Basic Electrical and Electronics Engineering

LECTURE 2.4

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BEEE102L

Basic Electrical and Electronics Engineering

1. DC Circuits
2. AC Circuits
3. Magnetic Circuits
4. Electrical Machines
5. Semiconductor Devices and Applications
6. Digital Systems
7. Sensors and Transducers

Books

Text Book

[1] John Bird, ‘Electrical circuit theory and technology’, Newnes publications, 4^{th} Edition, 2010.

Reference Book

[2] Allan R. Hambley, ‘Electrical Engineering - Principles & Applications’ Pearson Education, First Impression, 6/e, 2013.

[3] Simon Haykin, ‘Communication Systems’ , John Wiley & Sons, 5^{th} Edition, 2009.

[4] Charles K Alexander , Mathew N O Sadiku, ‘Fundamentals of Electric Circuits’, Tata Mc Graw Hill , 2012.

[5] Batarseh, ‘Power Electronics Circuits’, Wiley, 2003.

[6] W. H. Hayt, J. E. Kemmerly and S. M. Durbin, ‘Engineering Circuit Analysis’, 6/e, Tata McGraw Hill, New Delhi, 2011.

[7] Fitzger ald, Higgabogan, Grabel, ‘Basic Electrical Engineering’, 5^{th} ed, McGraw Hill, 2009.

[8] S.L.Uppal, ‘Electrical Wiring Estimating and Costing’ , Khannapublishers, NewDelhi, 2008.

Module II. AC Circuits

Alternating voltages and currents, AC values,
Single Phase RL, RC, RLC Series circuits,
Power in AC circuits - Power Factor,
Three Phase Systems,
Star and Delta Connection,
Three Phase Power Measurement,
Electrical Safety, Fuses and Earthing, Residential wiring.

BASIC TRIGONOMETRY

ESSENTIAL IDENTITIES

$$\sin(\alpha+\beta)=\sin\alpha\cos\beta+\cos\alpha\sin\beta$$

$$\cos(\alpha+\beta)=\cos\alpha\cos\beta-\sin\alpha\sin\beta$$

$$\sin(-\alpha)=-\sin\alpha$$

$$\cos(-\alpha)=\cos\alpha$$

SOME DERIVED IDENTITIES

$$\sin(\alpha-\beta)=\sin\alpha\cos\beta-\cos\alpha\sin\beta$$

$$\cos(\alpha-\beta)=\cos\alpha\cos\beta+\sin\alpha\sin\beta$$

$$\sin\alpha\cos\beta=\frac{1}{2}\sin(\alpha+\beta)+\frac{1}{2}\sin(\alpha-\beta)$$

$$\cos\alpha\cos\beta=\frac{1}{2}\cos(\alpha+\beta)+\frac{1}{2}\cos(\alpha-\beta)$$

RADIANS AND DEGREES

2π radians $=$ 360 degrees

$$\theta(\text{rads})=\frac{180}{\pi}\theta\,(\text{degrees})$$

ACCEPTED EE CONVENTION

$$\sin(\omega t+\frac{\pi}{2})=\sin(\omega t+90°)$$

APPLICATIONS

$$\cos\omega t=\sin(\omega t+\frac{\pi}{2})$$

$$\sin\omega t=\cos(\omega t-\frac{\pi}{2})$$

$$\cos\omega t=-\cos(\omega t\pm\pi)$$

$$\sin\omega t=-\sin(\omega t\pm\pi)$$

PHASORS

- The notion of solving ac circuits using phasors was first introduced by Charles Steinmetz in 1893.
- Sinusoids are easily expressed in terms of phasors, which are more convenient to work with than sine and cosine functions.

A phasor is a complex number that represents the amplitude and phase of a sinusoid.

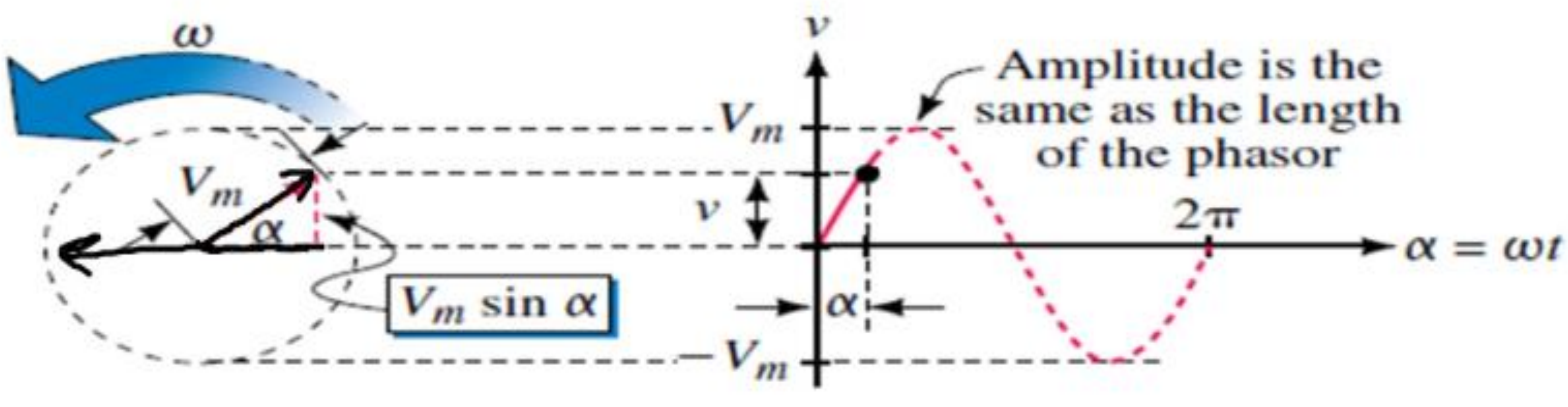
A complex number z can be written in rectangular form as $j = \sqrt{-1}$

$$z = x + jy$$

x is the real part of z; y is the imaginary part of z.

Phasor

- For analysis of alternating circuits, a sinusoidal quantity (voltage or current) is represented by a *line of definite length rotating in anti-clock wise direction with the same angular velocity as that of the sinusoidal quantity*.
- This rotating line is called a 'Phasor'.
- A sinusoid is specified by its amplitude and phase angle, they are termed as Phasor.
- *A phasor is a complex number that represents the amplitude and phase of a sinusoid.*



(a) Phasor

(b) Resulting sine wave

a sinusoidal waveform can be created by plotting the vertical projection of a phasor that rotates in the counterclockwise direction at constant angular velocity ω. If the phasor has a length of V_m, the waveform represents voltage; if the phasor has a length of I_m, it represents current. Note carefully: **Phasors apply only to sinusoidal waveforms.**

Phasors

A phasor is a complex number that represents the amplitude and phase of a sinusoid.

Representation

There are four ways of representing a phasor in the mathematical form *viz.*

(i) Rectangular form

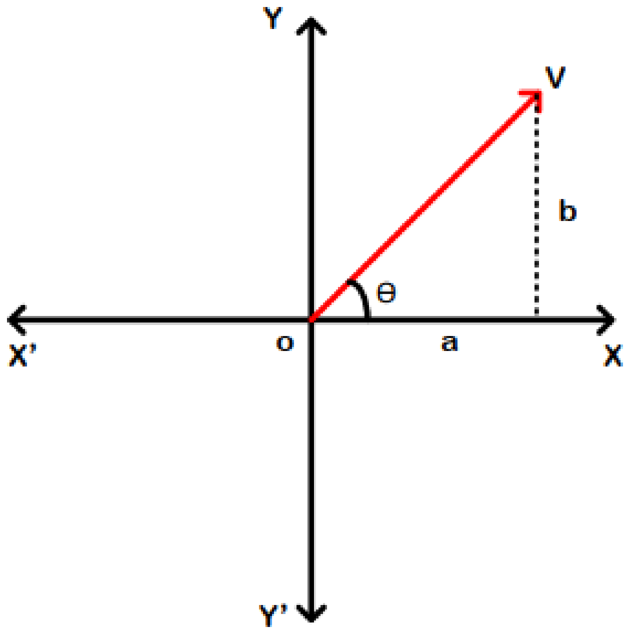
(ii) Trigonometrical form

(iii) Polar form

(iv) Exponential form.

Rectangular form

In this representation, the phasor is resolved into horizontal and vertical components and is expressed in the complex form



$$\mathbf{V} = a + jb$$

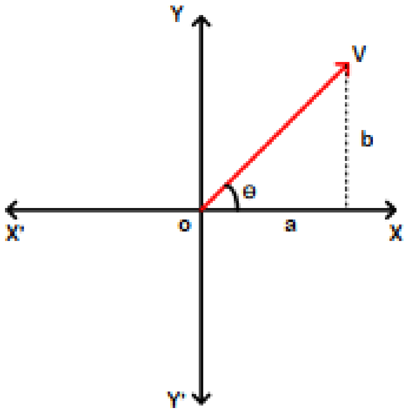
$$V = \sqrt{a^2 + b^2}$$

$$\theta = tan^{-1}\frac{b}{a}$$

where $\mathbf{j} = \sqrt{-1}$; a is the real part of **V**; b is the imaginary part of **V**.

Trigonometrical form

It is similar to the rectangular form except that in-phase and quadrature components of the phasor are expressed in the trigonometrical form.



$$a = V\cos\theta$$

$$b = V\sin\theta$$

$$\mathbf{V} = V\,(\cos\theta + j\sin\theta)$$

In general

$$\mathbf{V} = V\,(\cos\theta \pm j\sin\theta)$$

Polar form

$$\mathbf{V} = V\angle\theta$$

V is the magnitude of the phasor and q is its phase angle measured CCW from the reference axis

In general $$\mathbf{V} = V\angle \pm \theta$$

Exponential form

According to Euler's equation :

$$e^{j\theta} = cos(\theta) + jsin(\theta)$$
$$e^{-j\theta} = cos(\theta) - jsin(\theta)$$

Trigonometrical form of **V**

$$\mathbf{V} = V(cos(\theta) \pm jsin(\theta))$$

$$\mathbf{V} = Ve^{\pm j\theta}$$

Basic Operations

$$\mathbf{V} = a + jb = V\angle\phi$$

Given the Complex number

$$\mathbf{V}_1 = a_1 + jb_1 = V_1\angle\theta_1 \qquad \mathbf{V}_2 = a_2 + jb_2 = V_2\angle\theta_2$$

Addition

$$\mathbf{V}_1 + \mathbf{V}_2 = (a_1 + a_2) + j(b_1 + b_2)$$

Subtraction

$$\mathbf{V}_1 - \mathbf{V}_2 = (a_1 - a_2) + j(b_1 - b_2)$$

Multiplication

$$\mathbf{V}_1\mathbf{V}_2 = V_1V_2\angle(\theta_1 + \theta_2)$$

Division

$$\frac{\mathbf{V}_1}{\mathbf{V}_2} = \frac{V_1}{V_2}\angle(\theta_1 - \theta_2)$$

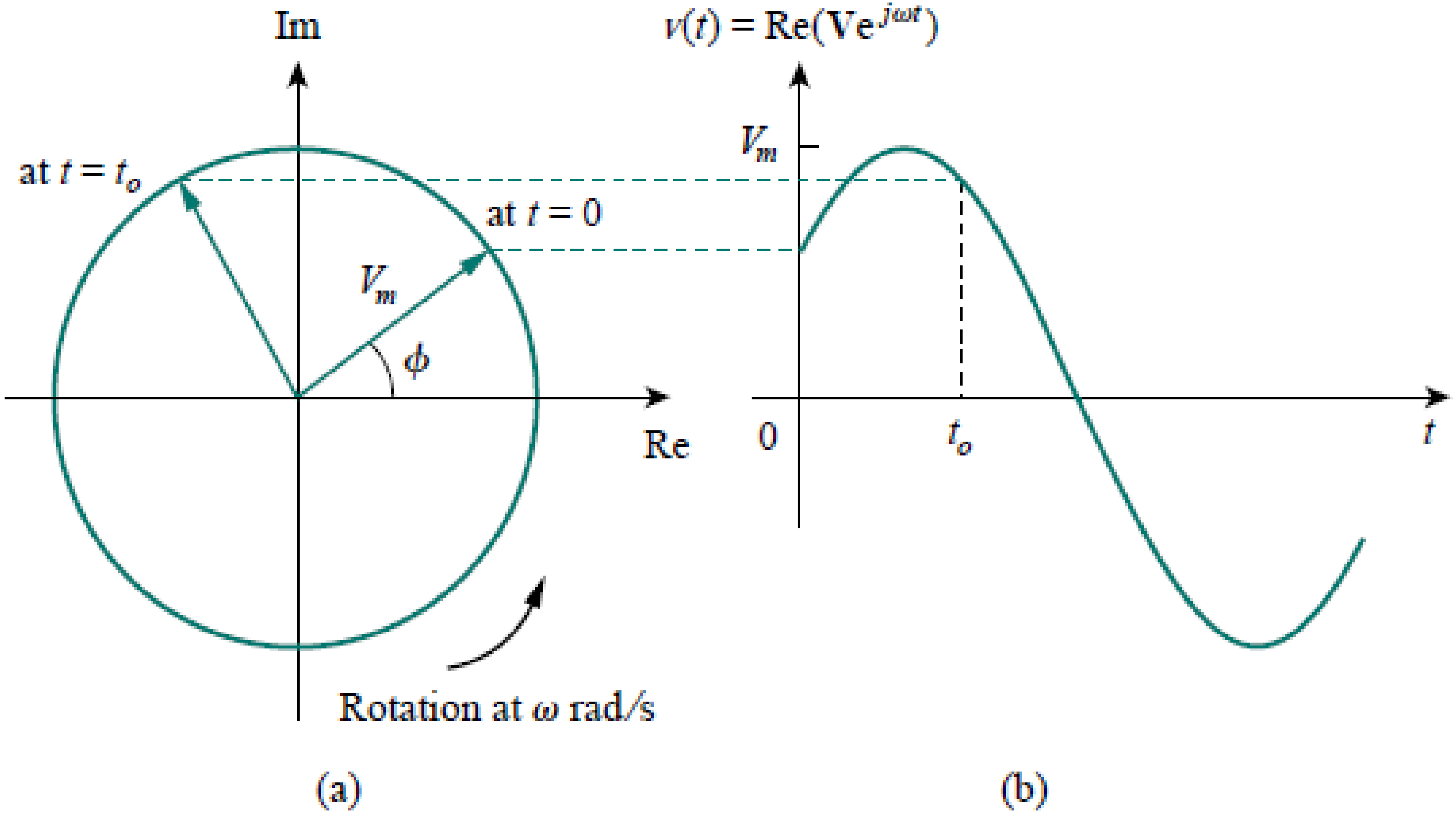
Reciprocal

$$\frac{1}{\mathbf{V}} = \frac{1}{V}\angle(-\theta)$$

Square Root

$$\sqrt{\mathbf{V}} = \sqrt{V}\angle(\theta/2)$$

Radians/seconds



Phasor Representation

Given a sinusoid

$$v(t) = V_m cos(\omega t + \phi)$$

$$v(t) = Re(V_m e^{j(\omega t+\phi)})$$

$$v(t) = Re(V_m e^{j\phi} e^{j\omega t})$$

$$v(t) = Re(\mathbf{V} e^{j\omega t})$$

$$\mathbf{V} = V_m e^{j\phi} = V_m \angle \phi$$

A phasor may be regarded as a mathematical equivalent of a sinusoid with the time dependence dropped.

V is thus the *phasor representation* of the sinusoid *v(t)*
i.e., a phasor is a complex representation of the magnitude and phase of a sinusoid.

$$v(t) = V_m cos(\omega t + \phi) \Leftrightarrow \mathbf{V} = V_m \angle \phi$$

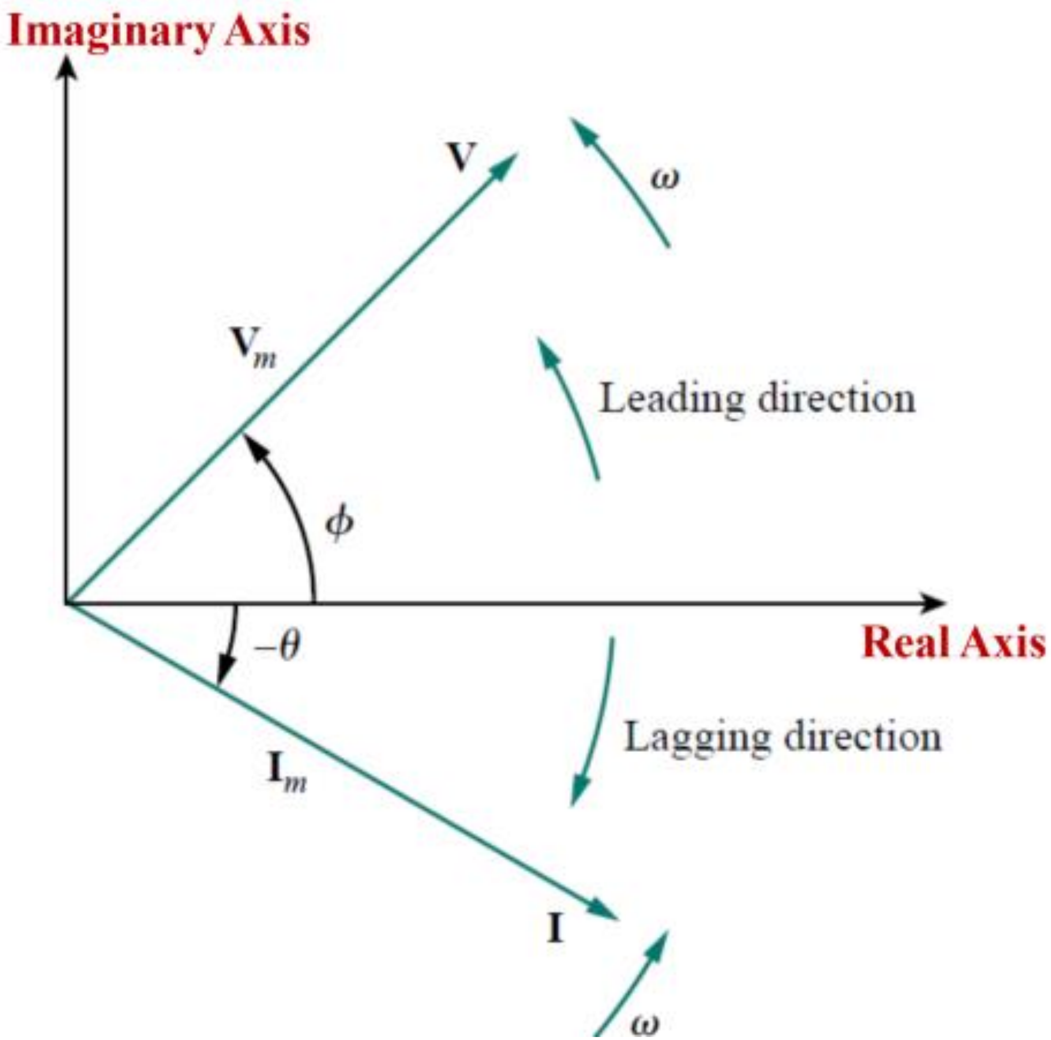
Sinusoid-Phasor Transformation

Time-domain representation	Phasor-domain representation
$V_m \cos(\omega t + \phi)$	$V_m \angle \phi$
$V_m \sin(\omega t + \phi)$	$V_m \angle \phi - 90^\circ$
$I_m \cos(\omega t + \theta)$	$I_m \angle \theta$
$I_m \sin(\omega t + \theta)$	$I_m \angle \theta - 90^\circ$

Phasor Diagram

$$\mathbf{V} = V_m \angle \phi$$

$$\mathbf{I} = I_m \angle -\theta$$



CONVERSION BETWEEN FORMS

Rectangular to Polar

$$\boxed{Z = \sqrt{X^2 + Y^2}}$$

$$\boxed{\theta = \tan^{-1} \frac{Y}{X}}$$

Polar to Rectangular

$$\boxed{X = Z \cos \theta}$$

$$\boxed{Y = Z \sin \theta}$$

Question 1

Convert the following from rectangular to polar form:

$$\mathbf{C} = 3 + j4$$

Convert the following from rectangular to polar form:

$$\mathbf{C} = 3 + j4$$

Solution:

$$Z = \sqrt{(3)^2 + (4)^2} = \sqrt{25} = 5$$

$$\theta = \tan^{-1}\left(\frac{4}{3}\right) = 53.13°$$

and

$$\mathbf{C} = \mathbf{5\angle 53.13°}$$

Question 2

Convert the following from polar to rectangular form:

$C = 10\,\angle 45°$

Convert the following from polar to rectangular form:

$$\mathbf{C} = 10 \angle 45°$$

Solution:

$$X = 10 \cos 45° = (10)(0.707) = 7.07$$

$$Y = 10 \sin 45° = (10)(0.707) = 7.07$$

and

$$\mathbf{C = 7.07 + \mathit{j}7.07}$$

Question 3

Convert the following from rectangular to polar form:

$$\mathbf{C} = -6 + j3$$

Convert the following from rectangular to polar form:

$$\mathbf{C} = -6 + j3$$

Solution:

$$Z = \sqrt{(6)^2 + (3)^2} = \sqrt{45} = 6.71$$

$$\beta = \tan^{-1}\left(\frac{3}{6}\right) = 26.57^\circ$$

$$\theta = 180^\circ - 26.57^\circ = 153.43^\circ$$

and

$$\mathbf{C = 6.71 \angle 153.43^\circ}$$

Question 4

Convert the following from polar to rectangular form:

$\mathbf{C} = 10 \angle 230°$

Convert the following from polar to rectangular form:

$$\mathbf{C} = 10 \angle 230°$$

Solution:

$$X = Z \cos \beta = 10 \cos(230° - 180°) = 10 \cos 50°$$
$$= (10)(0.6428) = 6.428$$
$$Y = Z \sin \beta = 10 \sin 50° = (10)(0.7660) = 7.660$$

and

$$\mathbf{C} = \mathbf{-6.43 - j7.66}$$

Mathematical operations with complex numbers

$$\boxed{j = \sqrt{-1}}$$

Thus, $$\boxed{j^2 = -1}$$

and $$j^3 = j^2 j = -1j = -j$$

with $$j^4 = j^2 j^2 = (-1)(-1) = +1$$

$$j^5 = j$$

and so on. Further,

$$\frac{1}{j} = (1)\left(\frac{1}{j}\right) = \left(\frac{j}{j}\right)\left(\frac{1}{j}\right) = \frac{j}{j^2} = \frac{j}{-1}$$

and $$\boxed{\frac{1}{j} = -j}$$

Complex Conjugate

The **conjugate** or **complex conjugate** of a complex number can be found by simply changing the sign of the imaginary part in the rectangular form or by using the negative of the angle of the polar form. For example, the conjugate of

$$\mathbf{C} = 2 + j3$$

is

$$2 - j3$$

as shown in Fig. 14.53. The conjugate of

$$\mathbf{C} = 2 \angle 30^\circ$$

is

$$2 \angle -30^\circ$$