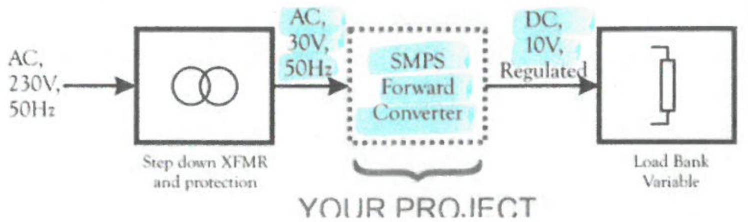
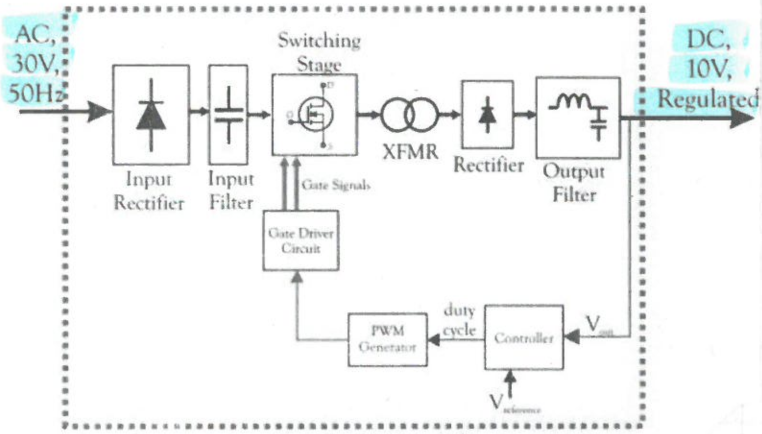
1 LWX

Energy project week 1

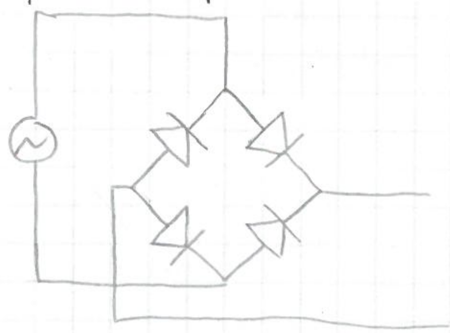
project aim: to design and build a practical SMPS (Switch Mode Power Supply) based on two-switch forward converter





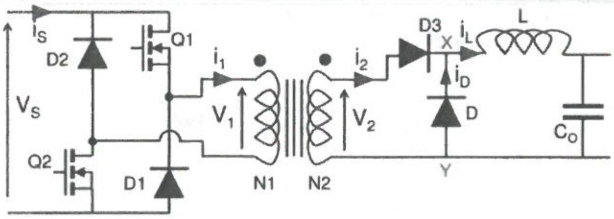
30V AC (50Hz) → 10DC

we can use full-bridge circuit to get a simple AC-DC converter



To avoid the saturation of the transformer, duty cycle for isolated forward converter is limited to 50%. ✓

Switching frequency: 75kHz - 150kHz   100kHz ✓



AC voltage: 30V   RMS value: $30\sqrt{2}$

$V_S = 30\sqrt{2} = 42.43V$

DC voltage: 12V

mean voltage $= dV_S$

if $d = 0.5$ mean voltage $= 21.22$

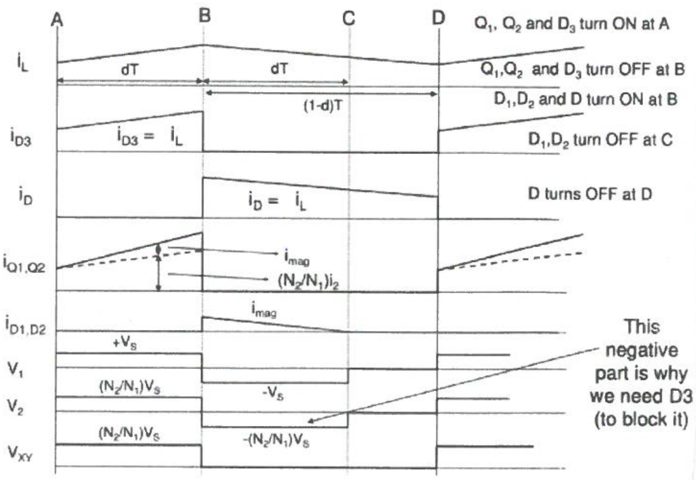
if $d = 0.33$ mean voltage $= 0.33 \cdot 42.43$

For safety, set the duty cycle as 0.33.

$V_O = \left(\frac{N_2}{N_1}\right) dV_S$.

$\frac{N_2}{N_1} = \frac{V_O}{dV_S} = \frac{10}{0.33 \cdot 42.43} = \frac{10}{14}$

$V_2 = \frac{N_2}{N_1} V_S = \frac{10}{14} \cdot 42.43 = 30.31V$.



2012/5/12

LWX

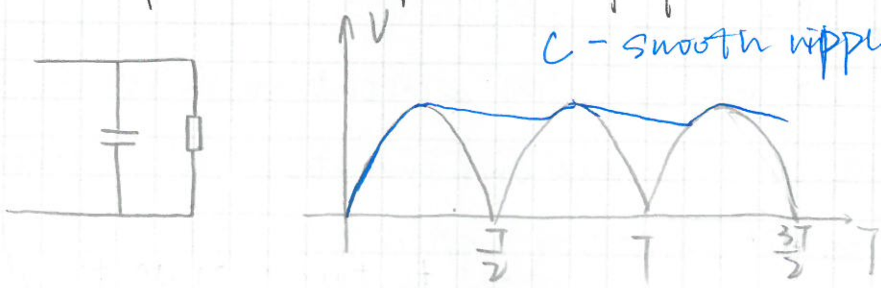
smps: an electronic circuit that converts power using switching devices that are turned on and off at high frequency. storage components (inductors. capacitors) to supply power when the switching is in its non-conduction state. 4 major catagories: AC-DC. DC-DC DC-AC AC-AC

Why linear power supply transformer is much bigger than smps and what is different?

smps transformer: the frequency go up. the core size go down.

For PLECS design. consider the non-ideal situation. set a resistor connect to the capacitor. (because there may be an inner resistance in capacitor) set the resistance: 0.01Ω

Attention: Input capacitor is to be limited to a maximum of 2000 uF. Changing the capacitance changes the ripple at the output of rectifier and changes all design prameters. (small capacitor V)



ripple factor

$$\frac{\text{RMS value of ac component of output}}{\text{average or dc component of output}}$$

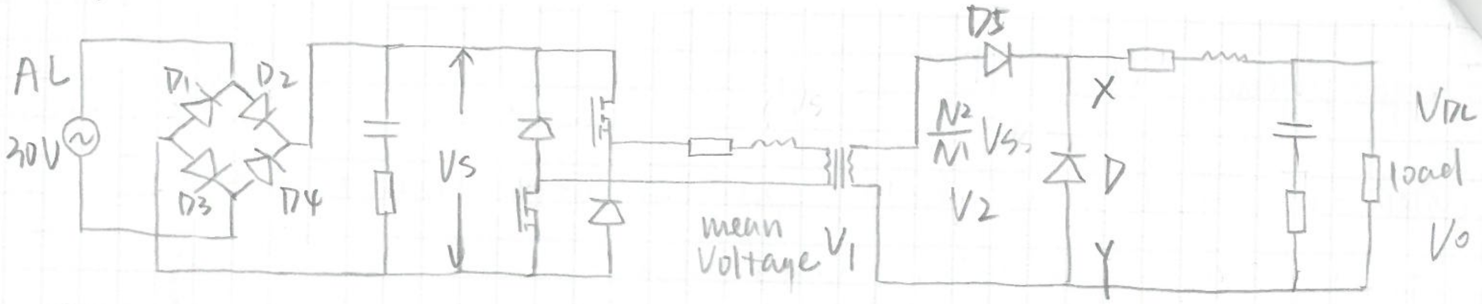
minimum load $50W \cdot 25\% = 12.5W$

$\frac{12.5W}{10V} = 1.25A$ ← output current.

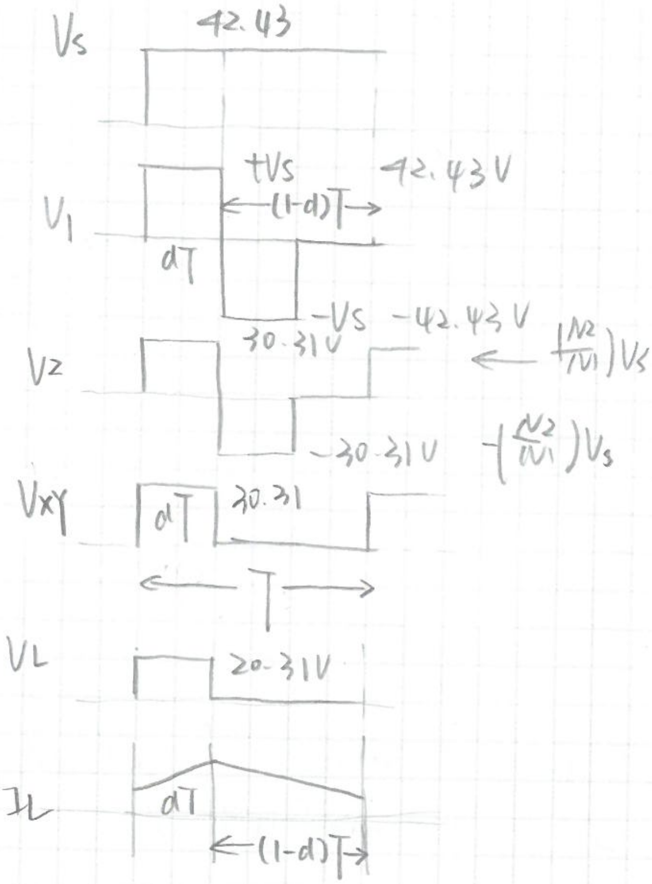
$R = \frac{10}{1.25} = 8\Omega$.

maximum load $\frac{50W}{10V} = 5A$ ← output current

$R = \frac{10}{5} = 2\Omega$.



AC	30V
V_s	$\sqrt{2}\cdot 30 = 42.43V$
V_1	$42.43V$
$\frac{N_2}{N_1}$	$\frac{10}{14}$
V_2	$\left(\frac{N_2}{N_1}\right)V_s = \frac{10}{14}\,42.43 = 30.31V$
V_{XY}	$\left(\frac{N_2}{N_1}\right) d\,V_s$
DC	$\left(\frac{N_2}{N_1}\right) d\,V_s \leftarrow 10V.$



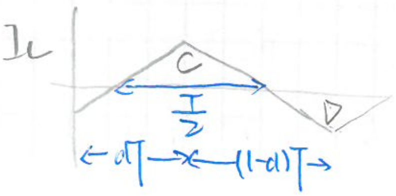
V_L	$V_2 - V_o = 30.31 - 10 = 20.31V.$
dV_L	$d\cdot 20.31 = 6.70V$
Power	50W min: $50\times\frac{1}{5} = 10W$
R	$\frac{V^2}{P} = \frac{100}{10} = 10\Omega$
I	$\frac{V}{R} = \frac{10}{10} = 1A$
ΔI	2A.
L	$\frac{\Delta V_L T}{\Delta I} = \frac{6.7\cdot\frac{1}{10^5}}{2} = 3.35\cdot 10^{-5}H$
ΔV_o	$0.1V$ ← ripple should less than 0.2V. so set as 0.1V.
C	$\frac{\Delta TA}{\Delta V} = \frac{1\cdot\frac{T}{2}\cdot\frac{1}{2}}{0.1} = 2.5\cdot 10^{-5}F$

$f = 100k$

$T = \frac{1}{f}$

$\Delta I_L = \frac{(V_s - V_o)dT}{L}$

capacitor:



AC:	amplitude	42.43V	diode of the bidge 
	frequency	2π·50 rad/s	VS-KBPC1
	phase	0	forward voltage 1.1V

use an isolator to protect the element, translate the information
⇒ use an LED.

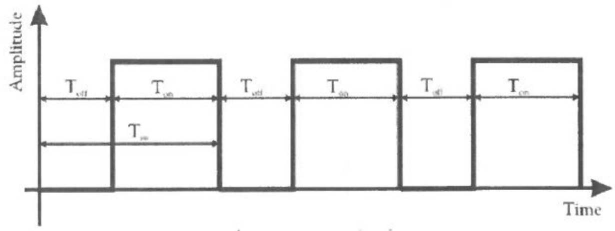
MOSFET: on-resistance 0.11 RF1530NPBF
initial conductively 0

Diode forward voltage 1.4 BYG20J
On-resistance 0

Diode forward voltage 0.44 MBRB2030CTLG.

PWM circuit generation

In real world, we need to realize a circuit to switch on the MOSFET. MOSFET needs quite some voltage and current to be switched on, so it's not possible to connect directly to logic circuit.



duty cycle $d = \frac{T_{on}}{T_{sw}}$

A UC3524 IC can be used as an open loop PWM generator with a variable duty cycle

5 Suggestion

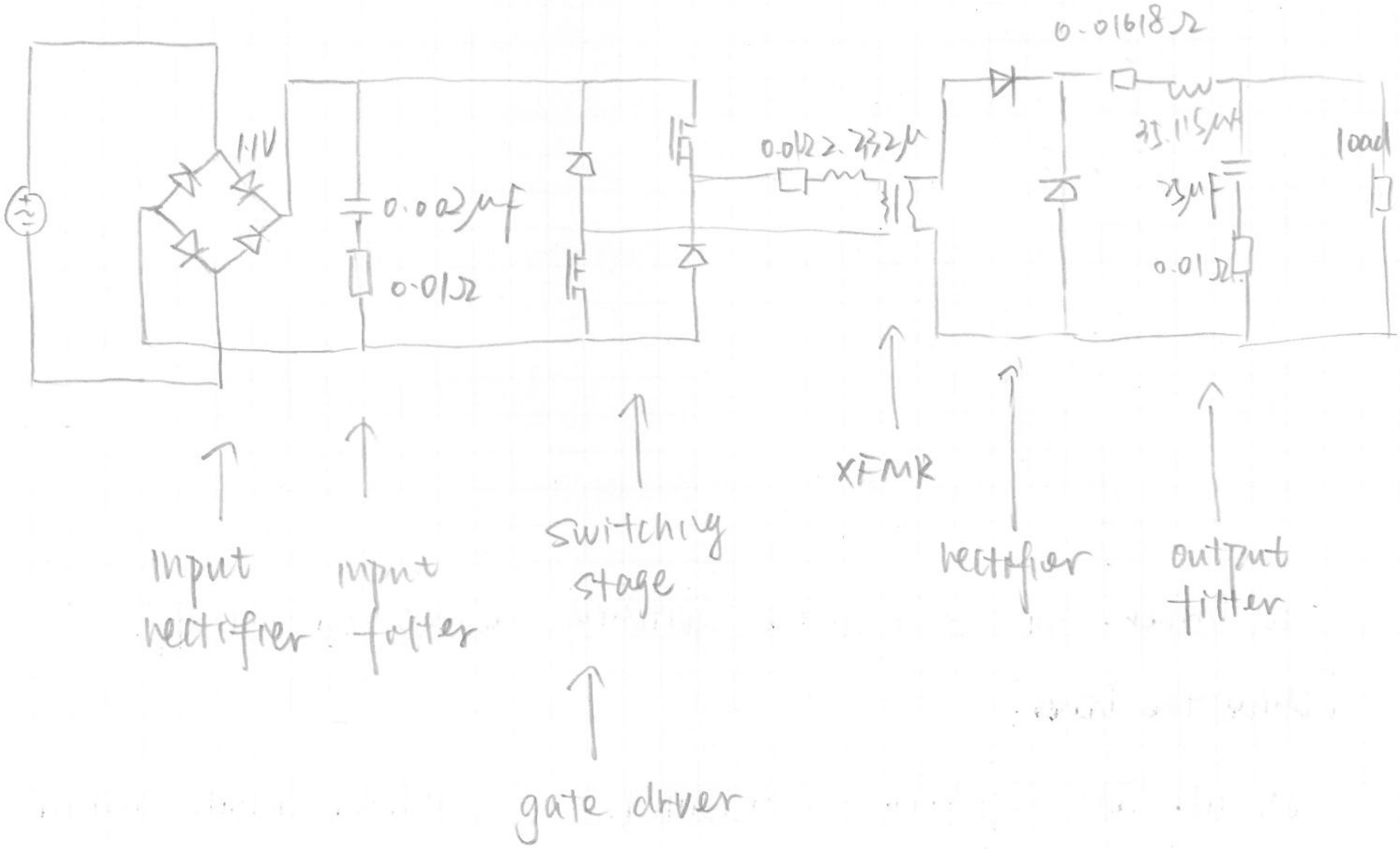
1. Input capactor maximum 2000uF smaller is better

2. Feedback control will compensate for the low frequency ripple at output voltage. (We can have a big ripple at out of rectifier)

3. Don't use RC rectifier (R dissipate power)

4. Use capacitor to filter the switch ripple

5. Supply transformer and its impedance => 1-[illegible]-2mH.
because the load will influence converter input voltage.



pulse generator → gate driver.

1. 3 legs with case → MOSFET.

UC3524AN PWM generator

max duty cycle 45%.

TC4425 power amplifier.

MCP6292 × 2

TC4425 × 1

UC3524AN × 1

UC3524AN $f = \frac{1.18}{R_T C_T}$ 120Hz ~ 500kHz.

output → controller → PWM → gate driver
MCP6292 UC3524AN TC4425.

Timing Resistor RT 1.8k - 100k

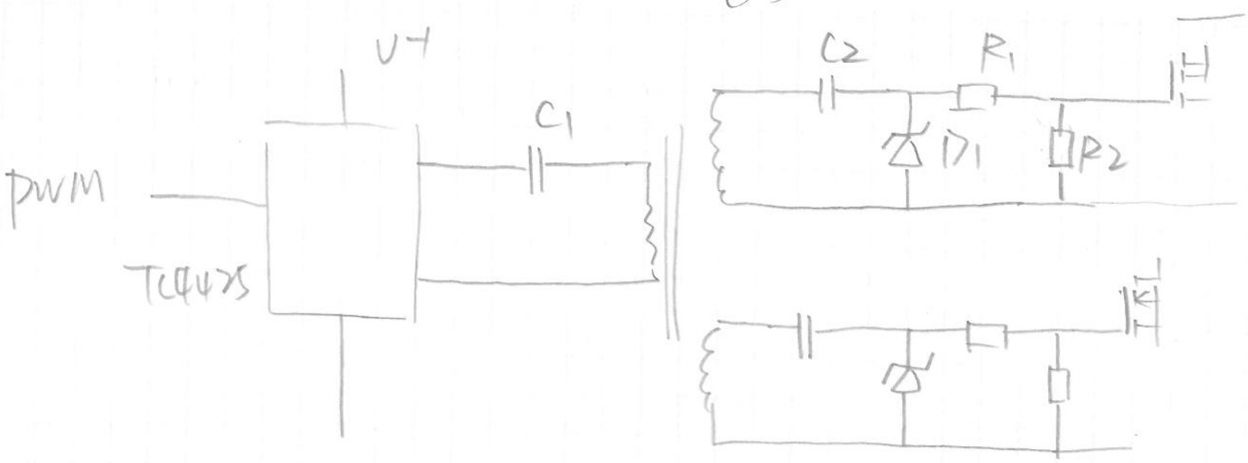
Timing Capacitor RC 0.001μF - 0.1μF.

In our design. set PWM duty cycle to 45%.
frequency to 100kHz.

Gate Driver. how to turn the switching devices on and off.
(Drive the Devices).

acts like an amplifier which controlled by low level signals and increase the voltage and current output to a level capable of driving the power devices

6.5



C1 not be too large <1000nF.
lead to constant saturation of the transformer

C2. maintain $V_{gs} > V_{th}$ during positive half cycle

D1. protect the gate from over voltage spikes.

R1 determine the current flow in the gate

R2 pull down resistor. discharge the gate.
stop the gate floating if gate driver fails.

Step

1. Select an airgap for an initial design 1mm
2. Calculate the number of turns required. 15 ~~24~~ 12
3. Check the peak flux density
4. Calculate the area of copper required for each turn of the winding.
5. Selecting the wire diameter. $A = \frac{\pi d^2}{4}$

Skin depth $\delta = \sqrt{\frac{\rho}{\pi f \mu}}$ frequency → 100KHz.

$f = 100k$

$\mu = 0.999$ $\Rightarrow \delta = 2.06 \times 10^{-4}$

$\rho = 1.678$

$Area = \pi R^2 = 0.133 mm^2$

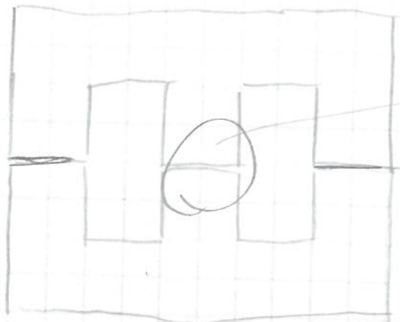
6. Calculating the power losses.

Design an Inductor

This inductor is used for secondary circuit of Forward Converter

Ferrite material

Ferrite is used because
- the frequency is too high to use steel.
- the power losses in the core would be too high



36.8×10^{-6} H → air gap

flux must pass

airgap ↓

inductor can store a significant amount of energy

shorted

wire	Cross section	Ohm	Typical current
20	0.5189	33.9	2
21	0.4116	42.7	1.6
23	0.2588	48.1	1.002
26	0.1281	143	0.506
28	0.0804	227	0.318
30	0.0507	361	0.2
32	0.0316	583	0.128

$$A = \frac{I_{rms}}{J} = \frac{\sqrt{\frac{24+36+24}{3}}}{J} = \frac{5.03}{J}$$

Energy stored: $\frac{1}{2}\frac{B^2}{\mu}$

$\frac{5.03}{4}$

! difference between a transformer and inductor

inductor : air gap

transformer : no air gap.

material N87 Ferrite.

shape of the core ETD (Economical transformer Design)

size ETD34 (longest dimension 34mm)

cores 0-0.5 1mm

Airgap 1mm N15 or 16. AWG 28.

$N=15$ $N=16$

$R_{ac}=0.0124\Omega$. $R=0.0133\Omega$.

total flux $\phi(t)=\frac{Ni(t)}{R}$

$$L=\frac{N\phi(t)}{i(t)}. \qquad L=\frac{N^2}{R}.$$

$$R=\frac{1}{A}\left[\frac{l_{core}}{\mu_r\mu_0}+\frac{g}{\mu_0}\right]$$

μ_0 permeability of free space

μ_r ferrite

A air of magnetic path

l_{core} length of the flux

g air gap length

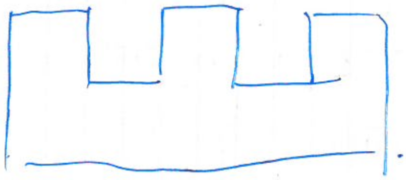
$$N=\sqrt{\frac{gL}{\mu_0 A}}$$ ☆ $\mu_0=4\pi\cdot10^{-7}$

$$B=\frac{\Phi}{A}=\sqrt{\frac{\mu_0 L}{gA}}\,\hat{i}$$

transformer

size ETD 34 in N87

shape



no airgap.

connections 4

turn ratio 11:10.

matrial Ferrite

the value of N_1 determines the peak flux in the core and the peak magnetic current

$V_1 = N_1 \frac{d\phi}{dt}$ $\hat{\phi} = \frac{V_s d T}{N_1}$ $i_{mag} = \frac{V_s d T}{L_{mag}}$ $N^2 A_L$ inductor factor

$\hat{\phi} = \frac{39.44877}{12} \checkmark \frac{0.3 \times 0.45}{100 \times 10^3}$ 3.2×10^{-6}

$B_{sat} = 0.425T$.

winding transformer reduce leakage inductance

leakage inductance : ringing in the voltage.

non-interleaved

snubbers across the diode.

Transformer for gate driver

Type — Ferrite (used for high frequency)

saturation flux density 0.4–0.5T.

3C90 ferrite.

Size — TN 13/7.5/5

TN 14/9/5

winds — 1:2

ration — 1:1:1

$V = N\frac{d\varphi}{dt}$ $\frac{1}{N}\int V dt = \varphi_1 - \varphi_0$.

$\frac{V T_A}{N A_{core}} = \Delta B$.

magnetic inductance $L_{mag} = \frac{N^2}{R}$.

$R = \frac{1}{A_{core}}\left(\frac{l_{core}}{\mu_r \mu_0}\right)$. μ_0 $4\pi 10^{-7}$

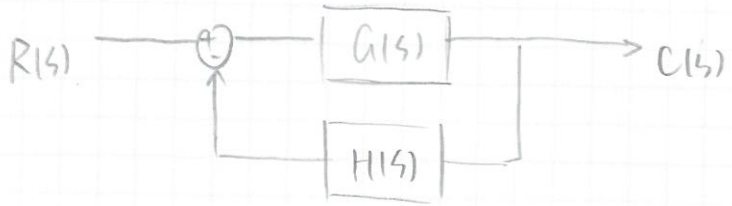
$L_{mag} = A_L N^2 = \underline{2.6 \cdot 10^{-4} H}$.

Size of wire. — cross sectional area A_{cu}.

Losses. — core losses

hysteresis losses

1. close loop control (week 8)



$$\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)}$$

2. Bode plot using MATLAB (week 9)

X-axis: $\log_{10}$(frequency)
y-axis: 20$\log_{10}$(magnitude)

X-axis: $\log_{10}$(frequency)
y-axis: 20$\log_{10}$(magnitude).

☆ method.

example: $G_p(s) = \frac{s^2+6s+5}{s^2+5s}$ $\qquad V(s) \longrightarrow \boxed{G_p(s)} \longrightarrow C(s)$

numerator: 1, 6, 5 $\qquad$ denominator: 1, 5, 0

input transfer function: Gp = tf([1 6 5], [1 5 0]).

plot bode plot: bode(Gp)

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

show the magnitude and phase: (Gpmag, Gpphase) = bode(Gp, wc)

3. Transfer function (conclusion).

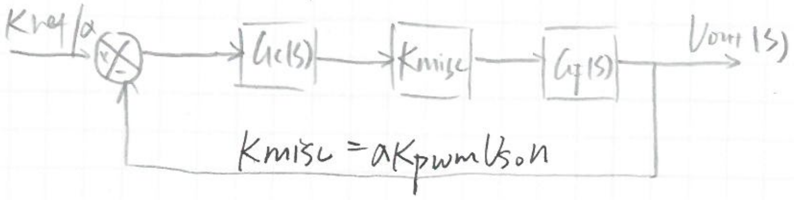
☆ A simple controller (Type 1)

a simple integrator. $G_c(s) = \frac{A}{s}$. $\qquad$ phase shift 90° (lagging)

how to define the gain of $G_c(s)$ $\Rightarrow G = |G_c(s)|_{w_c} = |G_c(jw_c)| = \frac{A}{w_c}$

use the method in ② to find out bode plot

calculate the value of K_{misc}



α: potential divider (change)

$K_{pwm} = \frac{d}{V_B - V_A}$

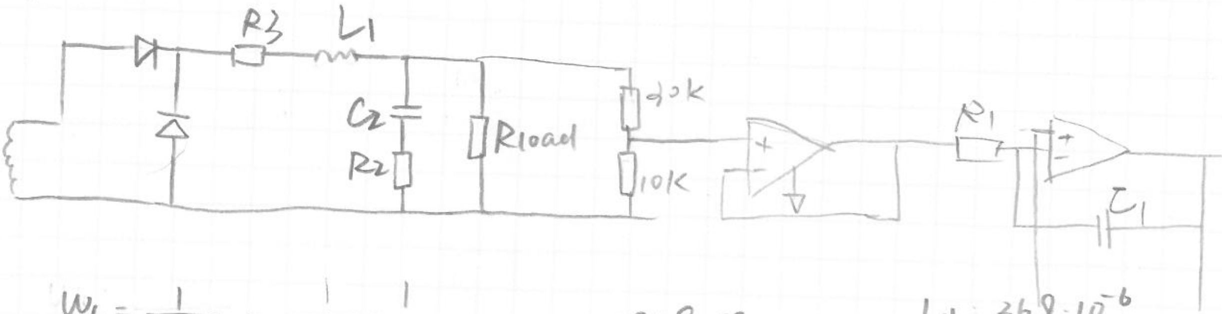
d: max 0.45

V_B, V_A: check datasheet

n: turn ratio. transformer (last semester) $\frac{11}{10}$

calculate the gain of controller $G = \frac{1}{K_{misc}|G_P(jw_c)|}$

For type 1



$$w_L = \frac{1}{10\sqrt{LC}} = \frac{1}{10\sqrt{368\cdot 10^{-6}\cdot 33\cdot 10^{-6}}} = 2869.59$$

L1 : $368\cdot 10^{-6}$

C2 : $33\cdot 10^{-6}$

R2 : 0.01

R1 : 10k

C1 : $4.7\cdot 10^{-8}$

$$G_F(s) = \frac{1+sR_LC}{s^2LC+s\left(\frac{L}{R}+CR_L\right)+1}$$

$$= \frac{1+0.01\cdot 33\cdot 10^{-6}s}{368\cdot 10^{-6}\cdot 33\cdot 10^{-6}s^2+s\left(\frac{368\cdot 10^{-6}}{2}+33\cdot 10^{-6}\cdot 0.01\right)+1}$$

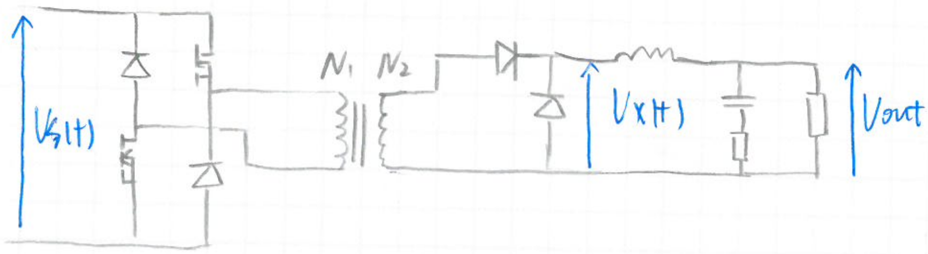
$$= \frac{10^6+0.33s}{1214.4\cdot 10^{-6}s^2+18.73s+10^6}$$

Appendix A. System Modeling.

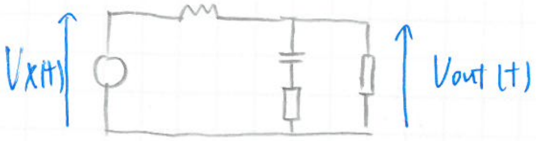
1. Power circuit modelling

ideal voltage source $V_s(t)$ $\qquad V_s(t) = V_{s0} + \hat{v}_s(t)$ $\begin{cases} V_{s0} & \text{steady} \\ \hat{v}_s(t) & \text{ripple} \end{cases}$

use the forward converter circuit



$V_x(t) = \frac{N_2}{N_1} V_s(t)$



In this case. the variations in $V_s(t), d(t)$ at 100Hz. switch frequency ≈100Hz.

$f = 100Hz \qquad T = \frac{1}{f} = 0.01s.$

$V_x(t) = \frac{N_2}{N_1} V_s(t)\, d(t). \qquad d(t) = D_0 + \hat{d}(t)$

$= \frac{N_2}{N_1}(V_{s0} + \hat{v}_s(t)) \cdot (D_0 + \hat{d}(t))$

$= \frac{N_2}{N_1}(V_{s0}(D_0 + \hat{d}(t)) + \hat{v}_s(t)(D_0 + \hat{d}(t)).$

$= \frac{N_2}{N_1}(V_{s0}\hat{d}(t) + D_0 \hat{v}_s(t)).$

output voltage $V_{out}(s)$ $\qquad V_{out}(s) = G_F(s) V_x(s)$

$= \left(\frac{N_2}{N_1}\right)(V_{s0} G_F(s) d(s) + D_0 G_F(s) V_s(s)).$

Appendix B - transfer function.

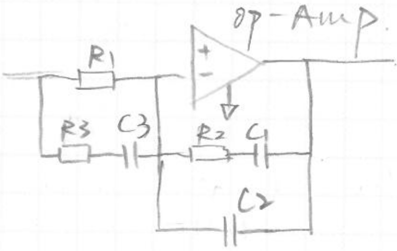
1. calculate filter transfer function.

$G_F(s) = \frac{V_{out}(s)}{V_x(s)} = \frac{1 + sR_cC}{s^2LC + s(\frac{L}{R} + CR_c) + 1}$

Amplifier transfer function

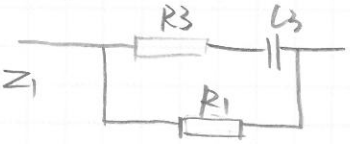
① Type 1

$$G_c(s) = \frac{A}{s} \qquad A = \frac{1}{C_1 R_1}$$

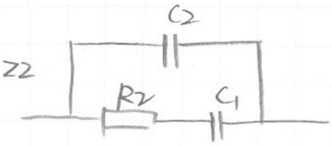


② Type 3.

Z_1



Z_2



$$G_c(s) = \frac{A\left(1+\frac{s}{w_{z1}}\right)\left(1+\frac{s}{w_{z2}}\right)}{s\left(1+\frac{s}{w_{p1}}\right)\left(1+\frac{s}{w_{p2}}\right)}$$

$$A = \frac{1}{(C_1+C_2)R_1} \qquad w_{z1} = \frac{1}{C_1R_2} \qquad w_{p1} = \frac{C_1+C_2}{C_2C_1R_2} \qquad w_{z2} = \frac{1}{C_3(R_1+R_3)} \qquad w_{p2} = \frac{1}{C_3R_3}$$

$R_1 = 10K \quad R_3 = 330 \quad R_2 = 20K \quad C_3 = 4.7\cdot10^{-9} \quad C_1 = 2.2\cdot10^{-9} \quad C_2 = 0.1\cdot10^{-9}$

$$A = \frac{1}{(C_1+C_2)R_1} = \frac{1}{2.3\cdot10^{-9}\cdot10\cdot10^3} = 43478.20$$

$$w_{z1} = \frac{1}{C_1R_2} = \frac{1}{2.2\cdot10^{-9}\cdot20\cdot10^3} = 22727.27$$

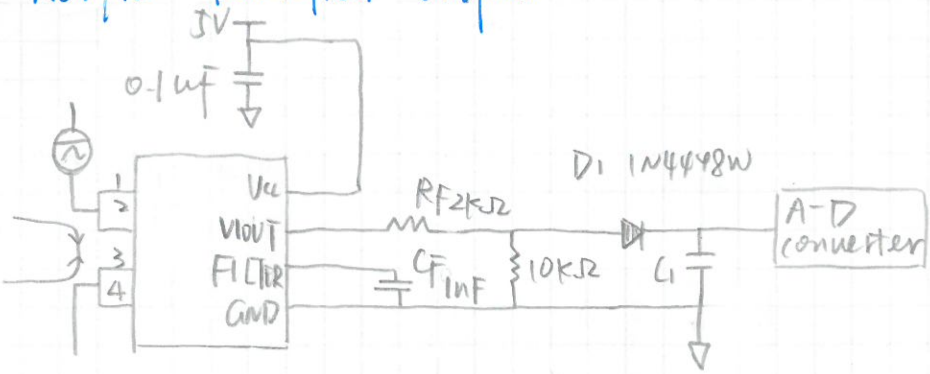
$$w_{p1} = \frac{C_1+C_2}{C_1C_2R_2} = \frac{2.3\cdot10^{-9}}{2.2\cdot10^{-9}\cdot0.1\cdot10^{-9}\cdot20\cdot10^3} = 522727.27$$

$$w_{z2} = \frac{1}{C_3(R_1+R_3)} = \frac{1}{4.7\cdot10^{-9}(10\cdot10^3+330)} = 20590.90$$

$$w_{p2} = \frac{1}{C_3R_3} = \frac{1}{330\cdot4.7\cdot10^{-9}} = 644745.33.$$

$$G_c(s) = \frac{A}{s}\,\frac{\left(1+\frac{s}{w_{z1}}\right)\left(1+\frac{s}{w_{z2}}\right)}{\left(1+\frac{s}{w_{p1}}\right)\left(1+\frac{s}{w_{p2}}\right)}$$

ACS712 Rectified output



1nf 102

0.1uf 104

use multimeter to check "short circuit"

tips : ① turn to "Ω"

② press yellow bottom at upper right corner .