Power Converters Control Technique

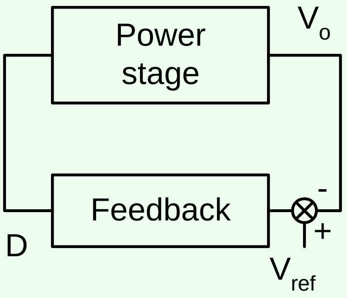
The Dynamic Problem

A closed loop converter is a feedback system

Issues:

- Stability
- Rejection of input voltage variations (audio susceptibility)
- Resistance to load changes
- Quick response to reference change - good tracking. Important for variable output voltage working in close loop.

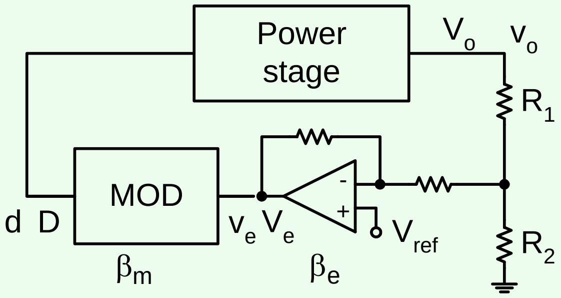
The Dynamic Problem



Power stage is a Switching system

Feedback is analog (or digital) control

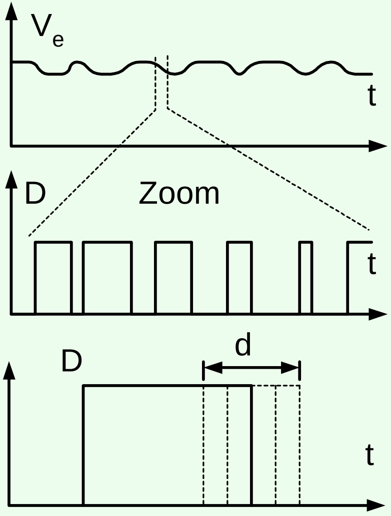
Closed Loop



$\frac{v_o}{v_e}(f)$ – Analog Function

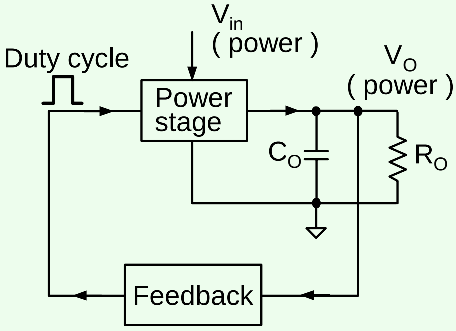
Feedback factor v_e (small signal) into d (small signal)

The Concept of d

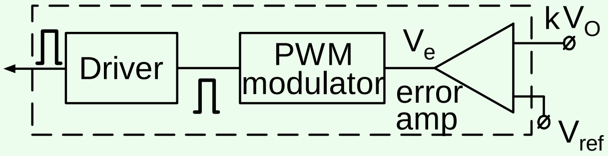


d is the AC component of D

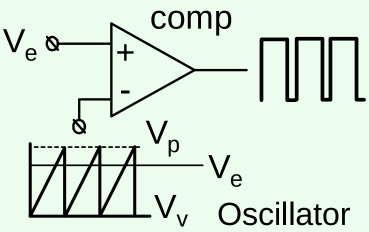
Control



The power conversion system

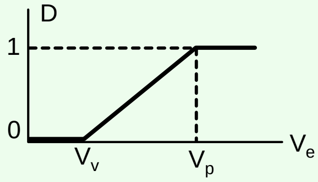


Modulator



$$V_t = \frac{(V_p - V_v)t}{T_s} + V_v$$

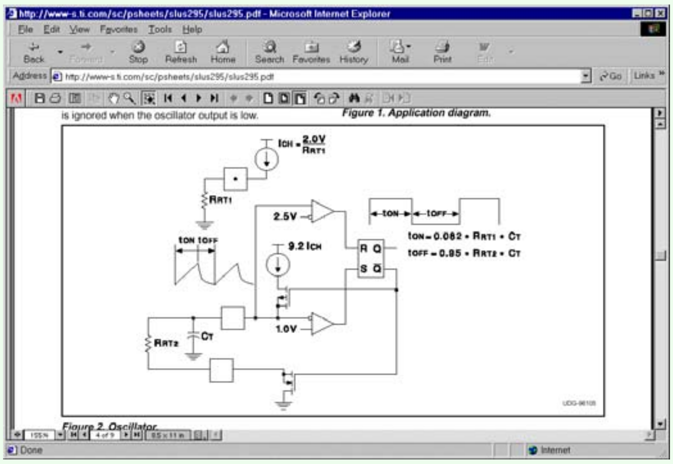
$$V_t = V_e = \frac{(V_p - V_v)t_{on}}{T_s} + V_v$$



$$\frac{t_{on}}{T_s} = D_{on} = \frac{(V_e - V_v)}{V_p - V_v}$$

Practical $D_{on\,max} \approx 0.8 \div 0.9$

Oscillator

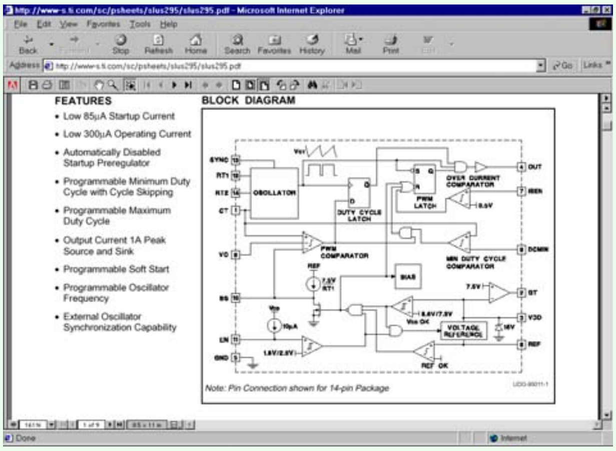


is ignored when the oscillator output is low.

Figure 1. Application diagram.

Figure 2. Oscillator

Complete controller - Voltage Mode (VM)



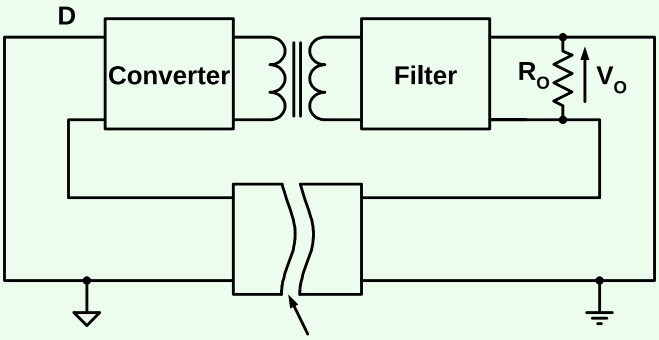
FEATURES

- Low 85μA Startup Current
- Low 300μA Operating Current
- Automatically Disabled Startup Preregulator
- Programmable Minimum Duty Cycle with Cycle Skipping
- Programmable Maximum Duty Cycle
- Output Current 1A Peak Source and Sink
- Programmable Soft Start
- Programmable Oscillator Frequency
- External Oscillator Synchronization Capability

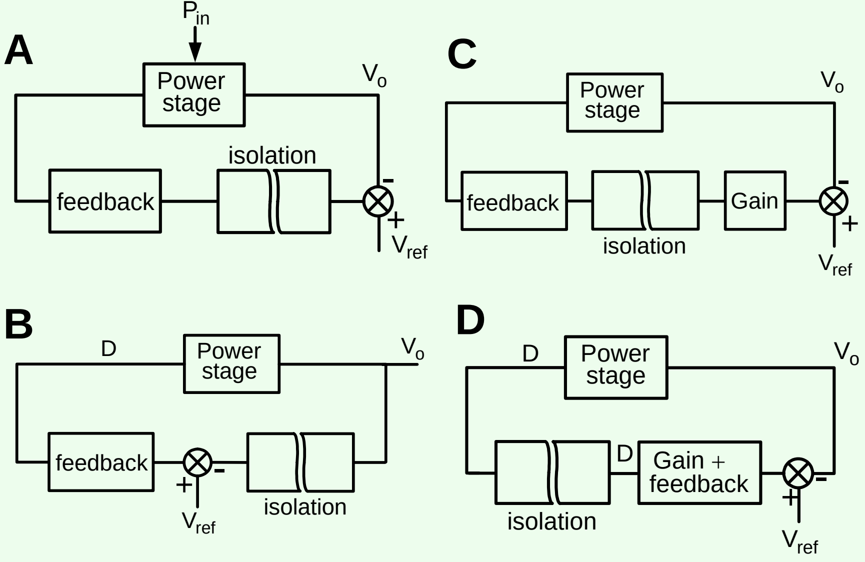
- This controller does not include an error amplifier

Primary to secondary isolation

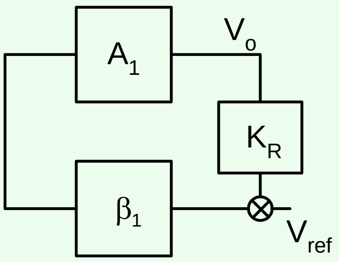
The problem :



Feedback Alternatives



Output Voltage Sampler

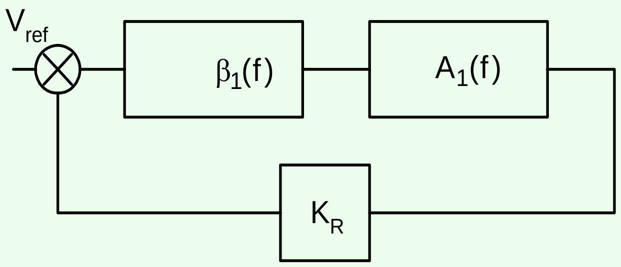


$$\left(\frac{V_o}{V_{ref}}\right) = \frac{\beta_1 A_1}{1+\beta_1 A_1 K_R}$$

$$\beta_1 A_1 K_R > 1$$

$$\left(\frac{V_o}{V_{ref}}\right) = \frac{1}{K_R}$$

LoopGain



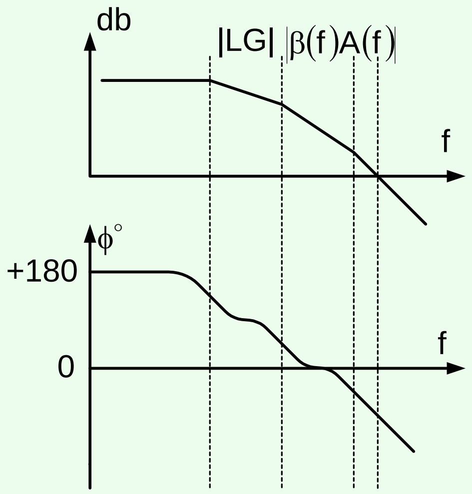
Stability and dynamic response depend on Loop Gain (LG)

$$LG = K_R \beta_1(f) A_1(f)$$

General representation

$$LG = A(f)\beta(f)$$

Bode Plot



In negative feedback

systems $\phi = 180^o\,(-180^o)$

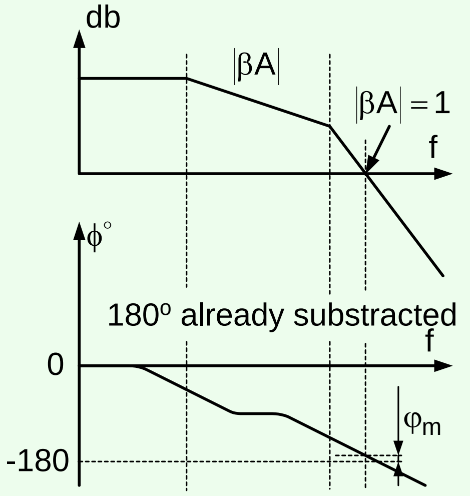
At f→0

Nyquist Criterion

$$A_{CL} = \frac{A(s)}{1+LG(s)}$$

- The system is unstable if {1+LG(s)} has roots in the right half of the complex plane.
- Nyquist criterium is a test for location of {1+LG(s)} roots.
- Nyquist criterium is normally translated into the Bode plane (frequency domain)

Bode Presentation

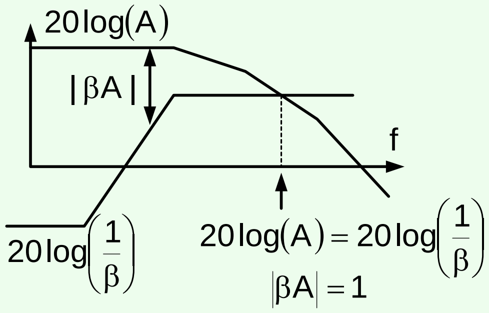


$$\varphi_m = \varphi_{|\beta A|=1} - (-180^\circ) = \varphi_{|\beta A|=1} + 180^\circ$$

The design problem

Given A(f)

Find β(f)

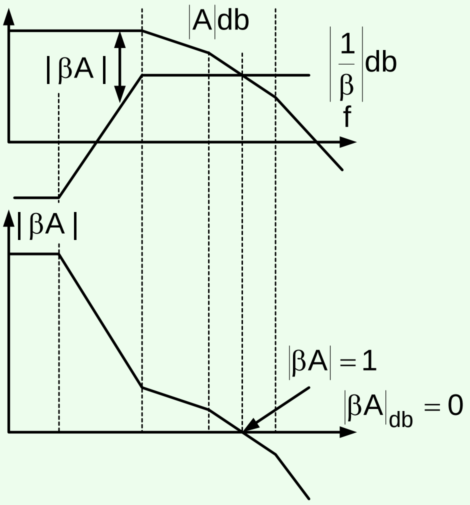


$$20\log(A) = 20\log\left(\frac{1}{\beta}\right)$$

$$|\beta A| = 1$$

$$20\log(A) - 20\log\left(\frac{1}{\beta}\right) = 20\log(\beta A)$$

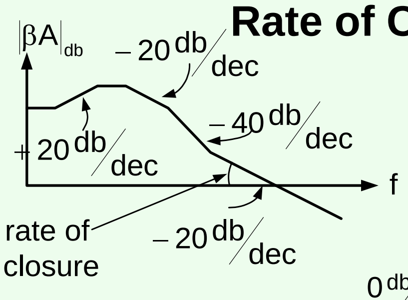
LG=1



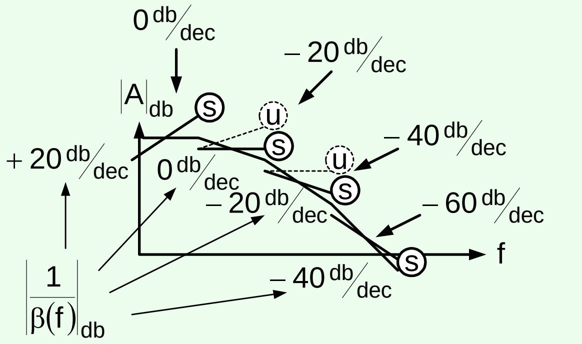
$$|\beta A| = 1$$

$$|\beta A|_{db} = 0$$

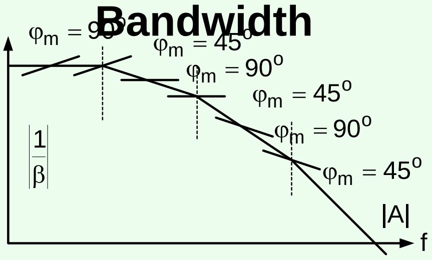
Rate of Closure

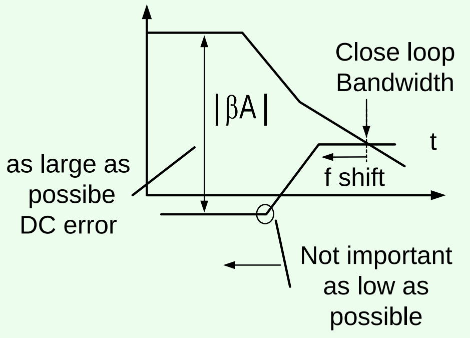


If rate of closure $-20\ ^{db}/_{dec}$ system is stable

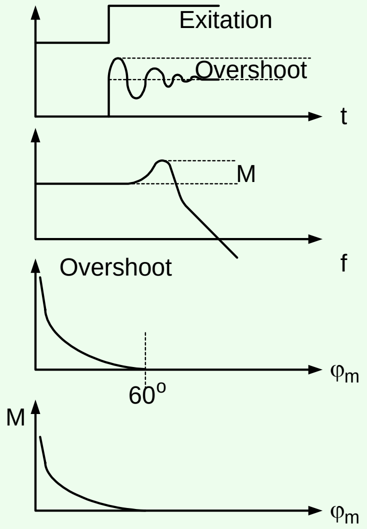


Bandwidth



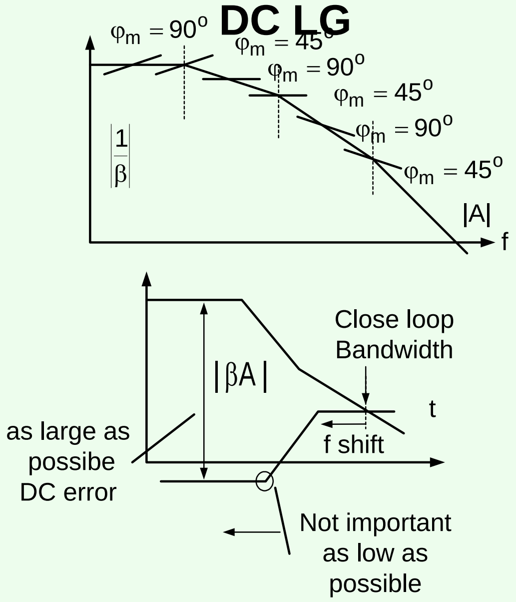


Phase Margin Effects



Choose $\varphi_m > 40^o$

DC LG

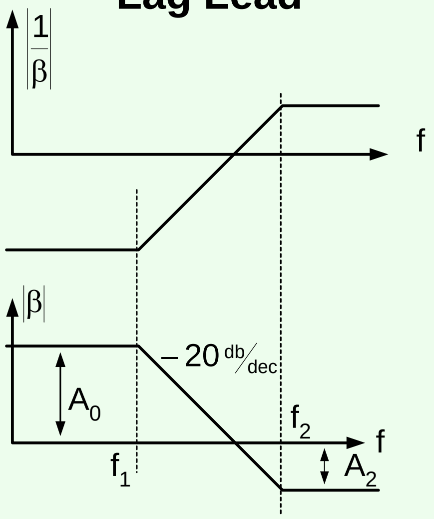


Close loop Bandwidth

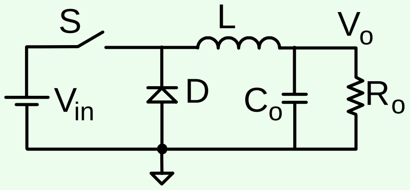
as large as possibe DC error

Not important as low as possible

Lag Lead



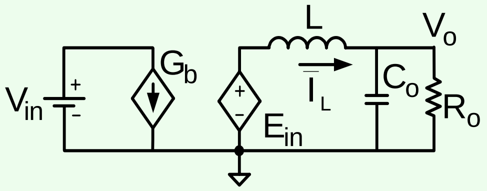
Average Model – AC Analysis



$E_{in} = V_{in} \cdot D_{on}$

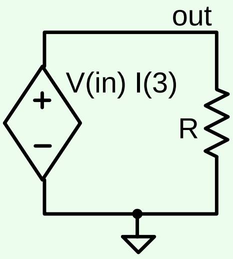
$G_b = \overline{I}_L \cdot D_{on}$

$E_{in} - V_o \rightarrow \overline{V}_L$



Polarity: (voltage and current sources) selected by inspection

Linearization

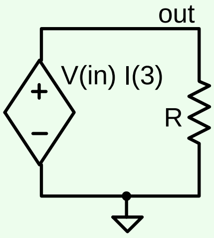


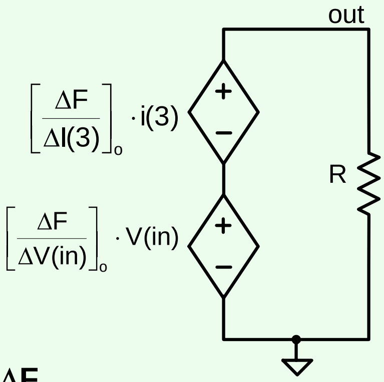
$$V(out) = V(in) * I(3)$$

$$d(V(out)) = \frac{\partial(V(out))}{\partial(V(in))} v(in) + \frac{\partial(V(out))}{\partial(I(3))} i(3)$$

$$V(out) = \frac{\Delta V(out)}{\Delta V(in)} v(in) + \frac{\Delta V(out)}{\Delta I(3)} i(3)$$

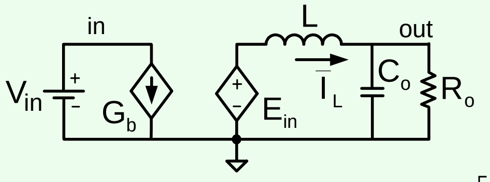
SPICE Linearization (AC Analysis)





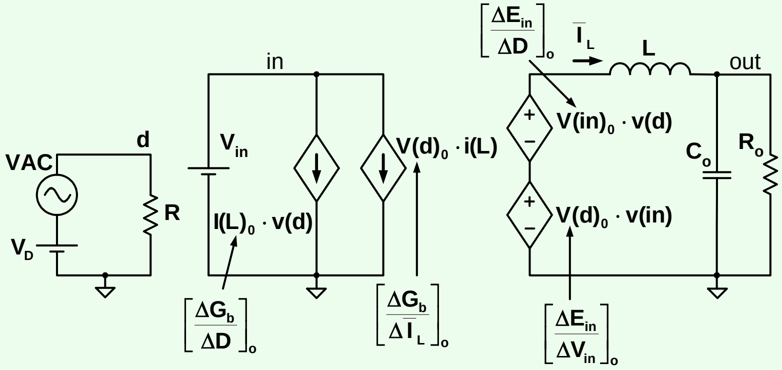
$$\mathbf{\frac{\Delta F}{\Delta V(in)} = I(3)_0} \qquad \mathbf{\frac{\Delta F}{\Delta I(3)} = V(in)_0}$$

Buck linearization

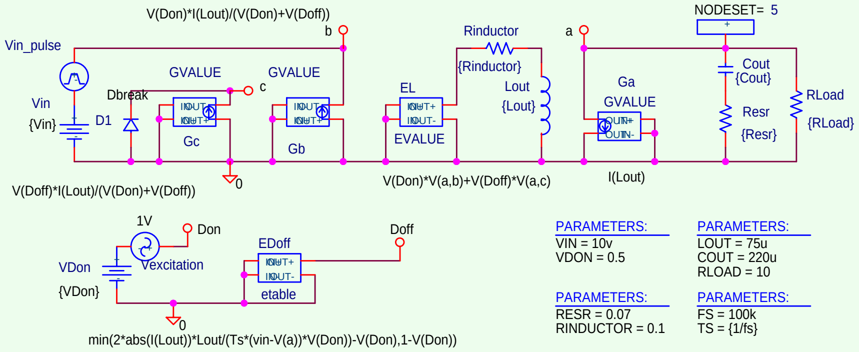


$E_{in} = V_{in}D$

$G_b = \bar{I}_L D$



Example: Buck Average Model Simulations



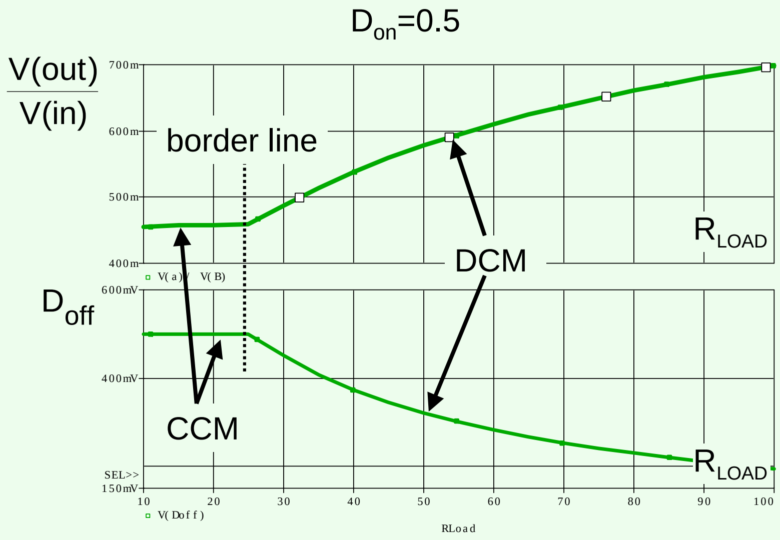
PARAMETERS:
VIN = 10v
VDON = 0.5

PARAMETERS:
LOUT = 75u
COUT = 220u
RLOAD = 10

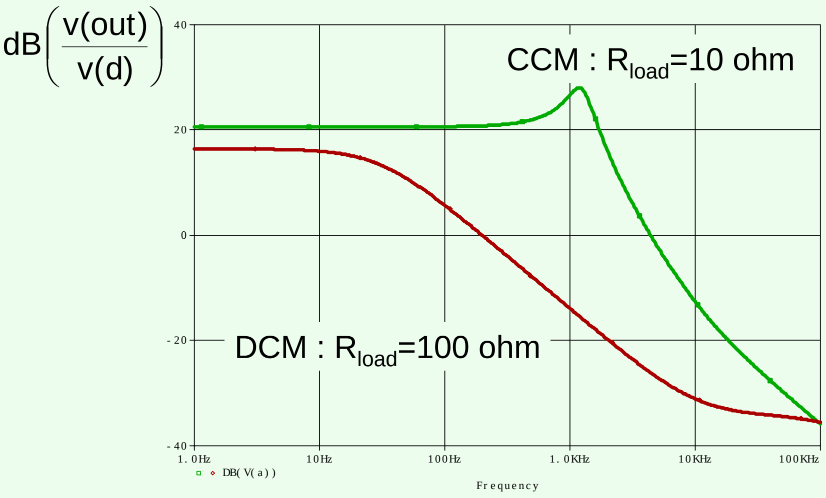
PARAMETERS:
RESR = 0.07
RINDUCTOR = 0.1

PARAMETERS:
FS = 100k
TS = {1/fs}

Example: Buck DC Sweep Analysis (CCM/DCM)



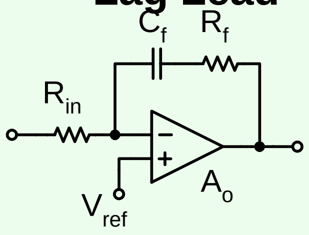
Example: Buck AC Analysis (CCM/DCM)



Buck AC Analysis (CCM/DCM) file .out

```
 ****     SMALL SIGNAL BIAS SOLUTION      TEMPERATURE =   27.000 DEG C

****     CURRENT STEP                    PARAM RLOAD =   10

******************************************************************************
NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE

(    a)    4.5455           (    B)   10.0000         (    C)    -.8182         (  DON)     .5000

( Doff)     .5000  (N00069)    -.0455 (N00141)    0.0000 (N000071)     .5000    (N000230)    0.0000


   VOLTAGE SOURCE CURRENTS
   NAME         CURRENT
   V_Vexcitation   0.000E+00
   V_VDon       0.000E+00
   V_Vin       -2.273E-01


****     CURRENT STEP                    PARAM RLOAD =  100

******************************************************************************
NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE

(    a)    6.9835  (    B)   10.0000  (    C)    -.7340  (  DON)     .5000

( Doff)     .1945  (N00069)    -.0070 (N00141)    0.0000 (N000071)     .5000    (N000230)    0.0000

   VOLTAGE SOURCE CURRENTS
   NAME         CURRENT

   V_Vexcitation   0.000E+00
   V_VDon       0.000E+00
   V_Vin       -5.028E-02
```

Lag Lead



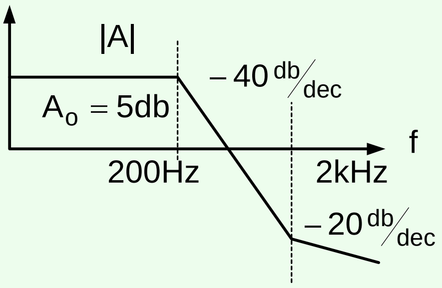
$$A_o = A_{OL}\,(\text{ampl.})$$

$$f_L = \frac{1}{2\pi C_f R_f}$$

$$A_2 = \frac{R_f}{R_{in}}$$

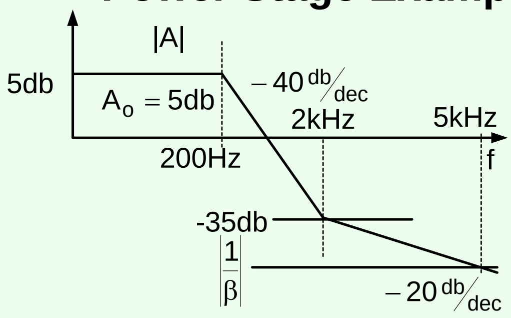
Exercise

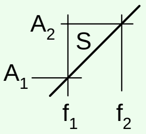
Given



Design β and feedback circuit for f_{el}=5kHz

Power Stage Example

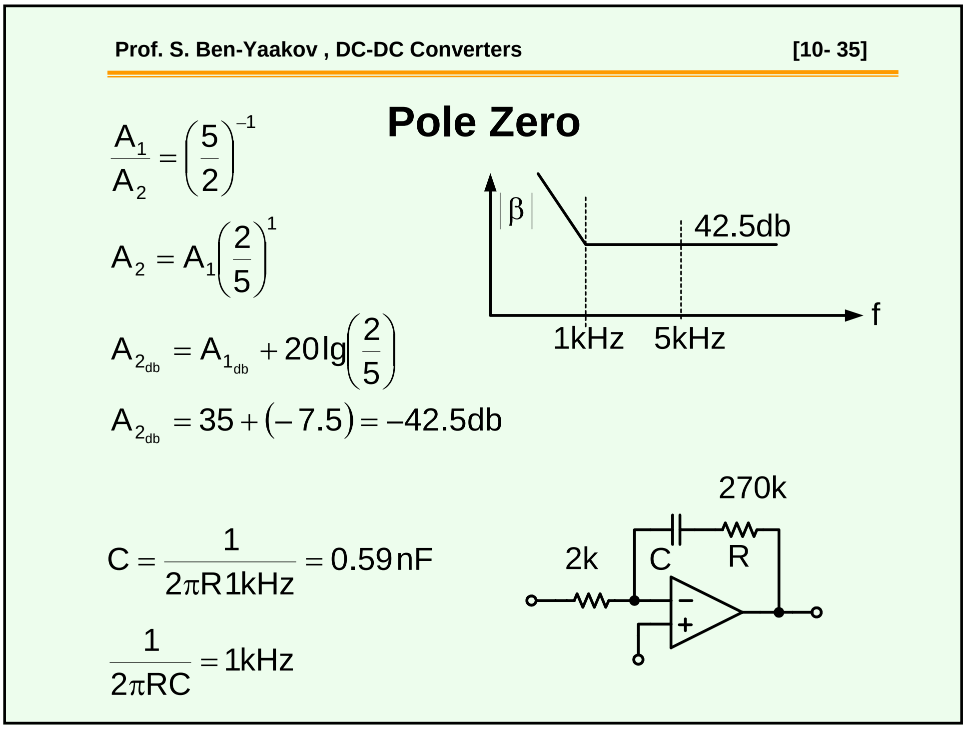




$S \quad 20\,{}^{db}/_{dec},\ -20\,{}^{db}/_{dec},$

$40\,{}^{db}/_{dec},\ -40\,{}^{db}/_{dec}$

$$\left(\frac{A_2}{A_1}\right) = \left(\frac{f_2}{f_1}\right)^{\frac{S}{20}}$$



Pole Zero

$$\frac{A_1}{A_2} = \left(\frac{5}{2}\right)^{-1}$$

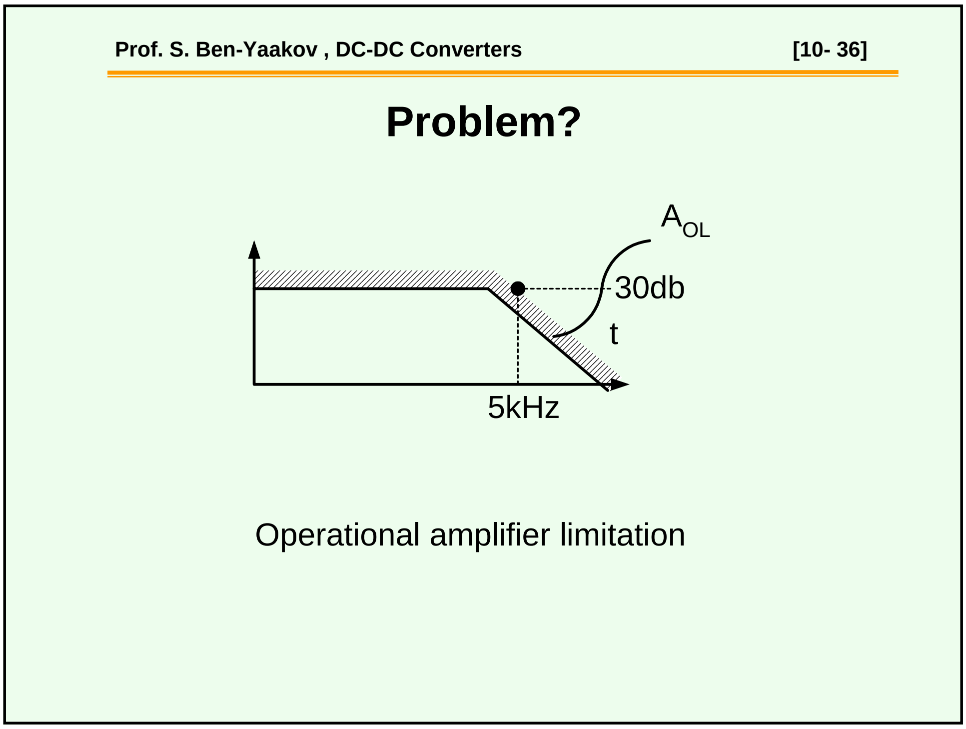
$$A_2 = A_1\left(\frac{2}{5}\right)^{1}$$

$$A_{2_{db}} = A_{1_{db}} + 20\lg\left(\frac{2}{5}\right)$$

$$A_{2_{db}} = 35 + (-7.5) = -42.5db$$

$$C = \frac{1}{2\pi R 1kHz} = 0.59\,nF$$

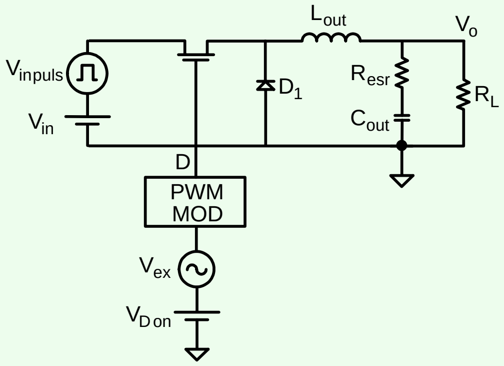
$$\frac{1}{2\pi RC} = 1kHz$$



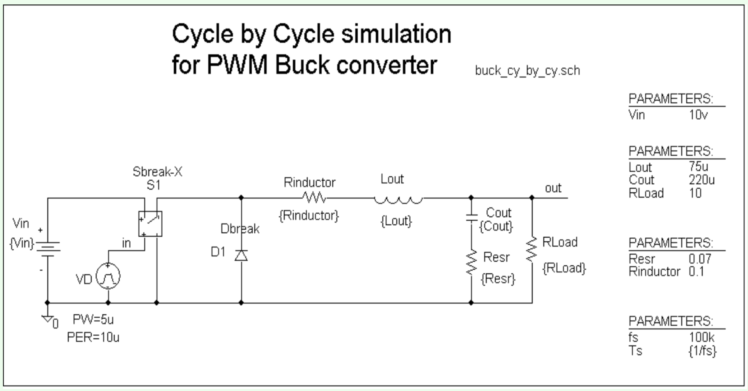
Problem?

Operational amplifier limitation

Buck



File: Buck_cy_by_cy.SCH


Cycle by Cycle simulation
for PWM Buck converter

buck_cy_by_cy.sch

PARAMETERS:
Vin 10v

PARAMETERS:
Lout 75u
Cout 220u
RLoad 10

PARAMETERS:
Resr 0.07
Rinductor 0.1

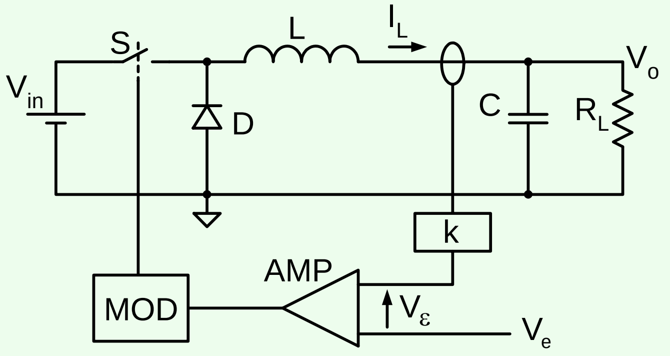
PARAMETERS:
fs 100k
Ts {1/fs}

Current Feedback

- The problem: transfer function is second order
- Solution: Add current Feedback

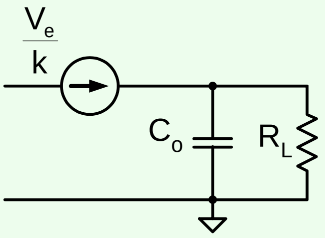
System order is reduced for each state variable feedback

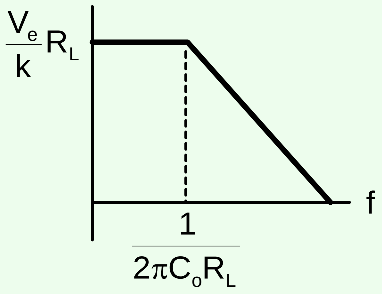
Current Feedback



- For strong feedback (A_{OL}>>1):

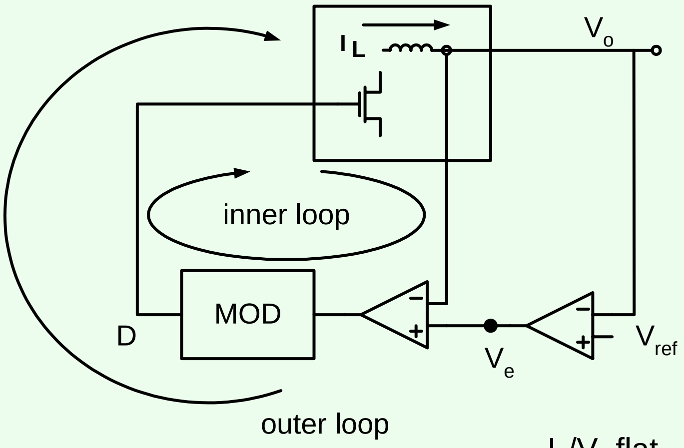
$$I_L = \frac{1}{k} V_e \qquad (V_\varepsilon \to 0)$$





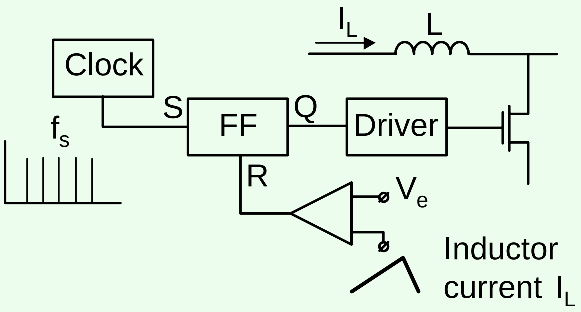
- First order system !

PCM & ACM



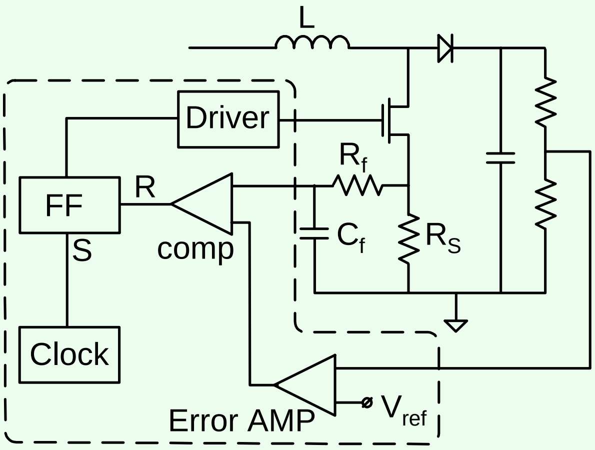
I_L/V_e flat

Current mode (CM) control



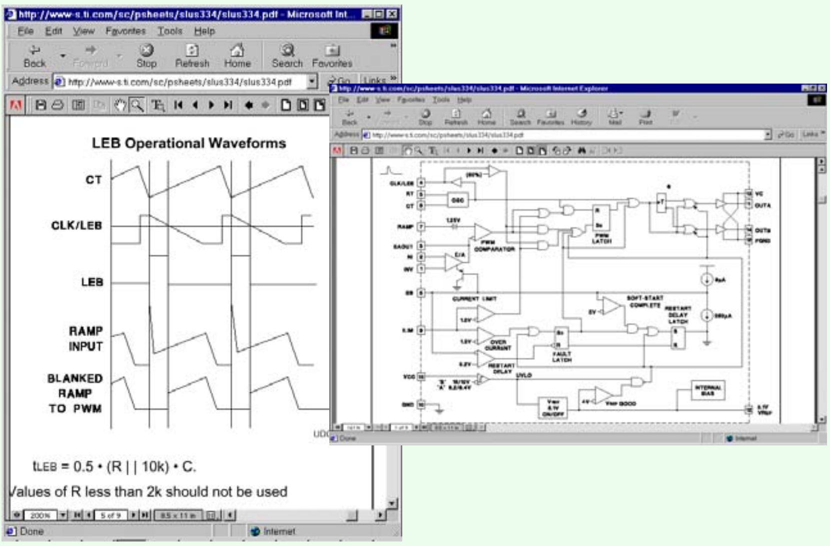
$$\frac{V_o}{V_{in}} = f(D_{on}) \text{ is the same !}$$

Implementation CM Boost



Some controllers have amplifiers for sensed current

CM Controller



LEB Operational Waveforms

tLEB = 0.5 • (R | | 10k) • C.

Values of R less than 2k should not be used

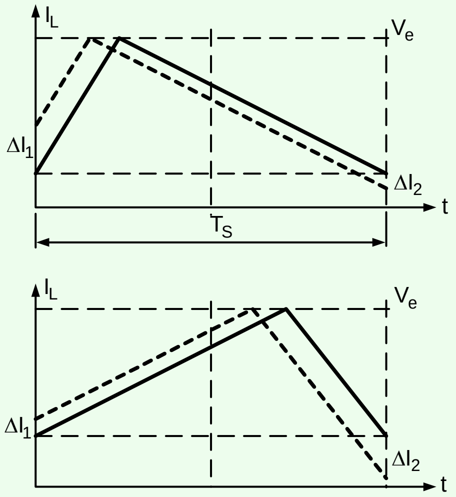
Advantages of peak CM (PCM)

- Cycle by cycle protection
- Better dynamics

Disadvantages

- Loading edge spike
- Subharmonic oscillation

The nature of Subharmonic Oscillations



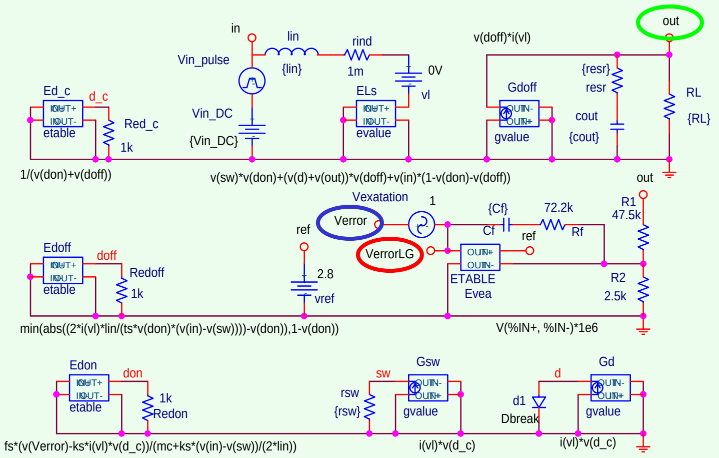
The geometric explanation

D<0.5 $\Delta I_2<\Delta I_1$

D>0.5 $\Delta I_2>\Delta I_1$

BOOST Average Model

AC analysis PCM (CCM & DCM)



PARAMETERS:
KS = 81.25m
TS = 40u
MC = 6250

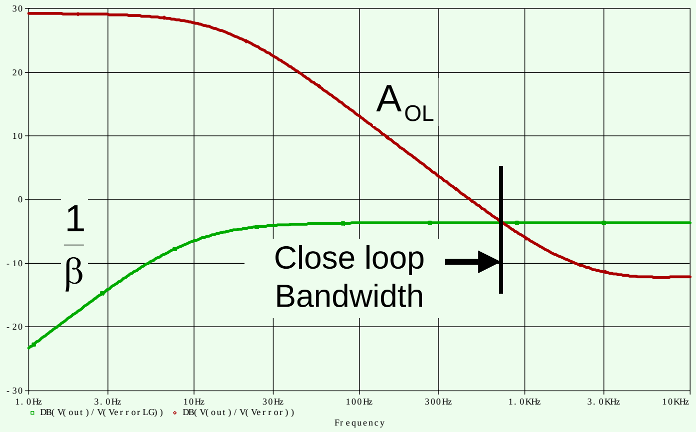
PARAMETERS:
LIN = 195u
RSEN = 0.025
FS = {1/ts}

PARAMETERS:
RSON = 1m
RSW = {rson+rsen}
RL = 11.2

PARAMETERS:
RESR = 0.012
COUT = 2m
VIN_DC = 28

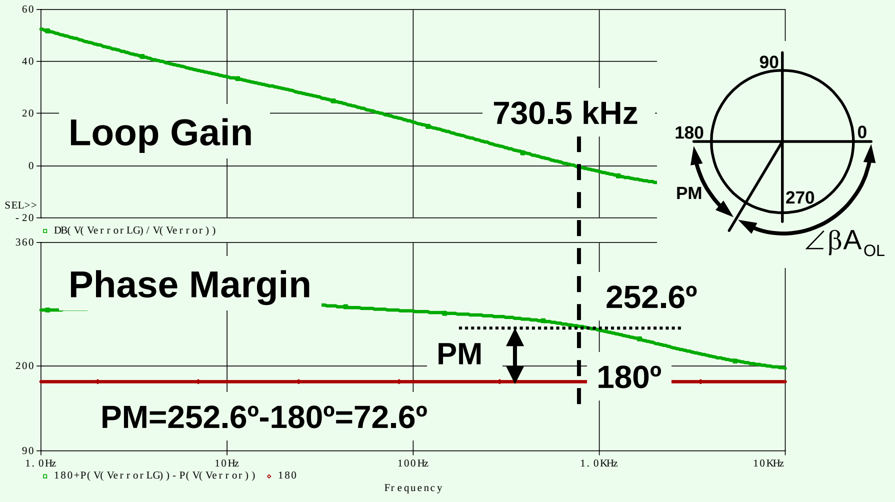
PARAMETERS:
CF = 0.23u

BOOST Average Model Simulation



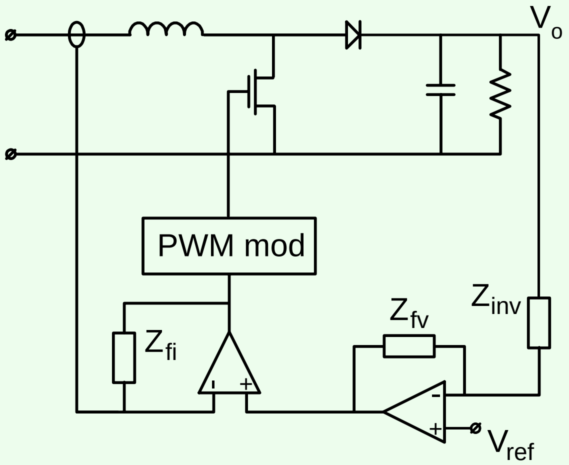
$\frac{1}{\beta}$: DB(V(out)/V(VerrorLG)) A_{OL} : DB(V(out)/V(Verror))

BOOST Average Model Simulation



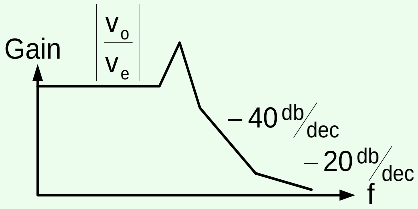
PM=252.6º-180º=72.6º

Average Current Mode (ACM) Control

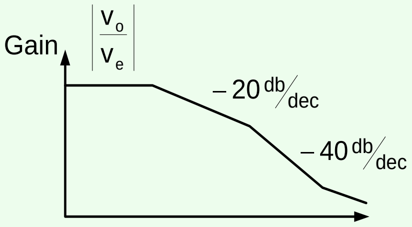


Current is filtered first to take out high frequency (f_S)

The advantages of current feedback (PCM or ACM)

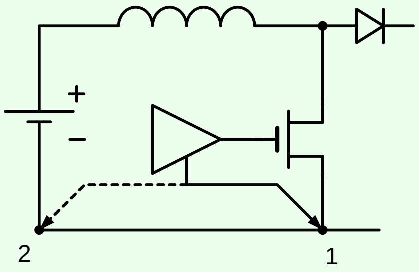


Typical power stage
VM



Same power stage
(outer loop) with
CM

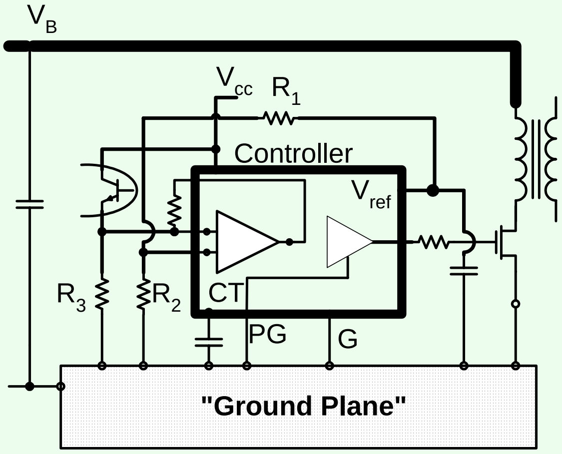
Parasitic effects: PCB trace resistance



$$V_1 \neq V_2$$

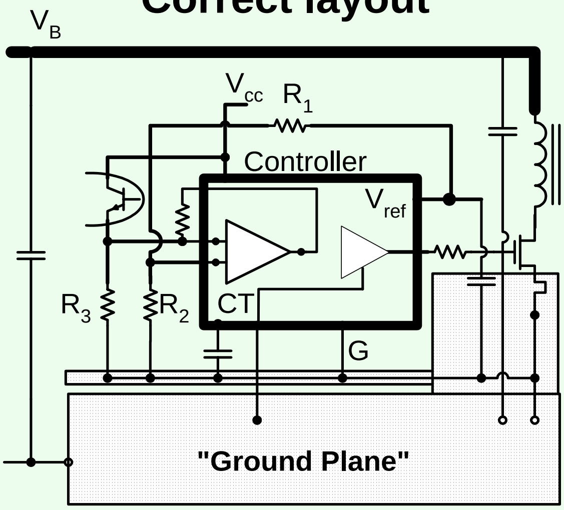
Ground Noise

Separate power ground from signal ground



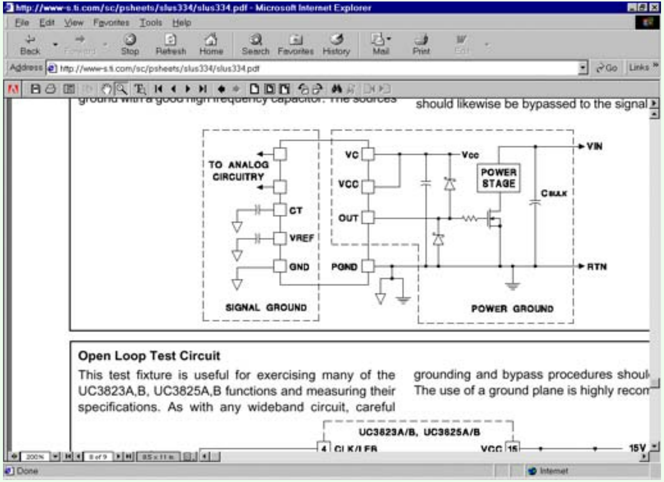
This circuit will probably not work. Why ?

Correct layout



Do not rely on “Ground Plane”

Schottky Diodes



ground with a good high frequency capacitor. The sources

should likewise be bypassed to the signal

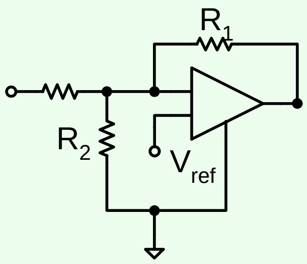
Open Loop Test Circuit

This test fixture is useful for exercising many of the UC3823A,B, UC3825A,B functions and measuring their specifications. As with any wideband circuit, careful

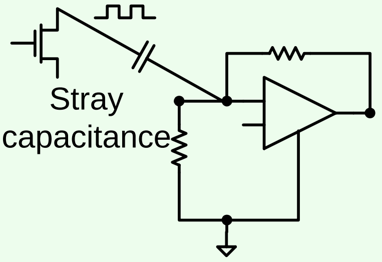
grounding and bypass procedures shoul

The use of a ground plane is highly recom

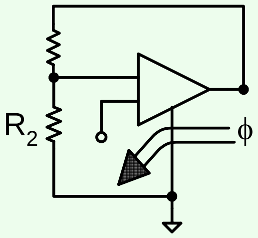
Parasitic effects: Interfering signal injection



Sensitive Part-Capacitive coupling



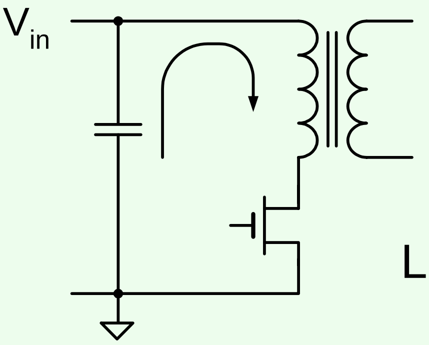
Parasitic effects: Inductive coupling



Do not put sensitive elements close to high voltage pulses or close to magnetic elements

Current Loop Area

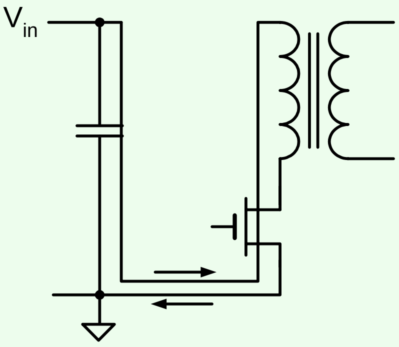
Avoid wide power line loops



$$L \sim \frac{\mu A n^2}{l}$$

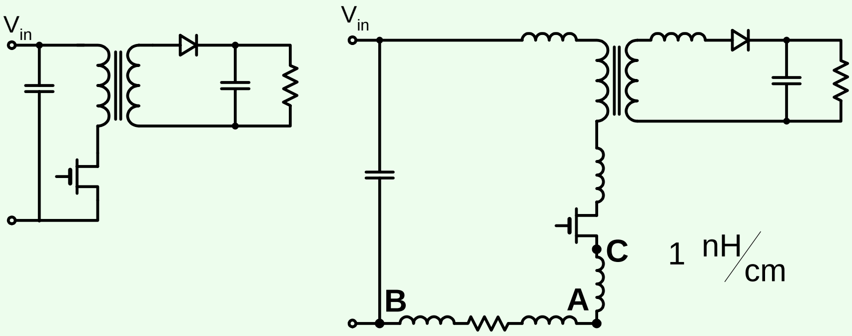
Stray inductance is proportional to area. So is the radiated wave.

Loop Area



Best way is to run the forward-return paths on two sides of the PCB

Parasitic effects: Stray inductance



Two points on power PCB trace will never have same potential $V_A \neq V_B \neq V_C$