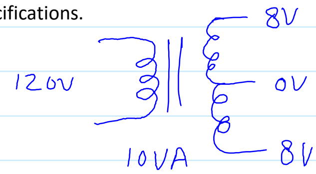
Lab1: Design implement and test a 120V, 60Hz, 10VA, 8V-0-8V step down transformer

(Complete in 2 weeks . Lab report should include the final design, all test results and the final specifications.

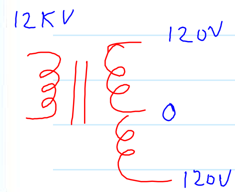
(Transformer to power your emergency light system)



Electrical transformers:

High Voltage Transformer

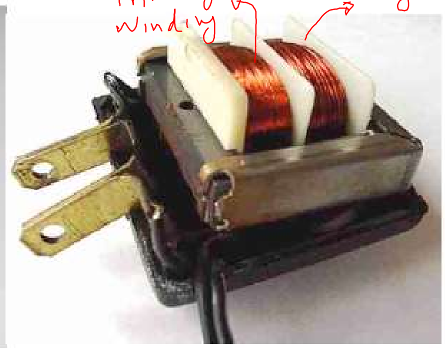
MVA



Low voltage / power transformer

Primary winding

secondary winding



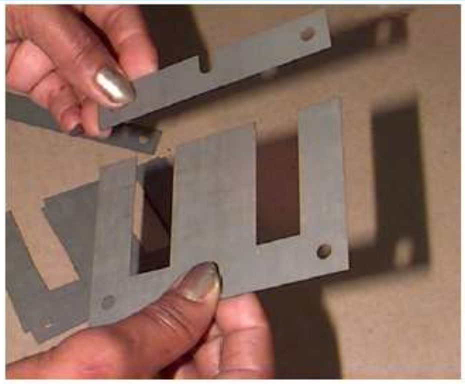
Toroidal

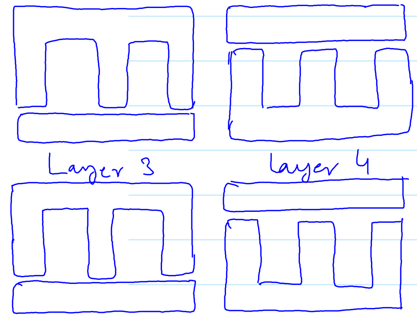
Placement

Layer 1 Layer 2

transformer laminations (Silicon Steel)

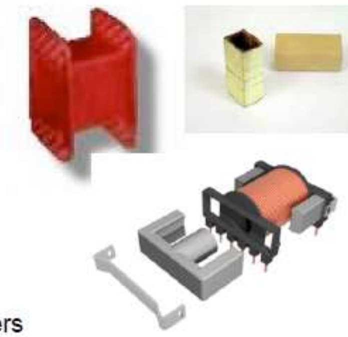
Reduce Eddy current losses





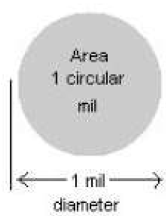
Ferrite Cores for high frequency transformers

Bobbins and winding



Wire Gauge

A **mil**, is a unit of length equal to 0.001 inches



enamelled copper wire

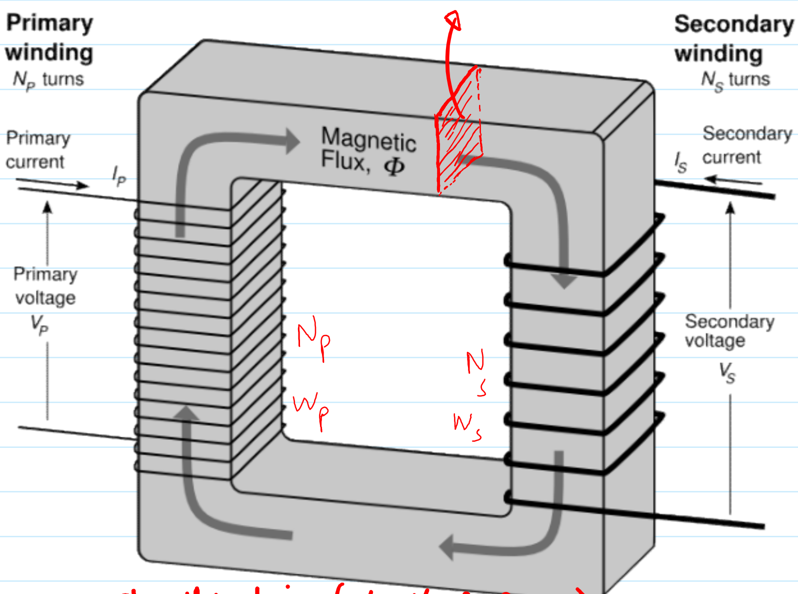
Winding machine

See a full table at http://www.powerstream.com/Wire_Size.htm

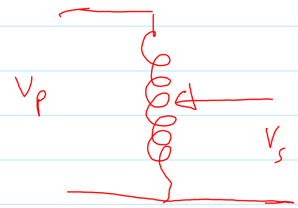
AWG Copper Wire Table

AWG	Diam. (mils)	Circular mils	Ohms/1000ft	Current Carrying	Fusing Current
0	324.85	105531	0.096	-	-
1	289.3	83694	0.1264	119.6	-
2	257.6	66358	0.1593	94.8	-
3	229.4	52624	0.2009	75.2	-
14	64.1	4109	2.575	5.87	166
15	57.1	3260	3.247	4.65	140
16	50.8	2581	4.094	3.69	117
17	45.3	2052	5.163	2.93	98.4
18	40.3	1624	6.510	2.32	82.9
19	35.9	1289	8.210	1.84	69.7
20	32.0	1024	10.35	1.46	58.4
21	28.5	812	13.05	1.16	-
22	25.3	640	16.46	.918	41.2
23	22.6	511	20.76	.728	-
24	20.1	404	26.17	.577	29.2
25	17.9	320	33.0	.458	-
26	15.9	253	41.62	.363	20.5
27	14.2	202	52.48	.288	-
28	12.6	159	66.17	.228	14.4
29	11.3	128	83.44	.181	-
30	10.0	100	105.2	.144	10.2
31	8.9	79	132.7	.114	-
32	8.0	64	167.3	.090	-

Core area (cross sectional area)

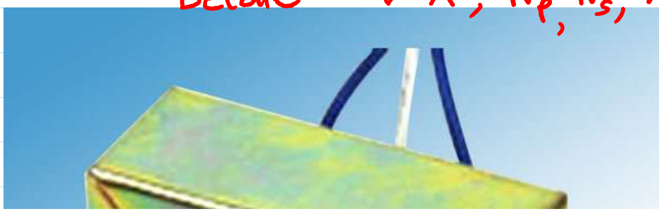


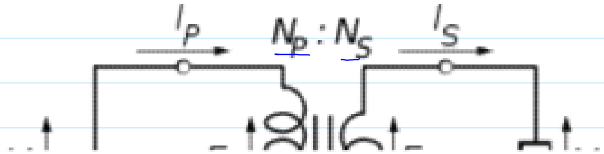
Auto transformer

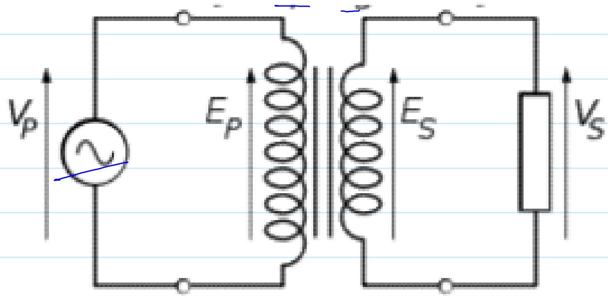


Design: specifications (V_{in}, V_o, f, Power)

Detail → A, N_p, N_s, W_p, W_s, Package







$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

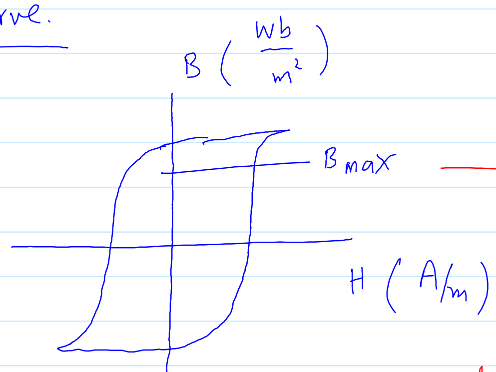
Ideal transformer , $\eta = 100\%$

$$P_o = P_{in}$$

$$V_s I_s = V_p I_p$$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

B-H curve.



B_{max} → Core material dependent

$$B = \mu_0 \mu_r H$$

H → magnetic field intensity

B → flux density.

μ_r → relative permeability (Core material) 2000 – 8000

μ_0 → Air permeability ($4\pi \times 10^{-7}$ H/m)

(Permeability Degree of magnetization of a material in response to magnetic field)

Flux $\phi = BA$ (Webers)

Some data at https://en.wikipedia.org/wiki/Permeability_(electromagnetism)

Faraday's law $V = N \dfrac{d\phi}{dt}$ $\quad V_{rms} = \dfrac{N}{\sqrt{2}} \dfrac{d\phi}{dt}$

N → Number of turns.

Input is sine voltage → ϕ is also sinusoidal

$$\phi = \phi_{max} \sin(\omega t) = B_{max} A \sin(\omega t) \qquad \omega = 2\pi f$$

$$V_{rms} = \frac{N}{\sqrt{2}} A B_{max} \frac{d \sin(\omega t)}{dt} = \underbrace{\frac{N}{\sqrt{2}} (2\pi f) A B_{max}}_{\text{magnitude}} \cos(\omega t)$$

(Phase difference between voltage and flux is 90°)

$$\boxed{V_{rms} = \frac{2\pi}{\sqrt{2}} N A B_{max} f}$$

Sine output

$$V_{rms} = 4.44\, N A B_{max} f$$

V_{rms} (Volts); N: number of turns; A: core area (m^2); B_{max}: maximum flux density (Wb/m^2); f: frequency (Hz)

A in m^2 and B in Wb/m^2 are too large for small tranformers.

Area in inches, B_{max} in # of lines/in^2

$$1\ wb = 10^8 \text{ lines}$$

$$\Rightarrow V_{rms} = 4.44 \frac{N f A B_{max}}{10^8} \quad \text{— (1)}$$

A: in^2; B_{max}: # of lines/in^2

(More useful equation)

Transformer Design:

Requirement specifications: B_{max}, A, f, V → Equation (1) → N

Core A?

Required core area is related to power

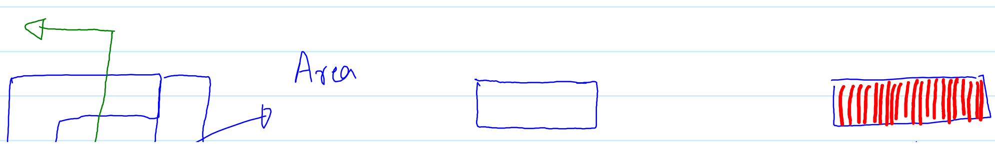
$$\boxed{A = 0.1725 \sqrt{P}} \quad \text{— (2)}$$

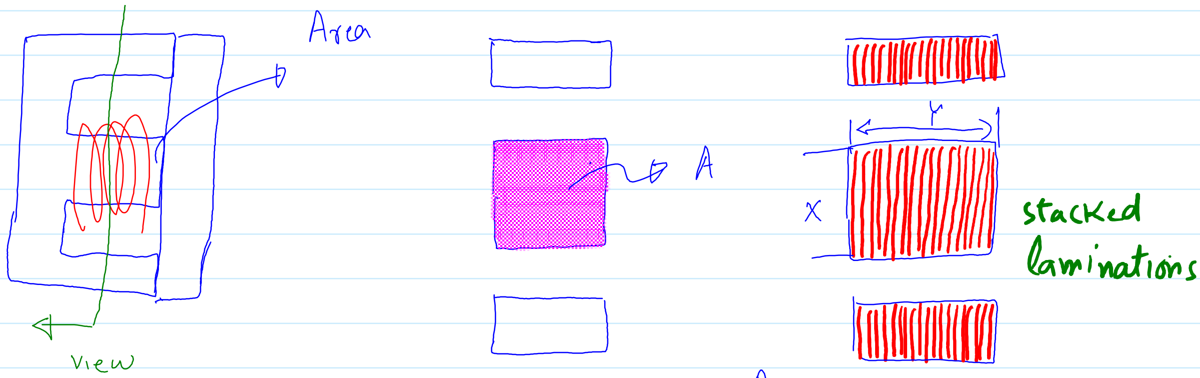
A (in^2), P: Power (W)

for 60Hz transformer

$$\boxed{A = \frac{10.35 \sqrt{P}}{f}}$$

For any other frequency





core area $A = XY$

Example

Say we need a 12VA, 12V step down transformer. (60Hz, 120V)

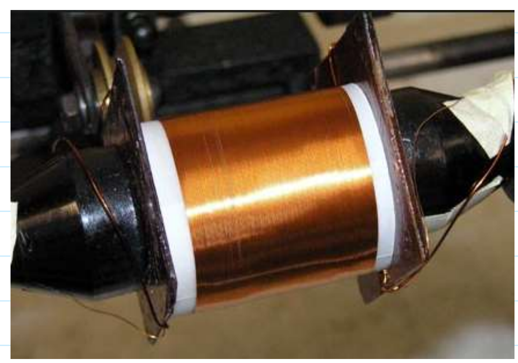
using (2) $A = 0.1725\sqrt{12} = 0.597 \ \text{in}^2$ Core area

Good Iron Core $B_{max} = \frac{1.2 \ \text{wb}}{m^2} = \frac{1.2 \times 10^8 \ \text{lines}}{(39.37)(39.37)} = 77420 \ \frac{\text{lines}}{\text{in}^2}$

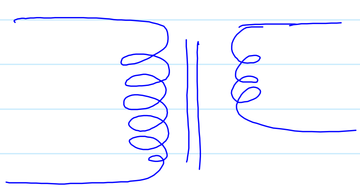
in/m in/m

using (1) $\frac{V}{N} = \frac{4.44 \times 60 \times 0.597 \times 77420}{10^8} = 0.123 \ \text{V/turn}$

$\frac{N}{V} = \frac{1}{0.123} = 8.13$ turns/volt.



Layer by layer winding



120V → $N_p = 120 \times 8.13 = 975$

12V $N_s = 12 \times 8.13 = 97$ (Integer value)

$A = 0.597 \ \text{in}^2$

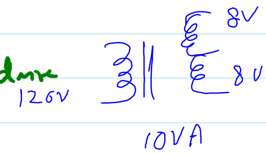
size $\underline{12\ VA}$, $V_p = 120V$ $I_p = \frac{12}{120} = 0.1\ A$ $W_{G_p} = 31$

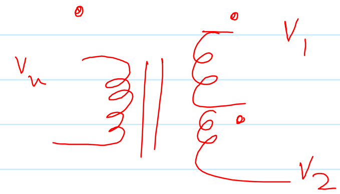
$I_s = \frac{12}{12} = 1A$ $W_{G_s} = 22$

Lab1: Design implement and test a 120V, 60Hz, 10VA, 8V-0-8V step down transformer

(requirement specifications)

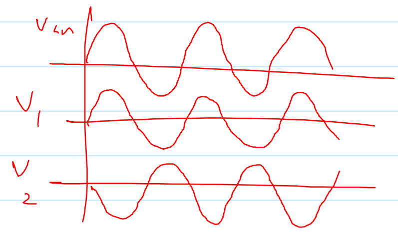
→ you design a transformer using the procedure described above.





→ Build your transformer in the lab.

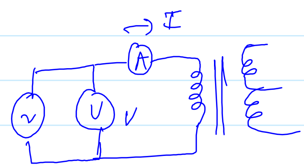
→ Test and list system specifications



<u>Testing</u>

#1 Measure No load output voltage

#2 Determine No load losses

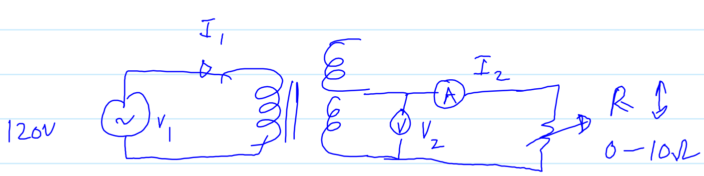


(Kill-a-watt meter may be used) losses $= VI$

Kill-a-watt meter

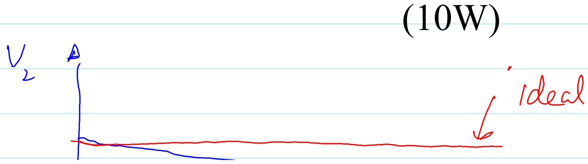
#3 Record output waveform and harmonics. (Scope)

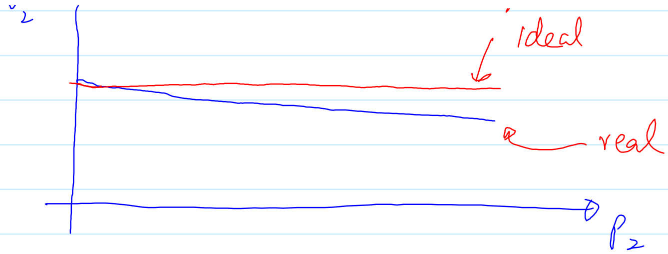
#4 measure output voltage regulation



(10W)

V_2	I_2	$P_2 = V_L I_2$





#5 Find Full load efficiency

select R such that

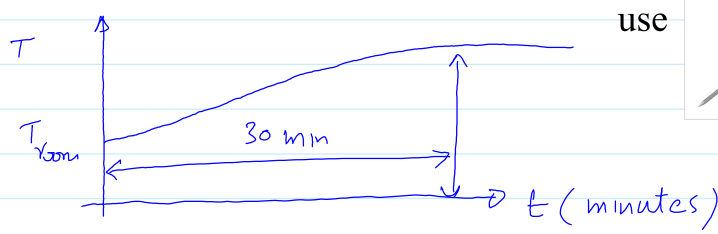
$$\eta = \frac{V_2 I_2}{V_1 I_1} = \frac{P_2}{P_1}$$

$P_2 = 10W$

(Measure P_1 using Kill-a-watt meter. P_2 using a voltmeter and ammeter)

#6 Record noise, vibrations, heating etc.

#7 Find temperature increase with time



use

Report: (in pdf format)

Include introduction, design calculations, photos (while building the transformer) above 7 test results, issues, problem faced and conclusions.