BSM307
İşaretler ve Sistemler

Dr. Seçkin Arı

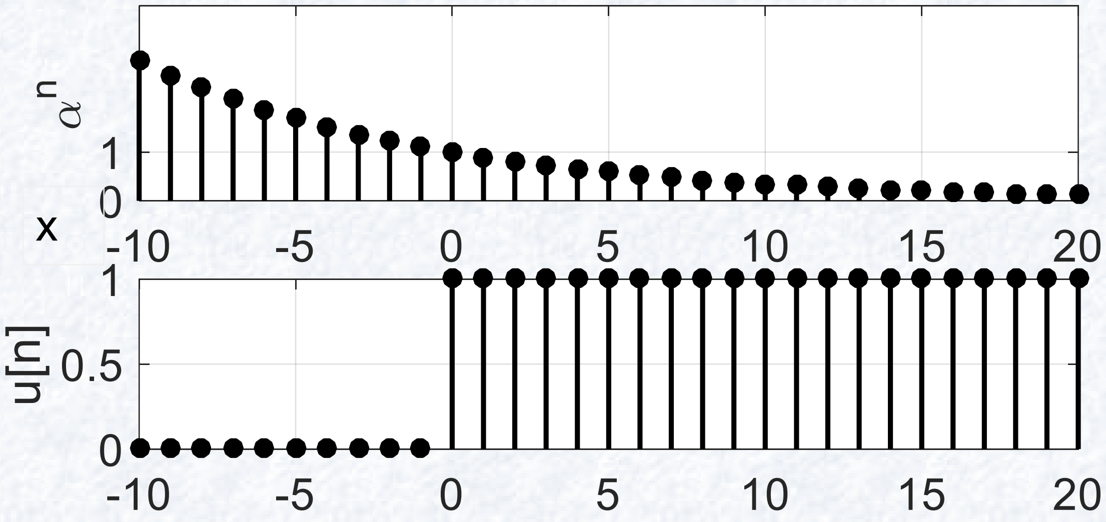
Konvolüsyon

İçerik

- Temel Sistem Özellikleri
- Doğrusal Zamanla Değişmez Sistemler
- Birim Darbe Cevabı

Örnek 1

- $x[n] = \alpha^n u[n]$



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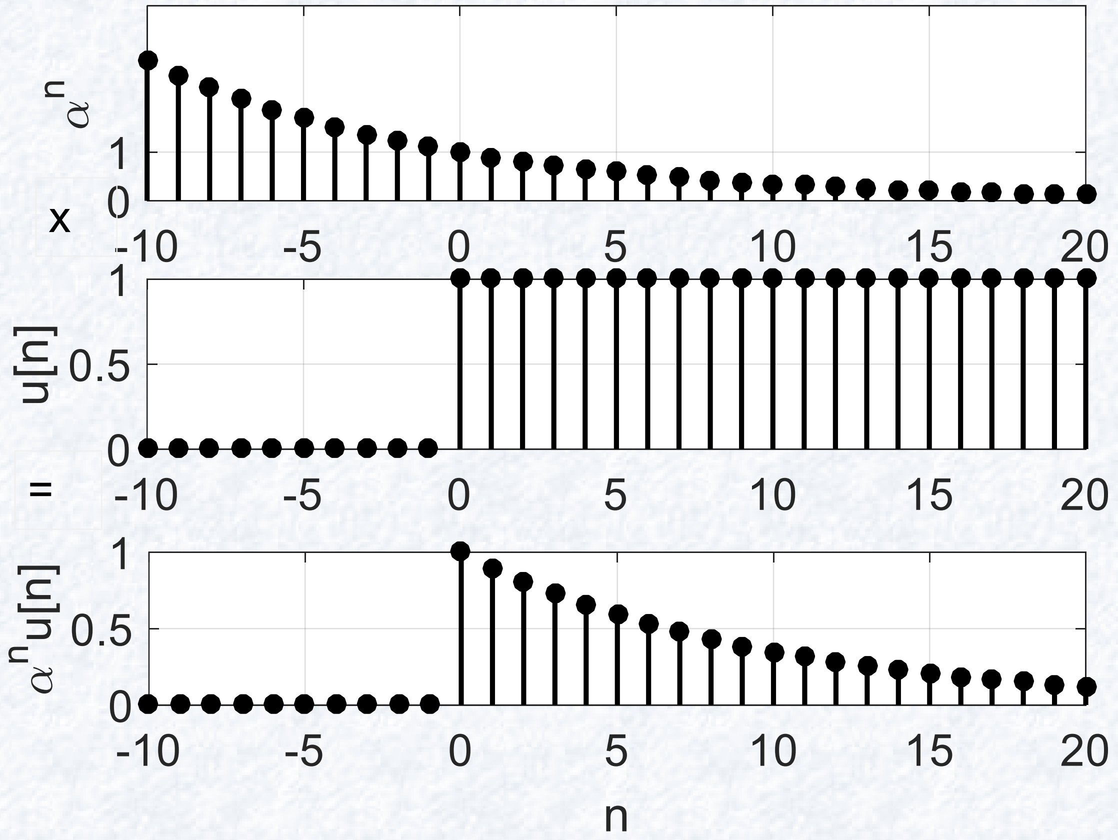
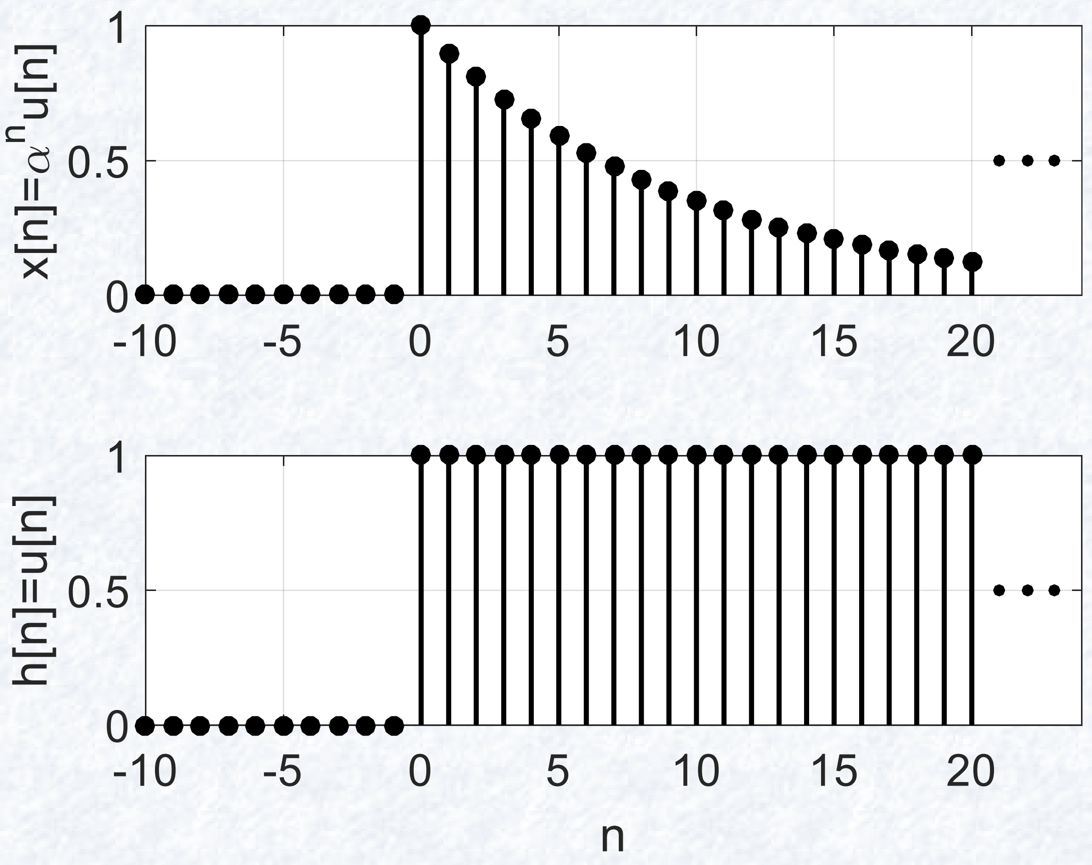


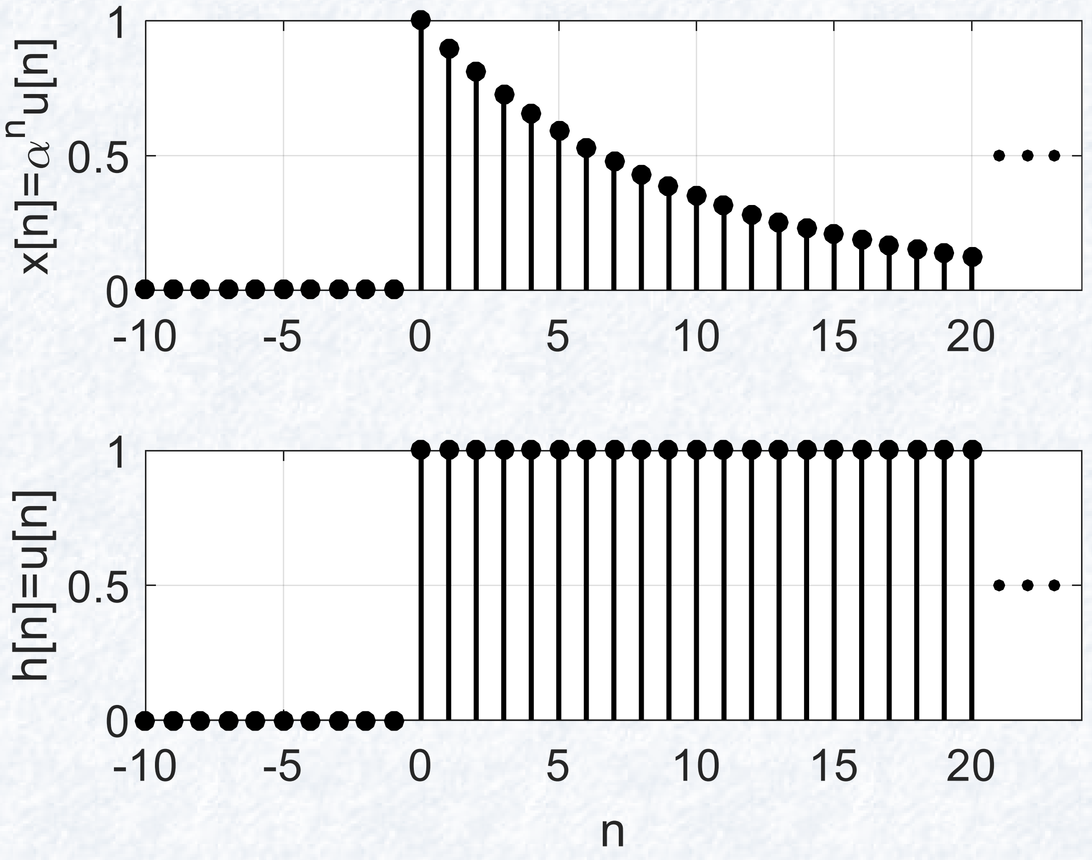
Örnek 1

- $x[n] = \alpha^n u[n]$
- $h[n] = u[n]$
- $y[n] = ?$



Örnek 1

- $x[n] = \alpha^n u[n]$
- $h[n] = u[n]$
- $y[n] = x[n] * h[n]$



Örnek 1

- $x[n] = \alpha^n u[n]$
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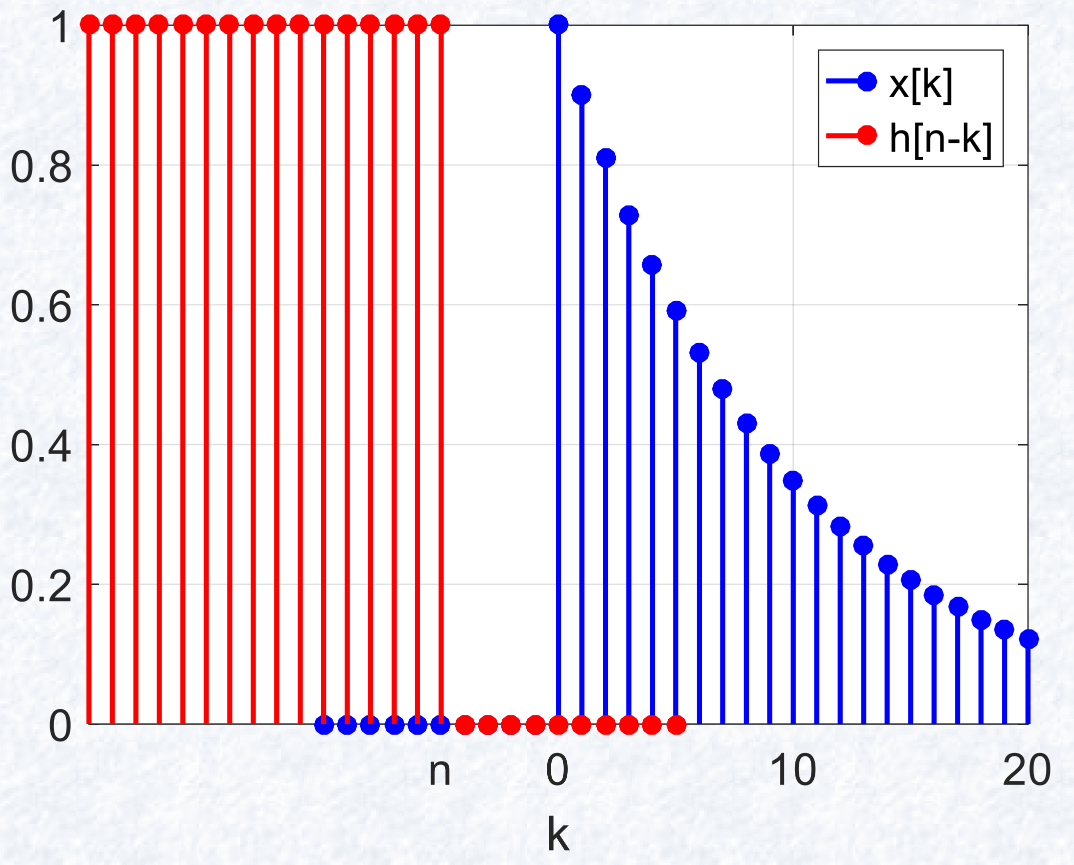
- $n < 0$ iken



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  - Çakışma yok
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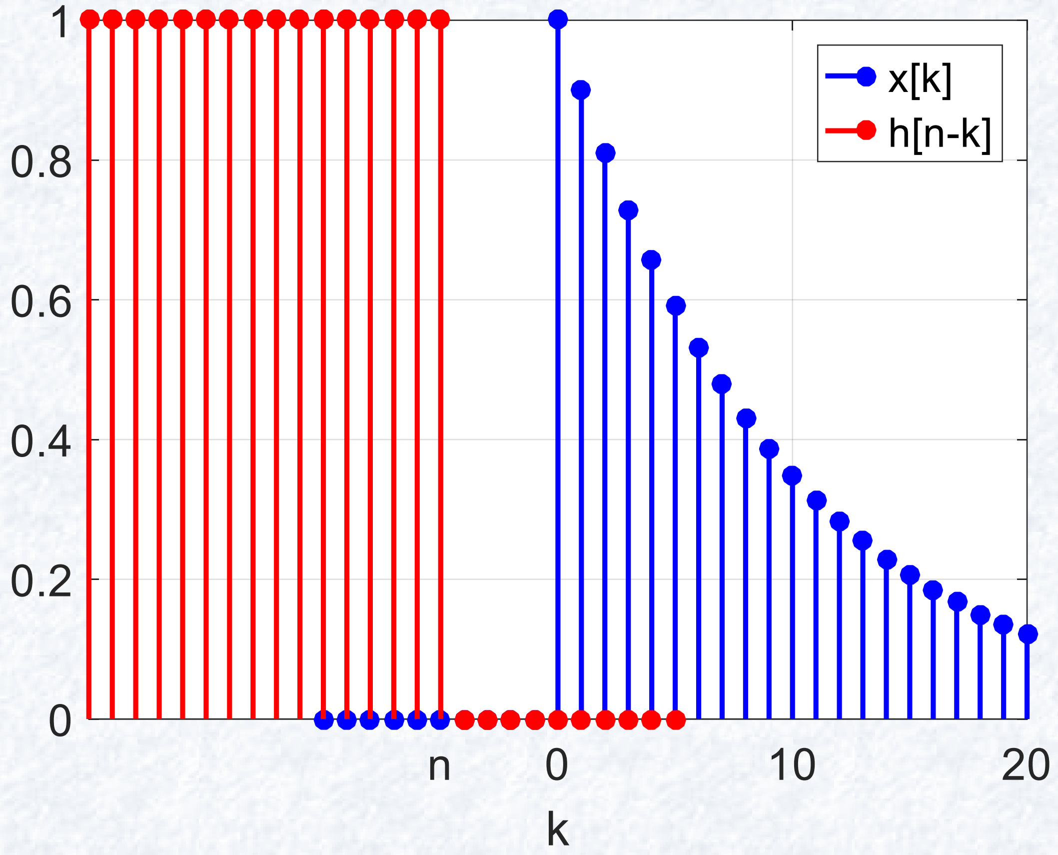

Örnek 1

- $x[n] = \alpha^n u[n]$
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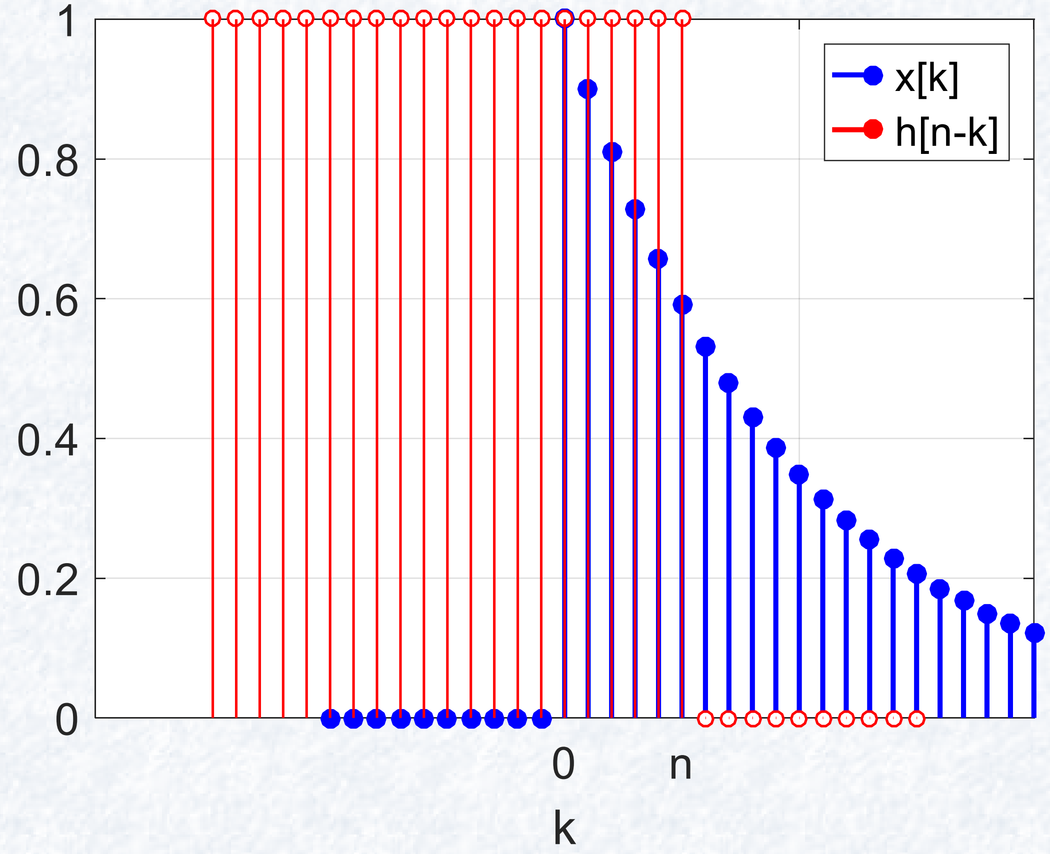
- $n \geq 0$ iken



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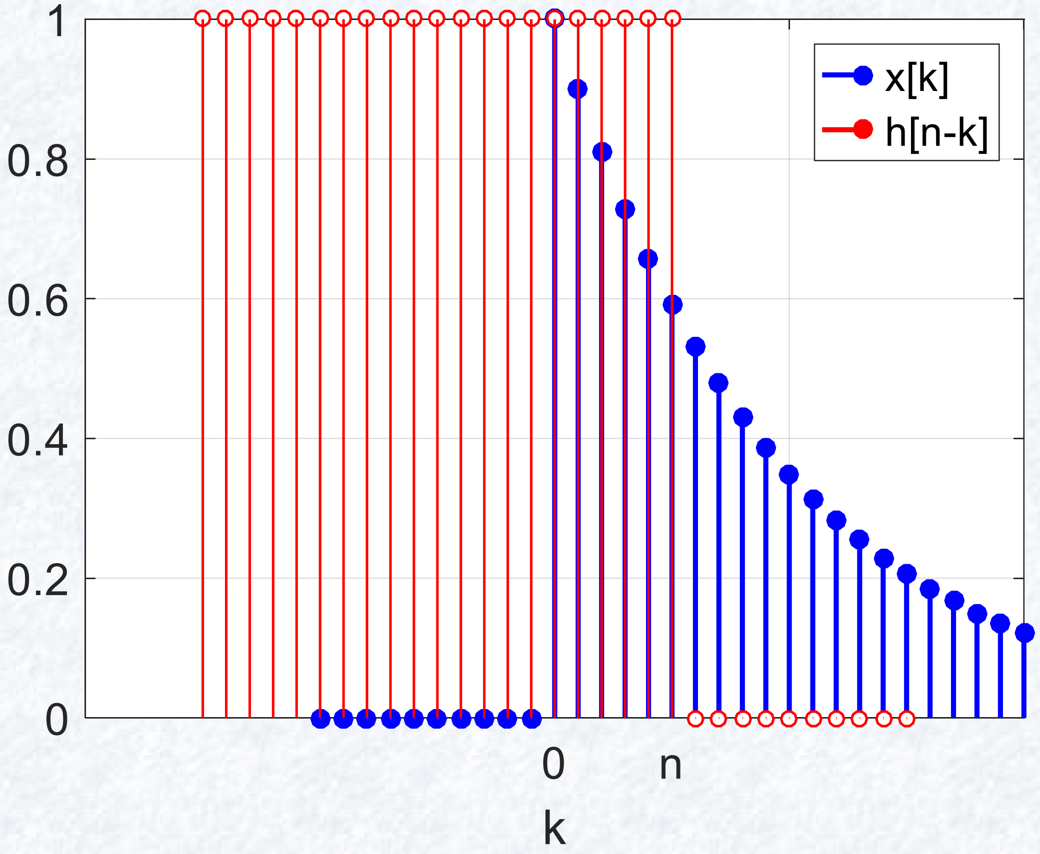

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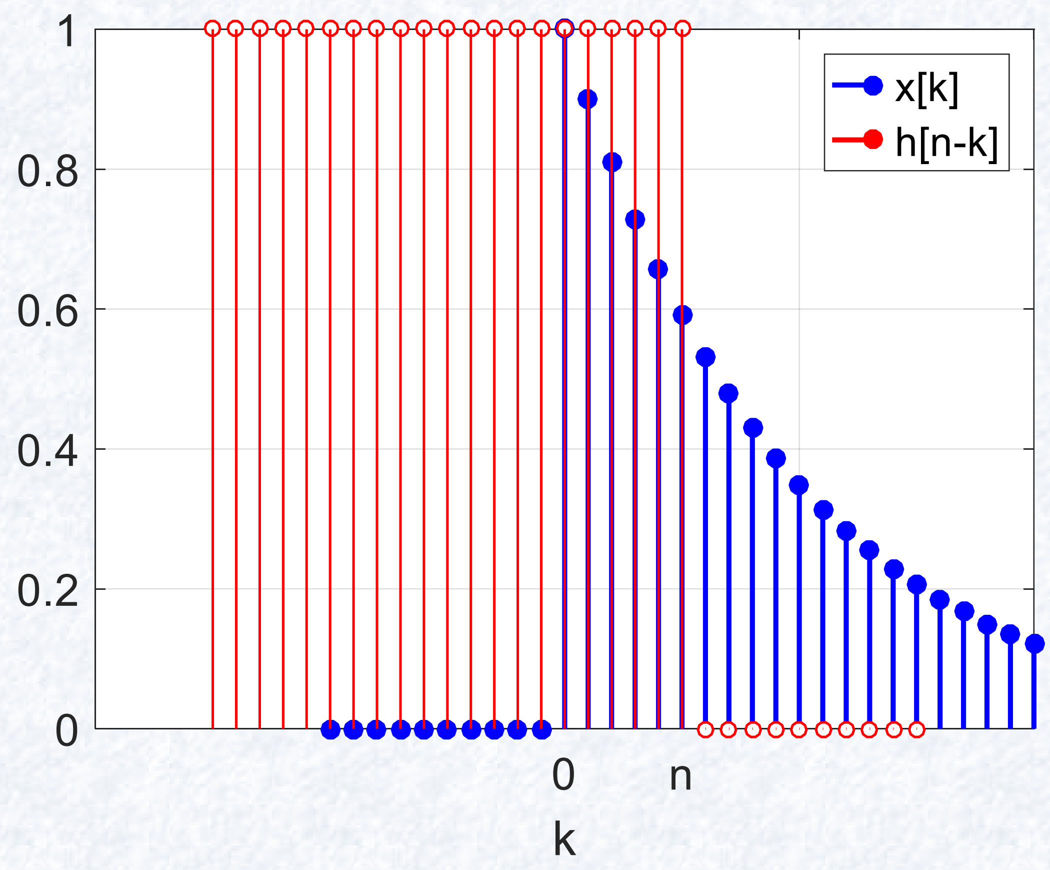
- $y[n] = \sum_{k=0}^{n} \alpha^k \cdot 1$
- $y[n] = \frac{1-\alpha^{n+1}}{1-\alpha}$



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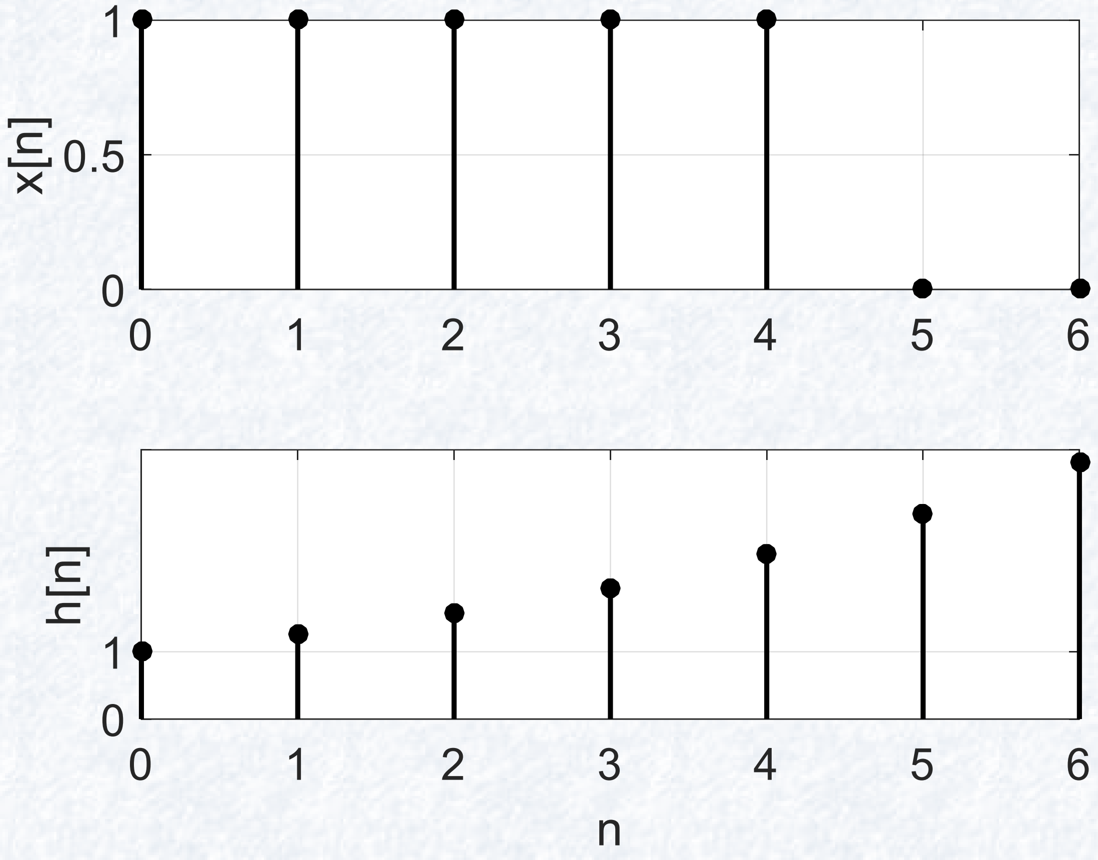
Örnek 2

- $x[n] = \begin{cases} 1, & 0 \le n \le 4 \\ 0, & \text{diğer} \end{cases}$

- $h[n] = \begin{cases} \alpha^n, & 0 \le n \le 6 \\ 0, & \text{diğer} \end{cases}$

- $y[n] = ?$



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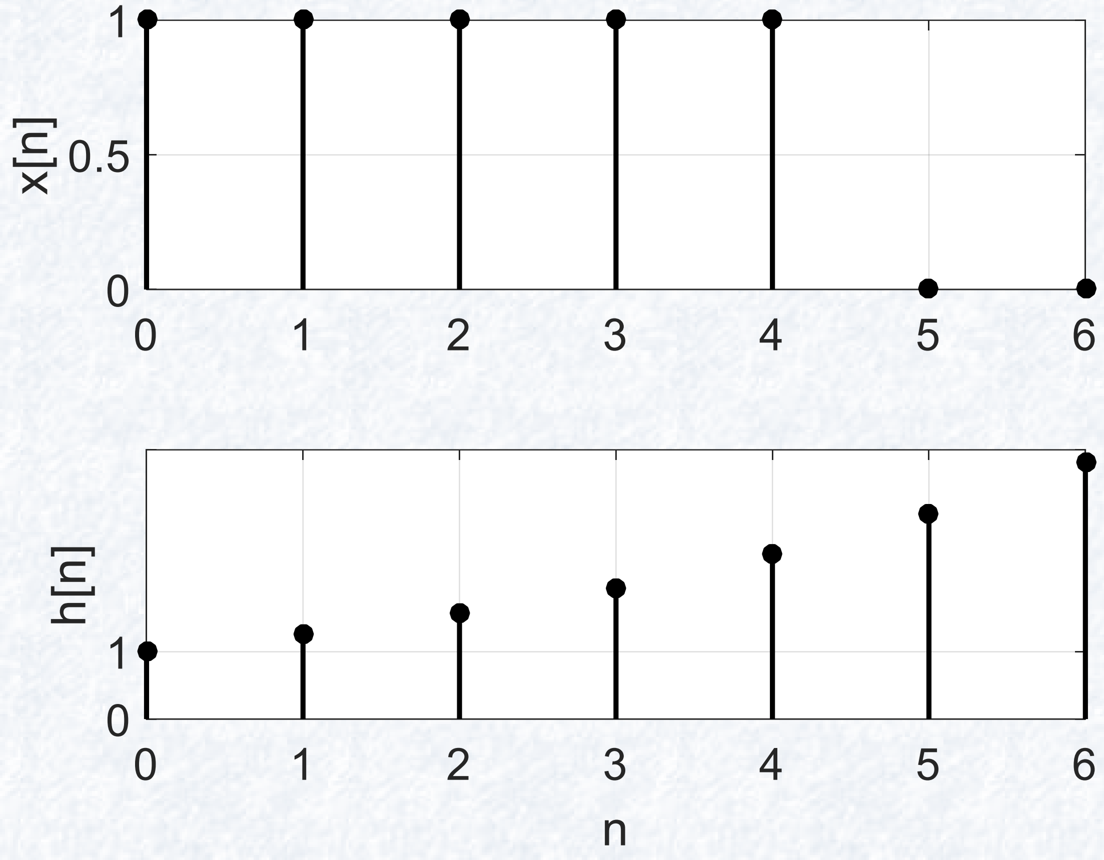
- $h[n] = \begin{cases} \alpha^n, & 0 \leq n \leq 6 \\ 0, & \text{diğer} \end{cases}$

- $y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k]$
- $n < 0$ iken



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- $n < 0$ iken
  - Çakışma yok
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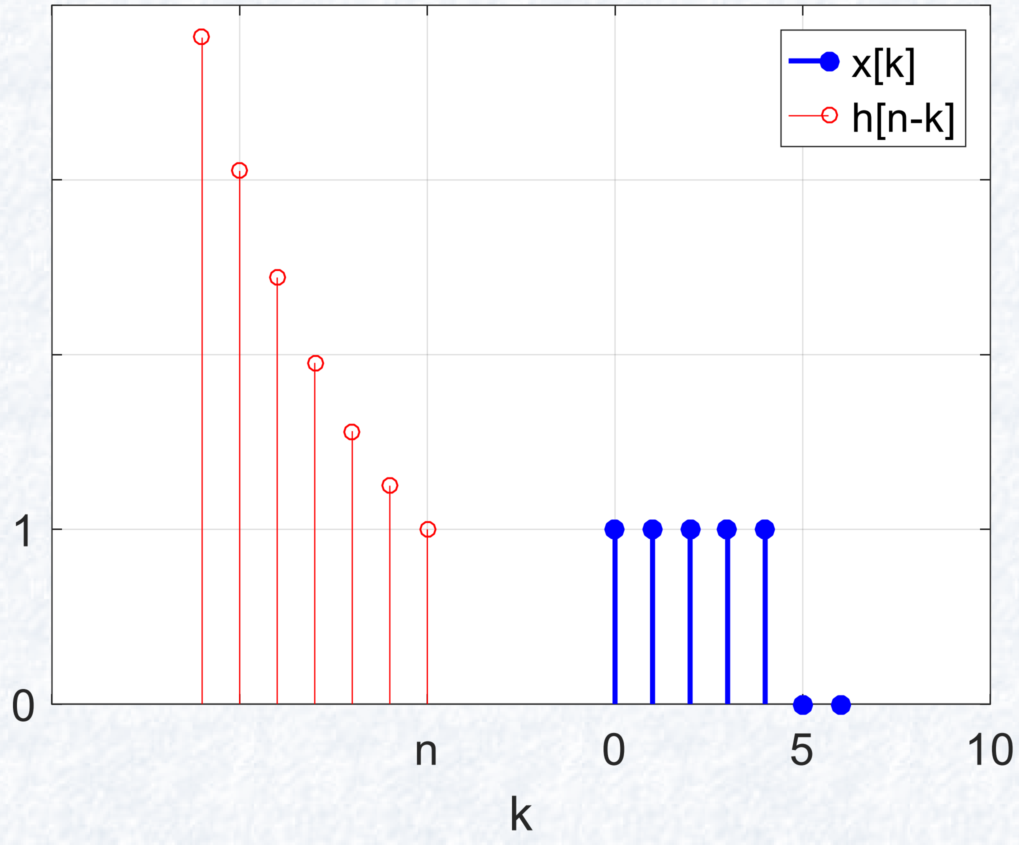
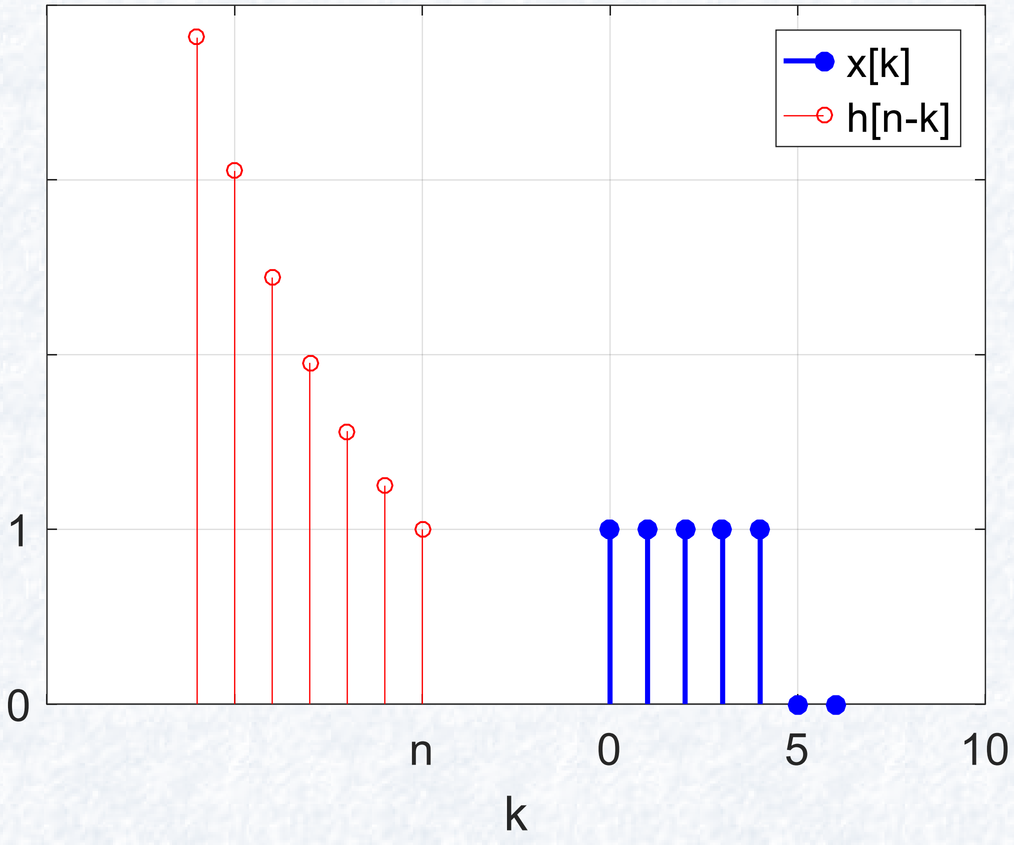


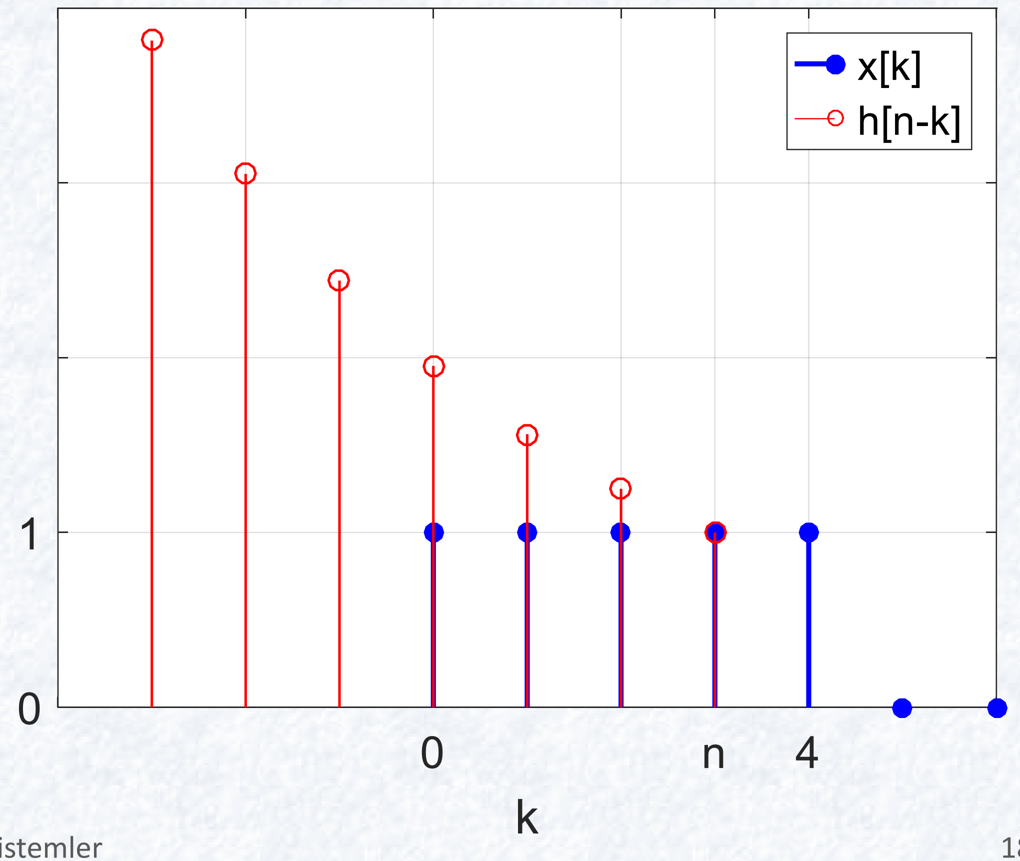
Örnek 2

- $0 \leq n \leq 4$ iken



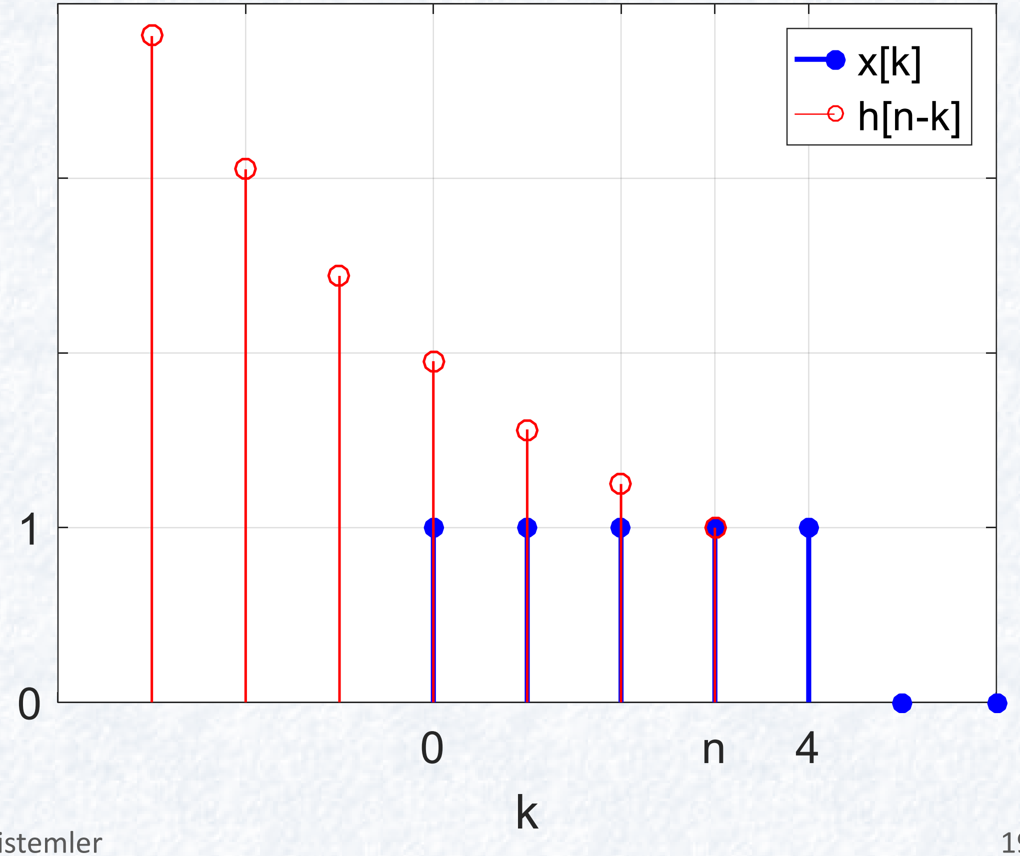
Örnek 2

- $0 \leq n \leq 4$ iken
  - ♦ Çakışma,



Örnek 2

- $0 \leq n \leq 4$ iken
  - ♦ Çakışma, 0-n arası
- $y[n] = \sum_{k=0}^{n} x[k]h[n-k]$
- $y[n] = \sum_{k=0}^{n} 1 \cdot \alpha^{n-k}$



Örnek 2

- $0 \leq n \leq 4$ iken
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- $y[n] = \sum_{k=0}^{n} x[k]h[n-k]$
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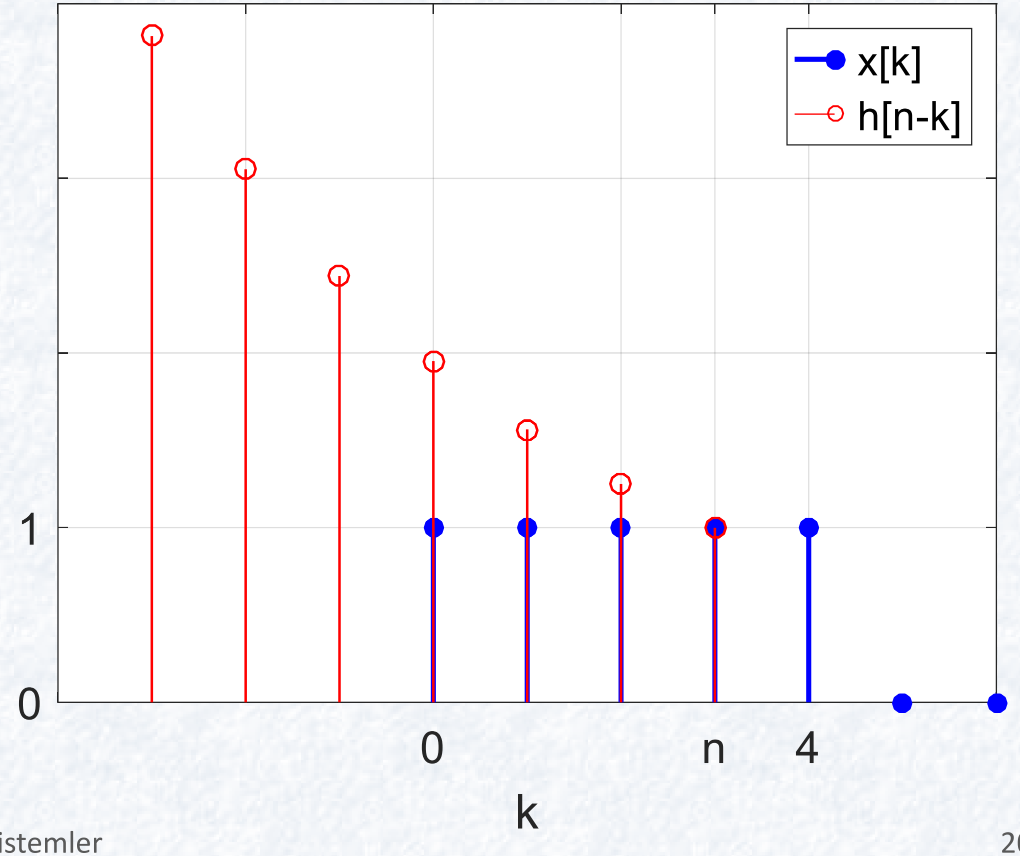

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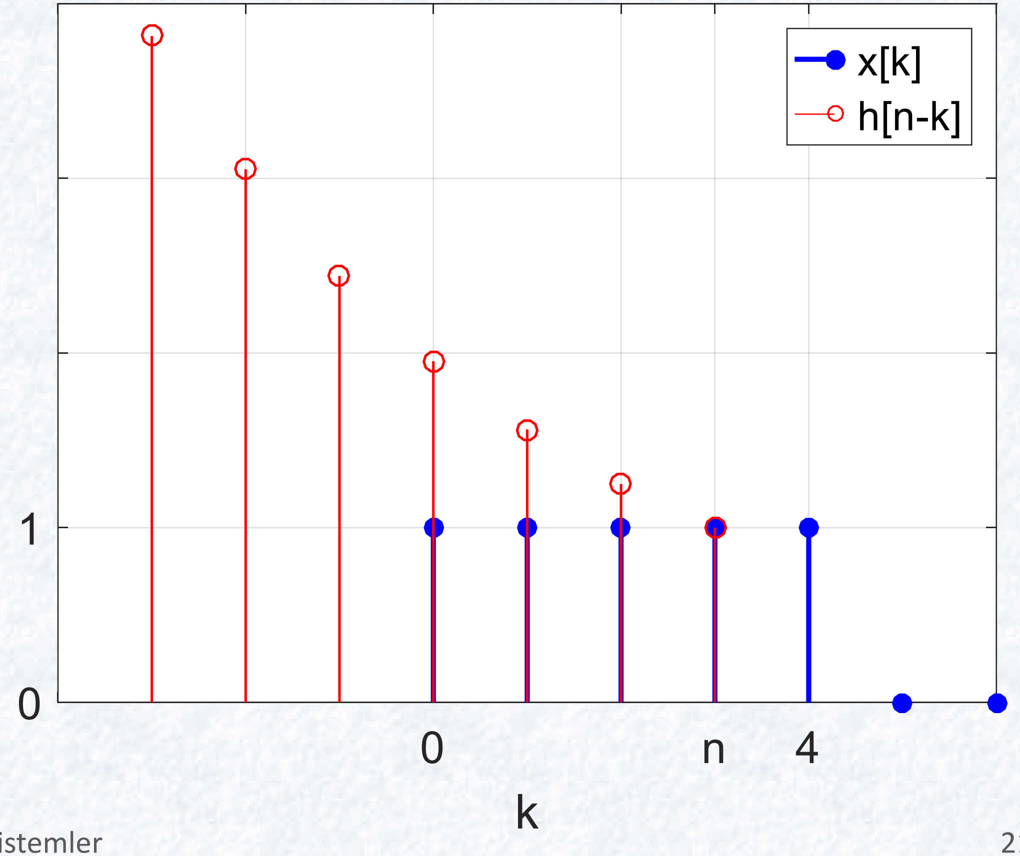

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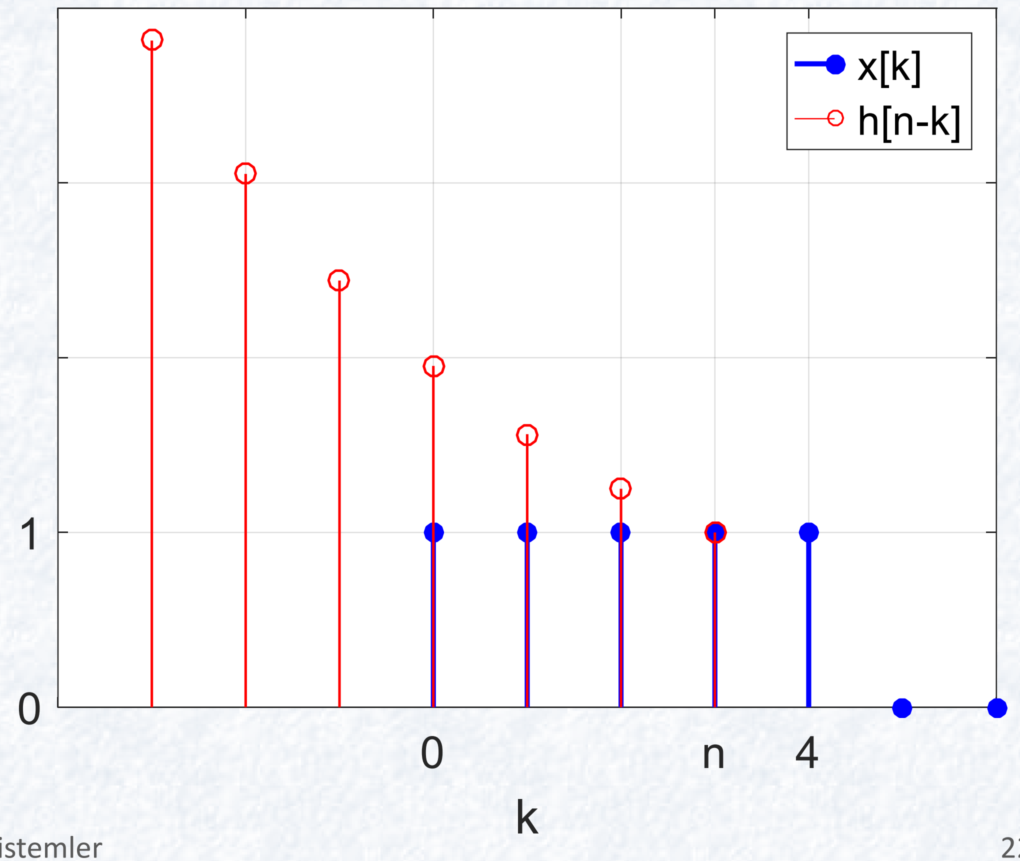
- $y[n] = \alpha^{n} \sum_{k=0}^{n} \left(\frac{1}{\alpha}\right)^{k}$



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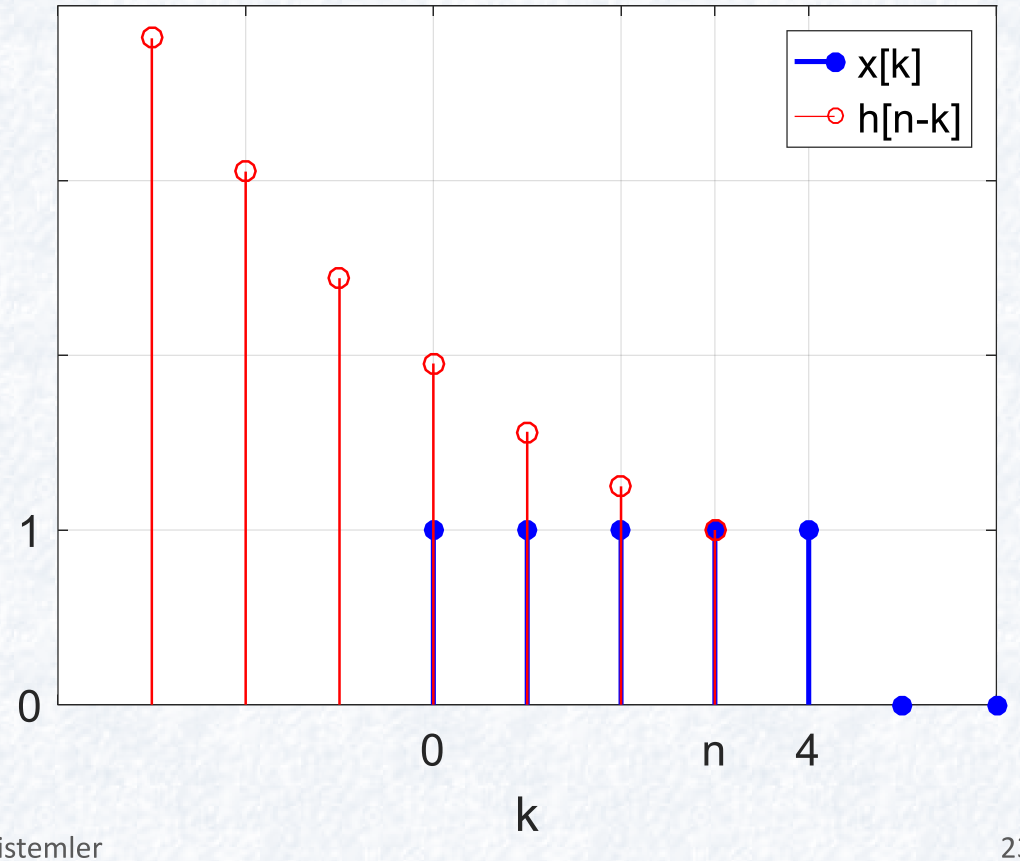
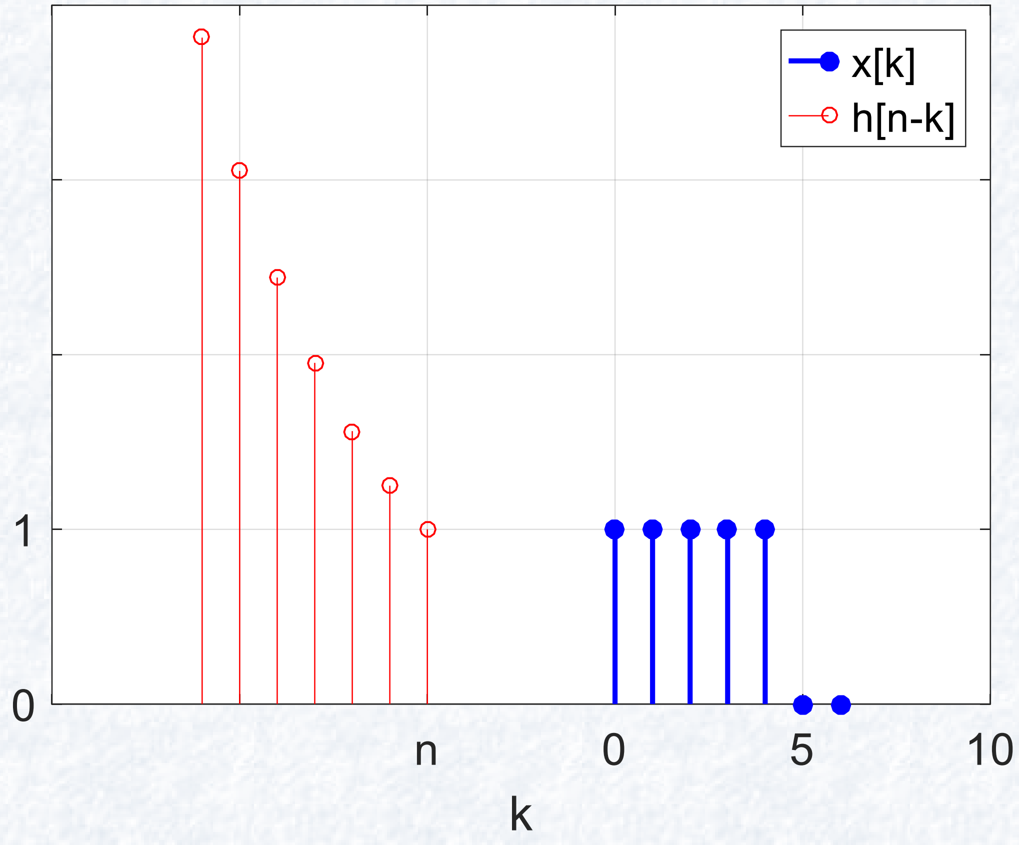
- $y[n] = \alpha^{n} \sum_{k=0}^{n} \left(\frac{1}{\alpha}\right)^{k}$
- $y[n] = \alpha^{n} \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}$



Örnek 2

- $4 < n \leq 6$ iken



Örnek 2

- $4 < n \leq 6$ iken
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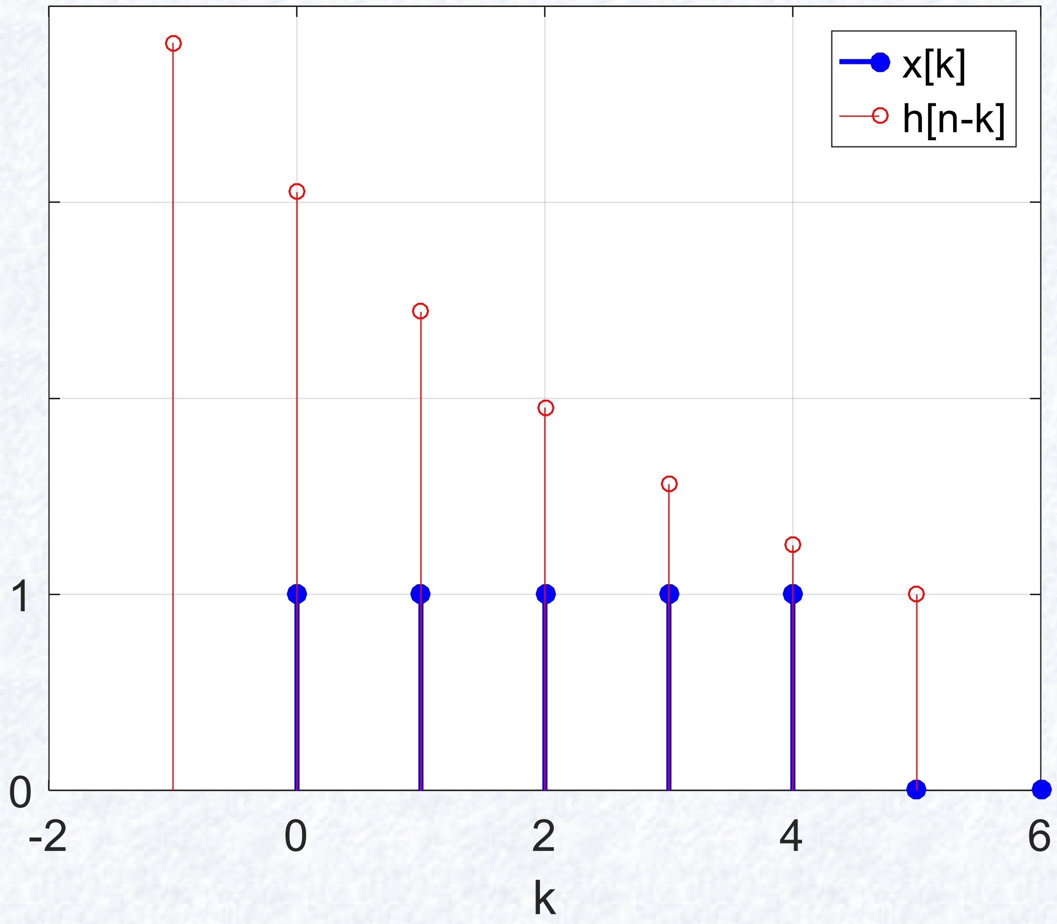

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- $4 < n \leq 6$ iken
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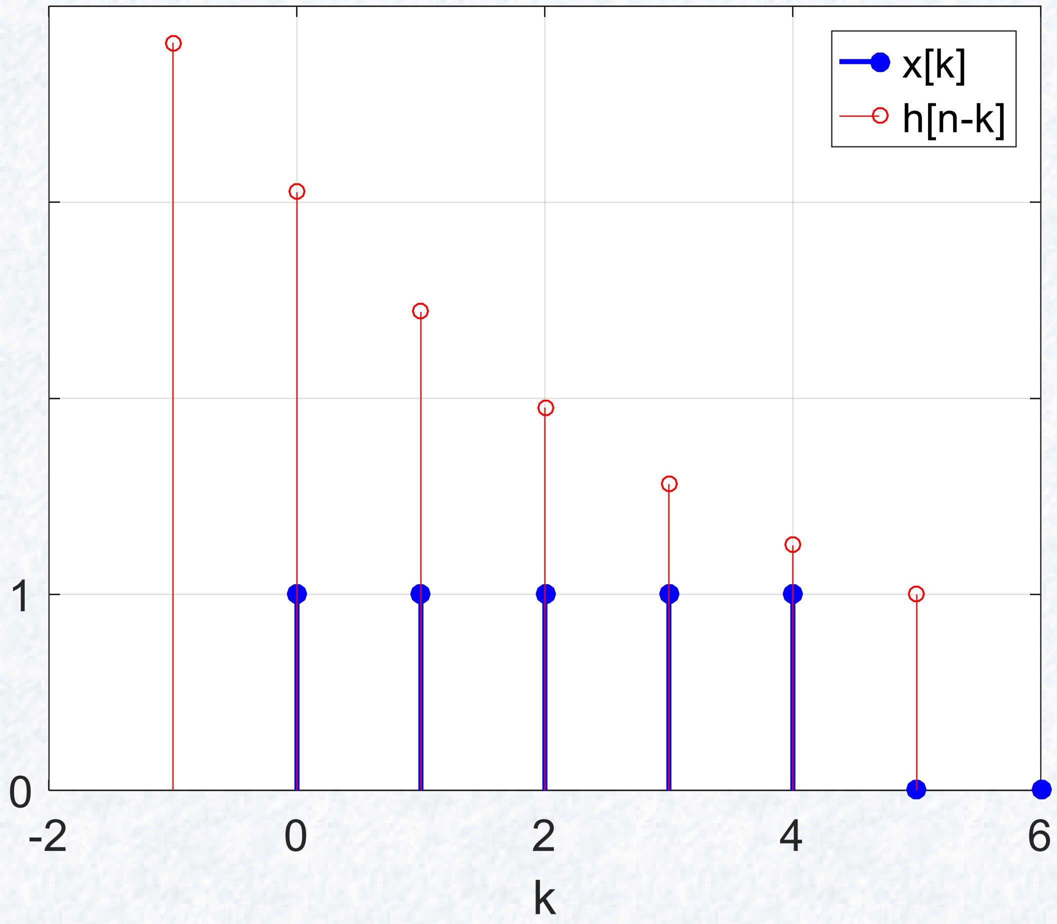

Örnek 2

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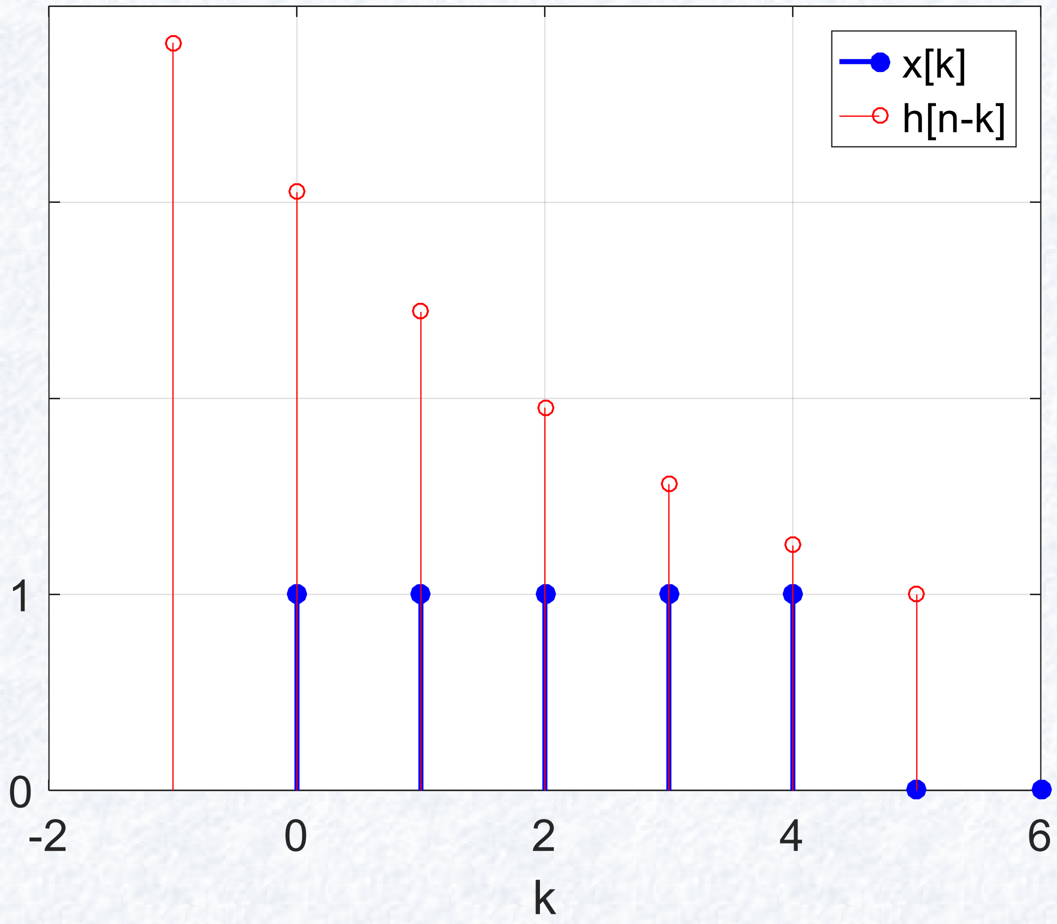

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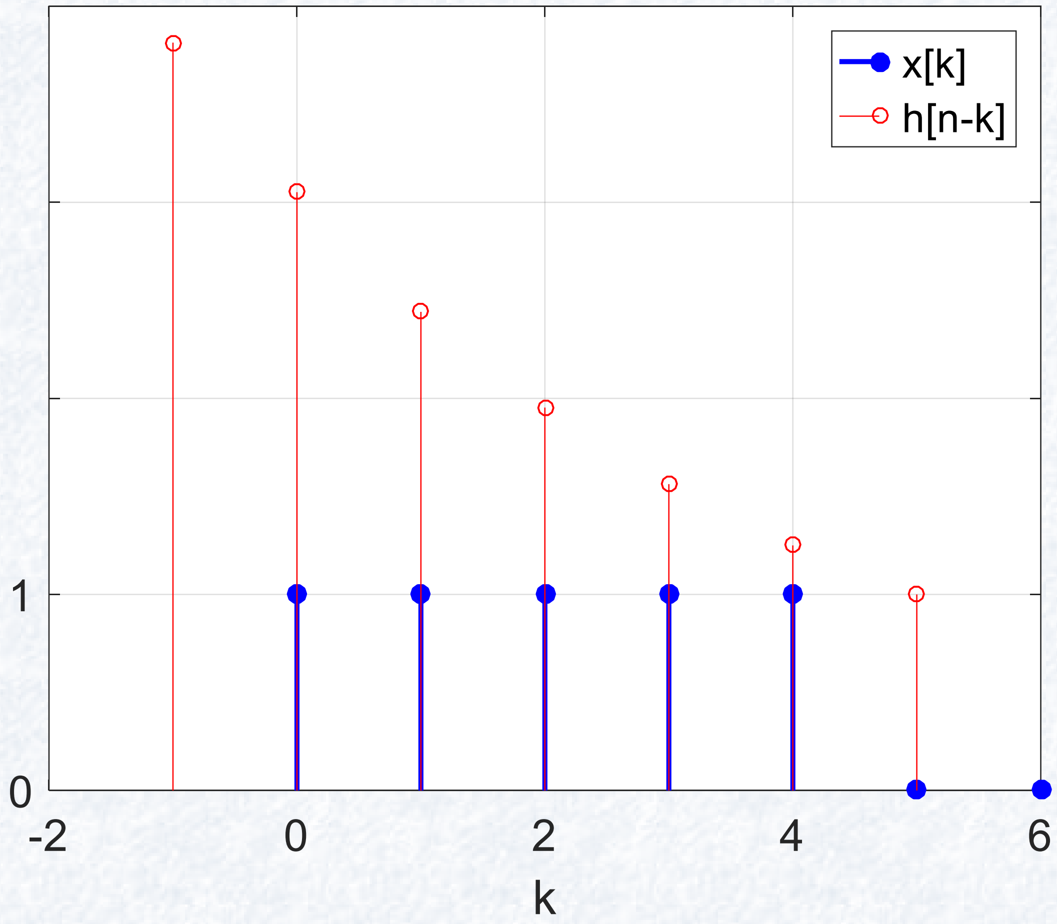
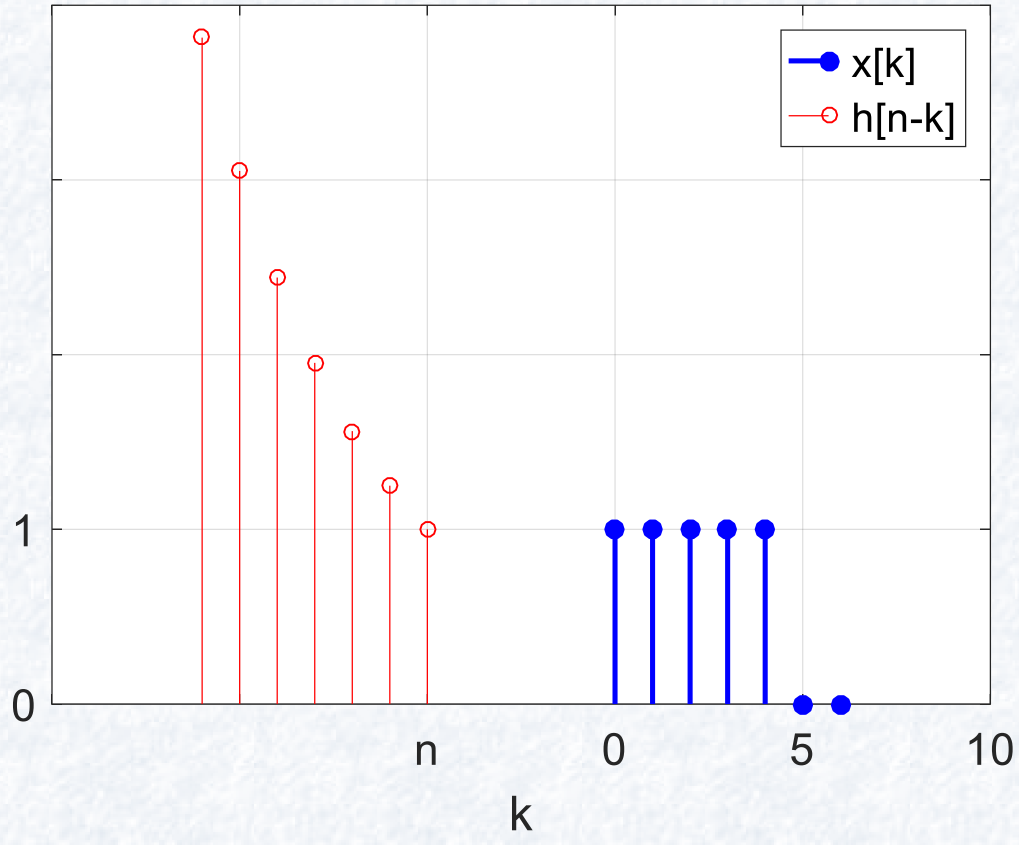


Örnek 2

- $6 < n \leq 10$ iken



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- $6 < n \leq 10$ iken
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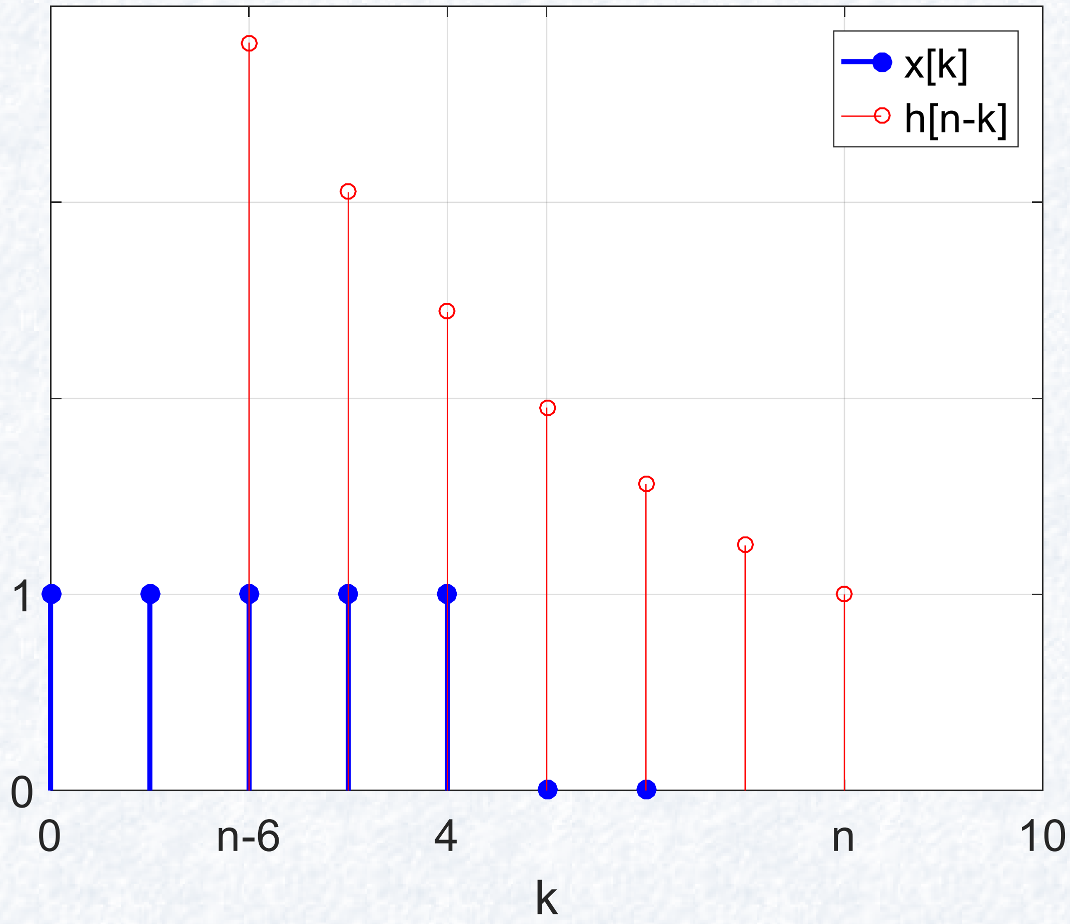
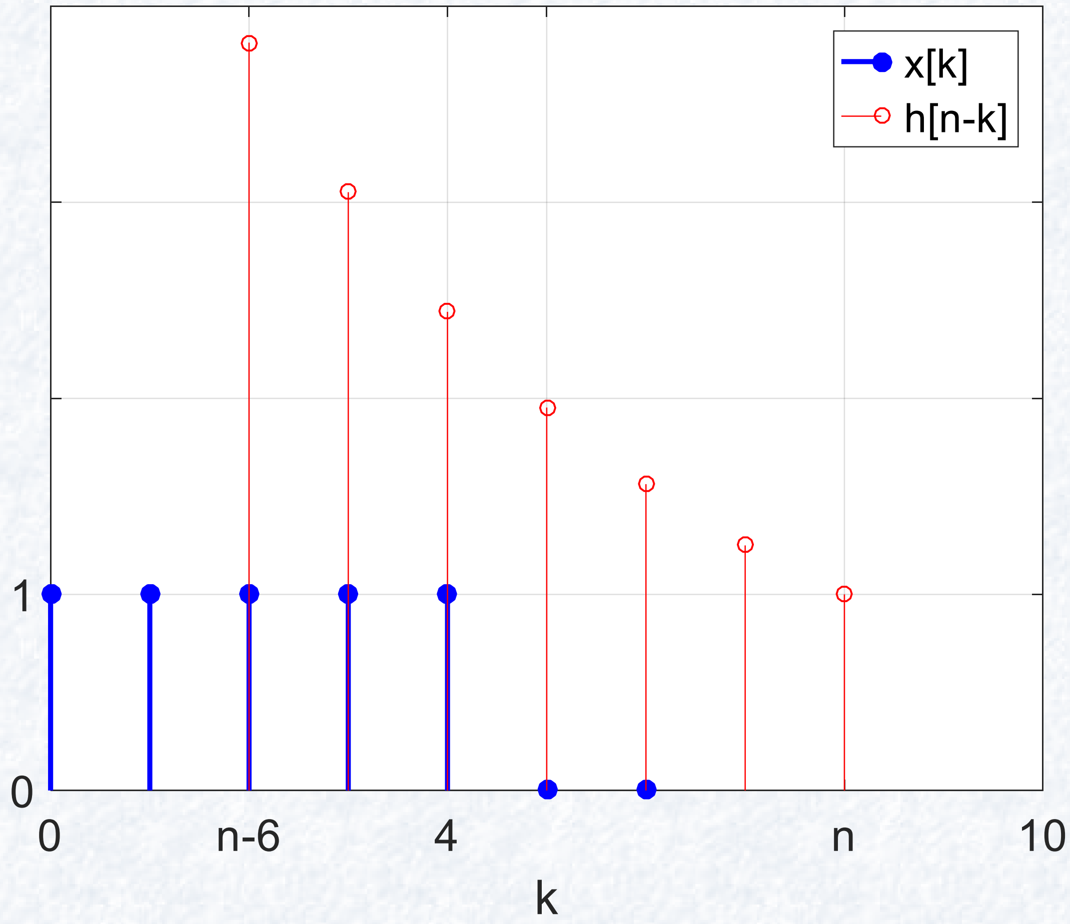


Örnek 2

- $6 < n \leq 10$ iken
  - ♦ Çakışma, n-6 – 4 arası



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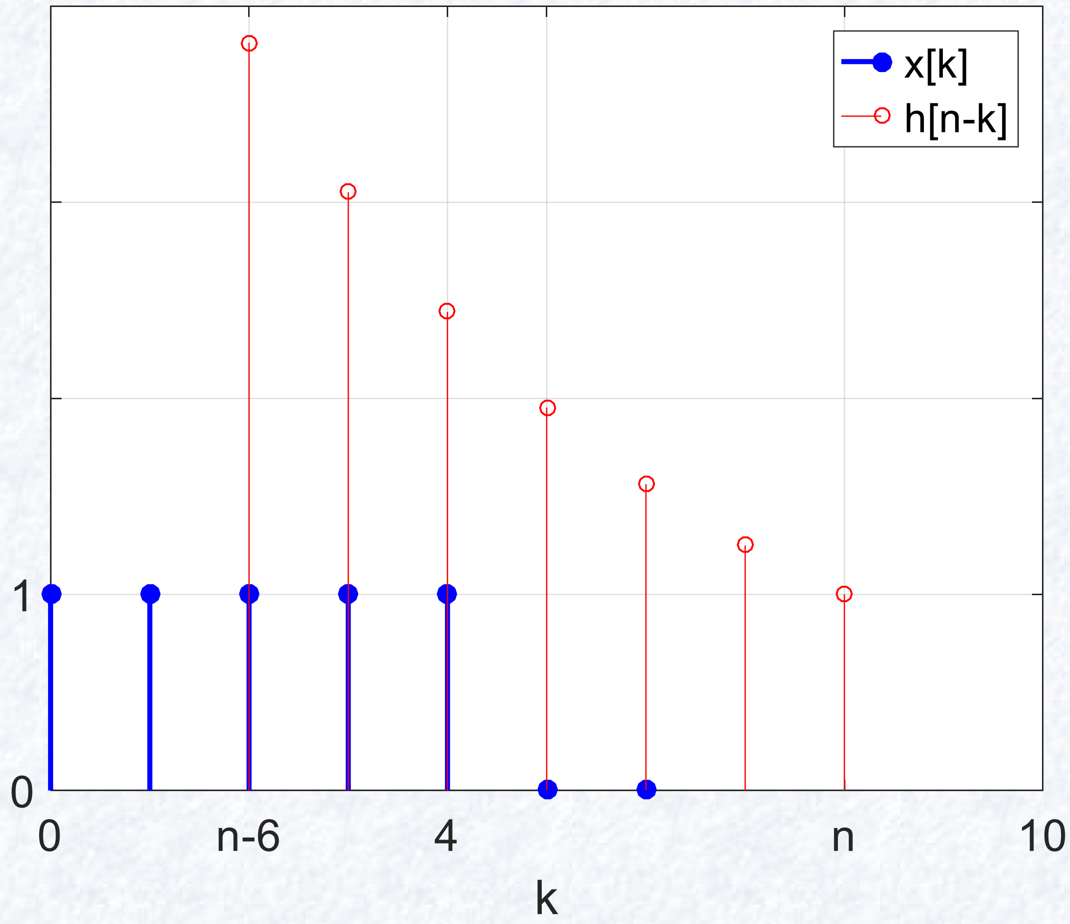
- $6 < n \leq 10$ iken
  - Çakışma, n-6 – 4 arası
- $y[n] = \sum_{k=n-6}^{4} x[k]h[n-k]$



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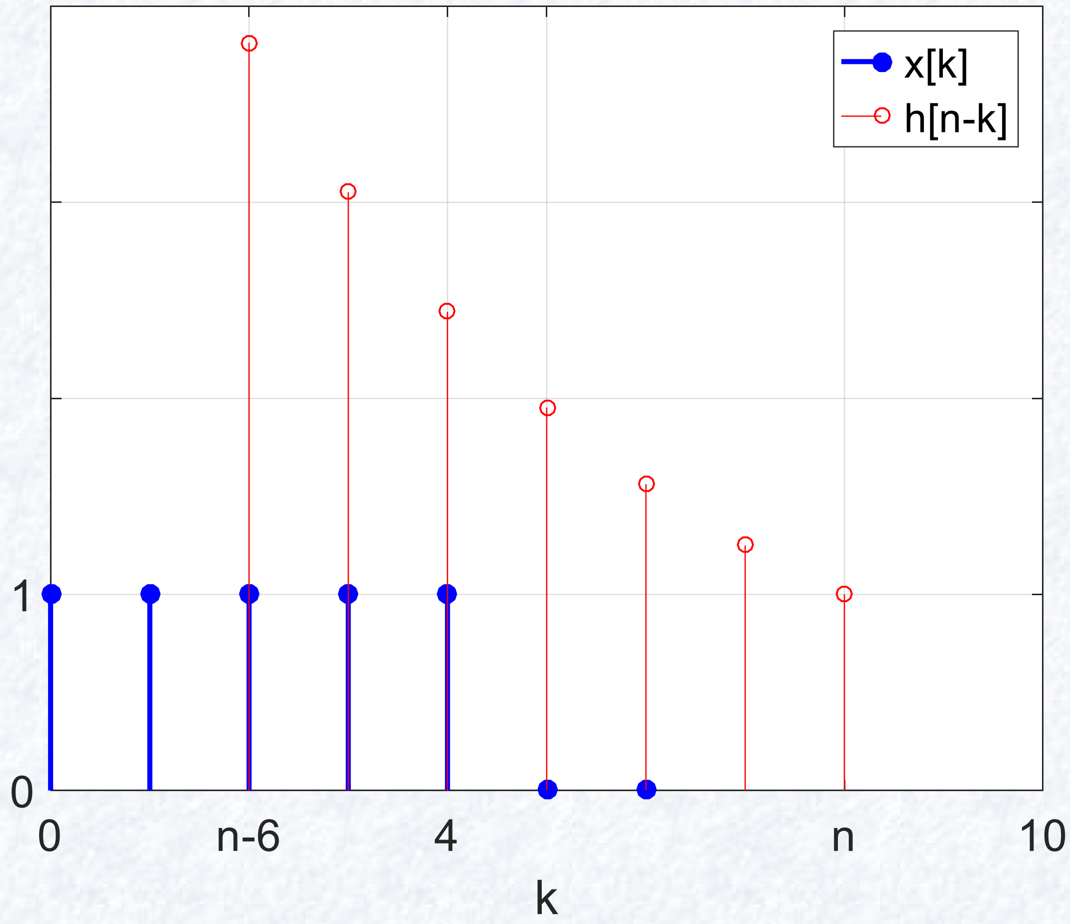
- $y[n] = \sum_{k=n-6}^{4} x[k]h[n-k]$
- $y[n] = \alpha^{n} \sum_{k=n-6}^{4} \alpha^{-k}$
  - $l = k - n + 6$



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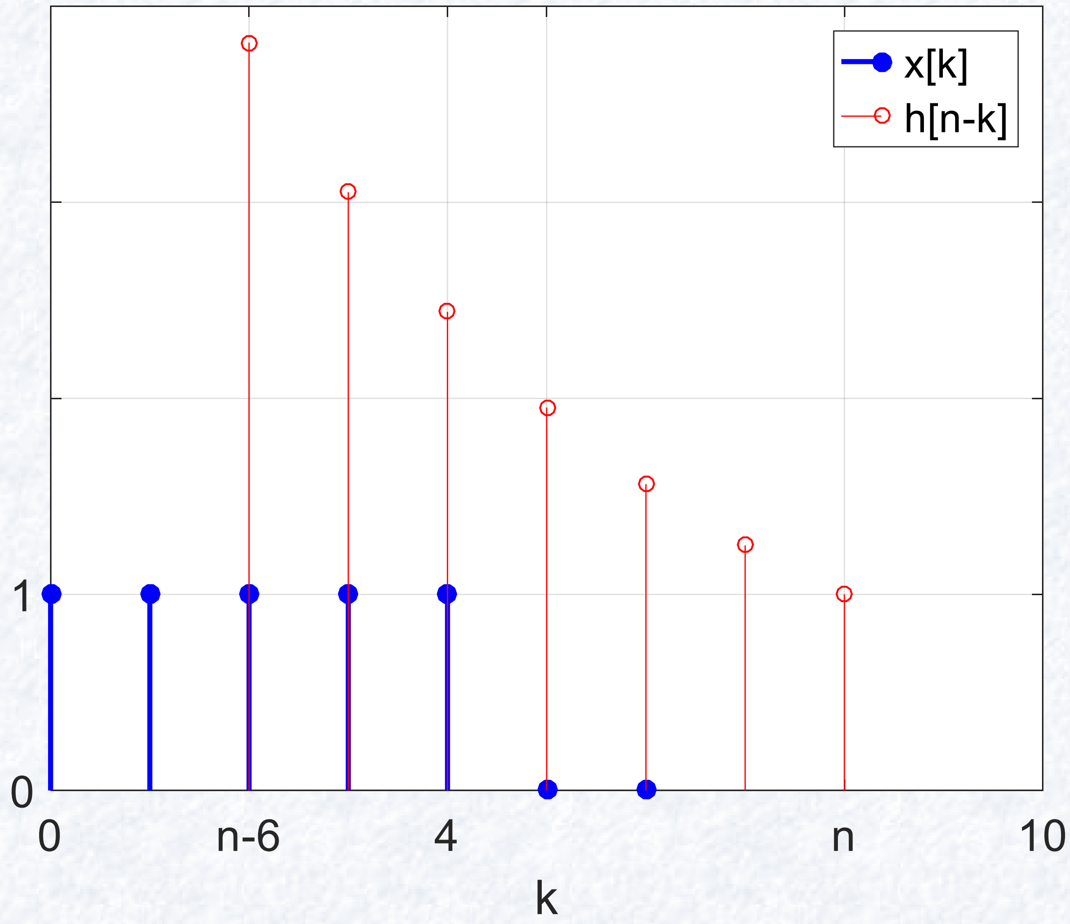

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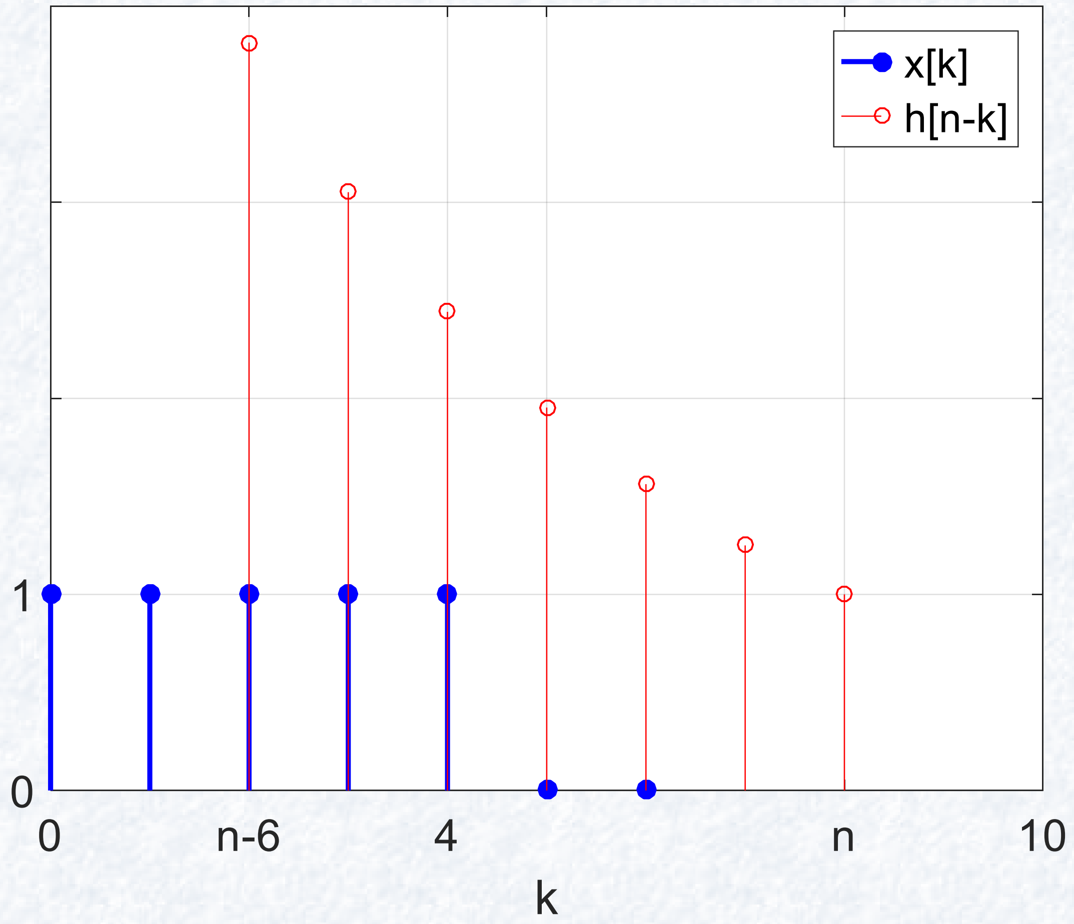

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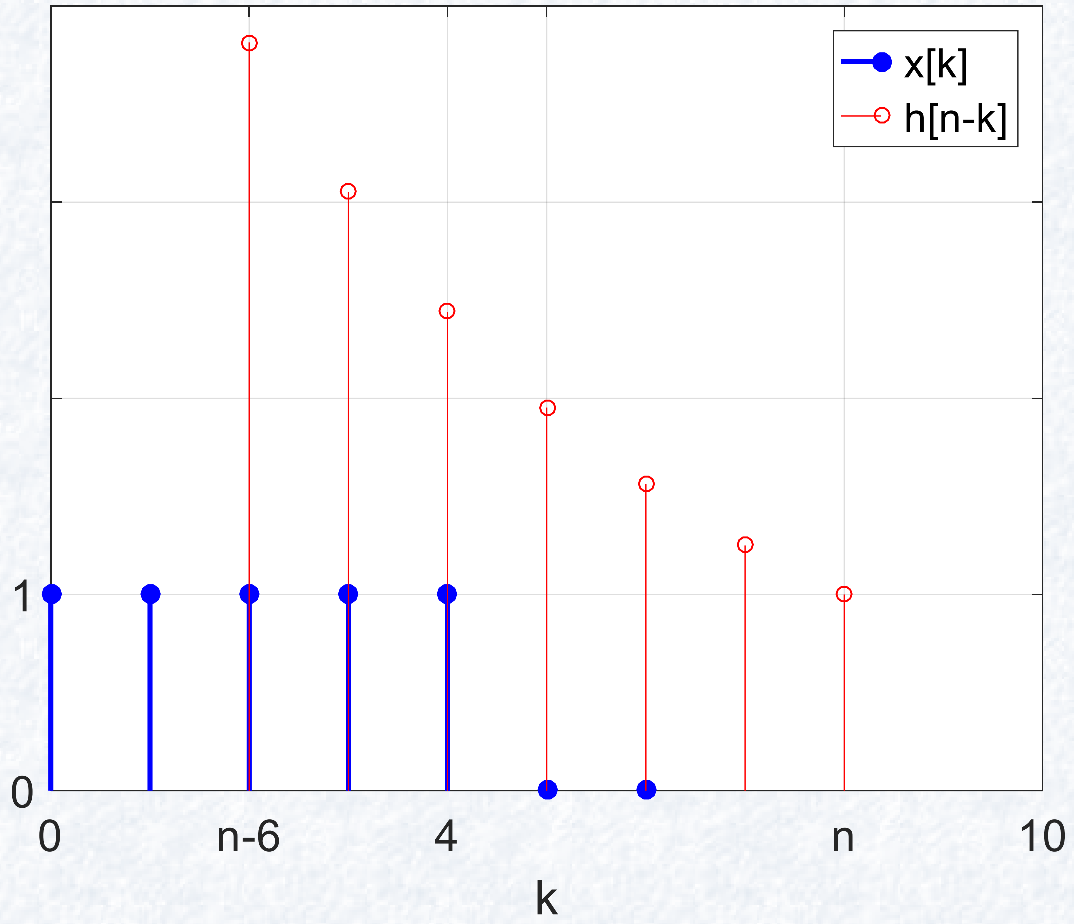
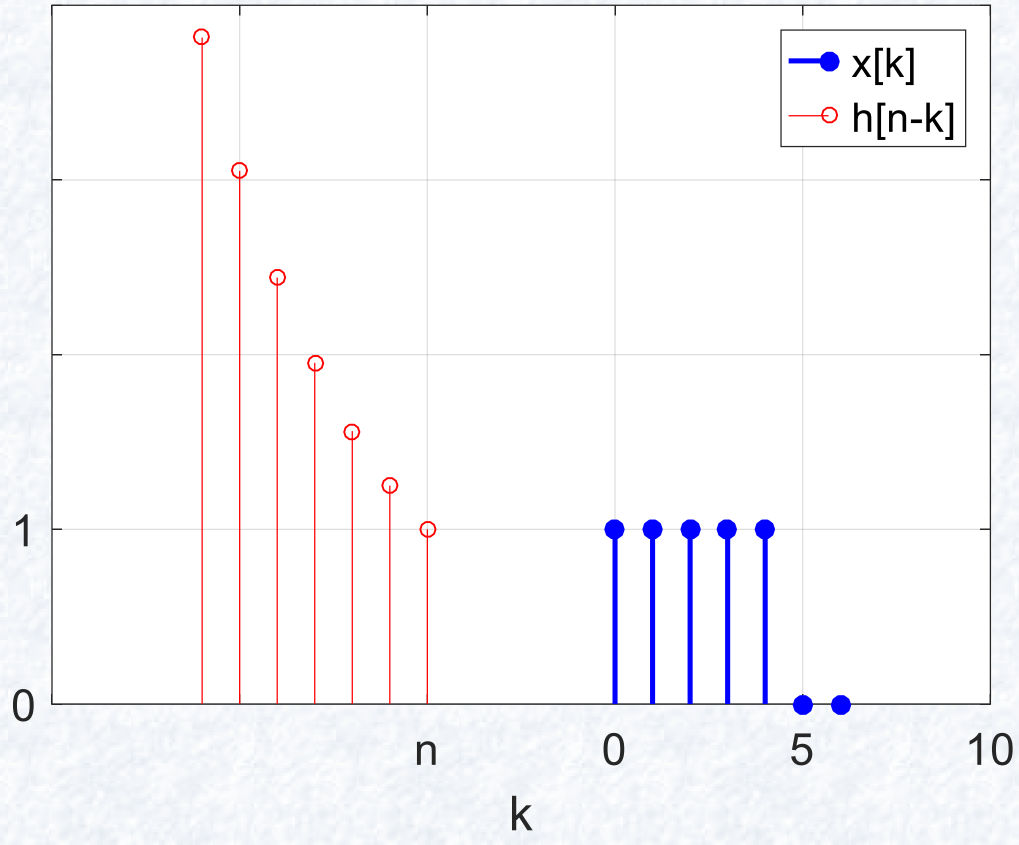
- $y[n] = \alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$



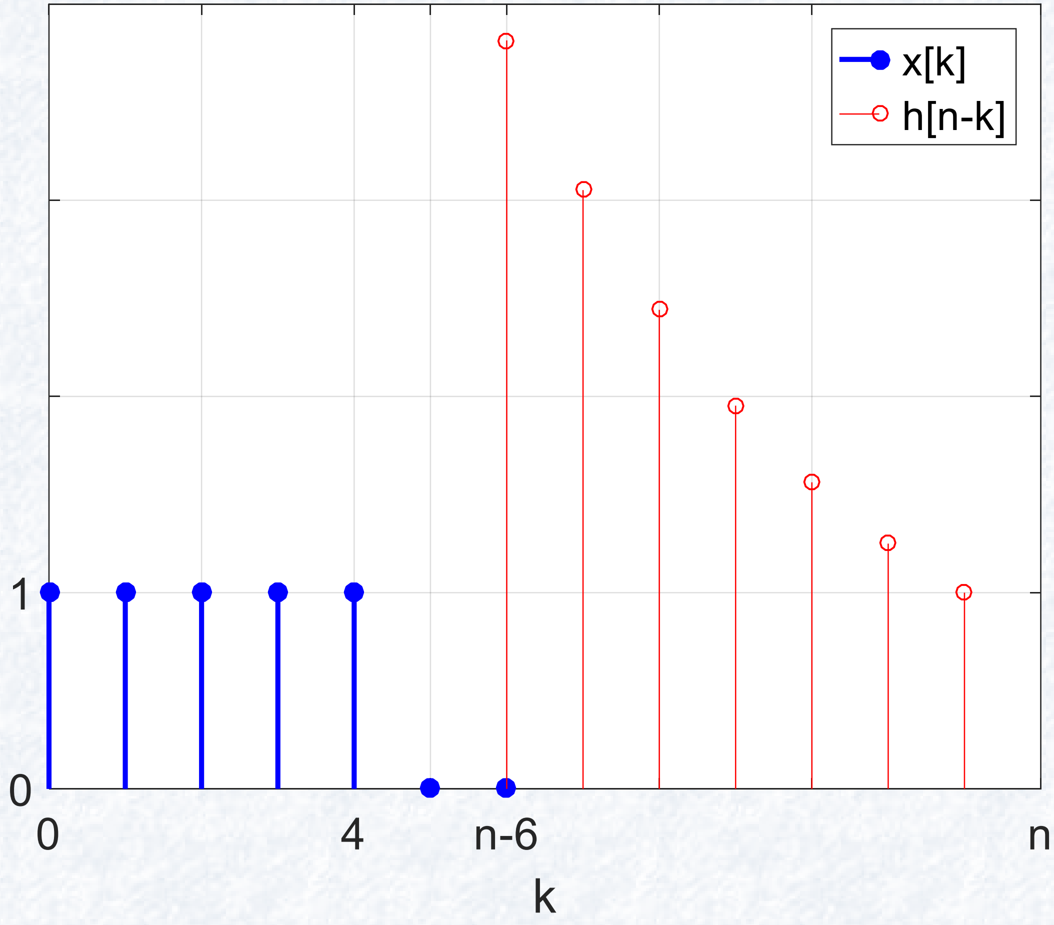
Örnek 2

- $10 < n$ iken



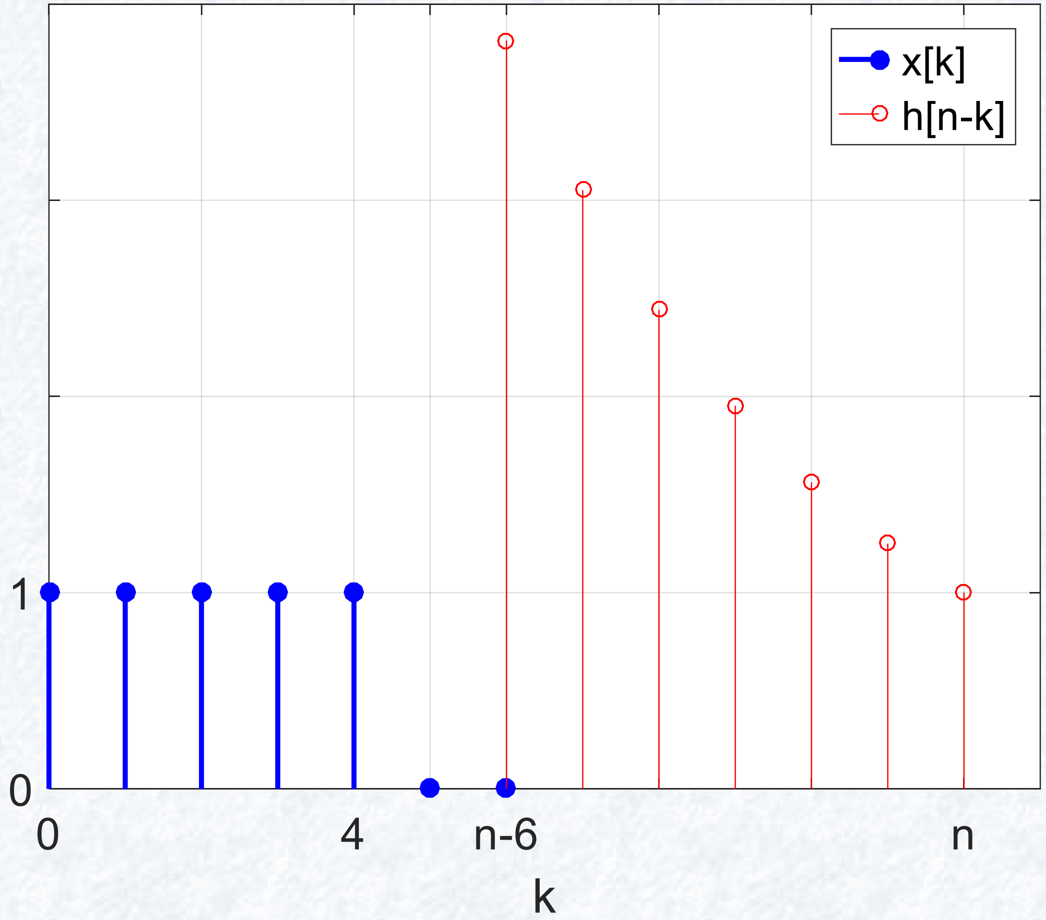
Örnek 2

- $10 < n$ iken
  - ♦ Çakışma yok.



Örnek 2

- $10 < n$ iken
  - ♦ Çakışma yok.
- $y[n] = 0$



Örnek 2

- $n < 0$ iken $y[n] = 0$
- $0 \leq n \leq 4$ iken $y[n] = \alpha^n \dfrac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}$
- $4 < n \leq 6$ iken $y[n] = \alpha^n \dfrac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}$
- $6 < n \leq 10$ iken $y[n] = \alpha^6 \dfrac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$
- $10 < n$ iken $y[n] = 0$
- $y[n] = ?$

Örnek 2

- $n < 0$ iken $y[n] = 0$
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- $6 < n \leq 10$ iken $y[n] = \alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$
- $10 < n$ iken $y[n] = 0$
- $y[n] = \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}\right)(\square - \square)$

Örnek 2

- $n < 0$ iken $y[n] = 0$
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- $10 < n$ iken $y[n] = 0$
- $y[n] = \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}\right)\left(u(n) - \square\right)$

Örnek 2

- $n < 0$ iken $y[n] = 0$
- $0 \leq n \leq 4$ iken $y[n] = \alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}$
- $4 < n \leq 6$ iken $y[n] = \alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}$
- $6 < n \leq 10$ iken $y[n] = \alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$
- $10 < n$ iken $y[n] = 0$
- $y[n] = \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}\right)\big(u(n) - u(n-5)\big) + \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}\right)(\quad)$

Örnek 2

- $n < 0$ iken $y[n] = 0$
- $0 \le n \le 4$ iken $y[n] = \alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}$
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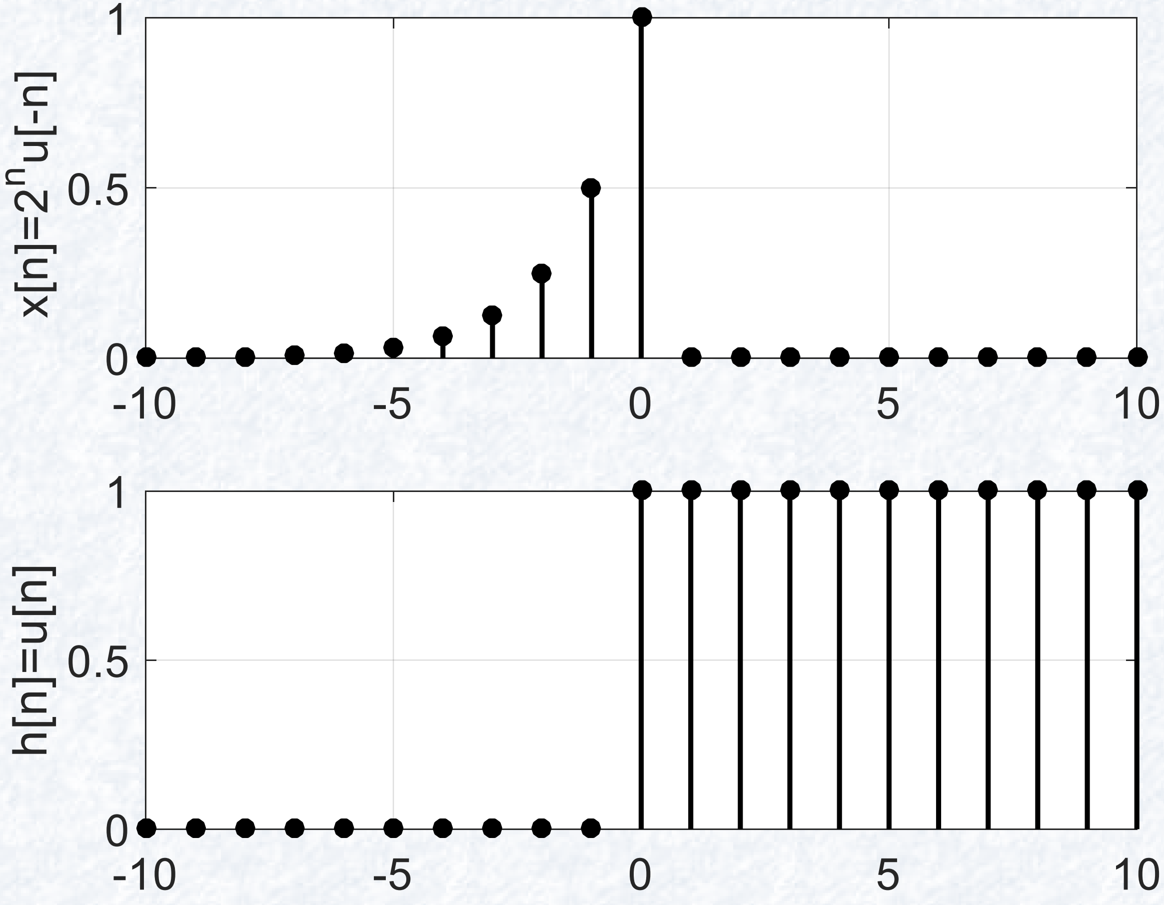
- $6 < n \le 10$ iken $y[n] = \alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$
- $10 < n$ iken $y[n] = 0$
- $y[n] = \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}\right)\left(u(n) - u(n-5)\right) + \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}\right)\left(u(n-5) - u(n-7)\right) + \left(\alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}\right)(\quad)$

Örnek 2

- $n < 0$ iken $y[n] = 0$
- $0 \leq n \leq 4$ iken $y[n] = \alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}$
- $4 < n \leq 6$ iken $y[n] = \alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}$
- $6 < n \leq 10$ iken $y[n] = \alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}$
- $10 < n$ iken $y[n] = 0$
- $$y[n] = \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{n+1}}{1-\frac{1}{\alpha}}\right)\big(u(n) - u(n-5)\big) + \left(\alpha^n \frac{1-\left(\frac{1}{\alpha}\right)^{5}}{1-\frac{1}{\alpha}}\right)\big(u(n-5) - u(n-7)\big) + \left(\alpha^6 \frac{1-\left(\frac{1}{\alpha}\right)^{11-n}}{1-\frac{1}{\alpha}}\right)\big(u(n-7) - u(n-11)\big)$$

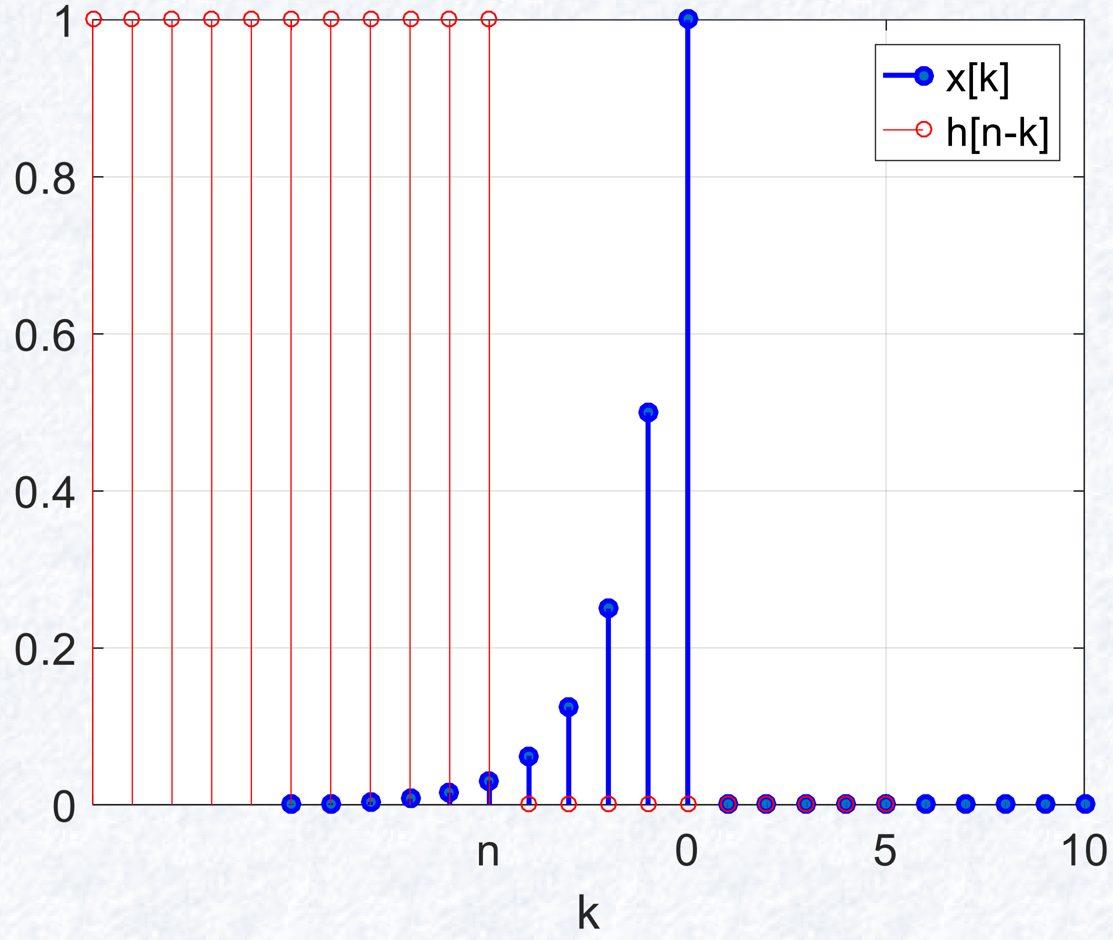
Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$
- $\mathrm{y}[n] = ?$



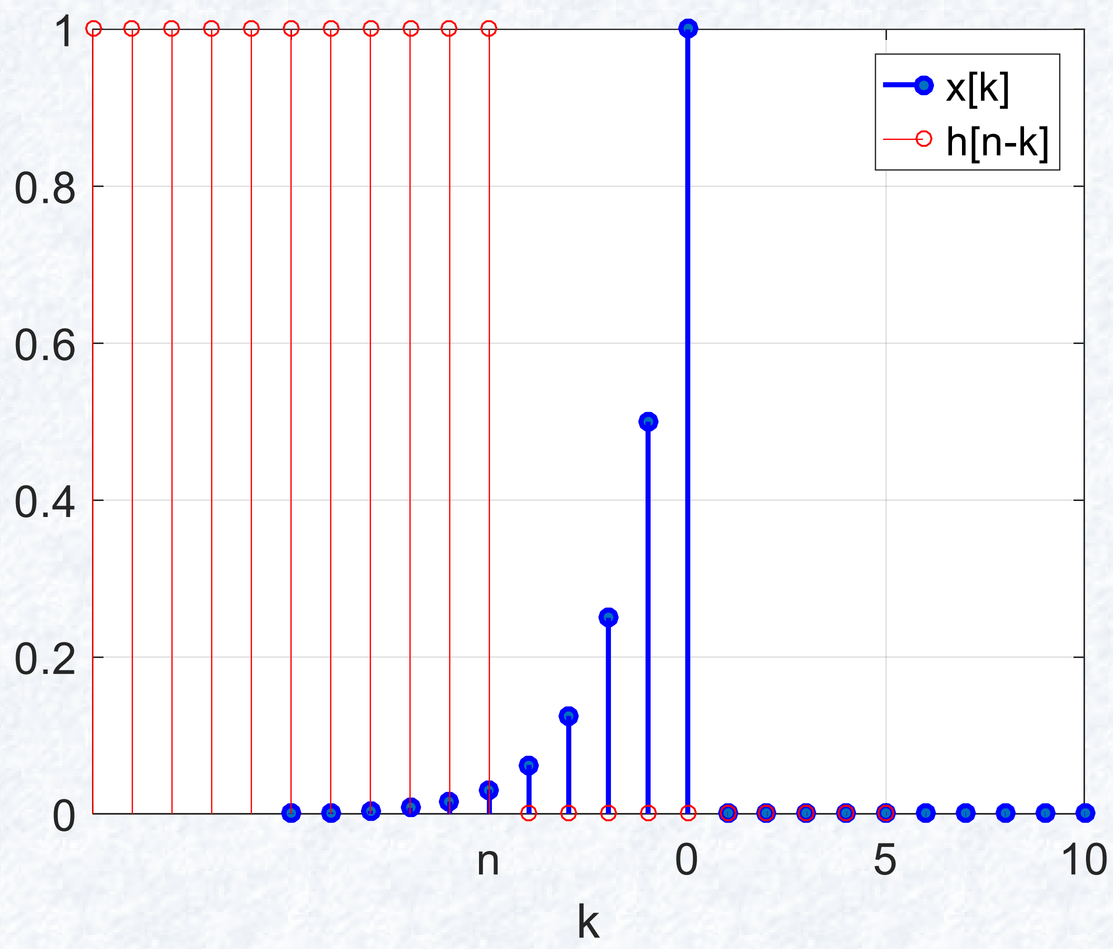
Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$
- $n < 0$ iken
  - ♦ Çakışma,



Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$
- $n < 0$ iken
  - ♦ Çakışma, $-\infty$ - n arası



Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$
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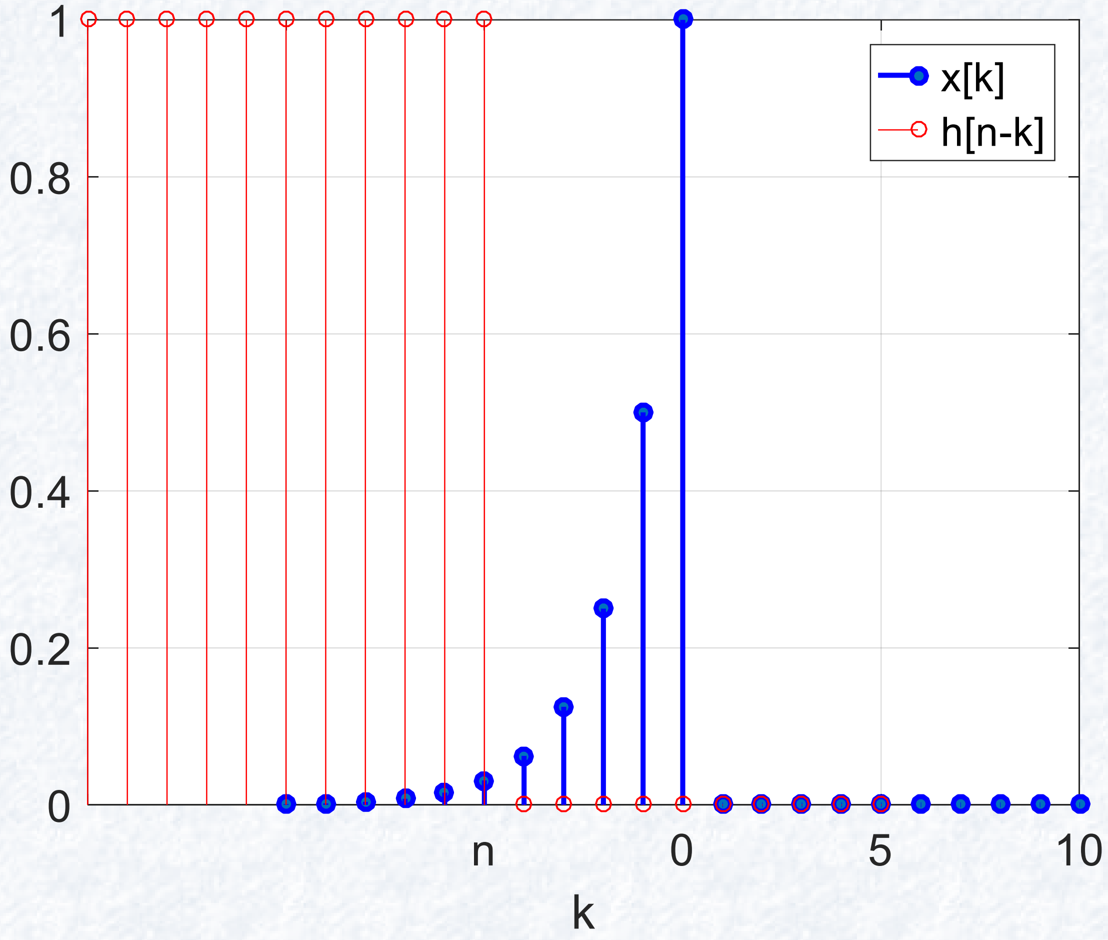
- $y[n] = \sum_{k=-\infty}^{n} x[k]h[n-k]$



Örnek 3

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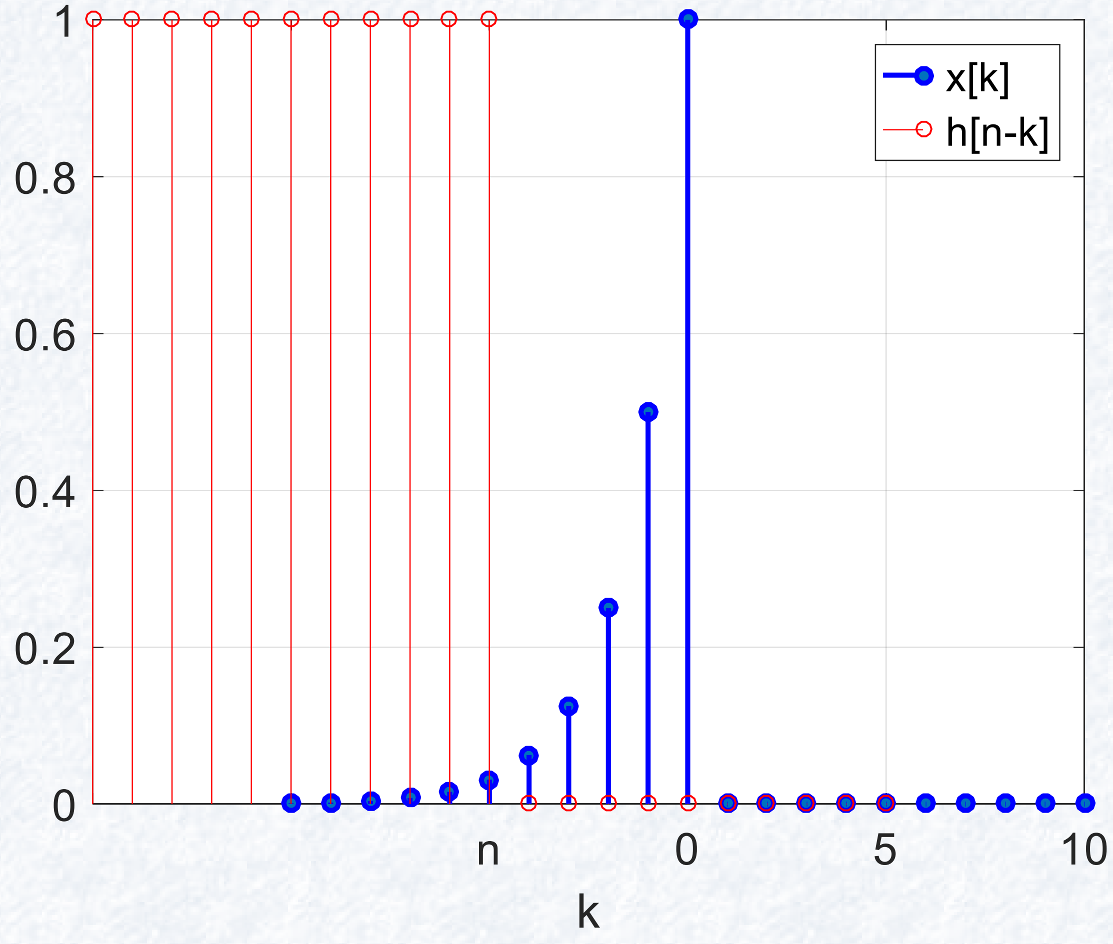

Örnek 3

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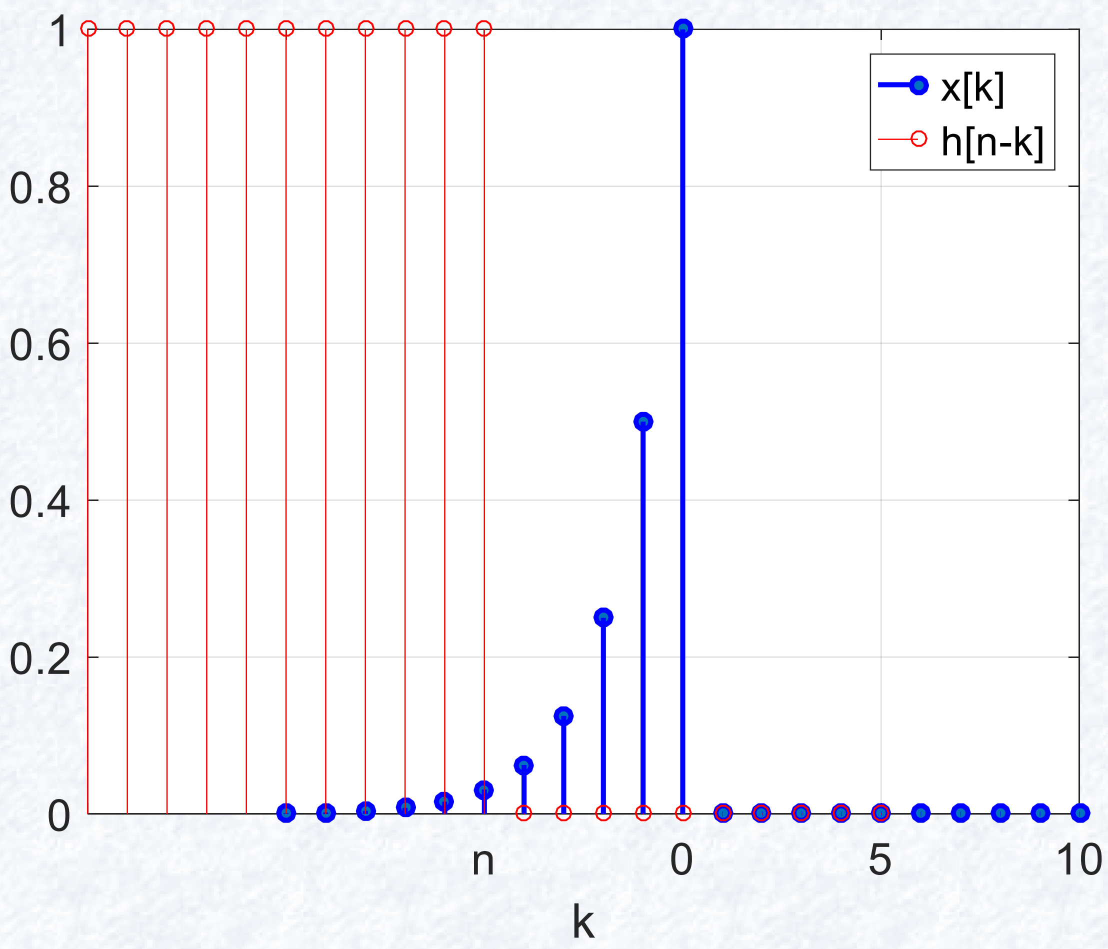
  - $l = -k + n$



Örnek 3

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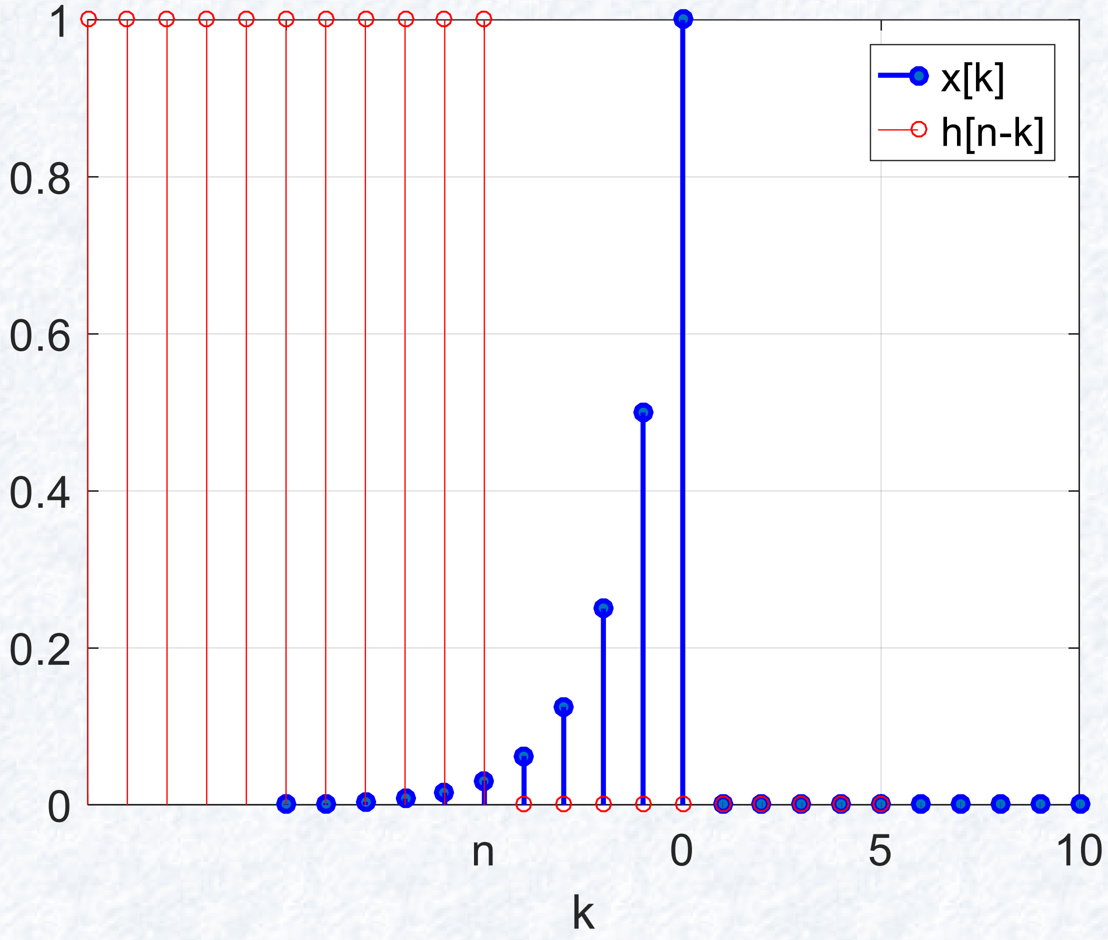
- $y[n] = \sum_{l=\infty}^{0} 2^{n-l} 1$



Örnek 3

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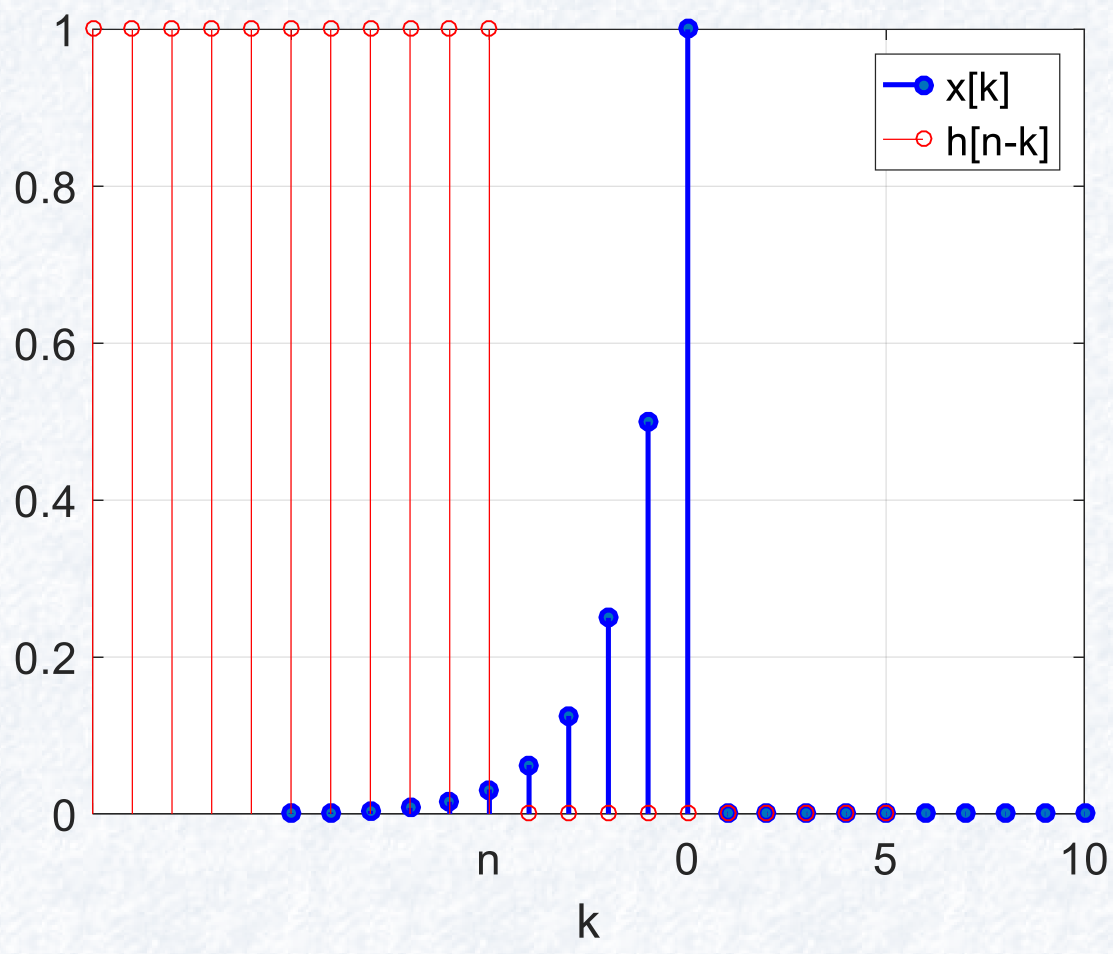

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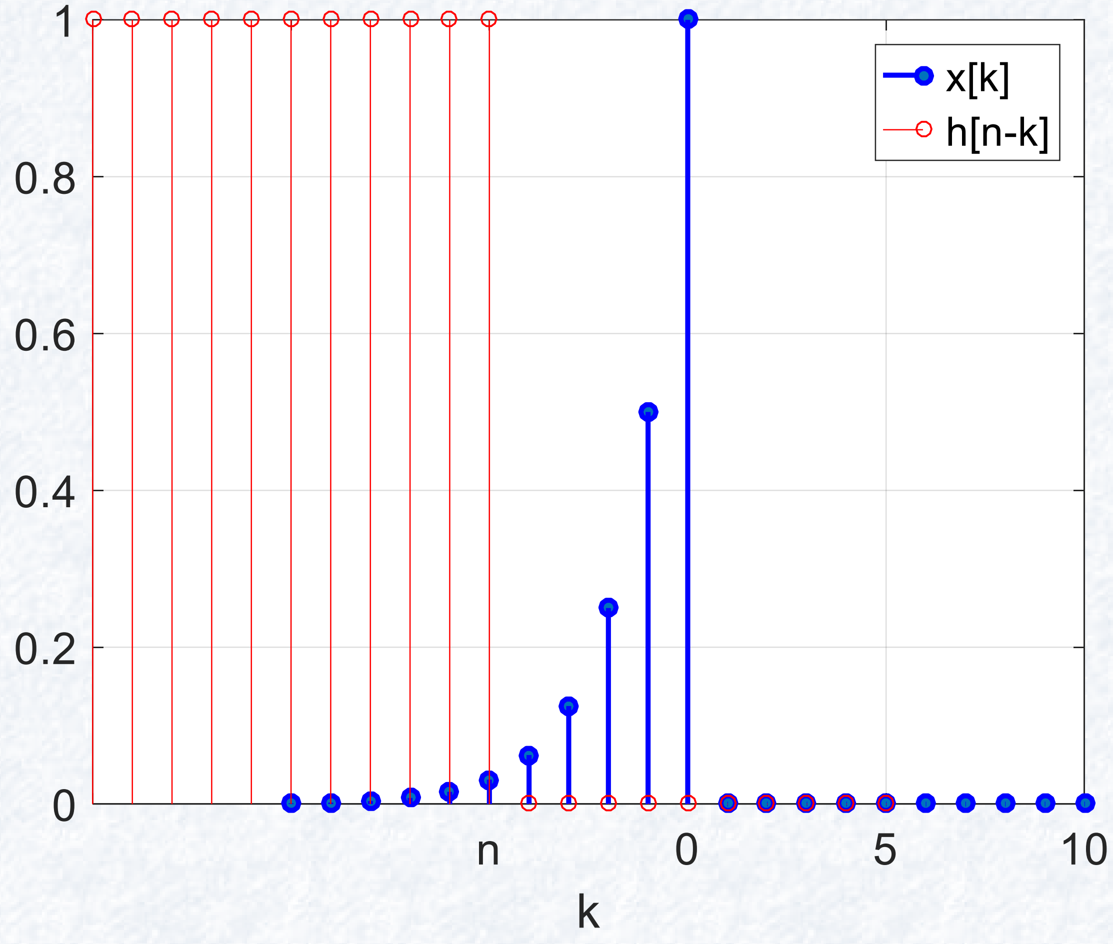
- $y[n] = \sum_{l=\infty}^{0} 2^{n-l} 1$
- $y[n] = \sum_{l=0}^{\infty} 2^n 2^{-l} 1$
- $y[n] = 2^n \sum_{l=0}^{\infty} \left(\frac{1}{2}\right)^l$



Örnek 3

- $x[n] = 2^n u[-n]$
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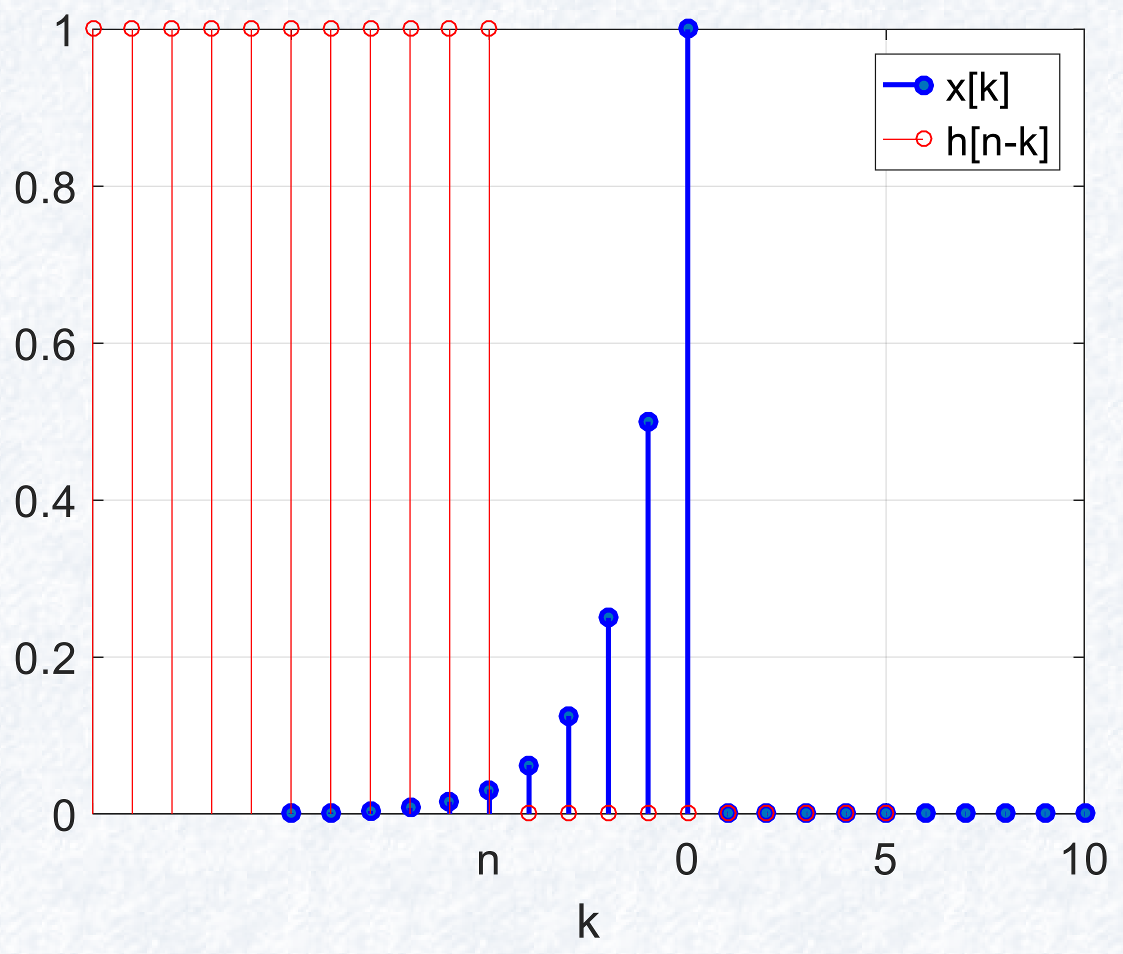
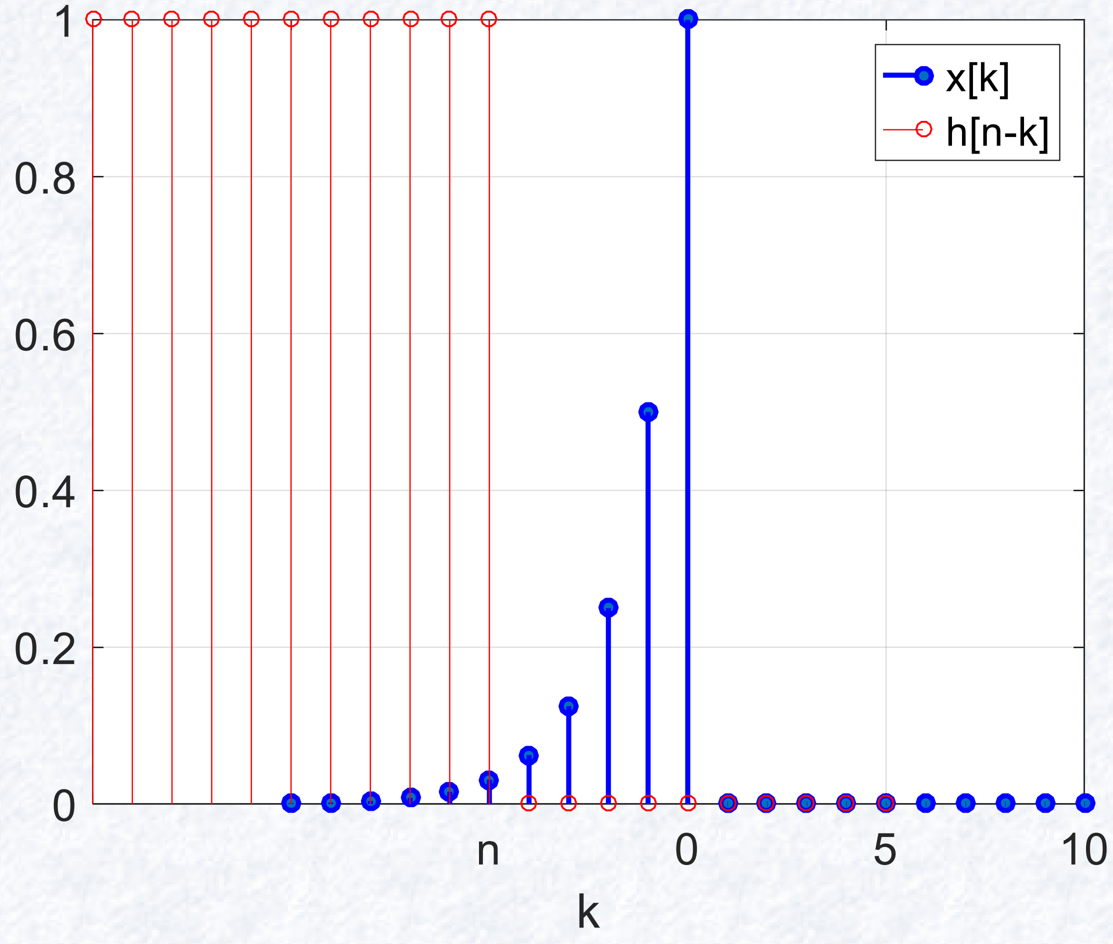
- $y[n] = 2^n \sum_{l=0}^{\infty} \left(\frac{1}{2}\right)^l$
  - $\sum_{l=0}^{\infty} a^l = \begin{cases} \frac{1}{1-a}, & a < 1 \\ \infty, & a \geq 1 \end{cases}$



Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$
- $n < 0$ iken

- $y[n] = 2^n \sum_{l=0}^{\infty} \left(\frac{1}{2}\right)^l$
  - ♦ $\sum_{l=0}^{\infty} a^l = \begin{cases} \frac{1}{1-a}, & a < 1 \\ \infty, & a \geq 1 \end{cases}$
- $y[n] = 2^n \frac{1}{1-\frac{1}{2}} = 2^{n+1}$



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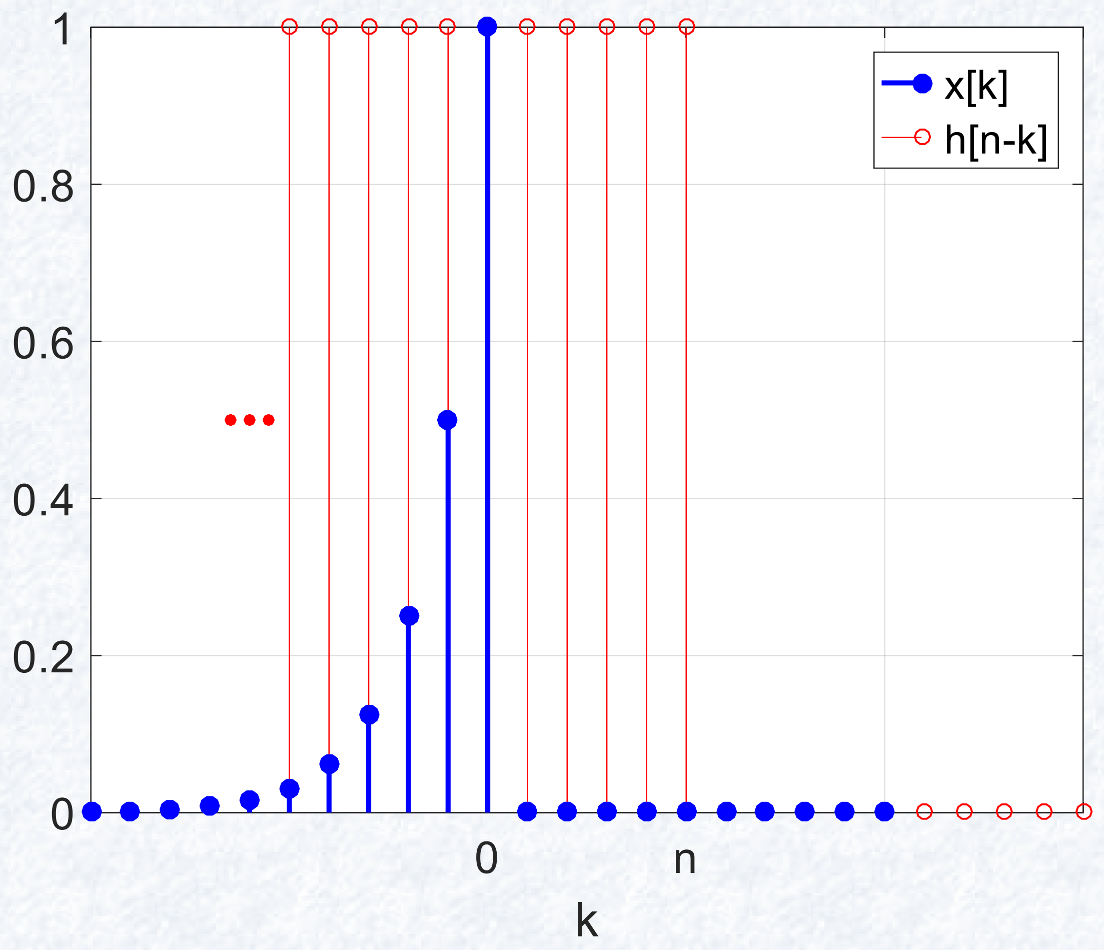

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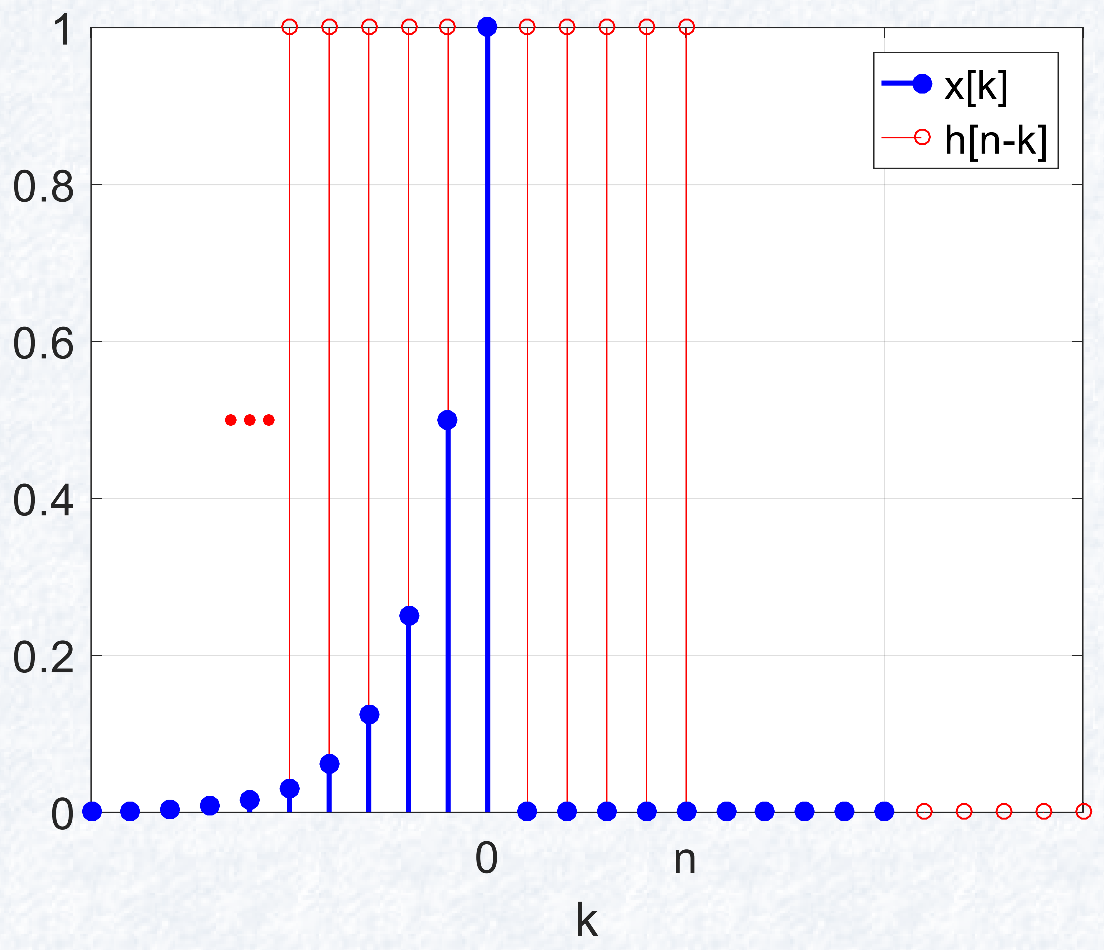

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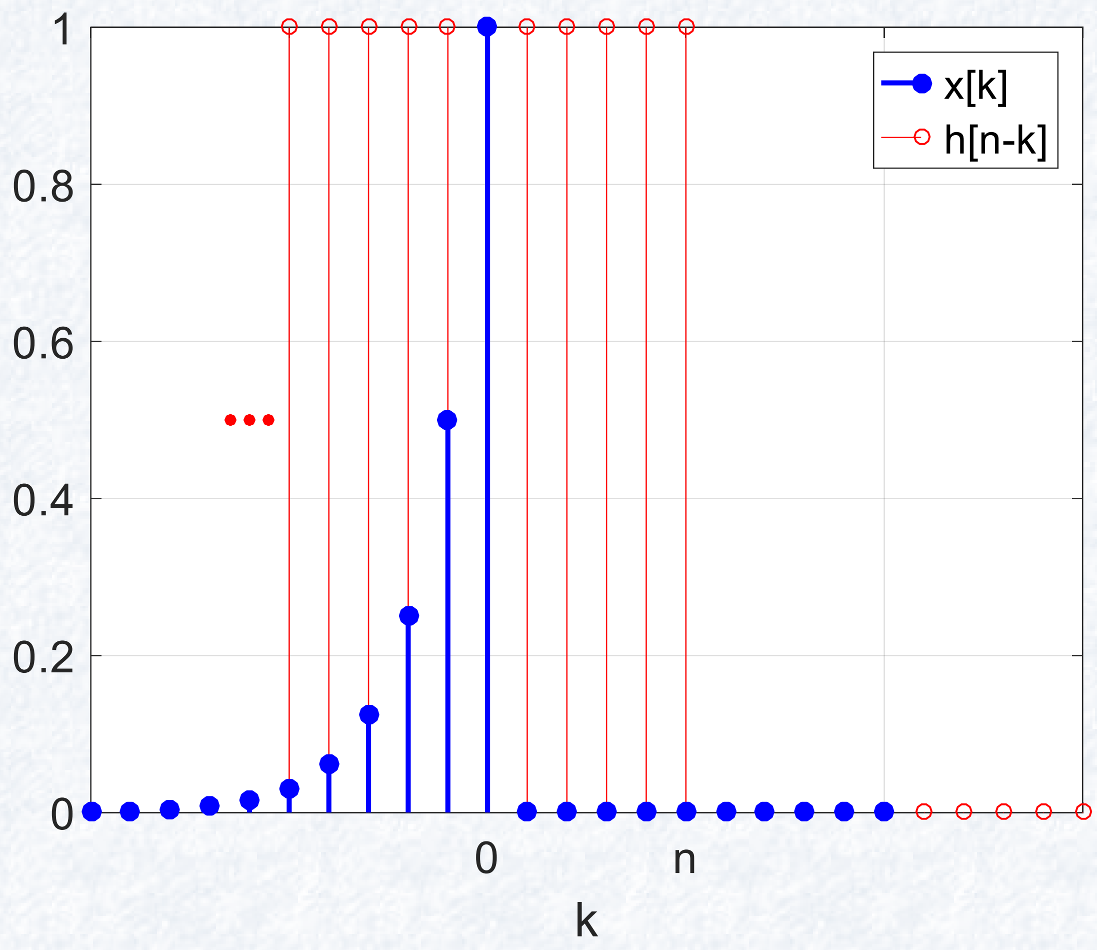

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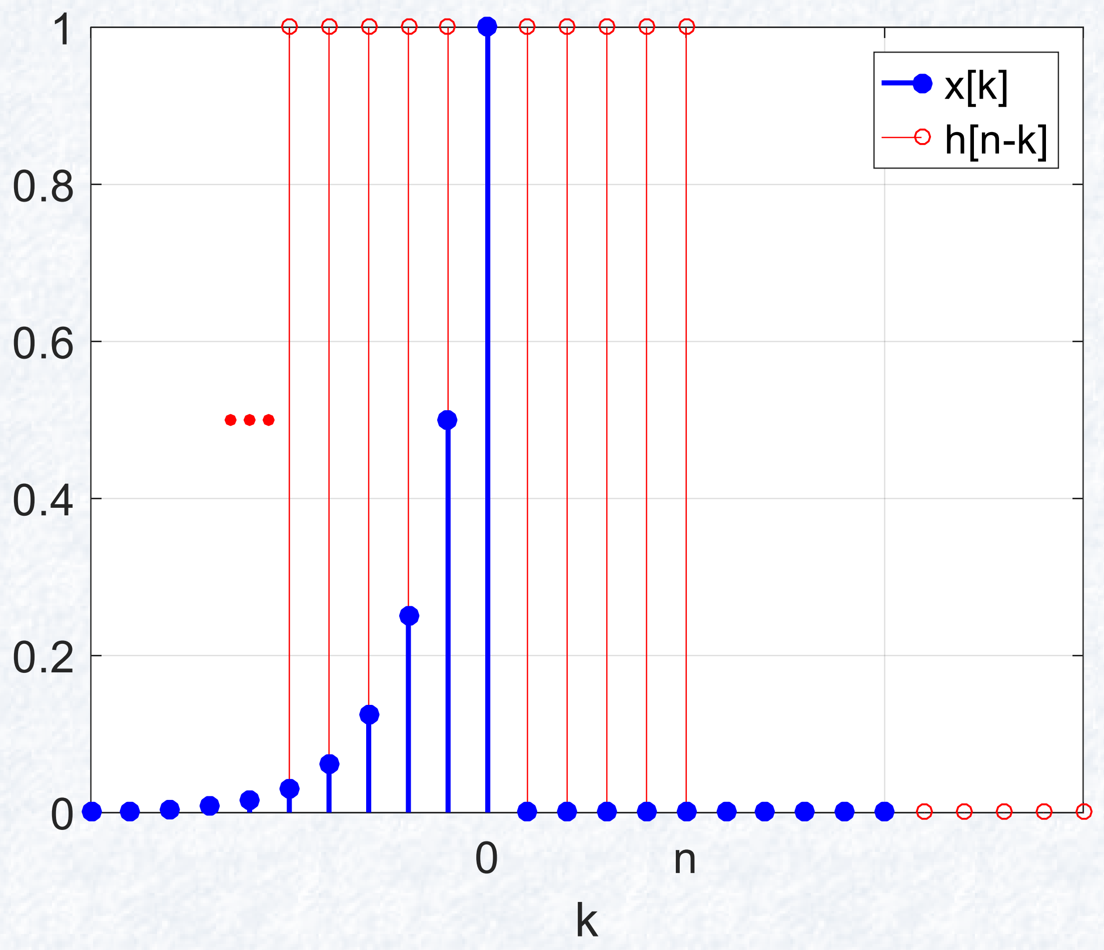

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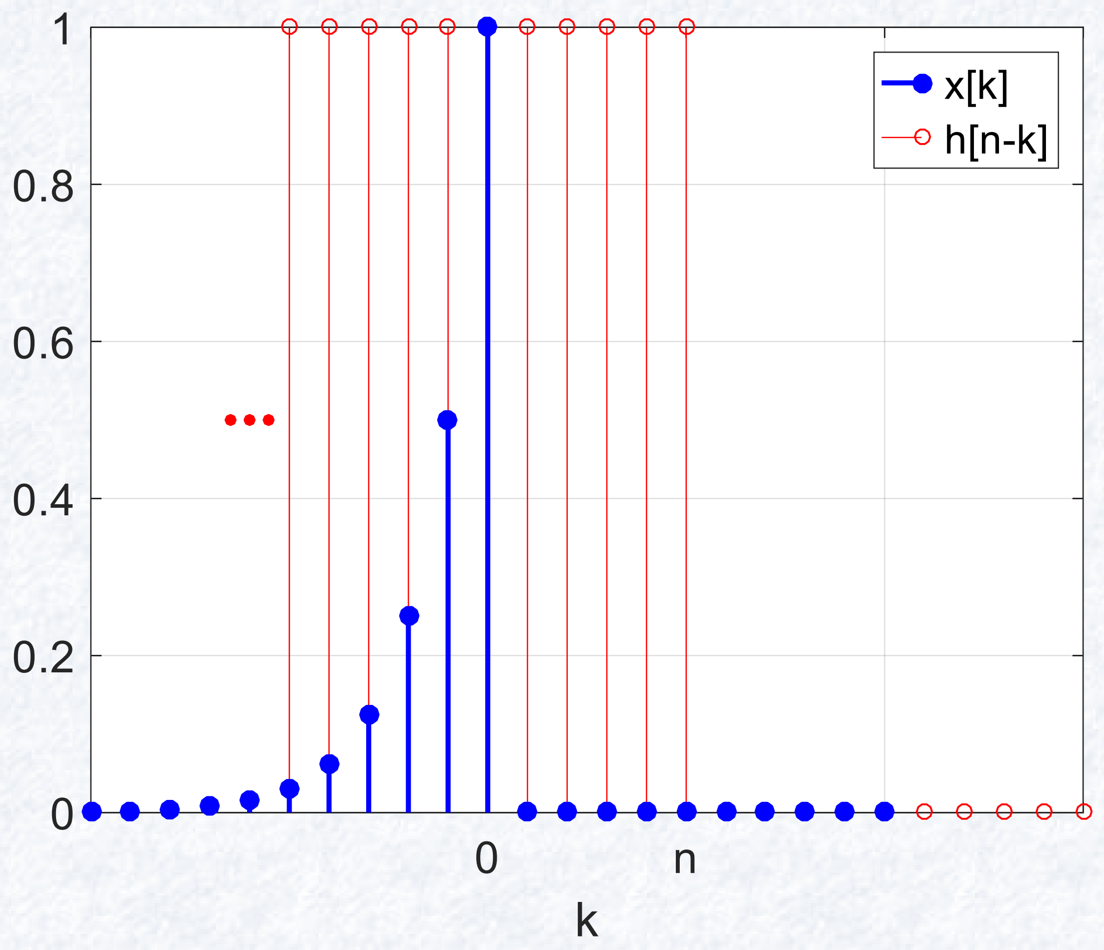

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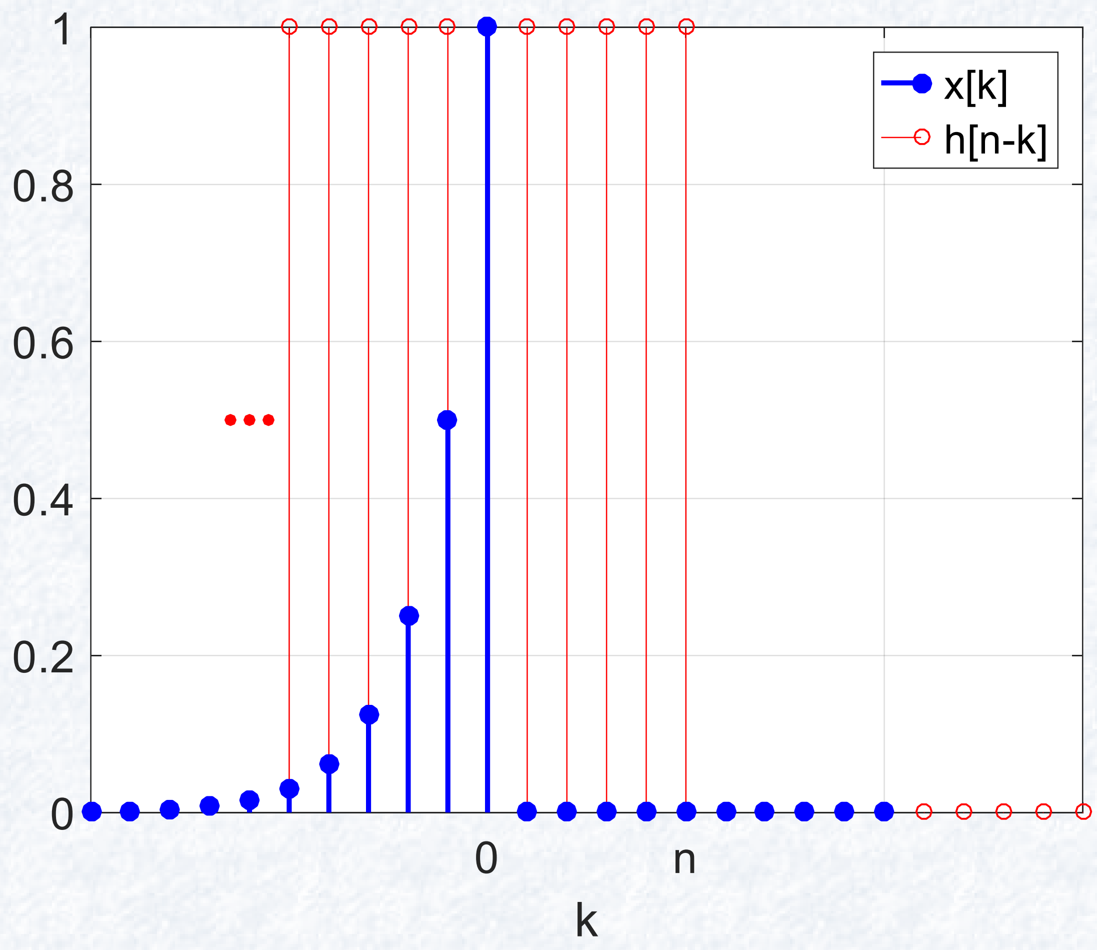

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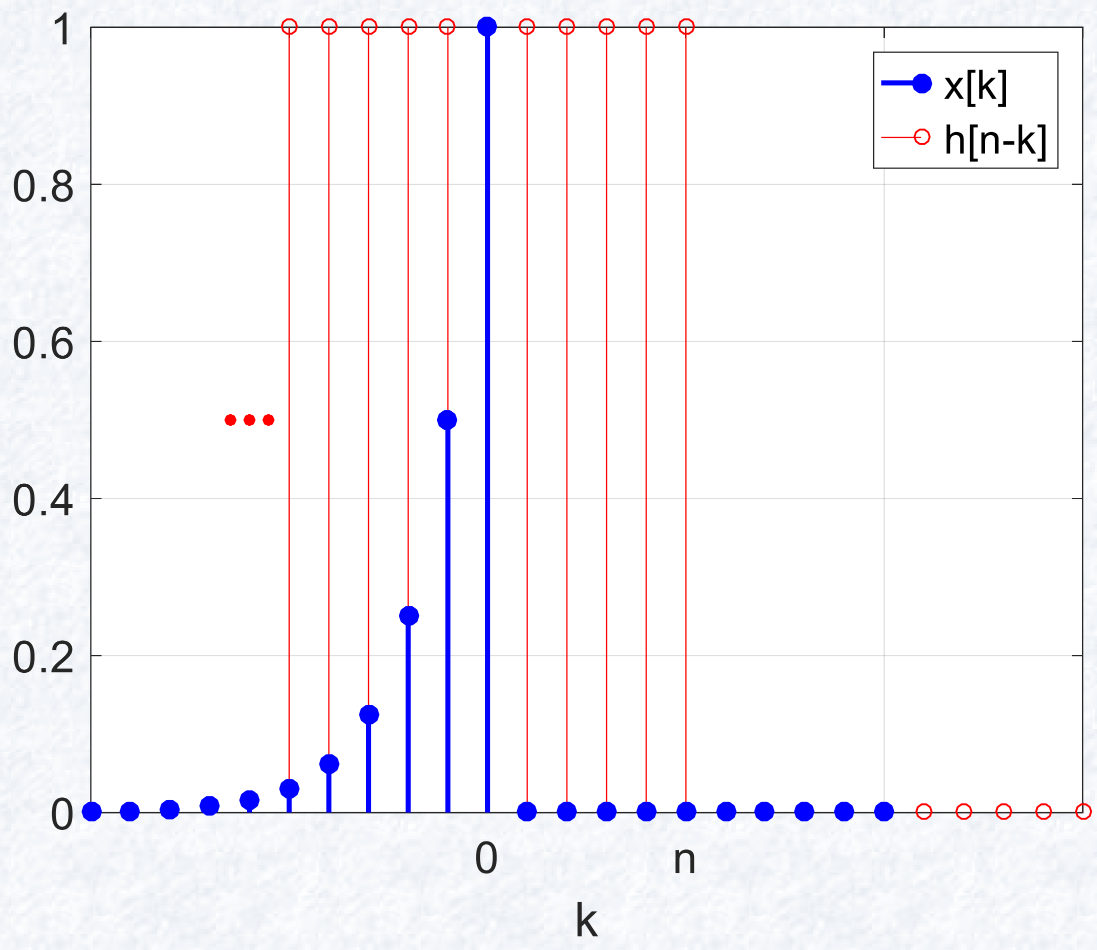

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  - $l = -k$
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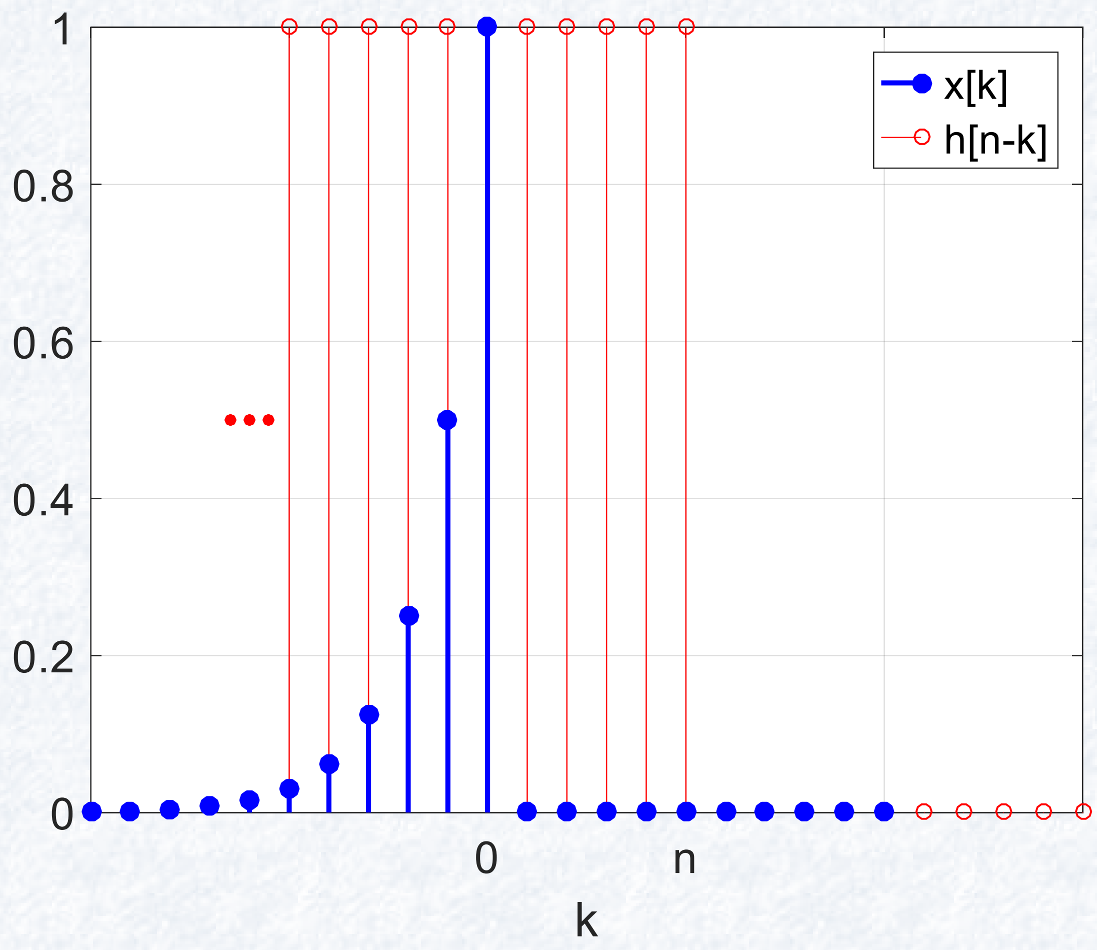
- $y[n] = \sum_{l=0}^{\infty} \left(\frac{1}{2}\right)^l = \frac{1}{1-\frac{1}{2}} = 2$



Örnek 3

- $x[n] = 2^n u[-n]$
- $h[n] = u[n]$

- $n < 0$ iken $y[n] = 2^n \frac{1}{1-\frac{1}{2}} = 2^{n+1}$
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- $y[n] =$

Örnek 3

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- $y[n] = 2^{n+1}u[-n-1] + 2u[n]$

Konvolüsyon Özellikleri

- Değişme Özelliği
  - $x[n] * h[n] = h[n] * x[n]$

Konvolüsyon Özellikleri

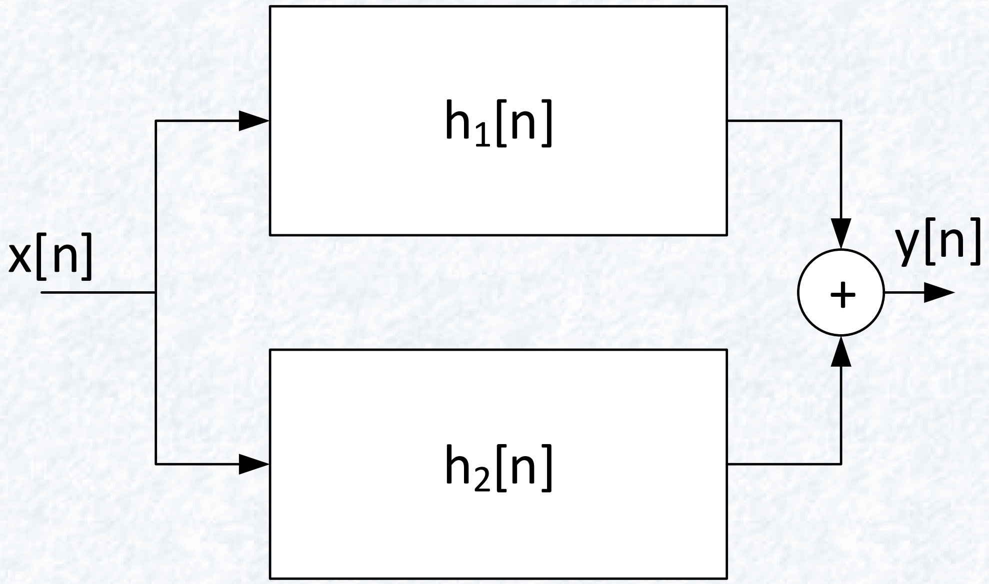
- Değişme Özelliği
  - $x[n] * h[n] = h[n] * x[n]$
- Dağılma Özelliği
  - $x[n] * (h_1[n] + h_2[n]) = x[n] * h_1[n] + x[n] * h_2[n]$

Konvolüsyon Özellikleri

- Değişme Özelliği
  - $x[n] * h[n] = h[n] * x[n]$
- Dağılma Özelliği
  - $x[n] * (h_1[n] + h_2[n]) = x[n] * h_1[n] + x[n] * h_2[n]$
- Birleşme Özelliği
  - $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$

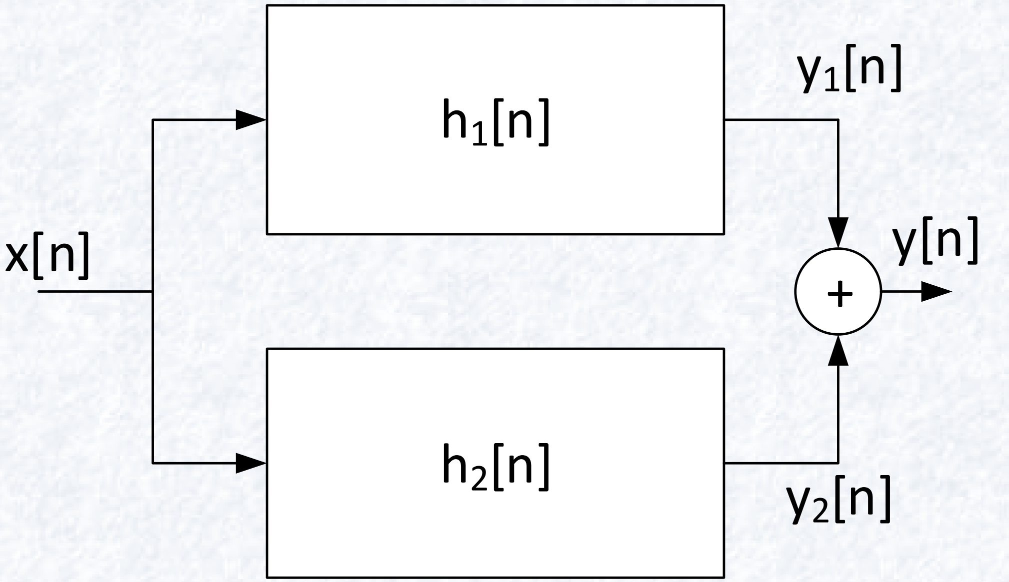
Konvolüsyon Özellikleri

- Dağılma Özelliği
- $y[n]=?$



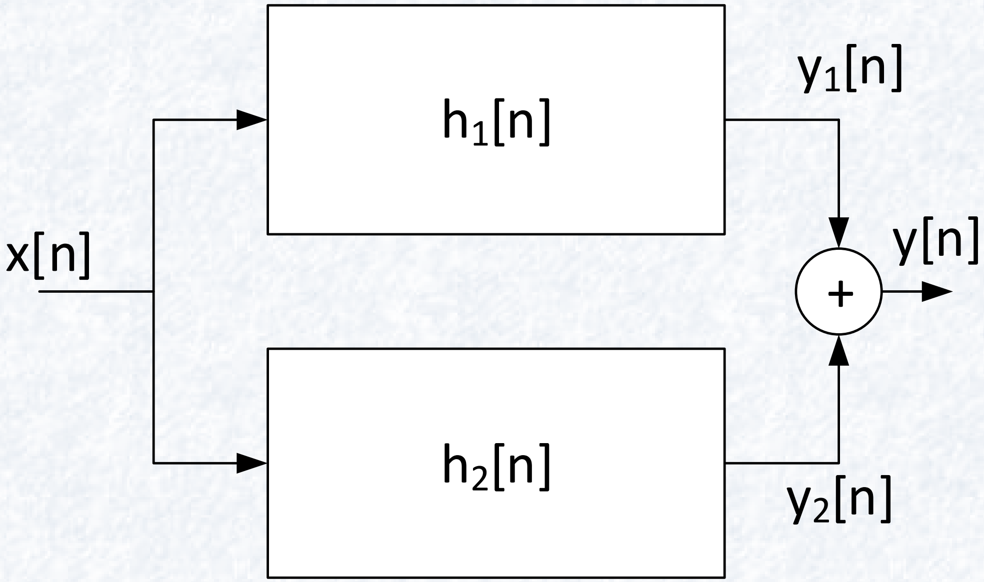
Konvolüsyon Özellikleri

- Dağılma Özelliği
- $y[n] =?$
- $y[n] = y_1[n] + y_2[n]$
- $y_1[n] =?$
- $y_2[n] =?$



Konvolüsyon Özellikleri

- Dağılma Özelliği
- $y[n] =?$
- $y[n] = y_1[n] + y_2[n]$
- $y_1[n] = x[n] * h_1[n]$
- $y_2[n] = x[n] * h_2[n]$



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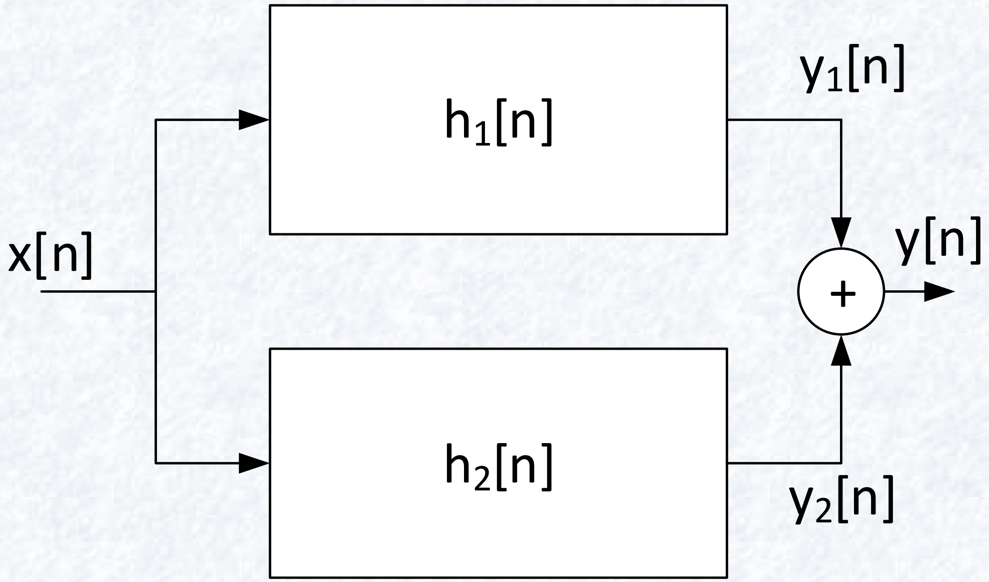

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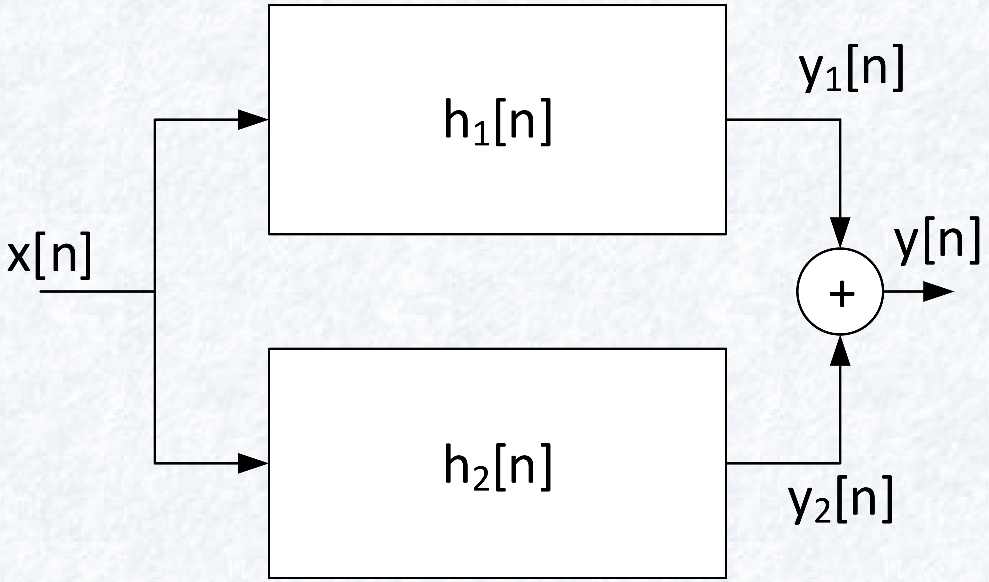

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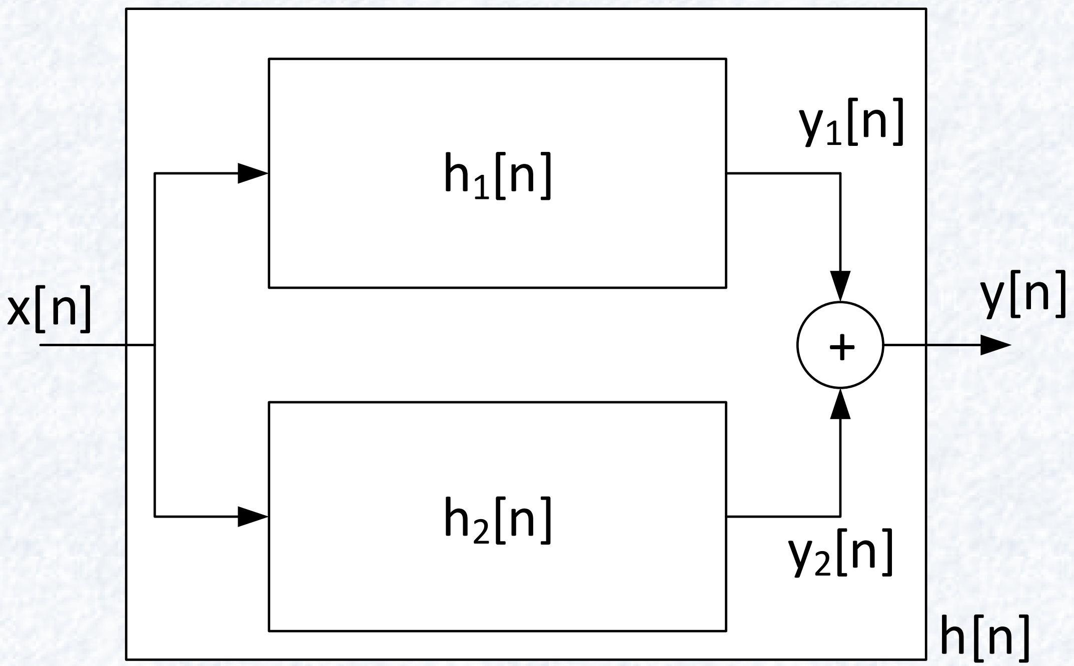
- $y[n] =$
- $h[n] = ?$



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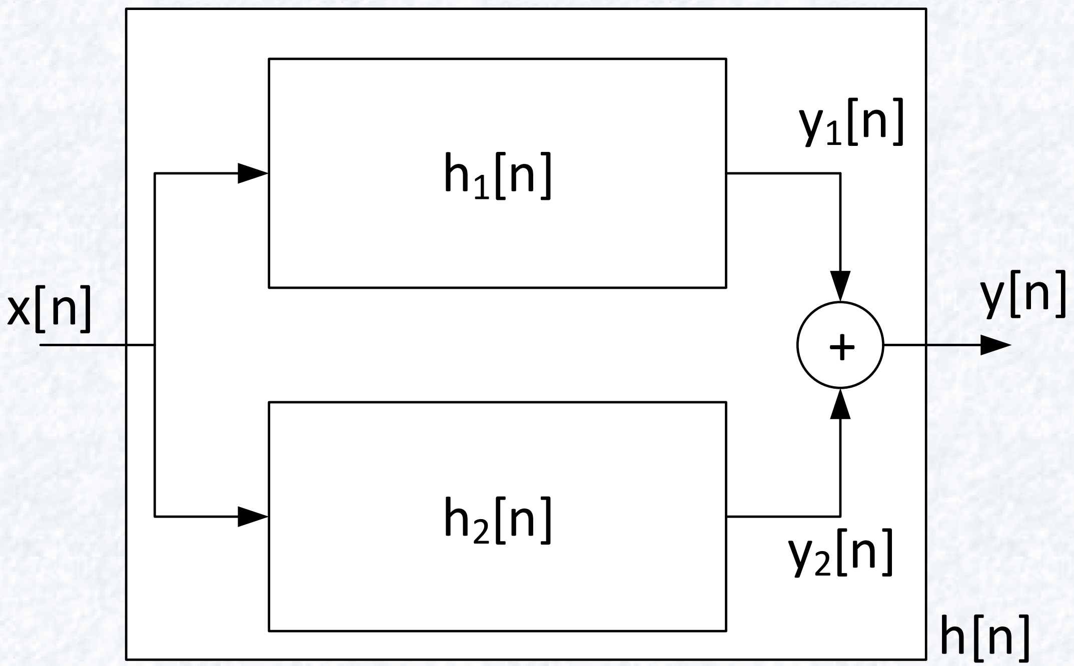
- $y_2[n] = x[n] * h_2[n]$
- $y[n] = x[n] * h_1[n] + x[n] * h_2[n]$
- $y[n] =$
- $y[n] = x[n] * h(n)$
- $h[n] =?$



Konvolüsyon Özellikleri

- Dağılma Özelliği
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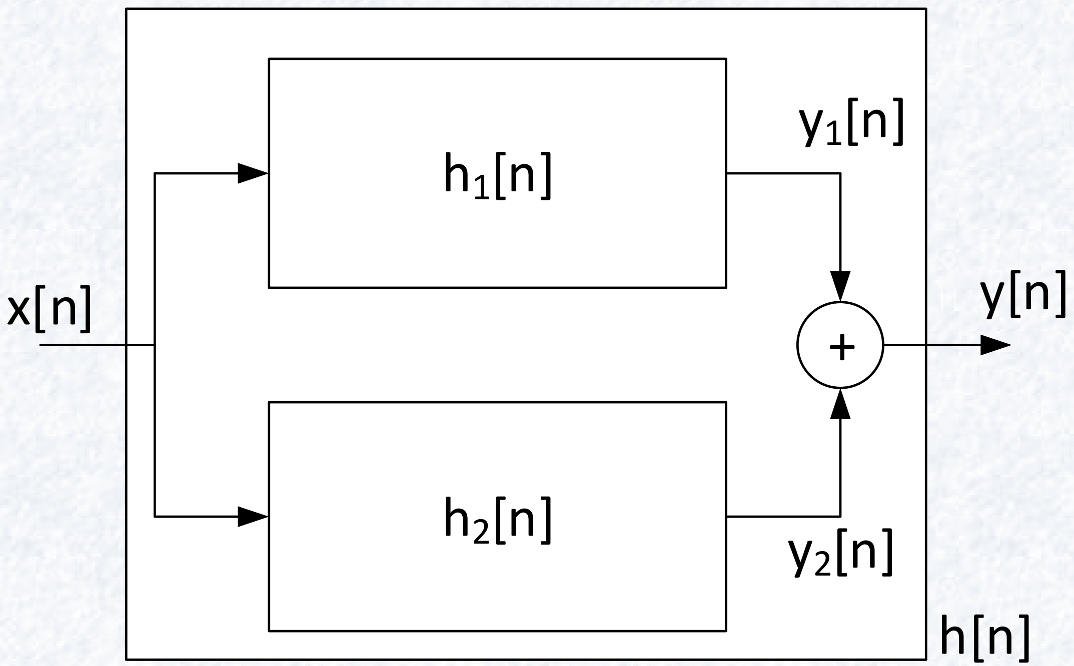

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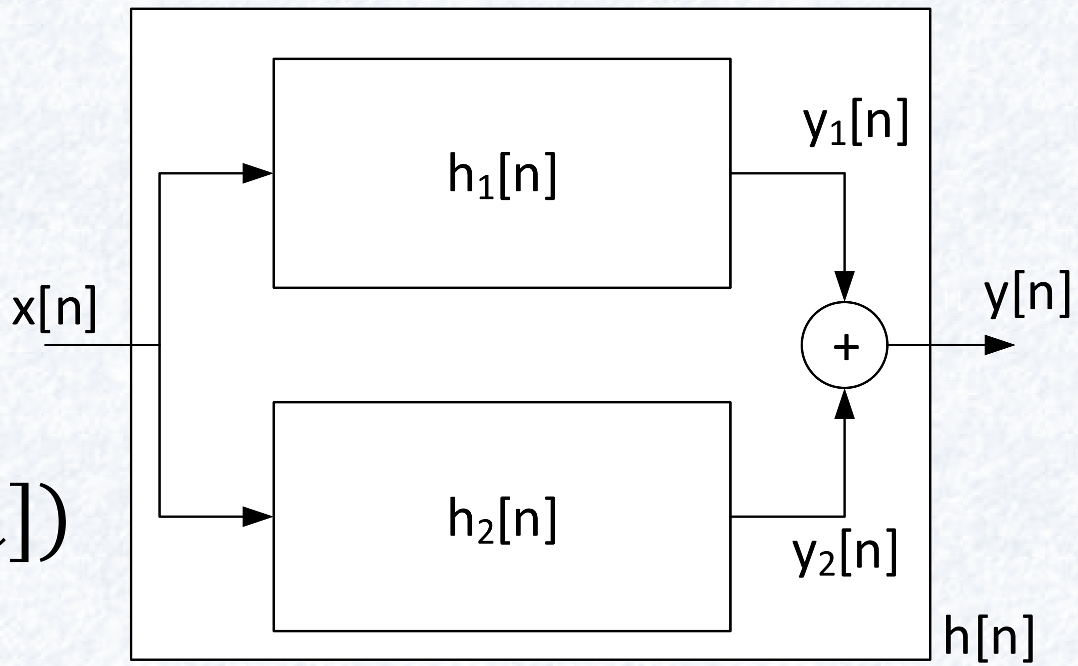

Konvolüsyon Özellikleri

- Dağılma Özelliği
- $y[n] = ?$
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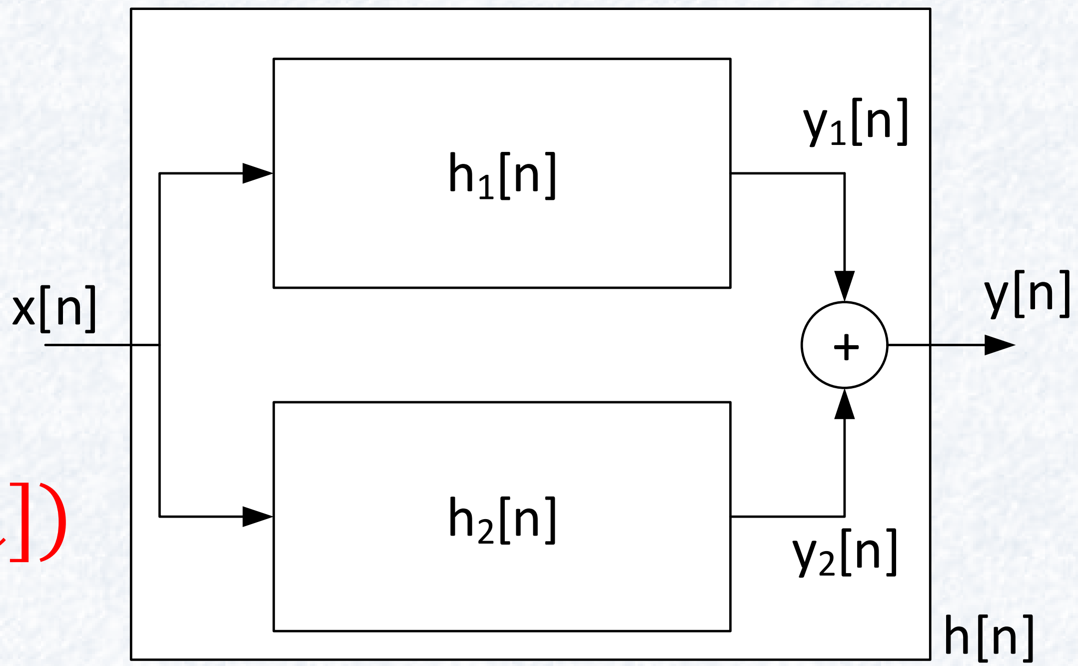
- $y[n] = x[n] * (h_1[n] + h_2[n])$
- $y[n] = x[n] * h(n)$
- $x[n] * \color{red}{h[n]} = x[n] * \color{red}{(h_1[n] + h_2[n])}$
- $h[n] = ?$



Konvolüsyon Özellikleri

- Dağılma Özelliği
- $y[n] = ?$
- $y[n] = x[n] * h_1[n] + x[n] * h_2[n]$
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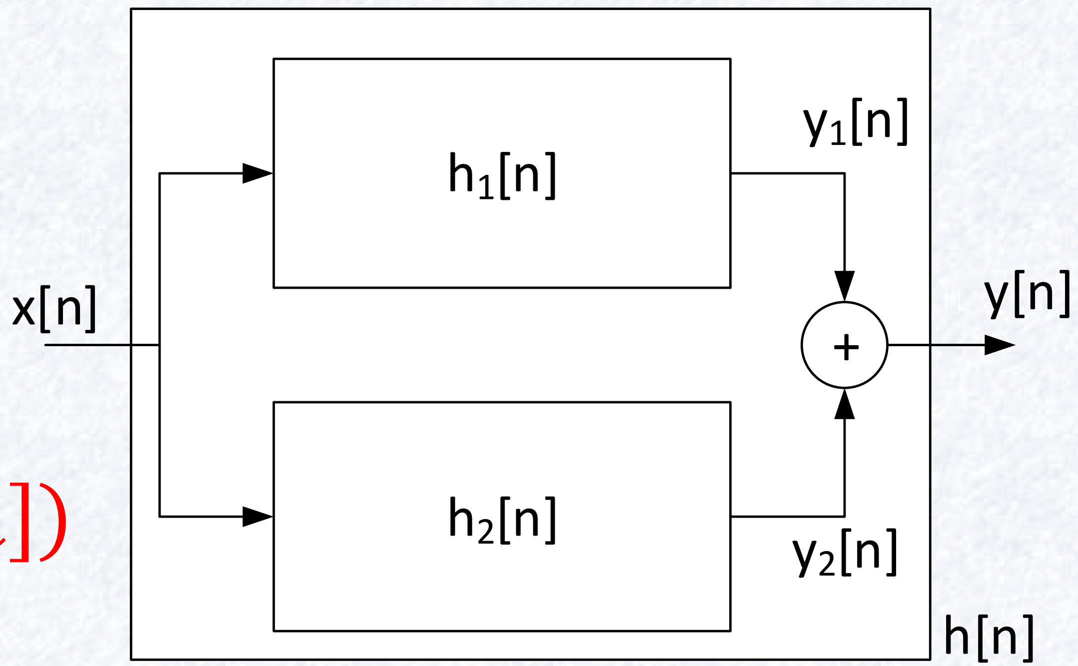
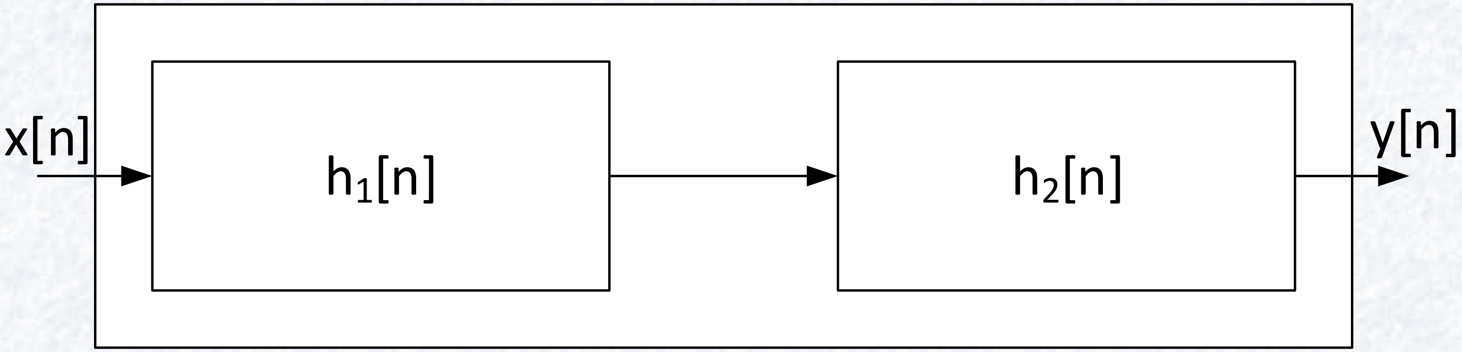
- $y[n] = x[n] * h(n)$
- $x[n] * \color{red}{h[n]} = x[n] * \color{red}{(h_1[n] + h_2[n])}$
- $h[n] = (h_1[n] + h_2[n])$



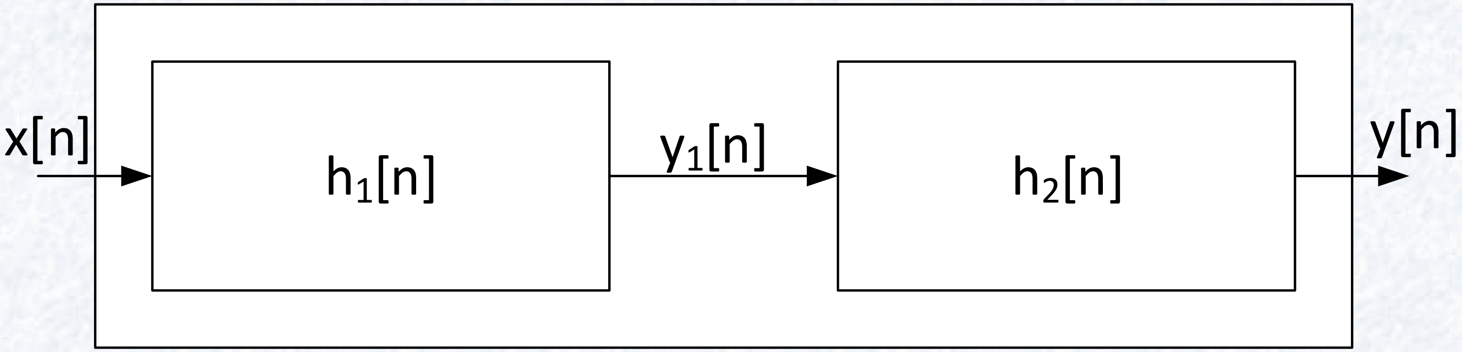
Konvolüsyon Özellikleri

- Birleşme Özelliği
  - ♦ $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$
- $y[n] = ?$



Konvolüsyon Özellikleri

- Birleşme Özelliği
  - $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$
- $y[n] = y_1[n] * h_2[n]$
- $y_1[n] = ?$



Konvolüsyon Özellikleri

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  - $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$
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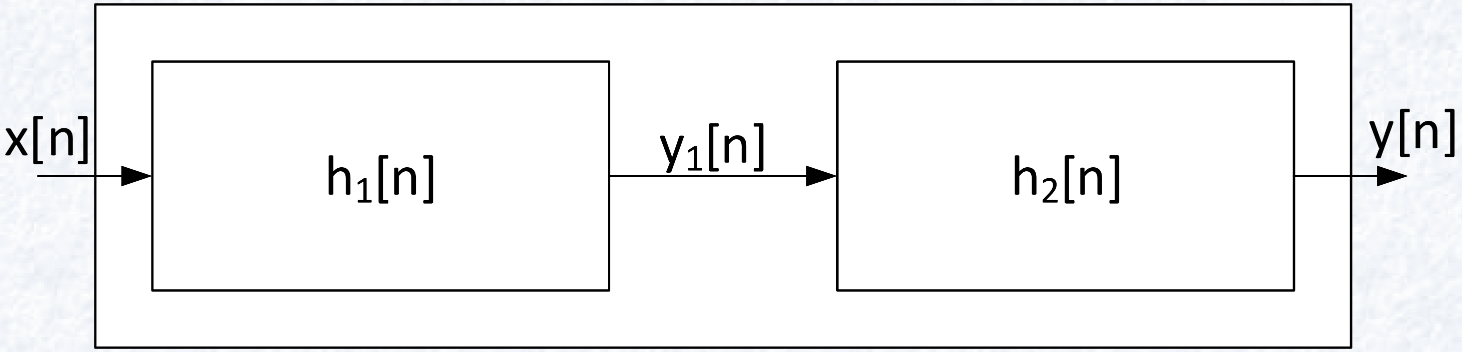
- $y_1[n] = x[n] * h_1[n]$
- $y[n] = ?$



Konvolüsyon Özellikleri

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  - $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$
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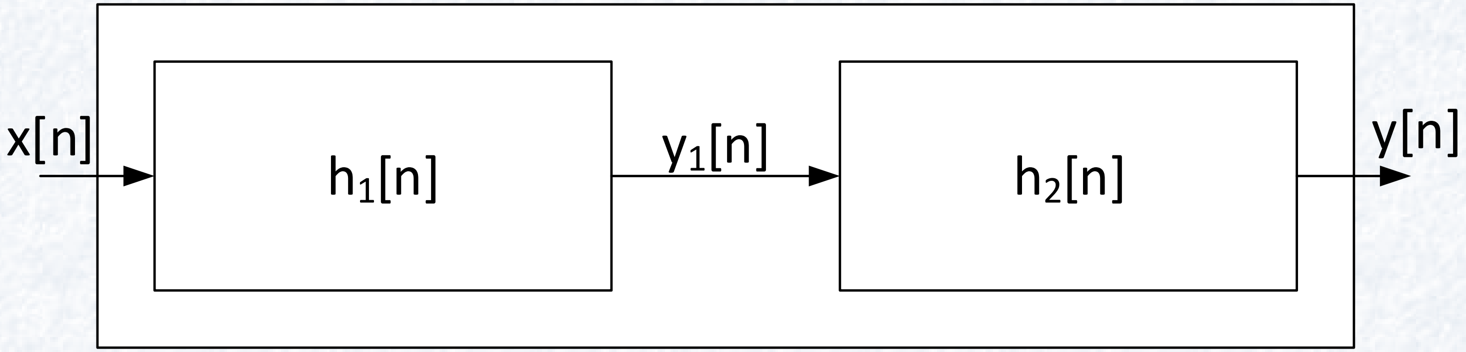
- $y[n] = x[n] * h_1[n] * h_2[n]$
- $y[n] =$
- $h[n] =?$



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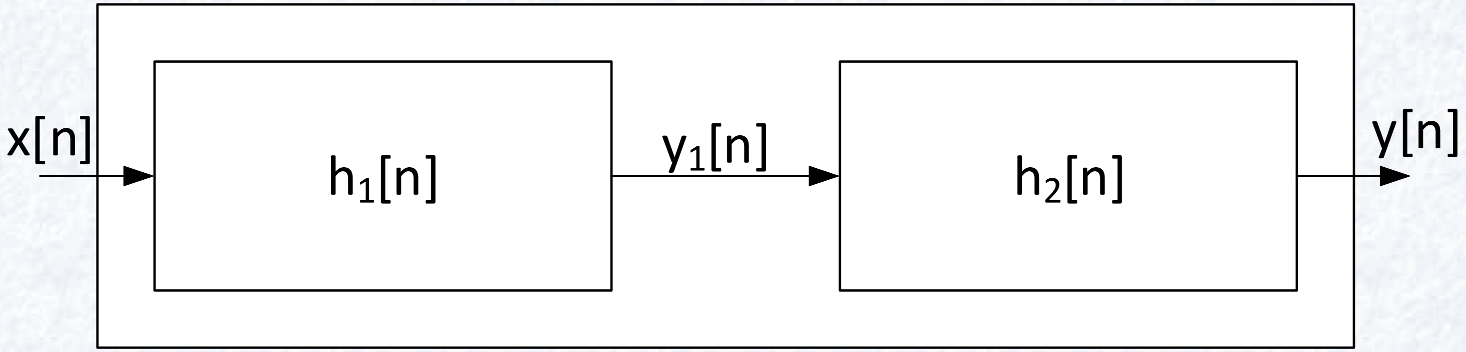

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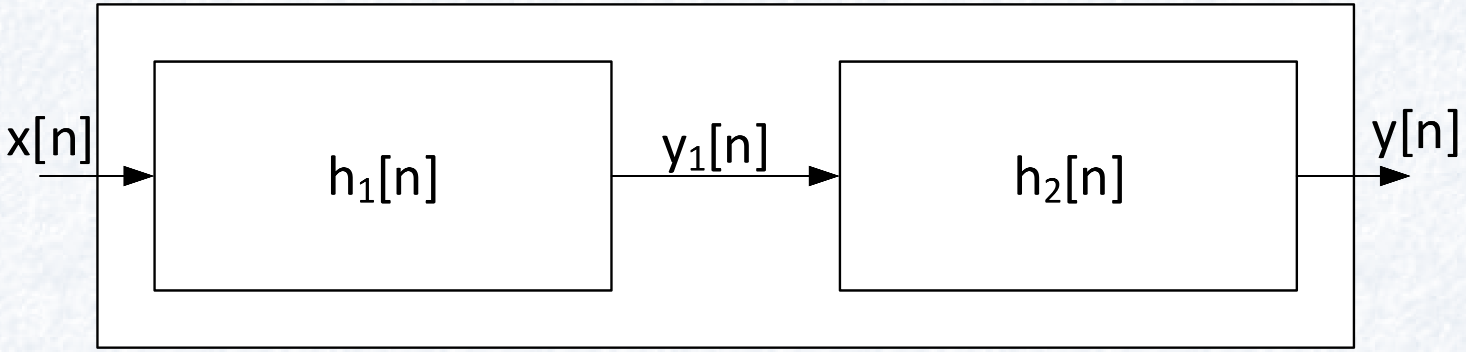

Konvolüsyon Özellikleri

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  - ♦ $x[n] * (h_1[n] * h_2[n]) = (x[n] * h_1[n]) * h_2[n]$
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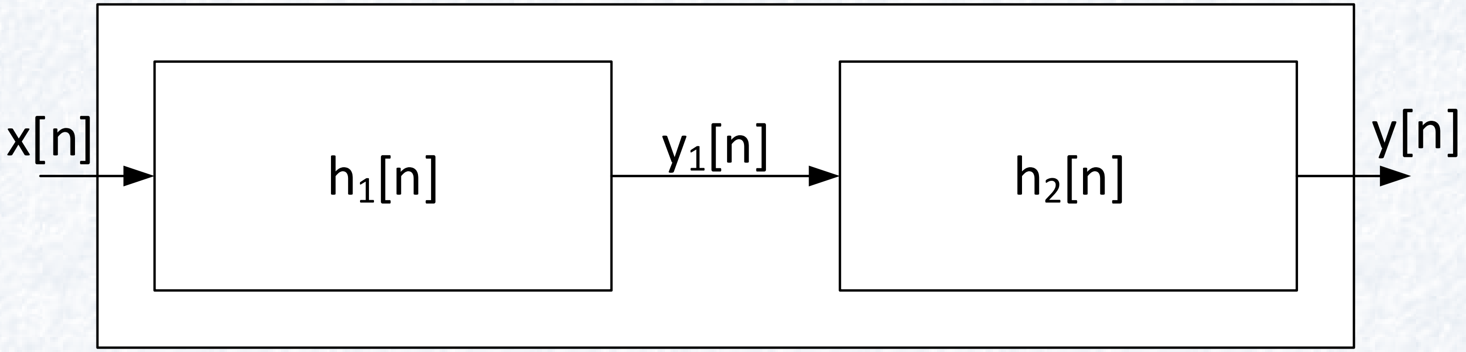

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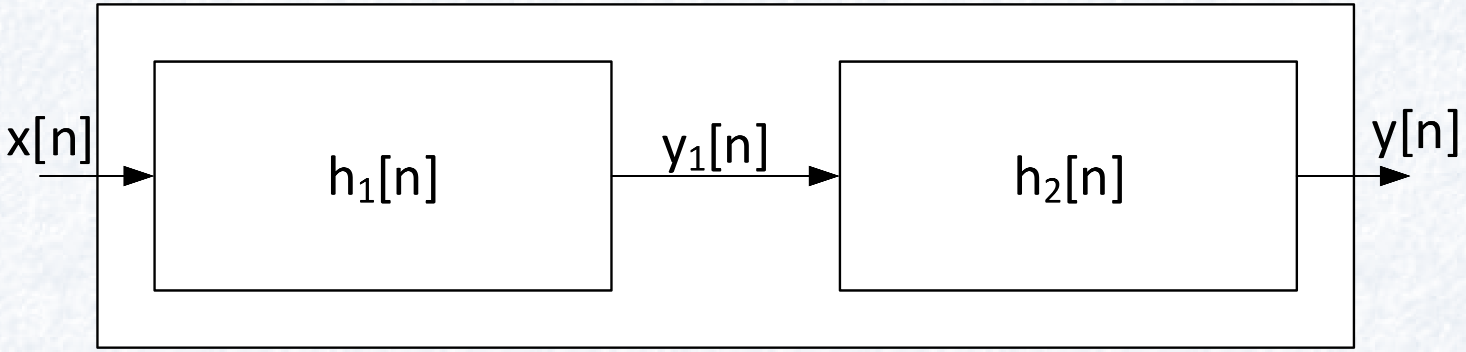
- $x[n] * h[n] = x[n] * h_1[n] * h_2[n]$
- $h[n] = h_1[n] * h_2[n]$



Sistem Özellikleri

- Hafızalılık
- Hafızasız
  - ♦ Sistem çıkışının, giriş işaretinin zamanın sadece o andaki bilgisine bağlı olması
- Hafızalı
  - ♦ Sistem çıkışının, giriş işaretinin ötelenmiş hallerine bağlı olması
- $\mathrm{y}[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k] = \sum_{k=-\infty}^{\infty} h[k]x[n-k]$
- $\mathrm{y}[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$

Sistem Özellikleri

- Hafızalılık
- Hafızasız
  - Sistem çıkışının, giriş işaretinin zamanın sadece o andaki bilgisine bağlı olması
- $y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k] = \sum_{k=-\infty}^{\infty} h[k]x[n-k]$
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Hafızasız: $y[n]$, sadece $x[n]$' ye bağlı olması

Sistem Özellikleri

- Hafızalılık
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Hafızasız: $y[n]$, sadece $x[n]$' ye bağlı olması
- $y[n] = \underbrace{\cdots + h[-1]x[n+1]}_{0} + h[0]x[n] + \underbrace{h[1]x[n-1] + \cdots}_{0}$
- $\forall\, n \neq 0$ iken $h[n] = 0$ olursa Hafızasız.

Sistem Özellikleri

- Hafızalılık
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
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Sistem Özellikleri

- Hafızalılık
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
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- $\forall\, n \neq 0$ iken $h[n] = 0$ olursa Hafızasız.
  - $h[n] = A\delta[n]$

Sistem Özellikleri

- Hafızalılık
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Hafızasız: $y[n]$, sadece $x[n]$' ye bağlı olması
- $\forall\, n \neq 0$ iken $h[n] = 0$ olursa Hafızasız.
  - $h[n] = A\delta[n]$
- $\exists\, n \neq 0$ iken $h[n] \neq 0$ olursa Hafızalı.
  - $h[n] \neq A\delta[n]$

Örnek 4

- $h[n] = a^n u[n]$, Hafızalı mıdır?

Örnek 4

- $h[n] = a^n u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] =?$

Örnek 4

- $h[n] = a^n u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$

Örnek 4

- $h[n] = a^n u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$
  - $n = 1$ iken $h[n] = a$
  - $n = 2$ iken $h[n] = a^2$
  - $\vdots$

Örnek 4

- $h[n] = a^n u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$
  - ♦ $n = 1$ iken $h[n] = a$
  - ♦ $n = 2$ iken $h[n] = a^2$
  - ♦ $\vdots$
- Hafızalı

Örnek 5

- $h[n] = \delta[n - n_0]$, Hafızalı mıdır?

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- $h[n] = \delta[n - n_0]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n]$
- $h[n] = \delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$

Örnek 5

- $h[n] = \delta[n - n_0]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n]$
- $h[n] = \delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$
  - ♦ $n_0 = 0$ ise

Örnek 5

- $h[n] = \delta[n - n_0]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n]$
- $h[n] = \delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$
    - ♦ $n_0 = 0$ ise Hafızasız
    - ♦ $n_0 \neq 0$ ise

Örnek 5

- $h[n] = \delta[n - n_0]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n]$
- $h[n] = \delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$
  - ♦ $n_0 = 0$ ise Hafızasız
  - ♦ $n_0 \neq 0$ ise Hafızalı

Örnek 6

- $h[n] = u[n]$, Hafızalı mıdır?

Örnek 6

- $h[n] = u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] =?$

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- $h[n] = u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$

Örnek 6

- $h[n] = u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$
  - $n = 1$ iken $h[n] = 1$
  - $n = 2$ iken $h[n] = 1$
  - $\vdots$

Örnek 6

- $h[n] = u[n]$, Hafızalı mıdır?
- $n \neq 0$ iken $h[n] \neq 0$
  - $n = 1$ iken $h[n] = 1$
  - $n = 2$ iken $h[n] = 1$
  - $\vdots$
- Hafızalı

Sistem Özellikleri

- Nedensellik
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Nedensel: $y[n]$, sadece

Sistem Özellikleri

- Nedensellik
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Nedensel: $y[n]$, sadece $x[n]$ ve/veya $x[n-k]$ 'ya bağlı olması
- $y[n] = \underbrace{\cdots + h[-1]x[n+1]}_{0} + h[0]x[n] + h[1]x[n-1] + \cdots$
- $\forall n < 0$ iken $h[n] = 0$ ise Nedensel.

Sistem Özellikleri

- Nedensellik
- $y[n] = \cdots + h[-1]x[n+1] + h[0]x[n] + h[1]x[n-1] + \cdots$
  - Nedensel: $y[n]$, sadece $x[n]$ ve/veya $x[n-k]$ ‘ya bağlı olması
- $y[n] = \underbrace{\cdots + h[-1]x[n+1]}_{0} + h[0]x[n] + h[1]x[n-1] + \cdots$
- $\forall n < 0$ iken $h[n] = 0$ ise Nedensel.
- $\exists n < 0$ iken $h[n] \neq 0$ ise Nedensel değil.

Örnek 7

- $h[n] = a^n u[n]$, Nedensel midir?
  - ♦ Hafızalı

Örnek 7

- $h[n] = a^n u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] =?$

Örnek 7

- $h[n] = a^n u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] = 0$

Örnek 7

- $h[n] = a^n u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] = 0$
  - $n < 0$ iken $u[n] = 0$

Örnek 7

- $h[n] = a^n u[n]$, Nedensel midir?
    - Hafızalı
- $n < 0$ iken $h[n] = 0$
    - $n < 0$ iken $u[n] = 0$
- Nedensel

Örnek 8

- $h[n] = \delta[n - n_0]$, Nedensel midir?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız

Örnek 8

- $h[n] = \delta[n - n_0]$, Nedensel midir?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
- $n < 0$ iken $h[n] =?$

Örnek 8

- $h[n] = \delta[n - n_0]$, Nedensel midir?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
- $n < 0$ iken $h[n] =?$
- $\delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$

Örnek 8

- $h[n] = \delta[n - n_0]$, Nedensel midir?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
- $n < 0$ iken $h[n] =?$
- $\delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$
- $n = n_0 < 0$ iken $h[n] = 1$
  - Nedensel değil.

Örnek 8

- $h[n] = \delta[n - n_0]$, Nedensel midir?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
- $n < 0$ iken $h[n] =?$
- $\delta[n - n_0] = \begin{cases} 0, & n \neq n_0 \\ 1, & n = n_0 \end{cases}$
- $n = n_0 < 0$ iken $h[n] = 1$
  - Nedensel değil.
- $n = n_0 \geq 0$ iken $h[n] = 1$
- $n < 0$ iken $h[n] = 0$
  - Nedensel.

Örnek 9

- $h[n] = u[n]$, Nedensel midir?
  - ♦ Hafızalı

Örnek 9

- $h[n] = u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] =?$

Örnek 9

- $h[n] = u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] = 0$

Örnek 9

- $h[n] = u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] = 0$
  - $n < 0$ iken $u[n] = 0$

Örnek 9

- $h[n] = u[n]$, Nedensel midir?
  - Hafızalı
- $n < 0$ iken $h[n] = 0$
  - $n < 0$ iken $u[n] = 0$
- Nedensel

Sistem Özellikleri

- Kararlılık
- $\sum_{n=-\infty}^{\infty} |h[n]| < \infty$ ise Kararlı.

Sistem Özellikleri

- Kararlılık
- $\sum_{n=-\infty}^{\infty} |h[n]| < \infty$ ise Kararlı.
- $\sum_{n=-\infty}^{\infty} |h[n]| \to \infty$ ise Kararsız.

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=-\infty}^{\infty} a^n u[n] = ?$

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=0}^{\infty} a^n = \begin{cases} \infty, & a \geq 1 \\ & \end{cases}$

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - ♦ Hafızalı
  - ♦ Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=0}^{\infty} a^n = \begin{cases} \infty, & a \geq 1 \\ \frac{1}{1-a} & a < 1 \end{cases}$

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=0}^{\infty} a^n = \begin{cases} \infty, & a \geq 1 \\ \frac{1}{1-a} & a < 1 \end{cases}$
- $a \geq 1$ iken Kararsız

Örnek 10

- $h[n] = a^n u[n]$, Kararlı mıdır?
    - Hafızalı
    - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=0}^{\infty} a^n = \begin{cases} \infty, & a \geq 1 \\ \frac{1}{1-a} & a < 1 \end{cases}$
- $a \geq 1$ iken Kararsız
- $a < 1$ iken Kararlı

Örnek 11

- $h[n] = \delta[n - n_0]$, Kararlı mıdır?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
  - $n_0 \geq 0$ ise Nedensel, $n_0 < 0$ ise Nedensel değil

Örnek 11

- $h[n] = \delta[n - n_0]$, Kararlı mıdır?
  - ♦ $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
  - ♦ $n_0 \geq 0$ ise Nedensel, $n_0 < 0$ ise Nedensel değil
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$

Örnek 11

- $h[n] = \delta[n - n_0]$, Kararlı mıdır?
  - ♦ $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
  - ♦ $n_0 \geq 0$ ise Nedensel, $n_0 < 0$ ise Nedensel değil
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=-\infty}^{\infty} \delta[n - n_0] =$

Örnek 11

- $h[n] = \delta[n - n_0]$, Kararlı mıdır?
    - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
    - $n_0 \geq 0$ ise Nedensel, $n_0 < 0$ ise Nedensel değil
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=-\infty}^{\infty} \delta[n - n_0] = 1$

Örnek 11

- $h[n] = \delta[n - n_0]$, Kararlı mıdır?
  - $n_0 \neq 0$ ise Hafızalı, $n_0 = 0$ ise Hafızasız
  - $n_0 \geq 0$ ise Nedensel, $n_0 < 0$ ise Nedensel değil
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=-\infty}^{\infty} \delta[n - n_0] = 1 < \infty$
- Kararlı

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
  - ♦ Hafızalı
  - ♦ Nedensel

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=-\infty}^{\infty} u[n] =$

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=-\infty}^{\infty} u[n] = \sum_{n=0}^{\infty} 1$

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
  - Hafızalı
  - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| = ?$
- $\sum_{n=-\infty}^{\infty} u[n] = \sum_{n=0}^{\infty} 1 = \infty$

Örnek 12

- $h[n] = u[n]$, Kararlı mıdır?
    - Hafızalı
    - Nedensel
- $\sum_{n=-\infty}^{\infty} |h[n]| =?$
- $\sum_{n=-\infty}^{\infty} u[n] = \sum_{n=0}^{\infty} 1 = \infty$
- Kararsız