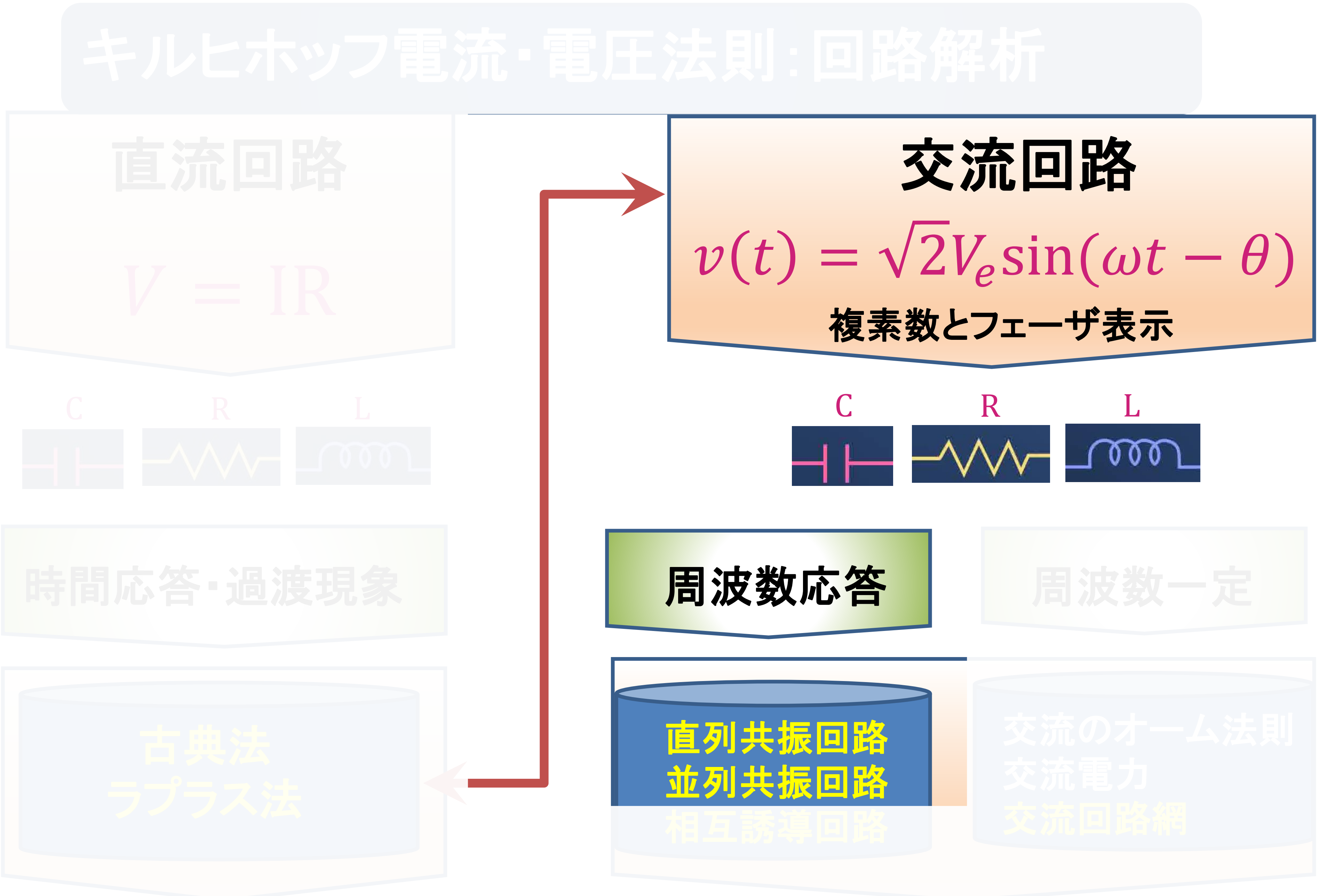
基礎電気回路CH-7

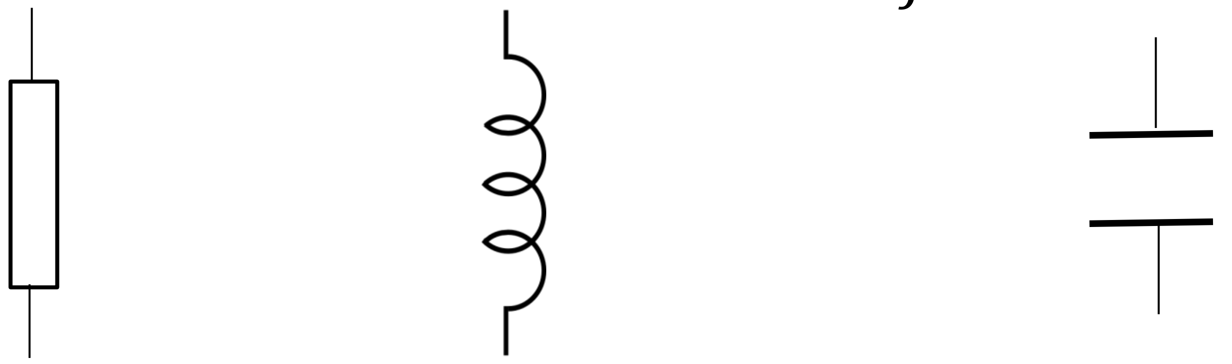


キルヒホッフ電流・電圧法則：回路解析
直流回路
V = IR
C
R
L
時間応答・過渡現象
古典法
ラプラス法
交流回路
$v(t)=\sqrt{2}V_e\sin(\omega t-\theta)$
複素数とフェーザ表示
C
R
L
周波数応答
直列共振回路
並列共振回路
相互誘導回路
周波数一定
交流のオーム法則
交流電力
交流回路網

交流回路の周波数特性

$$v(t) = \sqrt{2}V_e \sin(\omega t - \theta)$$

$R\angle 0$ $\quad$ $j\omega L = \omega L \angle 90^0$ $\quad$ $\dfrac{1}{j\omega C} = \dfrac{1}{\omega C}\angle -90^o$



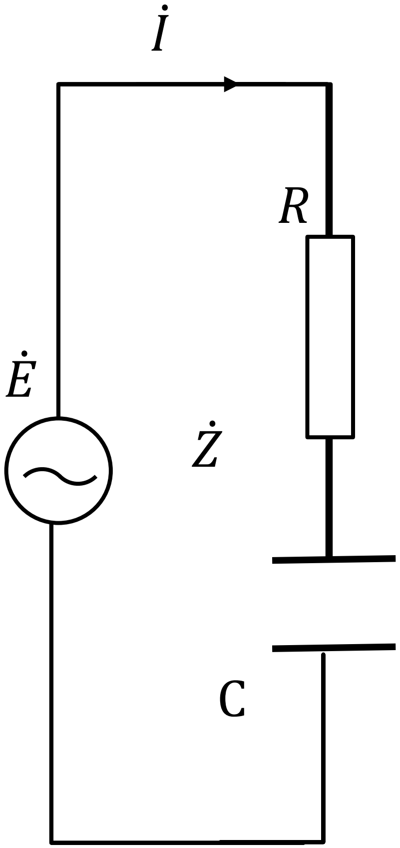
周波数特性: f $\quad$ **角周波数特性:** $\omega = 2\pi f$

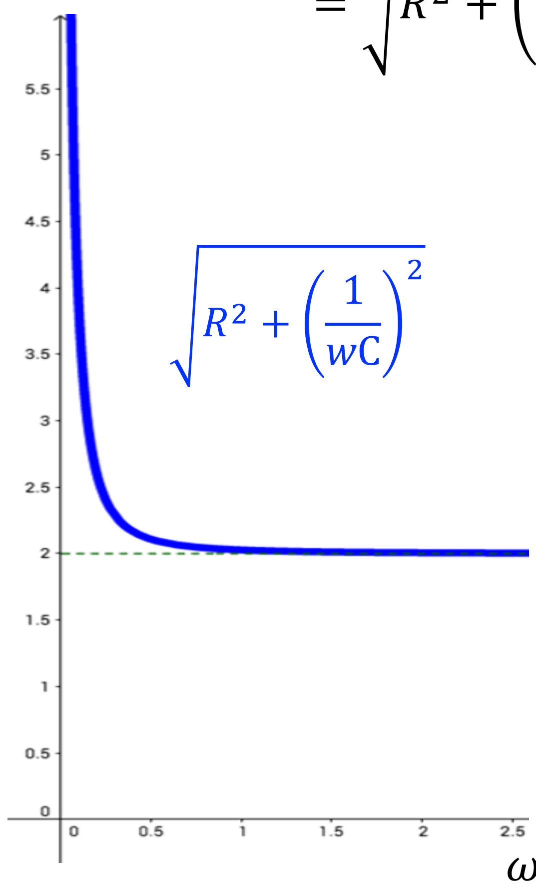
抵抗RとキャパシタンスCの直列回路の周波数特性

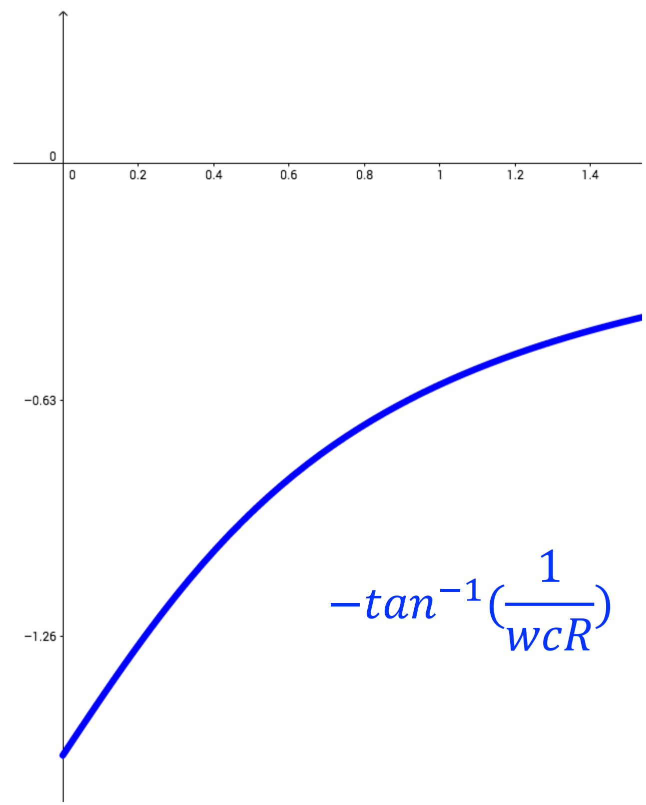
インピーダンス: $\dot{Z} = R + \frac{1}{jwC}$

$$\dot{Z} = R - j\frac{1}{wC}$$

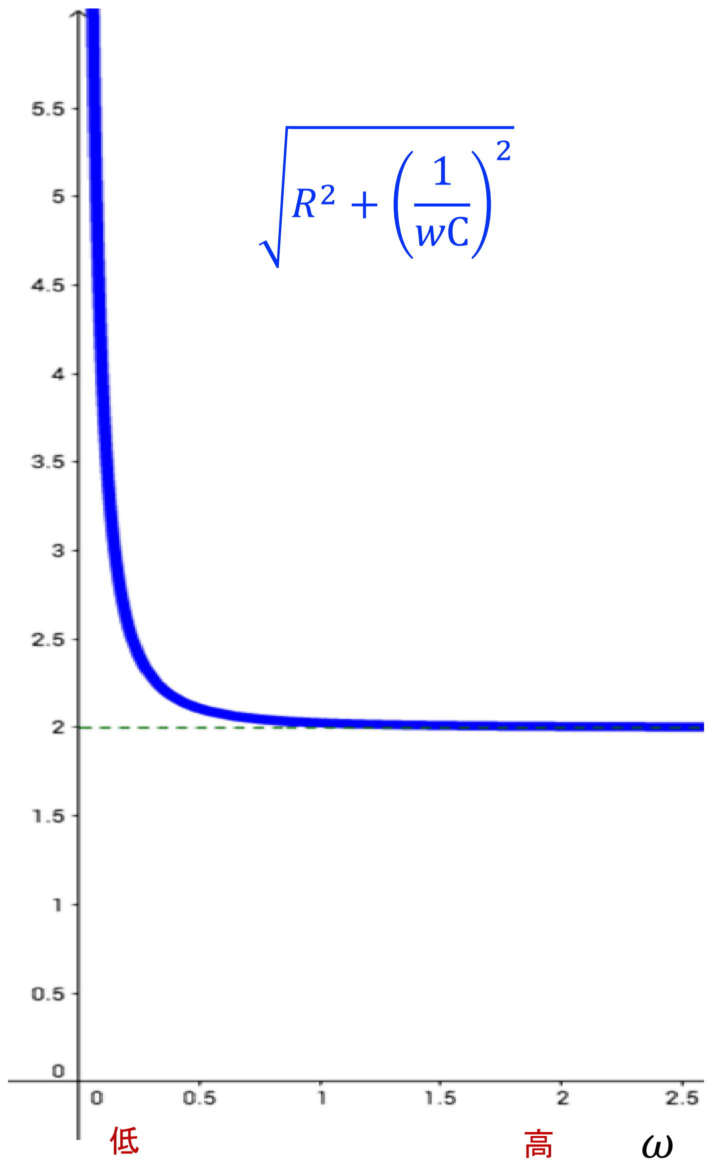
$$= \sqrt{R^2 + \left(\frac{1}{wC}\right)^2} \angle -tan^{-1}\left(\frac{1}{wcR}\right)$$

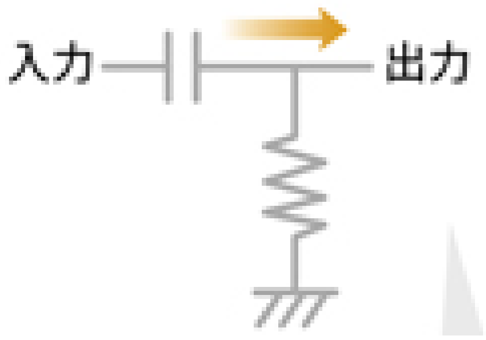




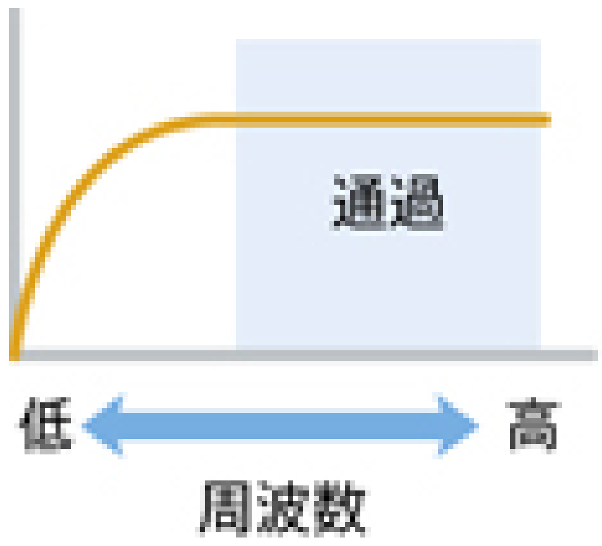


直列R-C回路の応用:ハイパスフィルタ

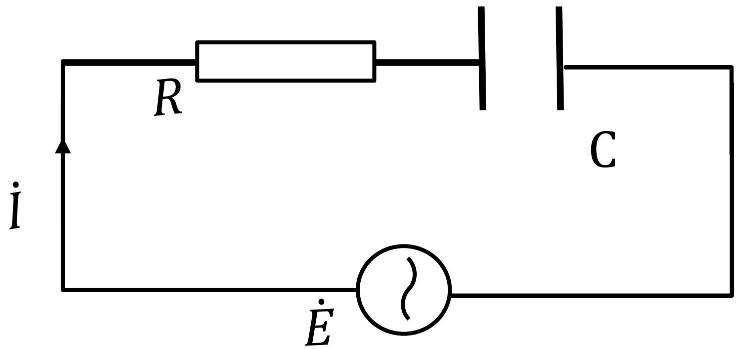


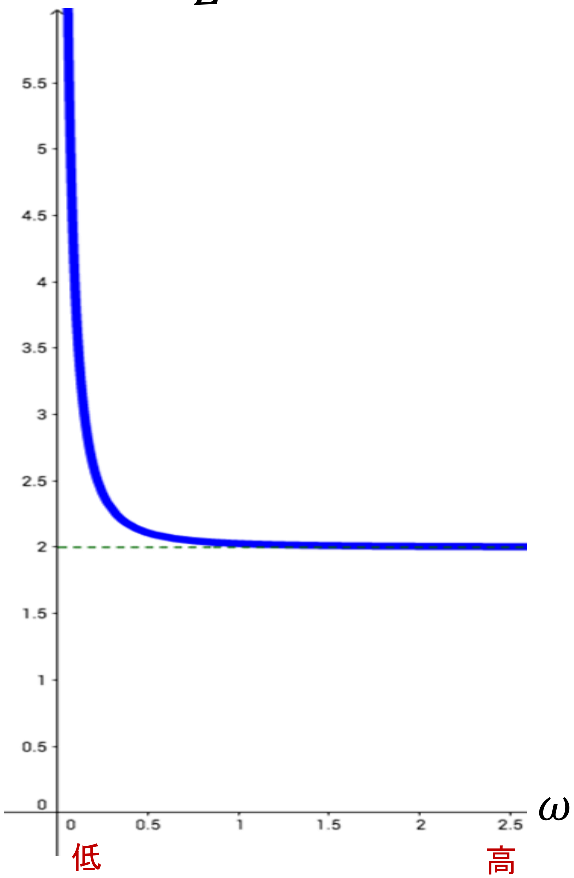


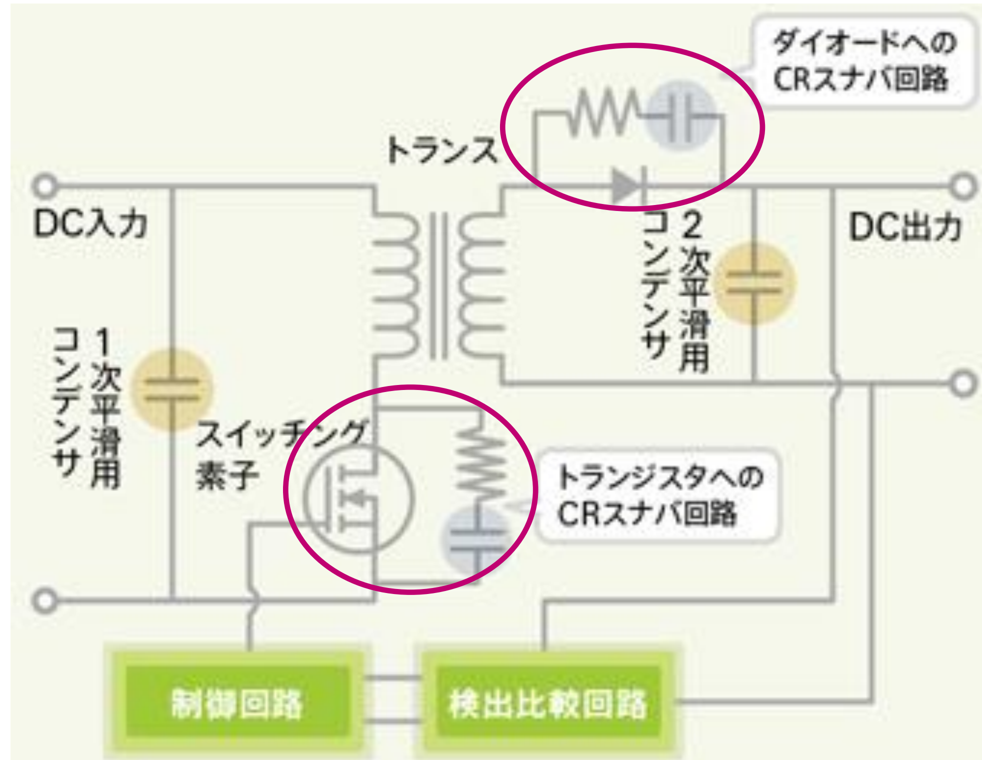
低い周波数成分を遮断し、高い周波数成分だけを通過させて出力する



直列R-C回路の応用：ハイパスフィルタ



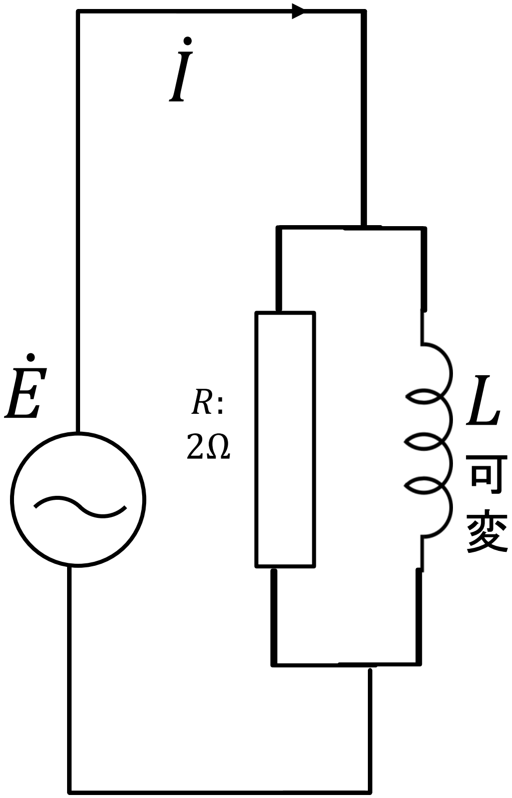




ノイズ対策にも不可欠な部品

DC-DCコンバータ

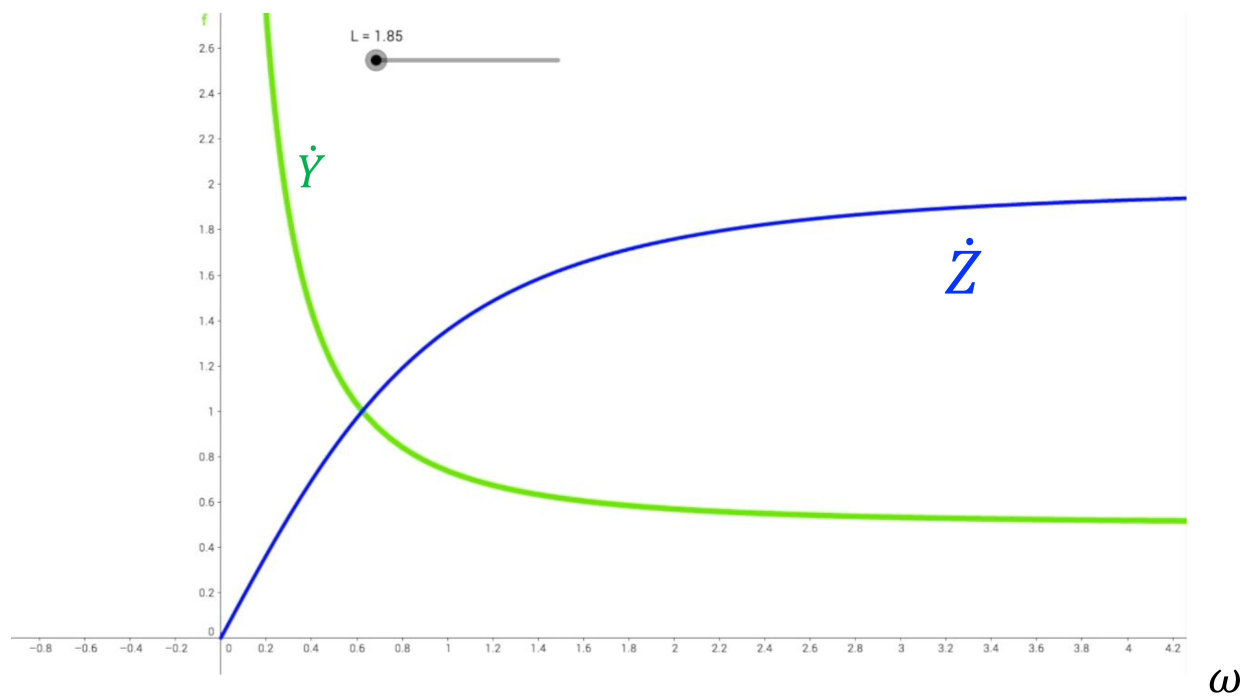
抵抗RとコイルLの並列回路の周波数特性



$$\dot{Y}=\frac{1}{\dot{Z}}=\frac{1}{R}+\frac{1}{jwL}$$

$$Y=\frac{1}{R}-j\frac{1}{wL}$$

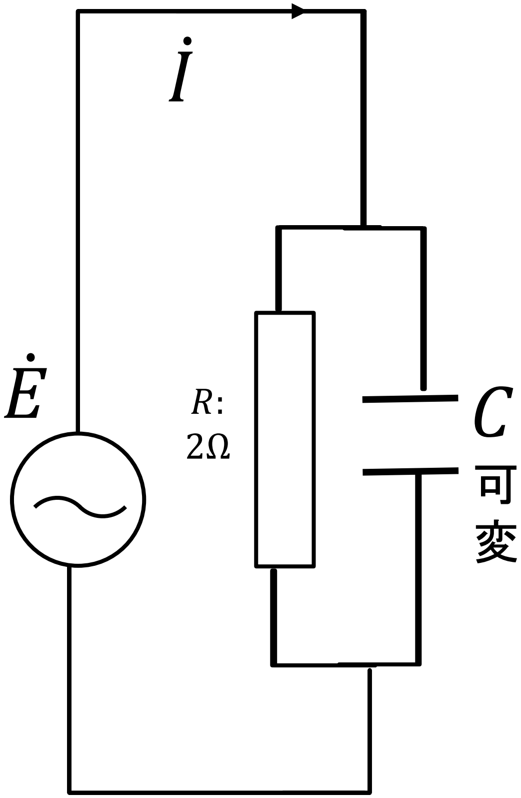
$$Y=\sqrt{(\frac{1}{R})^2+(\frac{1}{wL})^2}\ \angle -tan^{-1}(\frac{R}{wL})$$

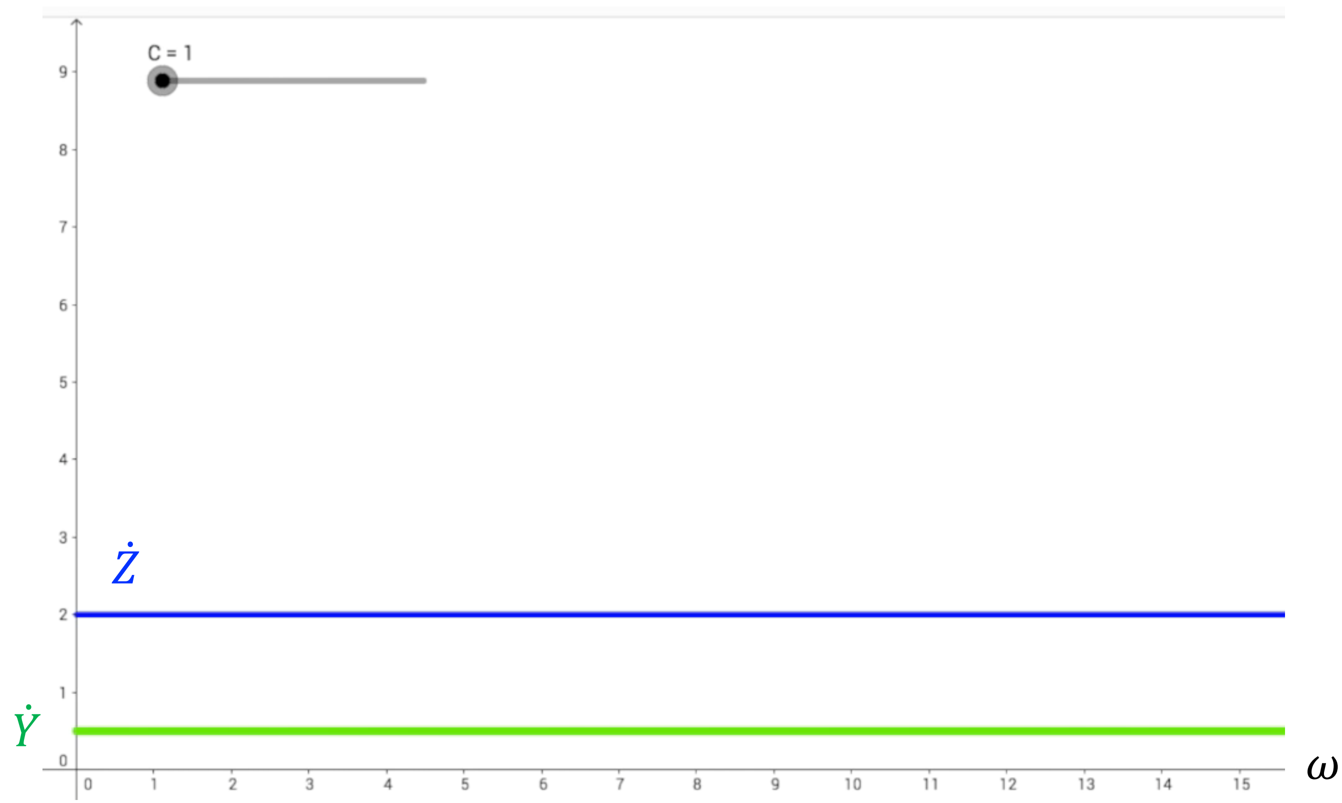


抵抗RとコンデンサCの並列回路の周波数特性

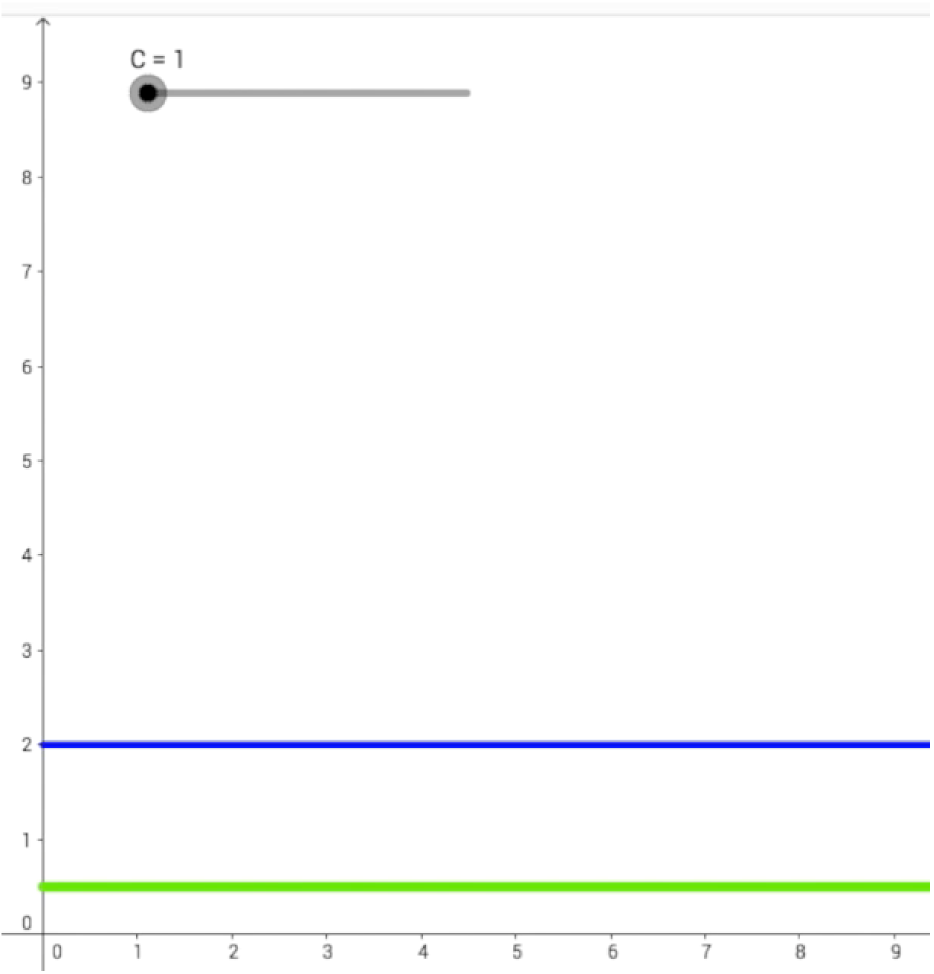
$$\dot{Y}=\frac{1}{\dot{Z}}=\frac{1}{R}+jwC$$

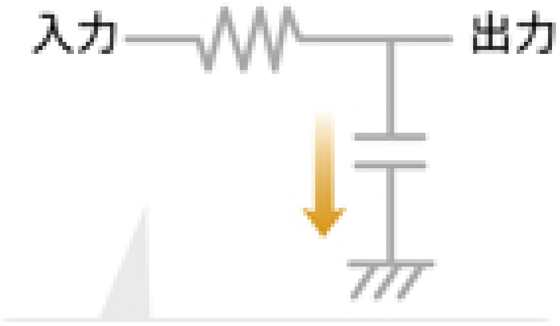
$$\dot{Y}=\sqrt{(\frac{1}{R})^2+(wC)^2}\ \angle tan^{-1}(wCR)$$



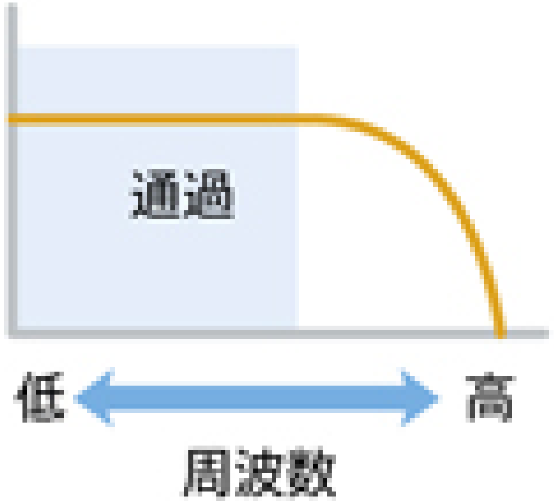


並列R-C回路の応用：ローパスフィルタ





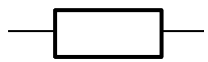
高い周波数成分をグランドに逃し、低い周波数成分だけを通過させて出力する



リアクタンス X(Ω)を使った複素数インピーダンス $\dot{Z}$の統一表現

$$\dot{Z} = R + j\,X$$

$\dot{Z}_R = R$

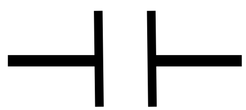


$\dot{Z}_R = R + j\ * 0$

$\dot{Z}_L = j\omega L$

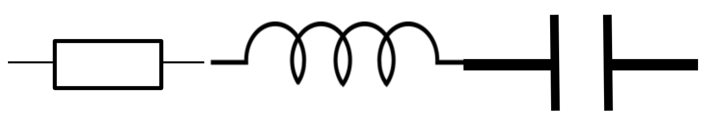
$\dot{Z}_L = 0 + jX_L$ $X_L > 0$

$\dot{Z}_C = \dfrac{1}{j\omega C}$



$\dot{Z}_C = 0 + j\,X_C$ $X_C < 0$

例：



$$\dot{Z} = R + jX_L + j\,X_C = R + j\,X$$

サセプタンス B(S)を使った複素数インピーダンス $\dot{Y}$の統一表現

$$\dot{Y} = G + j\,B$$

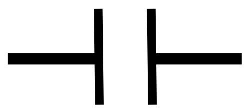
$\dot{Y}_R = R$

$\dot{Y}_R = G + j\ * 0$

$\dot{Y}_L = \dfrac{1}{j\omega L}$

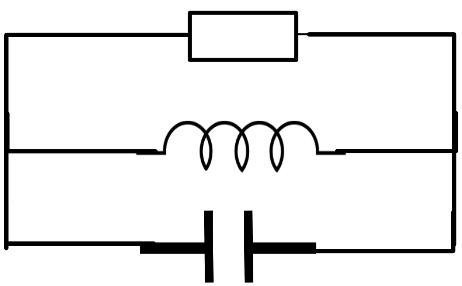
$\dot{Y}_L = 0 + jB_L$ $B_L < 0$

$\dot{Y}_C = j\omega C$



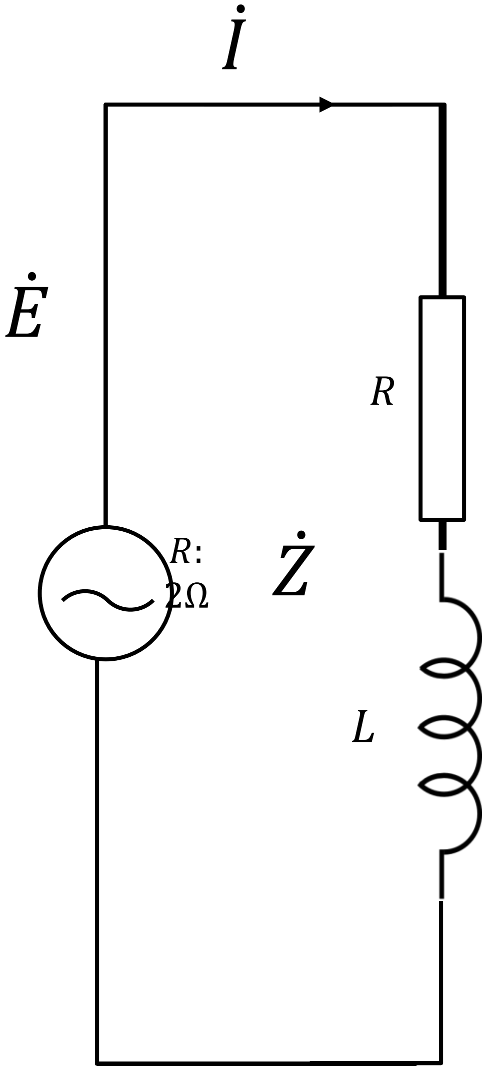
$\dot{Z}_C = 0 + j\,B_C$ $B_C > 0$

例：



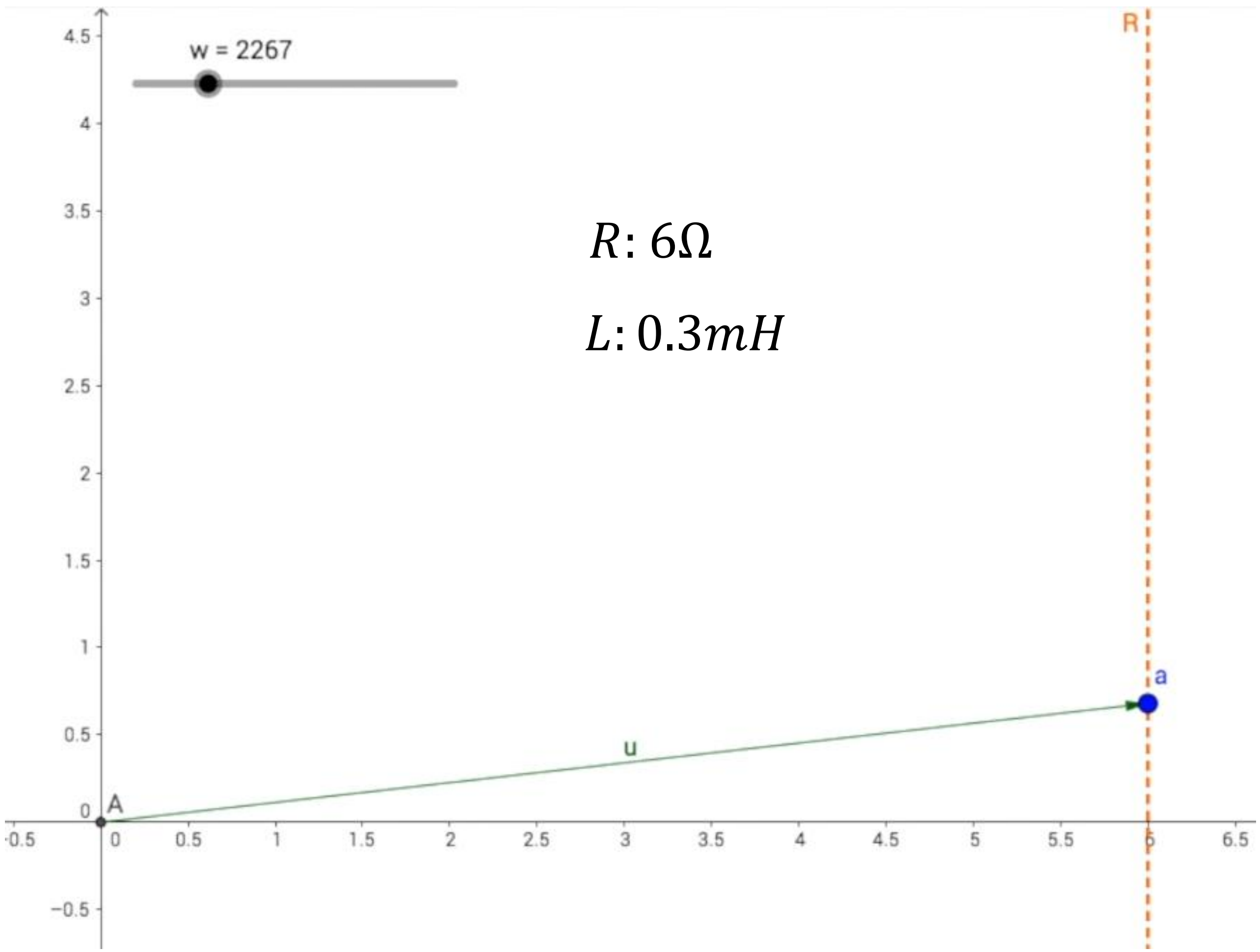
$\dot{Y} = G + jB_L +$
$j\,B_C = G + j\,\mathrm{B}$

R–L直列回路のインピーダンス面の軌跡



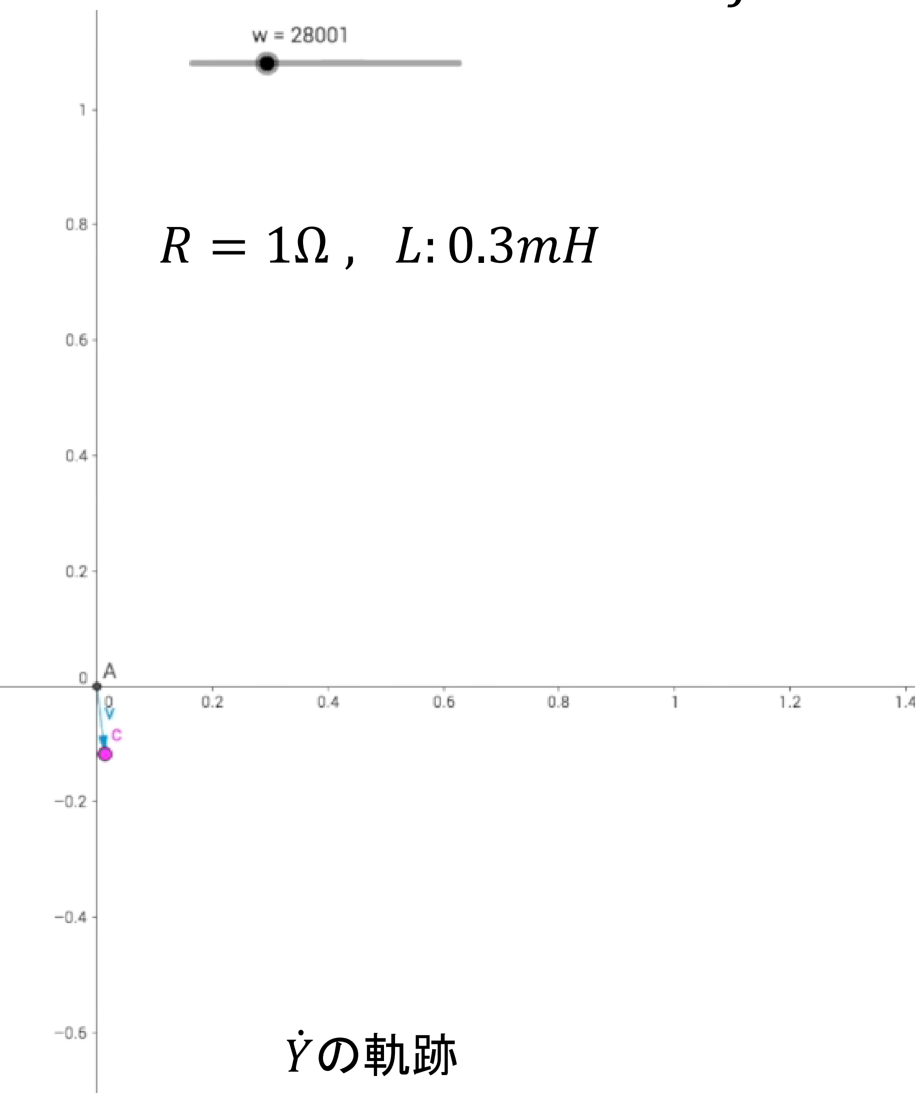
インピーダンス: $\dot{Z} = R + jwL$

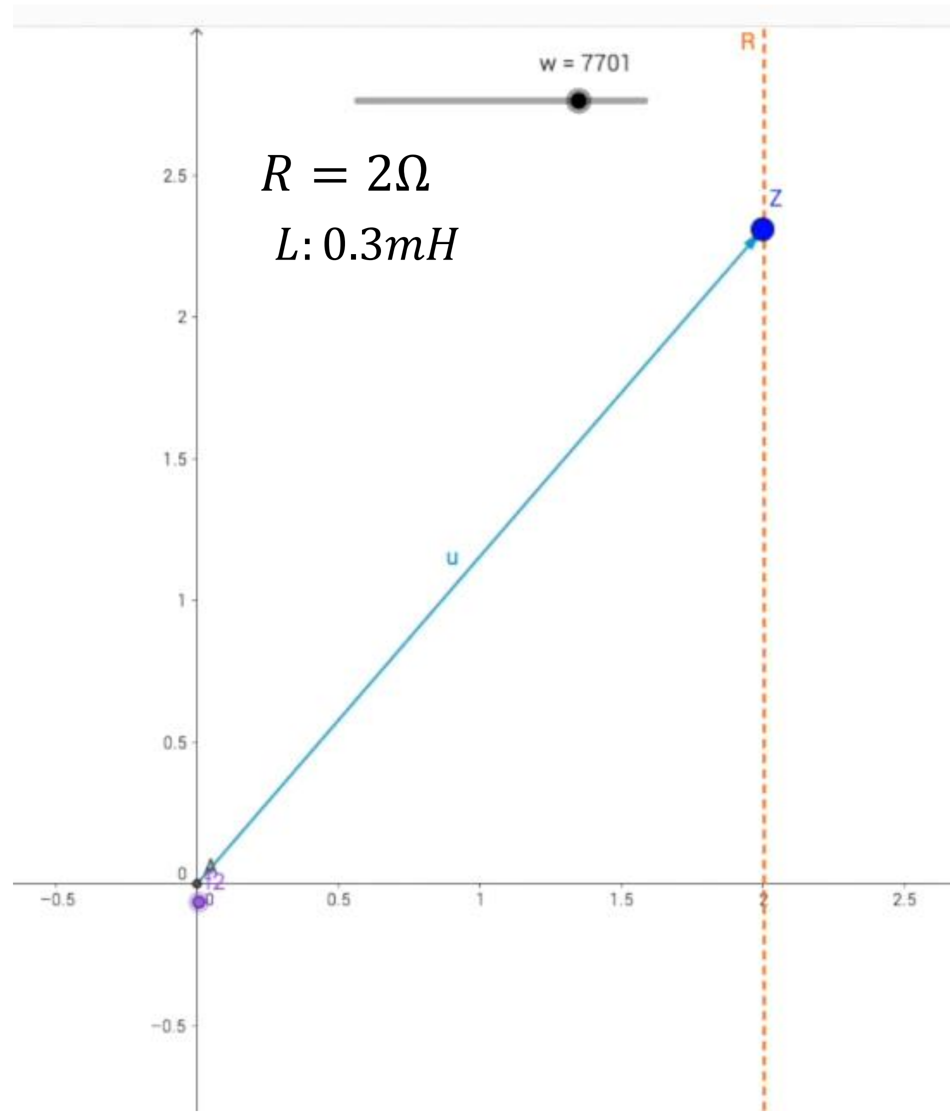
インピーダンス: $\dot{Z} = R + jX$



R–L直列回路のアドミタンス面の軌跡

アドミタンス：$\dot{Y} = \dfrac{1}{R+jwL}$

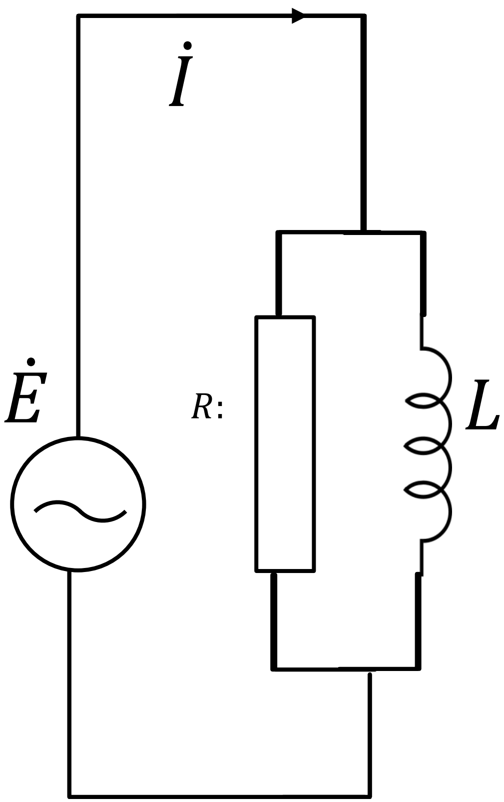


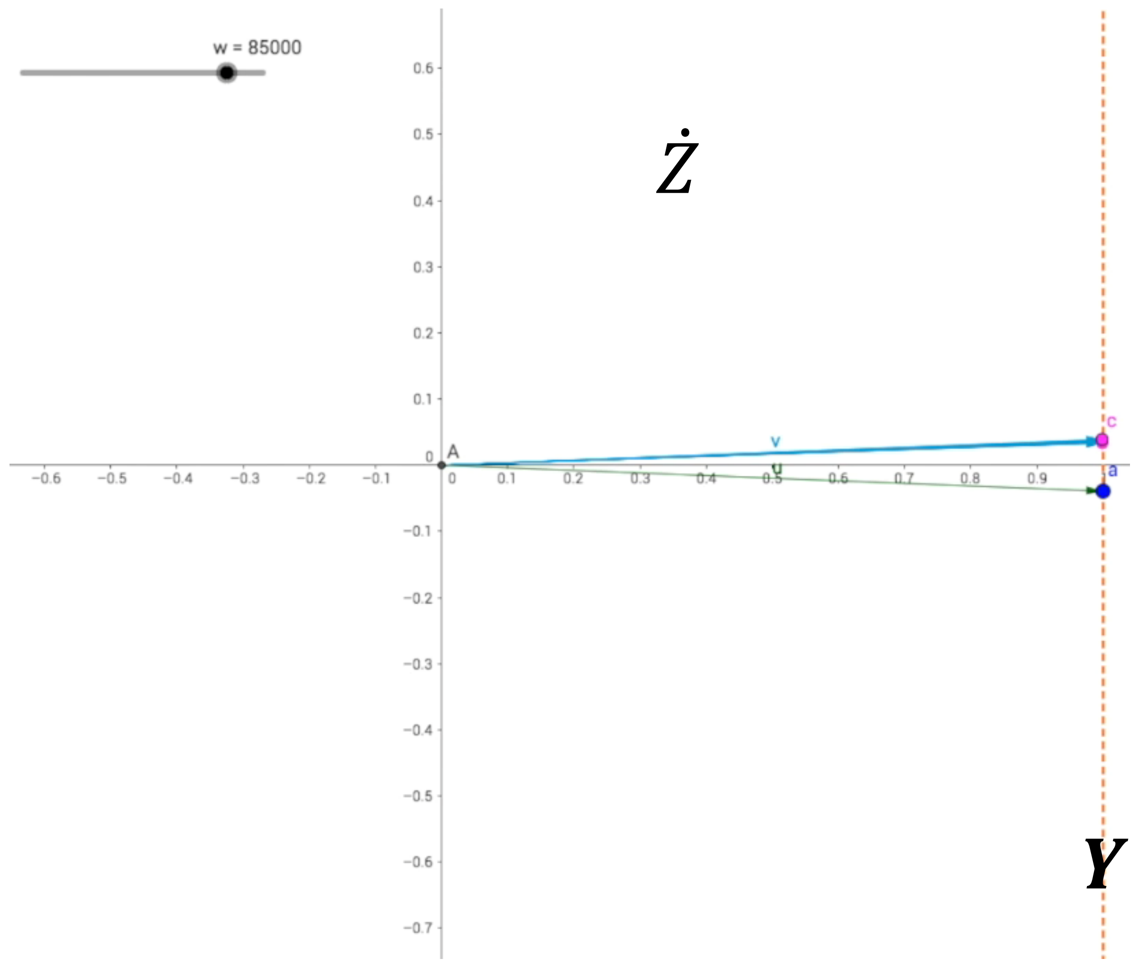


R−L並列回路のアドミタンス面とインピーダンスの軌跡

$$\dot{Y} = G + jB$$

$$\dot{Y} = \frac{1}{\dot{Z}} = \frac{1}{R} + \frac{1}{jwL} \qquad \dot{Y} = \frac{1}{R} - j\frac{1}{wL} \qquad \dot{Z} = \frac{1}{Y}$$





究極のフィルタ回路：共振回路

目的：

ある特定の周波数だけを
通過する（通過しない）回路

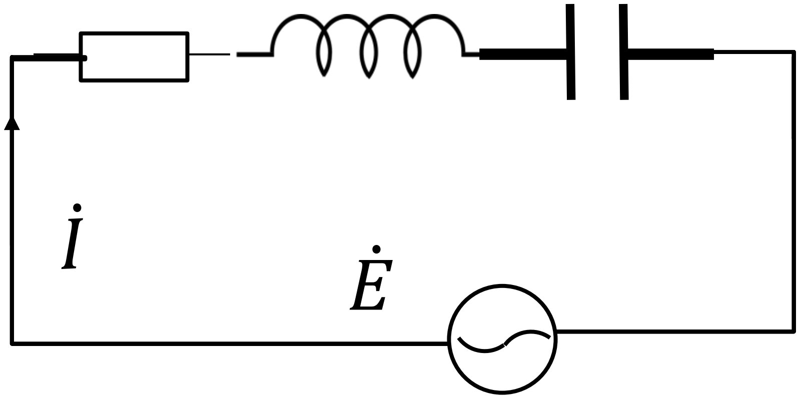
R−L-C直列共振回路:

$$\dot{Z} = R + jwL + \frac{1}{jwC}$$

$$= R + jwL - j\frac{1}{wC}$$

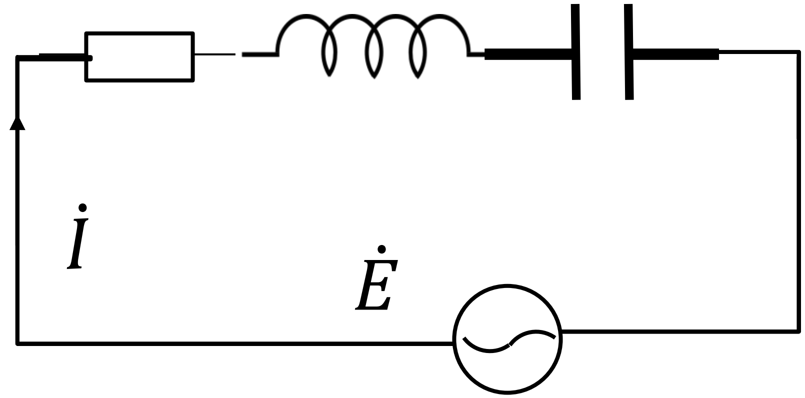
$$= R + j(wL - \frac{1}{wC})$$

$$= \sqrt{R^2 + (wL - \frac{1}{wC})^2} \angle tan^{-1}\frac{wL - \frac{1}{wC}}{R} = Z\angle\theta$$



R-L-C直列共振回路:

$$\dot{Z} = R + jwL + \frac{1}{jwC}$$



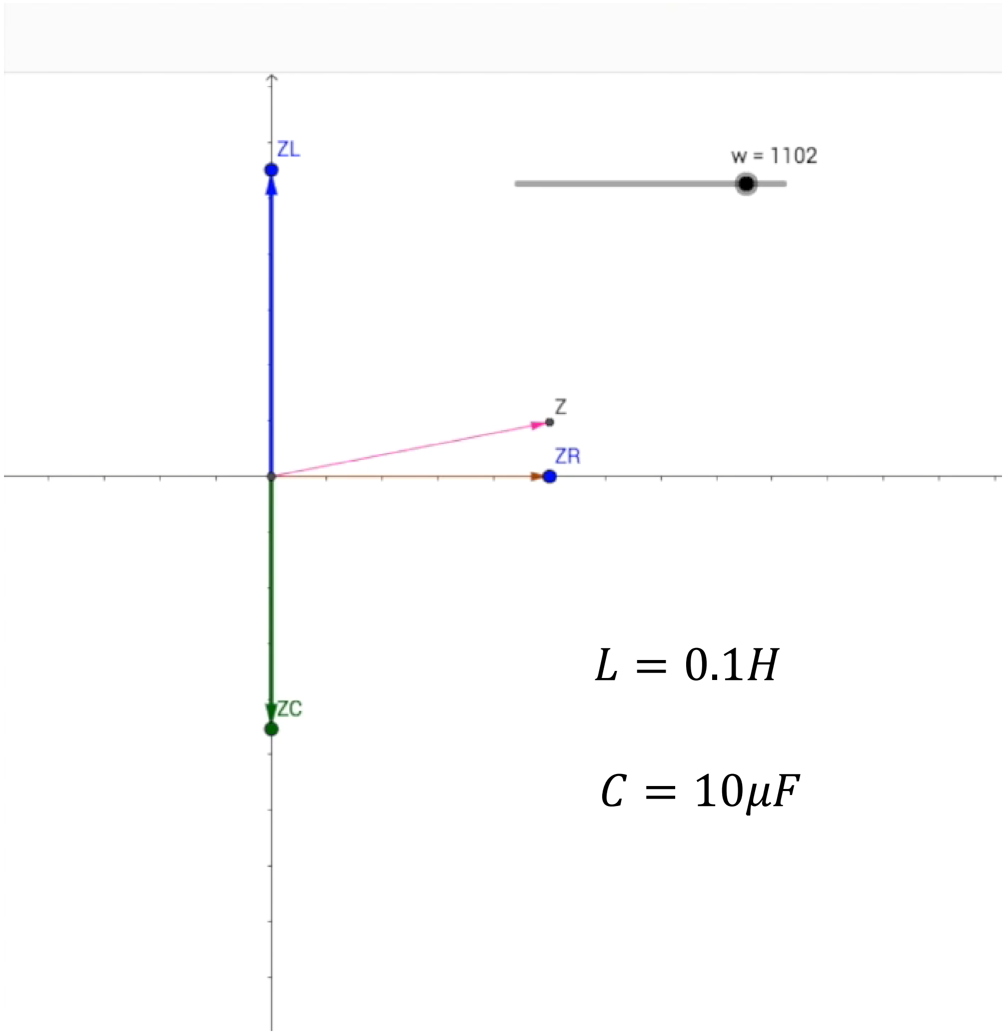
$$= R + jwL - j\frac{1}{wC}$$

$$= R + j(wL - \frac{1}{wC})$$

$$= \sqrt{R^2 + (wL - \frac{1}{wC})^2} \angle tan^{-1}\frac{wL - \frac{1}{wC}}{R} = Z\angle\theta$$

R–L-C直列共振回路のインピーダンス面の軌跡:

$$\dot{Z} = R + jwL + \frac{1}{jwC}$$



$$\dot{Z}_L = jwL$$

$$\dot{Z}_C = \frac{1}{jwC}$$

$L = 0.1H$

$C = 10\mu F$

$$|\dot{Z}| = \sqrt{R^2 + (wL - \frac{1}{wC})^2}$$

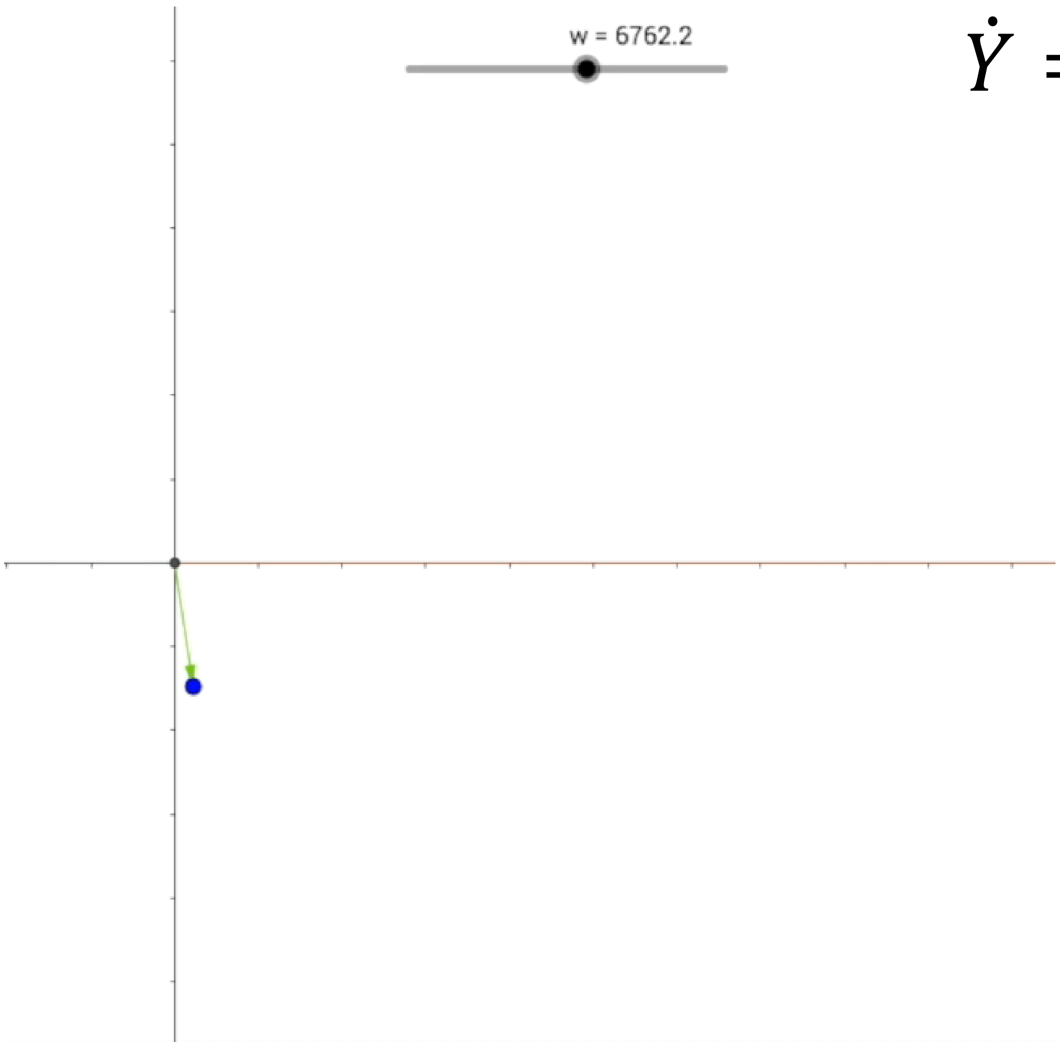
$$\left|\dot{Z}_C\right| = \left|\dot{Z}_L\right|$$

$$\left|I * \dot{Z}_C\right| = \left|I * \dot{Z}_L\right|$$

$$\left|\dot{V}_C\right| = \left|\dot{V}_L\right|$$

コイルとコンデンサにかかる電圧の大きさが同じなとき、共振が起きる

R−L-C直列共振回路のアドミタンス面の軌跡:



$$\dot{Y} = \frac{1}{\dot{Z}} = \frac{1}{R + jwL + \frac{1}{jwC}}$$

R−L-C直列共振回路:電流の周波数依存性:

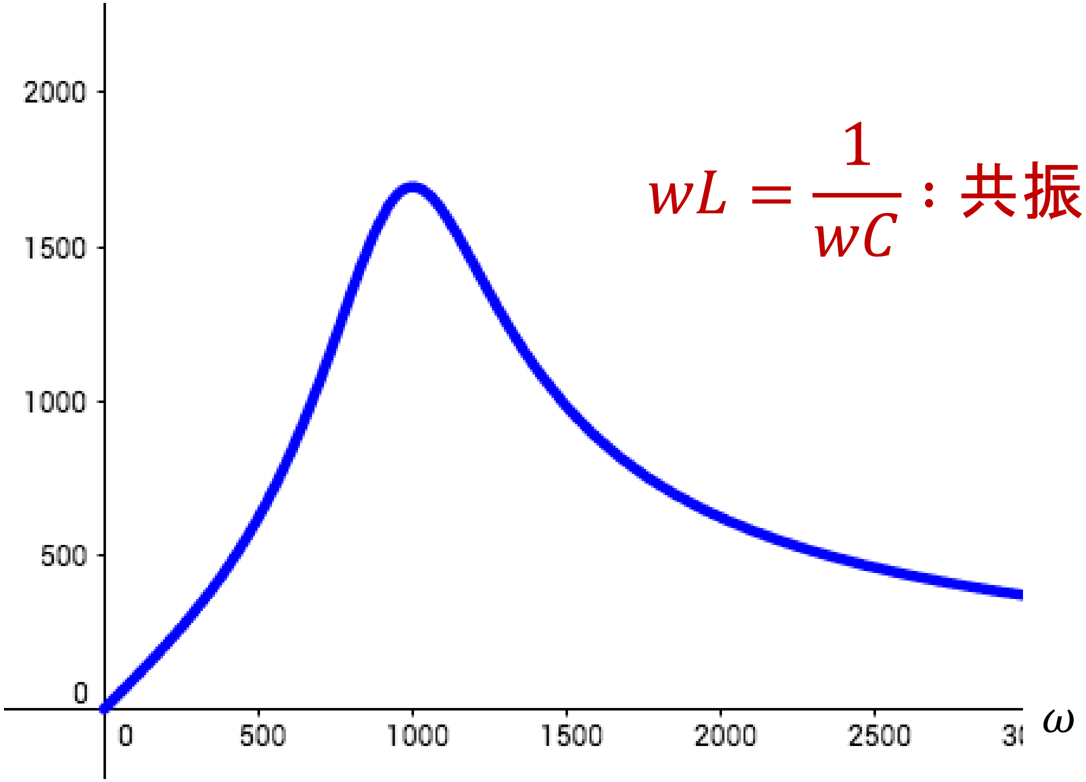
$$wL - \frac{1}{wC} = 0$$

$$i = \frac{1}{\sqrt{R^2 + (wL - \frac{1}{wC})^2}} \mathrm{E}$$

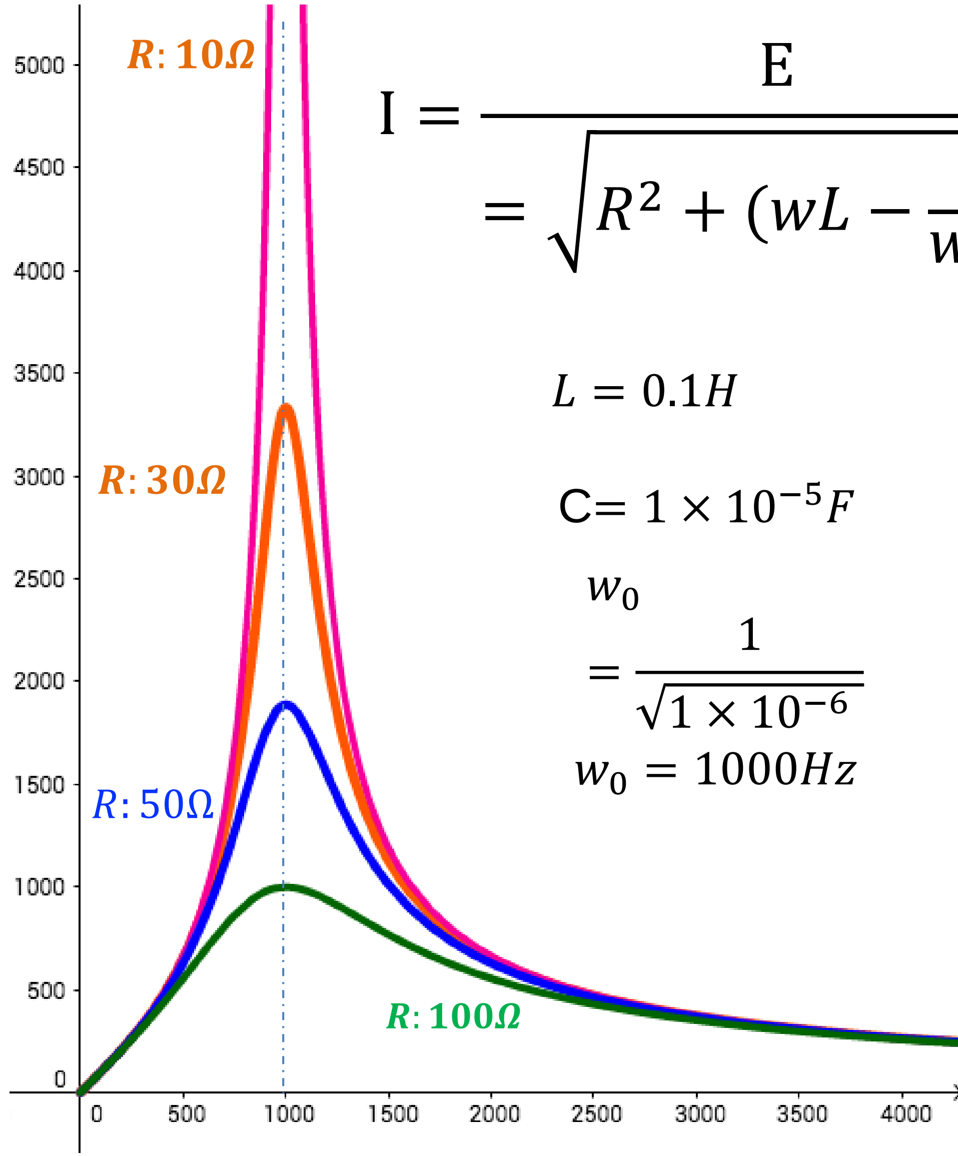
$${w_0}^2 = \frac{1}{LC}$$

$$w_0 = \frac{1}{\sqrt{LC}}$$

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



共振の条件:



$$\mathrm{I} = \frac{\mathrm{E}}{= \sqrt{R^2 + (wL - \frac{1}{wC})^2}}$$

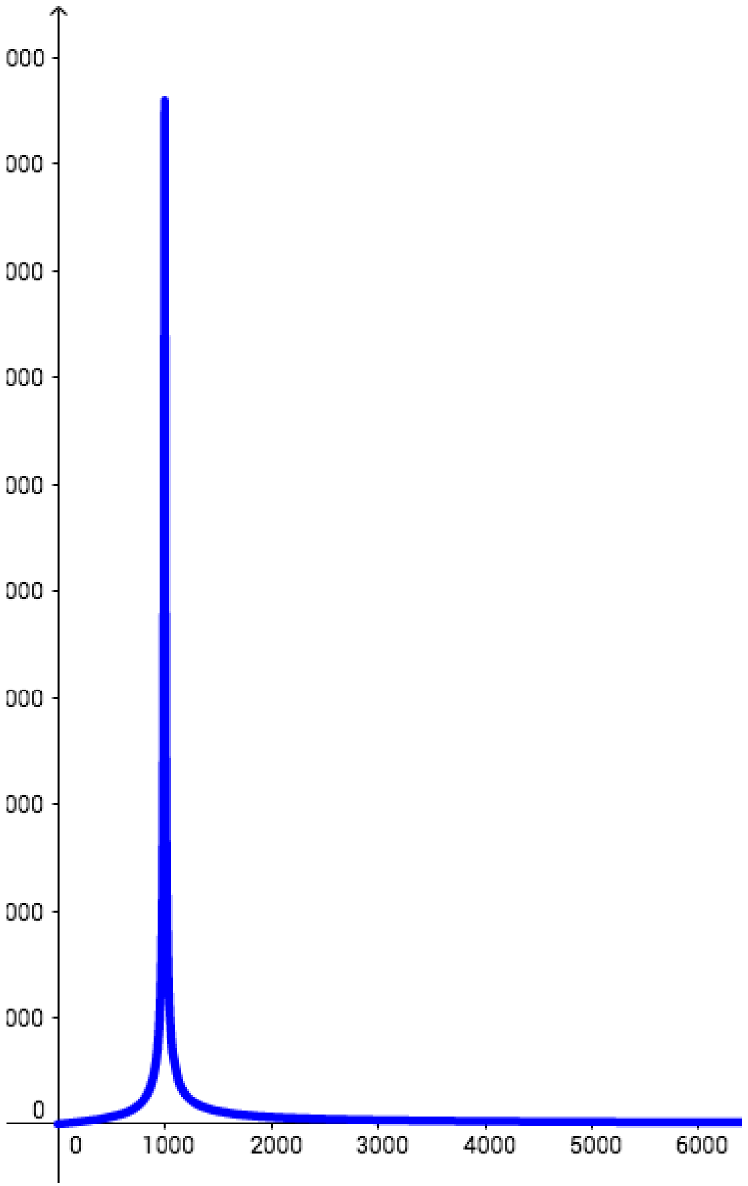
$$L = 0.1H$$

$$\mathrm{C} = 1 \times 10^{-5} F$$

$$w_0 = \frac{1}{\sqrt{1 \times 10^{-6}}}$$

$$w_0 = 1000Hz$$

共振ピークの鋭さ:



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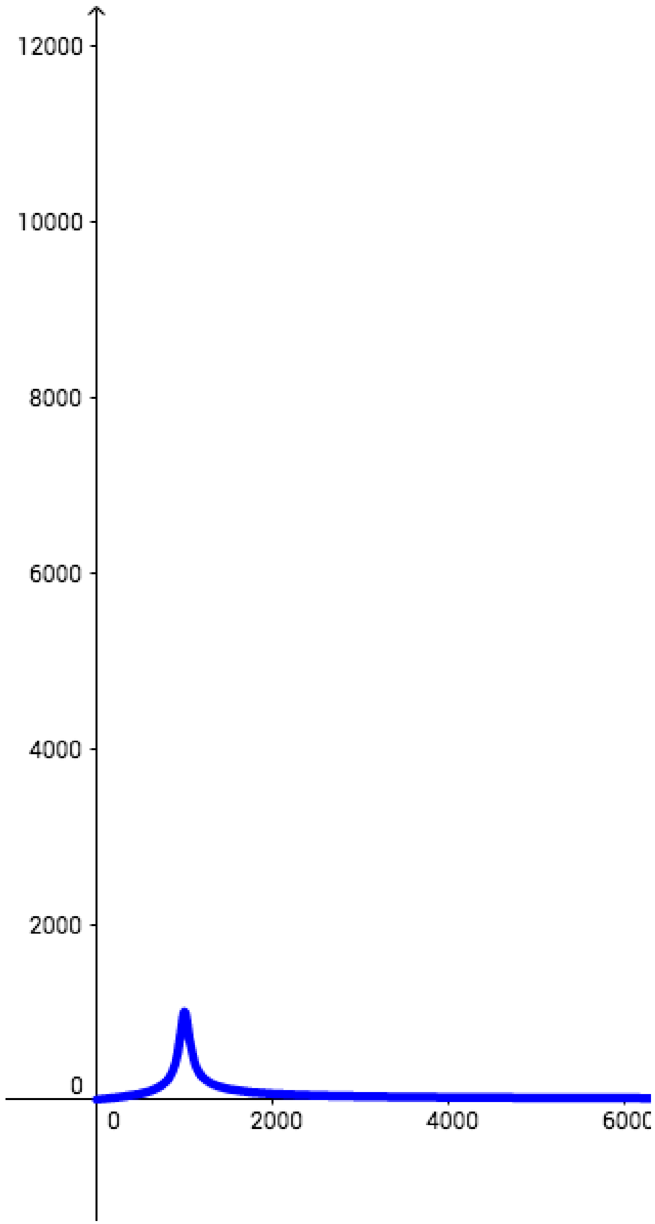

12000
10000
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6000
4000
2000
0
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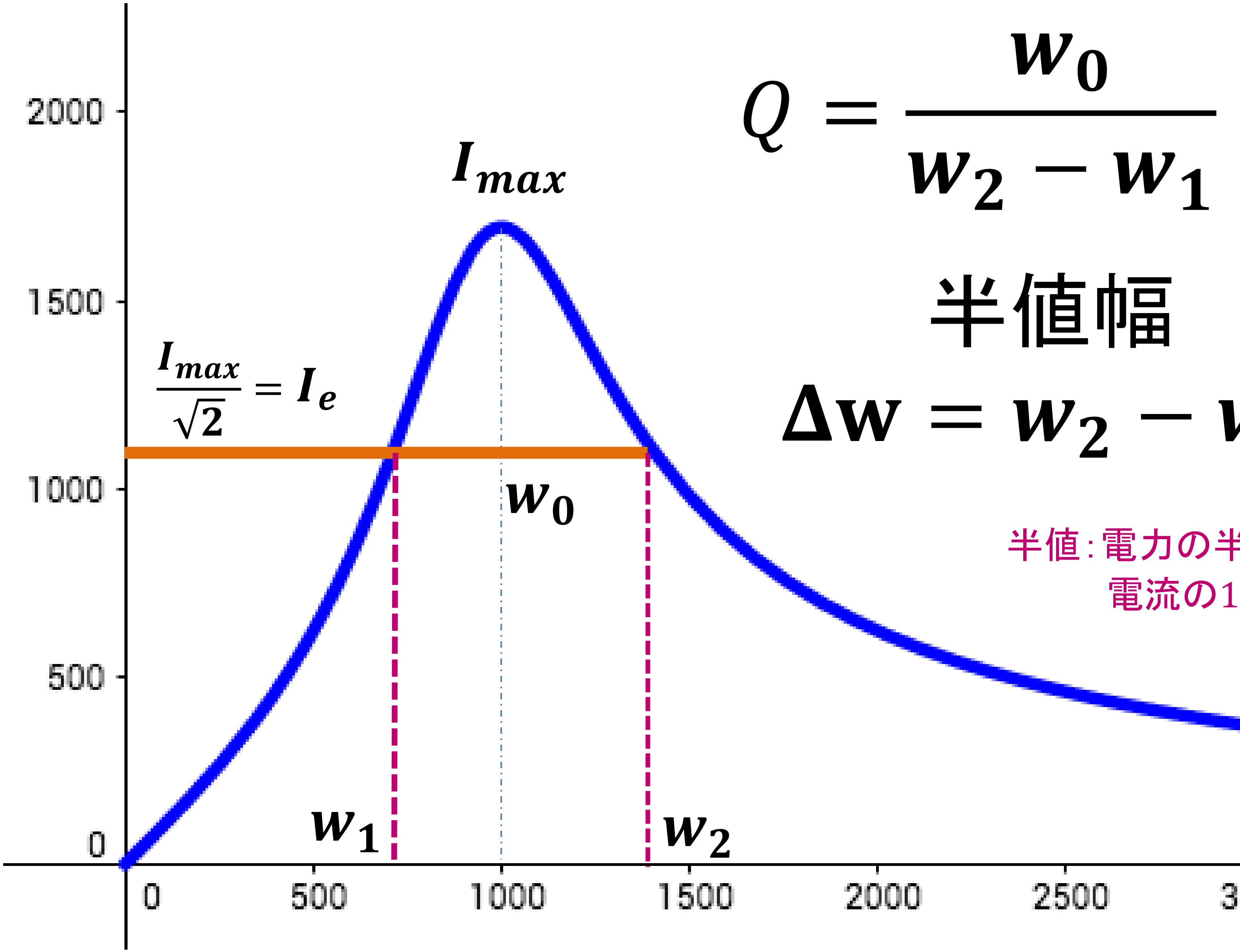
2000
4000

共振ピークの鋭さを表すQ値：



$$Q = \frac{w_0}{w_2 - w_1}$$

半値幅

$$\Delta w = w_2 - w_1$$

半値：電力の半分
電流の$1/\sqrt{2}$

R-L-C直列共振回路におけるQ値の計算式を導く

$$\mathrm{I} = \frac{|\dot{E}|}{|\dot{Z}|} = \frac{\mathrm{E}}{= \sqrt{R^2 + (wL - \frac{1}{wC})^2}}$$

$$\mathrm{I} = \frac{|\dot{E}|}{|\dot{Z}|} = \frac{\mathrm{E}}{R} \frac{1}{\sqrt{1 + \frac{(wL - \frac{1}{wC})^2}{R^2}}}$$

$$\mathrm{I} = \frac{|\dot{E}|}{|\dot{Z}|} = I_{max} \frac{1}{\sqrt{1 + \frac{(wL - \frac{1}{wC})^2}{R^2}}}$$

R-L-C直列共振回路におけるQ値の計算式を導く

$$\frac{(wL - \frac{1}{wC})^2}{R^2} = 1 \qquad \frac{wL - \frac{1}{wC}}{R} = \pm 1$$

$$w^2 - w\frac{R}{L} - \frac{1}{LC} = 0$$

$$w_2 = \frac{1}{2}\left(\frac{R}{L} + \sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}} \right)$$

R-L-C直列共振回路におけるQ値の計算式を導く

$$w^2 + w\frac{R}{L} - \frac{1}{LC} = 0$$

$$w_1 = \frac{1}{2}\left(-\frac{R}{L} + \sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}}\right)$$

$$Q = \frac{\boldsymbol{w_0}}{\boldsymbol{w_2 - w_1}} = \frac{\boldsymbol{w_0 L}}{\boldsymbol{R}} = \frac{\boldsymbol{I * |j w_0 L|}}{\boldsymbol{I * R}}$$

$$Q = \frac{w_0}{w_2 - w_1} = \frac{w_0 L}{R}$$

$$= \frac{I * |jw_0 L|}{I * R}$$

$$= \frac{I * |jw_0 L|}{I * R} = \frac{|I * jw_0 L|}{|I * R|} = \frac{|V_L|}{|V_R|}$$

コイルにかかる電圧と抵抗にかかる電圧の大きさの比である

$$w_0{}^2 = \frac{1}{LC}$$

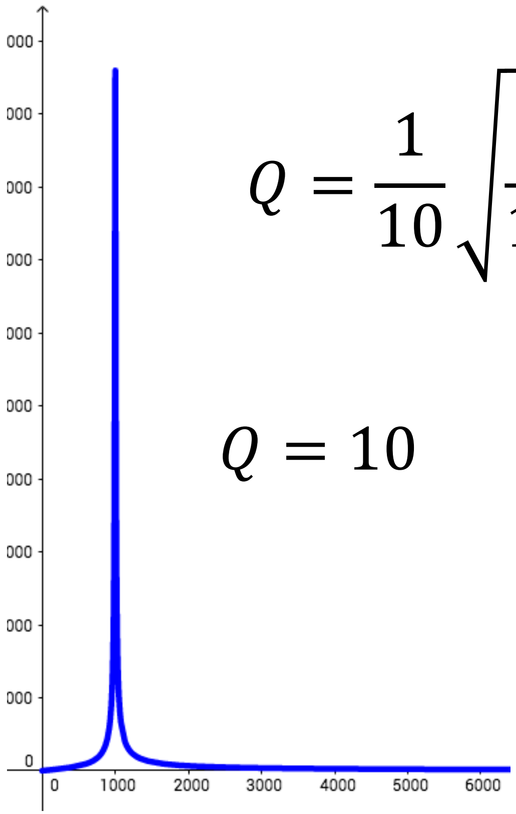
$$Q = \frac{w_0 L}{R} = \frac{w_0 \frac{1}{w_0{}^2 C}}{R} = \frac{\frac{1}{w_0 C}}{R}$$

$$Q = \frac{w_0 L}{R} = \frac{w_0 \frac{1}{w_0{}^2 C}}{R} = \frac{\left| I * \frac{1}{j w_0 C} \right|}{|I * R|} = \frac{|V_C|}{|V_R|}$$

R-L-C直列共振回路におけるQ値を使ってみる！

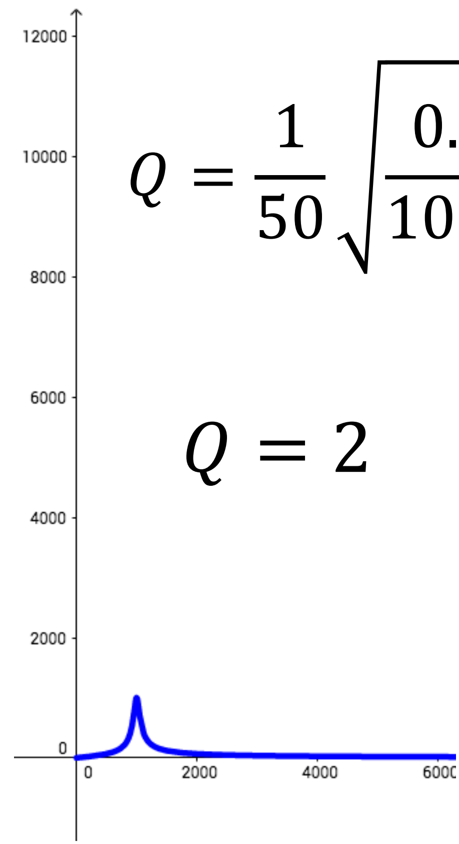
$$Q = \frac{L}{R}\sqrt{\frac{1}{LC}}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$



$$Q = \frac{1}{10}\sqrt{\frac{0.1}{10^{-5}}}$$

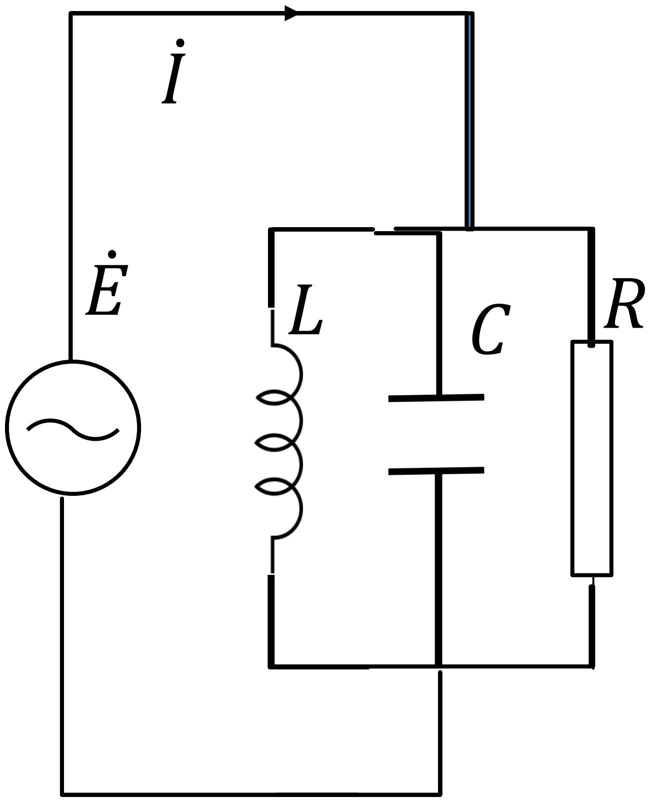
$$Q = 10$$



$$Q = \frac{1}{50}\sqrt{\frac{0.1}{10^{-5}}}$$

$$Q = 2$$

R-L-C并列共振回路:



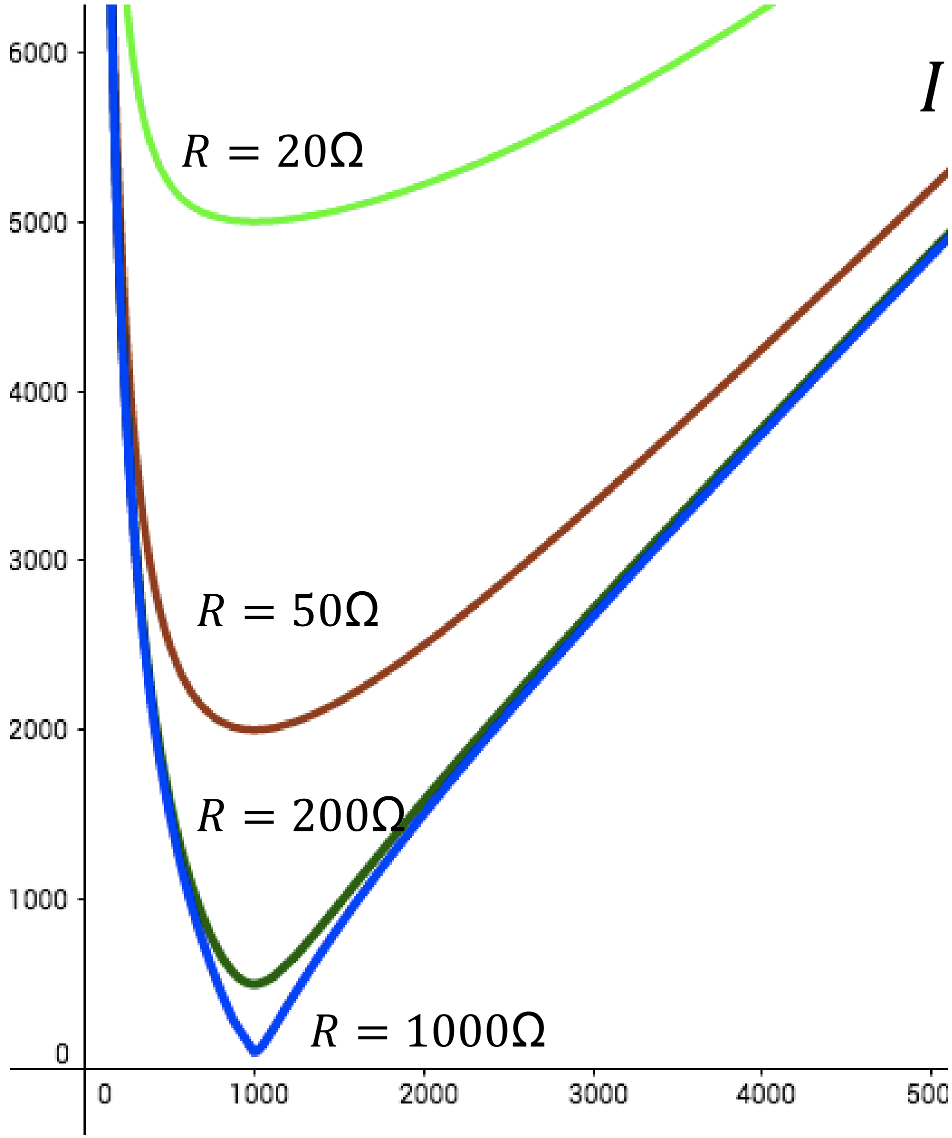
$$\dot{Y}=\frac{1}{\dot{Z}}=\frac{1}{R}+\frac{1}{jwL}+jwC$$

$$\dot{I}=\dot{Y}\dot{E}=(\frac{1}{R}+\frac{1}{jwL}+jwC)\ \dot{E}$$

$$\dot{I}=\dot{Y}\dot{E}=\{\frac{1}{R}+j\left(wC-\frac{1}{wL}\right)\}\ \dot{E}$$

$$I=YE=\sqrt{(\frac{1}{R})^2+(wC-\frac{1}{wL})^2}\ E$$

R-L-C並列共振回路における電流の周波数依存性



$$I = \sqrt{\left(\frac{1}{R}\right)^2 + \left(wC - \frac{1}{wL}\right)^2}\, E$$

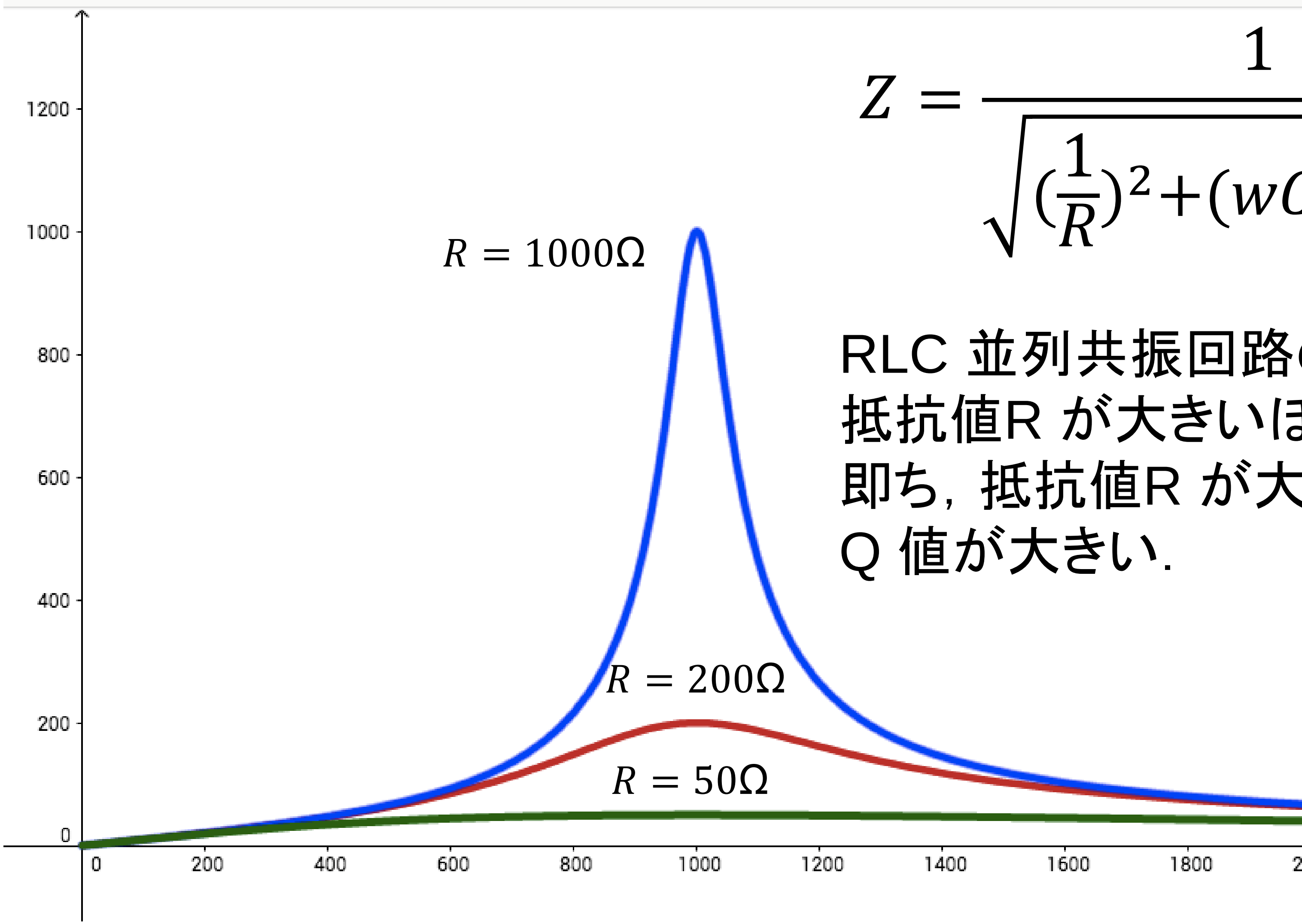
$$L = 0.1H$$

$$C = 1 \times 10^{-5} F$$

$$w_0 = \frac{1}{\sqrt{1 \times 10^{-6}}}$$

$$w_0 = 1000Hz$$

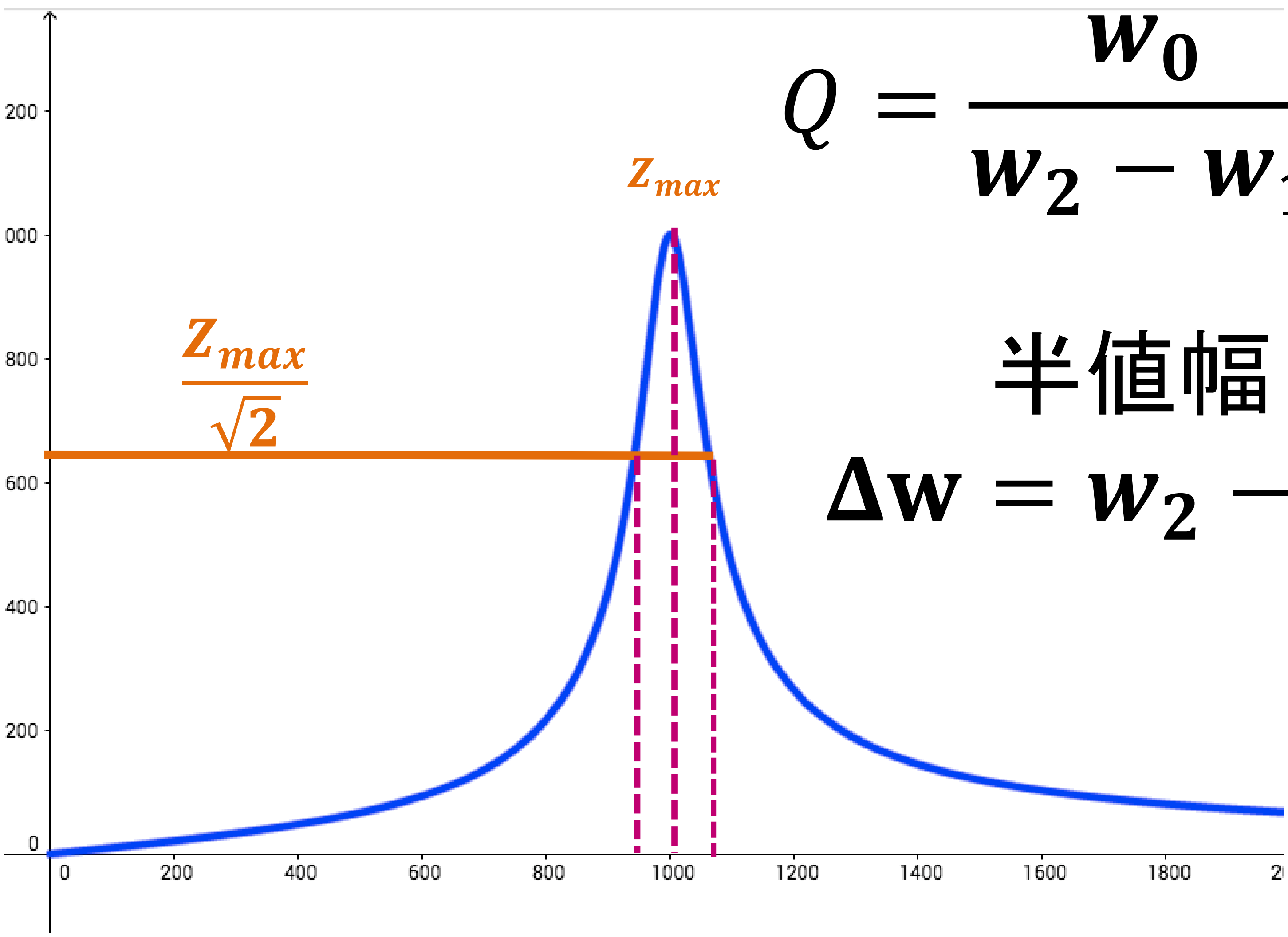
R-L-C並列共振回路のインピーダンスの周波数依存性



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

RLC 並列共振回路の鋭さは，抵抗値R が大きいほど鋭い．即ち，抵抗値R が大きいほどQ 値が大きい．

並列共振回路のQ値：インピーダンスを使う



$$Q = \frac{w_0}{w_2 - w_1}$$

半値幅

$$\Delta \mathrm{w} = w_2 - w_1$$

R-L-C並列共振回路におけるQ値の計算式を導く

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

$$wC - \frac{1}{wL} = \pm \frac{1}{R}$$

$$\begin{cases} w^2 - w\frac{1}{RC} - \frac{1}{LC} = 0 \\ w^2 + w\frac{1}{RC} - \frac{1}{LC} = 0 \end{cases}$$

R-*L*-*C*並列共振回路におけるQ値の計算式を導く

$$\omega_2 = \frac{1}{2LCR}\left\{L + \sqrt{L^2 + 4LCR^2}\right\}$$

$$\omega_1 = \frac{1}{2LCR}\left\{-L + \sqrt{L^2 + 4LCR^2}\right\}$$

$$\boldsymbol{Q = \frac{w_0}{w_2 - w_1} = w_0 CR = R\sqrt{\frac{C}{L}}}$$

$$Q = \frac{w_0}{w_2 - w_1} = w_0 CR = R\sqrt{\frac{C}{L}}$$

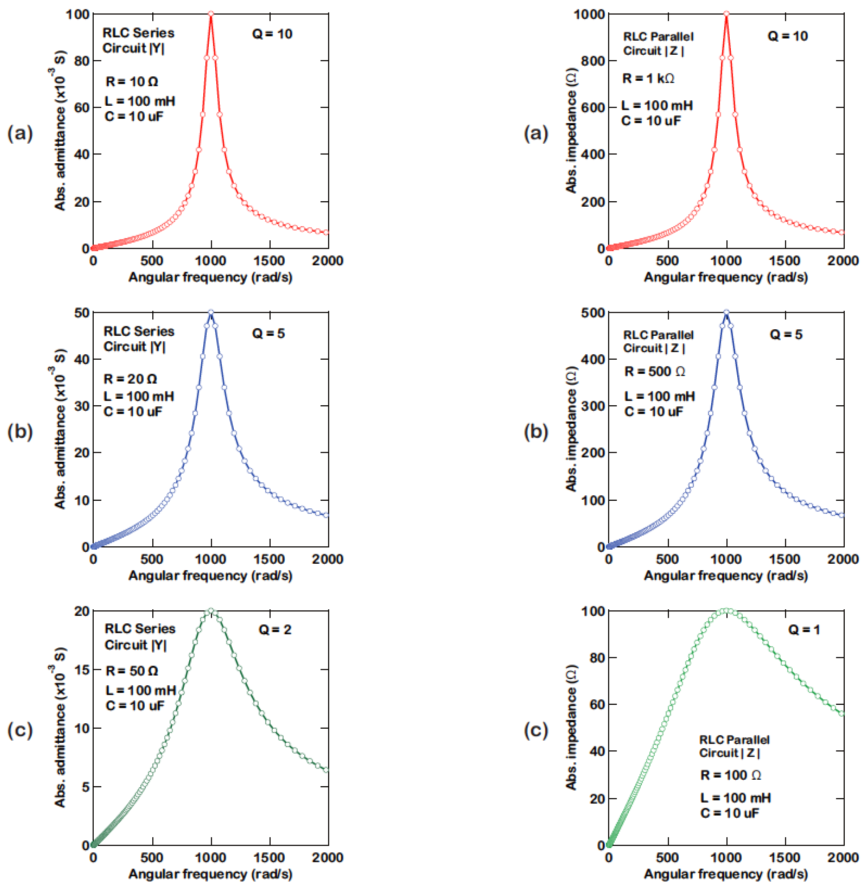
$$Q = w_0 CR = \frac{w_0 C}{\frac{1}{R}} = \frac{V * w_0 C}{V * \frac{1}{R}}$$

$$= \frac{V/(\frac{1}{w_0 C})}{V * \frac{1}{R}} = \frac{V/(\frac{1}{|jw_0 C|})}{V * \frac{1}{R}}$$

$$\frac{V/\left(\frac{1}{|jw_0C|}\right)}{V*\frac{1}{R}}=\frac{|V/Z_c|}{|V/R|}=\frac{|I_C|}{|I_R|}$$

コンデンサに流れる電流と抵抗に流れる電流の大きさの比である

共振回路における抵抗の役割を吟味しましょう

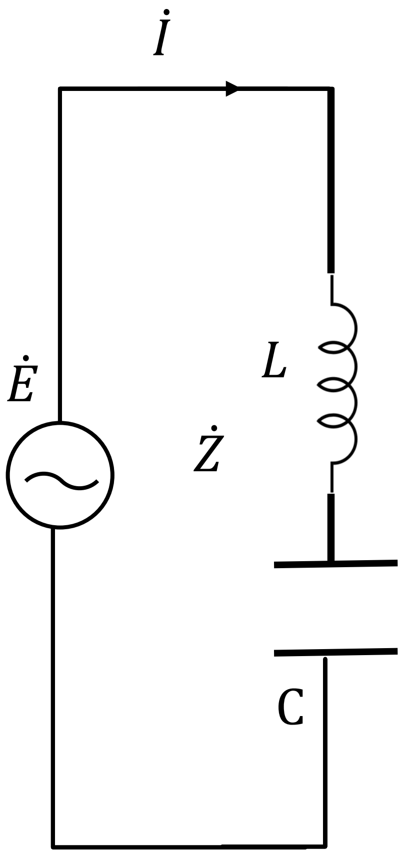


直列共振回路では，R は小さい方がよい（究極の状態は直列接続された抵抗が無い状態：R = 0 Ω）• 並列共振回路では，R が大きい方がよい（究極の状態は並列接続された抵抗が無い状態：R =∞ Ω）
ということは，

最初から抵抗なんか接続せずに，LC 直列共振回路，LC 並列共振回路にすればよいのである．そうすれば共振特性の鋭さを表すQ 値は無限大となり，究極の鋭さを持つ回路を作ることができる*3.

なぜ，わざわざ抵抗の入った回路について勉強したのか？

純粋なLC共振回路



$$\dot{Z} = jwL + \frac{1}{jwC}$$

$$\dot{Z} = jwL - j\frac{1}{wC}$$

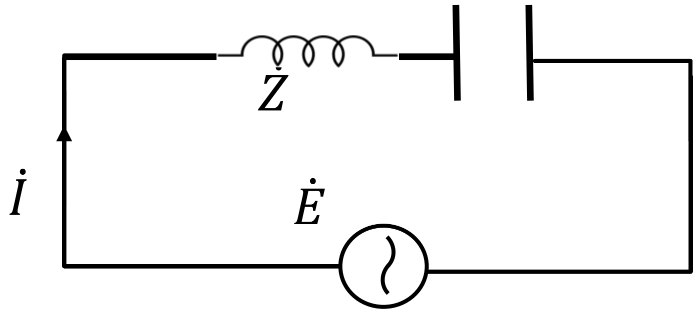
$$\dot{Z} = j(wL - \frac{1}{wC})$$

$$\dot{Z} = \ (wL - \frac{1}{wC})\angle\theta$$

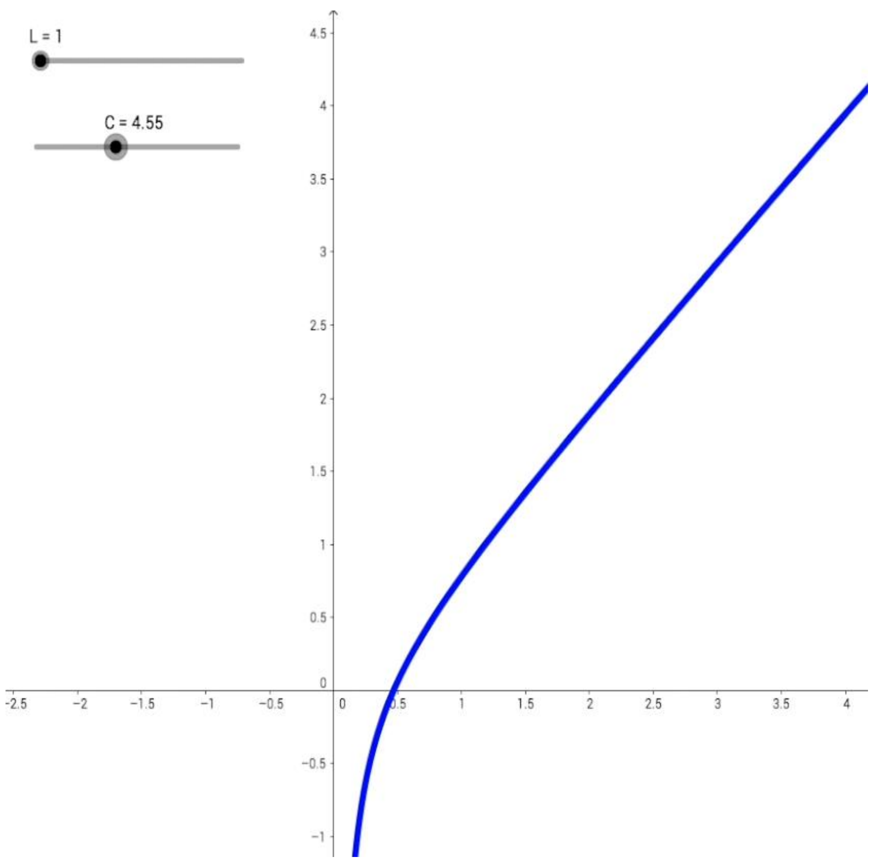
$$\theta = 90, wL > \frac{1}{wC}$$

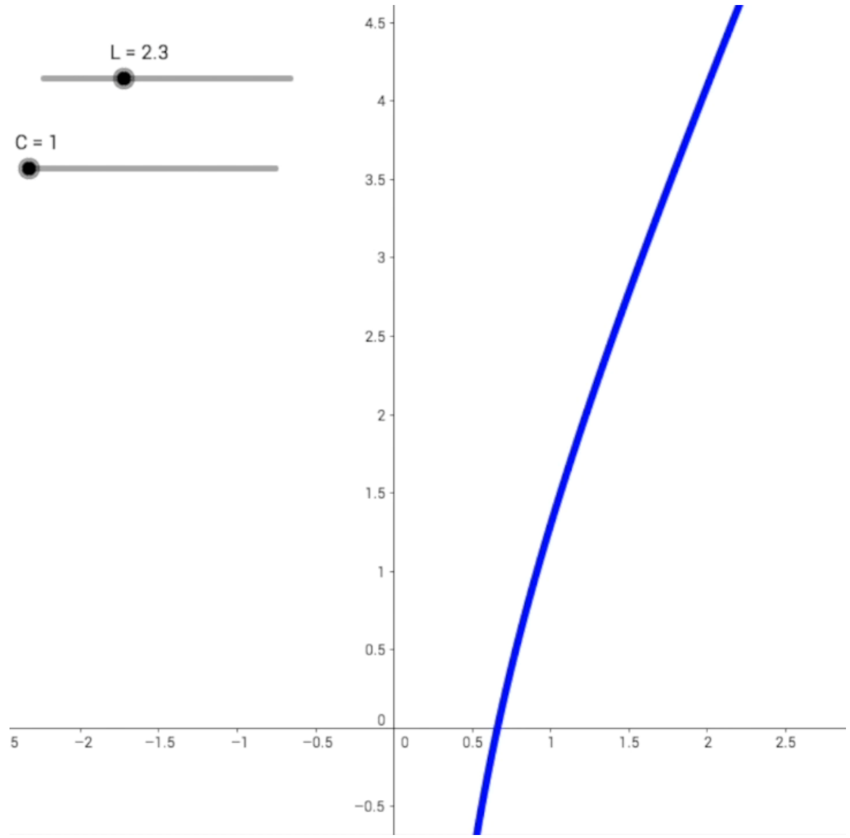
$$\theta = -90, wL < \frac{1}{wC}$$

純粋なLC共振回路



$$\dot{Z} = \left(wL - \frac{1}{wC}\right)\angle\theta$$

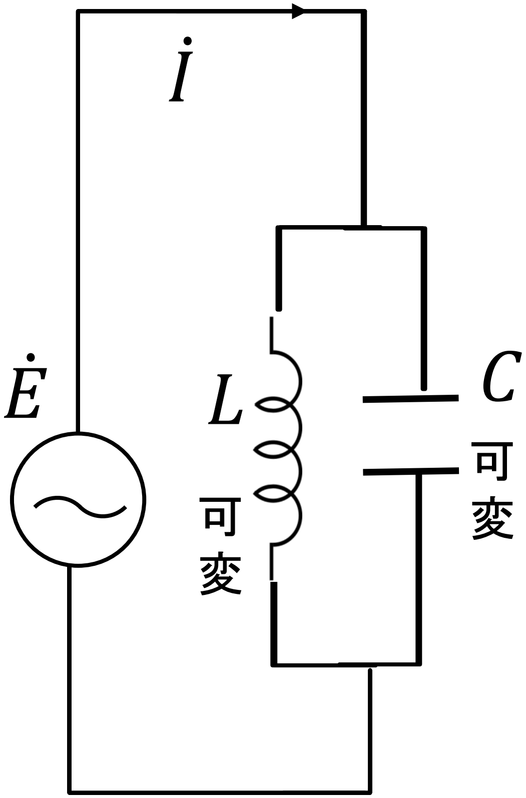


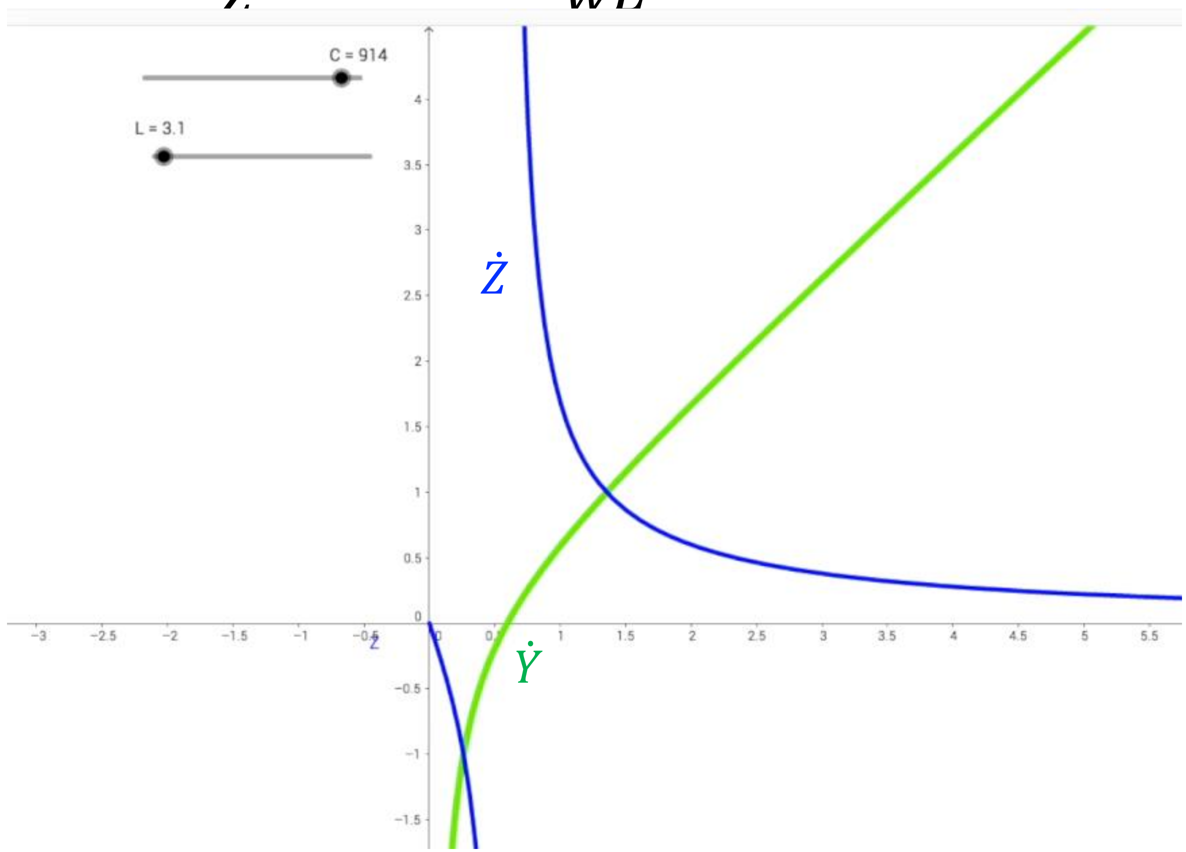


純粋なLC共振回路

$$\dot{Y} = \frac{1}{\dot{Z}} = \frac{1}{jwL} + jwC$$

$$\dot{Y} = \frac{1}{\dot{Z}} = jwC - j\frac{1}{wL}$$



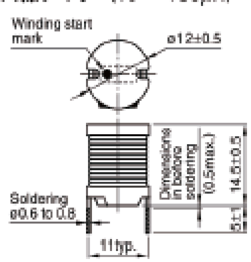


抵抗のないコイルやコンデンサは存在しない！

電気的特性

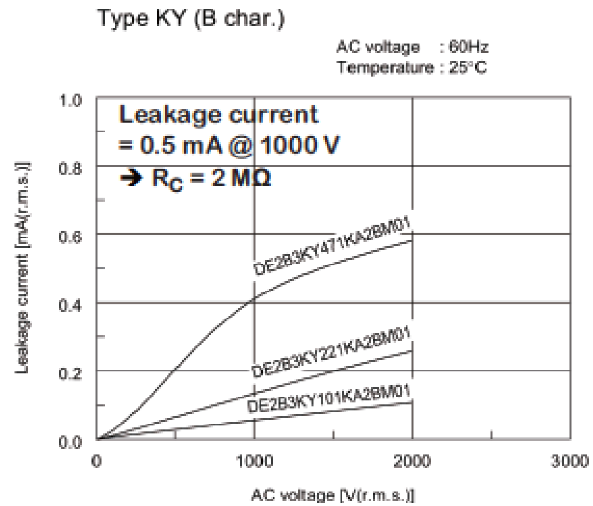
インダクタンス (μH)	インダクタンス 許容差	直流抵抗 (Ω)max.
10	±10%	0.019
15	±10%	0.022
22	±10%	0.031
33	±10%	0.044
47	±10%	0.059
68	±10%	0.073
100	±10%	0.1
150	±10%	0.15
220	±10%	0.26
330	±10%	0.32
470	±10%	0.48
680	±10%	0.73
1000	±10%	0.96
1500	±10%	1.4
2200	±10%	2.5
3300	±10%	3.3
5600	±10%	6.4

形状・寸法
共線タイプ（10～100μH）

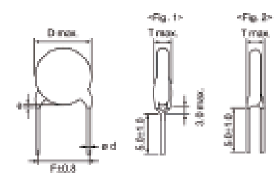


TDK

品番	交流定格電圧 (Vac)	温度特性	静電容量 (pF)
DEJE3E2102Z□□□	250	E	1000 +80/-20%
DEJE3E2222Z□□□	250	E	2200 +80/-20%
DEJE3E2332Z□□□	250	E	3300 +80/-20%
DEJE3E2472Z□□□	250	E	4700 +80/-20%
DEJF3E2472Z□□□	250	F	4700 +80/-20%
DEJF3E2103Z□□□	250	F	10000 +80/-20%



muRata

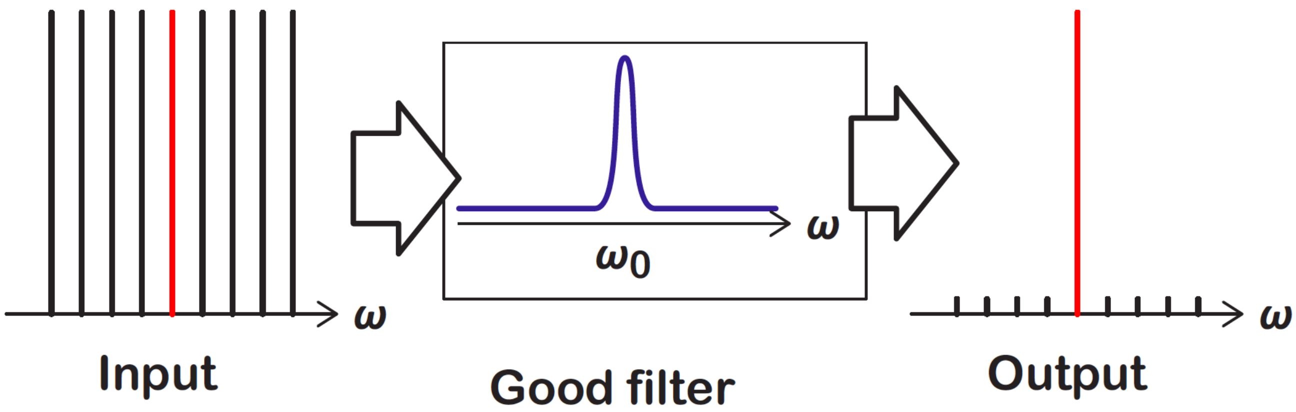


(in mm)

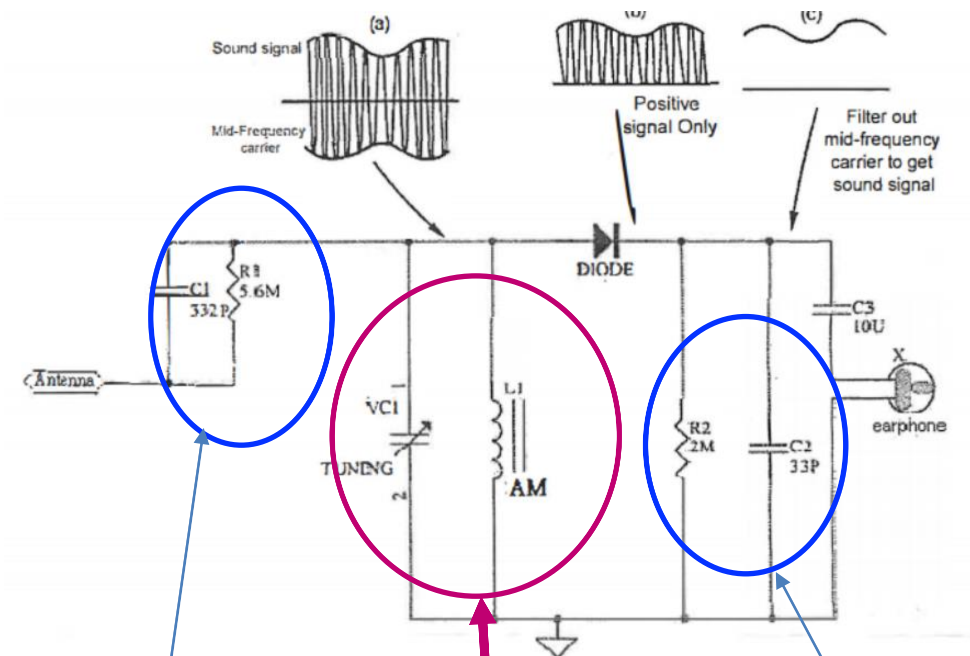
[単品]
タテクリンプショート(B3)
ストレートショート(D3)

Lead Code	Coating Extension e	ø d	Style
B3	Up to the end of crimp	0.6±0.05	Fig. 1
D3	3.0 max.	0.6±0.05	Fig. 2

周波数選別に用いられるフィルタの機能



ゲルマラジオに使用した共振回路

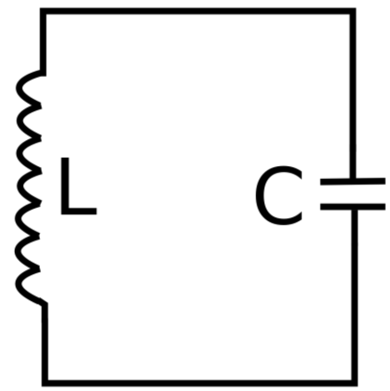


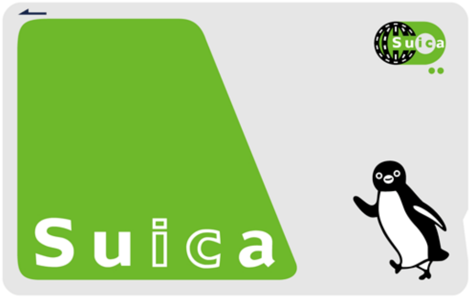
共振回路

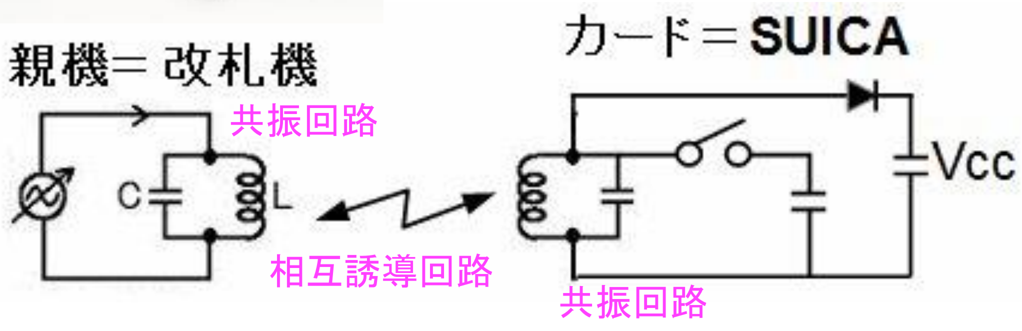
ハイパスフィルタ

ローパスフィルタ

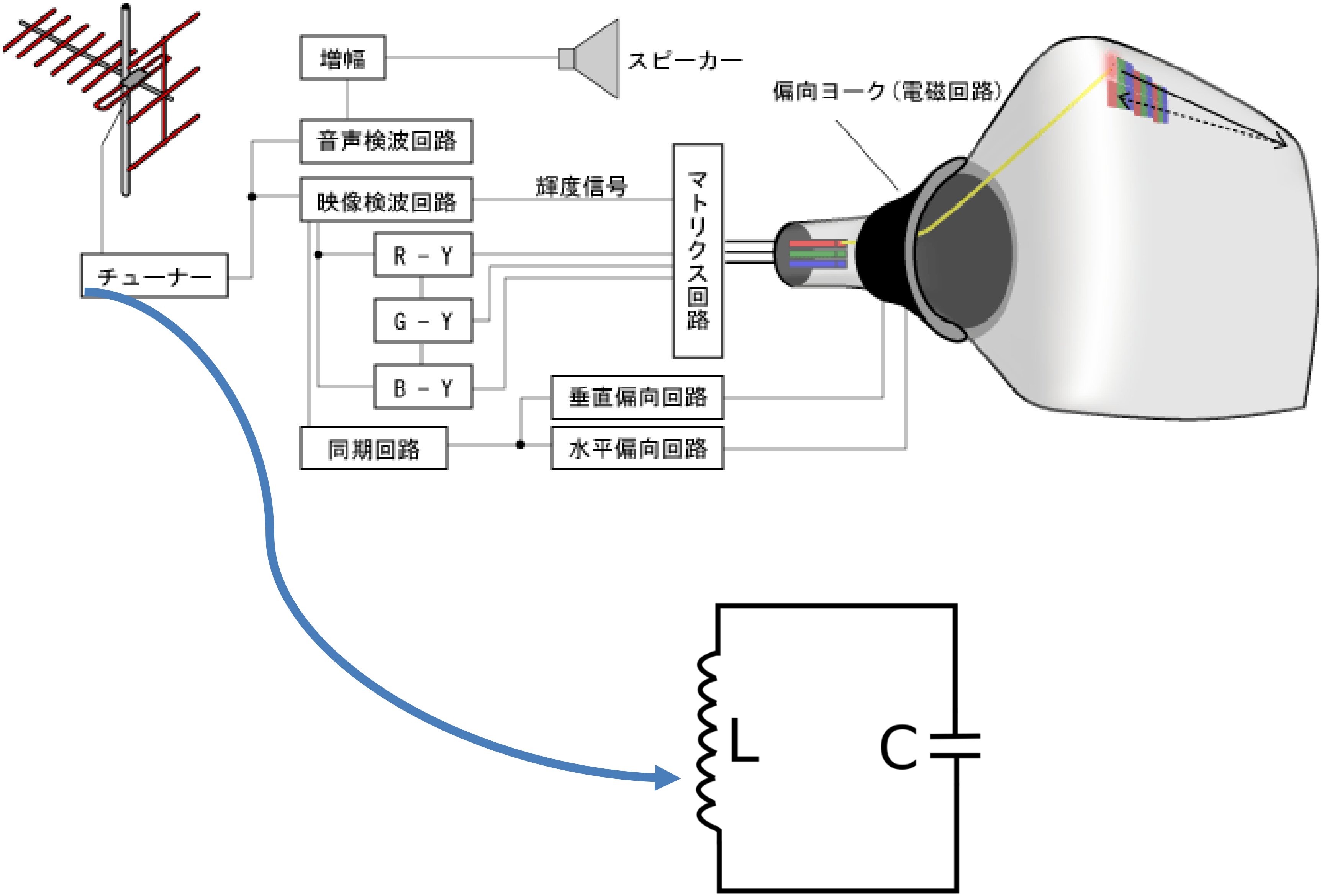
更に、私達の身の回りの共振回路:







更に、私達の身の回りの共振回路:



共振という条件に注意してください

$$\dot{Z} = \sqrt{R^2 + (wL - \frac{1}{wC})^2} \angle tan^{-1} \frac{wL - \frac{1}{wC}}{R} = Z\angle\theta$$

$$\dot{I} = \frac{\dot{V}}{\dot{Z}}$$

$$\dot{Z}_L = jwL \qquad \dot{V}_L = jwL * \dot{I}$$

$$\dot{Z}_C = \frac{1}{jwC} \qquad \dot{V}_C = \frac{1}{jwC} * \dot{I}$$

$$w_0 = \frac{1}{\sqrt{LC}}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$Q = \frac{w_0 L}{R}$$