BSM307
İşaretler ve Sistemler

Dr. Seçkin Arı

Fourier Seri Açılımı

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- Farklı frekanstaki sinüsoidal işaretlerin toplamı
- Tüm Sürekli Zaman Periyodik İşaretler
  - ♦ Fourier Seri Açılımı ile ifade edilir.
  - ♦ Frekans spektrumu elde edilir.

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  - $a_k = \frac{1}{T_0} \int_{t_1}^{t_2} x(t) e^{-jk\omega_0 t} dt$: Fourier seri katsayısı

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  - ♦ $a_k = \frac{1}{T_0}\int_{t_1}^{t_2} x(t)e^{-jk\omega_0 t}dt$: Fourier seri katsayısı
    - $t_2 - t_1 = T_0$ (Bir periyot boyunca integral)

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    - Sabit
    - İlgili frekans bileşeninin ne kadar etkin olduğunu belirler.

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- $x(t) = \sum_{k=-\infty}^{\infty} a_k e^{jk\omega_0 t}$
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- $a_{\pm 1}$: Birinci harmonik bileşenler, temel bileşenler

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- a_0: Frekansı olmayan bileşen
  - DC bileşen

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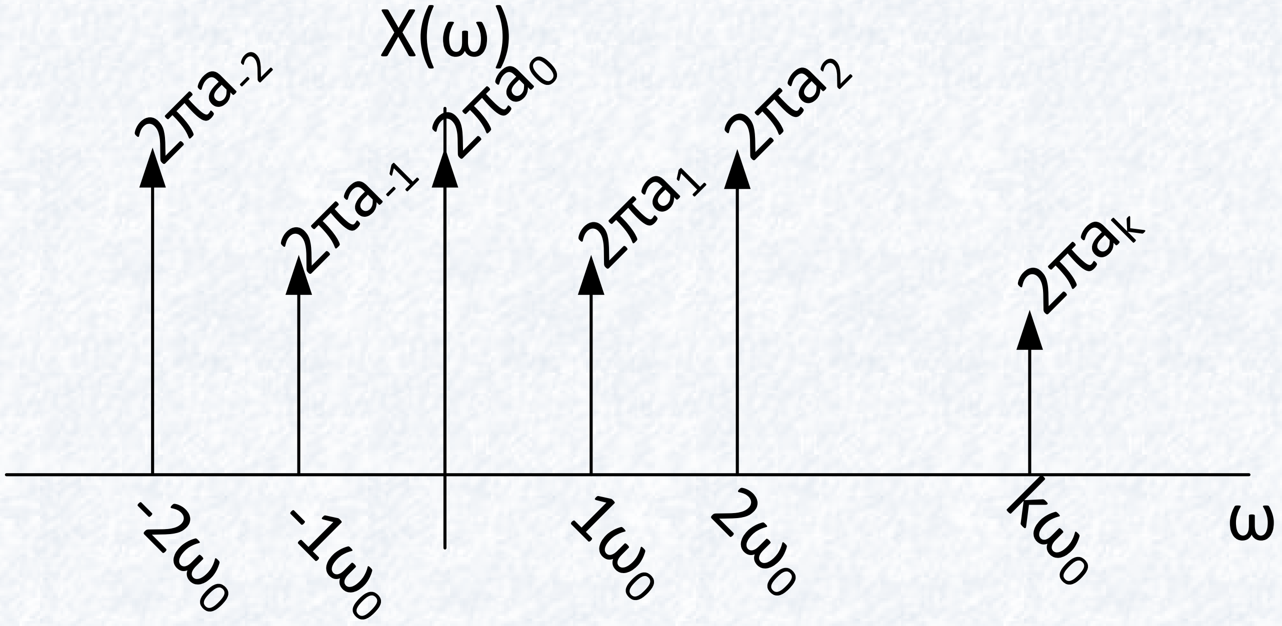

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- $x(t) = \cos(2t)$ ise $\omega_0 =?$, $a_k =?$

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- $\omega_0 = 2$
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- $x(t) = \cos(2t)$ ise $\omega_0 =?$, $a_k =?$
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- $a_0 = 0, a_{\pm 2} = 0$

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- Spektrum?

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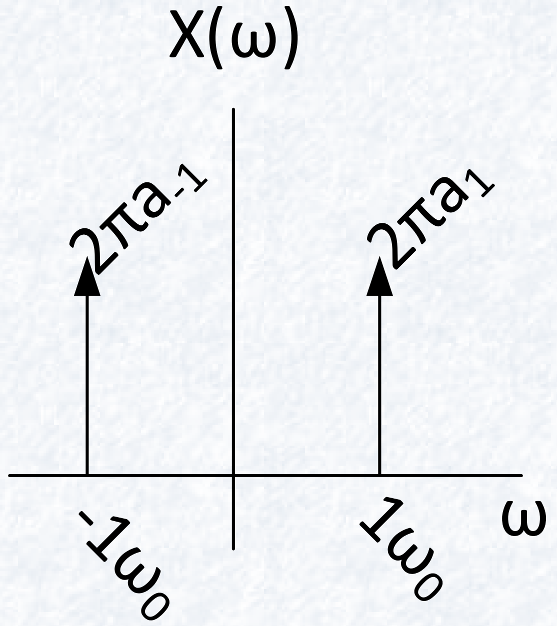

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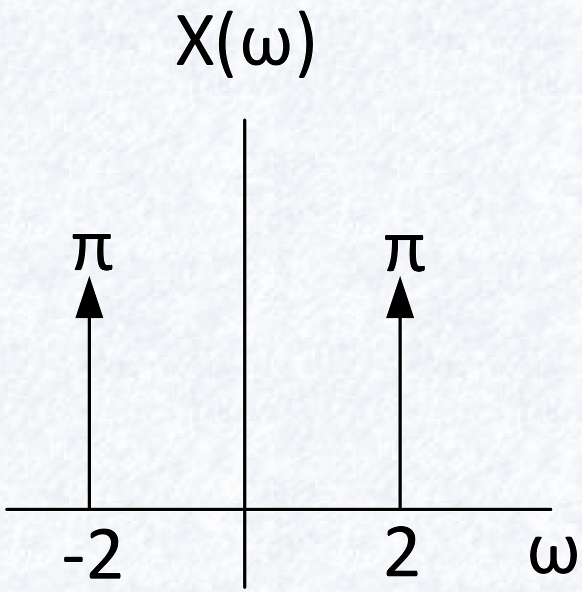

Örnek 2

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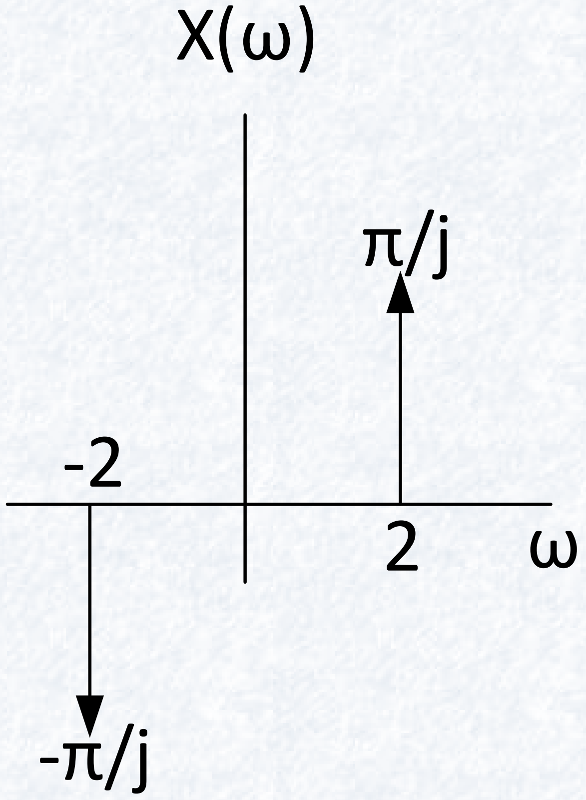

Örnek 3

- $x(t) = \sin\left(2t + \frac{\pi}{4}\right)$ ise $\omega_0 =?$, $a_k =?$
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- $x(t) = \sin\left(2t + \frac{\pi}{4}\right)$ ise $\omega_0 = ?$, $a_k = ?$
- $\omega_0 = 2$
- $a_1 = \frac{e^{j\frac{\pi}{4}}}{2j}, a_{-1} = -\frac{e^{-j\frac{\pi}{4}}}{2j}$
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Örnek 3

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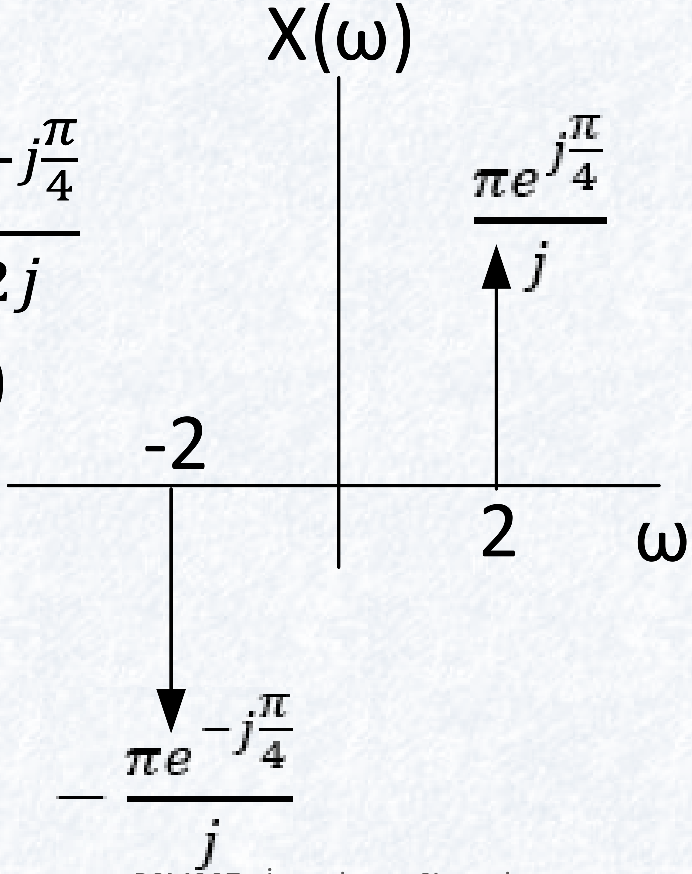

Örnek 4

- $x(t) = \cos(4t) + \sin(6t)$ ise ω_0 =?, a_k =?

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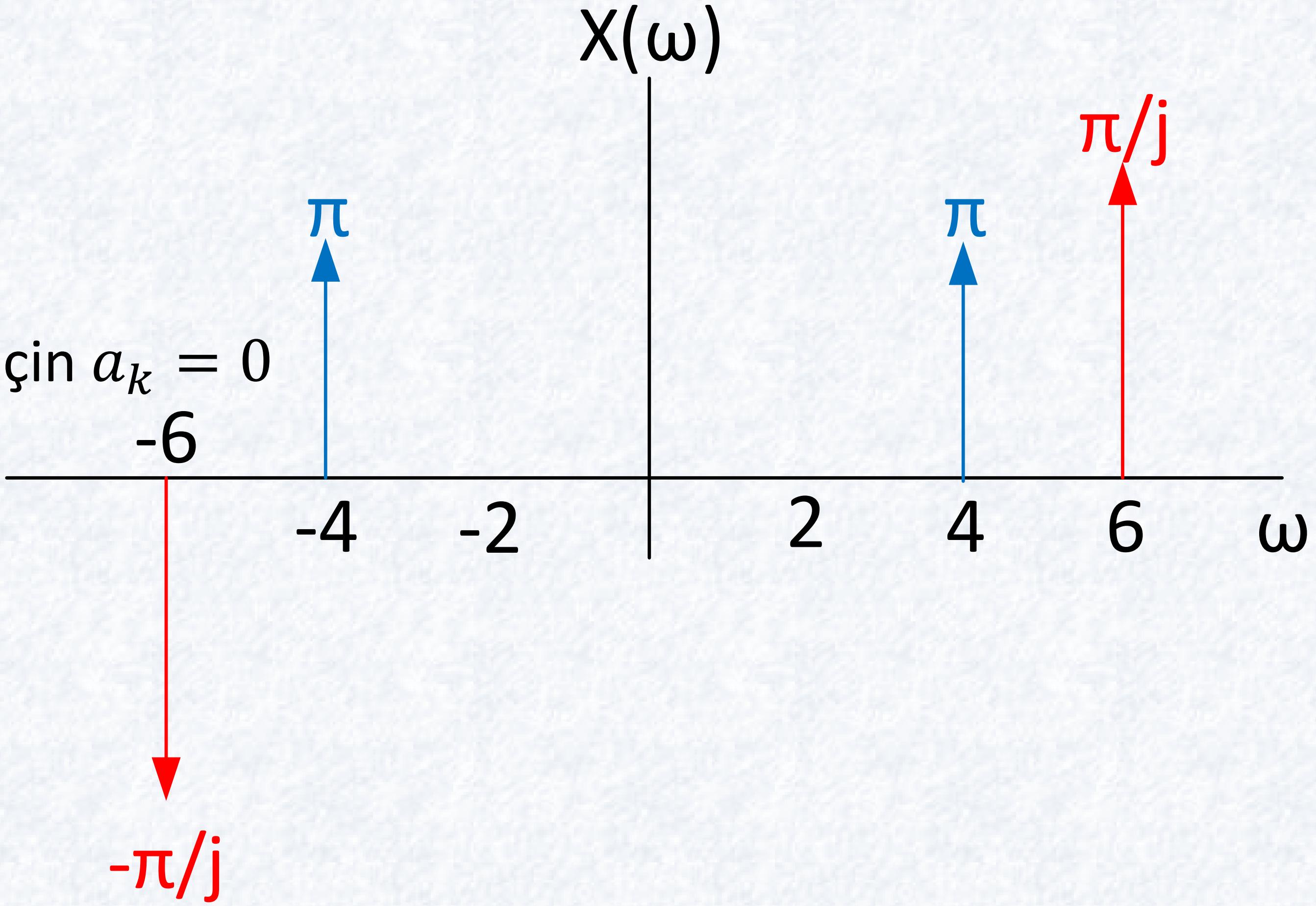

Örnek 5

- $x(t) = \sin^2(2t)$ ise $\omega_0 =?$, $a_k =?$
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Örnek 5

- $x(t) = \sin^2(2t)$ ise $\omega_0 =?$, $a_k =?$
- $x(t) = \left(\frac{e^{j2t} - e^{-j2t}}{2j}\right)^2 =$

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- $x(t) = \sin^2(2t)$ ise $\omega_0 =?, a_k =?$
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- $x(t) = \sin^2(2t)$ ise $\omega_0 =?$, $a_k =?$
- $x(t) = \left(\frac{e^{j2t} - e^{-j2t}}{2j}\right)^2 = \frac{e^{j4t} - 2 + e^{-j4t}}{-4} = -\frac{1}{4}e^{j4t} + \frac{1}{2} - \frac{1}{4}e^{-j4t}$
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- $\forall k \neq \pm 1\ ve\ \forall k \neq 0$ için $a_k = 0$

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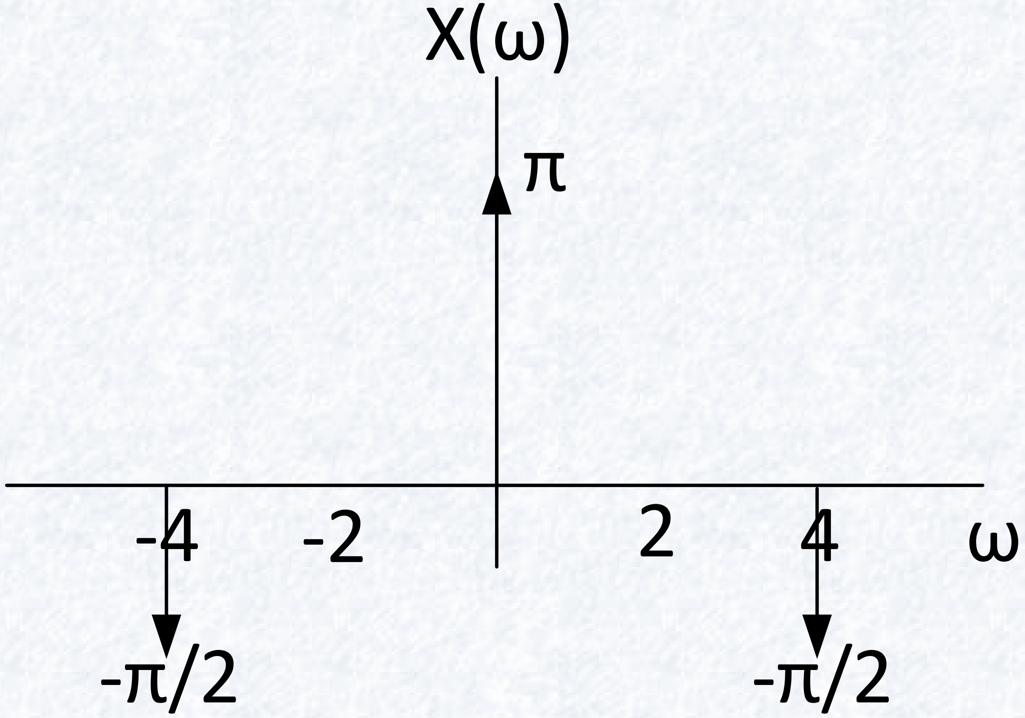
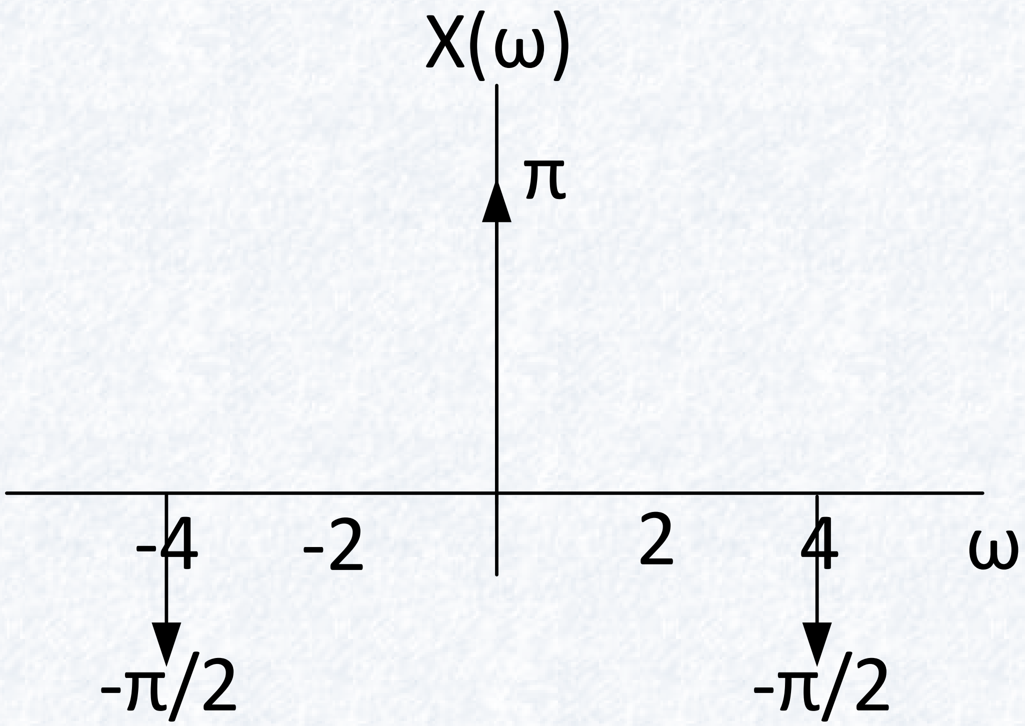
- $x(t) =$



Örnek 5

- $x(t) = \sin^2(2t)$ ise $\omega_0 =?,\ a_k =?$
- $\omega_0 = 4$
- $a_1 = -\frac{1}{4}, a_{-1} = -\frac{1}{4}$
- $a_0 = \frac{1}{2}$
- $\forall k \neq \pm 1\ ve\ \forall k \neq 0$ için $a_k = 0$
- $x(t) = \frac{1}{2} +$



Örnek 5

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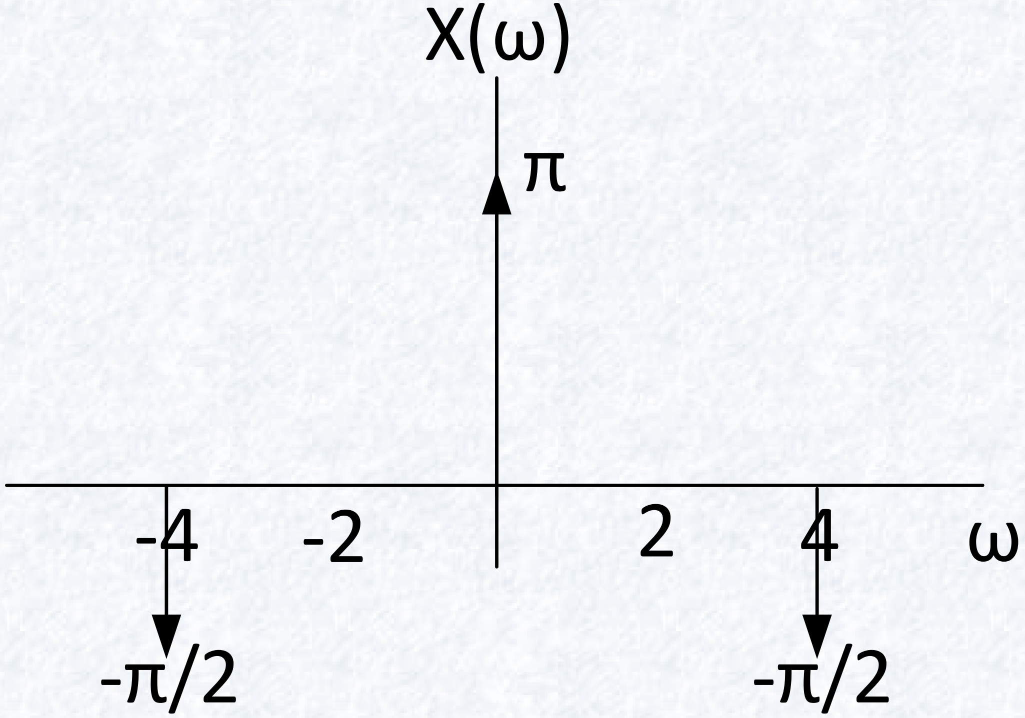
- $\forall k \neq \pm 1\ ve\ \forall k \neq 0$ için $a_k = 0$
- $x(t) = \frac{1}{2} - \frac{1}{2}\cos(4t)$



Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{4}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t) =?$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{4}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t)$ =?
- $x(t) = \sum_{k=-4}^{4} a_k e^{jk\omega_0 t}$

Örnek 6

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- $x(t) = \sum_{k=-4}^{4} a_k e^{jk\omega_0 t}$
  $= a_{-4}e^{-j8\pi t} + a_{-3}e^{-j6\pi t} + a_{-2}e^{-j4\pi t} + a_{-1}e^{-j2\pi t} + a_0$
  $+ a_4 e^{j8\pi t} + a_3 e^{j6\pi t} + a_2 e^{j4\pi t} + a_1 e^{j2\pi t}$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{4}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t) =?$
- $x(t) = \sum_{k=-4}^{4} a_k e^{jk\omega_0 t}$

$$= a_{-4}e^{-j8\pi t} + a_{-3}e^{-j6\pi t} + a_{-2}e^{-j4\pi t} + a_{-1}e^{-j2\pi t} + a_0$$
$$+a_4 e^{j8\pi t} + a_3 e^{j6\pi t} + a_2 e^{j4\pi t} + a_1 e^{j2\pi t}$$
$$= \frac{1}{2}e^{-j8\pi t} + 0e^{-j6\pi t} + \frac{1}{3}e^{-j4\pi t} + \frac{1}{4}e^{-j2\pi t} + 1$$
$$+\frac{1}{2}e^{j8\pi t} + 0e^{j6\pi t} + \frac{1}{3}e^{j4\pi t} + \frac{1}{4}e^{j2\pi t}$$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{4}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t) = ?$
- $x(t) = \frac{1}{2}e^{-j8\pi t} + 0e^{-j6\pi t} + \frac{1}{3}e^{-j4\pi t} + \frac{1}{4}e^{-j2\pi t} + 1 + \frac{1}{2}e^{j8\pi t} + 0e^{j6\pi t} + \frac{1}{3}e^{j4\pi t} + \frac{1}{4}e^{j2\pi t}$
- $x(t) = 1 +$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{4}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t) = ?$
- $x(t) = \frac{1}{2}e^{-j8\pi t} + 0e^{-j6\pi t} + \frac{1}{3}e^{-j4\pi t} + \frac{1}{4}e^{-j2\pi t} + 1 + \frac{1}{2}e^{j8\pi t} + 0e^{j6\pi t} + \frac{1}{3}e^{j4\pi t} + \frac{1}{4}e^{j2\pi t}$
- $x(t) = 1 + \frac{1}{2}\cos(2\pi t)$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{2}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t)$ =?
- $x(t) = \frac{1}{2}e^{-j8\pi t} + 0e^{-j6\pi t} + \frac{1}{3}e^{-j4\pi t} + \frac{1}{4}e^{-j2\pi t} + 1 + \frac{1}{2}e^{j8\pi t} + 0e^{j6\pi t} + \frac{1}{3}e^{j4\pi t} + \frac{1}{4}e^{j2\pi t}$
- $x(t) = 1 + \frac{1}{2}\cos(2\pi t) + \frac{2}{3}\cos(4\pi t)$

Örnek 6

- $\omega_0 = 2\pi$
- $a_0 = 1, a_{\pm 1} = \frac{1}{2}, a_{\pm 2} = \frac{1}{3}, a_{\pm 4} = \frac{1}{2}$ ise $x(t) = ?$
- $x(t) = \frac{1}{2}e^{-j8\pi t} + 0e^{-j6\pi t} + \frac{1}{3}e^{-j4\pi t} + \frac{1}{4}e^{-j2\pi t} + 1 + \frac{1}{2}e^{j8\pi t} + 0e^{j6\pi t} + \frac{1}{3}e^{j4\pi t} + \frac{1}{4}e^{j2\pi t}$
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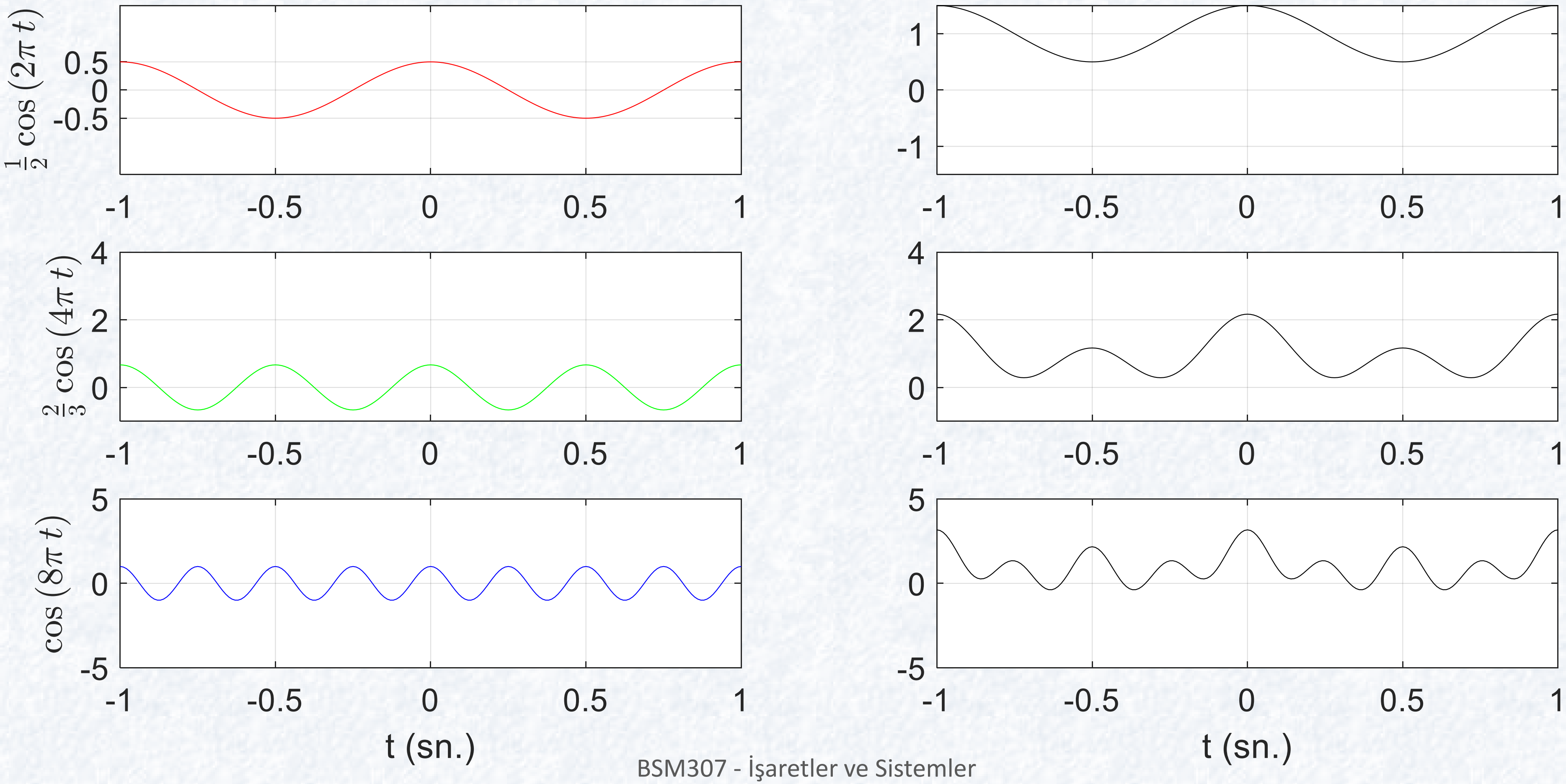
Örnek 6

- $x(t) = 1 + \frac{1}{2}\cos(2\pi t) + \frac{2}{3}\cos(4\pi t) + \cos(8\pi t)$



Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) + \cos\left(\omega_0 t + \frac{\pi}{4}\right)$ Fourier Seri Açılımı?

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t} e^{j\frac{\pi}{4}} + e^{-j\omega_0 t} e^{-j\frac{\pi}{4}}}{2} =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$

- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t} e^{j\frac{\pi}{4}} + e^{-j\omega_0 t} e^{-j\frac{\pi}{4}}}{2}$

$$= 1 + \left(\frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2}\right) e^{j\omega_0 t} - \left(\frac{1}{2j} + \frac{e^{-j\frac{\pi}{4}}}{2}\right) e^{-j\omega_0 t} + e^{j2\omega_0 t} + e^{-j2\omega_0 t}$$

- $a_0 =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t}e^{j\frac{\pi}{4}} + e^{-j\omega_0 t}e^{-j\frac{\pi}{4}}}{2}$
  $= 1 + \left(\frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2}\right)e^{j\omega_0 t} - \left(\frac{1}{2j} + \frac{e^{-j\frac{\pi}{4}}}{2}\right)e^{-j\omega_0 t} + e^{j2\omega_0 t} + e^{-j2\omega_0 t}$
- $a_0 = 1$
- $a_1 =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t} e^{j\frac{\pi}{4}} + e^{-j\omega_0 t} e^{-j\frac{\pi}{4}}}{2}$

$$= 1 + \left(\frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2}\right) e^{j\omega_0 t} - \left(\frac{1}{2j} + \frac{e^{-j\frac{\pi}{4}}}{2}\right) e^{-j\omega_0 t} + e^{j2\omega_0 t} + e^{-j2\omega_0 t}$$

- $a_0 = 1$
- $a_1 = \frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2} = 0{,}9239 e^{-j112{,}5°}$
- $a_{-1} =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t}e^{j\frac{\pi}{4}} + e^{-j\omega_0 t}e^{-j\frac{\pi}{4}}}{2} = 1 + \left(\frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2}\right)e^{j\omega_0 t} - \left(\frac{1}{2j} + \frac{e^{-j\frac{\pi}{4}}}{2}\right)e^{-j\omega_0 t} + e^{j2\omega_0 t} + e^{-j2\omega_0 t}$
- $a_0 = 1$
- $a_1 = \frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2} = 0{,}9239e^{-j112{,}5°}$
- $a_{-1} = -\frac{1}{2j} - \frac{e^{-j\frac{\pi}{4}}}{2} = 0{,}9239e^{j112{,}5°}$
- $a_2 = a_{-2} =$

Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
- $x(t) = 1 + \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j} + e^{j2\omega_0 t} + e^{-j2\omega_0 t} - \frac{e^{j\omega_0 t}e^{j\frac{\pi}{4}} + e^{-j\omega_0 t}e^{-j\frac{\pi}{4}}}{2} = 1 + \left(\frac{1}{2j} - \frac{e^{j\frac{\pi}{4}}}{2}\right)e^{j\omega_0 t} - \left(\frac{1}{2j} + \frac{e^{-j\frac{\pi}{4}}}{2}\right)e^{-j\omega_0 t} + e^{j2\omega_0 t} + e^{-j2\omega_0 t}$
- $a_0 = 1$
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Örnek 7

- $x(t) = 1 + \sin(\omega_0 t) + 2\cos(2\omega_0 t) - \cos\left(\omega_0 t + \frac{\pi}{4}\right)$
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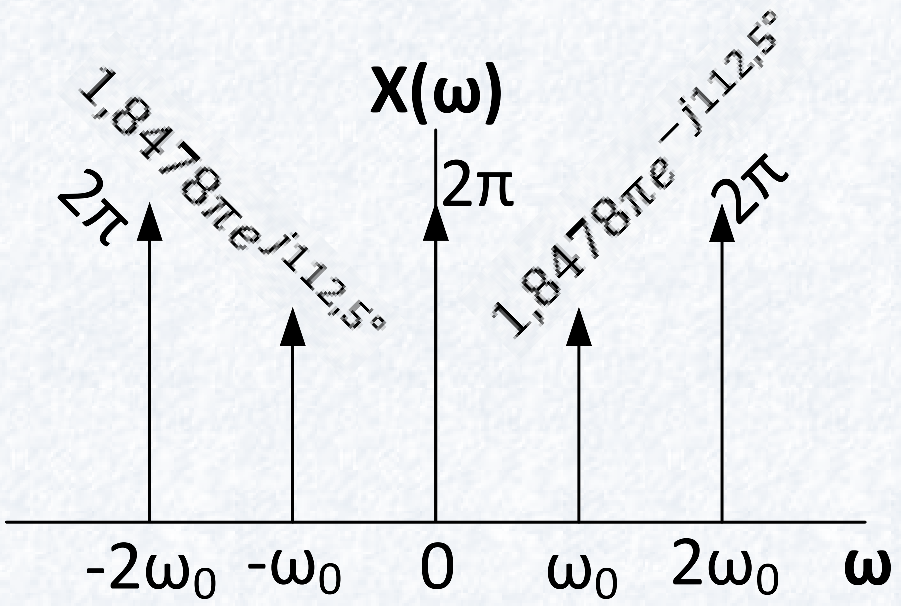
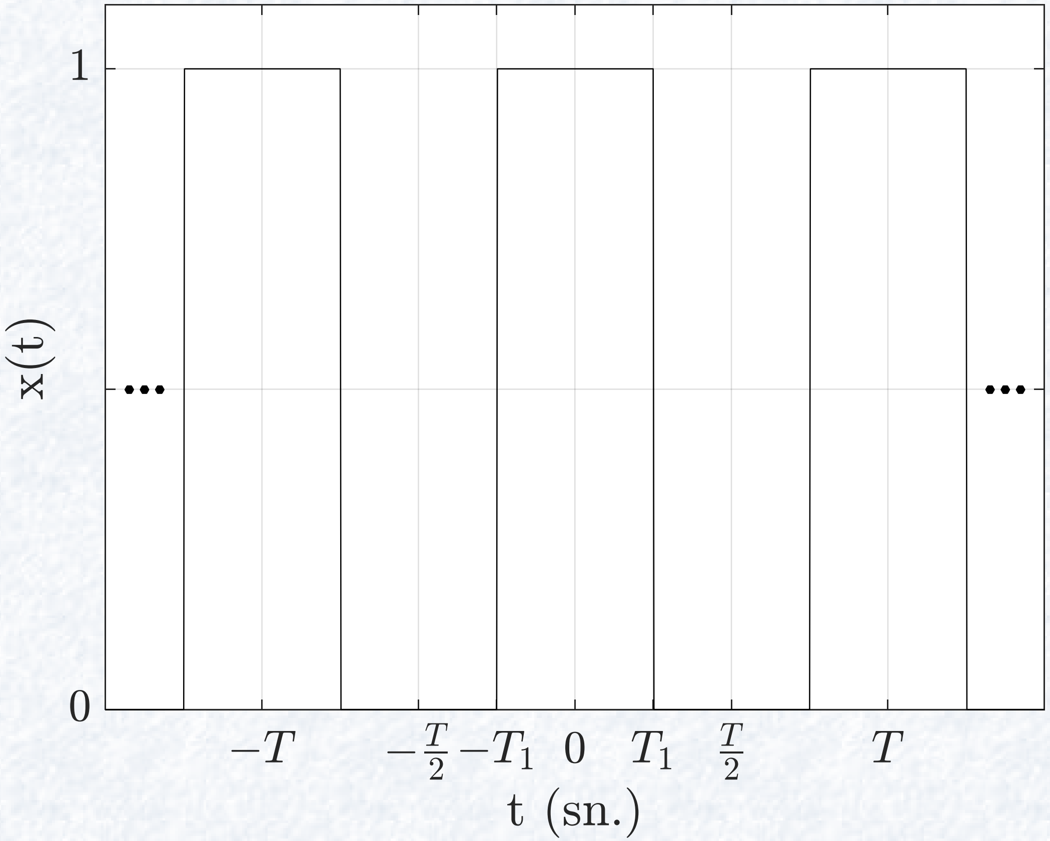
- $a_{-1} = -\frac{1}{2j} - \frac{e^{-j\frac{\pi}{4}}}{2} = 0{,}9239e^{j112{,}5°}$
- $a_2 = a_{-2} = 1$



Örnek 8

- Fourier seri açılımı?



- $\omega_0 =$

Örnek 8

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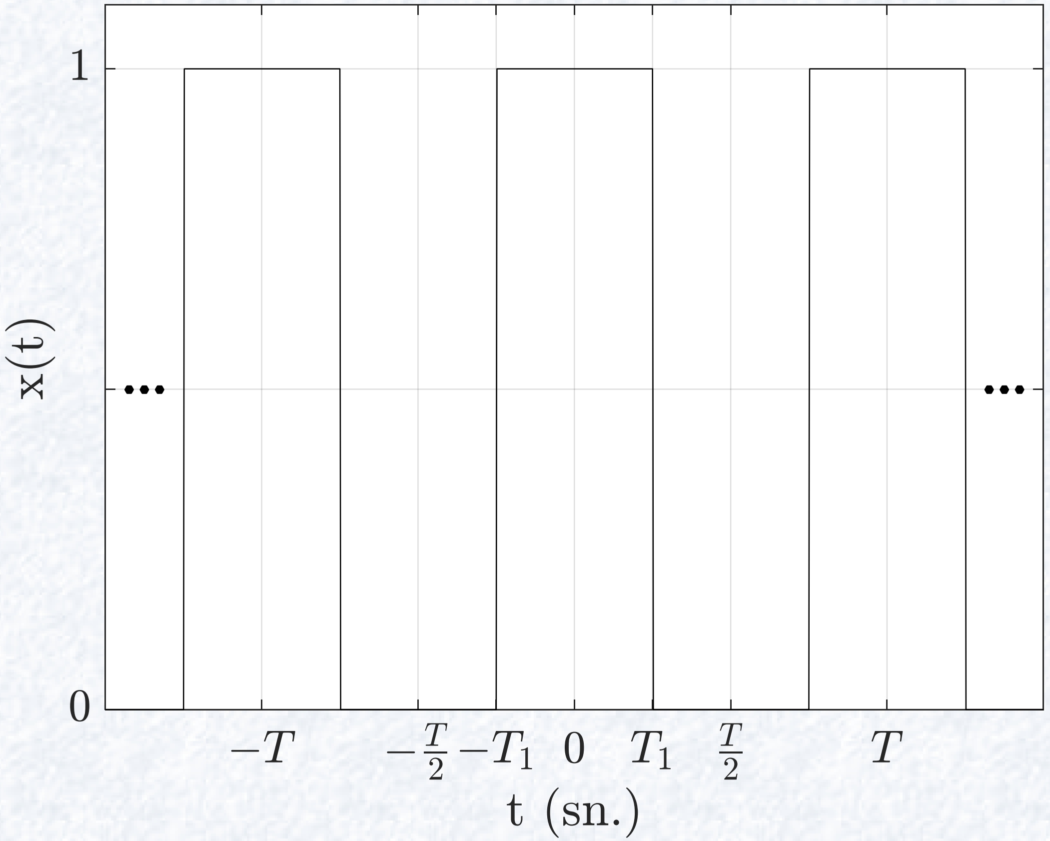
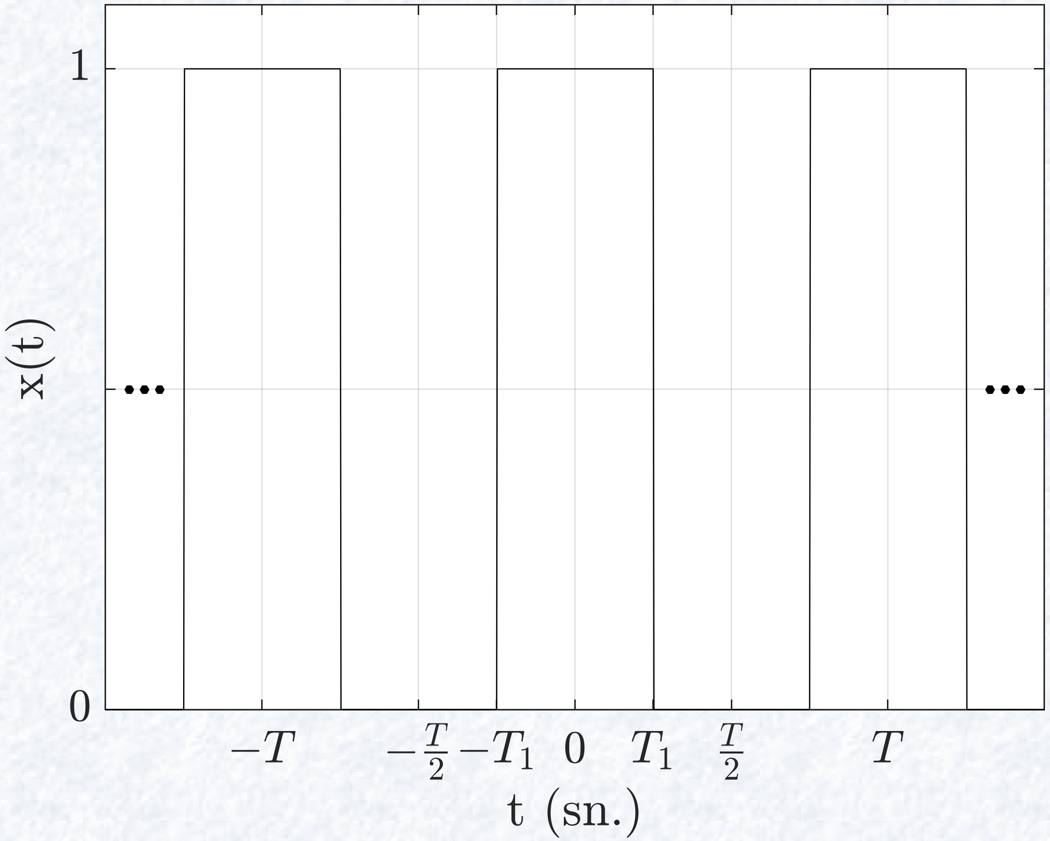


- $\omega_0 = \frac{2\pi}{T}$

Örnek 8

- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T_0}\int_{t_1}^{t_2} x(t)\, e^{-jk\omega_0 t} dt$

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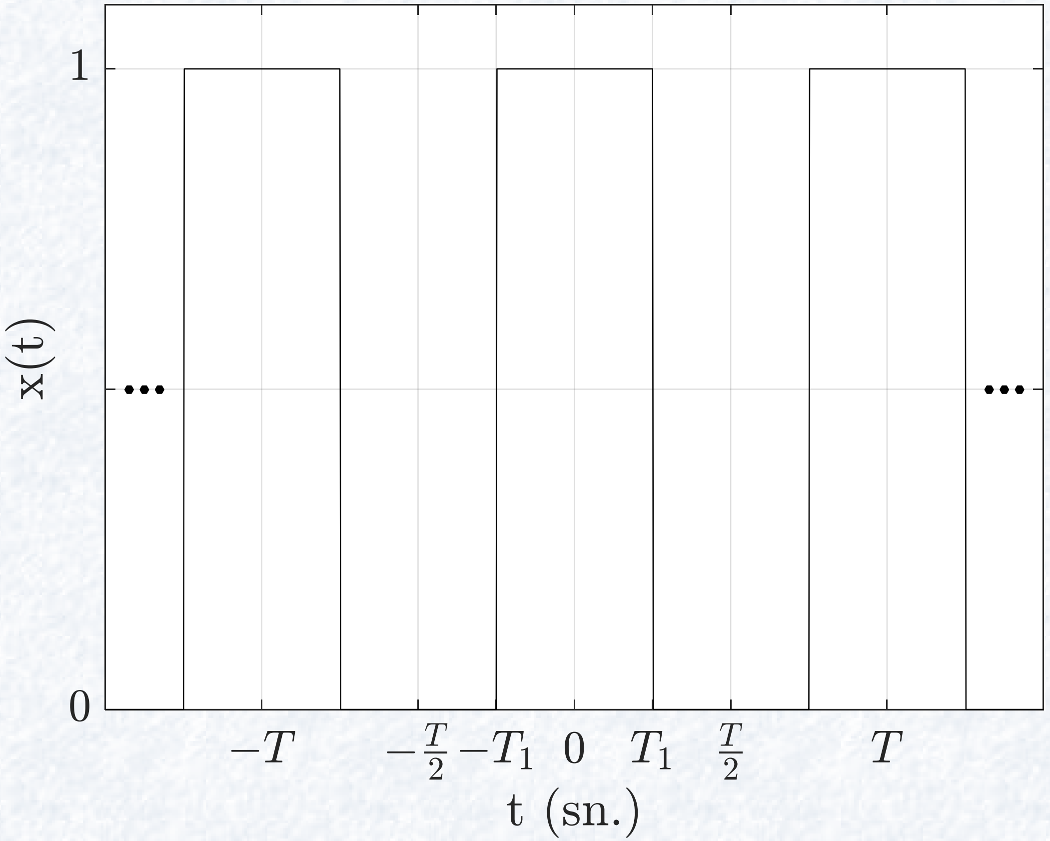

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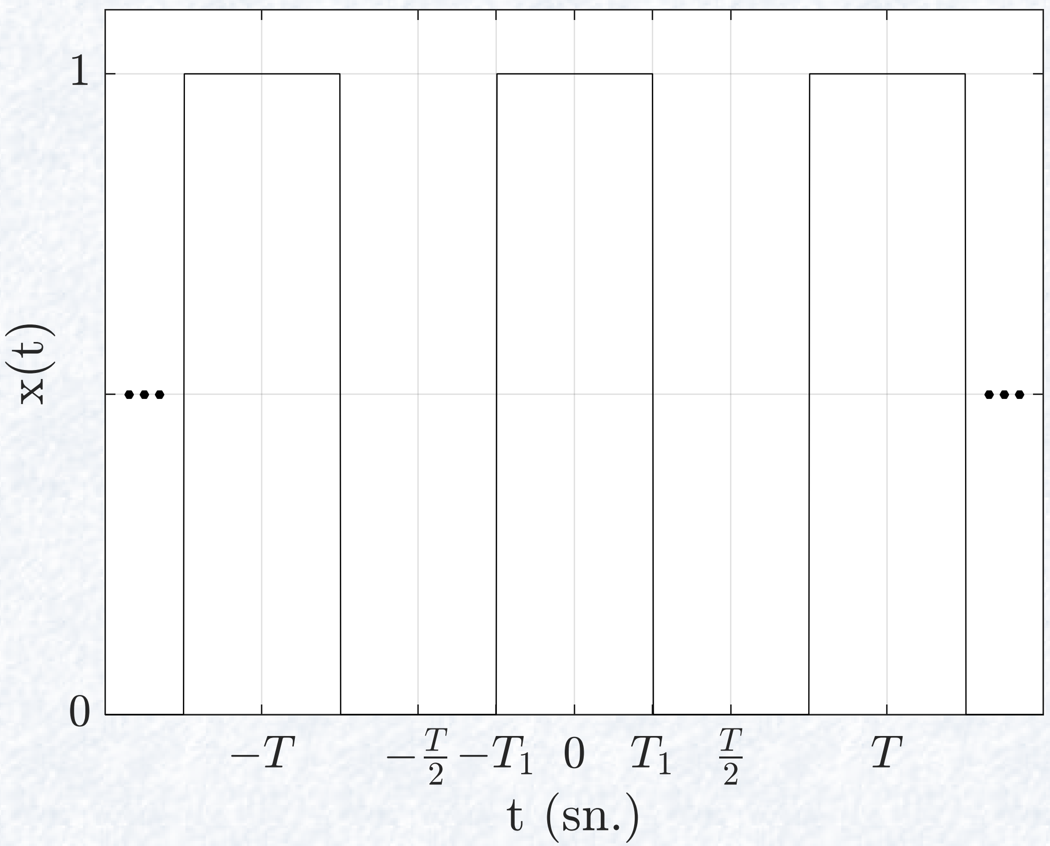

- $\omega_0 = \frac{2\pi}{T}$
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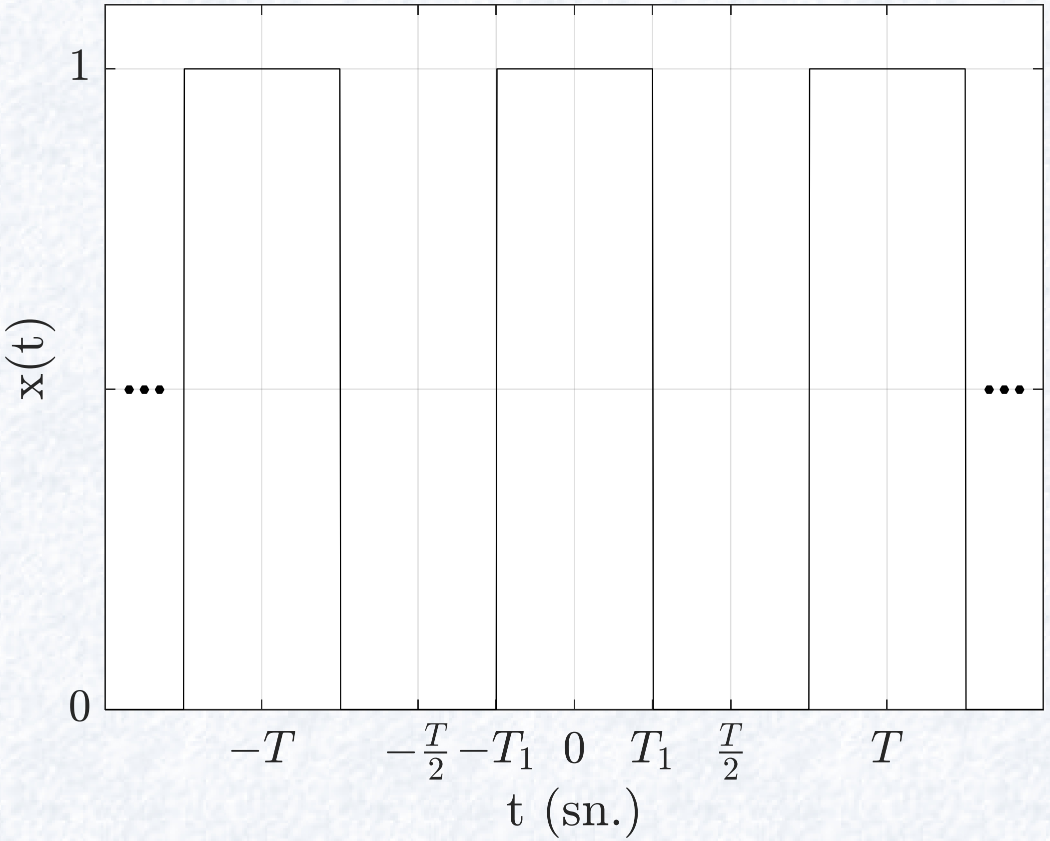
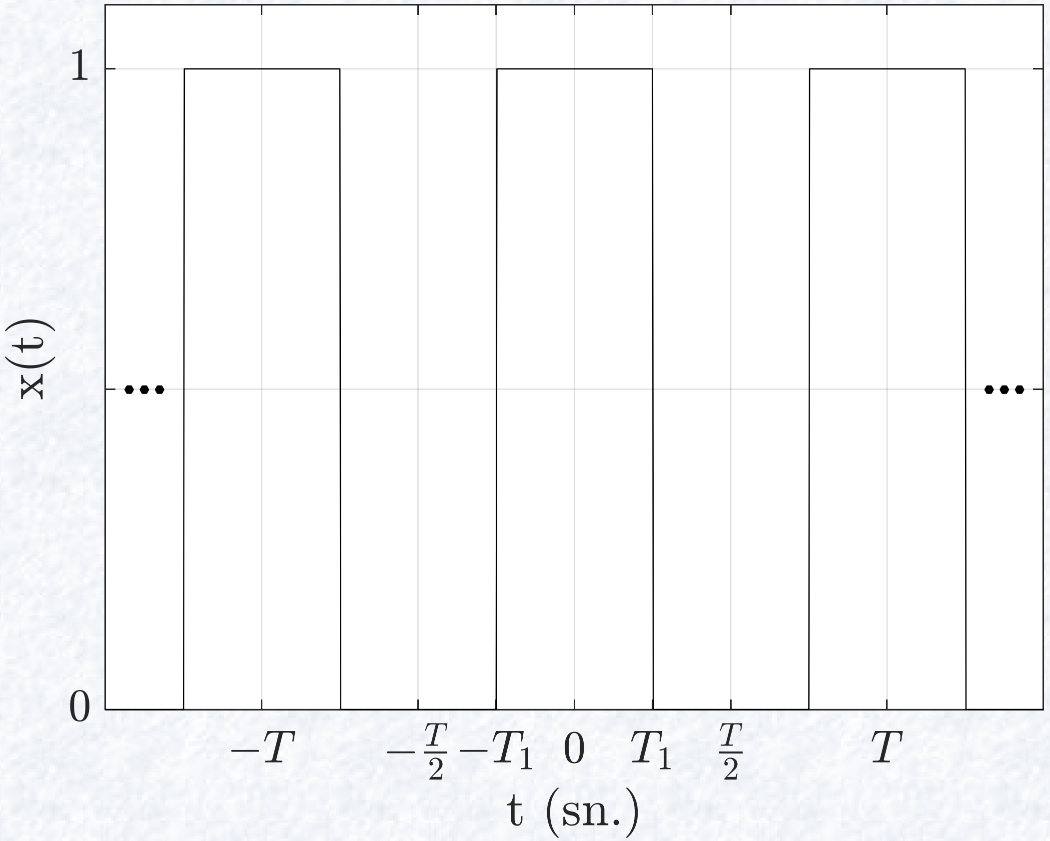


- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T}\int_{-T/2}^{T/2} x(t)\, e^{-jk\omega_0 t} dt$
- $a_k = \frac{1}{T}\int_{-T/2}^{-T_1} \quad + \int_{-T_1}^{T_1} \quad + \int_{T_1}^{T/2}$

Örnek 8

- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
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- $a_k = \frac{1}{T}\int_{-T_1}^{T_1} 1 e^{-jk\omega_0 t} dt$

Örnek 8

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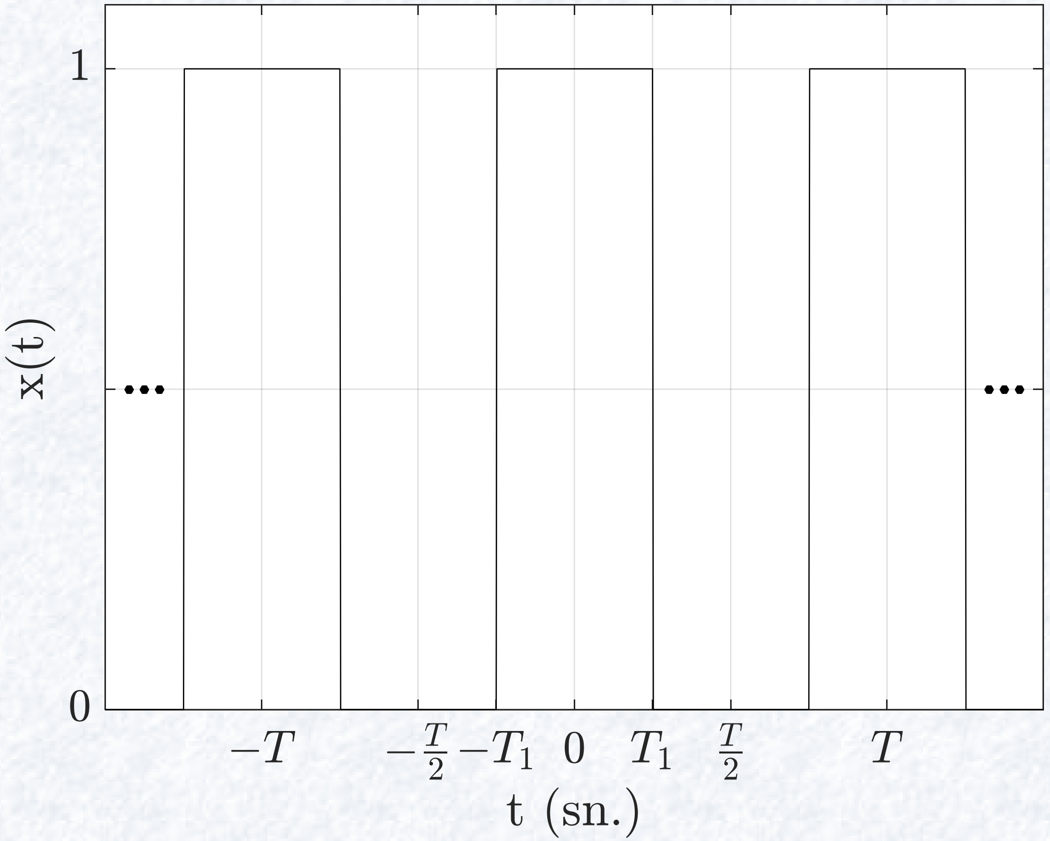

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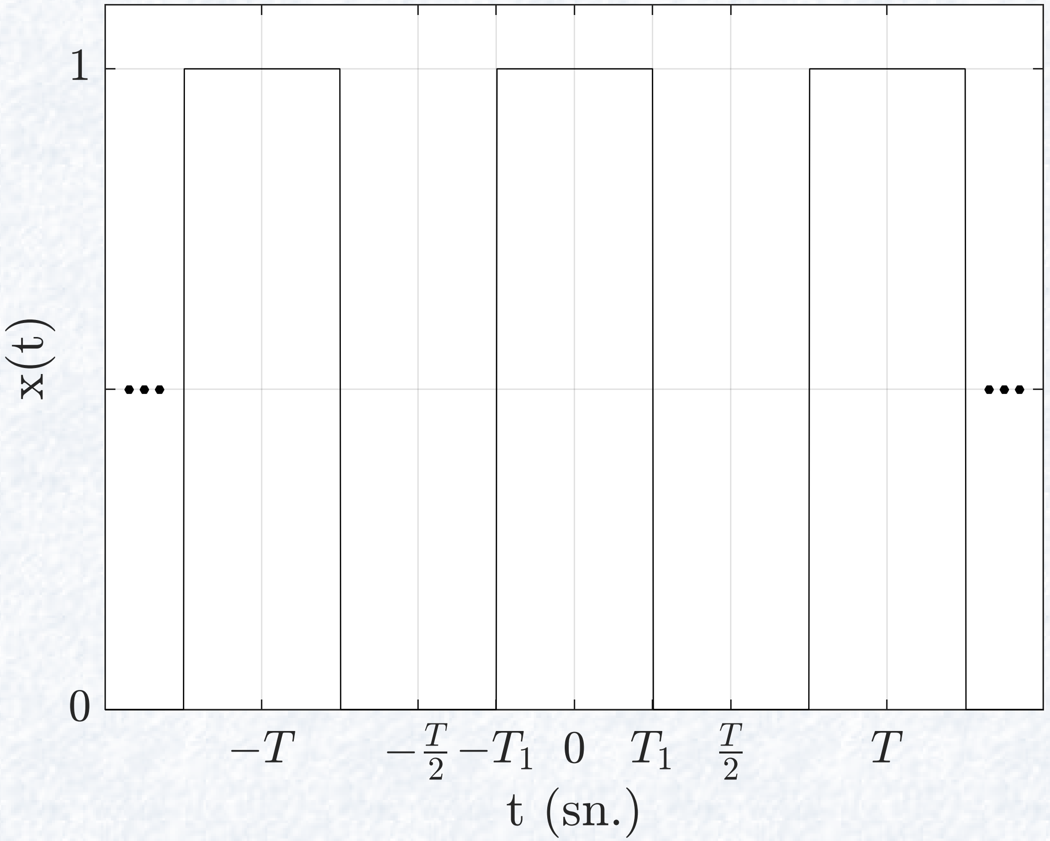
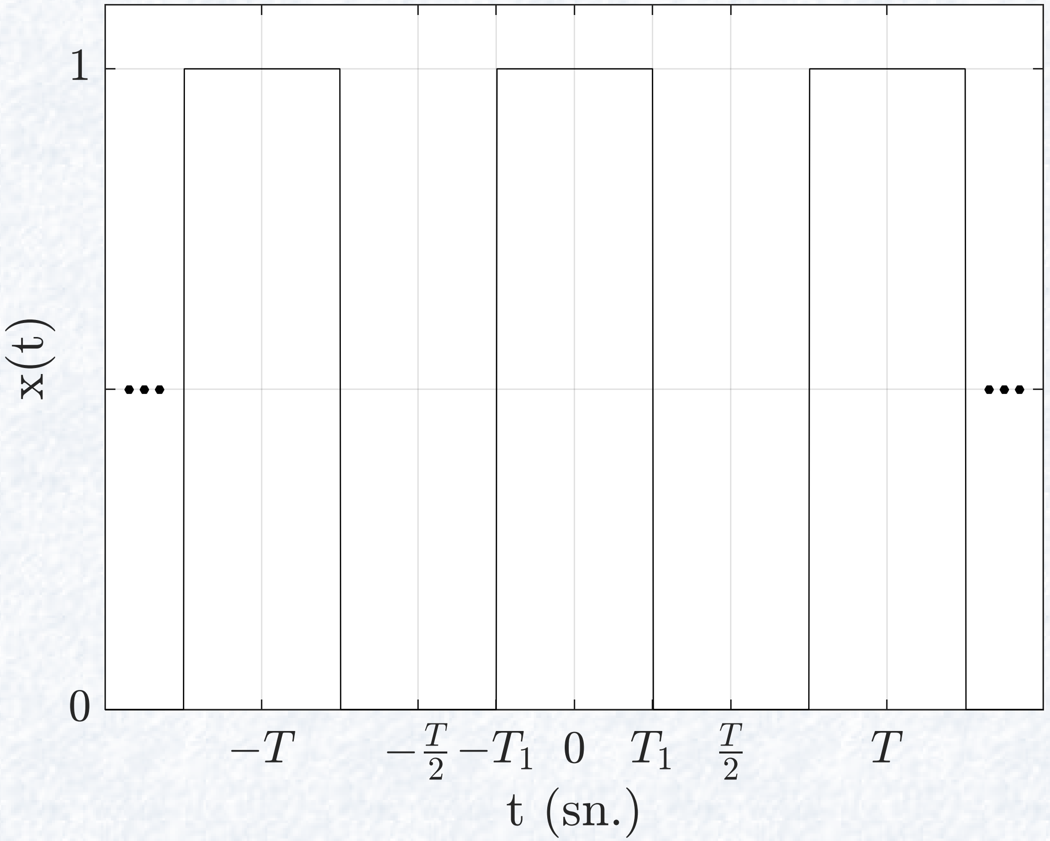


- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T}\int_{-T_1}^{T_1} 1e^{-jk\frac{2\pi}{T}t}dt$
- $a_k =$

Örnek 8

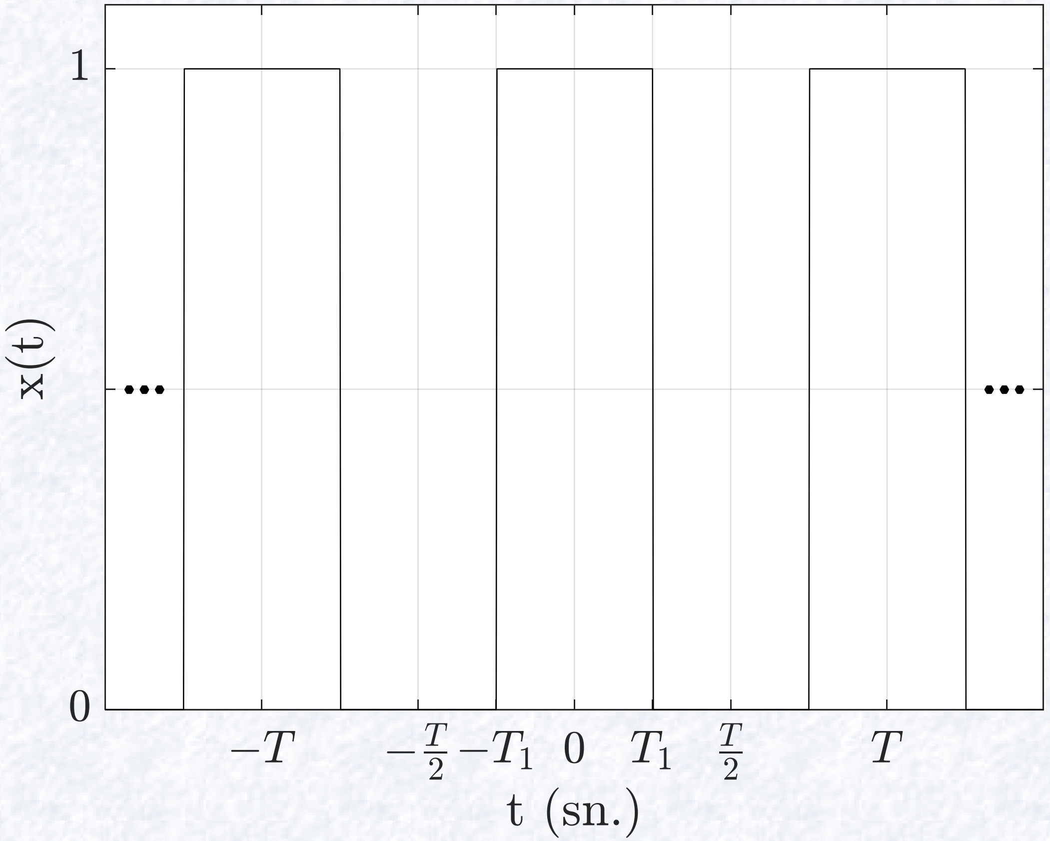
- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T}\int_{-T_1}^{T_1} 1e^{-jk\frac{2\pi}{T}t}dt$
- $a_k = \frac{1}{T}\frac{-1}{jk\frac{2\pi}{T}}e^{-jk\frac{2\pi}{T}t}\Big|_{-T_1}^{T_1}$

Örnek 8

- Fourier seri açılımı?



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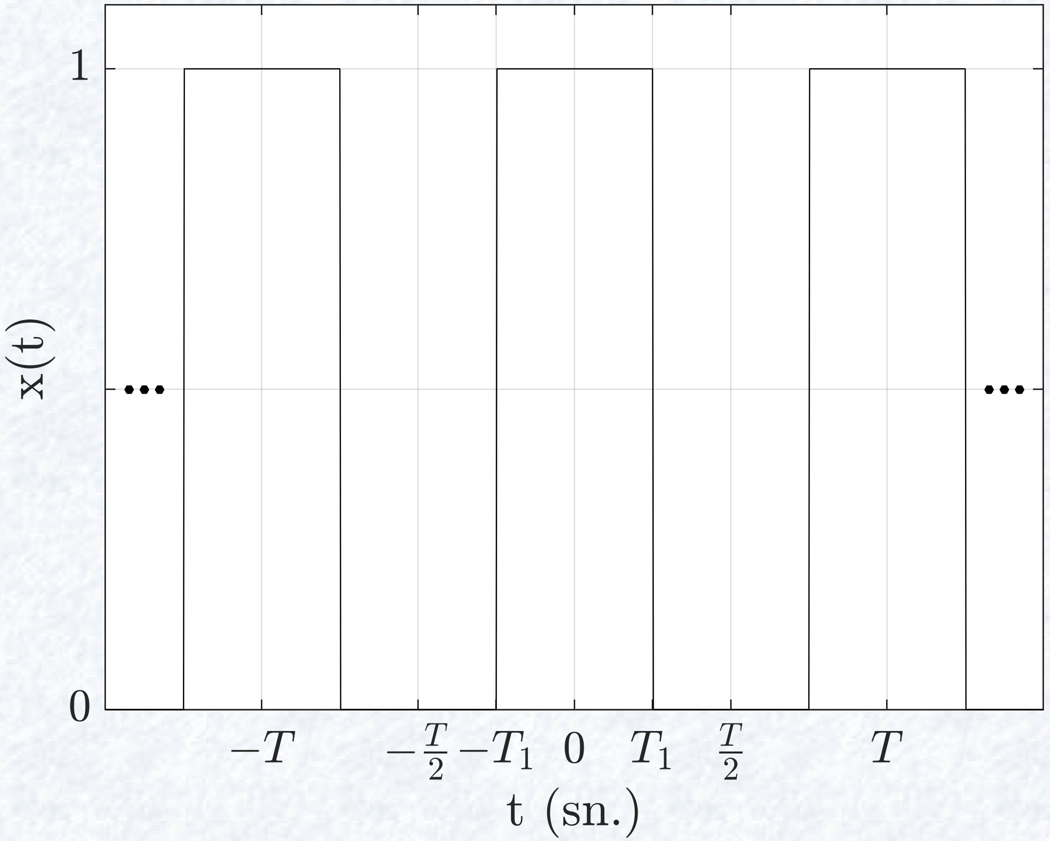
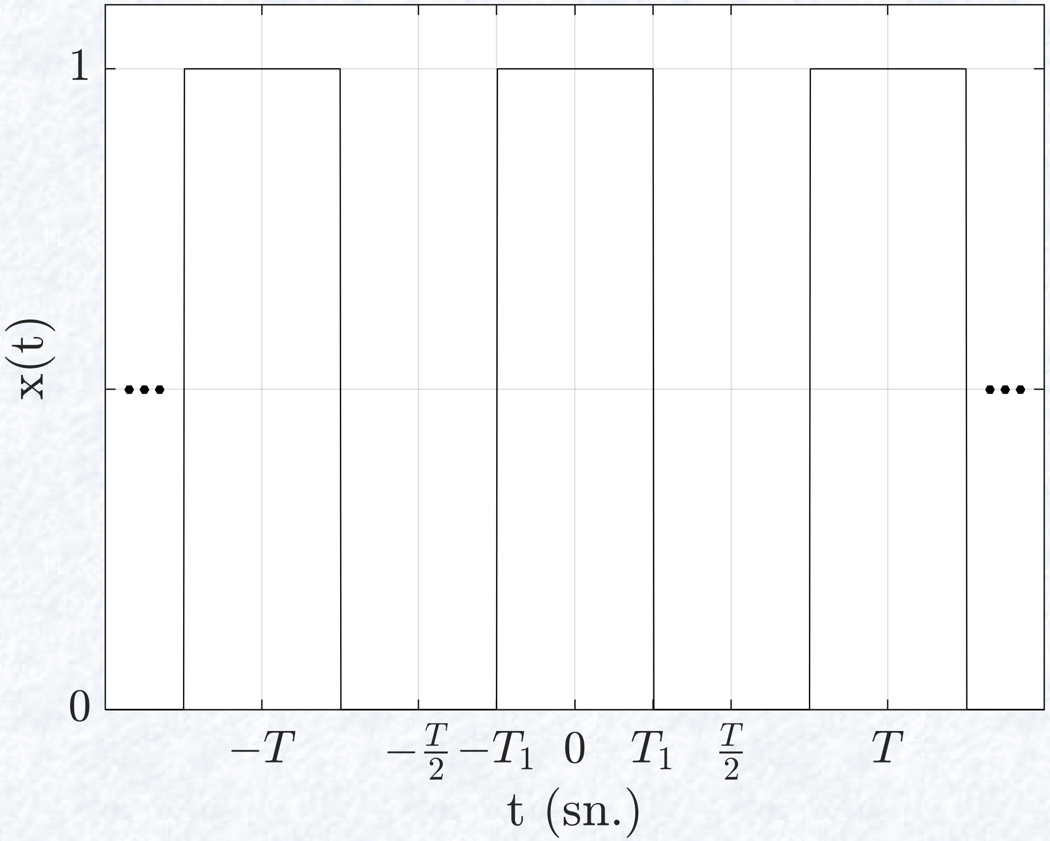


- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T}\int_{-T_1}^{T_1} 1e^{-jk\frac{2\pi}{T}t}dt$
- $a_k = \frac{1}{T}\frac{-1}{jk\frac{2\pi}{T}}e^{-jk\frac{2\pi}{T}t}\Big|_{-T_1}^{T_1}$
- $a_k = \frac{-1}{j2\pi k}\left(e^{-jk\frac{2\pi T_1}{T}} - e^{jk\frac{2\pi T_1}{T}}\right)$

Örnek 8

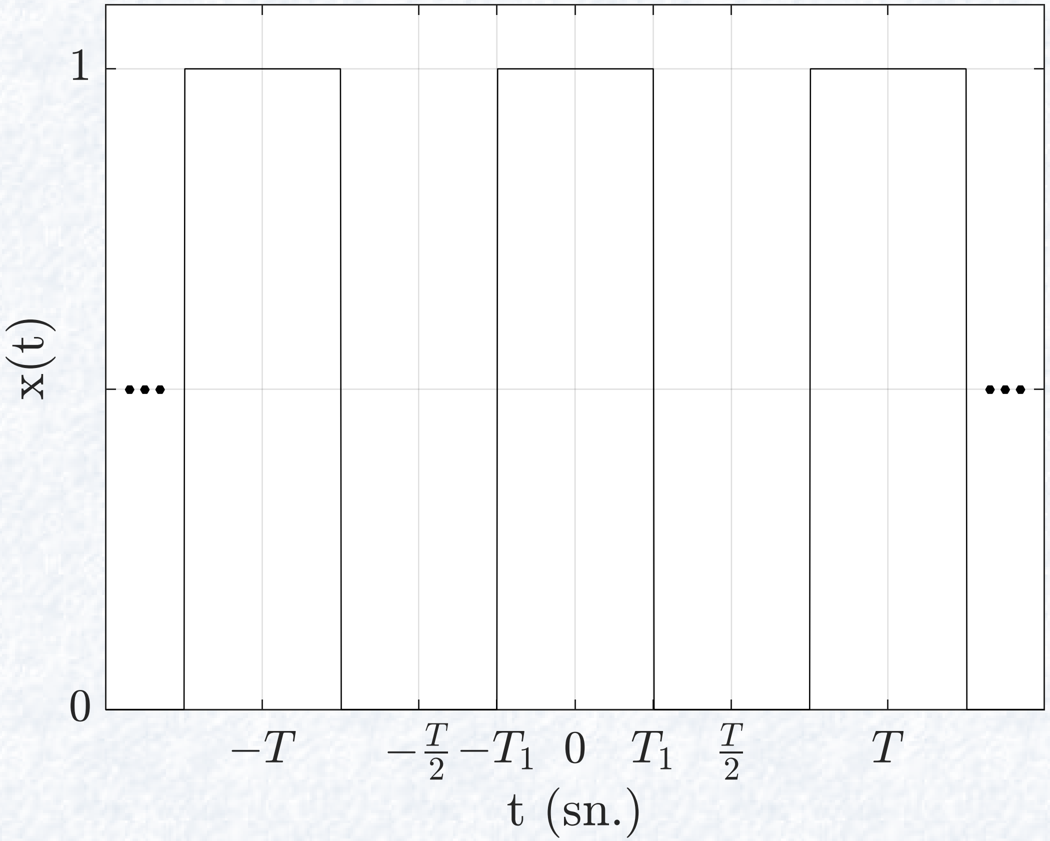
- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{j2\pi k}\left(-e^{-jk\frac{2\pi T_1}{T}} + e^{jk\frac{2\pi T_1}{T}}\right)$
- $a_k = \frac{1}{\pi k}\left(\frac{e^{jk\frac{2\pi T_1}{T}} - e^{-jk\frac{2\pi T_1}{T}}}{2j}\right)$
- $a_k =$

Örnek 8

- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{j2\pi k}\left(-e^{-jk\frac{2\pi T_1}{T}} + e^{jk\frac{2\pi T_1}{T}}\right)$
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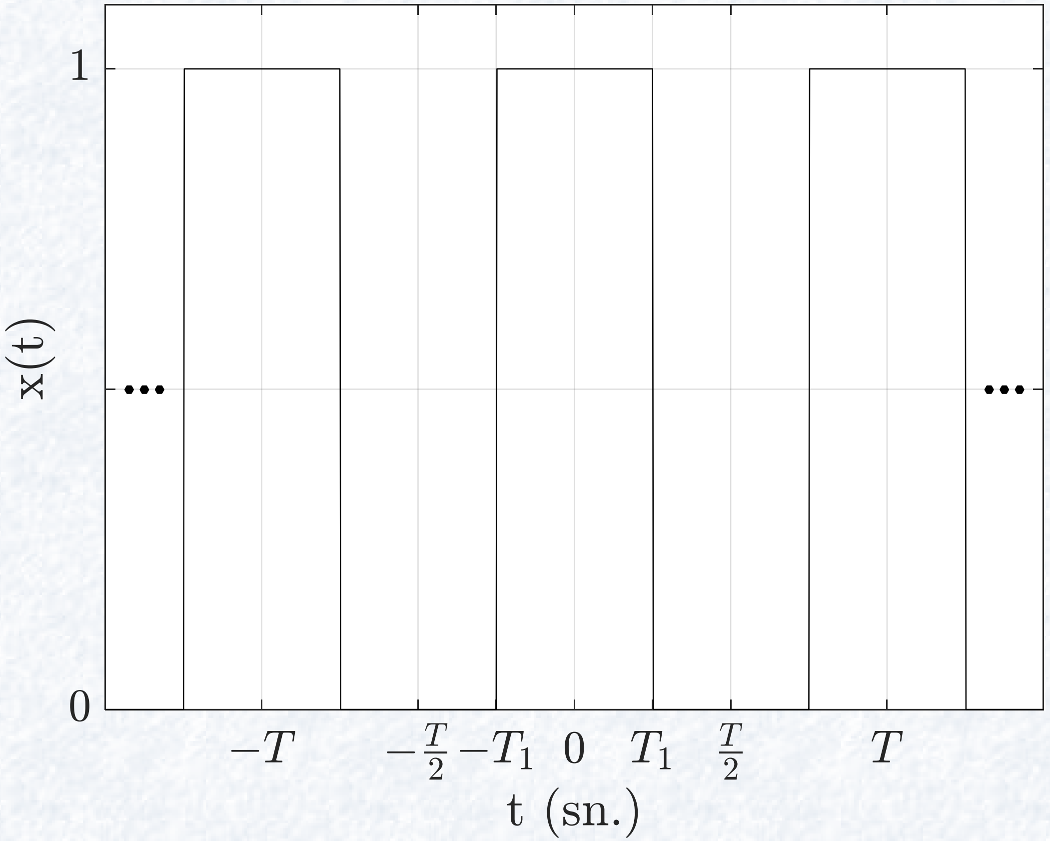
- $a_k = \frac{\sin\left(k\frac{2\pi T_1}{T}\right)}{\pi k}$

Örnek 8

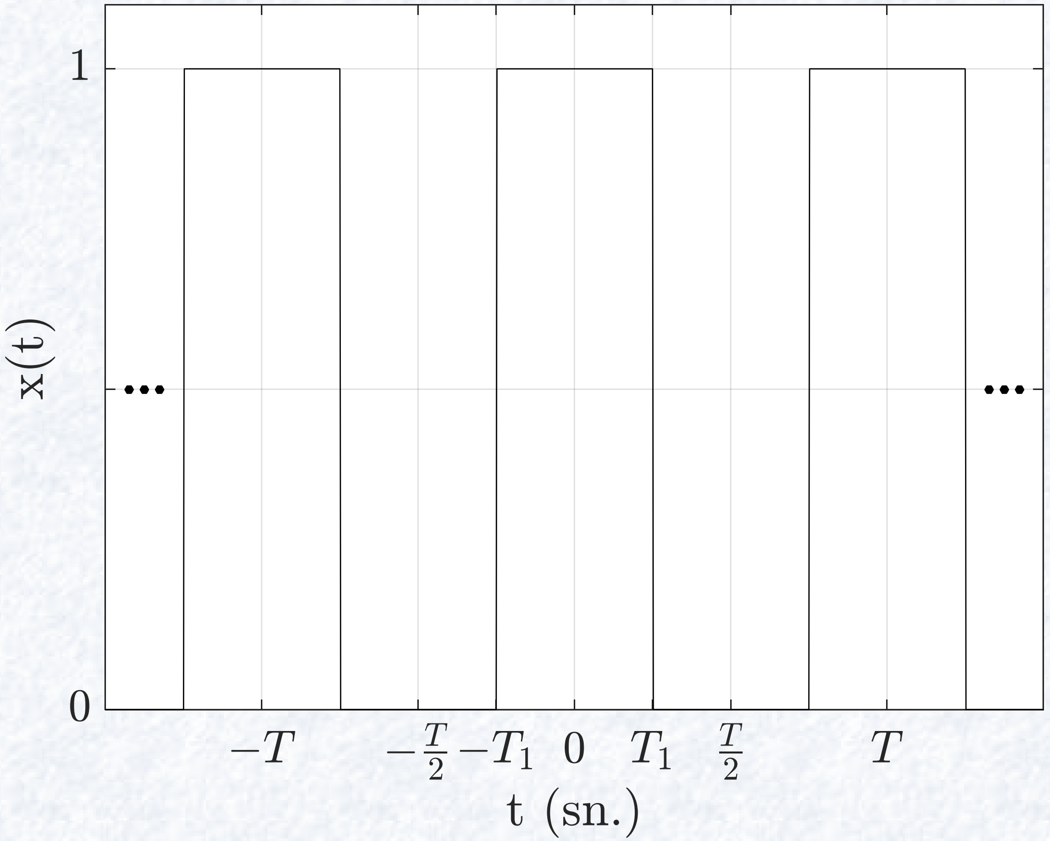
- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{\sin\left(k\frac{2\pi T_1}{T}\right)}{\pi k}$
  - $\text{sinc}(\theta) = \frac{\sin(\pi\theta)}{\pi\theta}$
- $a_0 =$

Örnek 8

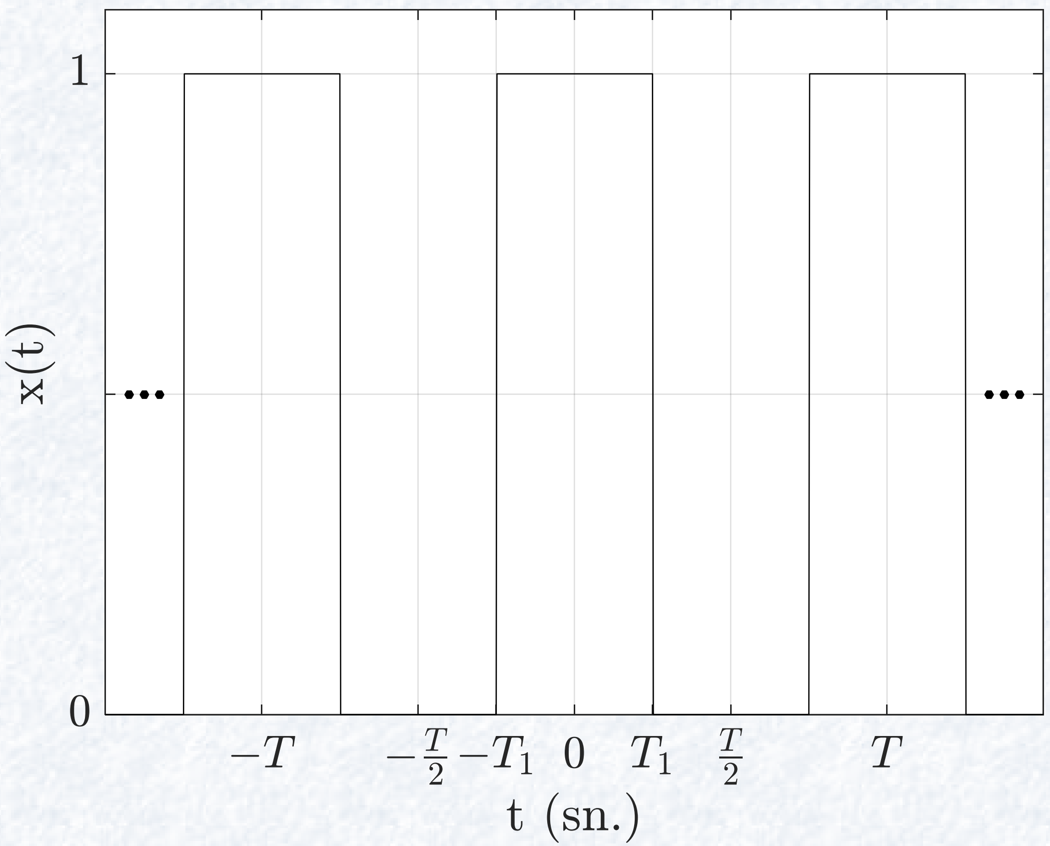
- Fourier seri açılımı?



- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{\sin\left(k\frac{2\pi T_1}{T}\right)}{\pi k}$
- $a_0 = \left.\frac{\frac{2\pi T_1}{T}\cos\left(k\frac{2\pi T_1}{T}\right)}{\pi}\right|_{k=0} = \frac{2T_1}{T}$

Örnek 8

- Fourier seri açılımı?



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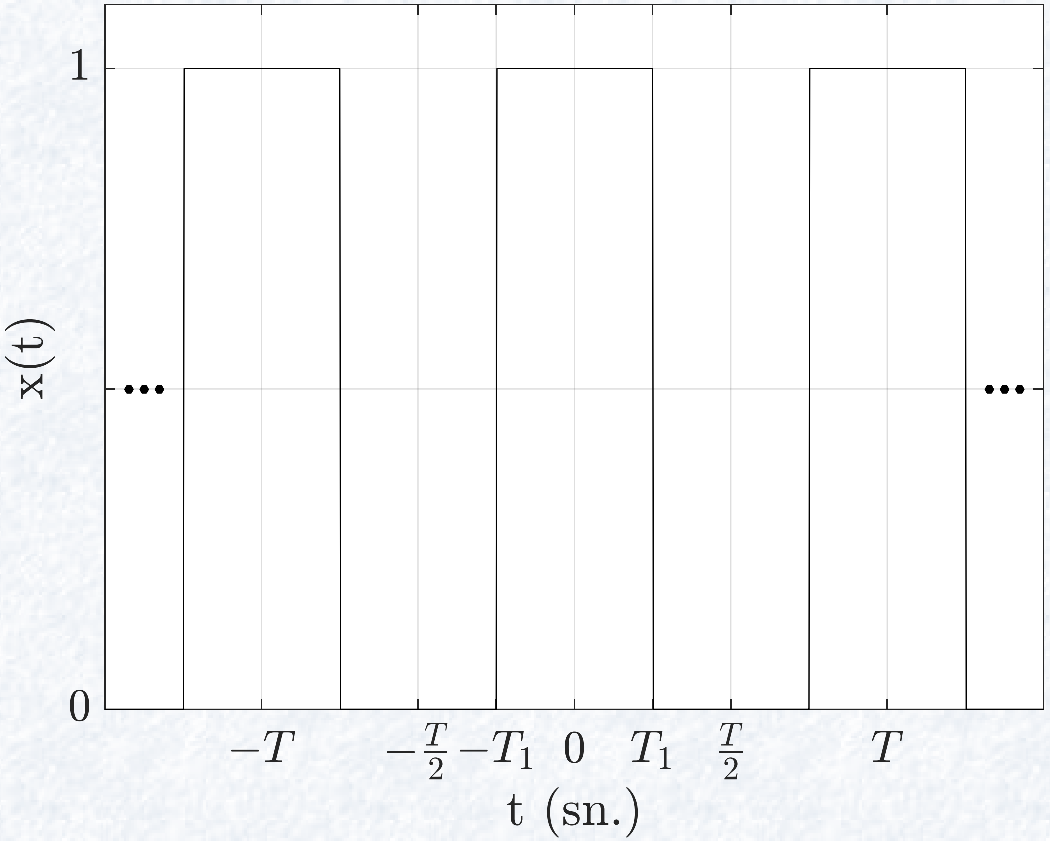
- $a_0 = \frac{1}{T}\int_{-T_1}^{T_1} 1e^{-j0\frac{2\pi}{T}t}dt$

Örnek 8

- Fourier seri açılımı?



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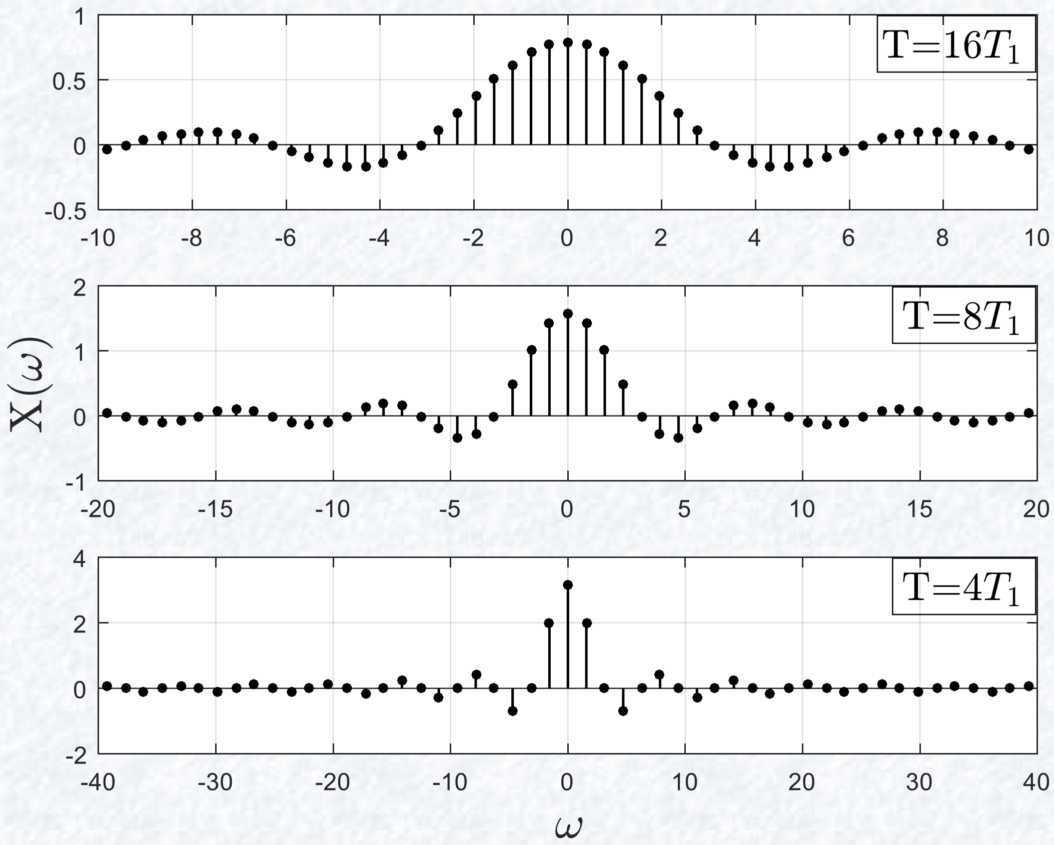

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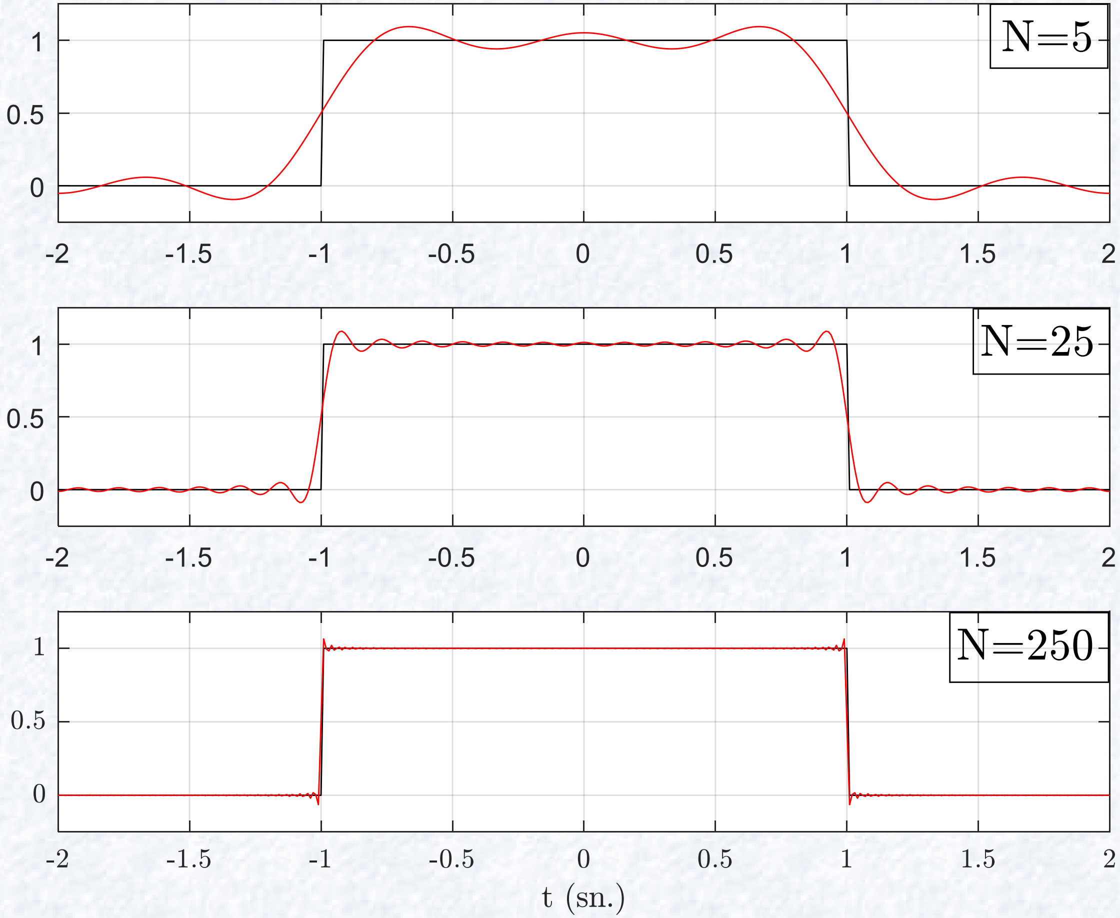


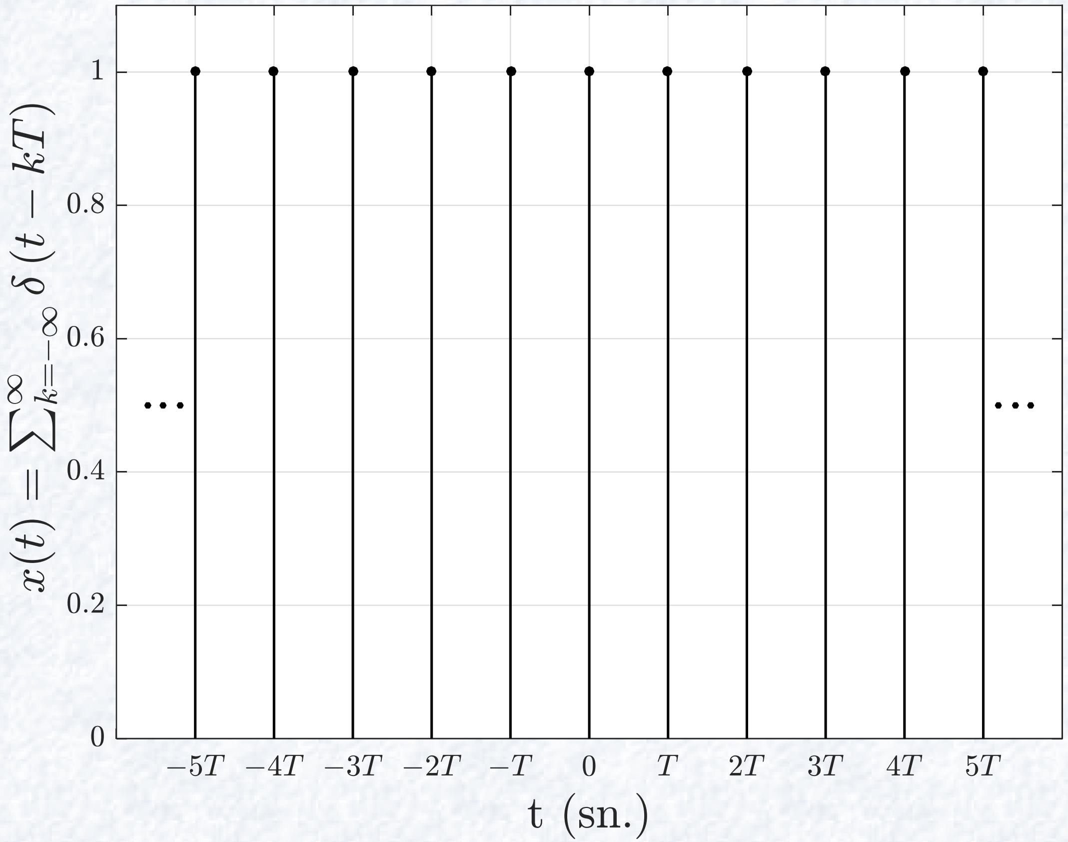
- $x(t) = \sum_{k=-5}^{5} a_k e^{jk\frac{2\pi}{T}t}$
- $x(t) = \sum_{k=-25}^{25} a_k e^{jk\frac{2\pi}{T}t}$
- $x(t) = \sum_{k=-250}^{250} a_k e^{jk\frac{2\pi}{T}t}$

Örnek 9

- $x(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT)$ ise Fourier seri açılımı?

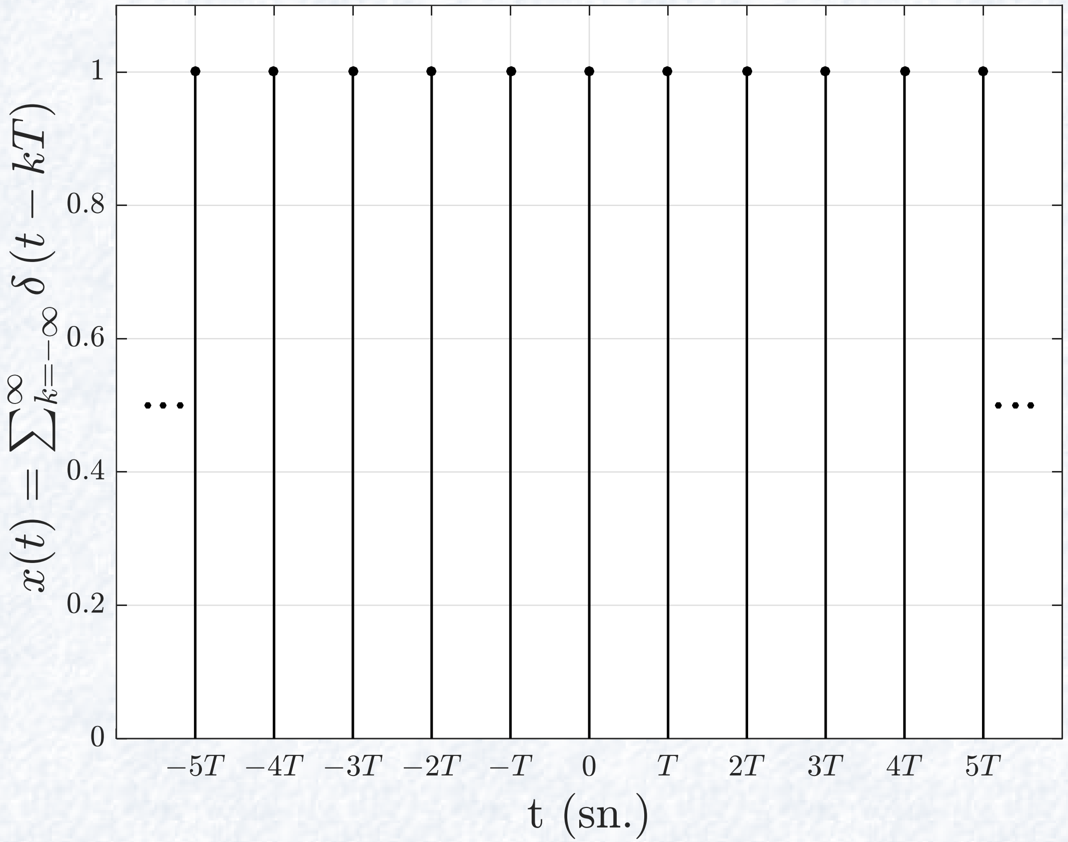
Örnek 9

- $x(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT)$ ise Fourier seri açılımı?
- $\omega_0 =$



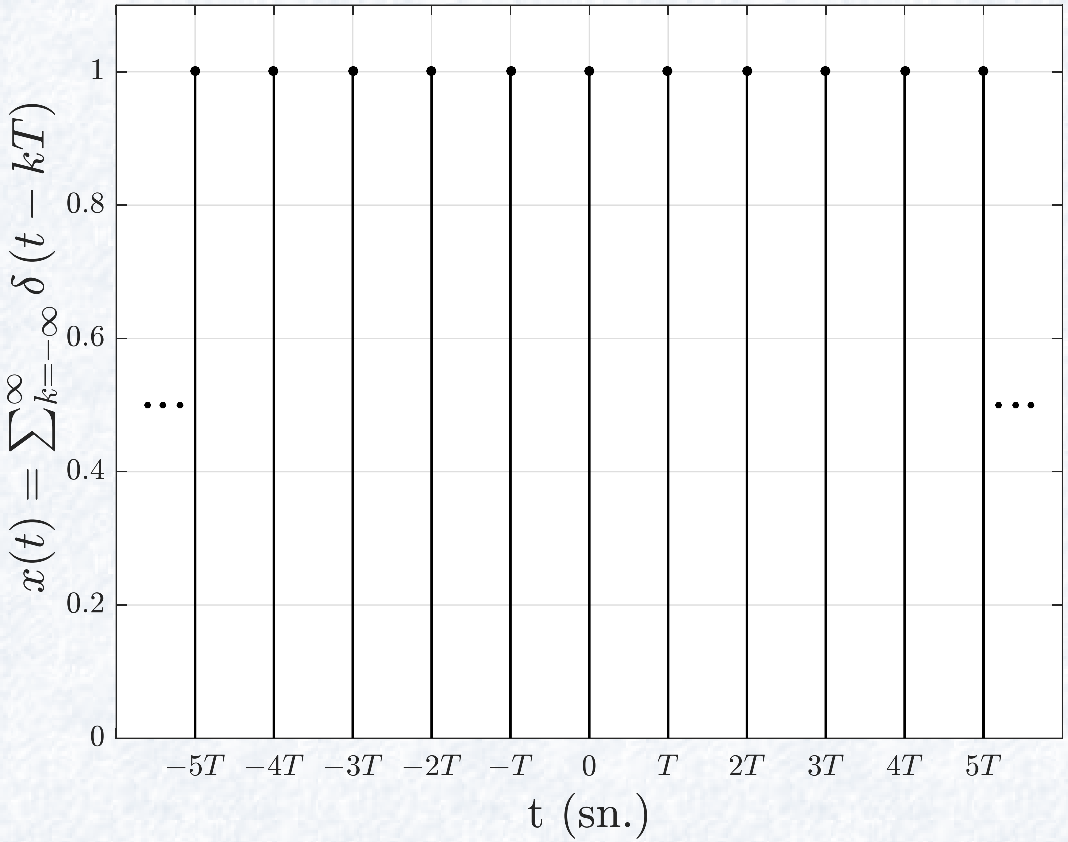
Örnek 9

- $x(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT)$ ise Fourier seri açılımı?
- $\omega_0 = \frac{2\pi}{T}$
- $a_k =$



Örnek 9

- $x(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT)$ ise Fourier seri açılımı?
- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T}\int_{-T/2}^{T/2} x(t) e^{-jk\omega_0 t} dt$



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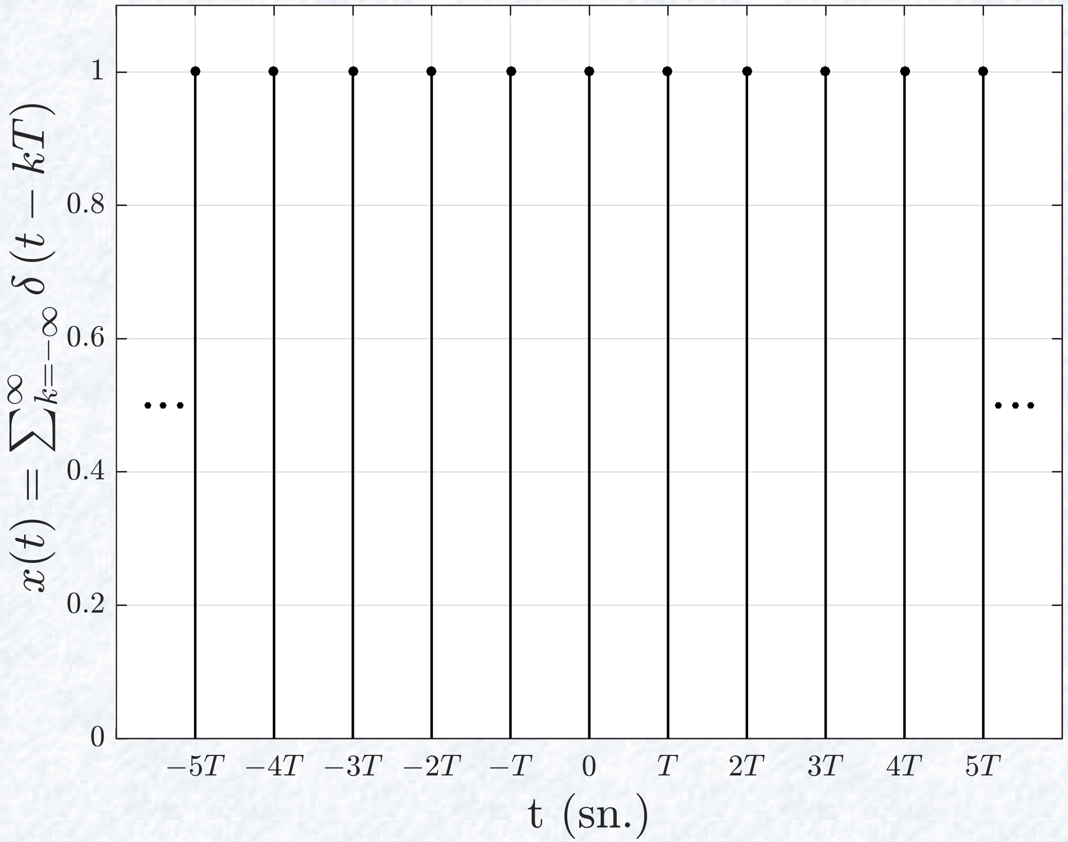
- $x(t) = \sum_{k=-\infty}^{\infty} \delta(t - kT)$ ise Fourier seri açılımı?
- $\omega_0 = \frac{2\pi}{T}$
- $a_k = \frac{1}{T} \underbrace{\int_{-T/2}^{T/2} \delta(t) e^{-jk\omega_0 t} dt}_{?}$
- $a_k = \frac{1}{T} \boxed{}$



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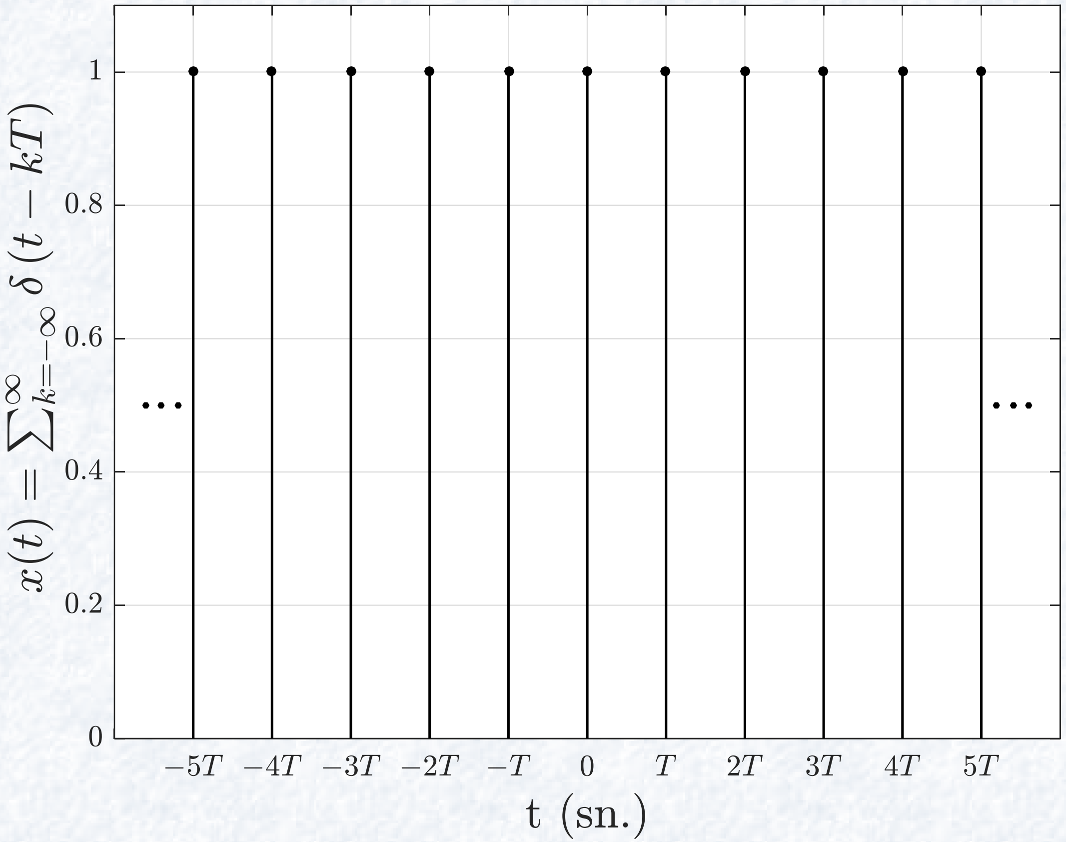
- $a_k = \frac{1}{T} 1 = \frac{1}{T}$
- $a_0 =$



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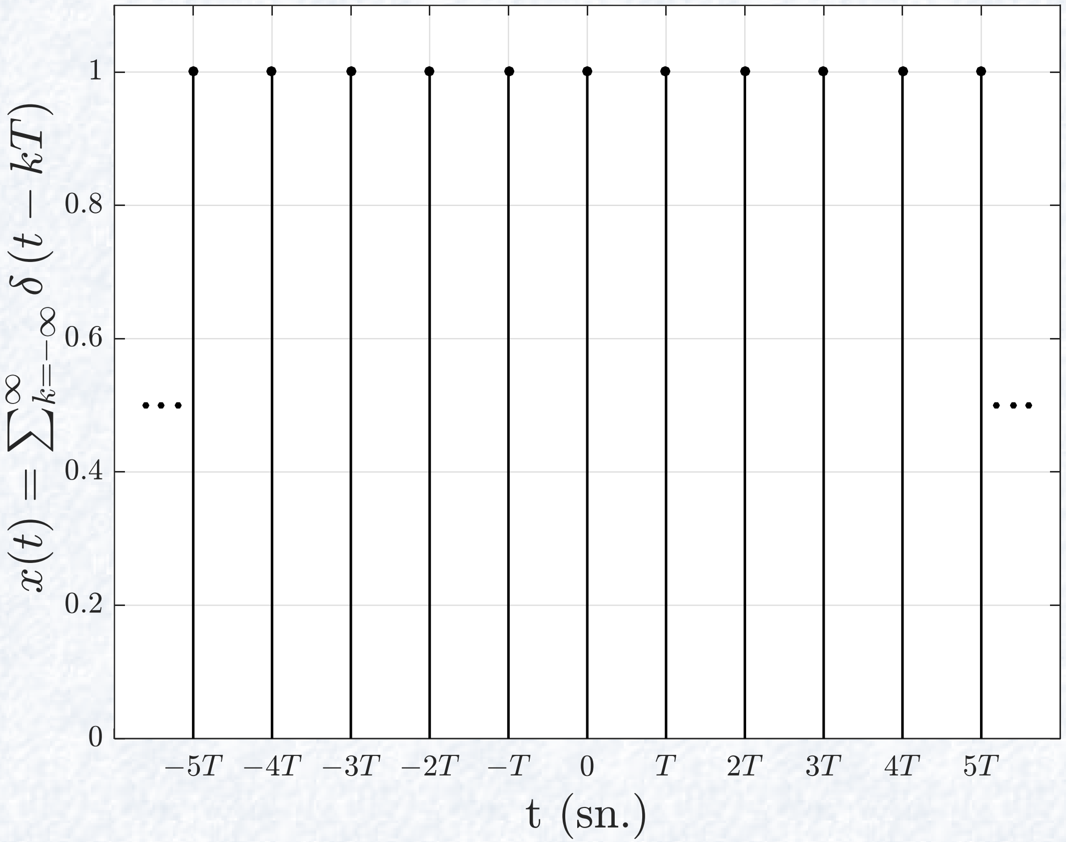
- $a_k = \frac{1}{T} 1 = \frac{1}{T}$
- $a_0 = \frac{1}{T}$
- $x(t) = \sum_{k=-\infty}^{\infty} \frac{1}{T} e^{jk\frac{2\pi}{T}t}$



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