

Near Field E&M

Example

- simple probe case
- demands relation of \vec{B}, \vec{E} to i, v
- Use Maxwell from last time

Wave Derivation

- per usual
- they do it?
- plane waves

Cert
group 3

Lumped vs. Distributed

- kVL & KCL from Maxwell

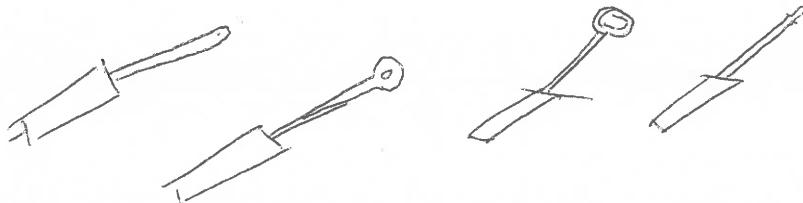
- relationship to C

- boundary

Near Field Probe Intro

- what are they
- why used...
- EMC
- how used
- complex case gotcha
- cabling

- 1st $\frac{1}{2}$ of class is about how Maxwell messes w/o assumptions about circuits
- Easiest way to observe this, which is still relevant for your RF practice, is to observe Near-field radiation from circuits
- do so w/ near field probes (pass around)



shielded vs. \vec{E}

- 3 sensitivity of B probe work by inducing current
- if E probe works by ~~induced voltage~~ -- other side of cap displacement current

- B probes

They do
↳ are they orientation sensitive? ← yes, face down towards current

↳ what do you trade off vs. sensitivity? ← area resolution

→ E doesn't care about orientation, already precise

Why - EMC
- Near field radiation can indicate a source of far field radiation

- Smoker/Debug probes

- Radiated coupling/noise ID

Not a guarantee! → frequency response
→ propagation
→ E/B → impedance

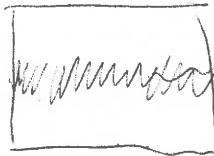
- 2 ~~temp~~ examples of near field measurements

#1

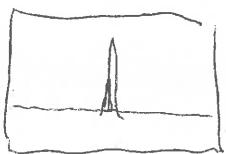
Ashwini



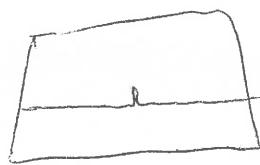
scope E



spec an/FFT E



not under test or B prob

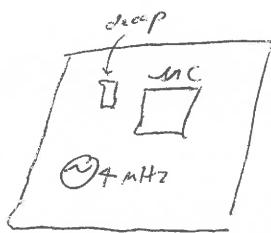


- issue: small signal, need to isolate from noise \rightarrow spec an. or FFT

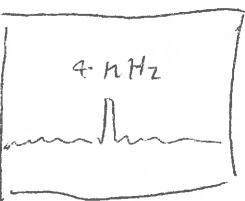
\hookrightarrow can id your signal by turning it off or changing f

- issue: cabling creates big stray fields, setup counts

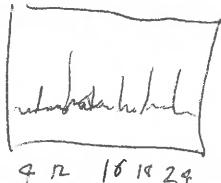
#2



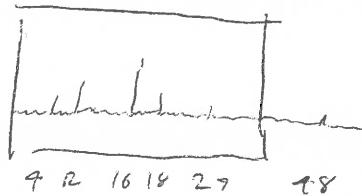
E @ osc



E/B @ MC



B @ cap

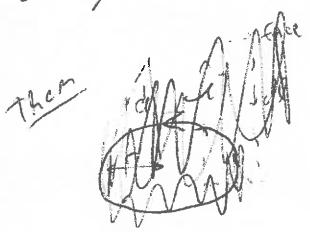


- do you have a radiation problem? maybe... eg wave length to cap could form harmonic on beam

- where are frequency components from? \rightarrow switching activity
 \rightarrow nonlinearity

- E/B difference from dE/dt vs. dB/dt

sample example:



- Find magnetic field ~~at centerline~~ @ distance d

- will a B probe measure this? if so @ what orientation

- Maxwell!

easiest example

- it simple, look up

- it tricky, FEM or solve up

- Biot-Savart

$$\oint B dl = \mu_0 \iint J \cdot d\sigma \text{ for each } d\theta$$

$$2\pi r B = \mu_0 I \rightarrow B = \frac{\mu_0 I}{2\pi r}$$

- B probe doesn't measure w/c DC. If H were AC, then feedback.

- Everything we've seen is quasi-static & instantaneous \rightarrow no reason for B to leave ^{U/I}
- I promised high frequency & wave behavior \rightarrow no current reflections

Maxwell in free space:

$$\nabla \cdot \mathbf{E} = 0 \quad \text{no } q$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \quad \text{no } J$$

Take

$$\bullet \nabla \times (\nabla \times \mathbf{E}) = \nabla \times -\frac{\partial \mathbf{B}}{\partial t} = -\frac{\partial}{\partial t} \nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\bullet \text{Recall } \nabla \times \nabla \times \mathbf{E} = \nabla (\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E} = -\nabla^2 \mathbf{E}$$

$$\bullet \text{Gives } -\nabla^2 \mathbf{E} + \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2} = 0$$

$$\bullet \text{symmetry } -\nabla^2 \mathbf{B} + \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{B}}{\partial t^2} = 0$$

- I can't examples of a class of PDE called wave equations

$$\nabla^2 \psi = \frac{1}{v} \frac{\partial^2 \psi}{\partial t^2} \quad \text{translational (constant)}$$

$$\text{assume 1D: } \frac{\partial^2 \psi}{\partial z^2} = \frac{1}{v} \frac{\partial^2 \psi}{\partial t^2} \quad \text{has sol'n } f(z \pm vt)$$

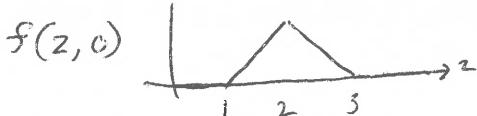
$\hookrightarrow f$ is any function

\hookrightarrow imagine constant t $\rightarrow f(z, 0)$

$$\omega v = z$$

\hookrightarrow propagates

\hookrightarrow at constant $z = 3$



often assume sinusoidal
 $A e^{j\omega(t+z/v)}$
 $= A e^{j(\omega t + k z)}$
 $k = \omega/v$

- Speed for us in our E&M wave equations is $\frac{1}{\sqrt{\mu_0 \epsilon_0}} \equiv c$ speed of light

- Changes when not in free space by $\sim 10\text{-}50\%$

- Can have propagating $\vec{E} \& \vec{B}$ fields & $\vec{E} \& \vec{B}$ fields make voltages & currents via Maxwell's

- When do we use static models or when wave models
- Get there by deriving KCL & KVL from Maxwell

Let $\epsilon_0 \neq 0 \rightarrow \nabla \times \vec{B} = \mu_0 \vec{J}$

$$\nabla \cdot \nabla \times \vec{B} = \mu_0 \nabla \cdot \vec{J}$$

$$\nabla \cdot \vec{J} = 0 \quad \text{- No current divergence; current } n = \text{current density (KCL)}$$

Revisit w/ $\mu_0 \vec{B} = \mu_0 H \rightarrow \text{let } \mu_0 \rightarrow 0$

$$\nabla \times \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t} = 0 \quad \text{so } \nabla \cdot \vec{E} = P/\epsilon_0 \quad \text{w/ no curl} \rightarrow \text{potential gradient}$$

$$V = \oint \vec{E} \cdot d\vec{l} = \int -\nabla \phi \cdot d\vec{l} = 0 \leftarrow \text{KVL}$$

- If μ_0 or $\epsilon_0 = 0$ then $C = \infty \rightarrow$ these approximations hold when waves are fast.

- So ignore about waves if $\ell \ll \lambda$

~~otherwise~~ ↑ ↑
size of highest wavelength
feature we care about

e.g.: thru hole resistor is 1cm, $\mu_r \approx 1$, $\epsilon_r \approx 9$

$$\hookrightarrow @ 1 \text{ kHz} \quad \frac{C}{L} = \lambda \cdot (1 \text{ kHz}) \rightarrow \lambda = 1.5 \text{e}^5 \text{ m} \quad \text{not a wave}$$

$$\hookrightarrow @ 10 \text{ GHz} \quad \frac{C}{L} = \lambda \cdot (10 \text{ GHz}) \rightarrow \lambda = 1.5 \text{ cm} \quad \text{wave 11fc}$$

Q Hollow Fiber optic $\epsilon_r = 10$, $\mu_r = 1$

- not a lumped R
- many elements

\hookrightarrow square light pulses @ 10 Gbps

\hookrightarrow shortest non-wave length