



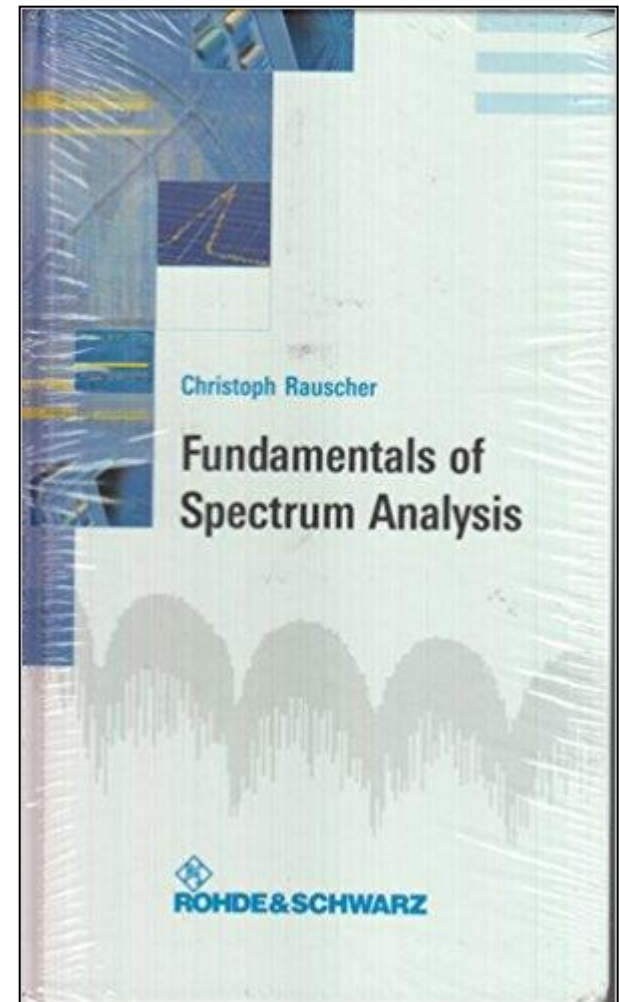
Telekomunikaciona merenja TM P04 2018

Profesor dr Miroslav Lutovac

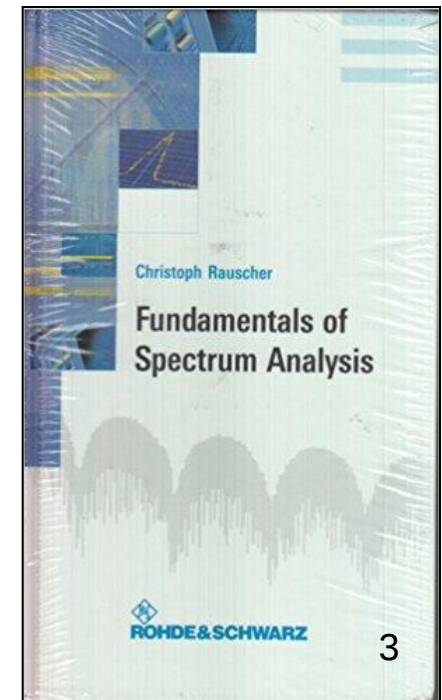
"This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein"

Osnove analize spektra

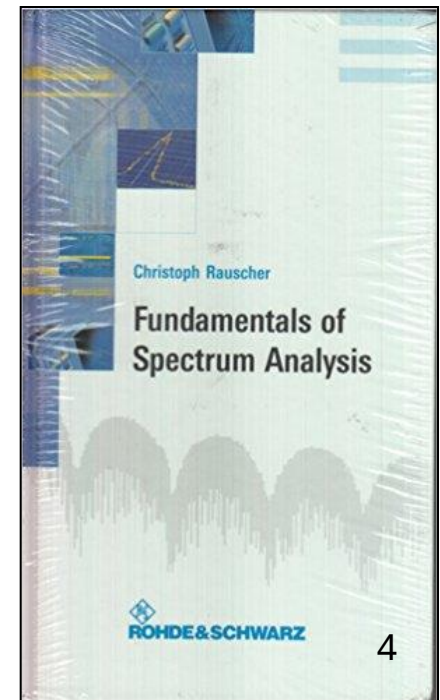
Rauscher C.,
Fundamentals of Spectrum
Analysis,
Rohde & Schwarz, 2006



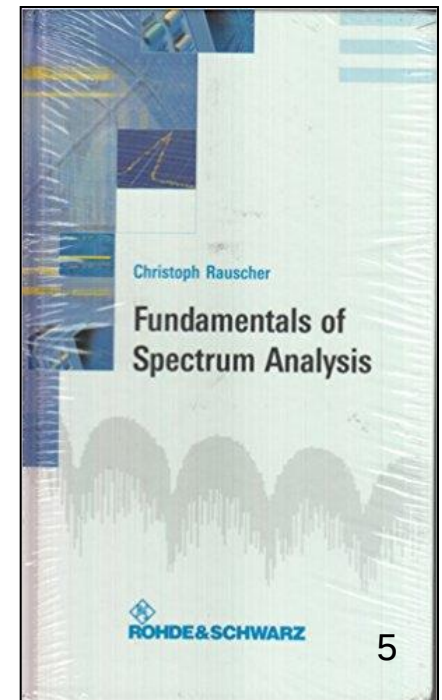
- Signals
 - Signals displayed in time domain
 - Relationship between time and frequency domain
- Configuration and control elements of a spectrum analyzer
 - Fourier analyzer (FFT analyzer)
 - Analyzers operating according to the heterodyne principle
 - Main setting parameters
- Practical realization of an analyzer operating on the heterodyne principle
 - RF input section
 - IF signal processing
 - Determination of video voltage and video filters
 - Detectors
 - Trace processing
 - Parameter dependencies
 - Sweep time, span, resolution and video bandwidths
 - Reference level and RF attenuation



- Performance features of spectrum analyzers
 - Inherent noise
 - Nonlinearities
 - Phase noise (spectral purity)
 - 1 dB compression point and maximum input level
 - Dynamic range
 - Immunity to interference
 - LO feed-through
 - Filter characteristics
 - Frequency accuracy
 - Level measurement accuracy
 - Error components
 - Calculation of total measurement uncertainty
 - Error due to low signal-to-noise ratio
 - Sweep time and update rate

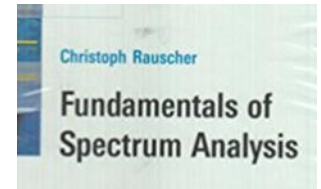


- Frequent measurements and enhanced functionality
 - Phase noise measurements
 - Measurement procedure
 - Selection of resolution bandwidth
 - Dynamic range
 - Measurements on pulsed signals
 - Fundamentals
 - Line and envelope spectrum
 - Resolution filters for pulse measurements
 - Analyzer parameters
 - Pulse weighting in spurious signal measurements
 - Channel and adjacent-channel power measurement
 - Introduction
 - Key parameters for adjacent-channel
 - Dynamic range in adjacent-channel
 - Methods for adjacent-channel power measurement using a spectrum analyzer



Analizator spektra i telekomunikacije

- Najčešća vrsta merenja
- Radio telekomunikacije, RF merni instrumenti
- Analiza signala u frekvencijskom domenu
- Pokriva se frekvencijski opseg od 0 do 40 GHz i preko
- Kablovske, bežične i mobilne komunikacije
- Razvoj, proizvodnja, instalacija i održavanje sistema
- Funkcionalnost i brzina merenja
- Usrednjen nivo šuma, dinamički opseg
- Merenje izlazne snage predajnika vremenskog multipleksa



✓ 0-40 GHz

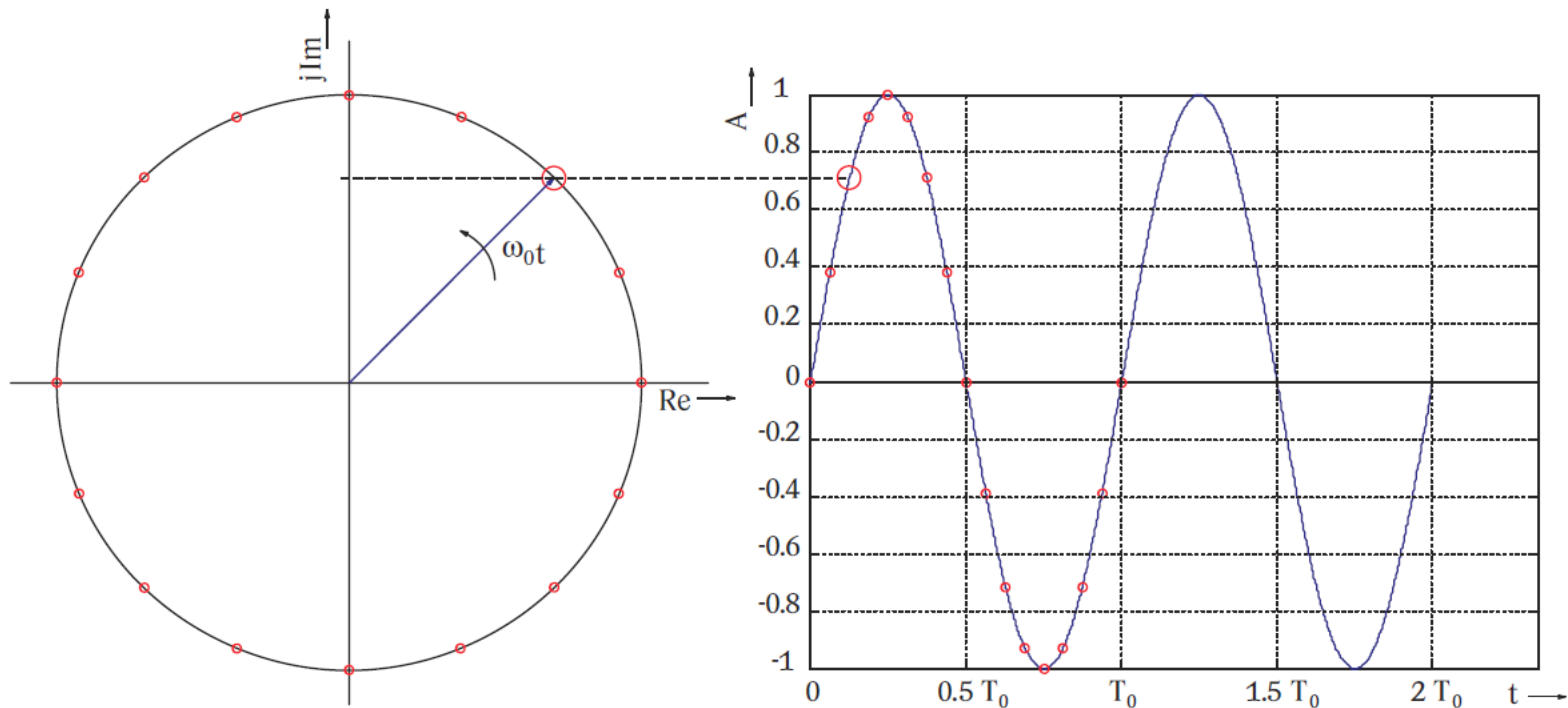
Analizatori spektra za merenja u vremenskom domenu

Analizator spektra i telekomunikacije

- Da se razumeju složeni merni instrumenti
- Poželjno, ali ne i neophodno poznavanje osnova teorije analize spektra
- Za one koji imaju znanja analize spektra biće ponovljeni osnovi teorije da bi se izbegle merne greške u praksi
- Tipične primene
 - Fazni šum
 - Merenje snage kanala

Signali u vremenskom domenu

- Vremenski domen, amplituda u funkciji vremena, osciloskop
- Fazori, vektorski prikaz



Prostoperiodični signali

- Sinusoidalne funkcije vremena
- ustaljeno, stacionarno ili ravnotežno stanje koje nastaje posle smirivanja prelaznih procesa

$$x(t) = X_m \sin(\omega t) = X_m \sin \omega t$$

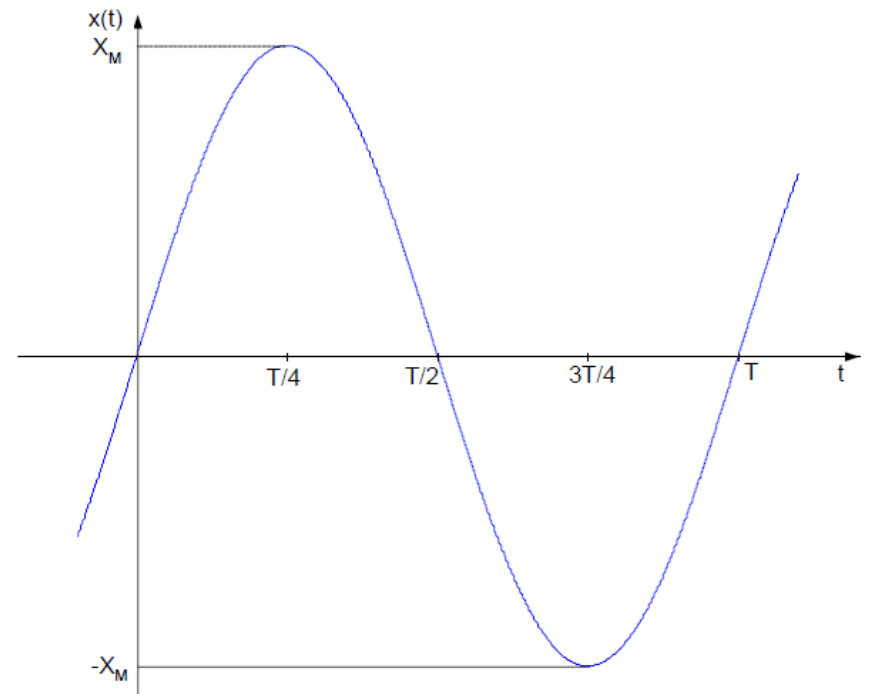
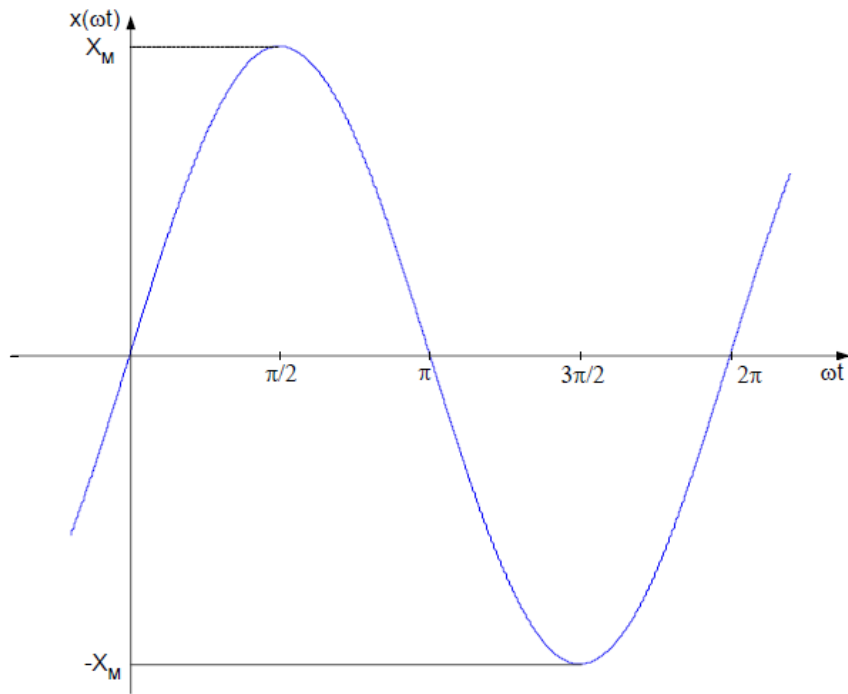
X_m je amplituda (maksimalna vrednost) napona ili struje
 ω se naziva kružna ili ugaona učestanost
 ωt je argument

$$x(t) = A \cdot \sin(2 \cdot \pi \cdot f_0 \cdot t)$$

$$x(t) = A \cdot \operatorname{Im} \left\{ e^{j \cdot 2\pi \cdot f_0 \cdot t} \right\}$$

$$\omega_0 = 2 \cdot \pi \cdot f_0$$

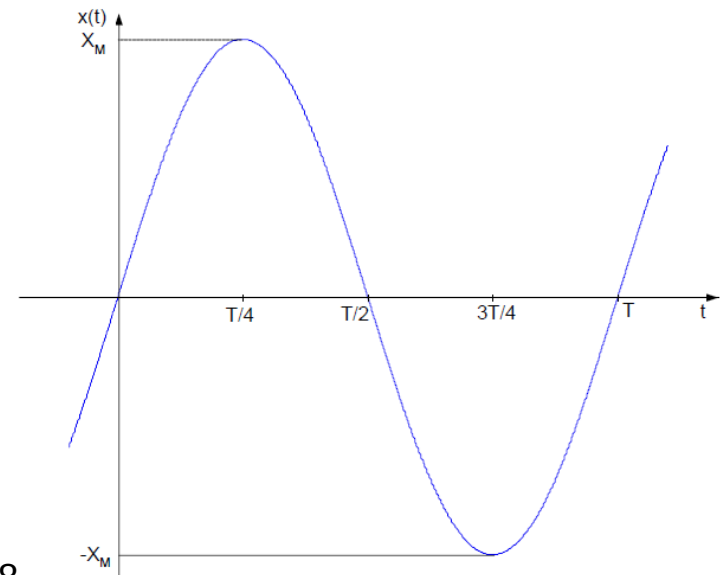
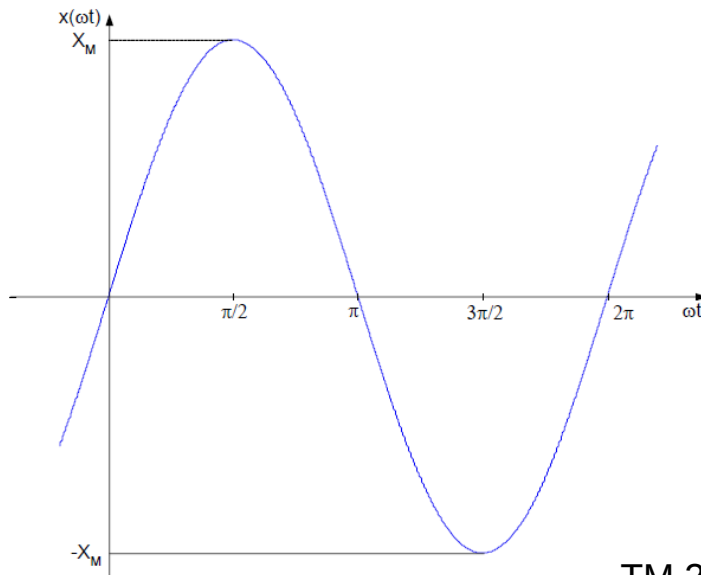
Sinusna funkcija u funkciji argumenta ωt i vremena t



Sinusna funkcija u funkciji argumenta ωt i vremena t

- periodična sa periodom od 2π radijana
- Period funkcije T
- učestanost sinusoide f
- $\omega = 2\pi f$

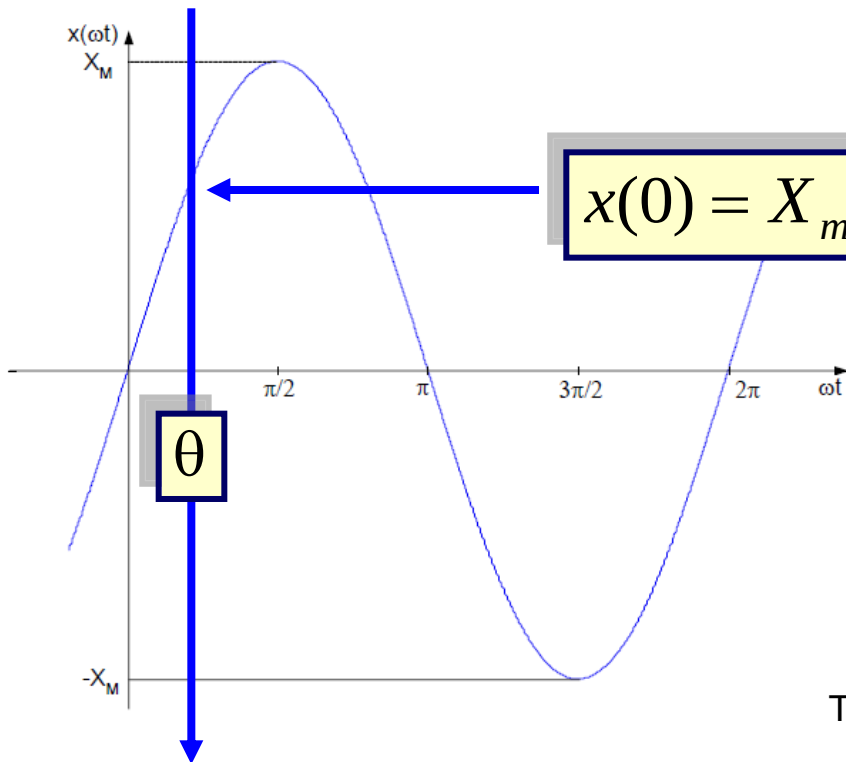
$$f = \frac{1}{T}$$



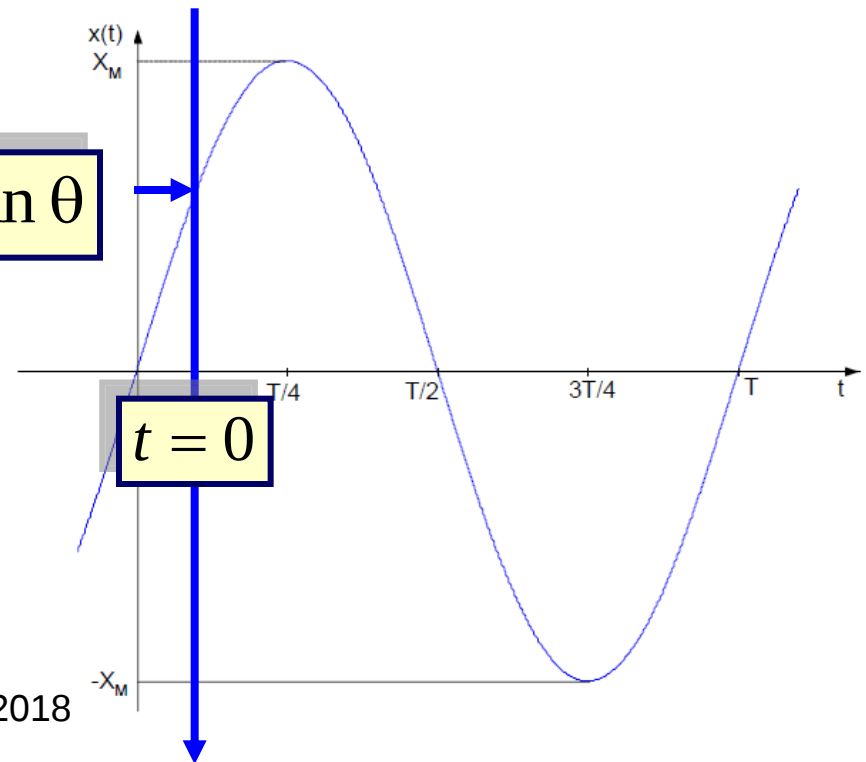
Opšti oblik sinusoidalne funkcije

- gde je θ *fazni ugao* ili *početna faza*

$$x(t) = X_m \sin(\omega t + \theta)$$



$$x(0) = X_m \sin \theta$$

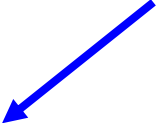


Ojlerova predstava kompleksnog broja

- realni deo je kosinusna funkcija
- imaginarni deo je sinusna funkcija

$$e^{j\omega t} = \cos \omega t + j \sin \omega t$$

$$v(t) = V_M e^{j\omega t} = V_M (\cos \omega t + j \sin \omega t)$$

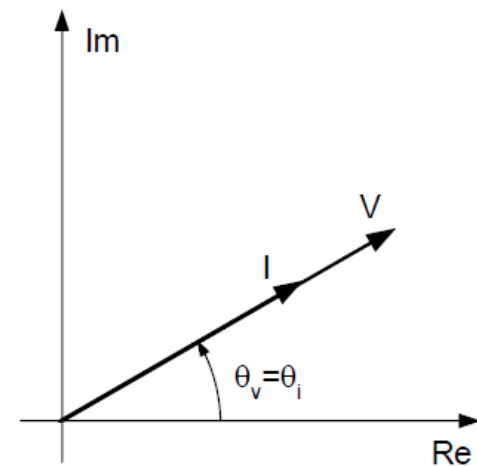
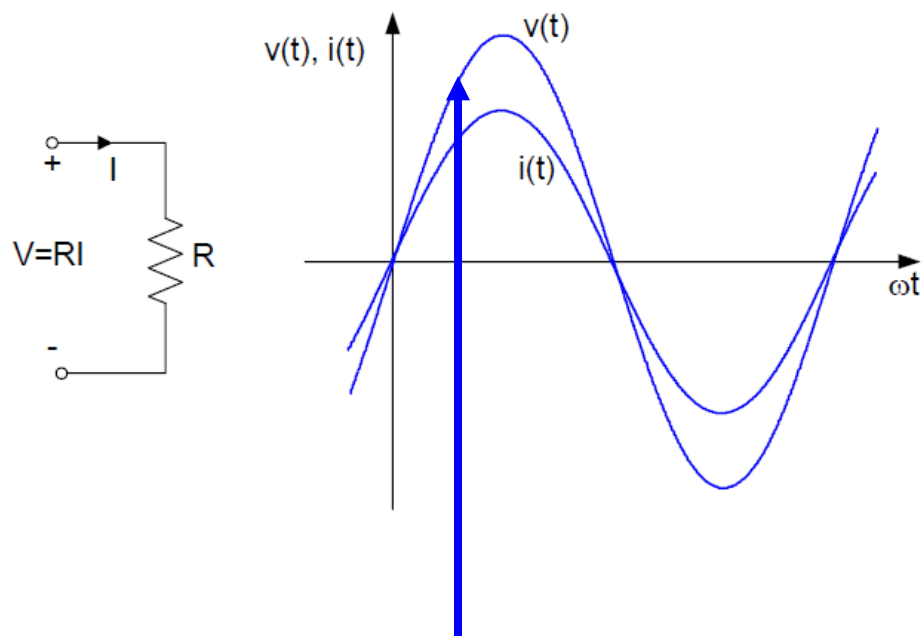
$$i(t) = I_M [\cos(\omega t + \phi) + j \sin(\omega t + \phi)] = I_M e^{j(\omega t + \phi)}$$


Fazor $X_M e^{j\phi}$

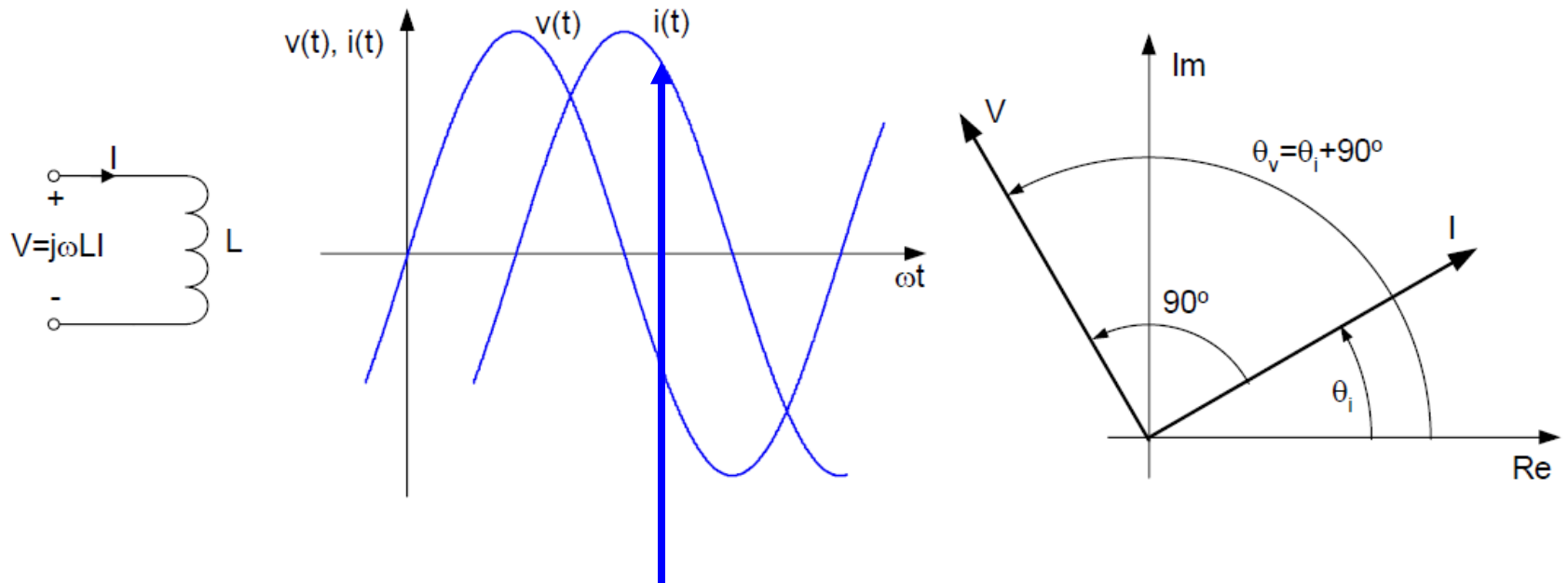
Kompleksna predstava struje ili napona naziva se fazor

$$x(t) = X_M \cos(\omega t + \phi) = \operatorname{Re} \left[X_M e^{j(\omega t + \phi)} \right] = \operatorname{Re} \left[(X_M e^{j\phi}) e^{j\omega t} \right]$$

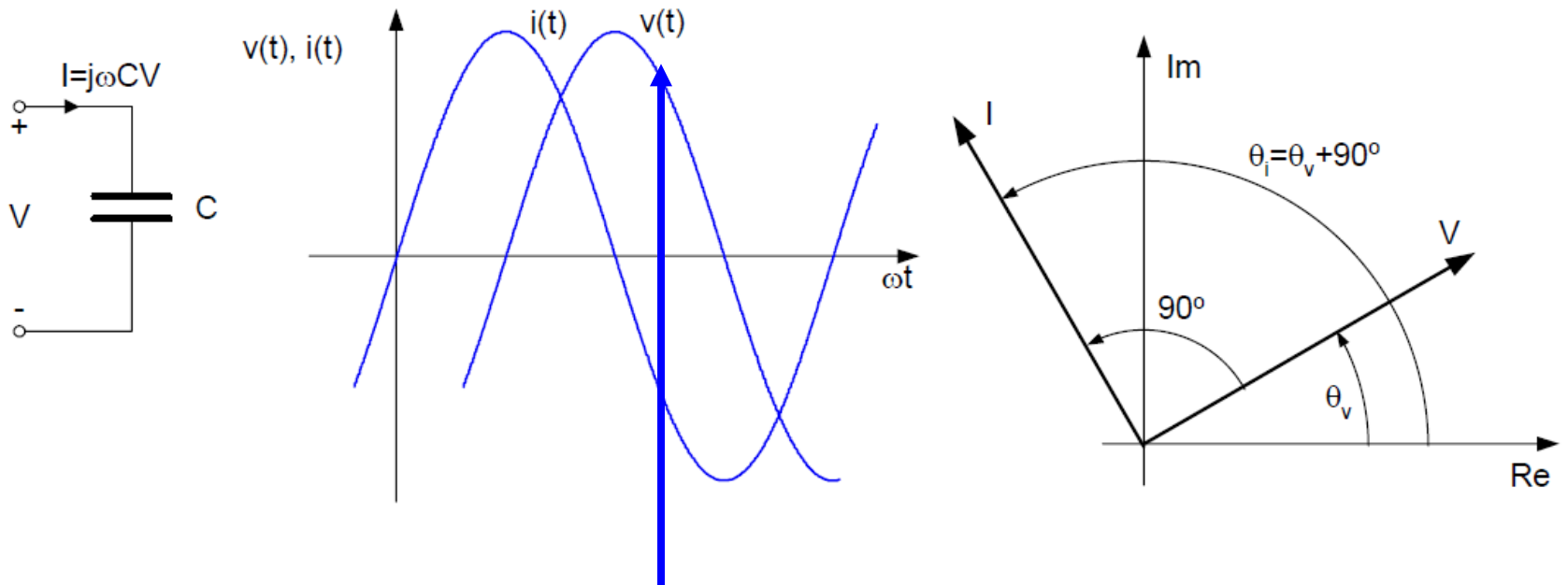
Otpornik



Kalem



Kondenzator



Snaga periodičnog signala

- po definiciji srednja vrednost proizvoda napona i struje u okviru jedne periode

$$\begin{aligned} P &= \frac{1}{T} \int_0^T V_M \cos(\omega t + \theta_v) I_M \cos(\omega t + \theta_i) dt \\ &= \frac{V_M I_M}{2T} \int_0^T [\cos(2\omega t + \theta_v + \theta_i) + \cos(\theta_v - \theta_i)] dt \\ &= \frac{V_M I_M}{2} \cos(\theta_v - \theta_i) = \frac{V_M I_M}{2} \cos \phi \end{aligned}$$

Diagrammatic annotations in the image:

- Two blue arrows point from the $\cos(2\omega t + \theta_v + \theta_i)$ term in the second line to a yellow box containing the number **0**.
- A blue arrow points from the $\cos(\theta_v - \theta_i)$ term in the third line to a larger yellow box containing the final formula: $P = \frac{V_M I_M}{2}$.

Snaga na otporniku

$$P = \frac{V_M I_M}{2} \cos \varphi$$

$$\varphi = 0s$$

$$P = \frac{V_M I_M}{2}$$

Snaga na otporniku

$$P = \frac{V_M I_M}{2} \cos \varphi$$

$$\varphi = 0$$

$$P = \frac{V_M I_M}{2}$$

$$P = \frac{R I_M^2}{2} = \frac{V_M^2}{2R}$$

Sinusoidalni signal

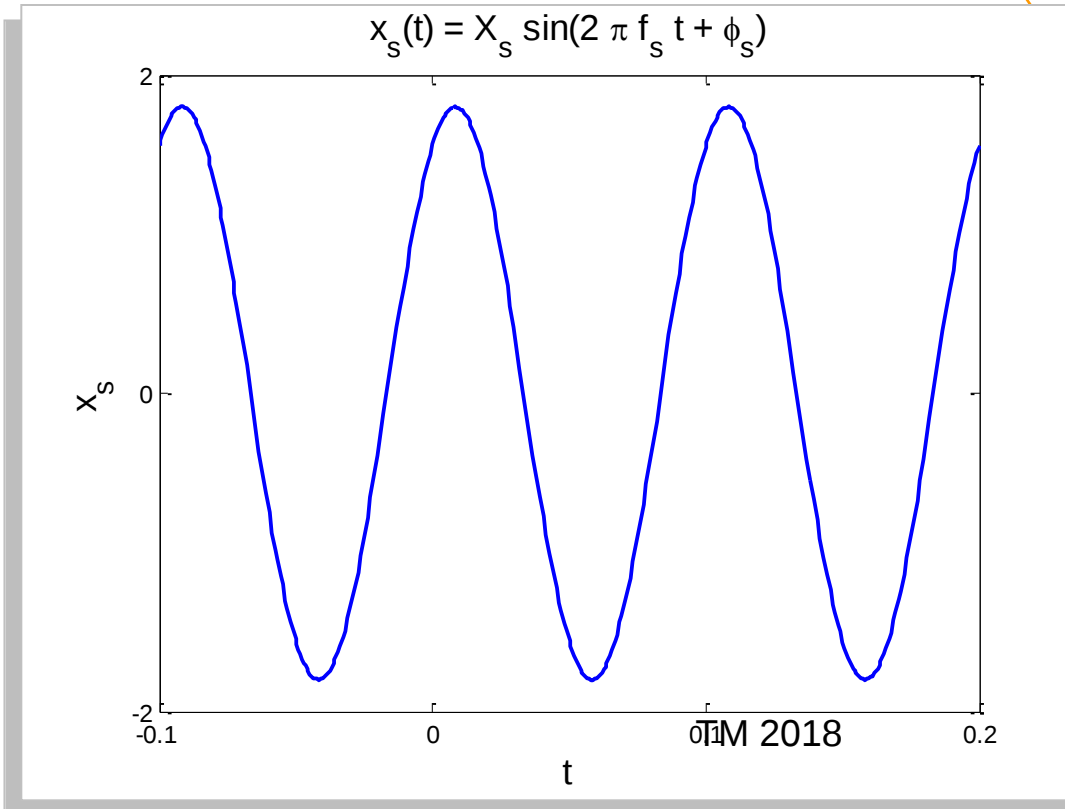
$$x_s(t) = X_s \sin(2\pi f_s t + \phi_s)$$

Amplituda

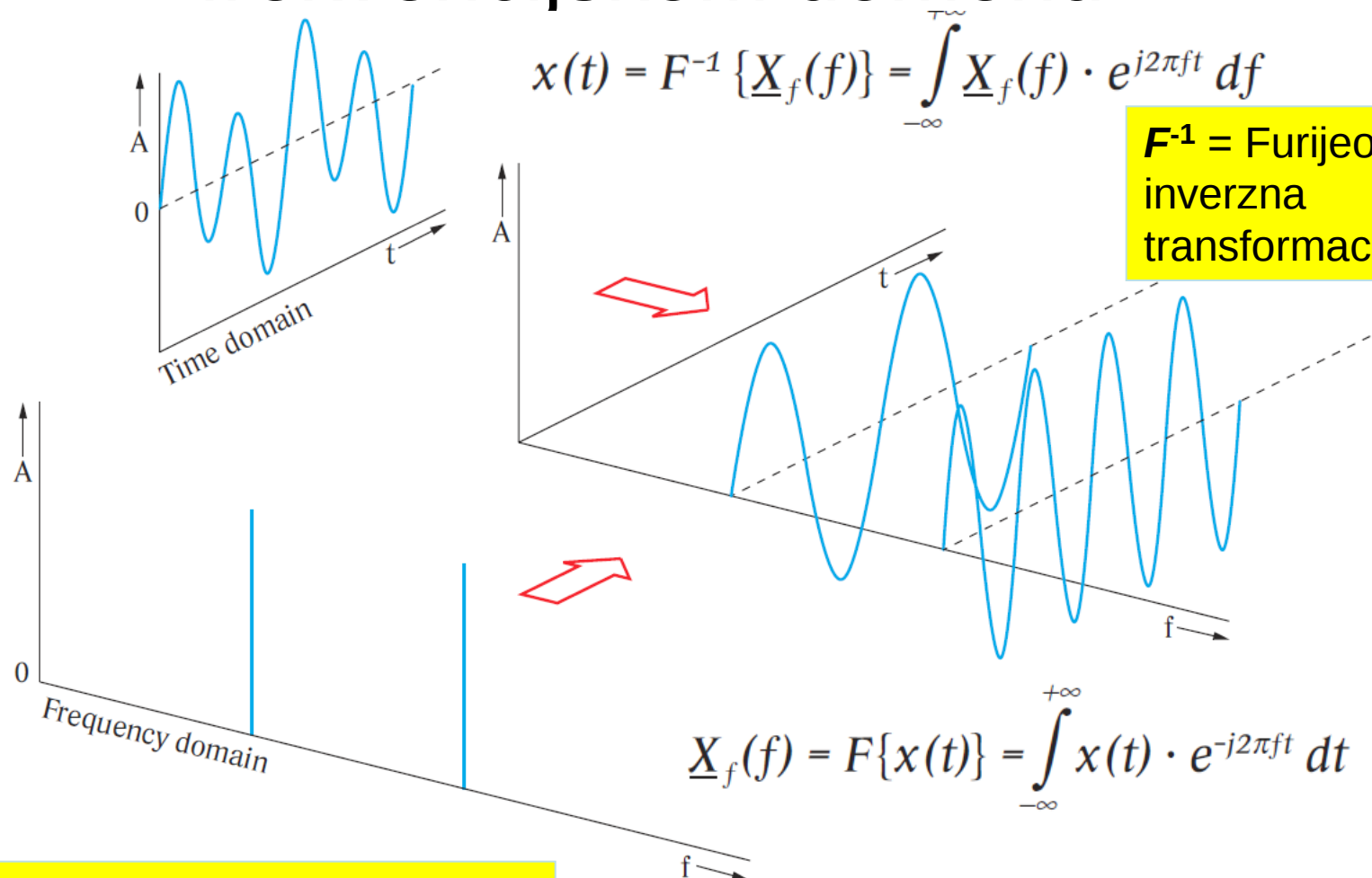
Faza u
radijanima

Vreme u
sekundama (s)

Frekvencija u
Hertz (Hz)



Signal u vremenskom i frekvencijskom domenu



F^{-1} = Furijeova
inverzna
transformacija

F = Fourier transform

Princip superpozicije

- Odziv $y(t)$ LTI sistema na ulaze $x_1(t), x_2(t), \dots x_N(t)$ jednak sumi odziva na svaki od ulaza dok su drugi 0, $y_i(t)$ je odziv na ulaz $x_i(t)$

$$y(t) = \sum_{i=1}^N y_i(t)$$

Periodični signali

- **Ne-sinusoidalni periodični signali**
- Predstavljaju se sinusoidalnim komponentama
- Primenom teorme superpozicije, odziv LTI sistema system na proizvoljnu periodičnu pobudu dobija se preko **fazorskog** metoda – harmonijskih komponenti

Periodični kontinualni signal

- Neka je $x(t)$ realni signal, a t realna nezavisno promenljiva takvi da je :
- $x(t+T) = x(t)$;
signal je periodičan sa periodom T
- $x(t)$ definisan na intervalu $\tau < t < \tau + T$
- $x(t)$ i $dx(t)/dt$ su kontinualni na intervalu $\tau < t < \tau + T$

Furijevov razvoj

Predstavljanje signala Furijeovim redom naziva se **spektralna analiza** ili harmonijska analiza

$$x(t) = C_0 + \sum_{n=1}^{+\infty} (A_n \cos(n\omega_1 t) + B_n \sin(n\omega_1 t))$$

$$C_0 = \frac{1}{T} \int_{\tau}^{\tau+T} x(t) dt$$

$$A_n = \frac{2}{T} \int_{\tau}^{\tau+T} x(t) \cos(n\omega_1 t) dt$$

$$B_n = \frac{2}{T} \int_{\tau}^{\tau+T} x(t) \sin(n\omega_1 t) dt$$

$$\omega_1 = \frac{2\pi}{T}$$

Osnovna ugaona učestanost

Furijeovi koeficijenti

Furijeova predstava sa kompleksnim koeficijentima

$$x(t) = \sum_{n=-\infty}^{+\infty} C_n e^{jn\omega_1 t}$$

$$C_n = \frac{1}{T} \int_{\tau}^{\tau+T} x(t) e^{-jn\omega_1 t} dt$$

$$C_{-n} = C_n^*$$

$$C_n = \frac{A_n - jB_n}{2}$$

Parsevalov identite

$$\frac{1}{T} \int_{\tau}^{\tau+T} |x(t)|^2 dt = C_0^2 + \frac{1}{2} \sum_{n=1}^{+\infty} (A_n^2 + B_n^2) = \sum_{n=-\infty}^{+\infty} |C_n|^2$$

$$\lim_{n \rightarrow \infty} A_n = 0$$

$$\lim_{n \rightarrow \infty} B_n = 0$$

Ako signal $x(t)$ predstavlja struju ili napon na otporniku, izraz daje srednju snagu u određenom vremenskom intervalu

Harmonici periodičnog signala

$$x(t) = \sum_{n=0}^{+\infty} x^{(n)}(t) = X^{(0)} + \sum_{n=1}^{+\infty} X_m^{(n)} \cos(n\omega_1 t + \xi^{(n)})$$

$$x^{(0)}(t) = X^{(0)} = C_0$$

dc komponenta

$$x^{(n)}(t) = X_m^{(n)} \cos(n\omega_1 t + \xi^{(n)})$$

$$X_m^{(n)} = \sqrt{A_n^2 + B_n^2}$$

$$\xi^{(n)} = \arg(A_n - jB_n)$$

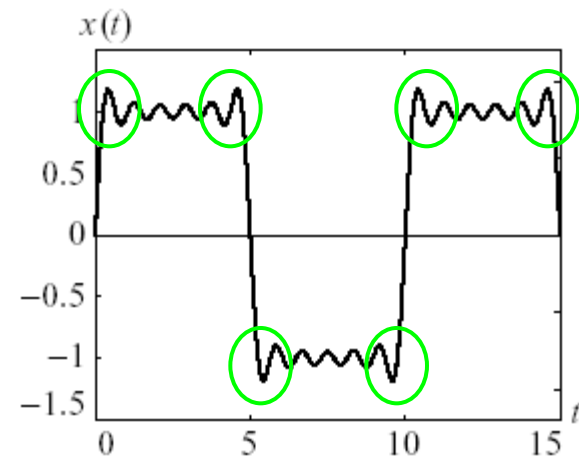
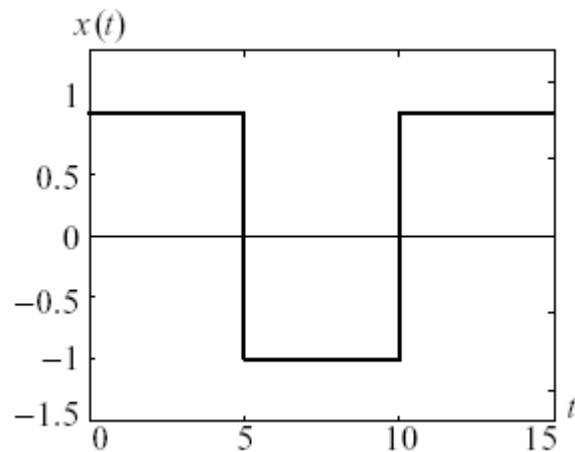
ac komponenta

n -ti harmonik

Gibsov fenomen

Kada signal ima naglu promenu vrednosti, i matematički ga predstavimo konačnim brojem komponenti, pojavljuju se premašenja na mestima nagle promene.

Bez obzira na povećanje broja komponenti, premašenja uvek postoje i ona se nazivaju **Gibsov fenomen**.



Definicije

$$X(j\omega) = \mathcal{F}(x(t)) = \int_{-\infty}^{+\infty} x(t) e^{-j\omega t} dt$$

Furijeova
transformacija

$$x(t) = \mathcal{F}^{-1}(X(j\omega)) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} X(j\omega) e^{j\omega t} d\omega$$

Inverzna
Furijeova
transformacija

Promenljiva ω je kontinualna

$$\lim_{T \rightarrow \infty} \int_{-T}^T |x(t)| dt < \infty \quad \text{Potreban uslov}$$

Parselvalova teorema i spektralna gustina energije

$$W = \int_{-\infty}^{\infty} |x(t)|^2 dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} E(\omega) d\omega$$

$$E(\omega) = |X(j\omega)|^2$$

Ukupna energija

Spektralna gustina energije

Furijeova transformacija

$$x(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} A_n \cdot \sin(n \cdot \omega_0 \cdot t) + \sum_{n=1}^{\infty} B_n \cdot \cos(n \cdot \omega_0 \cdot t)$$

$$A_0 = \frac{2}{T_0} \int_0^{T_0} x(t) dt$$

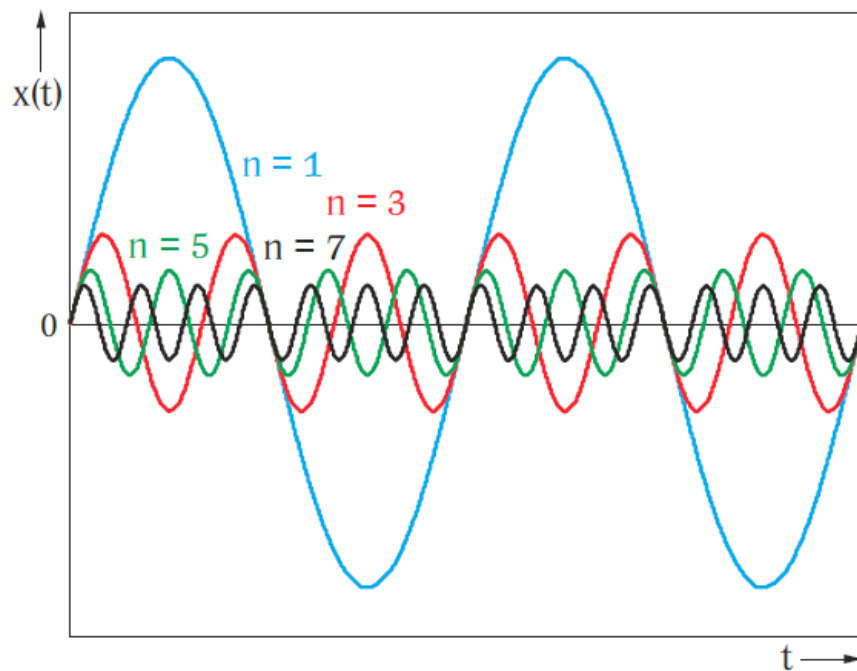
$$A_n = \frac{2}{T_0} \int_0^{T_0} x(t) \cdot \sin(n \cdot \omega_0 \cdot t) dt$$

$$B_n = \frac{2}{T_0} \int_0^{T_0} x(t) \cdot \cos(n \cdot \omega_0 \cdot t) dt$$

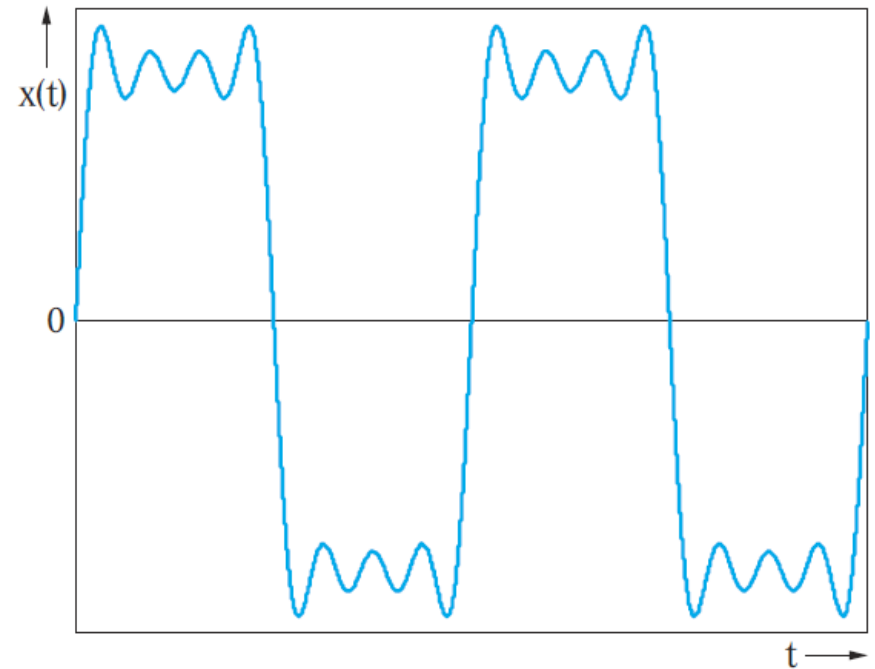
$\frac{A_0}{2}$	=	DC component
$x(t)$	=	signal in time domain
n	=	order of harmonic oscillation
T_0	=	eriod
ω_0	=	angular frequency

Harmonici

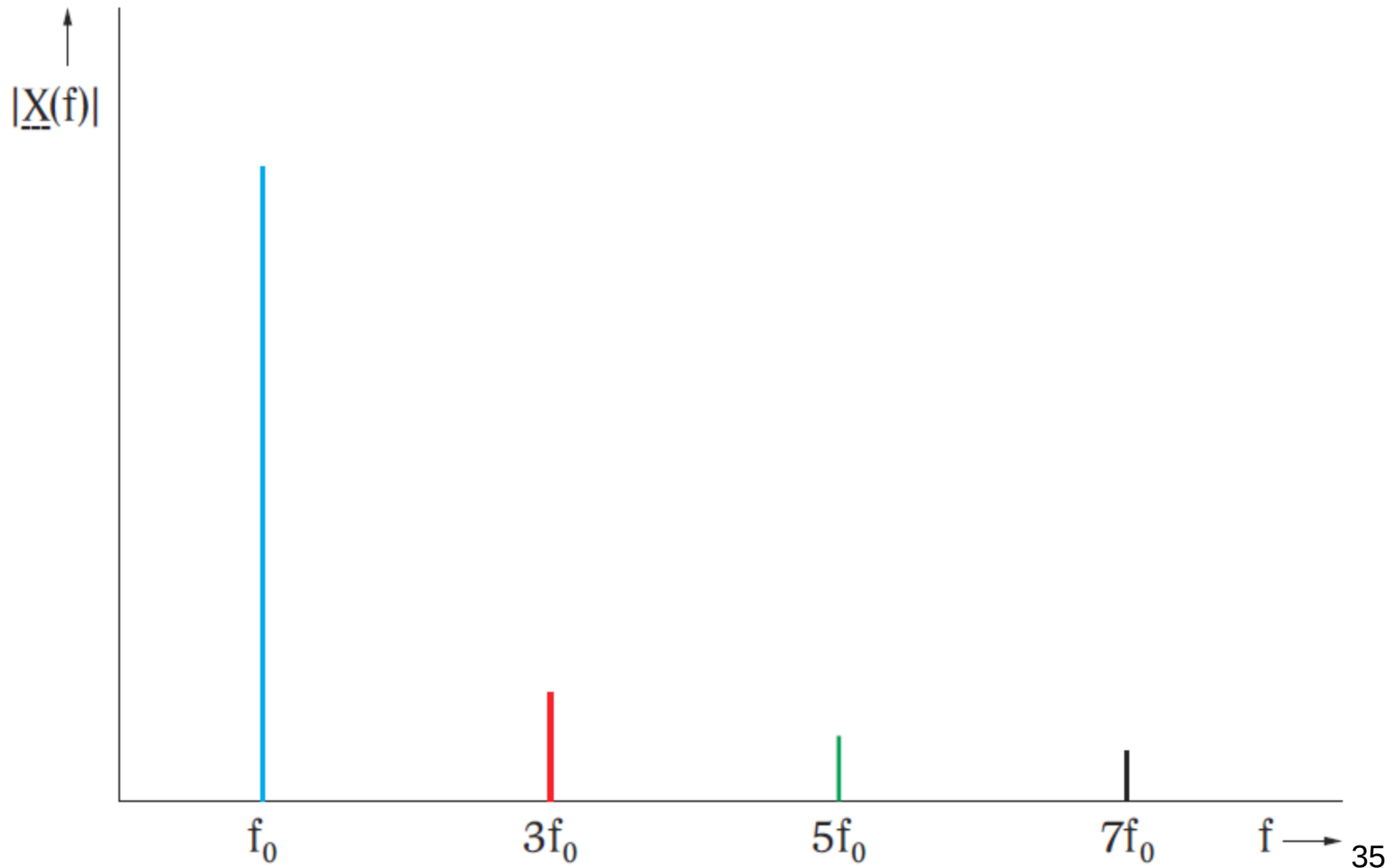
Harmonics



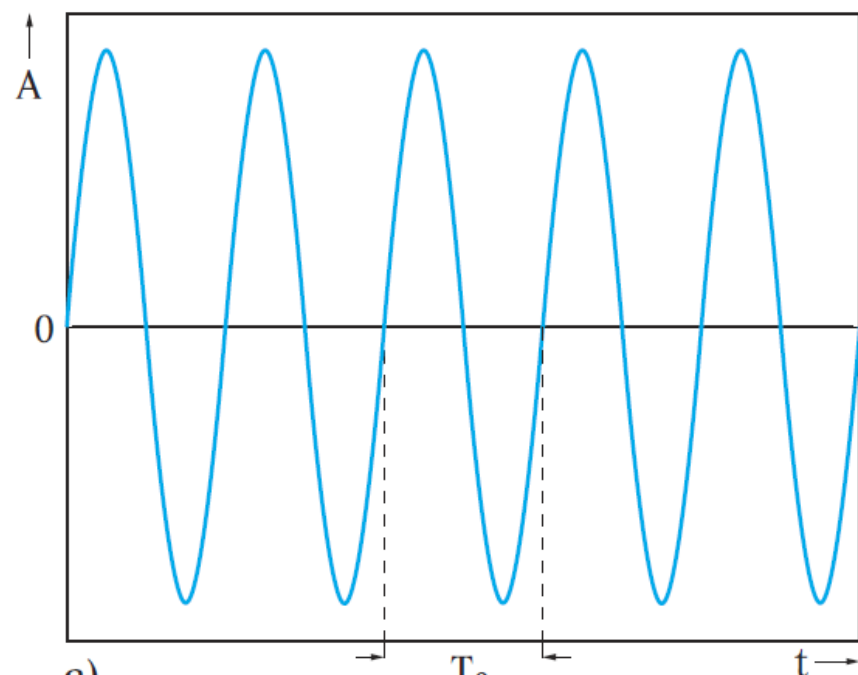
Sum of harmonics



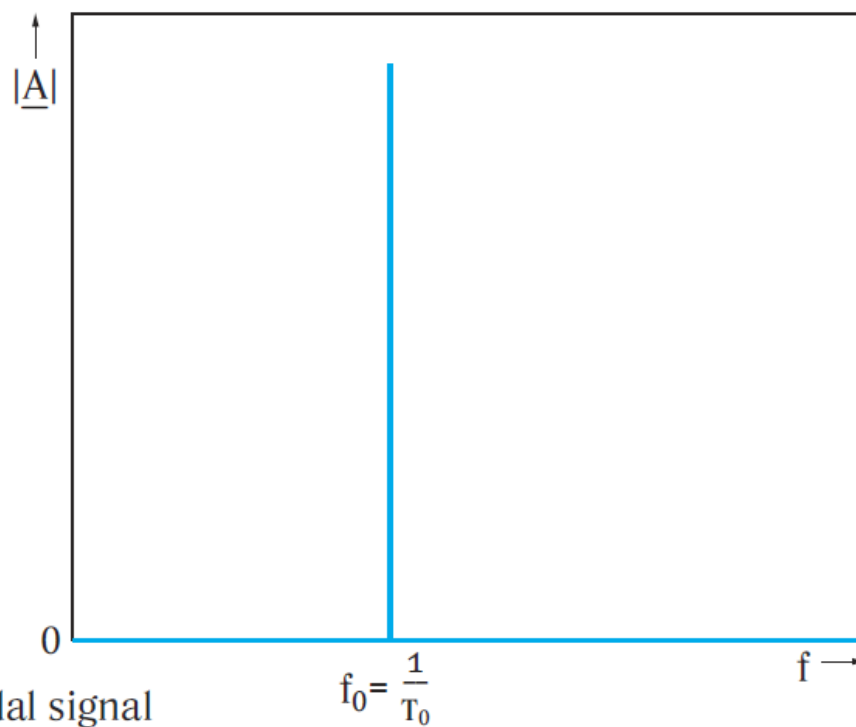
Harmonici



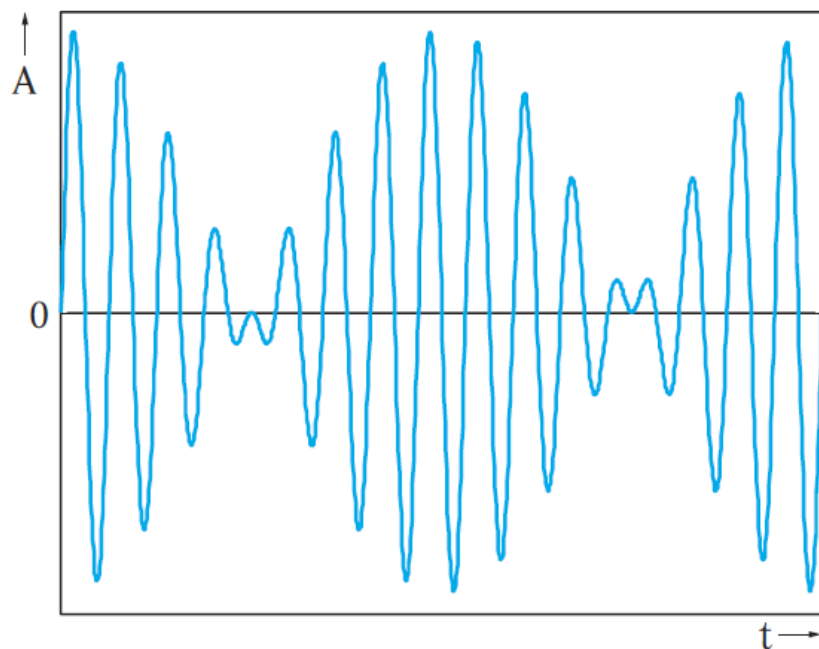
Periodični signali



Sinusoidal signal

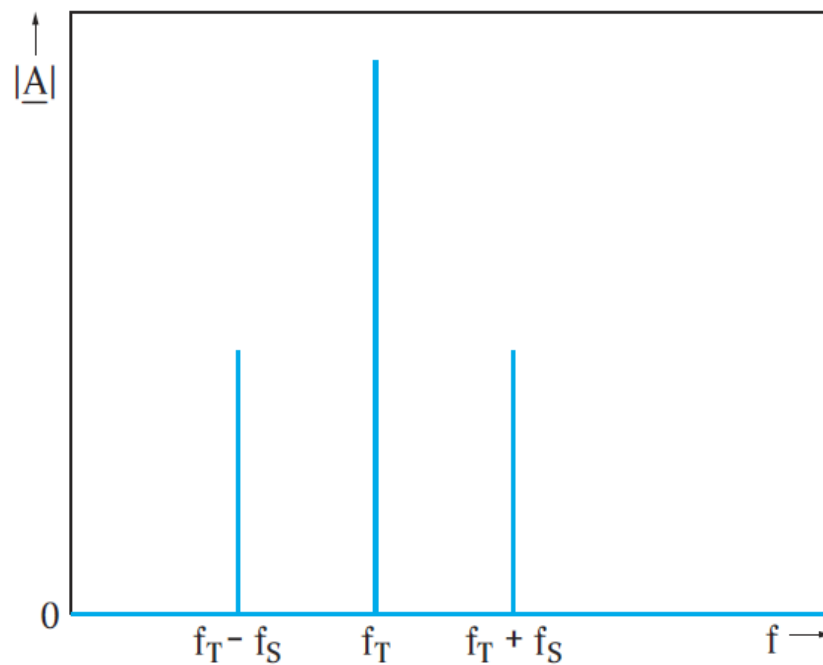


Periodični signali

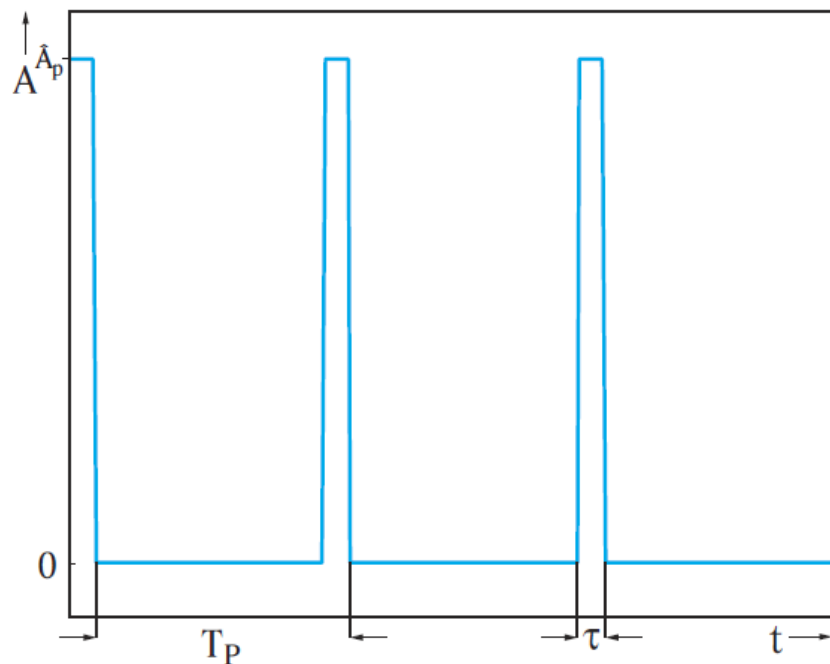


b)

Amplitude-modulated signal

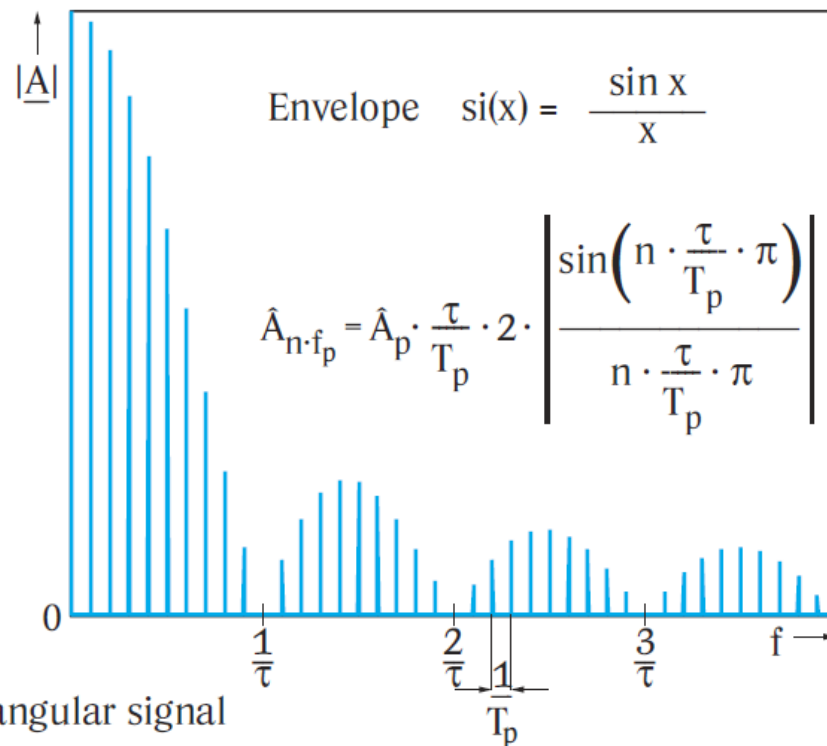


Periodični signali

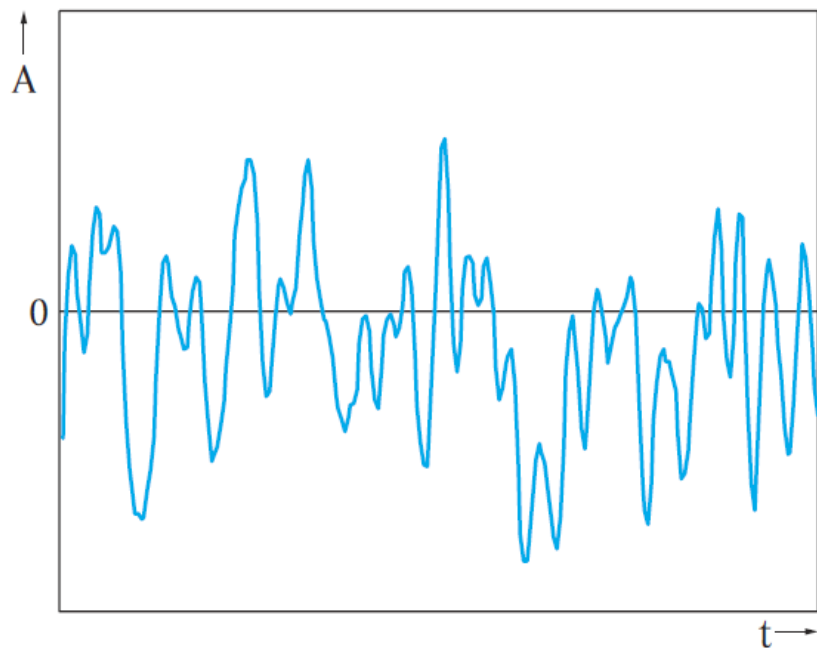


c)

Periodic rectangular signal

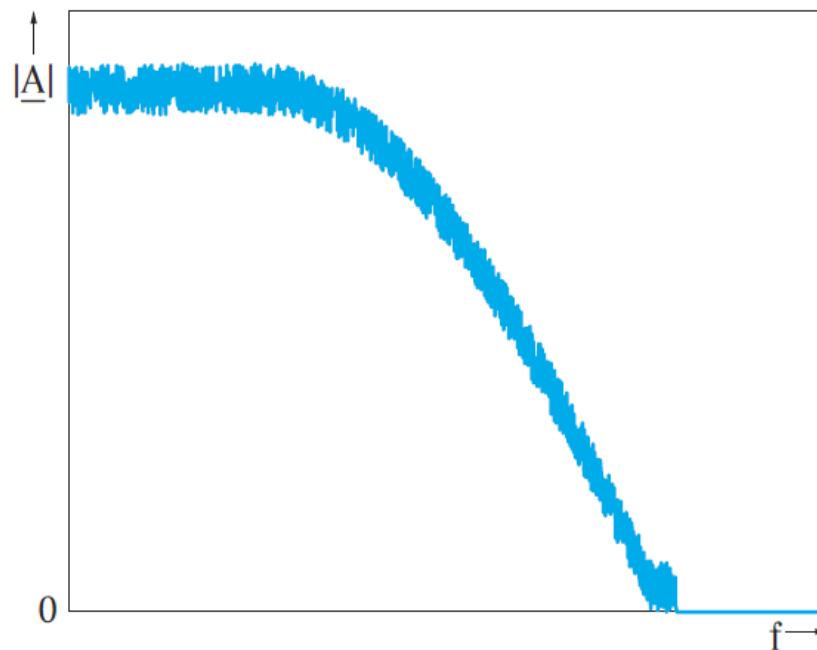


Frekvencijski ograničen šum



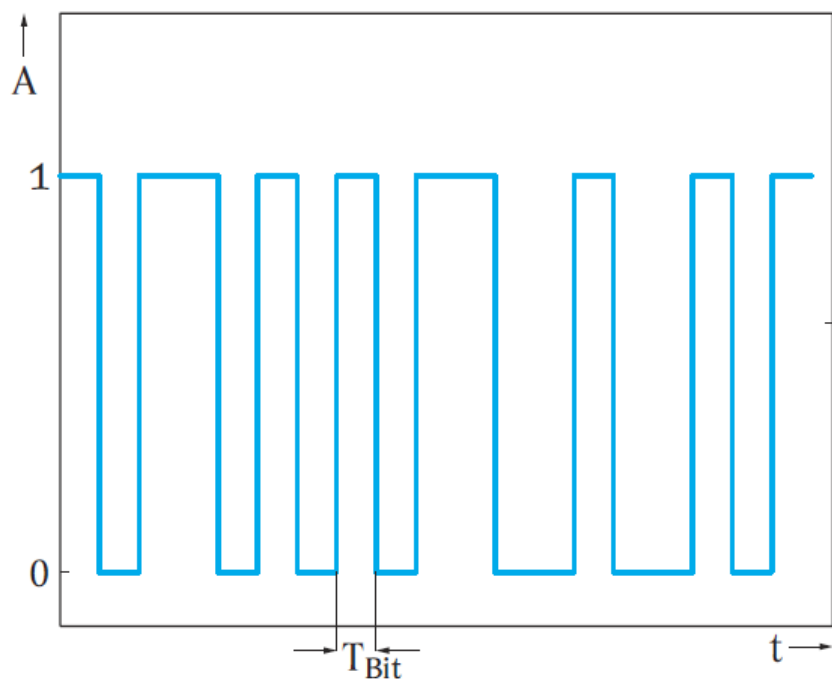
b)

Band-limited noise



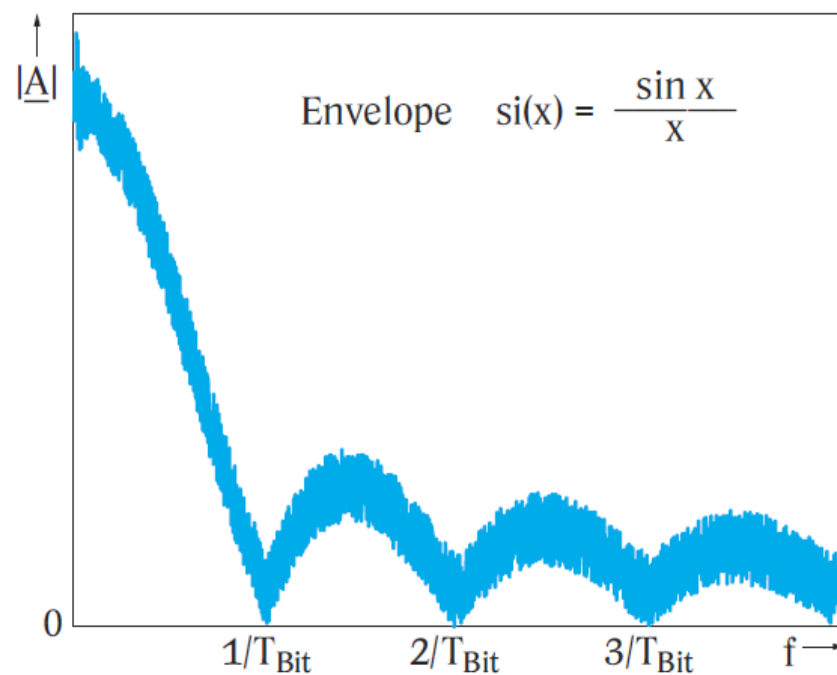
Obojeni šum

Sekvenca slučajnih bita

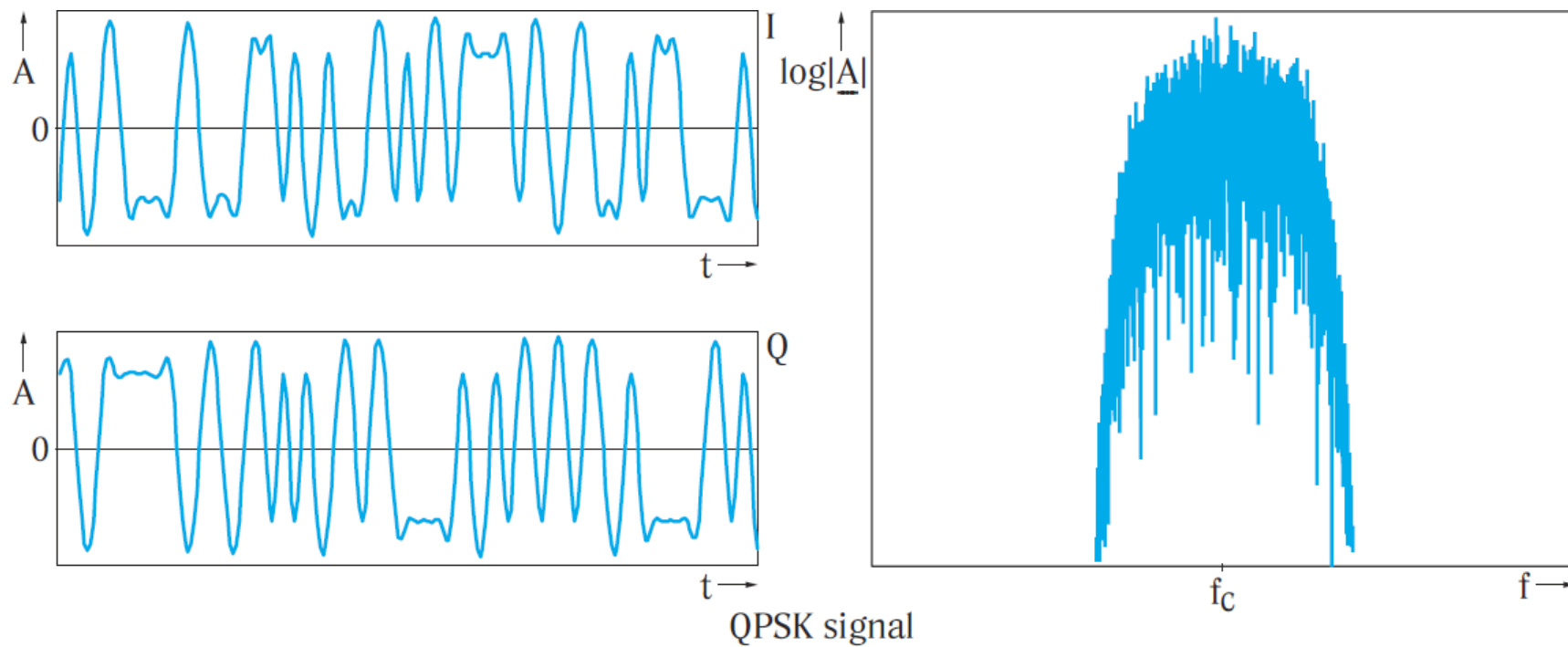


a)

Random bit sequence

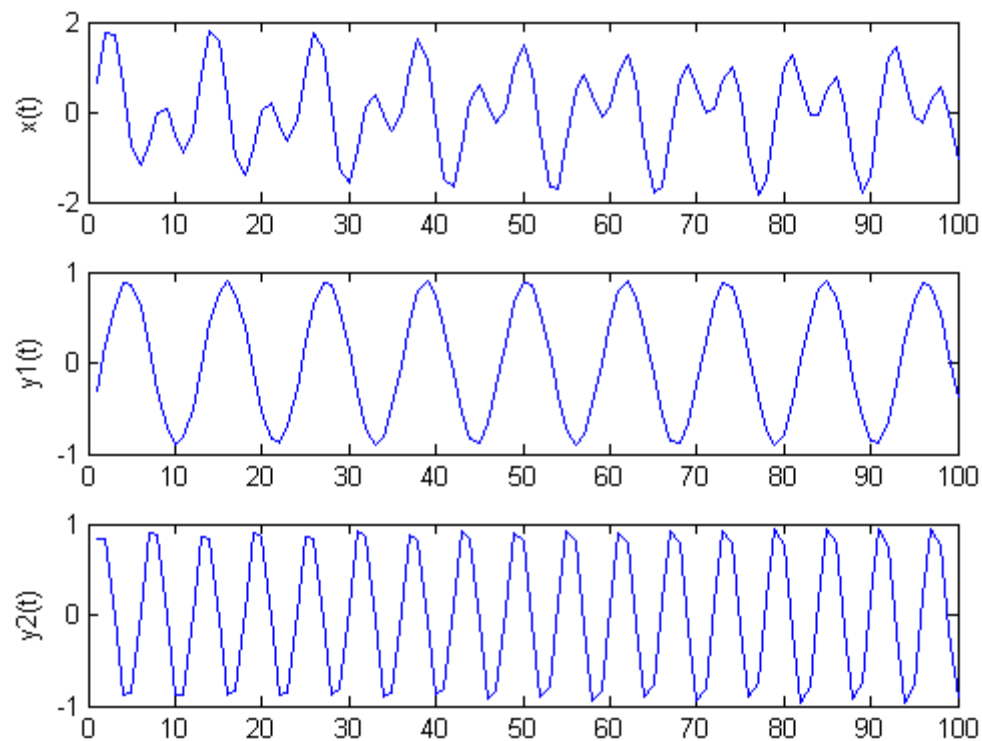
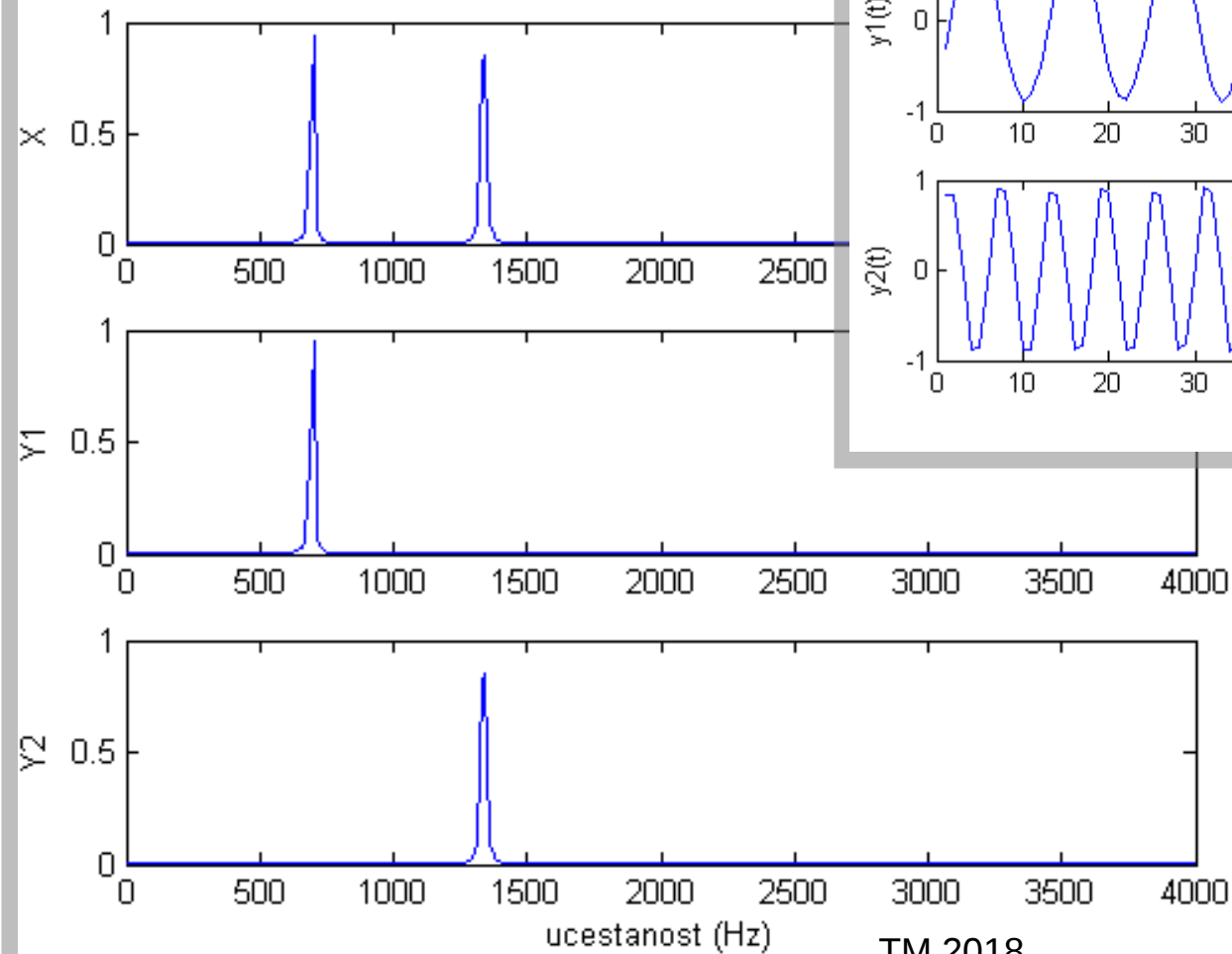


QPSK signal

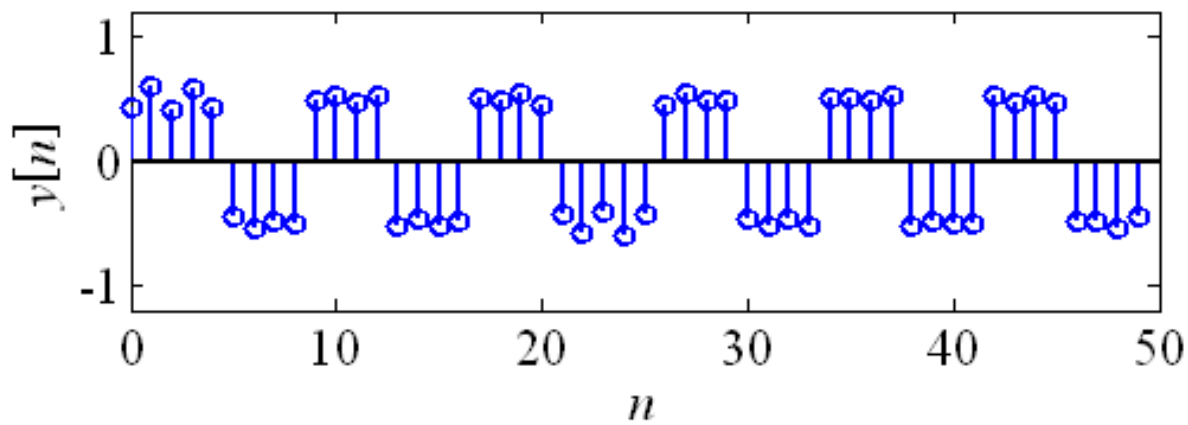
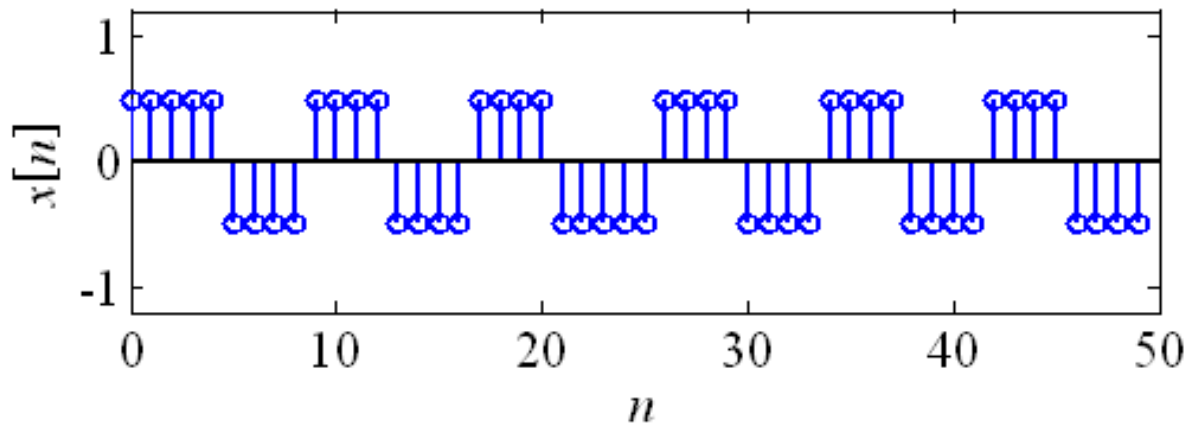


Telefon #2

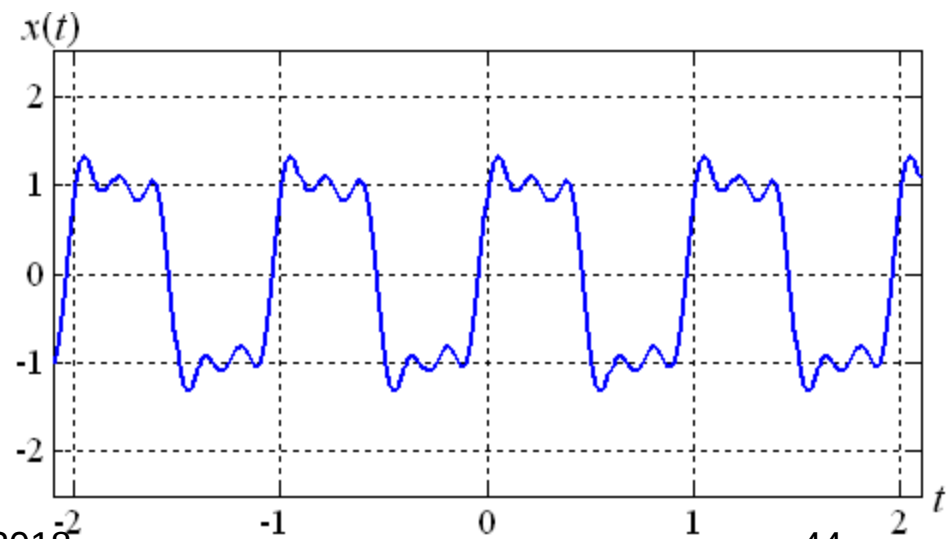
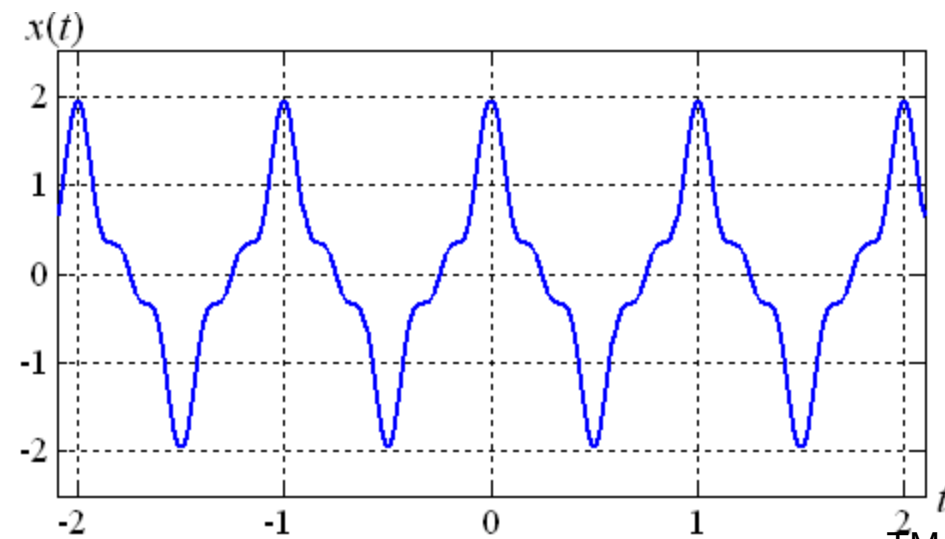
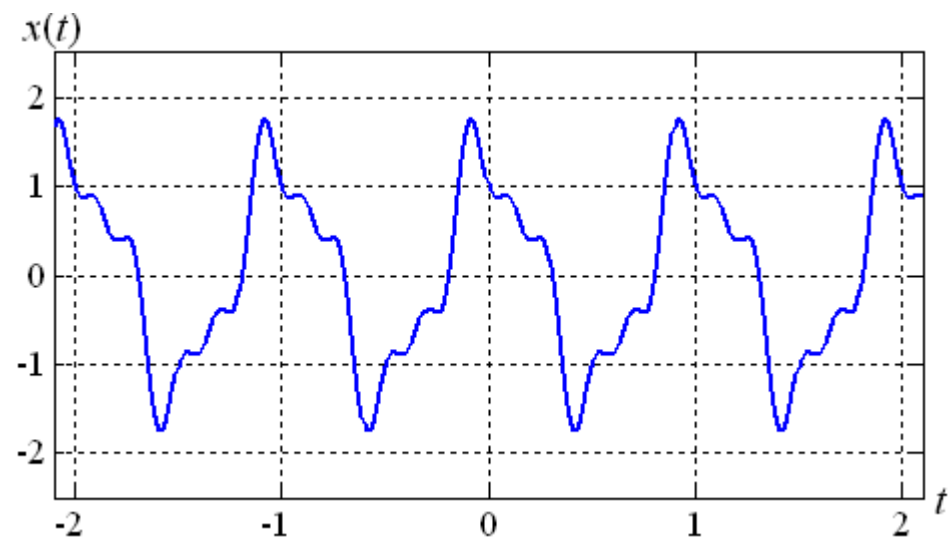
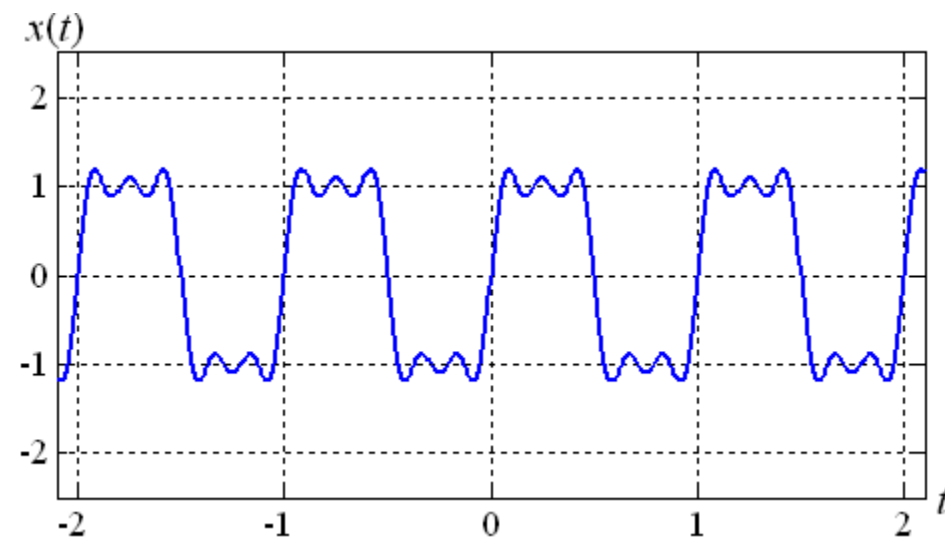
697Hz + 1336 Hz



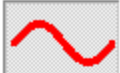
Uticaj ograničenja spektra



Uticaj fazne karakteristike



Signal Generator Control



Done

Help

Output

☒ Differential ☐ Single-ended

Signal Data

Peak Amplitude

2 Volts

Differential Offset

0 Volts

Frequency

2.3 k Hz

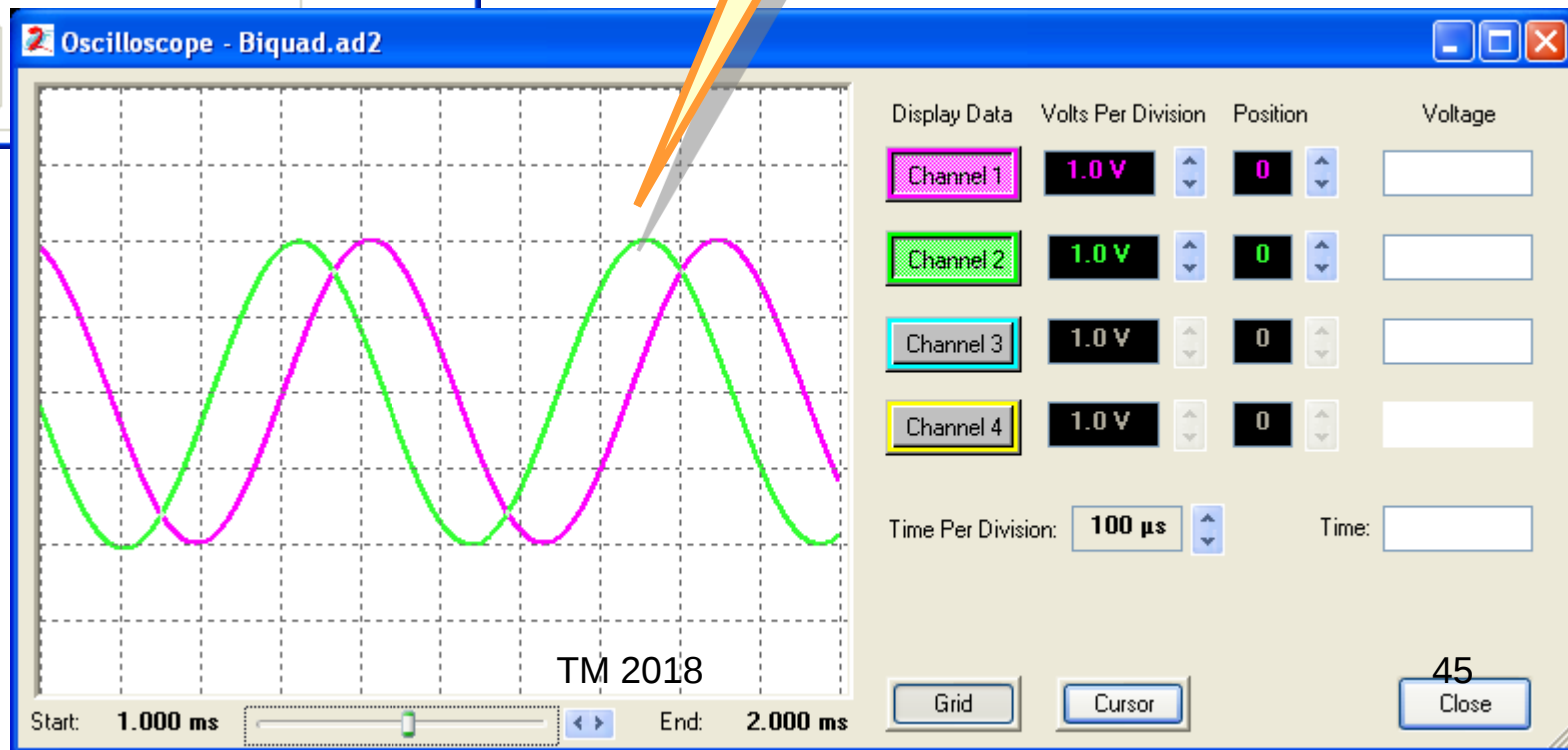
Phase

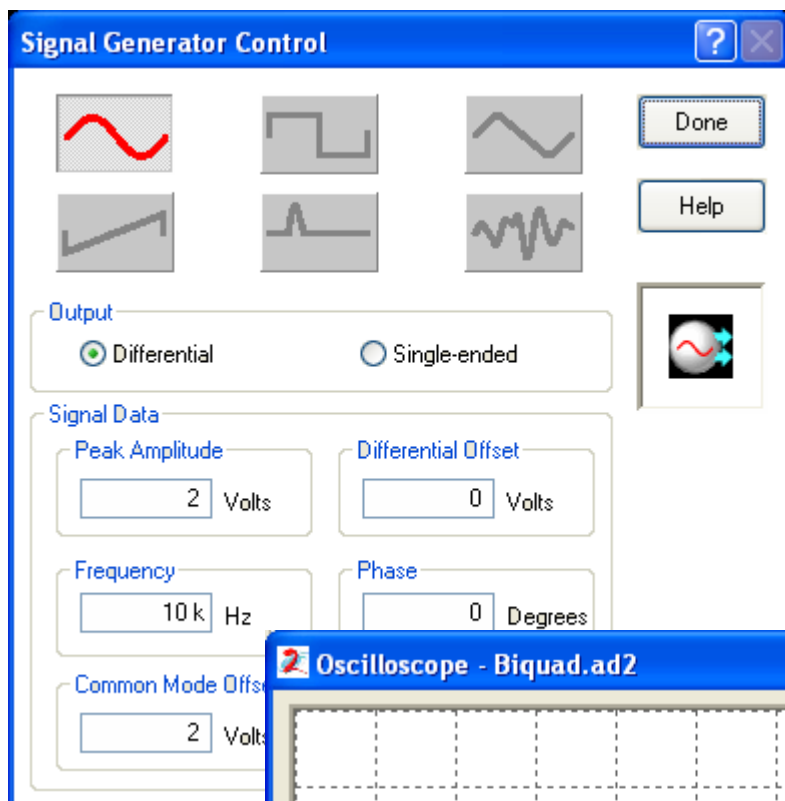
0 Degrees

Common Mode Offset

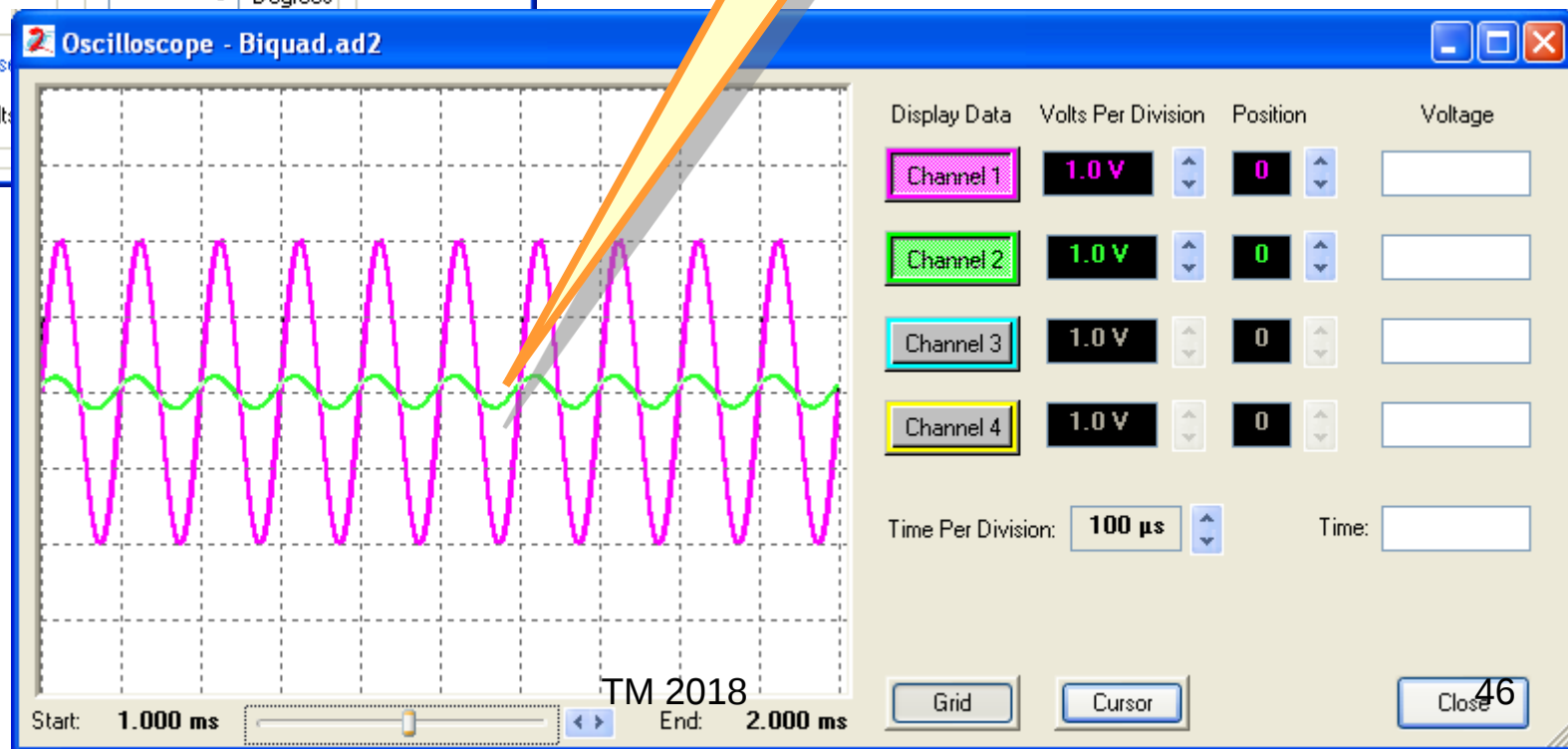
2 Volts

Propusni opseg

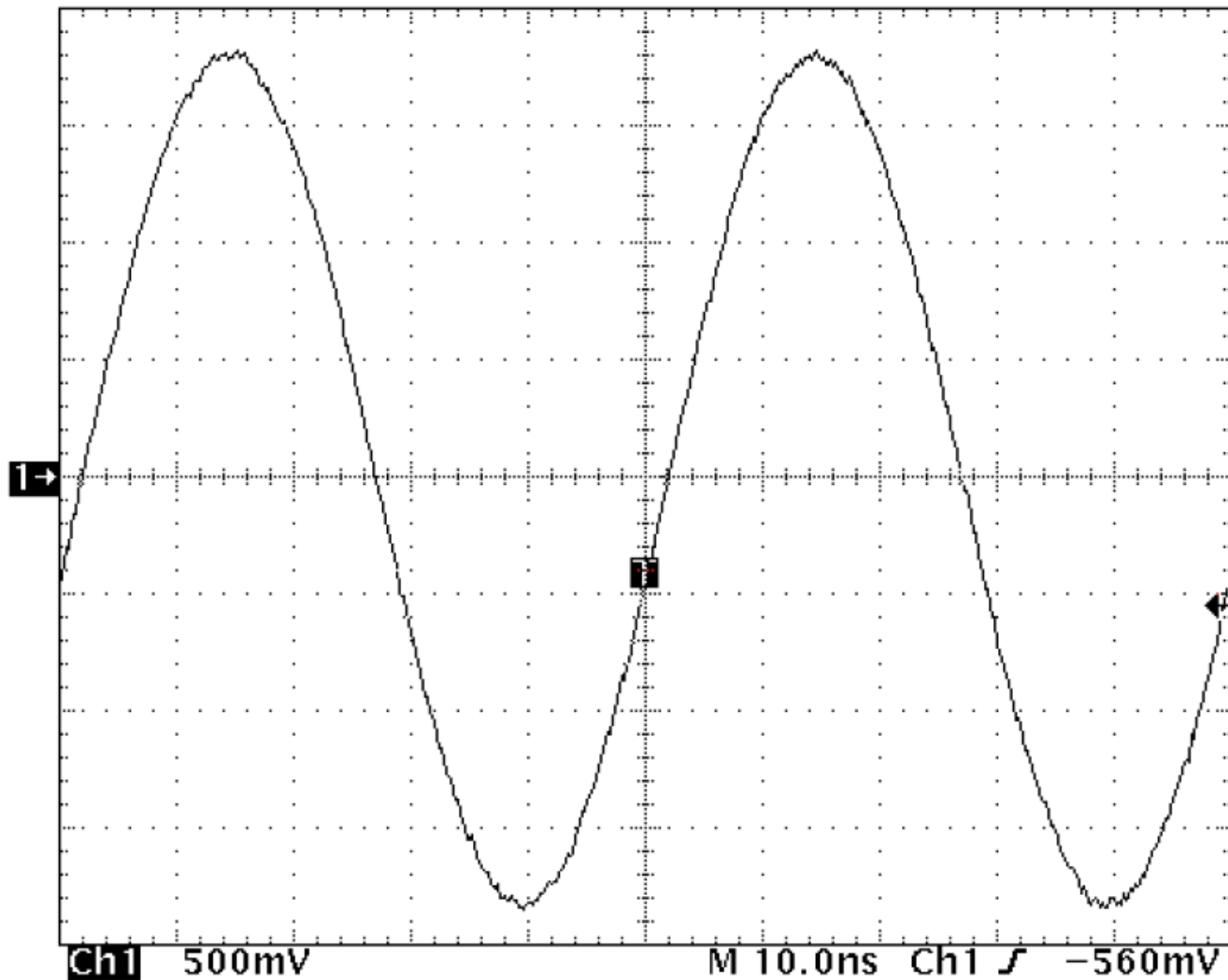




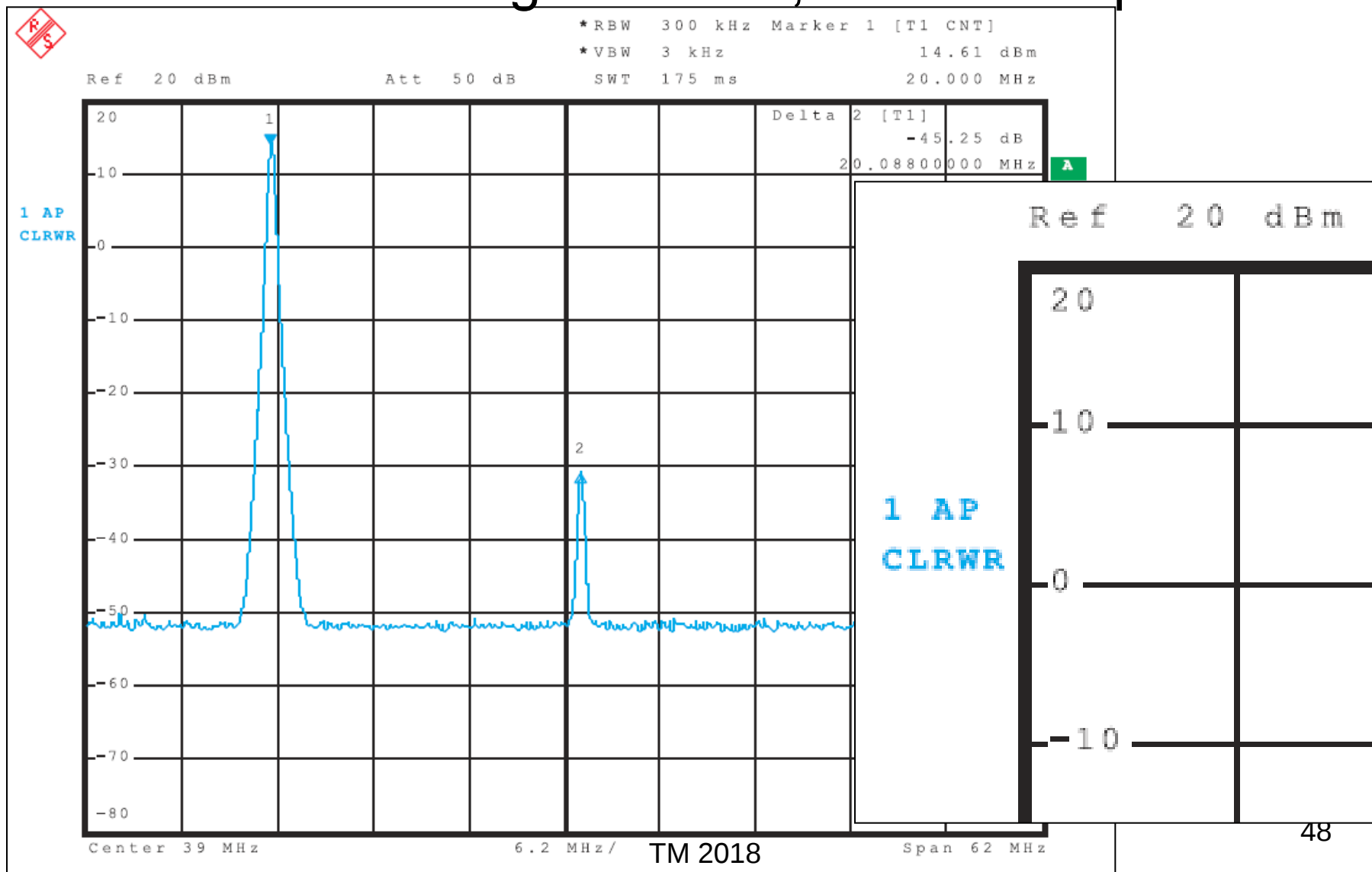
Nepropusni opseg



Sinusoidal signal ($f = 20 \text{ MHz}$) na osciloskopu



Sinusoidal signal + šum, analizator spektra



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Ova prezentacija je nekomercijalna.

Slajdovi mogu da sadrže materijale preuzete sa Interneta, stručne i naučne građe, koji su zaštićeni Zakonom o autorskim i srodnim pravima.

Ova prezentacija se može koristiti samo privremeno tokom usmenog izlaganja nastavnika u cilju informisanja i upućivanja studenata na dalji stručni, istraživački i naučni rad i u druge svrhe se ne sme koristiti –

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(1) javno izvođenje ili predstavljanje objavljenih dela u obliku neposrednog poučavanja na nastavi;

- ZAKON O AUTORSKOM I SRODNIM PRAVIMA

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