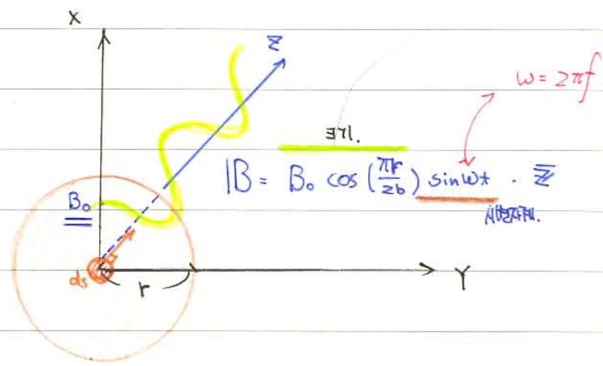
6-2-1 시변자계 내에서 정지 Loop 에 유도되는 emf = ?
(변압기 기전력)
transformer emf.

예제 6-1



$\omega = 2\pi f$

크기.

$$\mathbb{B} = B_0 \cos\left(\frac{\pi r}{2b}\right) \sin\omega t \cdot \bar{z} = B_0 \sin\omega t \ \bar{z}$$

시변자계.

$$emf = ? = V$$

$$V = -\frac{\partial \Phi}{\partial t} \quad (6\text{-}12식)$$

우선 Φ = ? = loop 와 $\mathbb{B}$ 가 쇄교했을 때 쇄교자속수.

where. $\Phi = \int \mathbb{B} \cdot d\mathbf{s}$

$$= \int \underbrace{B_0 \sin\omega t \ \bar{z}}_{운동자계} \cdot d\mathbf{s}$$

where. $d\mathbf{s} = \underbrace{ds}_{코일의\ 미소면적} \ \bar{n}$

$(S = \pi r^2)$ 미분

$ds = 2\pi r \ dr$

$$= \int B_0 \sin\omega t \ \bar{z} \cdot 2\pi r \cdot dr \ \bar{z}$$

$$= \int_0^b B_0 \sin\omega t \cdot 2\pi r \cdot dr = B_0 \sin\omega t \ 2\pi \int_0^b r \ dr$$

$\{0 \le b \le r\}$

$$= B_0 \sin\omega t \; 2\pi \left| \frac{r^2}{2} \right|_0^b$$

$$\Phi = B_0 \sin\omega t \cdot \pi b^2 \quad [wb]$$

※ $\cos\omega t = -\omega \sin\omega t$

$\sin\omega t = \omega\cos\omega t$

$$\therefore \; V = -\frac{\partial\Phi}{\partial t} = -\frac{\partial}{\partial t}\left(B_0 \sin\omega t \; \pi b^2 \right)$$

$$V = -B_0 \omega \cos\omega t \; \pi b^2$$

$$= -B_0 \pi b^2 \omega \cos\omega t$$

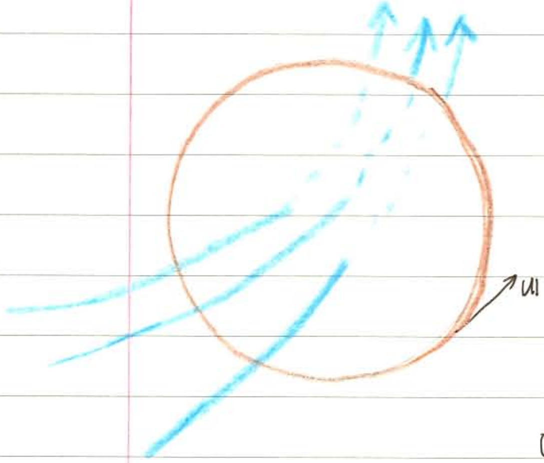
여기서 coil $= N$ 회 이므로.

$$V = -N B_0 \pi b^2 \omega \cos\omega t$$

$\therefore$ B 와 V 는 $90°$ 위상차가 존재

6-2-3 정자계 (시불변 자계) 내에서 Loop 가 움직이는 경우

(운동에 의한 emf → 운동 E)



$V = -\,d\Phi / dt$: 사용불가능

Φ : B가 coil 과 쇄교하는 자속수

다른 방법

Loop 내의 전하가 힘을 받음 by B.

$$\mathbf{F} = Q\,\mathbf{u} \times \mathbf{B}$$
$$= q\,\mathbf{u} \times \mathbf{B}$$

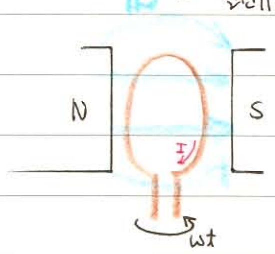
: Ampere's force law

$$\mathbf{F}/Q = \mathbf{u} \times \mathbf{B}$$
$$\downarrow$$
$$\mathbf{E} = \mathbf{u} \times \mathbf{B}$$

$$\therefore\ V = \int \mathbf{E} \cdot d\mathbf{l}$$

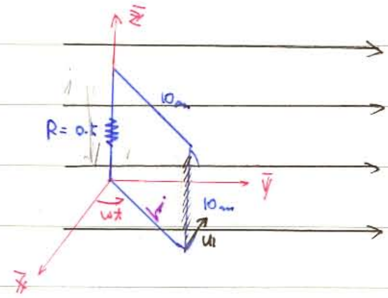
$$= \int \mathbf{u} \times \mathbf{B} \cdot d\mathbf{l} \qquad (6\text{-}23)$$

B = 발전기 ~~전동기~~



flux cutting emf.

예.문 6-5



$\mathbb{B} = 0.04\,\bar{y}$ [T] Tesla. $[\mathrm{wb}/\mathrm{m}^2]$

a) by - 6-22 식.

$$V = \int \mathbb{E} \cdot dl = \int u \times \mathbb{B} \cdot dl$$

$$= u \times \mathbb{B} \cdot \underbrace{\oint dl}_{\text{Loop의 전체 둘레에서 세로부분만 필요.}}$$

$$= u(-\bar{x}) \times B(\bar{y}) \cdot \underbrace{(0.1)}_{10\,\mathrm{cm}}(-\bar{z})$$

$$= uB \sin\theta \, (-\cancel{\bar{z}}) \cdot (0.1) \cdot (-\cancel{\bar{z}})$$

where, $\theta = \omega t$

$$= uB \sin\omega t \, (0.1)$$

★ 물리II 참고. "등속원운동"

$$\therefore V = (0.1)\, uB \underbrace{\sin\omega t}_{\text{교류}}$$

"원운동 속도"★

여기서, $u = \dfrac{2\pi\,(\text{원의반지름})}{\text{주기}}$

$$= 2\pi r / T = 2\pi r \cdot f$$

문제에서

$\omega = 100\pi$

$2\pi f = 100\pi$, $\therefore f = 50$ Hz

$$\therefore u = 2\pi f \cdot r$$

$$= 2\pi \cdot 50\,\mathrm{Hz} \cdot 0.1$$

$$= 10\pi.$$

$\therefore \; v = (0.1)(10\pi)(0.04) \sin 100\pi t$

$= 0.126 \sin 100\pi t.$

$\therefore \; i = v/R = \dfrac{0.126 \sin 100\pi t}{0.5}$

$= 0.251 \sin 100\pi t$ [A] - 자기 유도 용량이 없을 때

(b) 우선 $Z = R + j\omega L$

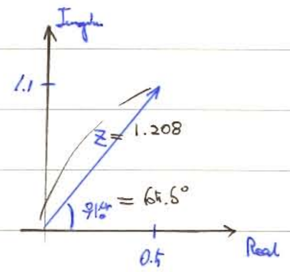
where, $R = 0.5$ [Ω]

$L = 0.035$ [H]

$\omega L = 100\pi\,(0.035)$

$= 1.1$ [Ω] - 교류에서의.

$Z = 0.5 + j\,1.1$ [Ω] $= \sqrt{0.5^2 + 1.1^2} \cdot \tan^{-1}(1.1/0.5)$



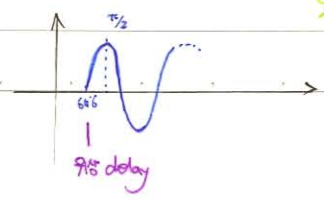
$= 1.208 \angle 65.6°$

$\therefore \; i = v/Z$

$= \dfrac{\overset{\text{크기}}{0.126}\; \sin 100\pi t}{\underset{\text{크기 (나눈다)}}{1.208} \angle 65.6°}$ 위상 (빼준다)

$= \underbrace{0.104}_{\text{크기}} \; \underbrace{\sin(100\pi t - 65.6°)}_{\text{위상}}$ [A] 크기위상

「크기 시간에 따라서 Sin wave 처럼 변한다.」



morning glory

6-2. 4 시변자계 내에 이동 Loop

☆

6-2-1 시변자계 내 정지 Loop $V = \oint \mathbb{E} \cdot d\mathbb{l} = -\frac{\partial}{\partial t} \int \mathbb{B} \cdot d\mathbb{s}$

6-2-3 : 불변자계 이동 Loop $V = \oint \mathbb{E} \cdot d\mathbb{l} = \int (\mathbb{u} \times \mathbb{B}) \cdot d\mathbb{l}$

6-2-4 : 시변, 이동 Loop $V = \oint \mathbb{E} \cdot d\mathbb{l} = \left[-\frac{\partial}{\partial t} \int \mathbb{B} \cdot d\mathbb{s} \right] + \int (\mathbb{u} \times \mathbb{B}) \cdot d\mathbb{l}$

rev)

Loop 단면에서 자속의 변화가 있으면 전류가 흐른다.

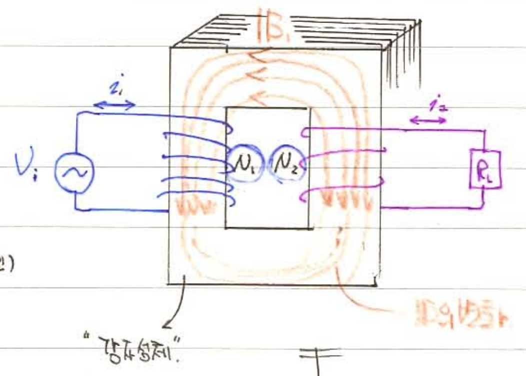
전위차가 생긴다.

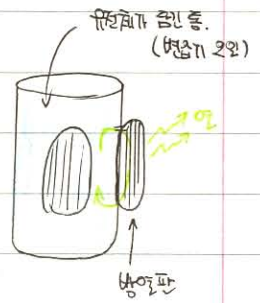
6-2. Transformer "변압기"

임피던스. (R+L) $Z = R + j\omega L$

< 전압. 전류, 저항 > 변화시키는 고유 소자.

hysteresis loss





$$\frac{i_1}{i_2} = \frac{N_2}{N_1}$$

역비례. / 전압은 비례

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

(6-14)

(6-19)

6-3. Maxwell's Equation.

★ 정전계 ! / 정자계 !

	steady . 시불변.	Time varying . 시변계.	
$\mathbb{E}$	$\nabla \cdot \mathbb{E} = e_v / \varepsilon_0$ $\nabla \cdot \mathbb{D} = e$ $(\mathbb{D} = \varepsilon_0 \mathbb{E})$	좌동	
	$\nabla \times \mathbb{E} = 0$	$\nabla \times \mathbb{E} = -\partial \mathbb{B} / \partial t = -\mu_0 \dfrac{\partial \mathbb{H}}{\partial t}$	→ Faraday's law
$\mathbb{H}$	$\nabla \cdot \mathbb{B} = 0$ $\nabla \cdot (\mu \mathbb{H}) = 0$	좌동	
	$\nabla \times \mathbb{H} = \mathbb{J}$ (Ampere's law) $\nabla \times \mathbb{B} = \mu \mathbb{J}$	? Maxwell eq.	$\nabla \times \mathbb{H} = \mathbb{J} + \dfrac{\partial e_v}{\partial t}$
$\mathbb{J}$ →	$\nabla \cdot \mathbb{J} = 0$	$\nabla \cdot \mathbb{J} = -\partial e_v / \partial t$	

지금 $\nabla \times \mathbb{H} = \mathbb{J}$, $\nabla \cdot \mathbb{J} = 0$

$$\nabla \cdot \underbrace{\nabla \times \mathbb{H}}_{\text{회전}} = 0$$

발산. ∴ 성립한다

$$\nabla \cdot \nabla \times \mathbb{H} = \nabla \cdot \mathbb{J} \neq 0$$

$$= -\partial \rho_v / \partial t.$$

Maxwell

$\therefore \nabla \times \mathbb{H} = \mathbb{J} \rightarrow \nabla \times \mathbb{H} = \mathbb{J} + \partial \rho_v / \partial t$ 로 교정

$\nabla \times \mathbb{H} = \mathbb{J} + \partial \rho_v / \partial t$ 의 검증

양변에 "발산".

vector 가 아니므로 ∇ 취할 수 없음.

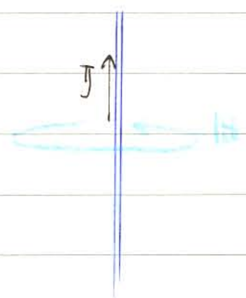
$$\nabla \cdot \nabla \times \mathbb{H} = \nabla \cdot \mathbb{J} + \partial \rho_v / \partial t$$

$$= \text{"}0\text{"}$$

$$\therefore \nabla \cdot \mathbb{J} = -\partial \rho_v / \partial t$$

$\therefore$ Maxwell 이 $\underbrace{\nabla \times \mathbb{H} = \mathbb{J}}_{\text{(Ampere's Circuital Law)}}$ 에 $\dfrac{\partial \rho_v}{\partial t}$ 를 삽입한 것은 옳았다.

$$\underset{\text{자계}}{\nabla \times \mathbb{H}} = \underset{\text{전류}}{\mathbb{J}} + \underbrace{\partial \rho_v / \partial t}_{\text{교류} = AC.} \quad : \text{Maxwell's Eq.}$$



$$\nabla \times \mathbb{H} = \mathbb{J} + \frac{\partial \rho_v}{\partial t}$$

양항에 Div.를 취하면.

$$\nabla \cdot \nabla \times \mathbb{H} = \nabla \cdot \mathbb{J} + \frac{\partial \rho_v}{\partial t}$$

where, $\nabla \cdot \mathbb{D} = \rho_v$

$$\therefore \nabla \cdot \nabla \times \mathbb{H} = \nabla \cdot \mathbb{J} + \frac{\partial (\nabla \cdot \mathbb{D})}{\partial t}$$

$$= \nabla \cdot \left(\mathbb{J} + \frac{\partial \mathbb{D}}{\partial t} \right)$$

$$= \nabla \cdot \left[\mathbb{J} + \frac{\partial (\varepsilon_0 \mathbb{E})}{\partial t} \right]$$

$\mathbb{J}$

Divergence를 떼어버리면,

$$\nabla \times \mathbb{H} = \mathbb{J} + \frac{\partial \mathbb{D}}{\partial t} \quad (6\text{-}44) \quad = \mathbb{J}_c + \mathbb{J}_d$$

※ 도전전류 Conduction Current

전도전류 변위전류 (유전체에서 흐르는 전류, 구속전하에 의해)

$$\left[\begin{array}{l} \nabla \times \mathbb{H} = \mathbb{J} + \varepsilon_0 \dfrac{\partial \mathbb{E}}{\partial t} \\ \nabla \times \mathbb{E} = -\dfrac{\partial \mathbb{B}}{\partial t} = -\mu \dfrac{\partial \mathbb{H}}{\partial t} \end{array} \right]$$

※ 변위전류 displacement Current
변위 전류.

시간에 따라 전계가 자계가 교번.

시변전계.

공기중에 전류가 흐른다? → 무선통신 가능

274p. 273p 증명. 미분형

$$\underset{\downarrow \text{자계}}{\nabla \times \mathbb{H}} = \mathbb{J} + \frac{\partial \mathbb{D}}{\partial t}$$

전속

$$= \mathbb{J} + \varepsilon_0 \frac{\partial \mathbb{E}}{\partial t}$$

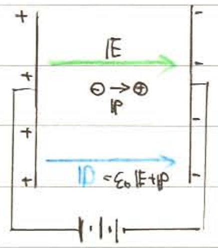
$$= \underbrace{\mathbb{J}_c + \mathbb{J}_d}_{\text{전류.}}$$

도전전류　　분극전류 - 부도체

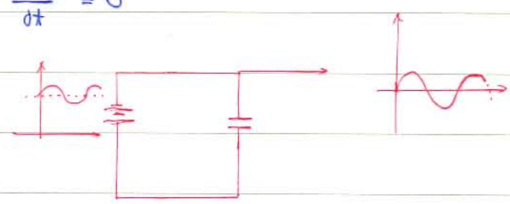
J

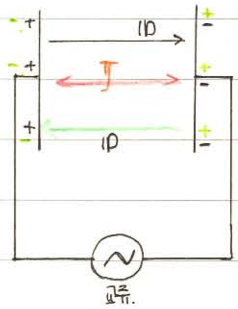
왜 콘덴서에서는
교류에서만
전류가 흐를까?

코일은 반대,



$$\frac{\partial \mathbb{E}}{\partial t} = \frac{\partial \mathbb{D}}{\partial t} = 0$$

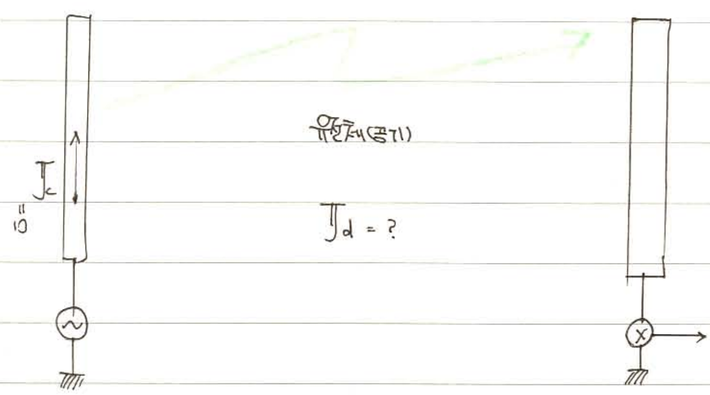




$$\frac{\partial \vec{\mathbb{D}}}{\partial t} \neq 0$$

→ 분극전류가 흐른다. , $\mathbb{H}$ 가 생긴다.

예1. $\mathbb{J}_c$ 와 $\mathbb{J}_d$ 와의 관계. , Antenna 의 기본이론.



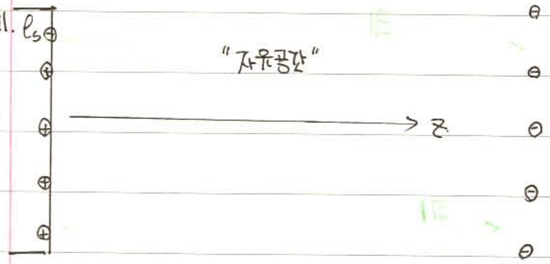
$\cos\omega t = \dfrac{e^{j\omega t} + e^{-j\omega t}}{2}$

도전전류와 변위전류의 관계.

도전전류에 의한 자유공간에서의 전계.

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

오일러



$\mathbb{J}_c = J_c e^{j\omega t} \cdot \hat{z}$

※ $\nabla \times \mathbb{H} = \mathbb{J}_c + \mathbb{J}_d$.

도전, 변위.

$$\nabla \times \mathbb{H} = \mathbb{J}_c + \varepsilon_0 \frac{\partial \mathbb{E}}{\partial t}$$

$$\mathbb{J}_c = J_c e^{j\omega t} \hat{z}, \quad \varepsilon_0 \frac{\partial \mathbb{E}}{\partial t} = \ ?$$

우선, $\mathbb{E}$ (= 유전체 내의 전계) 를 구해야

그런데, $\mathbb{E} = \dfrac{\rho_s}{\varepsilon_0} \hat{z}$ $\left(\mathbb{E} = \dfrac{\rho_s}{\varepsilon_0} \hat{n} \right)$

∴ ρ_s 를 구한다. → 전하밀도

전류 방정식

$$\nabla \cdot \mathbb{J} = \underbrace{0}_{\text{DC}}$$

$$= \underbrace{-\frac{\partial \rho}{\partial t}}_{\text{AC}} \quad (\neq 0)$$

$$\nabla \cdot \mathbb{J} = -\frac{\partial \rho}{\partial t}$$

$$\nabla \cdot \mathbb{J}_c = -\frac{\partial \rho_s}{\partial t}$$

양변을 체적 적분

대전하의 전체량

$$\int \nabla \cdot \mathbb{J} \, ds = -\frac{\partial}{\partial t} \overbrace{\int \rho_s \, dv}$$

$$\int \mathbb{J}_c \cdot ds = -\frac{\partial Q}{\partial t}$$

where, $Q = \rho_s \cdot A$

$$\therefore \frac{\partial(\rho_s A)}{\partial t} = -\int \mathbb{J}_c \cdot ds$$

도체 표면의 미소면적

$$= -\int J_c e^{j\omega t} \cdot \hat{z} \cdot \overline{\overline{ds}}$$

전계방향에서 반대방향이므로

$$= \cancel{-}\int J_c e^{j\omega t} \cdot \cancel{\hat{z}} \cdot ds\,(\cancel{-\hat{z}})$$

$$= J_c e^{j\omega t} \underbrace{\int ds}_{= A}$$

$$= J_c e^{j\omega t} \cdot A$$

$$\therefore \frac{\partial \rho_s}{\partial t} = J_c e^{j\omega t}$$

양변적분.

$$\rho_s = \int_0^t J_c e^{j\omega t} dt = J_c \int_0^t e^{j\omega t} dt$$

$$= J_c \frac{1}{j\omega} \left| e^{j\omega t} \right|_0^t = J_c \frac{1}{j\omega} \left(e^{j\omega t} - 1 \right)$$

$$\therefore \mathbb{E} = \frac{1}{\varepsilon_0}\left[\frac{1}{j\omega} J_c \left(e^{j\omega t} - 1\right)\right] \bar{z}$$

$$\mathbb{E} = \frac{1}{j\omega\varepsilon_0} J_c \left(e^{j\omega t} - 1\right)$$

그런데, $J_d = \dfrac{\partial \mathbb{D}}{\partial t} = \dfrac{\partial(\varepsilon_0 \mathbb{E})}{\partial t}$

$$\therefore J_d = \frac{\partial \cancel{\varepsilon_0}}{\partial t}\left[\frac{1}{j\omega\cancel{\varepsilon_0}} J_c \left(e^{j\omega t} - 1\right)\right]$$

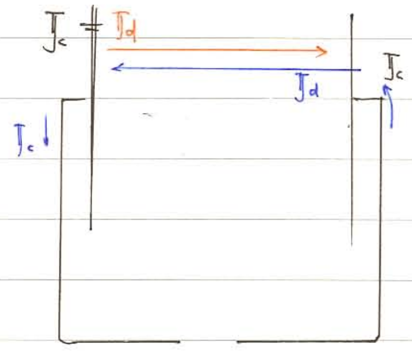
$$= \frac{1}{j\omega} J_c \frac{\partial}{\partial t}\left(e^{j\omega t} - 1\right)$$

$$= \frac{J_c}{\cancel{j\omega}} \cdot \left(\cancel{j\omega} \cdot e^{j\omega t}\right)$$

$$= J_c \cdot e^{j\omega t} \cdot \bar{z}$$

$$\therefore J_d = \underbrace{J_c\, e^{j\omega t}\, \bar{z}}_{J_c}$$

∴ 도전전류 = 분극전류



전자파.
EMI

「저주파 $J_c > J_d$
고주파 $J_c \ll J_d$ 」

전자레인지 2.45GHz