Chapter 16: Magnetic Materials and a Few Devices

16.1 For the magnetic circuit given in Figure 1 containing linear materials (free space surrounds the core), determine the flux, magnetic flux density, and magnetic field everywhere in the core and small gap. Assume the cross-sectional area is equal to A everywhere and the relative permeabilities of the core materials are much greater than one. Then, determine the inductance of the N-turn coil. Use superposition and "current" and "voltage" division, and do not simplify the expressions.

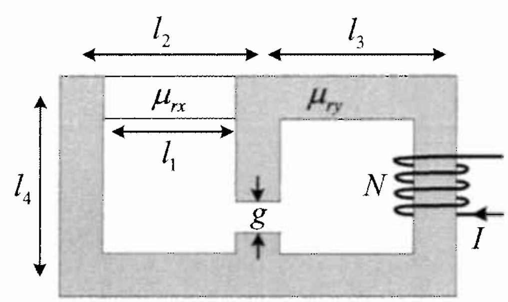


Figure 1

16.2 For the magnetic circuit given in Figure 2 containing linear materials (free space surrounds the core), determine the flux, magnetic flux density, and magnetic field everywhere in the core and small gap. Assume the cross-sectional area is equal to A everywhere and the relative permeabilities of the core materials are much greater than one. Use superposition and "current" and "voltage" division, and do not simplify the expressions.

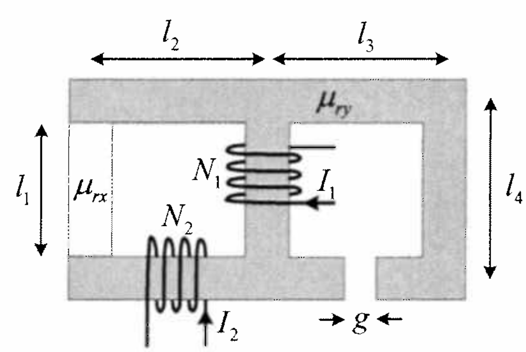


Figure 2

16.3 A current probe placed around (both conductors of) air twin-lead line reads 1 mA. When the current probe is placed around only one conductor it reads –0.3 mA. If an ideal common-mode choke is placed on this line, determine the new current level in each conductor. Note whether the magnitude of the current increases or decreases in each conductor.

16.4 For two-conductor cables such as twin-lead, carefully explain why the entire cable can be wrapped around a toroid if a common-mode choke is desired rather than physically separating the two conductors and then individually winding them around the toroid.

16.5 Why would Litz wire be used for the winding of a coil with a ferrite core?

16.6 A short piece of speaker wire that is connected to an amplifier is accessible (the remaining portion of the wire is hidden in the wall). Various types of common-mode chokes are used at this location. They have little effect on the interference. Does this imply that the interference is entering the system from another route? Explain. To (help) ensure that it is not entering via the speaker wire, what can be done?

16.7SC Modeling a wire inside a ferrite bead as a parallel *RLC* circuit, determine the geometry factor K and the value for the R, L, and C for three different beads by using actual measured impedance characteristics. Plot the magnitude of the impedance of the *RLC* circuit for each bead from 1 to 1,000 MHz and compare to the measured values. [Fair-Rite]

16.8 For the popular 43 ferrite material, a formula seen for the saturation current of a ferrite bead is $I_{sat} = 10R$ where R is the outer radius of the bead in cm. Determine the validity and limitations of this formula. [Kimmel, '94]

16.9SC Compare analytically and numerically the idealized inductance equation for a wire inserted in a bead versus the inductance equation for a one-turn toroidal-wound coil.

16.10 Explain how a ferrite bead can be used as a common-mode choke.

16.11 How could a ferrite filter around a shielded cable actually increase the susceptibility of a circuit to ESD?

16.12 For two-hole ferrite bead, where is the bead most likely to saturate first? State all assumptions.

16.13S It is stated that about 10 dB of insertion loss is possible from 1 MHz to 1 GHz for certain ferrite beads. Determine whether this is reasonable. Clearly state all assumptions.

16.14 If the common-mode signals on a line are not sinusoidal, will the common-mode choke still function properly? Explain.

16.15 If all three wires of an electrical power line (the hot, neutral, and ground wires) are wound on one common-mode choke, will it still function as a choke to common-mode signals? Will it affect the desirable signals on the power line? [Nave]

16.16S Explain how one paper towel cardboard roll and several bunches of steel wool could (in theory) be used as a crude RFI reducer for a television set. Assume the interference is conducted. Steel wool consists of long fine fibers of low-cost, low-strength low-carbon steel. Steel wool can be purchased in different grades (different fiber diameters and fineness) and is used in a wide variety of applications ranging from polishing woods to scouring pans. Measure the inductance of one conductor of a typical power cord with and without this steel-wool filter. What frequency(s) is the inductance meter using to determine the inductance? How does this affect the inductance measurement?

16.17 For differential-mode currents, for real loads, and for real characteristic line impedances, it is stated in this chapter that when the load impedance is small compared to the characteristic impedance, then the current is large at the load. Using the transmission line equations show that this statement is true.

16.18 Why are ferrite-loaded antennas typically only used for receiving and not transmitting?

16.19 Sometimes an air gap is introduced into the core of a coil wrapped around a toroid. Does the air-gap decrease or increase the maximum dc current that can be handled by the toroid before saturation? Does the air gap decrease or increase the leakage flux and the inductance of a winding on the toroid?

16.20 Graphically show that the differential permeability can be less than or greater than the relative permeability.

16.21 What is the saturation flux density for copper?

16.22 Derive the expression given in this chapter for the total power dissipated per cycle due to hysteresis losses:

$$P_{d,total} = \frac{8}{3}\nu H_m^3 fV \text{ W/cycle}$$

This assumes that the *B-H* curve can be described by the Rayleigh-loop expression:

$$B = \left(\mu_i + 2\nu H_m\right) H \pm \nu\left(H_m^2 - H^2\right)$$

Notice that B is given as a function of H not H as a function of B. Nevertheless, the hysteresis energy loss per unit volume per cycle is the area enclosed by the hysteresis curve.

16.23 An approximation for the demagnetization factor for a general ellipsoid is

$$N_a = \frac{1}{a}\left(\frac{abc}{ab + ac + bc}\right)$$

where a, b, and c are the lengths of the three axes of the ellipsoid. The magnetic field is parallel to the a axis. Determine whether this is a reasonable expression by providing three unique checks of this result with expressions provided in the chapter. [Watson]

16.24 Design, if possible, a 2 mH air-gap toroidal inductor with a total length of less than 5 cm if the dc current is 1.2 A and the ac signal amplitude is 20 mA. Use the Hanna curves given in this chapter.

16.25 Design, if possible, a 2 mH air-gap toroidal inductor with a gap length of greater than 100 mils if the dc current is 1.2 A and the ac signal amplitude is 20 mA. Use the Hanna curves given in this chapter.

16.26 Determine the net torque about the z axis for a circular loop carrying a current of I when in a magnetic field of

$$\vec{H} = H_x \hat{a}_x$$

where H_x is a constant. The loop has a radius of a, is centered about the origin, and is located in the xy plane. Is this torque equal to $\vec{m} \times \mu_o \vec{H}$? Why or why not?

16.27 Determine the net torque about the z axis for a circular loop carrying a current of I when in a magnetic field of

$$\vec{H} = H_\rho \hat{a}_\rho + H_\phi \hat{a}_\phi + H_z \hat{a}_z$$

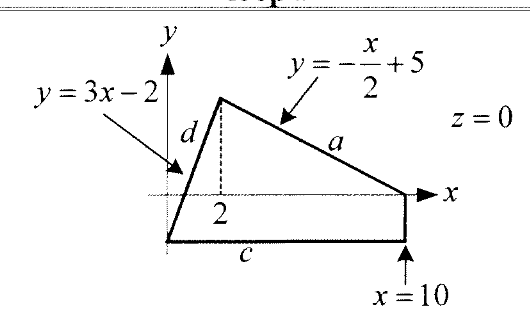
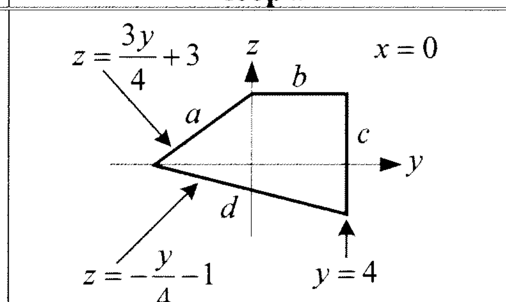
where H_ρ, H_ϕ, and H_z are not a function of position. The loop has a radius of a, is centered about the origin, and is located in the xy plane. Is this torque equal to $\vec{m} \times \mu_o \vec{H}$? Why or why not?

16.28 For the given four-sided loop # in Table 2 (provided by your instructor) in a magnetic field $\vec{H}_\#$ given in Table 1 (provided by your instructor), determine the force (a vector) on each side of the loop. Then, determine the net force on the loop. The current in the loop, I, is either clockwise or counterclockwise (provided by your instructor). Then, determine the torque about the origin for side X (provided by your instructor).

Table 1

#	$\vec{H}_\#$	#	$\vec{H}_\#$
1	$2z\hat{a}_x + (x^2 + y)\hat{a}_y - z\hat{a}_z$	4	$(2z - y)\hat{a}_x + x^2\hat{a}_y + y\hat{a}_z$
2	$-2xy\hat{a}_x - (y^2 + 1)\hat{a}_y + 4yz\hat{a}_z$	5	$y\hat{a}_x - (z - x)\hat{a}_y + (2x - 1)\hat{a}_z$
3	$(z - y)\hat{a}_x + (3z^2 - y)\hat{a}_y + z\hat{a}_z$	6	$2y\hat{a}_x - (2xy - 1)\hat{a}_y + 2xz\hat{a}_z$

Table 2

#	**loop #**	#	**loop #**
1		4	

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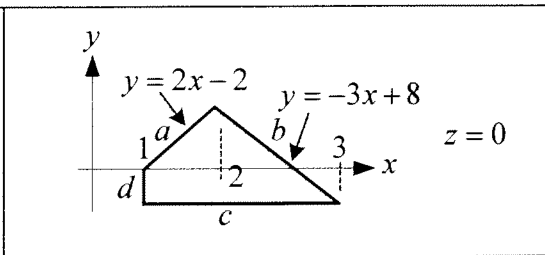

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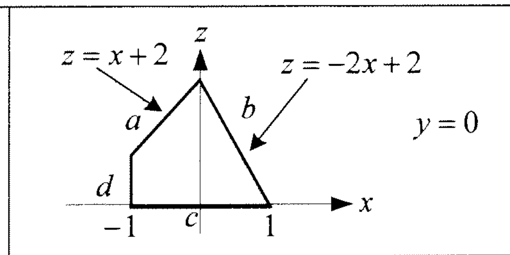

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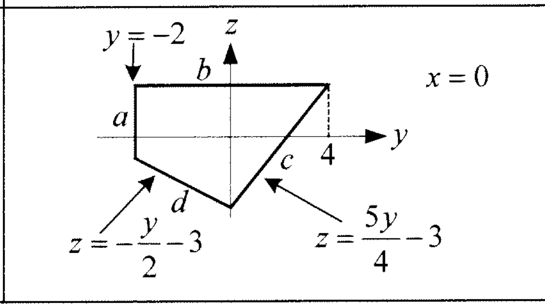

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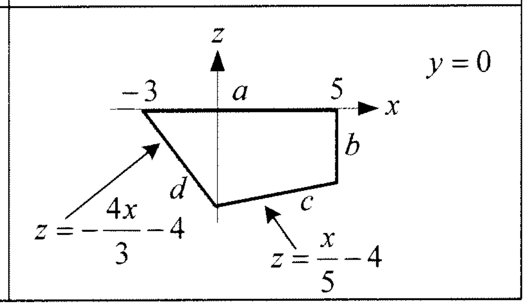


16.29 Determine the magnetizing volume and surface currents for a rod of total length d and radius a that has been magnetized to

$$\vec{M} = M_o(\rho + a)\hat{a}_z$$

The axis of the cylindrical rod is along the z axis and the rod is centered about the origin. Note that the magnetization, which is along the length of the rod, varies in the ρ direction.

16.30 Using the hysteresis model

$$B = \frac{B_s B_r (H + H_c)}{B_r H + B_s H_c}$$

for a permanent magnet in the second quadrant, derive the expressions provided in this chapter for B_m and H_m corresponding to the location of the maximum energy product.

16.31 When is the following integral expression true?

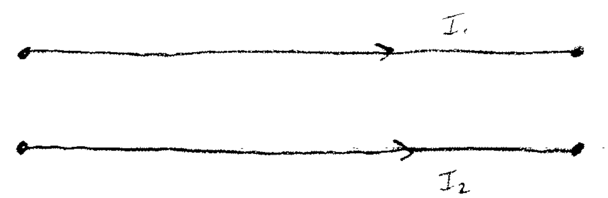
$$\int_0^B H dB = -\int_B^0 H dB$$

16.32 A solid sphere of radius R is uniformly magnetized to $M_o\hat{a}_r$. Free space surrounds this magnet. Determine the volume magnetic charge density within the sphere and the surface magnetic charge density at $r = R$. Determine the net charge inside the sphere and along the surface of the sphere. Is this result surprising? Then, using the analogous expressions for the electric field from real charges, determine the magnetic field both inside and outside the magnetized sphere. From this information, determine whether the self energy of this magnet is given by the expression

$$E = \frac{2\pi\mu_o M_o^2 R^3}{3}$$

Section 11

(1)



current probe reads:
$I_1 + I_2 = 1mA$
$I_2 = -.3mA$

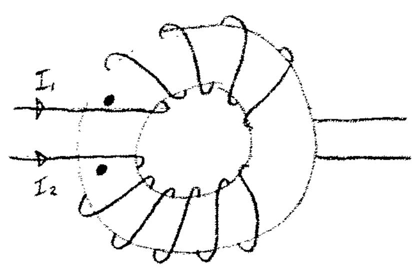
Place an ideal common-mode choke on the line.

$I_1 = I_D + I_C$ common-mode: same direction
$I_2 = -I_D + I_C$ differential-mode: equal + opposite

$I_C = \frac{I_1 + I_2}{2}$ $\qquad I_D = \frac{I_1 - I_2}{2}$

$I_C = \frac{1mA}{2}$ $\qquad I_D = I_C - I_2$

$I_C = .5mA$ $\qquad I_D = .8mA$ $\qquad I_1 = 1.3mA$



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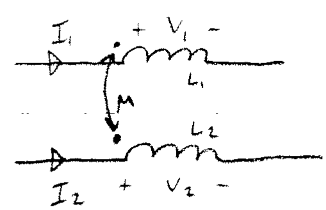


$Z_1 = V_1 / I_1 = \frac{j\omega L_1 I_1 + j\omega M I_2}{I_1}$ $\qquad Z_2 = \frac{V_2}{I_2} = \frac{j\omega L_2 I_2 + j\omega M I_1}{I_2}$

$\left.\begin{array}{l}\text{ideal coupling: } k = 1 \\ L_1 = L_2 = L\end{array}\right\} \quad M = 1\sqrt{L_1 L_2} = L$

impedance seen by differential-mode: $I_1 = I_D = -I_2$

$Z_1 = \frac{j\omega L I_D + j\omega L(-I_D)}{I_D} = 0$, $\quad Z_2 = 0$

impedance seen by common-mode: $I_1 = I_C$, $I_2 = I_C$

$Z_1 = \frac{j\omega L I_C + j\omega L I_C}{I_C} = 2j\omega L$ $\qquad Z_2 = 2j\omega L$

+3

Problem 4
In a large open-air twin-lead line, a noncontact current probe is used to measure the current in each conductor. A current of 2.5 mA ac is measured in one conductor and –0.5 mA ac in the return conductor.

+1 a) Determine the common-mode current on each conductor.

$$I_C = \frac{I_1 + I_2}{2} = \frac{2.5 - .5}{2} = \frac{2}{2} = 1\,mA$$

+1 b) Determine the differential-mode current on each conductor.

$$I_D = \frac{I_1 - I_2}{2} = \frac{2.5 - (-.5)}{2} = \frac{3}{2} = 1.5\,mA$$

check: $I_1 = I_C + I_D = 2.5\,mA$ ✓ $I_2 = -I_D + I_C = -.5\,mA$ ✓

+1 c) If an ideal common-mode choke is placed on this line, determine the new current level on each conductor.

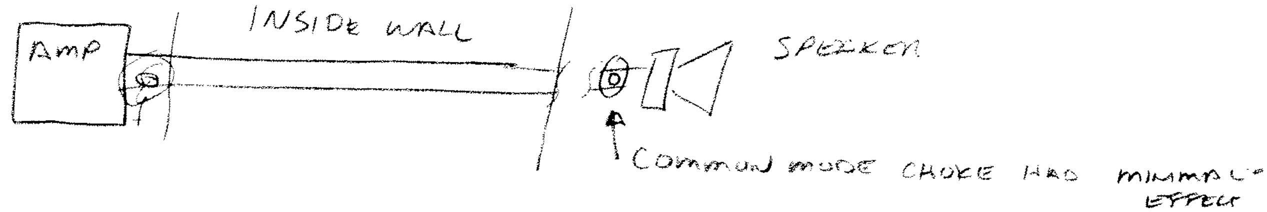
If $j\omega L \to \infty$ for each coil of the ideal (CM) choke, then $I_C \to 0$ and

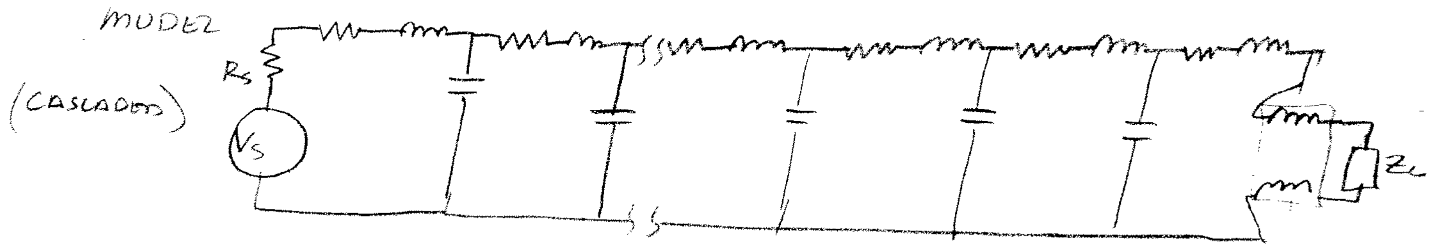
$$I_1 = 1.5\,mA$$

$$I_2 = -1.5\,mA$$

11-25-95 ECE-640 WEEK 4 [redacted]

11-17 **LOCATION OF CHOKE**





YES - IMPLIES MAY BE ANOTHER NOISE PATH

A. INTERFERENCE INTO AMPLIFIER

- PLACING CHOKE AT LOAD MAY NOT BE EFFECTIVE AS UNWANTED, COMMON MODE SIGNALS CAN BE PICKED-UP ALONG THE WIRES AND REFLECTED OFF THE CHOKE.
- DISTRIBUTED IMPEDANCES OF WIRES ISOLATE CHOKE FROM THE AMPLIFIER END
- WITH CHOKE AT SPEAKER END, WIRES CAN STILL BE THE PATH OF NOISE INTO AMPLIFIER

TO INSURE NOISE INTO AMPLIFIER NOT FROM SPEAKER WIRES.

1) - INSTALL COMMON MODE CHOKE AT AMPLIFIER END OF WIRES AND ALONG WIRES IF POSSIBLE.

OR) 2) INVESTIGATE SHIELDED WIRES (TRI-AX, TWISTED SHIELDED PAIR, etc)

[redacted]

Section 11

(19) The minimal effect on the interference due to the common mode choke does not necessarily mean that the interference is entering in from another location. If the wire is electrically long, the impedance of the wire will vary along its length. If the common mode choke is placed in a high impedance part of the speaker wire, the common mode choke would not be as effective at blocking the common mode currents. The higher impedance section of the speaker wire could be comparable in impedance in comparison to the impedance of the common mode choke.

$\frac{V}{I}$ I small

One way of finding out if the noise is coming from the speaker wires is to disconnect those speaker wires and attach some short speaker wires directly to some speakers. If the noise is still present then it is probably coming from a different source.

or add long wire +4

[redacted]

EE632

11-20) A common mode choke near the load will block common mode currents from entering the load. this is especially true if the load impedence is low compared to the source. (least resistance) If the transmission line is elec. long it is going to be a good radiator of any common mode currents that exist on the line.

Need to understand what would happen with a high impedence load.

If load is high impedence, choke impedence will be insignificant for blocking noise voltages and it will drop on load (IE. voltage division)

Current levels important for ~~for~~ at load for choke to act effectively

Current levels must be high enough to create cancelling fluxes in the choke. If the current levels (common mode) are too high however, the core could saturate but this is not normally a problem for common mode currents. Differential currents have a cancelling flux.

Ken Kaiser

[redacted]

EE632

11-3) If the wire could be wound into a tightly coupled coil, common mode currents would be reduced without distorting differential mode currents needed to drive the speaker. Common mode currents could possibly affect receiver operation or they could cause radio interference with other household devices. The coil should be wound close to the receiver since it is more susceptible to common mode noise on the cable than the speaker. Also it would protect against noise from the receiver's digital section from getting on to the line.

(Common mode choke close to receiver.)

section 11

2. Much extra twin-lead wire is available to match a speaker to a receiver.

The extra wire can be coiled up and placed in between the speaker and receiver or placed closer to the speaker.

Ken Kaiser [redacted]

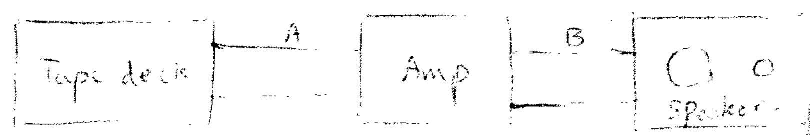
11.11) If the chokes have minimal effect on the interference, then there maybe a lot of reasons

(a) The chokes may not be placed as close as possible to the point of entry to the speaker box

(b) The interference may be present in DM components since the chokes may filter out only common mode currents. One solution is to place ferrite beads over each wire & around the entire harness

(c) The load may be unbalanced. Due to this, the ~~ma~~ common mode currents produce a voltage across the load. The effect of CM interference is a function of the amount of CM to DM conversion that results from circuit impedance imbalance.

(d) Level of susceptibility:



The wires connecting the tape deck and the Amp carry the lowest level signals and are highly susceptible to interference. Using EMI control methods here may help resolve the problem.

Ken Kaiser

11.4

Problem 11.4 modelling a wire inserted inside a ferrirte bead as a parallel rlc dirduit determine the gometry factor K and the value for R,L, and C for 3 different beads by using actuall measured impedance characteristics. Plot the magnitude of the impedance of the rlc circuit for each bead from 1 to 1000 Mhz.

Professor Kaiser provided a similar set of curves and component values. The associated sheets are attached. The curves of the associated rlc circuits are plotted and compared to the provided charts they seem to match very closely. Then the K is calculated using an equation from the kaiser text page 255.

The values of the RLC circuit can be deterimined almost by inspection. The value of the R is read from the measured impedance graph at the resonant frequency. The values of L and C are determined from the solving the following equations using the values of BW,Wc, and R from the graph. The equations used are R=R @ Wc BW=1/RC and Wc=1/sqareroot(LC). To verify this sense I already have the solution to this problem I will plug the solution values in and verify that the proper BW and Wc are the result, which will prove this is the correct method and the equations are correct. The R is not solved since it is verified by inspection. The center frequency is very close to the expected value, However it is dificult to get the actual bandwidth for the graph since it does not vary long enough in frequency.

The equations are taken from the kaiser text page 133. The equation for the Band width is arrived at by the fact that Rs in parrallel to Rl Reduces to Rl when Rs goes to infinity.

$$\mathrm{BW}(R,c) := \frac{1}{c\cdot R} \qquad \mathrm{Wc}(l,c) := \frac{1}{\sqrt{l\cdot c}}$$

$$\mathrm{BW}\left(85, 1\cdot10^{-12}\right) = 1.176\cdot10^{10} \qquad \mathrm{Wc}\left(500\cdot10^{-9}, 1\cdot10^{-12}\right) = 1.414\cdot10^{9}$$

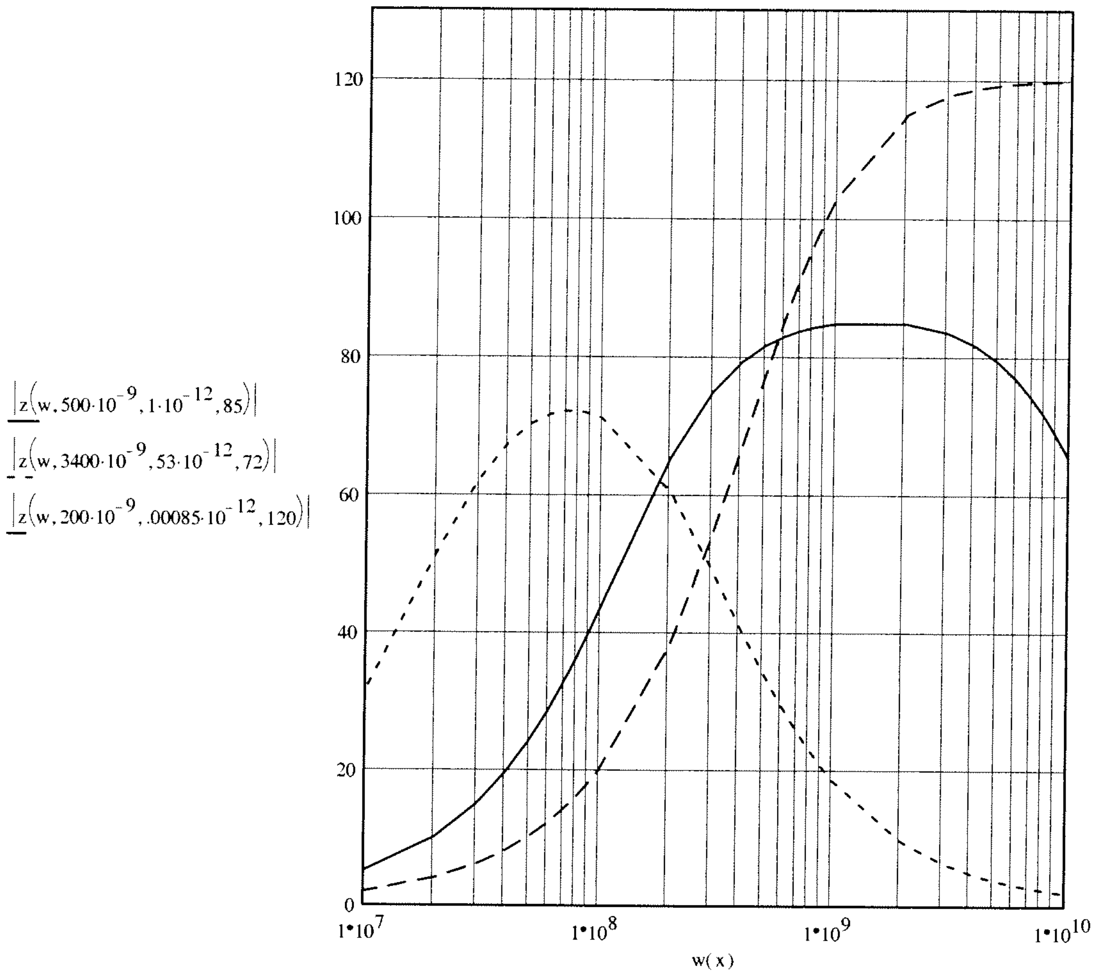
$$\mathrm{BW}\left(72, 53\cdot10^{-12}\right) = 2.621\cdot10^{8} \qquad \mathrm{Wc}\left(3400\cdot10^{-9}, 53\cdot10^{-12}\right) = 7.449\cdot10^{7}$$

$$\mathrm{BW}\left(120, .00085\cdot10^{-12}\right) = 9.804\cdot10^{12} \qquad \mathrm{Wc}\left(200\cdot10^{-9}, .00085\cdot10^{-12}\right) = 7.67\cdot10^{10}$$

$$x := 60, 61 .. 100$$

$$w(x) := \left[(x+1) - 10\cdot\mathrm{floor}\left(\frac{x}{10}\right)\right]\cdot 10^{\mathrm{floor}\left(\frac{x}{10}\right)}$$

$$z(w,l,c,R) := \frac{1}{\left[\dfrac{R\cdot(j\cdot w(x)\cdot l) + j\cdot w(x)\cdot l\cdot\dfrac{1}{j\cdot w(x)\cdot c} + \dfrac{1}{j\cdot w(x)\cdot c}\cdot R}{R\cdot(j\cdot w(x)\cdot l)\cdot\dfrac{1}{j\cdot w(x)\cdot c}}\right]}$$



the following is the equation for K given the dimensions of the bead

$$K\left(L_{bead}, len, b, a\right) := \frac{L_{bead}}{len \cdot \ln\left(\frac{b}{a}\right)}$$

$$K\left(500 \cdot 10^{-9}, .296 \cdot 25.4 \cdot 10^{-3}, .295 \cdot 25.4 \cdot 10^{-3}, .094 \cdot 25.4 \cdot 10^{-3}\right) = 5.815 \cdot 10^{-5}$$

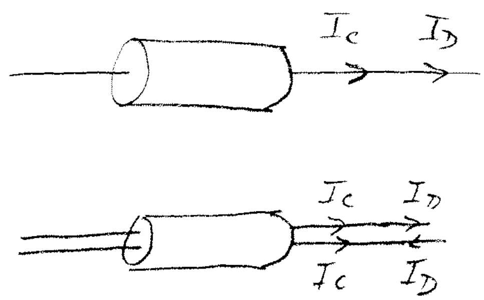
$$K\left(3400 \cdot 10^{-9}, .296 \cdot 25.4 \cdot 10^{-3}, .295 \cdot 25.4 \cdot 10^{-3}, .094 \cdot 25.4 \cdot 10^{-3}\right) = 3.954 \cdot 10^{-4}$$

$$K\left(200 \cdot 10^{-9}, .296 \cdot 25.4 \cdot 10^{-3}, .295 \cdot 25.4 \cdot 10^{-3}, .094 \cdot 25.4 \cdot 10^{-3}\right) = 2.326 \cdot 10^{-5}$$

MAGNETIC DEVICES

11.11

Ferrite beads provide impedances up to several hundred ohms. Discuss the filtering differences between passing one wire through the bead versus both the wire and its return.



$I_D = \frac{1}{2}(I_1 - I_2)$

$I_C = \frac{1}{2}(I_1 + I_2)$

Ferrite bead acts as inductance to both common and differential mode currents for single wire.

Ferrite bead acts as inductance to common mode currents only if wire and return pass through. Differential mode currents have flux in opposite directions ⇒ cancel each other out, and no impedance or effect.

$\mu_0 := 4\cdot\pi\cdot10^{-7} \quad j := \sqrt{-1}$

Magnetics

$r_{inner} := .275\cdot10^{-3} \quad r_{outer} := .675\cdot10^{-3} \quad l := 6.6\cdot10^{-3} \quad r_w := r_{inner}$

$$L_{wire} := \frac{\mu_0}{2\cdot\pi}\cdot l\cdot\left[\ln\left[\frac{l}{r_w}+\sqrt{\left(\frac{l}{r_w}\right)^2+1}\right]+\frac{r_w}{l}-\sqrt{\left(\frac{r_w}{l}\right)^2+1}\right] \qquad L_{wire} = 3.844\cdot10^{-9}$$

1) Material 61

$LossFactor_{61} := 32\cdot10^{-6} \quad Initial\mu_{r61} := 125 \quad f_{61} := 1000, 2000 .. 30\cdot10^6$

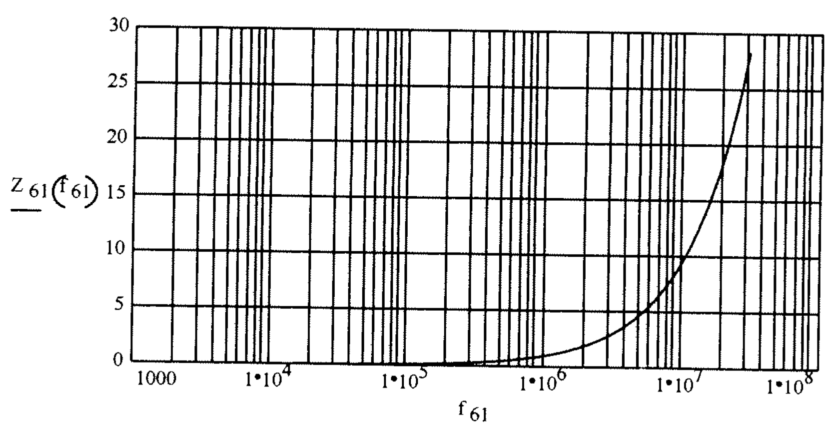
$$LossTan_{61} := LossFactor_{61}\cdot Initial\mu_{r61} \qquad LossTan_{61} = 0.004$$

$$\Delta L_{61} := \frac{\mu_0\cdot l\cdot\left(Initial\mu_{r61}-1\right)}{2\cdot\pi}\cdot\ln\left(\frac{r_{outer}}{r_{inner}}\right) \qquad \Delta L_{61} = 1.47\cdot10^{-7}$$

$$L_{s61} := L_{wire} + \Delta L_{61} \qquad L_{s61} = 1.508\cdot10^{-7}$$

$$R_{s61}(f_{61}) := LossTan_{61}\cdot2\cdot\pi\cdot f_{61}\cdot L_{s61}$$

$$Z_{61}(f_{61}) := \left|R_{s61}(f_{61}) + j\cdot2\cdot\pi\cdot f_{61}\cdot L_{s61}\right|$$



$Z_{61}(100) = 9.476\cdot10^{-5}$

$Z_{61}(5\cdot10^5) = 0.474$

$Z_{61}(30\cdot10^6) = 28.429$

2) Material 44

$LossFactor_{44} := 85 \cdot 10^{-6}$ $\quad$ $Initial\mu_{r44} := 500$ $\quad$ $f_{44} := 1000, 2000 .. 1 \cdot 10^{6}$

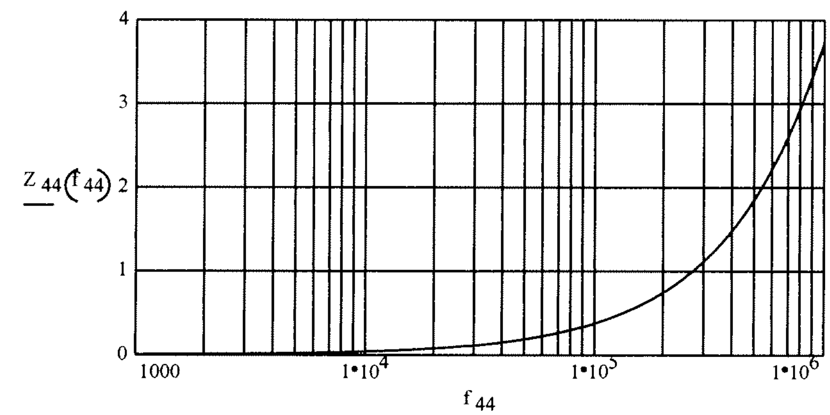
$LossTan_{44} := LossFactor_{44} \cdot Initial\mu_{r44}$ $\qquad$ $LossTan_{44} = 0.042$

$$\Delta L_{44} := \frac{\mu_0 \cdot l \cdot (Initial\mu_{r44} - 1)}{2 \cdot \pi} \cdot \ln\left(\frac{r_{outer}}{r_{inner}}\right) \qquad \Delta L_{44} = 5.915 \cdot 10^{-7}$$

$L_{s44} := L_{wire} + \Delta L_{44}$ $\qquad$ $L_{s44} = 5.953 \cdot 10^{-7}$

$R_{s44}(f_{44}) := LossTan_{44} \cdot 2 \cdot \pi \cdot f_{44} \cdot L_{s44}$

$Z_{44}(f_{44}) := \left| R_{s44}(f_{44}) + j \cdot 2 \cdot \pi \cdot f_{44} \cdot L_{s44} \right|$



$Z_{44}(100) = 3.744 \cdot 10^{-4}$

$Z_{44}(5 \cdot 10^{5}) = 1.872$

$Z_{44}(1 \cdot 10^{6}) = 3.744$

3) Material 43

$LossFactor_{43} := 120 \cdot 10^{-6}$ $\quad$ $Initial\mu_{r43} := 1000$ $\quad$ $f_{43} := 1000, 2000 .. 5 \cdot 10^{6}$

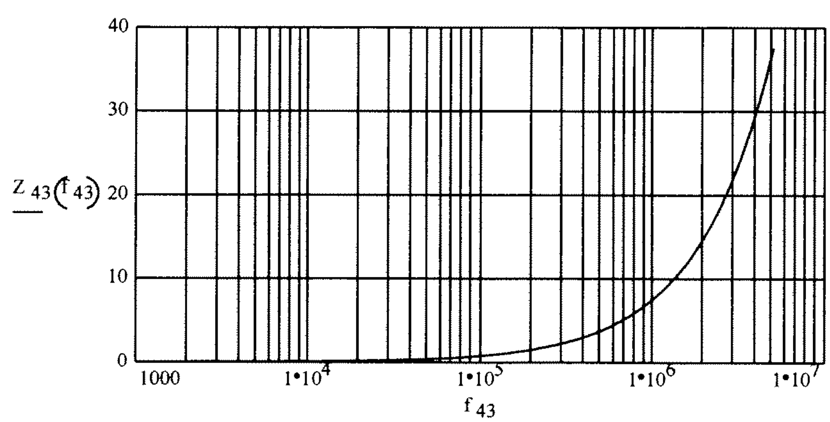
$LossTan_{43} := LossFactor_{43} \cdot Initial\mu_{r43}$ $\qquad$ $LossTan_{43} = 0.12$

$$\Delta L_{43} := \frac{\mu_0 \cdot l \cdot (Initial\mu_{r43} - 1)}{2 \cdot \pi} \cdot \ln\left(\frac{r_{outer}}{r_{inner}}\right) \qquad \Delta L_{43} = 1.184 \cdot 10^{-6}$$

$L_{s43} := L_{wire} + \Delta L_{43}$ $\qquad$ $L_{s43} = 1.188 \cdot 10^{-6}$

$R_{s43}(f_{43}) := LossTan_{43} \cdot 2 \cdot \pi \cdot f_{43} \cdot L_{s43}$

$Z_{43}(f_{43}) := \left| R_{s43}(f_{43}) + j \cdot 2 \cdot \pi \cdot f_{43} \cdot L_{s43} \right|$



$Z_{43}(100) = 7.518 \cdot 10^{-4}$

$Z_{43}(5 \cdot 10^{5}) = 3.759$

$Z_{43}(5 \cdot 10^{6}) = 37.588$

4) Material 73

$LossFactor_{73} := 7\cdot 10^{-6}$ $\quad$ $Initial\mu_{r73} := 2500$ $\quad$ $f_{73} := 1000, 2000 .. 1\cdot 10^{6}$

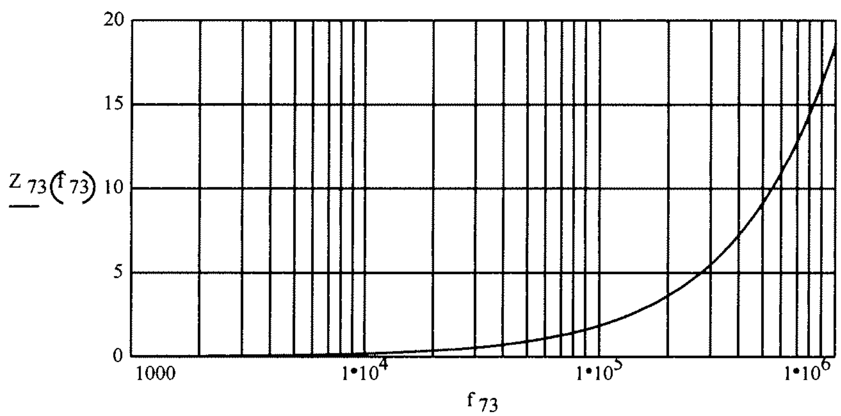
$LossTan_{73} := LossFactor_{73}\cdot Initial\mu_{r73}$ $\qquad$ $LossTan_{73} = 0.017$

$$\Delta L_{73} := \frac{\mu_0 \cdot l \cdot (Initial\mu_{r73} - 1)}{2\cdot\pi}\cdot \ln\left(\frac{r_{outer}}{r_{inner}}\right) \qquad \Delta L_{73} = 2.962\cdot 10^{-6}$$

$L_{s73} := L_{wire} + \Delta L_{73}$ $\qquad$ $L_{s73} = 2.966\cdot 10^{-6}$

$R_{s73}(f_{73}) := LossTan_{73}\cdot 2\cdot\pi\cdot f_{73}\cdot L_{s73}$

$Z_{73}(f_{73}) := |R_{s73}(f_{73}) + j\cdot 2\cdot\pi\cdot f_{73}\cdot L_{s73}|$



$Z_{73}(100) = 0.002$

$Z_{73}(5\cdot 10^{5}) = 9.319$

$Z_{73}(1\cdot 10^{6}) = 18.638$

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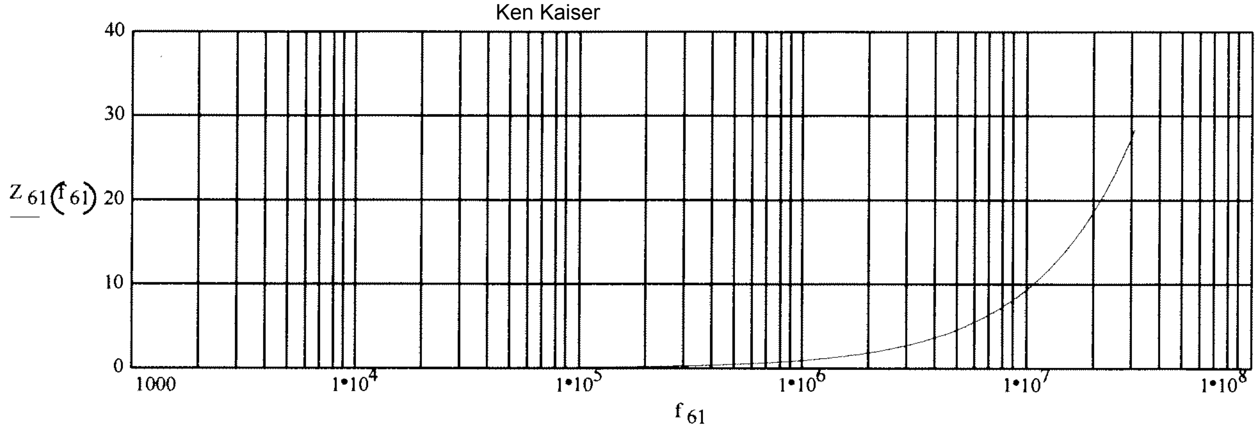
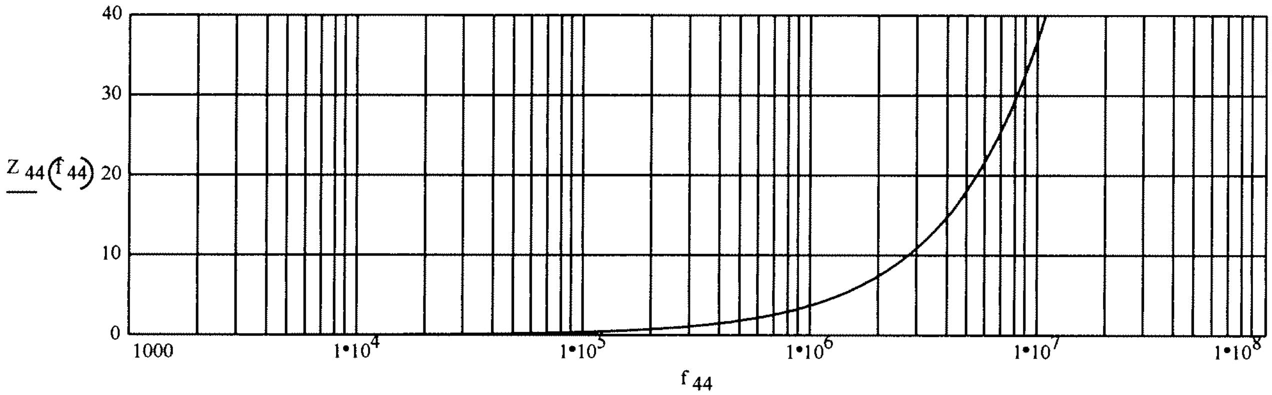
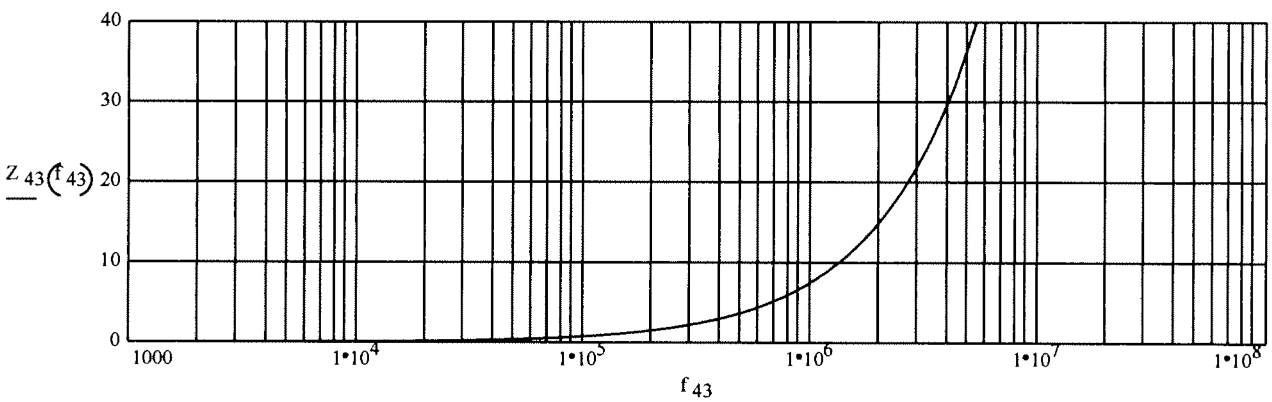


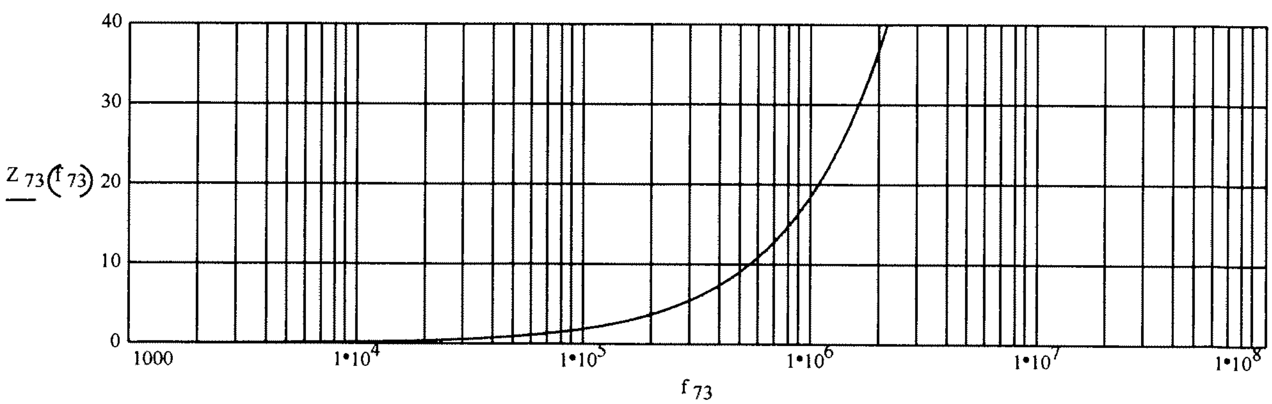
40
30
Z 61(f 61) 20
10
0
1000
1•10^4
1•10^5
1•10^6
1•10^7
1•10^8
f 61



40
30
Z 44(f 44) 20
10
0
1000
1•10^4
1•10^5
1•10^6
1•10^7
1•10^8
f 44



40
30
Z 43(f 43) 20
10
0
1000
1•10^4
1•10^5
1•10^6
1•10^7
1•10^8
f 43



40
30
Z 73(f 73) 20
10
0
1000
1•10^4
1•10^5
1•10^6
1•10^7
1•10^8
f 73

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Assignment #4

Section 11

7. Work Problem 11.10

Answer:

When passing a wire several times through a multihole bead, the inductance increases since the flux increase. However, due to the flux increase, the bead is easier to became saturated, and so the current in the circuit is further limited. Because passing the wire several times, the increase in inductance and resistance will lower the cutoff frequency and the voltage on load will decrease.

For two hole bead, the part between the two holes is most likely to saturate first, since that is where H is maximum. When the bead is used with in its frequency range, the inductance is the major part of impedance, and which is ideally speaking proportional to the square of turn numbers. However, due to the nonlinearity in the hysteresis curve (or say the nonlinearity in μ w.r.t. H), and the saturation property of the ferrite materials, the increase in impedance is limited. So the data is reasonable.

19. Work Problem 11.25
Discuss the ideal and nonideal effects of common-mode dc signal on a common-mode ferrite choke.

Answer:

Ideally, if μ does not change with H, and the ferrite choke does not saturate, then common-mode dc signal has no effect on common-mode ac signal. But since the hysteresis curve exsists, and the ferrite material does saturate, the common-mode dc signal will reduce the effective inductance of the choke. If the choke is satuated under dc current, the there will be no inductance to ac signal.

SECTION 12

2. Repeat Problem 12.1 for the following function.

3. Expain how one paper towel cardboard roll and a few bunches of steel wool could be used as a crude RFI reducer for a television set. Assume the Interfererce is conducted.

Answer:

When correctly constructed as a common-mode choke, this device will reduce the RF interference since the interference is a common-mode signal. Assume the RFI reducer has a inductance of 2 μF, then the impedance will be greater then 2.5 KΩ at 200 MHz, which is significantly bigger compare with the 50 Ω input impedance of the TV set.

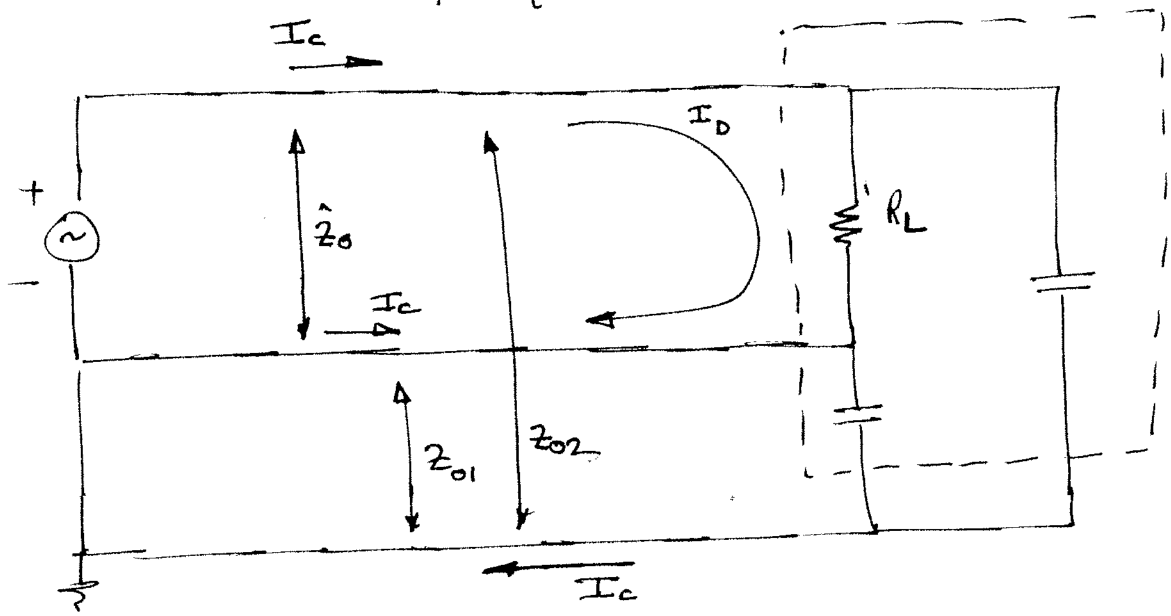
$\omega := 2\cdot\pi\cdot 200\cdot 10^{6}$ $\quad L := 2\cdot 10^{-6}$

$Z := j\cdot\omega\cdot L$ $\quad |Z| = 2.513\cdot 10^{3}$

Location of a Common-Mode Choke.

For low Impedance Load ($R_L << Z_o$)

and Electrically long transmission Line.



For Differential Mode:

$$I_D = \text{max. for } R_L = 0$$

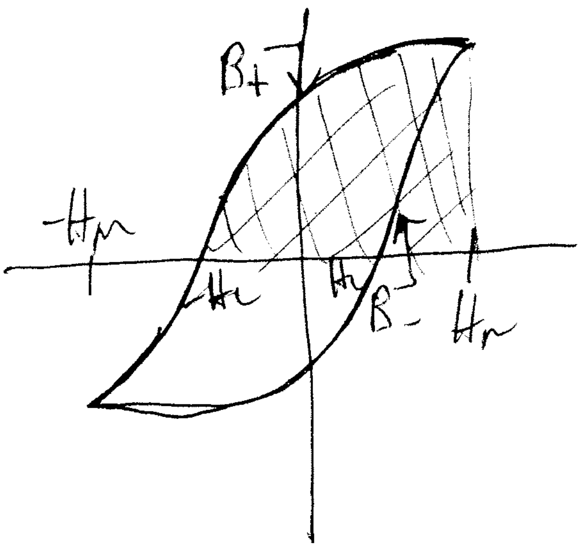
By Definition: $Z_o = \sqrt{\frac{L}{C}}$

For max. effectiveness of the common-mode choke it should be placed at a low impedance point in the transmission line.

In this example we would expect the lowest impedance to ground of each line to be at the load. (eg. where the wires enter the enclosure). Therefore placing the choke at this point should max. its effectiveness because I_c should be a max. at this low-impedane point.

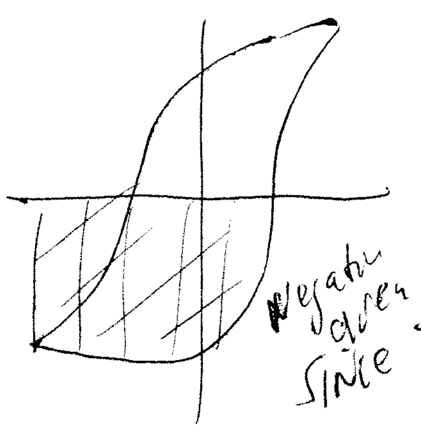
$B = f(H)$ Rayleigh

still need area enclosed by curve



$$\int_{-H_c}^{H_m} B_+(H)\,dH \quad \text{positive area}$$

$$- \int_{H_c}^{H_m} B_-(H)\,dH$$



$$- \left[\int_{-H_m}^{H_c} B_-(H)\,dH - \int_{-H_m}^{-H_c} B_+(H)\,dH \right]$$

If $B_-(H) = (\mu_i + 2\nu H_m)H + \nu(H_m^2 - H^2)$

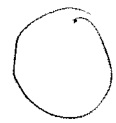
$B_+(H) = (\mu_i + 2\nu H_m)H - \nu(H_m^2 - H^2)$

then $= \frac{8}{3}\nu H_m^3$ via Mathcad agrees with Hecht p. 129

$$N_a = \frac{1}{a}\left(\frac{abc}{ab+ac+bc}\right)$$

Problem Soln

If $a=b=c$



$$N_a = \frac{1}{a}\,\frac{a^3}{3a^2} = \frac{1}{3}$$ ✓ sphere

If a=

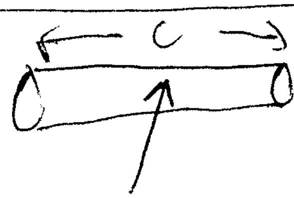
thin disk

$b=c$

$a \ll b=c$

$$\frac{1}{a}\,\frac{ab^2}{ab+ab+b^2} \approx \frac{ab^2}{a(b^2)} = 1$$ ✓

rod



$a=b,\ c \gg a=b$

$$N_a = \frac{1}{a}\,\frac{a^2c}{a^2+ac+ac} = \frac{1}{a}\,\frac{a^2c}{a^2+2ac}$$

$$= \frac{ac}{2ac} = \frac{1}{2}$$ ✓

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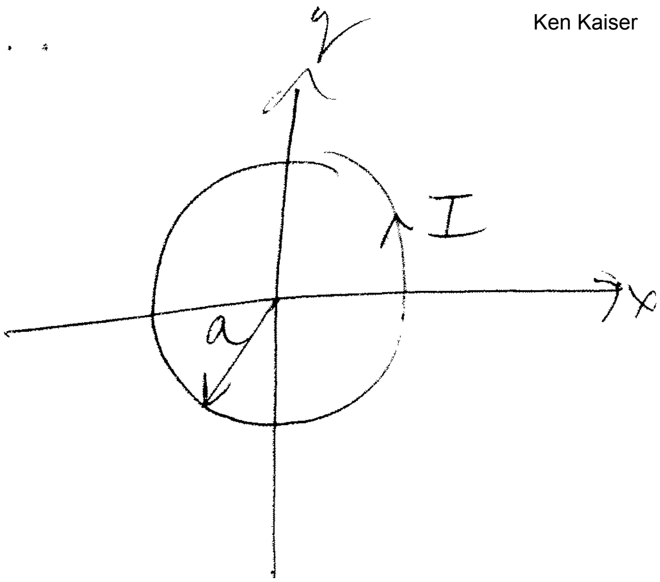
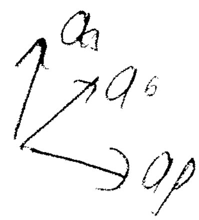


$$\vec{H} = H_x \hat{a}_x$$



$$d\vec{F} = I d\vec{L} \times \mu_0 \vec{H}$$

$$= \underline{\mu_0 I}\, a\, d\phi\, \hat{a}_\phi \times H_x \hat{a}_x$$

$$= \underline{\mu_0 I}\, a\, d\phi\, \hat{a}_\phi \times H_x [\cos\phi\, \hat{a}_\rho - \sin\phi\, \hat{a}_\phi]$$

$$= \mu_0 I a\, d\phi\, H_x [-\cos\phi\, \hat{a}_z]$$

$$dT = \vec{R} \times d\vec{F} = \mu_0 a \hat{a}_\rho \times I a\, d\phi\, \cancel{H_x} [-\cos\phi\, \hat{a}_z]$$

$$= a^2 I \mu_0 H_x \cos\phi\, (-\hat{a}_\phi$$

$$= a^2 I \mu_0 H_x \cos\phi\, \hat{a}_\phi$$

[redacted]

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$$T = \int_0^{2\pi} a^2 I \mu_0 H_x \cos\phi \left[-\sin\phi \, \hat{a}_x + \cos\phi \, \hat{a}_y \right] d\phi$$

$$= a^2 I \mu_0 H_x \left[\hat{a}_x \underbrace{\int_0^{2\pi} -\cos\phi \sin\phi \, d\phi}_{=0} + \hat{a}_y \int_0^{2\pi} \cos^2\phi \, d\phi \right]$$

$$= a^2 I \mu_0 H_x \hat{a}_y \left[\int_0^{2\pi} \left(\frac{1+\cos 2\phi}{2} \right) d\phi \right]$$

$$= a^2 I \mu_0 H_x \hat{a}_y \left[\frac{\phi}{2} + \frac{\sin 2\phi}{2} \right] \Big|_0^{2\pi}$$

$$= a^2 I \mu_0 H_x \hat{a}_y \pi$$

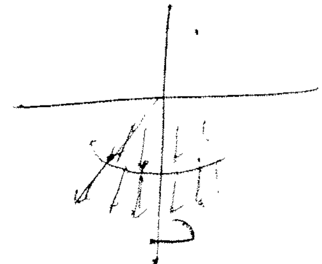
$$= \pi a^2 I \mu_0 H_x \hat{a}_y$$

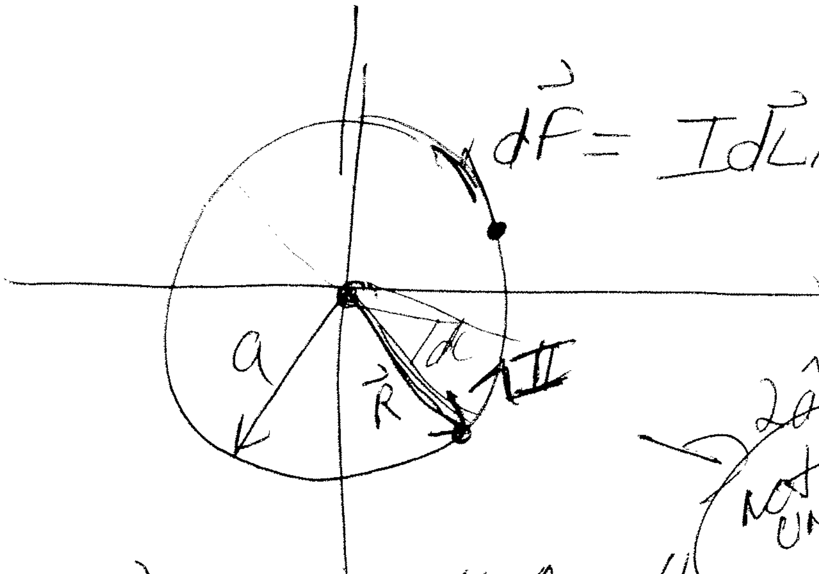
$$\vec{m} \times \mu_0 \vec{H} = \left(\pi a^2 I \hat{a}_z \right) \times \mu_0 H_x \hat{a}_x$$

$$= \pi a^2 I \mu_0 H_x \hat{a}_y$$

yes ✓ great

to

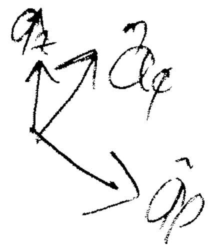




$$d\vec{F} = I\,d\vec{L} \times \mu_0 \vec{H}$$

$2\hat{a}_\rho + 3\hat{a}_\phi$

Not uniform



$$\vec{H} = H_\rho \hat{a}_\rho + H_\phi \hat{a}_\phi + H_z \hat{a}_z$$

$$d\vec{L} = a\,d\phi\,\hat{a}_\phi$$

$$d\vec{F} = I a\,d\phi\,\hat{a}_\phi \times \mu_0 (H_\rho \hat{a}_\rho + H_\phi \hat{a}_\phi + H_z \hat{a}_z)$$

$$= I a \mu_0\,d\phi \left[-H_\rho \hat{a}_z + H_z \hat{a}_\rho \right]$$

$$d\vec{T} = \vec{R} \times d\vec{F} = a\hat{a}_\rho \times \left[I a \mu_0\,d\phi \left(-H_\rho \hat{a}_z + H_z \hat{a}_\rho \right) \right]$$

$$= I a^2 \mu_0\,d\phi \left[H_\rho \hat{a}_\phi \quad \cancel{H_z}^{\,0} \right]$$

$$= I a^2 \mu_0\,d\phi\,H_\rho \hat{a}_\phi$$

$$T = \int_0^{2\pi} I a^2 \mu_0\,d\phi\,H_\rho \hat{a}_\phi$$

$$I a^2 \mu_0 H \rho \int_0^{2\pi} d\phi \hat{a}_\phi$$

$$I a^2 \mu_0 H \rho \int_0^{2\pi} d\phi \left[-\sin\phi \hat{a}_x + \cos\phi \hat{a}_y \right]$$

$$I a^2 \mu_0 H \rho \left[-\hat{a}_x \int_0^{2\pi} \sin\phi \, d\phi + \hat{a}_y \int_0^{2\pi} \cos\phi \, d\phi \right]$$

$$I a^2 \mu_0 H \rho \left[+\hat{a}_x \cos\phi \Big|_0^{2\pi} + \hat{a}_y \sin\phi \Big|_0^{2\pi} \right]$$

$$I a^2 \mu_0 H \rho \hat{a}_x \left[1 - 1 \right] = 0 \ ?$$

$$\boxed{T = a I B_z} \ ?$$

No

$I B \cos\theta$

$T = \vec{m} \times \mu_0 \vec{H}$

$$\frac{d}{dH}\left[H\frac{B_s\cdot B_r\cdot(H+H_c)}{B_r\cdot H+B_s\cdot H_c}\right]$$

$$B_r\cdot B_s\cdot\frac{\left(B_r\cdot H^2+2\cdot H\cdot B_s\cdot H_c+B_s\cdot H_c^{\,2}\right)}{\left(B_r\cdot H+B_s\cdot H_c\right)^2}$$

Given

$$\left[B_s\cdot B_r\cdot\frac{\left(B_r\cdot H^2+2\cdot H\cdot B_s\cdot H_c+B_s\cdot H_c^{\,2}\right)}{\left(B_r\cdot H+B_s\cdot H_c\right)^2}\right]=0$$

Second soln larger than -Hc

$$\mathrm{Find}(H)\rightarrow\left[\frac{1}{(2\cdot B_r)}\cdot\left[-2\cdot B_s+2\cdot\left(B_s^{\,2}-B_s\cdot B_r\right)^{\left(\frac{1}{2}\right)}\right]\cdot H_c\quad\frac{1}{(2\cdot B_r)}\cdot\left[-2\cdot B_s-2\cdot\left(B_s^{\,2}-B_s\cdot B_r\right)^{\left(\frac{1}{2}\right)}\right]\cdot F\right.$$

$$\frac{1}{(2\cdot B_r)}\cdot\left[-2\cdot B_s+2\cdot\left(B_s^{\,2}-B_r\cdot B_s\right)^{\left(\frac{1}{2}\right)}\right]\cdot H_c$$

$$-\left[B_s-\left[B_s\cdot(B_s-B_r)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}$$

B

$$\frac{B_s\cdot B_r\cdot\left[-\left[B_s-\left[B_s\cdot(B_s-B_r)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}+H_c\right]}{B_r\cdot\left[-\left[B_s-\left[B_s\cdot(B_s-B_r)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}\right]+B_s\cdot H_c}$$

0

$$-B_s\cdot\frac{B_s-\left[B_s\cdot(B_s-B_r)\right]^{\left(\frac{1}{2}\right)}-B_r}{\left[B_s\cdot(B_s-B_r)\right]^{\left(\frac{1}{2}\right)}}$$

$$\frac{\left[-\left[B_s - \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}\right]}{\left[-B_s\cdot\frac{\left[B_s - \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)} - B_r\right]}{\left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}}\right]}$$

$$-\left[-B_s + \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{\left[B_r\cdot B_s\cdot\left[B_s - \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)} - B_r\right]\right]}\cdot\left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}$$

$$\left[-B_s + \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right]\cdot H_c\cdot\frac{\left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}}{\left[B_r\cdot B_s\cdot\left[-B_s + \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)} + B_r\right]\right]}$$

$$B_s \cdot \frac{\left[-B_s + \left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)} + B_r\right]}{\left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}} \cdot \left[-\left[B_s - \left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right] \cdot \frac{H_c}{B_r}\right]$$

$$\frac{-\left[B_s - \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}}{\left(\frac{H_c\cdot B_s}{B_r}\right)\cdot\sqrt{1 - \frac{B_r}{B_s}} - 1}$$

$$\left[B_s - \left[B_s\cdot\left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right]$$

$$\frac{-\left[B_s - \left[B_s\cdot(B_s - B_r)\right]\right]}{\left[B_s\cdot\left(\frac{-B_r}{B_s}\right)^{\left(\frac{1}{2}\right)}\right]}$$

$B_s := 2.1 \qquad B_r := 1.9 \qquad H_c := 330$

$$B_s\cdot\frac{\left[-B_s + \left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)} + B_r\right]}{\left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)}} = 1.452$$

$$\frac{\left[B_s\cdot\frac{\left[-B_s + \left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)} + B_r\right]}{\left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)}}\right]}{\left[-\left[B_s - \left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r}\right]} = -5.758\times 10^{-3}$$

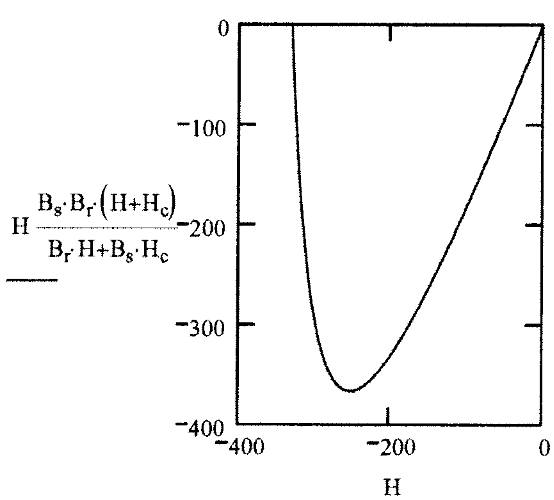
$$B_s - \left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)} = 1.452$$

$$-\frac{B_r}{H_c} = -5.758\times 10^{-3}$$

$$-\left[B_s - \left[B_s\cdot(B_s - B_r)\right]^{\left(\frac{1}{2}\right)}\right]\cdot\frac{H_c}{B_r} = -252.177$$

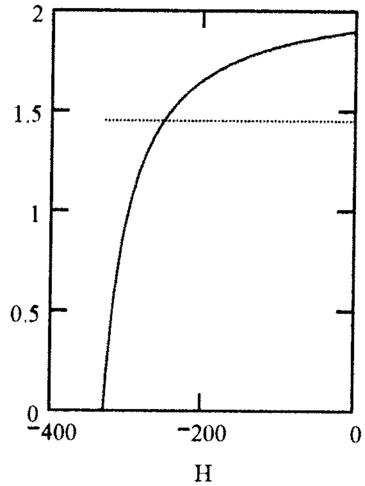
$$\frac{1}{(2\cdot B_r)}\cdot\left[-2\cdot B_s - 2\cdot\left(B_s^{\,2} - B_r\cdot B_s\right)^{\left(\frac{1}{2}\right)}\right]\cdot H_c =$$

$H := -H_c, -0.99\cdot H_c \,..\, 0$



$$\frac{B_s \cdot B_r \cdot \left(H+H_c\right)}{B_r \cdot H+B_s \cdot H_c}$$

$$B_s \cdot \frac{\left[-B_s+\left[B_s \cdot \left(B_s-B_r\right)\right]^{\left(\frac{1}{2}\right)}+B_r\right]}{\left[B_s \cdot \left(B_s-B_r\right)\right]^{\left(\frac{1}{2}\right)}}$$

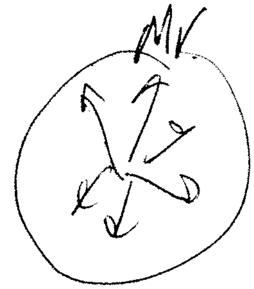


$$I_c \Big]$$

$$_s \cdot B_r \cdot \frac{\left[B_r \cdot \left[-\left[B_s - \left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right] \cdot \frac{H_c}{B_r}\right]^2 + 2 \cdot \left[-\left[B_s - \left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right] \cdot \frac{H_c}{B_r}\right] \cdot B_s \cdot H_c + B_s \cdot H_c^{\,2}\right]}{\left[B_r \cdot \left[-\left[B_s - \left[B_s \cdot \left(B_s - B_r\right)\right]^{\left(\frac{1}{2}\right)}\right] \cdot \frac{H_c}{B_r}\right] + B_s \cdot H_c\right]^2}$$

–477.297

Problem



$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 I_s\right) = -\rho_m$$

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 \frac{\rho_m}{2}\right) = -\rho_m$$

$$\frac{1}{r^2}\frac{d}{dr}\left(\frac{r^3}{3}\right)$$

$$\frac{1}{r^2}\frac{3r^2}{3}$$

If $\vec{m} = M_0 \hat{a}_r$

$$\rho_{vm} = -\frac{\mu_0}{r^2}\frac{d}{dr}\left(r M_r\right)$$

$$= -\frac{\mu_0}{r^2} 2r M_r = -\frac{2\mu_0}{r} M_r$$

$$\rho_{sm} = -\mu_0 (0 - M_r) = \mu_0 M_r$$

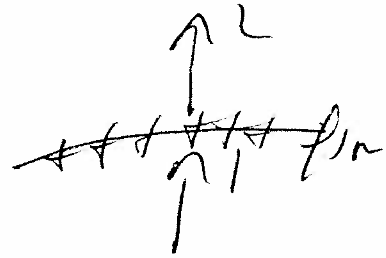
$$\rho_{total} = 4\pi R^2 \rho_{sm} = 4\pi R^2 \mu_0 M_r$$

no net charge on equal but opposite pole

$$\rho_{total} = \int_0^{2\pi}\int_0^{\pi}\int_0^{R} -\frac{2\mu_0}{r} M_r \, dr\, r\, r\, d\theta \sin\theta$$

$$= 4\pi(-2\mu_0 M_r)\int_0^R r\,dr = -8\pi\mu_0 M_0 \frac{R^2}{2} = -4\pi\mu_0 M_0 R^2$$

$$\rho_{sm} = -\mu_0 (M_{n2} - M_{n1})$$



$$\rho_{vm} = -\nabla \cdot (\mu_0 \vec{M})$$

$$\nabla \cdot \vec{M} = \frac{1}{r^2} \frac{d}{dr} (r^2 A_r)$$

$$\rho_{vm} = -\frac{\mu_0}{r^2} \frac{d}{dr} (r^2 A_r)$$

Ken Kaiser

. Zero $\vec{H}$ outside sphere since $Q_{total\ enclosed} = 0$

For H_{inside} will use analogy with E field

If $\rho_V = \frac{K}{r} \Rightarrow \vec{E} = \frac{K}{2\varepsilon_r \varepsilon_0} \hat{a}_r \quad r < a$

$\rho_{VM} = \frac{-2\mu_0 M_0}{r} \Rightarrow \vec{H} = \frac{-2\mu_0 M_0}{2\mu_0} \hat{a}_r$

$= -M_0 \hat{a}_r$

$E_d = -\frac{\mu_0}{2} \vec{m} \cdot \vec{H} = \frac{-\mu_0}{2} M_0 \hat{a}_r \cdot (-M_0 \hat{a}_r)$

$= \frac{+\mu_0 M_0^2}{2}$

$E_t = \frac{4}{3} \pi R^3 \frac{\mu_0 M_0^2}{2} = \frac{2}{3} \pi R^3 \mu_0 M_0^2 \ J$

From Chikazumi

$U = \frac{I_s^2}{\mu_0} \frac{2\pi}{3} R^3 = \frac{(\mu_0 M)^2}{\mu_0} \frac{2\pi}{3} R^3 = \mu_0 M^2 \frac{2\pi}{3} R^3$