2026aug01

02_15001

15. Chapter 15: Alternating Current (AC)

02_15002

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15.1 Complex Number Math

a) History of Number (in brief)

There were always:

Integers (positive integers) 1, 2, 3, ...

↓

Fractions: Ratios of integers

$$\frac{I_1}{I_2} \text{ etc.}$$

also now called rational numbers

However, ancient Egyptian mathematicians had anxiety about fractions that were NOT unit fractions

Unit fractions $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \ldots$

But I recall, they though $2/3$ was OK.

↓

Irrational Number $\sqrt{2}$ that be written as fractions

Greek mathematicians had anxiety about irrationals

↓

0 = zero sometime in the Middle Ages

and it made place value arithmetic possible

↓

1500?

Negative numbers
$-1, -2, -\frac{1}{2}, -\sqrt{2} \ldots$

sometime 17th century?

Real numbers: All of the above

Complex Numbers: $\sqrt{-2}$ ...
Sometime 17th century?

b) Complex Number Math

They can be written
as an ordered pair (x, y),
and so are sort of vectors,
But they point in an
abstract complex number space
and have a funny multiplication rule.

To make this rule we write them

$$\underbrace{z}_{\text{The complex number}} = \underbrace{x}_{\text{the real part}} + i \underbrace{y}_{\text{the imaginary part}}$$

Note $z_1 + z_2 = (x_1 + x_2) + i(y_1 + y_2)$

z, x, y are just generic symbols

real and imaginary are just jargon names.
Both x and y are real numbers.

and i is the imaginary unit
that has the property
that $i^2 = -1$,
and so somewhat symbollicay $i = \sqrt{-1}$.

c) Complex Number Rules

i) But i gives the funny multiplication rule

$$Z_1 Z_2 = (x_1 + iy_1)(x_2 + iy_2)$$
$$= x_1 x_2 - y_1 y_2 + i(x_1 y_2 + y_1 x_2)$$

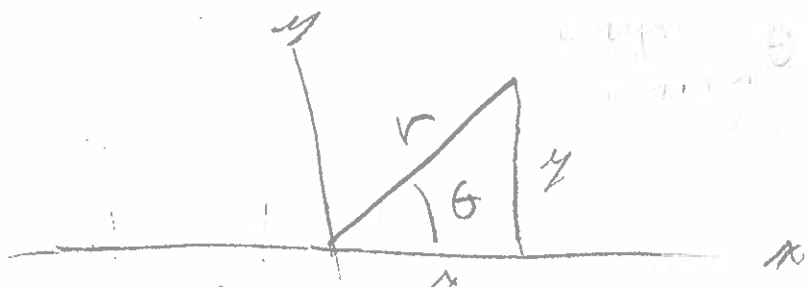
ii) Complex conjugate operation $*$ < Asterisk

z^* is the complex conjugate of z $\quad z^* = (x + iy)^* = x - iy$ (Arf-356)

iii) Modulus or Magnitude (Arf-354, 356)

$$r = |z| = \sqrt{zz^*}$$
$$= \sqrt{(x+iy)(x-iy)}$$
$$= \sqrt{x^2 + y^2} \quad \text{a pure real}$$

iv) Argand diagram (Just x-y plane)



$\tan\theta = y/x$

$\theta = \tan^{-1}(x, y)$

$\tan^{-1}$ is inverse tangent
also called arctangent and symbolized arctan or atan

θ is called ~~call~~ the argument but in AC circuitry the phase and with symbol ϕ.

02.05006

In fact, computer languages often us

$$\theta = \mathrm{atan}\left(\frac{y}{x}\right)$$

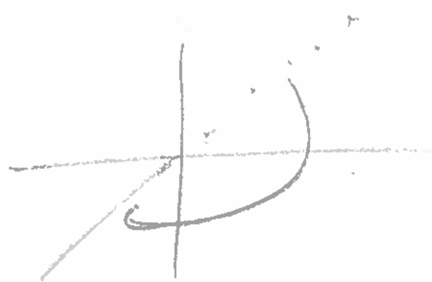
but assume $x > 0$

$\therefore$ $\theta = \mathrm{atan}\left(\frac{y_+}{x_+}\right)$ is correct and is in $[0, \pi/2]$

$\theta = \mathrm{atan}\left(\frac{y_-}{x_+}\right)$ is correct and is in $[-\frac{\pi}{2}, 0]$

but $\theta = \mathrm{atan}\left(\frac{y_+}{x_-}\right)$ gives a value in $[-\frac{\pi}{2}, 0]$ and you have add π

and $\theta = \mathrm{atan}\left(\frac{y_-}{x_-}\right)$ gives a value in $[0, \frac{\pi}{2}]$ and you have to add $-\pi$



Of course $\theta + 2\pi n$ where n is the same as θ in most contexts but NOT in complex math

v) $\theta = \tan^{-1}(x, y)$ (evaluated correctly)

is the phase of a complex number and phase is why complex numbers are so useful for quantities with phase as in AC.

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vi) Now $z = x + iy$ is Cartesian representation

good for addition and subtraction (see p. 02-15004)

and $z = re^{i\theta}$ is the polar representation

good for multiplication and division

For example

$$z_1 z_2 = r_1 r_2 e^{i[\theta_1 + \theta_2]}$$ The moduli multiply and the phases add.

vii) How to change representations

$$r = |z| = \sqrt{zz^*}$$

and $\theta = \tan^{-1}(x, y)$

and gives $z = re^{i\theta}$

Note,
$z^* = (re^{i\theta})^*$
$= r(e^{i\theta})^*$
$= r[\cos\theta + i\sin\theta]^*$
$= r[\cos\theta - i\sin\theta]$
$= re^{-i\theta}$
as expected

Now Euler's formula (Wik)

$$e^{i\theta} = \cos\theta + i\sin\theta$$

Proven by equating infinite series expansions.

viii) Re and Im functions for $z = x + iy$

$$\mathrm{Re}[z] = x$$
$$\mathrm{Im}[z] = y$$

The outputs are pure reals

02.15008

d) What are Complex Numbers Good For?

Well, they are rich area for new math theorems

But for our purposes, they treat quantities with phases very easily.

AC without complex number math involves endless trigonometric transformations with trig identities,

But these operations are simple with complex numbers:

$e^{i\theta}$ replaces $\cos\theta$ and $\sin\theta$.

Of course, electric currents are real quantities, and so at the end of solution you have to convert to pure real solutions but those tricks are well known.

Complex numbers are actually essential for quantum mechanics, but that is a story for later.

Now intro textbooks in physics like ours generally feel introducing complex number math is beyond scope, but they have introduce AC by klutzy procedures. including phasor diagrams which are just a way of visualizing complex numbers in the x-y plane. NOT a useful way either for most people it seems.

e) A conflict of Conventions

The imaginary unit is given the symbol $i = \sqrt{-1}$ in all fields except electrical engineering where j is used.

In electrical engineering, i is used for current as a function of time (i.e., $i = i(t)$) and I is used for current amplitude (maximum absolute value) (Text-625).

Also $v = v(t)$ is voltage as a function of time and V for amplitude.

We will stick with the electrical engineering convention But for clarity, I'll use I_0 and V_0 for amplitudes.

15010

15.2 Intro to AC circuitry by Means of a driven LRC circuit

a) We solved (in great detail) the undriven LRC circuit p. 02-14011 ff.

Here we add a AC driven:

Note, the real-in-both-senses driver is $V(t) = V_0 \cos(\omega t)$ and $t = 0$ is just a fiducial $t = 0$ point for a perpetually repeating periodic solution.

$$V(t) = V_0 e^{i\omega t}$$

amplitude, and so a constant

$e^{j\omega t}$ is the complex time variation.

$$e^{j\omega t} = \cos(\omega t) + j\sin(\omega t)$$ by Euler's formula (Wik)

real part

imaginary part

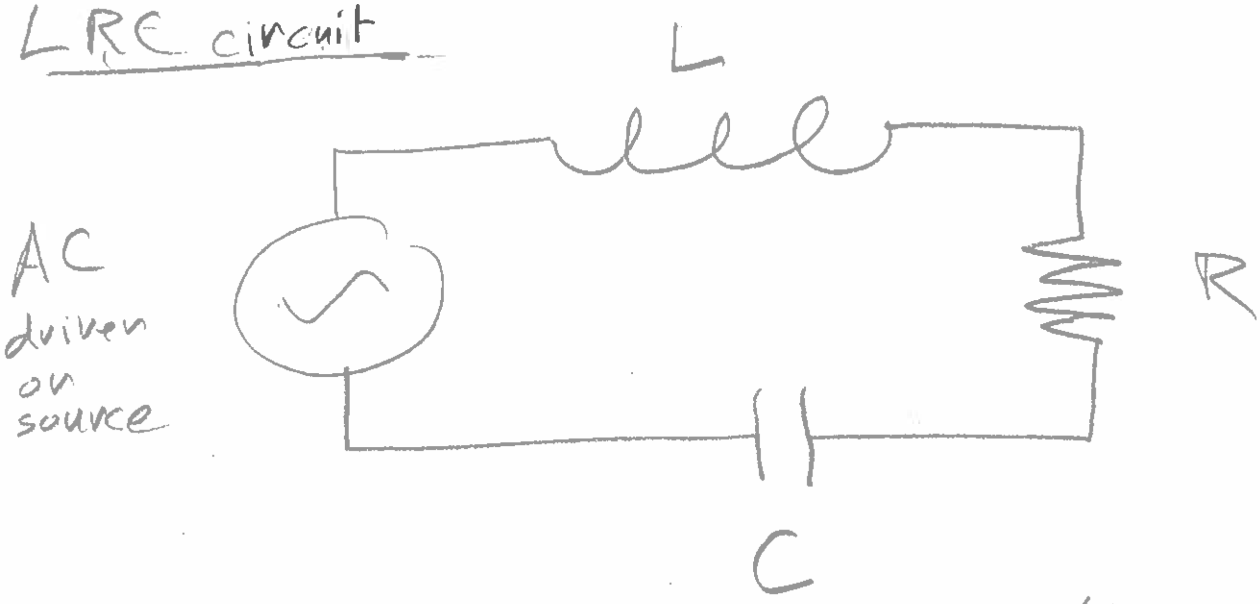
$j = \sqrt{-1}$ is complex unit (here j NOT i)

Polar form of a complex number with modulus $r = 1$

Just a phase factor "includes" sinusoidal functions

(2026aug01) (0215U11)

b) LRC circuit



We apply Kirchhoff's Voltage law

$$v(t) = Li' + iR + \frac{q}{C}$$

$q = q(t)$ and Q_0 is amplitude

$$q = \int_0^t i\,dt + Q_0$$

and so this is an integro-DE.

We differentiate to get a

2nd order ordinary linear DE

highest derivative of order 2

Just one independent variable time t

Independent means one cannot be created from the other

solutions of the homogeneous part can be added to make new solutions and 2 independent solutions of the homogeneous part

The homogeneous part
is the part containing only $i(t)$
and its derivatives.

The driver $v(t) = V_0 e^{i\omega t}$
is the inhomogeneous part.

Note the homogeneous solutions
can always be added
to the inhomogeneous solution
since they contribute
nothing to the Left-Hand-Side (LHS).

The homogeneous solutions decay
as shown on p. 02_14011ff
exponentially and can be used
to match initial conditions,
but then decay. See p 02_14011ff.
They are transient solutions

Here, we are only interested
in the inhomogeneous periodic solution.

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The DE is

$$\underbrace{j\omega V_0 e^{j\omega t}}_{\text{where } v = V_0 e^{j\omega t}} = L i'' + i'R + i/C$$

We ansatz (ie, assume) a solution of the form

$$i = \underbrace{\tilde{I}_0}_{\text{current amplitude which the unknown to solve for.}} e^{j\omega t}$$

$\tilde{I}$, because we define I_0 differently below

If this is the right form, it will solve the DE.

Substituting in $i = \tilde{I}_0 e^{j\omega t}$ cancelling common factors gives

$$j\omega \frac{V_0}{\tilde{I}_0} = -\omega^2 L + j\omega R + \frac{1}{C}$$

$$\frac{V_0}{\tilde{I}_0} = \frac{-\omega L}{j} + R + \frac{1}{j\omega C}$$

Now $\frac{1}{j} = \frac{j}{j^2} = -j$

$$\frac{V_0}{\tilde{I}_0} = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

Cartesian form of a complex number like $z = x + iy$

which in polar form is

$$\frac{V_0}{I_0} = \sqrt{R^2 + \left(wL - \frac{1}{wC}\right)^2}\, e^{j\phi}$$

Symbol ϕ is more common in this context than θ used on p. 02_15004

where phase $\phi = \tan^{-1}\left(\dfrac{wL - \frac{1}{wC}}{R}\right)$

Note, $\cos\phi = \dfrac{R}{Z}$

$\sin\phi = \dfrac{X_L - X_C}{Z}$

where there is NO $\tan^{-1}()$ ambiguity since $R > 0$ always (see p. 02_15006)

Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$ (Text-633)

capital Z with bar to make it clean
it is NOT the complex z nor Zorro

where $X_L = wL$ is inductive reactance (Text-629)

$X_C = \dfrac{1}{wC}$ is capacitive reactance (Text-627)

Now $\phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$ Text-633

$|e^{j(wt-\phi)}| = 1$

The complex solution for $i = i(t)$ is

$$i = \tilde{I}_0 e^{jwt} = \frac{V_0}{Z} e^{j(wt - \phi)} = I_0 e^{j(wt-\phi)}$$

Now if you go back to our original integro DE on p. 02_15011, all the coefficients of I_0 and q are pure real.

Note $I_0 \equiv \dfrac{V_0}{Z}$ is a new definition

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Now pure real x_1 times
complex $z_2 = x_2 + i y_2$
gives $x_1 z_2 = x_1 x_2 + i x_1 y_2$.

So those coefficients
cannot change
the real/imaginary part of i
into imaginary/real terms.

So the real and imaginary
parts of $i(t) = \frac{V}{Z} e^{j(\omega t - \phi)}$
on the right-hand side (RHS)
separately satisfy the
real and imaginary parts
on the left hand side (LHS)
∴ which are $V_0 \cos\omega t$ and $V_0 \sin\omega t$
using Euler's formula
$e^{j\omega t} = \cos\omega t + j\sin\omega t$
(see p. 02_15007)

∴ $i(t) = \frac{V_0}{Z} \cos(\omega t - \phi)$

where $\frac{V_0}{Z} = I_0$ is the current solution

and $V(t) = V_0 \cos(\omega t)$

So they differ by the phase factor

02_150016

c) But what is $q(t)$ from p. 02-150011?

Well, $q(t) = \int_0^t i\, dt' + Q_0 = \int_0^t \frac{V}{Z}\cos(\omega t' - \phi)\, dt' + Q$

$$= \frac{V_0}{Z}\frac{1}{\omega}\sin(\omega t' - \phi)\Big|_0^t + Q_0$$

$$= \frac{V_0}{Z}\frac{1}{\omega}\left[\sin(\omega t - \phi) - \sin(-\phi)\right] + Q_0$$

$$= \frac{V_0}{Z}\frac{1}{\omega}\left[\sin(\omega t - \phi) + \sin\phi\right] + Q_0$$

and so $q(t=0) = Q_0$ which is NOT a surprise,

and what satisfies Kirchhoff's Voltage law at time $t = 0$?

Well,
$$V(t=0) = V_0\cos(\omega t)\Big|_{t=0} = V_0$$

$$i(t=0) = \frac{V_0}{Z}\cos(\omega t - \phi)\Big|_{t=0} = \frac{V_0}{Z}\cos(-\phi) = \frac{V_0}{Z}\cos\phi$$

$$i'(t=0) = \frac{V_0}{Z}\left[-\omega\sin(\omega t - \phi)\right]_{t=0} = \frac{V_0}{Z}\omega\sin\phi$$

And so Kirchhoff's law at $t = 0$ is

$$V_0 = L\frac{V_0}{Z}\omega\sin\phi + \frac{V_0}{Z}\cos\phi\, R + \frac{Q_0}{C}$$

$$Q_0 = CV_0\left[1 - \frac{\omega L}{Z}\sin\phi - \frac{R}{Z}\cos\phi\right]$$

$$= CV_0\left[1 - \frac{X_L(X_L - X_C)}{Z^2} - \left(\frac{R}{Z}\right)^2\right]$$

using results on p. 02-150014

I don't see any further simplifications.
There is nothing special about this Q_0 value.
It is just the capacitor charge for the perpetually repeating periodic solution when $V(t = 2\pi n) = V_0$ where n is any integer (i.e., $n = 0, \pm 1, \pm 2, \pm 3, \ldots$).

d) In AC work, the averages over a period (and every period is the same for perpetual AC) of $\cos^2(\omega t)$, $\sin^2(\omega t)$, and $\cos(\omega t)\sin(\omega t)$.

One can find those using usual trigonometric functions, but in the interest of complex math, let's use complex way.

Recall Euler's formula (Wiki)

$$e^{\pm i\theta} = \cos\theta \pm i\sin\theta$$

$$\therefore \quad \frac{1}{2}(e^{i\theta} \pm e^{-i\theta}) = \begin{cases} \cos\theta & \text{for + case} \\ i\sin\theta & \text{for the − case} \end{cases}$$

$$\therefore \quad \cos\theta = \frac{1}{2}(e^{i\theta} + e^{-i\theta}) \text{ and } \sin\theta = \frac{1}{2i}(e^{i\theta} - e^{-i\theta})$$

$$\therefore \quad \left.\begin{matrix} \langle\cos^2\theta\rangle \\ \langle\sin^2\theta\rangle \end{matrix}\right\} = \frac{1}{2\pi}\int_0^{2\pi}\left(\pm\frac{1}{4}\right)\left(e^{2i\theta} + e^{-2i\theta} \pm 2\right)d\theta$$

$$= \frac{1}{2} + \underbrace{\frac{1}{2\pi}\left(\pm\frac{1}{4}\right)\left[\frac{e^{2i\theta}}{2i} + \frac{e^{-2i\theta}}{-2i}\right]_0^{2\pi}}_{= 0 \text{ since } e^{i(\theta+2\pi)} = e^{i\theta}}$$

$$\left\{\begin{matrix} \langle\cos^2\theta\rangle \\ \langle\sin^2\theta\rangle \end{matrix}\right\} = \frac{1}{2}$$

and then the root-mean-square (RMS) averages are

$$\sqrt{\left\{\begin{matrix} \langle\cos^2\theta\rangle \\ \langle\sin^2\theta\rangle \end{matrix}\right\}} = \frac{1}{\sqrt{2}}$$

Now $\langle\cos\theta\sin\theta\rangle = \frac{1}{2\pi}\int_0^{2\pi}\frac{1}{4i}(e^{2i\theta} - e^{-2i\theta})\,d\theta$ by difference of squares

$\langle\cos\theta\sin\theta\rangle = 0$ similarly to

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d) Power and Power Factor

$$P_{source} = i V_{source}$$

$$= \frac{V_0}{Z}\cos(\omega t - \phi)\, V_0 \cos\omega t$$

$$= \frac{V_0^2}{Z}\left[\cos\omega t \cos\phi + \sin\omega t \sin\phi\right]\cos\omega t$$

$$\langle P_{source}\rangle = \frac{V_0^2}{Z}\left[\cos\phi\left(\tfrac{1}{2}\right) + \langle \sin\omega t\cos\omega t\rangle \sin\phi\right]$$

$$\langle \sin\omega t \cos\omega t\rangle$$

$$= \frac{1}{T}\int_0^T \sin\omega t \cos\omega t \, dt$$

$$= \frac{1}{T}\left[\frac{\sin^2\omega t}{2}\right]_0^T$$

$$\Leftarrow 0$$

$$\langle P_{source}\rangle = \frac{1}{2} I_0 V_0 \cos\phi$$

Note, we count potential rises and potential drops both as positive

$$\therefore \langle P_{source}\rangle = \langle P_{sink}\rangle$$

$$P_{sink} = i V_{resistor} = i^2 R$$

$$= \left[\frac{V_0}{Z}\cos(\omega t - \phi)\right]^2 R$$

$$= \frac{V_0^2}{Z}\sin^2(\omega t - \phi)\cos\phi$$

$$\langle P_{sink}\rangle = \frac{V_0^2}{Z}\cos\phi \, \frac{1}{T}\int_{\phi/\omega}^{T+\phi/\omega} \sin^2(\omega t - \phi)\, dt$$

$$\frac{1}{\omega T}\int_0^{2\pi} \sin^2 x \, dx$$

where $T = \frac{1}{f} = \frac{2\pi}{\omega}$

and $x = \omega t - \phi$

$dx = \omega\, dt$

so $x(t = \phi/\omega) = 0$

$x(t = T + \phi/\omega) = \omega T = 2\pi$

$$\frac{1}{2\pi}\int_0^{2\pi} \sin^2 x\, dx$$

$$\frac{1}{2\pi}\int_0^{2\pi}\frac{1}{2}(1-\cos 2x)\,dx$$

$$= \frac{1}{2\pi}\frac{1}{2}\left[x - \frac{\sin 2x}{2}\right]_0^{2\pi}$$

$$= \frac{1}{2}$$

$$\langle P_{sink}\rangle = \frac{V_0^2}{Z}\cos\phi\left(\frac{1}{2}\right)$$

$$= \frac{1}{2}\frac{V_0^2}{Z}\cos\phi$$

$$= \frac{1}{2} I_0 V_0 \cos\phi = I_{RMS} V_{RMS}\cos\phi$$

(see p.02_15021 for RMS)

$\therefore$ $P_{ave} = \frac{1}{2} I_0 V_0 \cos\phi = \frac{1}{2} \frac{V_0^2}{Z} \cos\phi$

where $I_0 \equiv \frac{V_0}{Z}$ see p 02_15014

and $\cos\phi = \frac{R}{Z}$ see p. 02_15014

Now

Power factor $\equiv$ $\cos\phi = \begin{cases} \frac{R}{Z} & \text{in general} \\ 1 & \text{if } \phi = 0 \\ 0 & \text{if } \phi = \pi/2 \end{cases}$
(Text - 636)

Recall Impedance $Z \equiv \sqrt{R^2 + (X_L - X_C)^2}$

(p. 02_15014)

and so the power factor
is maximum for $X_L - X_C = 0$

which implies $\omega L - \frac{1}{\omega C} = 0$

or $\omega_0 = \frac{1}{\sqrt{LC}}$ or $f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$

This is impedance matching
for a simple LRC circuit.

From p. 02_14010, $\omega_0 = \frac{1}{\sqrt{LC}}$ is the
resonance frequency of the simple LC circuit

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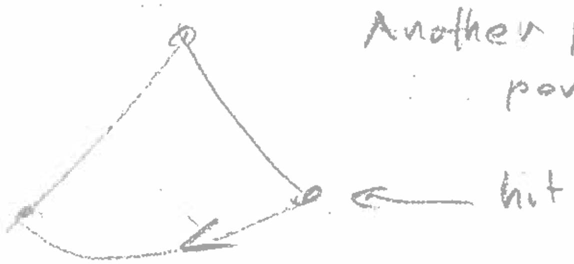
Since $I_0 = \frac{V_0}{Z}$

$$I_0(\omega = \omega_0) = \frac{V_0}{R} > I_0(\omega \neq \omega_0).$$

So on resonance you get the biggest oscillations.

This is actually a general result in physics. If you drive a system at its resonance you get the biggest oscillations since the driver isn't fighting the system.

You know this on the playground. When you pumped a playground swing on resonance, the oscillations get bigger and bigger until you got scared and quit.



Another perspective hit a pendulum just on resonance, you always adding to its energy not trying to cancel it.

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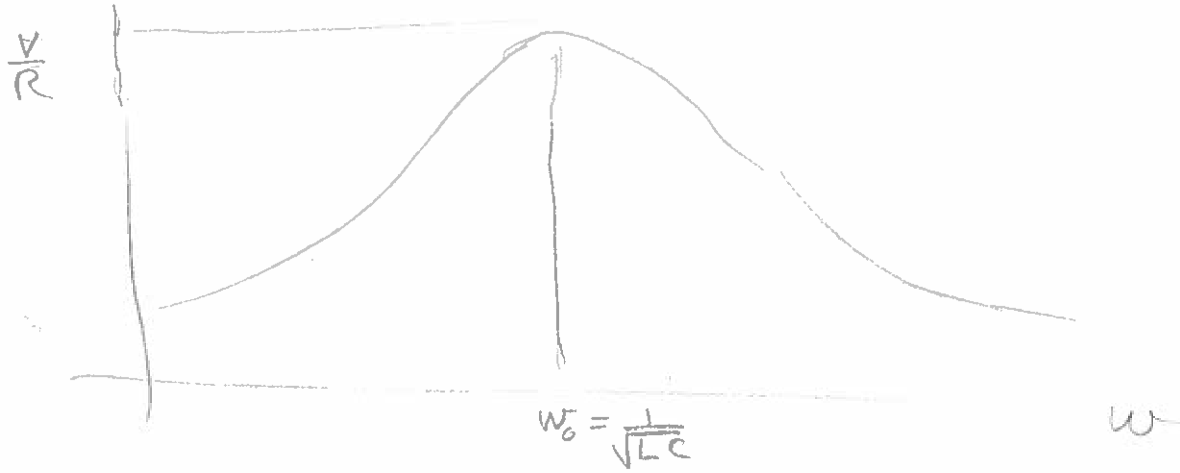

$$I_0 = \frac{V_0}{\sqrt{R^2 + (wL - \frac{1}{wC})^2}}$$

It is not a symmetric peak

However, $w' = w_0 + \delta w$

$$= w_0 (1 + \frac{\delta w}{w_0})$$

$$wL - \frac{1}{wC} \doteq w_0 L (1 + \frac{\delta w}{w_0}) - \frac{1}{(w_0 + \delta w) C}$$

$$\doteq w_0 L (1 + \frac{\delta w}{w_0}) - \frac{1}{w_0 C}(1 - \frac{\delta w}{w_0})$$

$$= \sqrt{\frac{L}{C}}(1 + \frac{\delta w}{w_0}) - \sqrt{\frac{L}{C}}(1 - \frac{\delta w}{w_0})$$

$$= \sqrt{\frac{L}{C}}(2 \frac{\delta w}{w_0})$$

$$\therefore I_0 \doteq \frac{V_0}{\sqrt{R^2 + 4\frac{L}{C}(\frac{\delta w}{w_0})^2}}$$ to lowest order in small $\frac{\delta w}{w_0}$

and so the $I_0(w)$ function is symmetrical about the resonance w_0 for small δw or to 1^{st} order in $\frac{\delta w}{w_0}$

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e) RMS Values, Power factor and Quality factor

Recall from p. 02_15018

$$P_{ave} = \tfrac{1}{2} I_0 V_0 \underbrace{\cos\phi}_{\text{power factor}}$$

and since Power$(t) = iv$

$$= i^2 R$$

$$= \frac{v^2}{R}$$

it follows that

$$I_{RMS} = \sqrt{\langle i^2 \rangle} = \frac{1}{\sqrt{2}} I_0$$

$$V_{RMS} = \sqrt{\langle v^2 \rangle} = \frac{1}{\sqrt{2}} V_0$$

Which are the RMS (root mean square) values (text - 636).

Then $P_{ave} = I_{RMS} V_{RMS} \cos\phi$

and it seems I_{RMS} and V_{RMS} are the quantities often cited

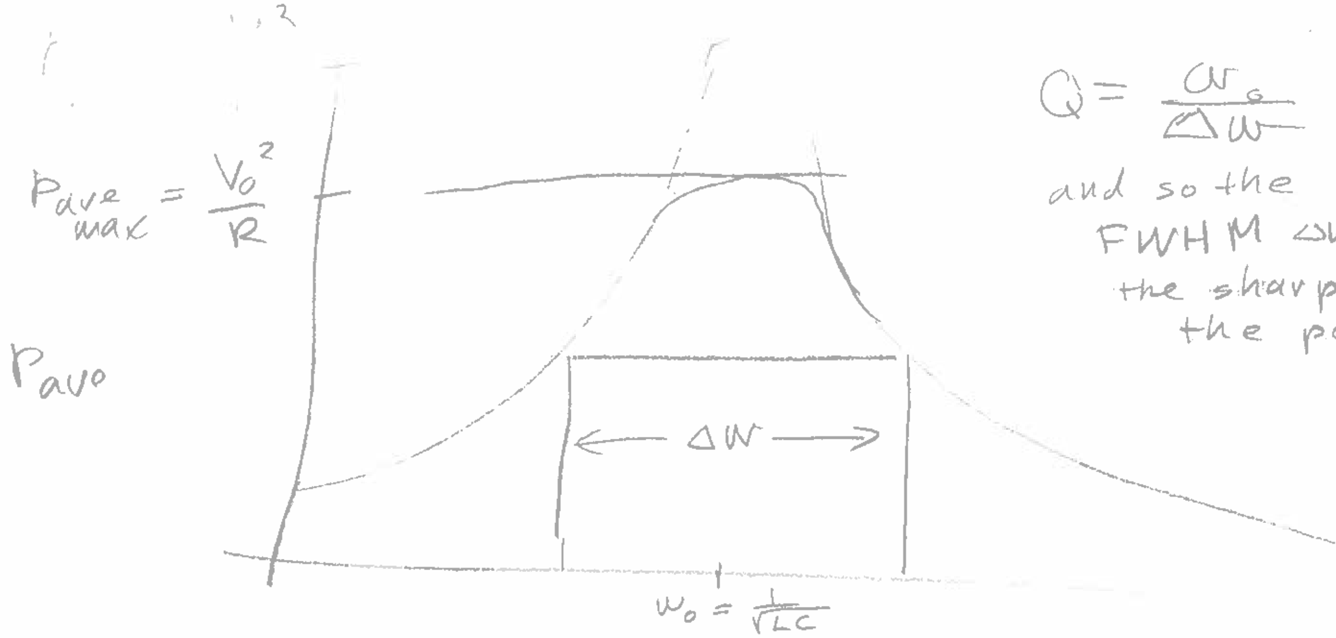
02_15022

NOT change

The quality factor = $Q = \frac{\omega_0}{\Delta\omega}$

where $\Delta\omega$ is chosen such that it is the ... full-width half maximum (FWHM) of Power (Text - 642).

For the LRC circuit



$Q = \frac{\omega_0}{\Delta\omega}$ and so the smaller FWHM $\Delta\omega$, the sharper the peak

Recall from 02_15018

$$P_{ave} = \frac{1}{2}\frac{V_0^2}{Z}\cos\phi$$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$ and $\cos\phi = \frac{R}{Z}$

$\frac{V_{RMS}^2}{R} \cdot 1$ is the maximum power

$$P_{ave} = \frac{V_{RMS}^2 R}{Z^2} = \frac{V_{RMS}^2 R}{R^2 + (X_L - X_C)^2}$$

We can solve for a formula for the quality for the LRC circuit,

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02-15023

$$P_{ave} \triangleq \frac{V_{rms}^2 R}{R^2 + 4\frac{L}{C}\left(\frac{\delta\omega}{\omega_0}\right)^2}$$

to lowest order in $\frac{\delta\omega}{\omega_0}$ from p 02-15022

$$\triangleq \frac{1}{2}\frac{V_{rms}^2}{R}$$

allows you to solve for the quality factor as long as P_{ave} is sufficiently sharply peaked.

Note $\Delta\omega = 2\delta\omega_{H}$

FWHM

half-width half-maximum

$$\frac{1}{2}\frac{1}{R} = \frac{R}{R^2 + \frac{L}{C}\left(\frac{\Delta\omega}{\omega_0}\right)^2}$$

$$R^2 + \frac{L}{C}\left(\frac{\Delta\omega}{\omega_0}\right)^2 = 2R^2$$

$$\frac{L}{C}\left(\frac{\Delta\omega}{\omega_0}\right)^2 = R^2$$

$$\left(\frac{\Delta\omega}{\omega_0}\right)^2 = \frac{C}{L}R^2$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$C = \frac{1}{\omega_0^2 L}$$

$$L = \frac{1}{\omega_0^2 C}$$

$$Q = \frac{\omega_0}{\Delta\omega} = R\sqrt{\frac{C}{L}} = \frac{R}{\omega_0 L} = \omega_0 RC$$

(Wiki: Quality factor: RLC circuit confirms)

There may NOT be a general exact analytic solution for quality factor Q.

02_15024

15.3 Transformers:

Step-up transformer and step-down transformers

Vaguely generalizing from the LRC circuit

$$P_{ave} = I_{rms} V_{rms} \underbrace{\cos\phi}_{\text{Power factor}}$$

and so power transmission depends on product $I_{rms} V_{rms}$ which is generally true.

So you can transmit the same power as long as $I_{rms} V_{rms}$ is held constant.

Now Ohmic losses are $P_{sink} = I_{rms}^2 R$

(see p. 02_15017)

and so they can be reduced by making I_{rms} smaller.

So in general you want low I_{rms} and high V_{rms} for transmission.

[Transformers to be completed sine die]