pi/10} k = \frac{4}{3} k \rightarrow N = 4$ 
  - ♦  $T_0 = \frac{2\pi}{\omega_0} = \frac{2\pi}{15}$

## Örnek 3

- $x_a(t) = e^{-\alpha t} u(t)$   $T_s$  periyodla örnekleniyor ise  $x(n) = ?$



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- $|z|$

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- $x(n) = e^{-\alpha n T_s} u(n)$
- $X(z) = \frac{1}{1 - e^{-\alpha T_s} z^{-1}}$
- $|z| > e^{-\alpha T_s}$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$



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- $x_a(t) = \cos(\omega_0 t)$  olabilir.

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- $x(n) =$

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- $x(n) = \cos(2\pi f_0 n T_s) =$

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- $x(n) = \cos(2\pi f_0 n T_s) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) =$

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- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos(2\pi f_0 n T_s) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi f_0 n \frac{1}{f_s} = \frac{\pi}{8}n \rightarrow f_0 =$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos(2\pi f_0 n T_s) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi f_0 n \frac{1}{f_s} = \frac{\pi}{8}n \rightarrow f_0 = \frac{\pi}{8} \frac{f_s}{2\pi} = \frac{f_s}{16} = 625\text{Hz}$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos(2\pi f_0 n T_s) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi f_0 n \frac{1}{f_s} = \frac{\pi}{8}n \rightarrow f_0 = \frac{\pi}{8} \frac{f_s}{2\pi} = \frac{f_s}{16} = 625\text{Hz}$
- $x_a(t) = \cos(1250\pi t)$
- Başka bir  $x_a(t)$  var mıdır?

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm \boxed{\phantom{00}}\right)$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi kn\right)$



## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \times 1\right)$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) =$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) = \cos\left(2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right)\right)$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) = \cos\left(2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right)\right) = \cos\left(\frac{\pi}{8}n\right)$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) = \cos\left(2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right)\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right) = \frac{\pi}{8}n$



## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) = \cos\left(2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right)\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right) = \frac{\pi}{8}n$ 
  - ♦  $k = -1$  için  $\frac{f_0 - f_s}{f_s} = \frac{1}{16} \rightarrow f_0 =$

## Örnek 4

- $x(n) = \cos\left(\frac{\pi}{8}n\right)$  ve  $f_s = 10\text{kHz}$  ise  $x_a(t) = ?$
- $x_a(t) = \cos(\omega_0 t) = \cos(2\pi f_0 t)$
- $x(n) = \cos\left(2\pi f_0 n \frac{1}{f_s}\right) = \cos\left(2\pi f_0 n \frac{1}{f_s} \pm 2\pi k n \frac{f_s}{f_s}\right)$
- $x(n) = \cos\left(2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right)\right) = \cos\left(\frac{\pi}{8}n\right)$
- $2\pi n \left(\frac{f_0}{f_s} \pm k \frac{f_s}{f_s}\right) = \frac{\pi}{8}n$ 
  - ♦  $k = -1$  için  $\frac{f_0 - f_s}{f_s} = \frac{1}{16} \rightarrow f_0 = \frac{f_s}{16} + f_s = 10625\text{Hz}$
  - ♦  $x_a(t) = \cos(21250\pi t)$

## Örnek 5

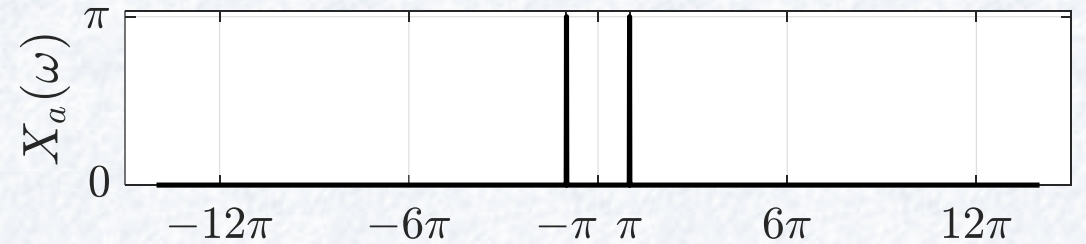
- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s =$

## Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
- $X_a(\omega) =$

# Örnek 5

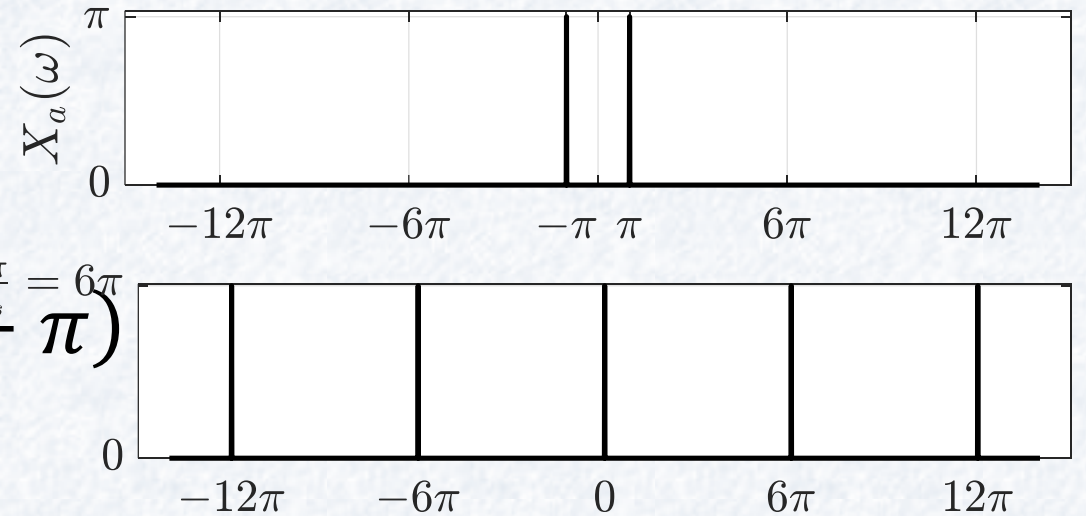
- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
- $X_a(\omega) = \pi\delta(\omega - \pi) + \pi\delta(\omega + \pi)$
- $S(\omega) =$





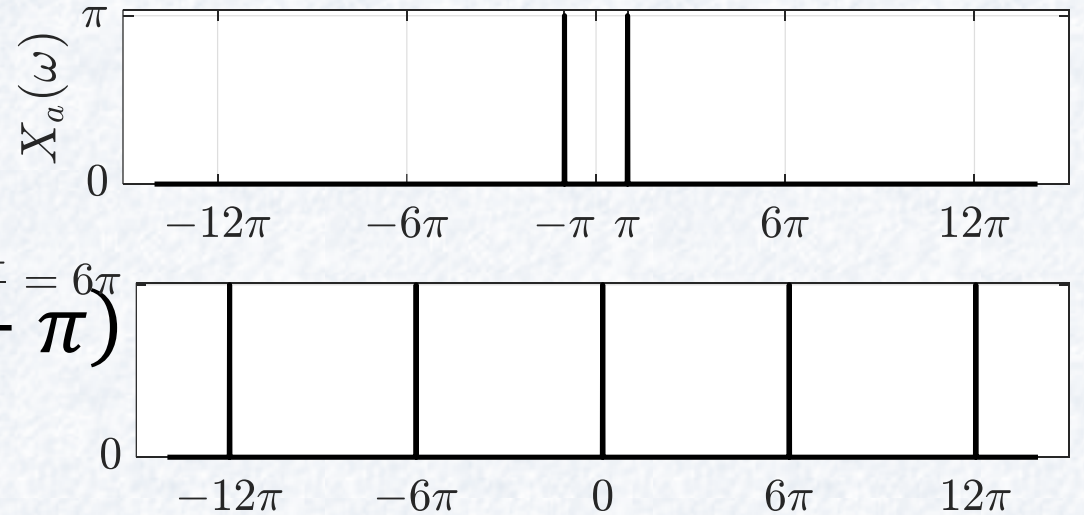
# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
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- $S(\omega) = \sum_{k=-\infty}^{\infty} 6\pi\delta(\omega - 6\pi k)$
- $X_s(\omega) =$



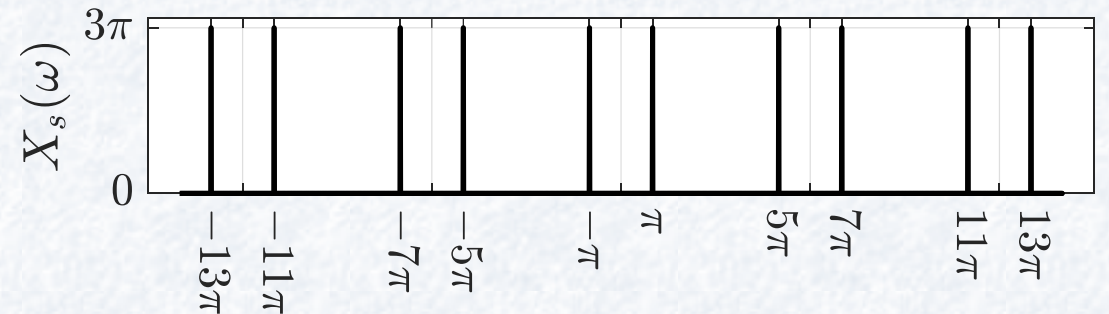
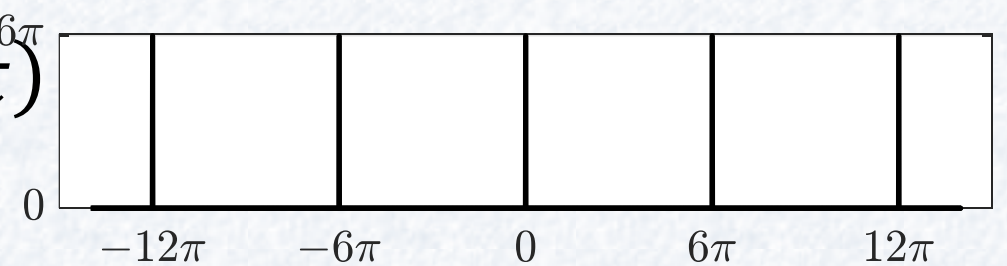
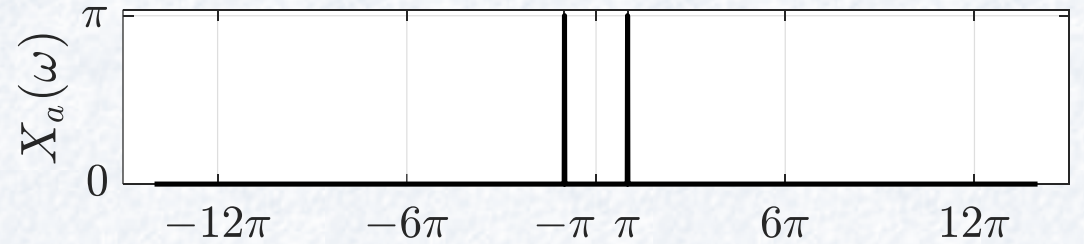
# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
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- $S(\omega) = \sum_{k=-\infty}^{\infty} 6\pi\delta(\omega - 6\pi k)$
- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$



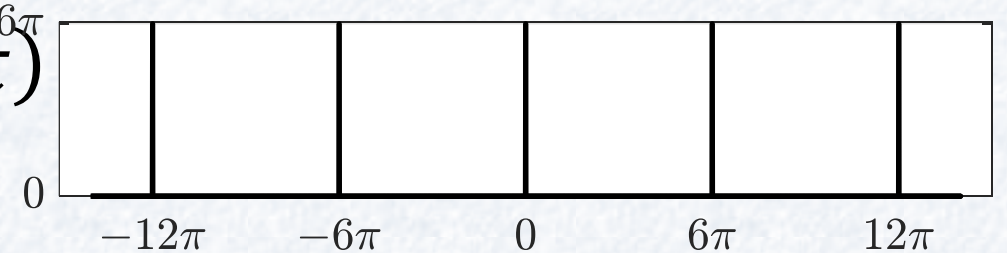
# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = \pi$  rad/sn. için  $X_s(\omega) = ?$
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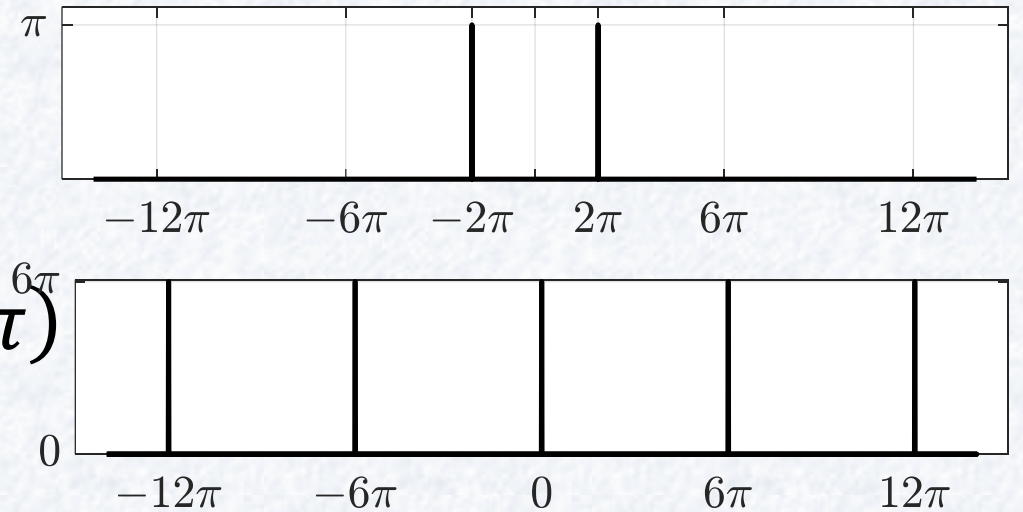
# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = 2\pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
- $X_a(\omega) = \pi\delta(\omega - \pi) + \pi\delta(\omega + \pi)$
- $S(\omega) = \sum_{k=-\infty}^{\infty} 6\pi\delta(\omega - 6\pi k)$
- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$



# Örnek 5

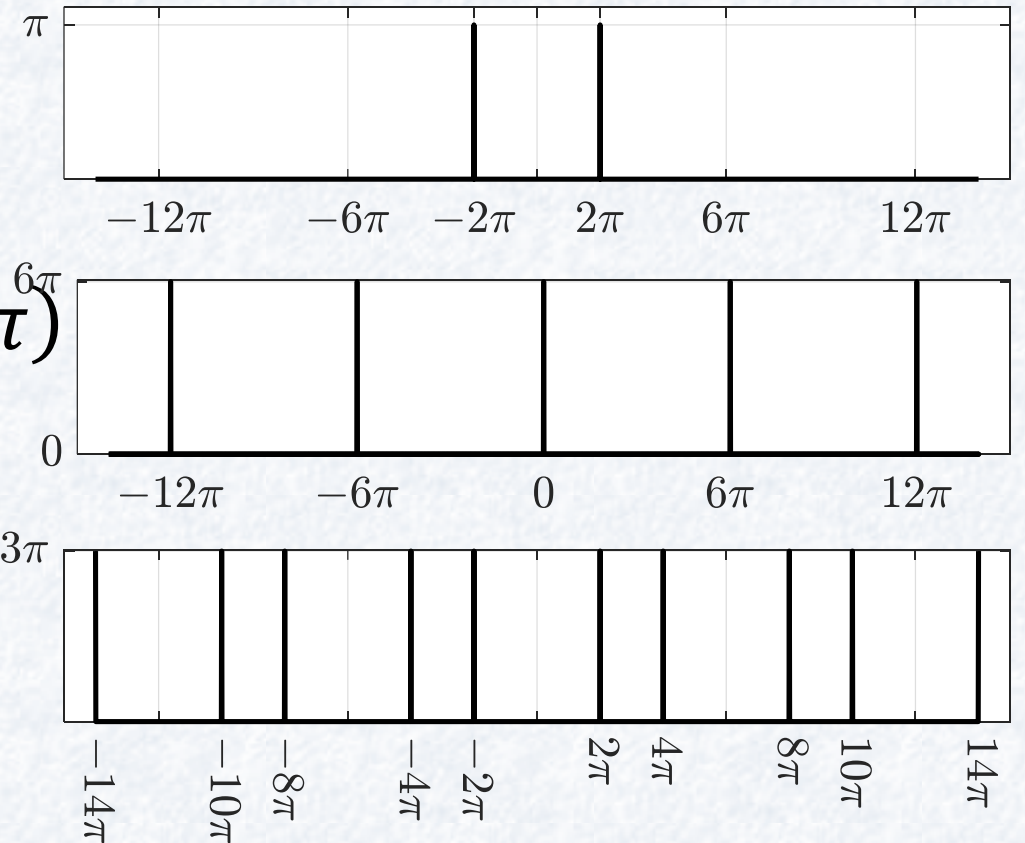
- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = 2\pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
- $X_a(\omega) = \pi\delta(\omega - \pi) + \pi\delta(\omega + \pi)$
- $S(\omega) = \sum_{k=-\infty}^{\infty} 6\pi\delta(\omega - 6\pi k)$
- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$





# Örnek 5

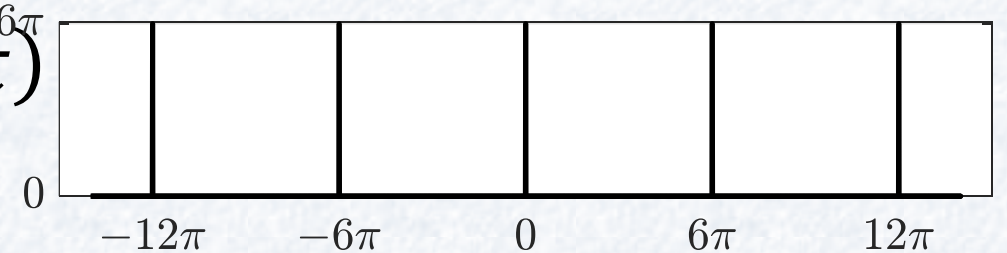
- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = 2\pi$  rad/sn. için  $X_s(\omega) = ?$
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- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$





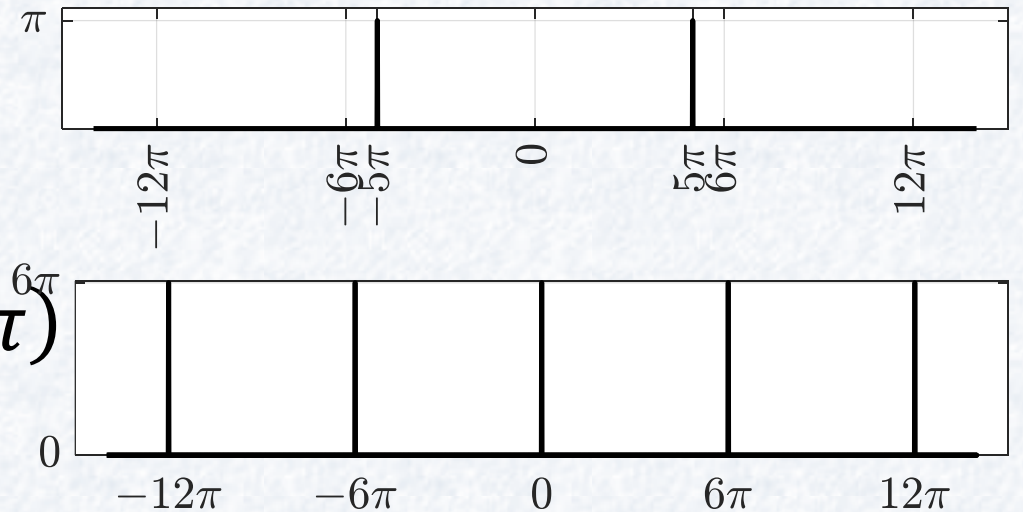
# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
- $\omega_0 = 5\pi$  rad/sn. için  $X_s(\omega) = ?$
- $\omega_s = \frac{2\pi}{T_s} = 6\pi$  rad/sn.
- $X_a(\omega) = \pi\delta(\omega - \pi) + \pi\delta(\omega + \pi)$
- $S(\omega) = \sum_{k=-\infty}^{\infty} 6\pi\delta(\omega - 6\pi k)$
- $X_s(\omega) = \frac{1}{2\pi} (X_a(\omega) * S(\omega))$



# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
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# Örnek 5

- $x_a(t) = \cos(\omega_0 t)$ ,  $T_s = \frac{1}{3}$  sn. ile örnekleniyor.
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