ANALOG SIGNAL PROCESSING

ECE 210 & 211

2022.4.14

Prof. Yang Xu （徐杨）

yangxu-isee@zju.edu.cn

Lab &Teaching Assistants:

Yue Dai (yuedai@zju.edu.cn) Baoyu Wang (by.wang@zju.edu.cn)
Weiming Ma (22141072@ zju.edu.cn) Jiangming Lin (3170104620@zju.edu.cn)
Yongliang Xie (22141005@zju.edu.cn) Shuang Li (l211493@zju.edu.cn)

ZJU-UIUC Institute

Zhejiang University / University of Illinois at Urbana-Champaign Institute

Objectives

- Orthogonal Projection and Fourier series
- Exponential Fourier series
- Periodic and non-periodic sums
- Shifting Property of signals
- Differentiation of signals

Objectives

- **Orthogonal Projection and Fourier series**
- **Exponential Fourier series**
- **Periodic and non-periodic sums**
- **Shifting Property of signals**
- **Differentiation of signals**

Orthogonal Projections and Fourier Series

- **There is a strong mathematical correlation between Fourier series and vector of *n-dimensional space***

- **Suppose a 3-D vector as,**

$$\vec{v} = (3, -2, 5)$$

can be re-written as a weighted sum of three mutually orthogonal vectors,

$$\overrightarrow{u_1} = (1, 0, 0), \qquad \overrightarrow{u_2} = (0, 1, 0), \qquad \overrightarrow{u_3} = (0, 0, 1)$$

as,

$$\vec{v} = 3\overrightarrow{u_1} - 2\overrightarrow{u_2} + 5\overrightarrow{u_3}$$

Orthogonal Projections and Fourier Series

In general, any 3D vector can be expressed as,

$$\vec{v} = \sum_{n=1}^{3} V_n \vec{u}_n \quad \text{where,} \quad V_n = \vec{v}.\vec{u}_n$$

- **The coefficient V_n of the $\vec{v}$ can be regarded as projections of $\vec{v}$ along the basis function $\vec{u}_n$**

- **By this analogy, a convergent Fourier series as**

$$f(t) = \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

Orthogonal Projections and Fourier Series

can be treated as an infinite weighted sum of orthogonal basis function,

$$e^{jn\omega_o t}, -\infty \leq n \leq \infty$$

satisfying an orthogonality condition,

$$\int_T \left(e^{jn\omega_o t}\right)\left(e^{jm\omega_o t}\right)dt = 0 \; for \; m \neq n$$

A Fourier coefficient F_m of *f(t)* is then the projection of *f(t)* *along basis function* $e^{jm\omega_o t}$.

Orthogonal Projections and Fourier Series

Inner product property for $\vec{a}$ with $\vec{b}$, is

$$\langle a,b \rangle = a^T b = [a_0, a_1, \ldots, a_n]\begin{bmatrix} b_1 \\ b_2 \\ \cdots \\ b_n \end{bmatrix} = \sum_{i=1}^{n} a_i b_i$$

Inner product property for $f[n]$ with $g[n]$, is

$$< f[n], g[n] > = \sum_{1}^{n} f[n] g^*[n]$$

Inner product property for $f(t)$ with $g(t)$, is

$$< f(t), g(t) > = \int_{a}^{b} f(t) g^*(t) dt$$

Orthogonal Projections and Fourier Series

Using inner product property for *f(t)* with $e^{jm\omega_o t}$, is

$$\int_T f(t)\left(e^{-jm\omega_o t}\right)dt = \int_T \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}\, e^{-jm\omega_o t} dt$$

$$= \int_T F_n \sum_{n=-\infty}^{\infty} e^{jn\omega_o t} \left(e^{jm\omega_o t}\right)^* dt = F_m$$

Only interchanging m with n, we may have,

$$F_n = \frac{1}{T}\int_T f(t) e^{-jn\omega_o t} dt$$

which can be used for any periodic and convergent signal (satisfying Dirichlet's conditions))

Orthogonal Projections and Fourier Series

Trigonometric Fourier series as Orthogonal Projection

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \underbrace{\boxed{\cos(n\omega_o t)}}_{} + b_n \underbrace{\boxed{\sin(n\omega_o t)}}_{}$$

Orthogonal Basis functions

$$F_n = a_n - jb_n$$

$$a_n = F_n + F_{-n}$$

$$b_n = j(F_n - F_{-n})$$

Objectives

- Orthogonal Projection and Fourier series
- Exponential Fourier series
- Periodic and non-periodic sums
- Shifting Property of signals
- Differentiation of signals

Exponential Fourier series

- A compact way to represent Fourier series is to put in to exponential form

- We need to use Euler's identity for sine and cosine functions,

$$\cos n\omega_0 t = \frac{1}{2}[e^{jn\omega_0 t} + e^{-jn\omega_0 t}]$$

$$\sin n\omega_0 t = \frac{1}{2j}[e^{jn\omega_0 t} - e^{-jn\omega_0 t}]$$

Exponential Fourier series

$$f(t) = \underbrace{a_0}_{\text{dc}} + \underbrace{\sum_{n=1}^{\infty} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t)}_{\text{ac}}$$

Using the values of cos $n\omega_o t$ and sin $n\omega_o t$,

$$f(t) = a_0 + \frac{1}{2} \sum_{n=1}^{\infty} [(a_n - jb_n)e^{jn\omega_0 t} + (a_n + jb_n)e^{-jn\omega_0 t}]$$

If we define a new coefficient c_n so that,

$$c_0 = a_0, \qquad c_n = \frac{(a_n - jb_n)}{2}, \qquad c_{-n} = c_n^* = \frac{(a_n + jb_n)}{2}$$

Exponential Fourier series

then *f(t)* becomes,

$$f(t) = c_0 + \sum_{n=1}^{\infty} (c_n e^{jn\omega_0 t} + c_{-n} e^{-jn\omega_0 t})$$

or,

$$\boxed{f(t) = \sum_{n=-\infty}^{\infty} c_n e^{jn\omega_0 t}}$$

Exponential /complex form of Fourier transform

Exponential Fourier series

- **The plots of the magnitude and phase of c_n versus $n\omega_o$ are called the *complex amplitude spectrum* and *complex phase spectrum* of *f(t)* , respectively**

- **The exponential Fourier series of a periodic function *f(t)* describes the spectrum of *f(t)* in terms of the amplitude and phase angle of ac components at positive and negative harmonic frequencies**

$$\boxed{A_n\angle\phi_n = a_n - jb_n = 2c_n}$$

Exponential Fourier series

Alternatively,

$$c_n = |c_n| \angle \theta_n = \frac{\sqrt{a_n^2 + b_n^2}}{2} \angle -\tan^{-1} b_n/a_n \quad \textbf{if positive } a_n$$

The rms value can be calculated as,

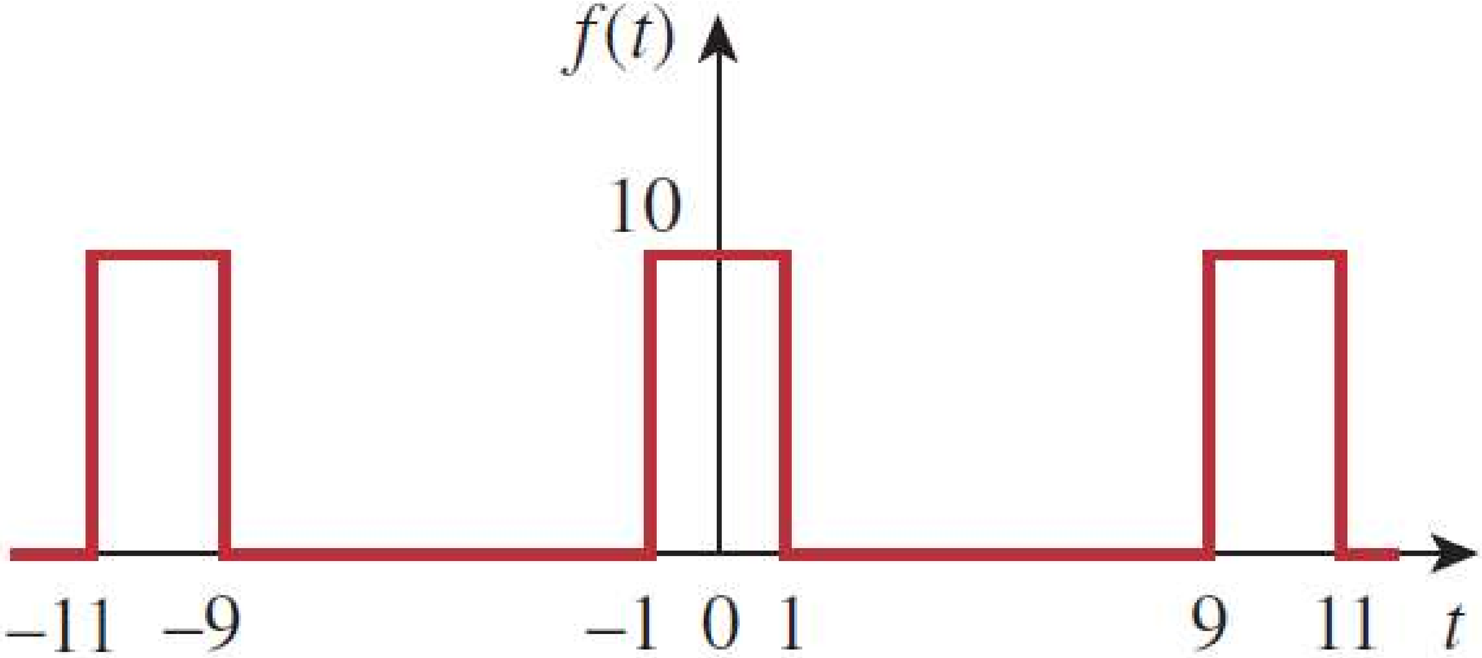
$$F_{\text{rms}} = \sqrt{\sum_{n=-\infty}^{\infty} |c_n|^2}$$

For a periodic input with period ω_o can be expressed,

$$F_{\text{rms}}^2 = |c_0|^2 + 2\sum_{n=1}^{\infty} |c_n|^2$$

Exponential Fourier series

Question: **Find the amplitude and phase spectra of the pulse train shown below?**



Exponential Fourier series

Solution: **The period of the pulse train is** ***T = 10 s*****, Thus the fundamental frequency will be** $\boldsymbol{\omega_o = \frac{\pi}{5}\ rad/s}$

$$c_n = \frac{1}{T}\int_{-T/2}^{T/2} f(t)e^{-jn\omega_0 t}\,dt = \frac{1}{10}\int_{-1}^{1} 10e^{-jn\omega_0 t}\,dt$$

$$= \frac{1}{-jn\omega_0}e^{-jn\omega_0 t}\Big|_{-1}^{1} = \frac{1}{-jn\omega_0}\left(e^{-jn\omega_0} - e^{jn\omega_0}\right)$$

$$= \frac{2}{n\omega_0}\frac{e^{jn\omega_0} - e^{-jn\omega_0}}{2j} = 2\frac{\sin n\omega_0}{n\omega_0}, \qquad \omega_0 = \frac{\pi}{5}$$

$$= 2\frac{\sin n\pi/5}{n\pi/5}$$

Exponential Fourier series

$$f(t) = 2 \sum_{n=-\infty}^{\infty} \frac{\sin n\pi/5}{n\pi/5} e^{jn\pi t/5}$$

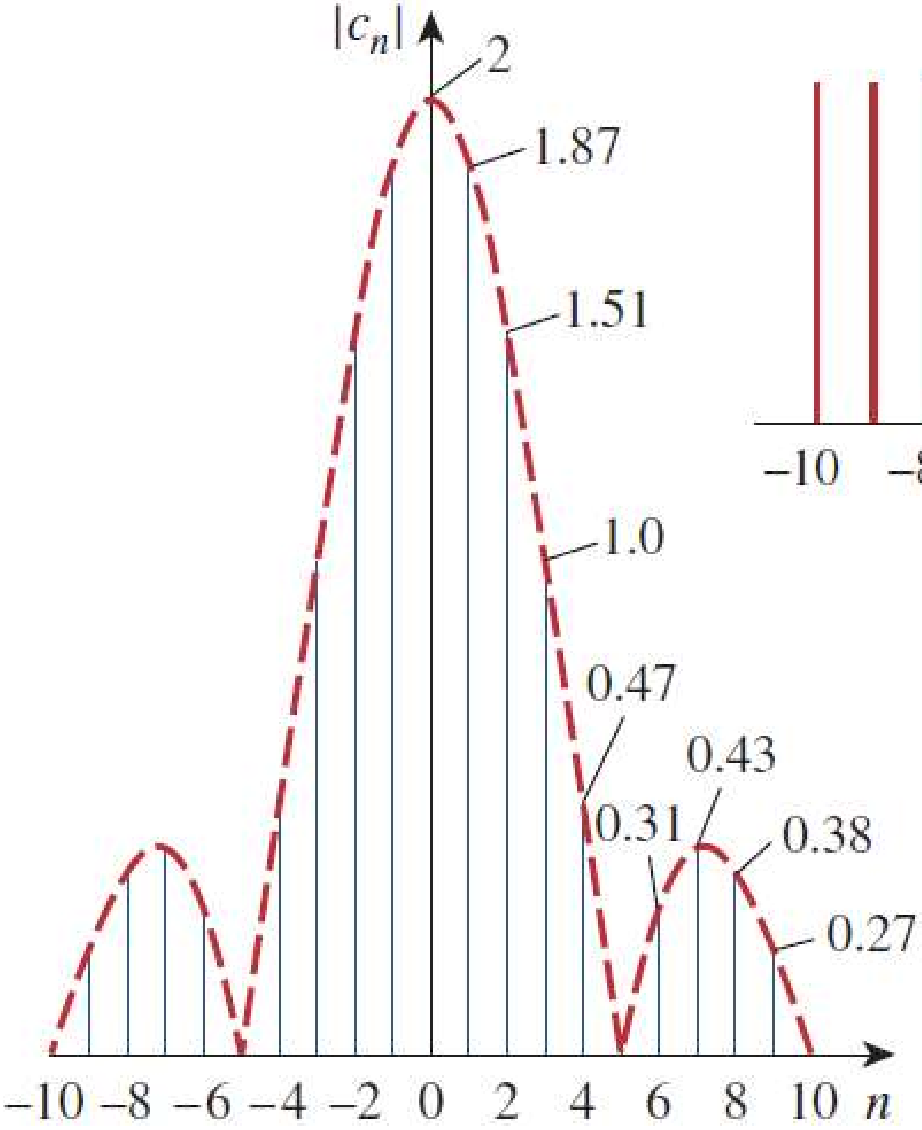
It is a ***Sinc function*****. Amplitude of the** ***f(t)*** **is,**

$$|c_n| = 2 \left| \frac{\sin n\pi/5}{n\pi/5} \right|$$

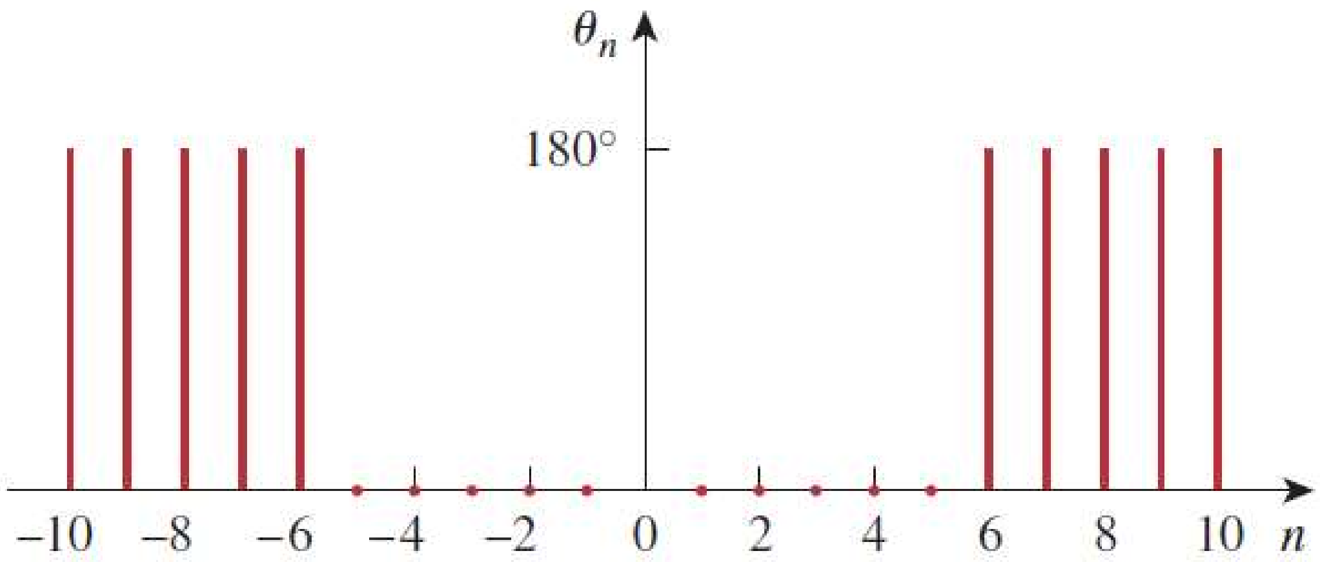
The phase of the ***f(t)*** **is,**

$$\theta_n = \begin{cases} 0^\circ, & \sin\dfrac{n\pi}{5} > 0 \\ 180^\circ, & \sin\dfrac{n\pi}{5} < 0 \end{cases}$$

Exponential Fourier series



Magnitude



Phase

Exponential Fourier series

Question: **Find the exponential Fourier expansion of the periodic function $f(t) = e^t, 0 < t < 2\pi$, with period 2π?**

Solution:

As $\omega_o = 1$ rad/s, Hence,

$$c_n = \frac{1}{T}\int_0^T f(t)e^{-jn\omega_0 t}\,dt = \frac{1}{2\pi}\int_0^{2\pi} e^t e^{-jnt}\,dt$$

$$= \frac{1}{2\pi}\frac{1}{1-jn}e^{(1-jn)t}\Big|_0^{2\pi} = \frac{1}{2\pi(1-jn)}[e^{2\pi}e^{-j2\pi n} - 1]$$

Exponential Fourier series

By using Euler's identity,

$$e^{-j2\pi n} = \cos 2\pi n - j\sin 2\pi n = 1 - j0 = 1$$

Thus,

$$c_n = \frac{1}{2\pi(1 - jn)}[e^{2\pi} - 1] = \frac{85}{1 - jn}$$

The complex Fourier series will be,

$$f(t) = \sum_{n=-\infty}^{\infty} \frac{85}{1 - jn} e^{jnt}$$

Exponential Fourier series

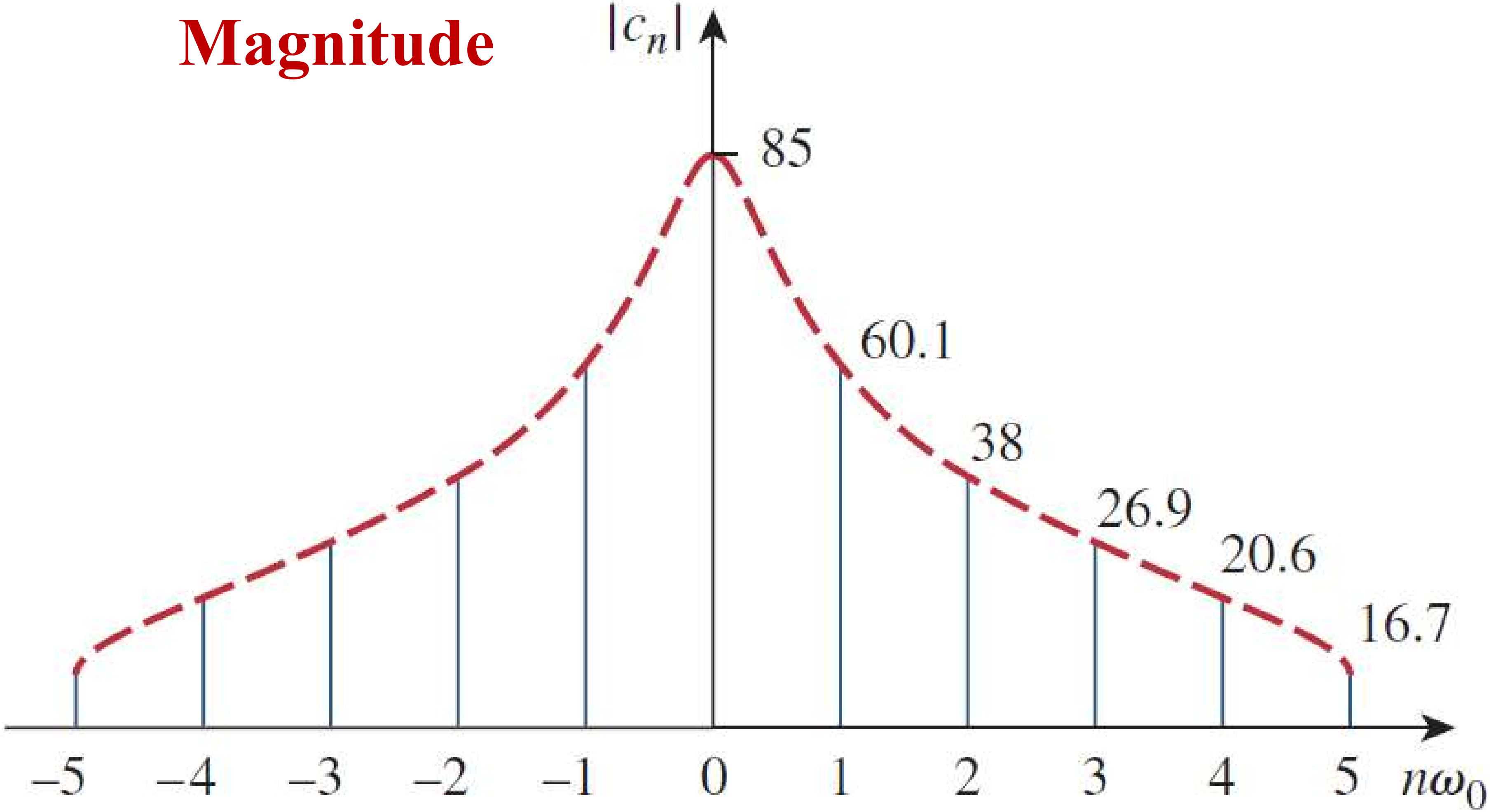
We may want to plot the complex frequency spectrum of *f(t)*. If we let $\boldsymbol{c_n = |c_n|\angle\theta_n}$, then,

$$|c_n| = \frac{85}{\sqrt{1+n^2}}, \qquad \theta_n = \tan^{-1} n$$

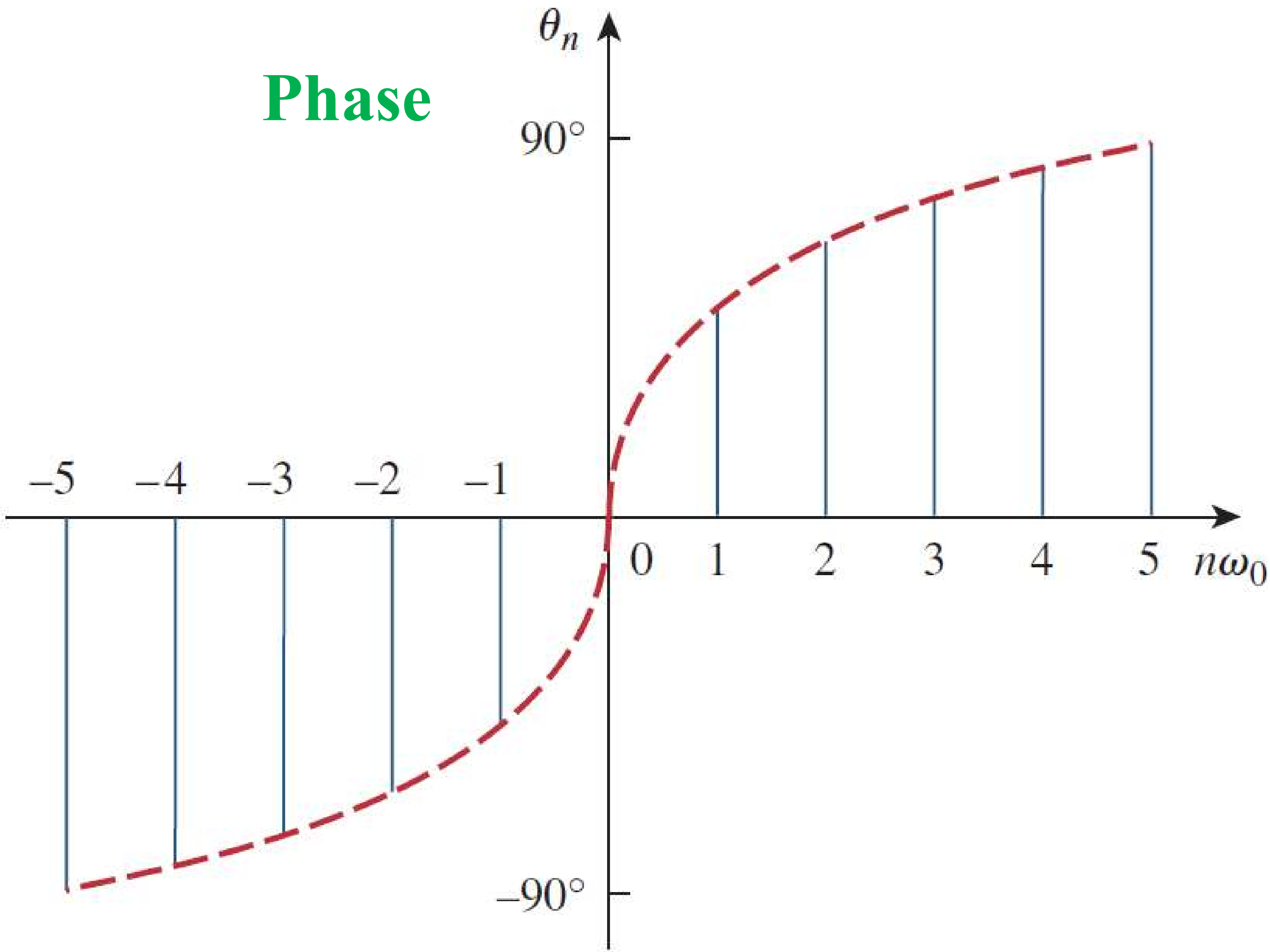
By inserting the positive and negative values of *n*, we can obtain the magnitude and phase of $\boldsymbol{c_n}$ versus $\boldsymbol{n\omega_o = n}$

Exponential Fourier series

Magnitude

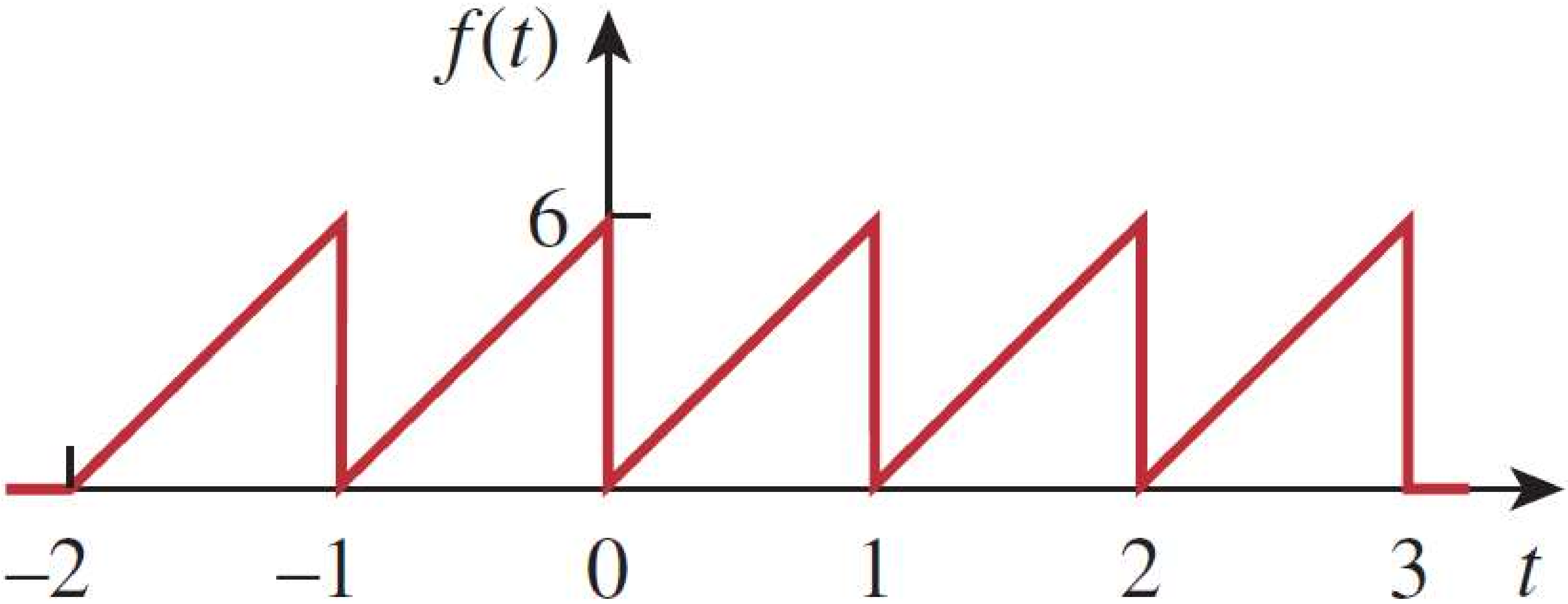


Exponential Fourier series



Exponential Fourier series

Question: **Find the exponential Fourier expansion of the sawtooth wave. Also plot amplitude and phase spectra?**



Exponential Fourier series

Solution: **As $\omega_o = 2\pi$ rad/s, Hence,**

$$c_n = \frac{1}{T}\int_0^T f(t)e^{-jn\omega_0 t}\,dt = \frac{1}{1}\int_0^1 te^{-j2n\pi t}\,dt$$

Applying integration,

$$c_n = \frac{e^{-j2n\pi t}}{(-j2n\pi)^2}(-j2n\pi t - 1)\Big|_0^1$$

$$= \frac{e^{-j2n\pi}(-j2n\pi - 1) + 1}{-4n^2\pi^2} = \frac{-j2n\pi}{-4n^2\pi^2} = \frac{j}{2n\pi}$$

Exponential Fourier series

This does not include the case when $n = 0$,So, considering this condition gives

$$c_0 = \frac{1}{T}\int_0^T f(t)\,dt = \frac{1}{1}\int_0^1 t\,dt = \frac{t^2}{2}\Big|_1^0 = 0.5$$

Hence,

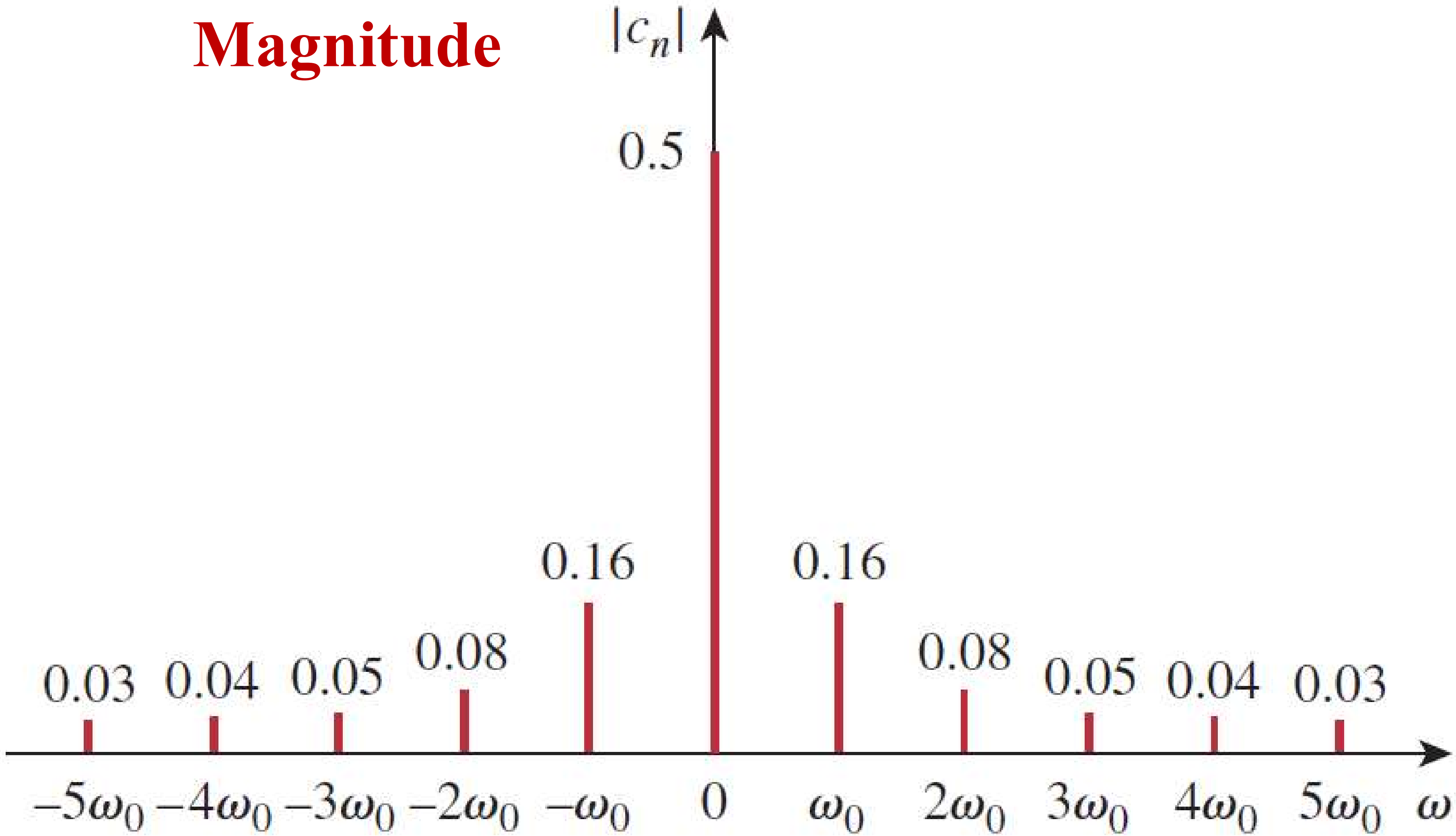
$$f(t) = 0.5 + \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} \frac{j}{2n\pi} e^{j2n\pi t}$$

So, the amplitude and phase is,

$$|c_n| = \begin{cases} \dfrac{1}{2|n|\pi}, & n \neq 0 \\ 0.5, & n = 0 \end{cases}, \qquad \theta_n = 90^\circ, \qquad n \neq 0$$

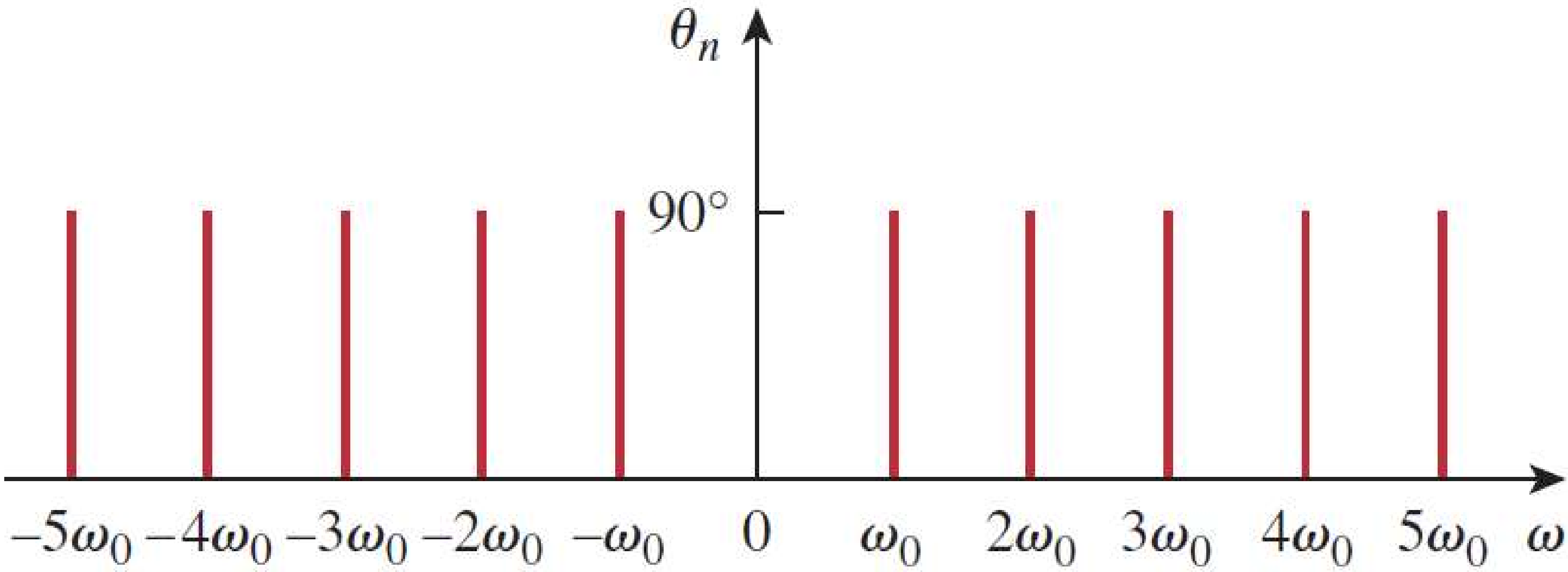
Exponential Fourier series

Magnitude



Exponential Fourier series

Phase



Objectives

- Orthogonal Projection and Fourier series
- Exponential Fourier series
- **Periodic and non-periodic sums**
- Shifting Property of signals
- Differentiation of signals

Periodic and non–periodic sums

- It is seen that ***not*** all the co-sinusoids or exponentials are periodic, as mentioned below,

$$g(t) = \sum_{k=1}^{\infty} c_k \cos(\omega_k t + \theta_k)$$

- **It is periodic only for any number ω_o that is all frequencies ω_k are integer multiple of ω_o**

- **If the sum is periodic then all possible ratios of ω_k are *rational***

- **ω_o: Largest number whose integer multiples *matches* each and every ω_k**

Non–periodic sums – Example 1

Consider a signal,

$$p(t) = 2\cos(\pi t) + 4\cos(2t)$$

Taking the ratio of two frequencies,

$$\frac{\pi t}{2t} = \boxed{\frac{\pi}{2}}$$

- **It is not a *rational number* so not a periodic signal**

Periodic sums – Example 2

Consider another signal,

$$q(t) = \cos(4t) + 5sin(6t) + 2cos(7t - \frac{\pi}{7})$$

is a periodic signal as frequencies 4,6 and 7 *rad/s* are integral multiples of *1 rad/s*

- **Fundamental frequency of signal is $\omega_o = 1\frac{rad}{s}$**
- **The period is 2π seconds**

Periodic sums – Example 3

For the signal,

$$f(t) = 1 + \cos(8\pi t) + 7.6sin(10\pi t)$$

It can be seen that 2π is the largest number whose integer multiples (×4 and ×5) matches frequencies 8π and 10π

- **Fundamental frequency of signal is $\omega_o = 2\pi \frac{rad}{s}$**
- **The period will be *1 second***
- **What are exponential Fourier series of *f(t)*?**

Exponential Fourier Series

we can re-write *f(t)* as,

$$f(t) = 1e^{j(0)\cdot 2\pi t} + \frac{e^{j(4)2\pi t} + e^{j(-4)2\pi t}}{2} + 7.6\,\frac{e^{j(5)2\pi t} - e^{j(-5)2\pi t}}{2j}$$

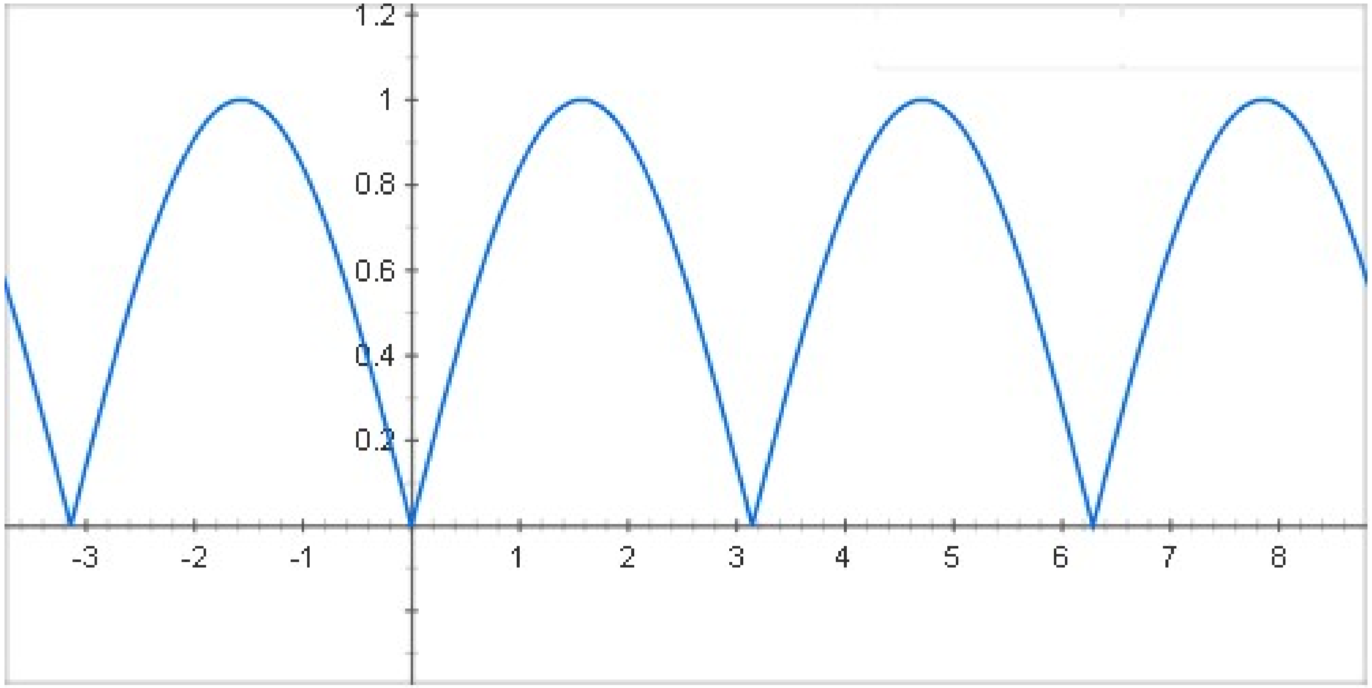
All the Fourier series coefficients F_n are zero except :

- $F_o = 1$
- $F_{4,-4} = \frac{1}{2}$
- $F_5 = \frac{7.6}{2j} = -j3.8$
- $F_{-5} = \frac{-7.6}{2j} = j3.8$

Periodic sums – Example 4

A sine modulus signal is shown below,

$$f(t) = |\sin(t)|$$



Find the exponential and compact Fourier coefficients for $f(t)$?

Periodic sums – Example 4

From the plot of $|\sin(t)|$, it can be seen that $\omega_o = 2\ rad/sec$ and $T = \pi\ seconds$, and it will be integrated over $[0, \pi]$, for exponential form:

$$F_n = \frac{1}{T}\int_T f(t)e^{-jn\omega_o t}dt = \frac{1}{\pi}\int_0^{\pi} sin(t)e^{-jn2t}dt$$

Solving the integral over the period gives,

$$F_n = -\frac{1}{2\pi}\left(\frac{e^{j(1-2n)\pi} - 1}{1-2n} + \frac{e^{-j(1+2n)\pi} - 1}{1+2n}\right)$$

Exponential Fourier series

$$F_n = \frac{1}{\pi}\left(\frac{1}{1-2n} + \frac{1}{1+2n}\right) = \frac{2}{\pi}\left(\frac{1}{1-4n^2}\right)$$

The exponential Fourier series for $|\sin(t)|$ is,

$$f(t) = \sum_{n=-\infty}^{\infty} \frac{2}{\pi}\left(\frac{1}{1-4n^2}\right) e^{jn2t}$$

The coefficients for compact form (for $n>1$) are,

$$c_n = 2|F| = 2\sqrt{\left[\frac{2}{\pi}\left(\frac{1}{1-4n^2}\right)\right]^2 + 0^2} = \frac{1}{\pi}\frac{1}{n^2-\frac{1}{4}}$$

$$\theta_n = \angle F_n = \pi\, rad$$

Compact form of Fourier series

Now, the compact form,

$$c_0 = F_0 = \frac{2}{\pi}$$

$$f(t) = \frac{2}{\pi} + \sum_{n=1}^{\infty} \frac{1}{\pi} \frac{1}{n^2 - \frac{1}{4}} cos(n2t + \pi)$$

As we know that *f(t)* is *continuous*, so the Fourier series *converges* to *f(t)* for all values of *t*

Objectives

- Orthogonal Projection and Fourier series
- Exponential Fourier series
- Periodic and non-periodic sums
- Shifting Property of signals
- Differentiation of signals

Shifting property

The shifting property states that,

$$f(t) \Leftrightarrow F_n \Rightarrow f(t-t_o) \Leftrightarrow F_n e^{-jn\omega_o t_o}$$

Expressing *f(t)* in Fourier series,

$$f(t)=\sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

replacing t with $t-t_o$ both sides,

$$f(t-t_o)=\sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o (t-t_o)}=\sum_{n=-\infty}^{\infty} \left(F_n e^{-jn\omega_o t_o}\right) e^{jn\omega_o t)}$$

The expression in the parenthesis is n-th Fourier coefficient of $f(t-t_o)$, proving shifting property

Time scaling property

Previously, we have seen that for $|\sin(t)|$

$$f(t) = \sum_{n=-\infty}^{\infty} \frac{2}{\pi}\left(\frac{1}{1-4n^2}\right)e^{jn2t}$$

to see *time scaling property*, we introduce

$$g(t) = \left|sin\left(\frac{t}{2}\right)\right|$$

note that $g(t) = f\left(\frac{t}{2}\right)$, replacing t with $\frac{t}{2}$ gives

$$g(t) = \sum_{n=-\infty}^{\infty} \frac{2}{\pi}\left(\frac{1}{1-4n^2}\right)e^{jnt}$$

Time scaling property

and for compact form,

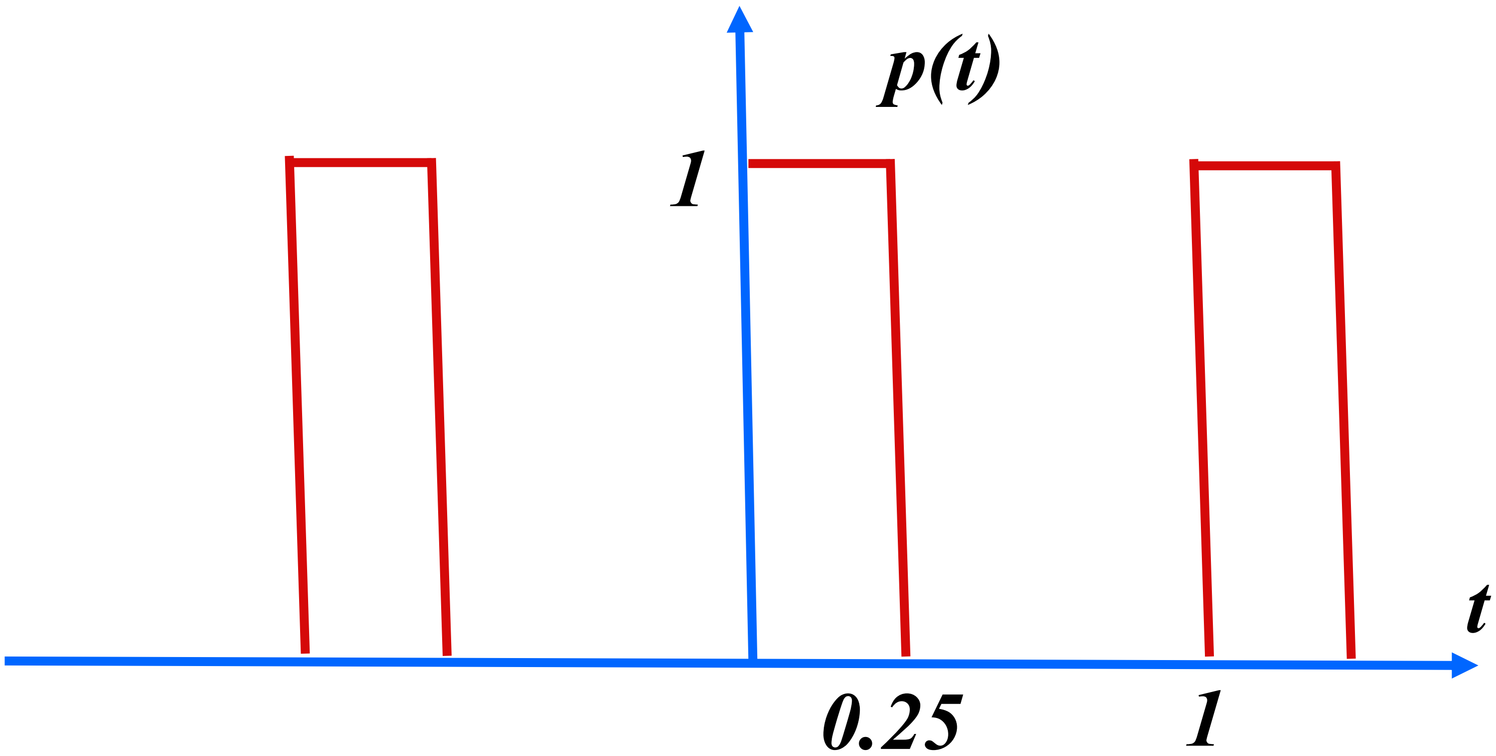
$$g(t) = \frac{2}{\pi} + \sum_{n=1}^{\infty} \frac{1}{\pi} \frac{1}{n^2 - \frac{1}{4}} \cos(nt + \pi)$$

- **We may observe a *stretching* or *squashing* of a periodic waveform corresponds to a change in *period* and *fundamental frequency***

- $g(t)$ **is stretched by factor of 2**

Periodic sums – Example 5

Question: **Find the exponential and compact form of Fourier series of given signal having *T=1 s* and *duty cycle 25%* and amplitude 1 unit?**



Periodic sums – Example 5

Solution: **We can express the signal as,**

$$p(t) = \begin{cases} 1 & 0 < t < D \\ 0 & D < t < 1 \end{cases} \qquad for\ D = 0.25$$

The signal has period of *1 s* so fundamental frequency is 2π , evaluating Fourier coefficients,

$$P_n = \frac{1}{T}\int_T p(t)e^{-jn\omega_o t}dt = \frac{1}{1}\int_0^D e^{-jn2\pi t}dt$$

For the case $n = 0$,

$$P_o = D$$

Periodic sums – Example 5

For the case $n \neq 0$,

$$P_n = \left.\frac{e^{-jn2\pi t}}{-jn2\pi t}\right|_0^D = \frac{e^{-jn2\pi D} - 1}{-jn2\pi t} = \frac{\sin n\pi D}{n\pi} e^{-jn\pi D}$$

So, the exponential form will be,

$$p(t) = \sum_{n=-\infty}^{\infty} \frac{\sin n\pi D}{n\pi} e^{j(n2\pi t - n\pi D)}$$

and compact form will be,

$$p(t) = D + \sum_{n=1}^{\infty} \frac{2\sin n\pi D}{n\pi} \cos(n2\pi t - n\pi D)$$

Periodic sums – Example 6

Question: **Find the compact trigonometric Fourier series for $q(t)$ having time period $T = 4\ s$?**

$$q(t) = \begin{cases} 2t & 0 < t < 2s \\ 0 & 2 < t < 4s \end{cases}$$

Solution: **The fundamental frequency is $\omega_o = \frac{\pi}{2}\ rad/s$**

First, for $n = 0$,

$$Q_o = \frac{1}{4}\int_0^2 2t dt = \frac{1}{4} t^2\Big|_0^2 = 1$$

Periodic sums – Example 6

secondly, for all other values of *n*,

$$Q_n = \frac{1}{4}\int_0^2 2te^{-jn\frac{\pi}{2}t}dt = \frac{1}{2}\int_0^2 t\frac{d}{dt}\cdot\left[\frac{e^{-jn\frac{\pi}{2}t}}{-jn\frac{\pi}{2}}\right]dt$$

using integration by part will result into,

$$Q_n = \begin{cases} \dfrac{j2}{\pi n} & for\ even\ n > 0 \\ -\dfrac{4 + j2\pi n}{\pi^2 n^2} & for\ odd\ n \end{cases}$$

Compact Form – Example 6

after finding the magnitude and phase of Q_n, for even and odd terms, we can write compact form as,

$$q(t) = 1 + \sum_{n=2(even)}^{\infty} \frac{4}{\pi n} cos\left(n\frac{\pi}{2}t + \frac{\pi}{2}\right) + \sum_{n=1(odd)}^{\infty} \frac{4\sqrt{4+\pi^2 n^2}}{\pi^2 n^2}$$

$$\times\, cos\left(n\frac{\pi}{2}t + \pi + tan^{-1}\frac{\pi n}{2}\right)$$

Objectives

- Orthogonal Projection and Fourier series
- Exponential Fourier series
- Periodic and non-periodic sums
- Shifting Property of signals
- **Differentiation of signals**

Differentiation of Signal – Example 7

Question: **Determine the exponential Fourier series and compact trigonometric Fourier series of $g(t)$?**

$$g(t) = \frac{df}{dt}$$

where,

$$f(t) = |\sin(t)|$$

Differentiation of Signal – Example 7

Solution:

From Example 4, $\omega_o = 2\,\frac{\text{rad}}{\text{s}}$

For continuous *f(t)* , differentiation property states,

$$\boxed{\textit{For Continuous } f(t): \qquad \frac{df}{dt} \Longleftrightarrow j\omega F_n = jn\omega_o F_n}$$

can be used, so putting the value of ω_0, and Fourier coefficient,

$$G_n = jn\omega_o F_n = jn2F_n \qquad \textbf{Eq. 1}$$

Compact form – Example 7

as we seen in example 4, the Fourier coefficient of $|\sin(t)|$ is,

$$F_n = \frac{2}{\pi}\frac{1}{1-4n^2}$$

Putting the value of F_n in Eq. 1 gives the Fourier coefficient for $g(t)$,

$$G_n = j\frac{n4}{\pi}\frac{1}{1-4n^2}$$

Compact form – Example 7

To obtain compact form, we differentiate *f(t) term by term*,

$$g(t) = \frac{df}{dt} = \frac{d}{dt}\left(\frac{2}{\pi}\right) + \sum_{n=1}^{\infty} \frac{1}{\pi} \frac{1}{n^2 - \frac{1}{4}} \frac{d}{dt}(cos(2nt + \pi))$$

Solving differentiation gives,

$$g(t) = \sum_{n=1}^{\infty} \frac{1}{\pi} \frac{2n}{n^2 - \frac{1}{4}} cos(n2t + \frac{3\pi}{2})$$

Summary

- **A periodic signal can be represented in orthogonal projections forms having a finite time period and satisfying Dirichlet's conditions**
- **The Dirichlet conditions are sufficient to satisfy Fourier series**
- **A compact way to represent Fourier series is to put in to exponential form**
- **The plots of the magnitude and phase of c_n versus $n\omega_o$ are called the *complex amplitude spectrum* and *complex phase spectrum* of *f(t)*, respectively**

Summary

- Periodic and non-periodic signals can be used for Fourier series taking their integral multiple of fundamental frequency

- It is periodic only for any number ω_o that is all frequencies ω_k are integer multiple of ω_o

- A stretching or squashing of a periodic waveform corresponds to a change in period and fundamental frequency

- The time scaling property holds for compact and exponential form of Fourier Transform

Further reading

1. Ch. 6 (page 190-208), E. Kudeki and D. C. Munson, ***Analog Signals and Systems,*** Prentice Hall, 2008.
2. Ch. 17 (page 760-780, page 787-791), C. K. Alexander and M. Sadiku, ***Fundamentals of Electric Circuits***, 5th ed., McGraw-Hill, 2013.
3. Ch. 15 (page 751-773), J. D. Irwin, and R. M. Nelms. ***Basic Engineering Circuit Analysis,*** 10th ed. Wiley, 2011.

Preview:

1. Ch. 6 (page 208-218), E. Kudeki and D. C. Munson, ***Analog Signals and Systems,*** Prentice Hall, 2008.

Homework 8

Deadline: 10:00 PM, 20th April, 2022

Thank you!