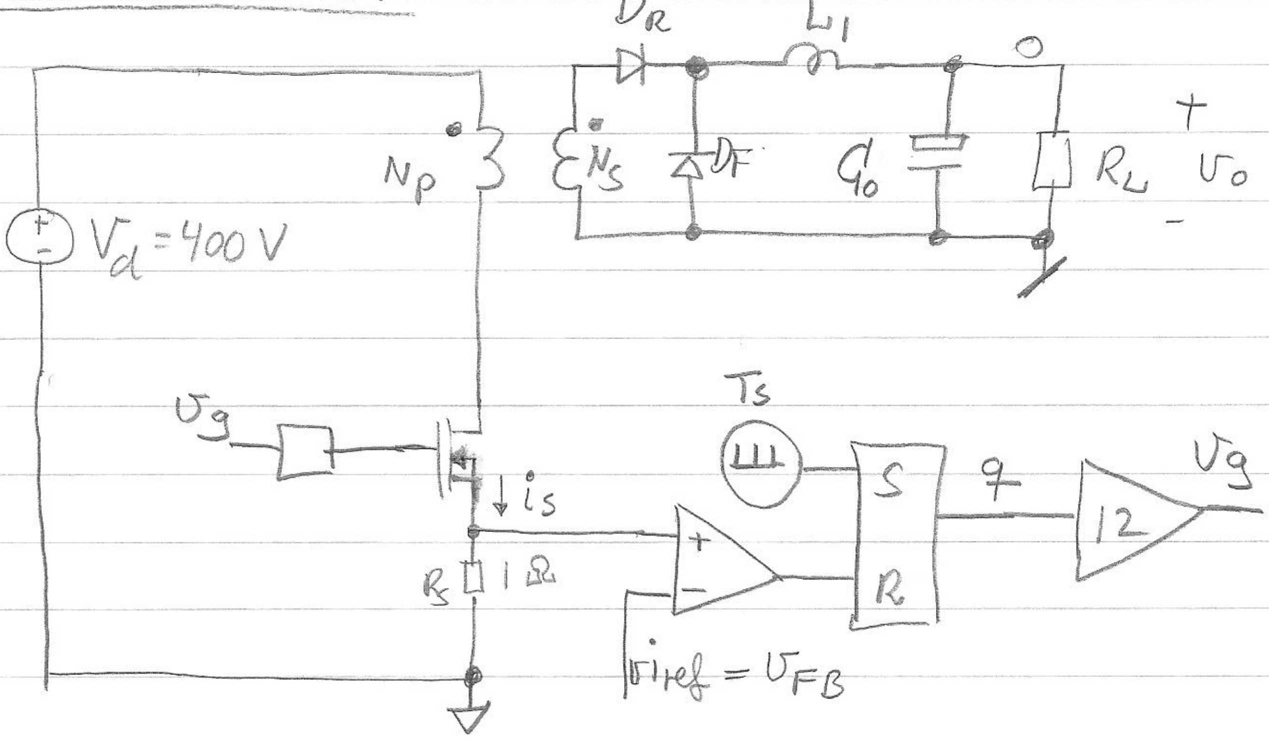
Problem 3 lecture

REFERENCE: AN4134

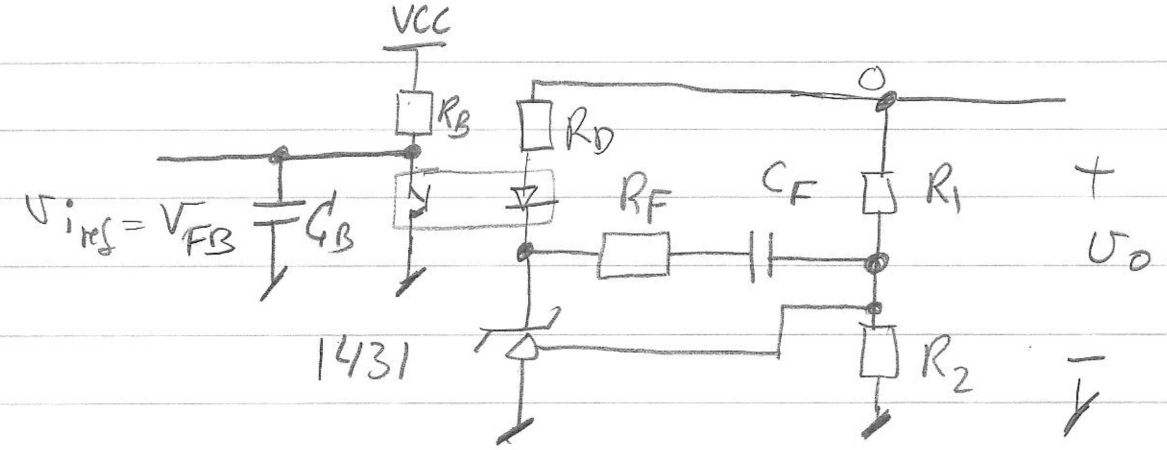


Spec: $V_o = 24V$ $\quad T_S = 20\,\mu s$

$L_1 = 200\,\mu H$ $\quad P_o = 70\,W$

$C_o = 300\,\mu F$

$N_P/N_S = 5$ $\quad \omega_{cross} = 20000\ rad/s$



0: Sketch plot of G_{vc}

1: Select value of $R1$ + R_2

2: Find desired gain at ω_{cross} $\left(\text{Gain\_wcross} \sim K_{op} \frac{R_B}{R_D} \right)$

3: Find $\omega_{zc} = \omega_{cross}/3$
select R_F and C_F

4: Find $\omega_{pc} = 3\,\omega_{cross}$
select R_D, R_B and C_B

5: Simulate in LT Spice

a) Build power circuit

b) Build current controller

c) Build controller

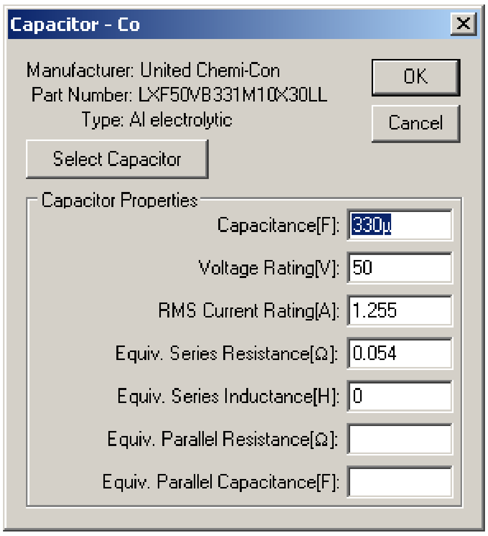
d) Simulate the converter.

Specification: Co = 300uF -> 330uF, L1=200uH, RL=8.2 Ohm, Vd=400, NP/NS=5, Vo = 24 V

W_{cross} = 20000 rad/s

Answer 0: Sketch plot of G_{vc}

Select a capacitor from the list of capacitors the nearest standard capacitance to 300uF is 330 uF, notice have to look out for RMS current rating is not exceeded.

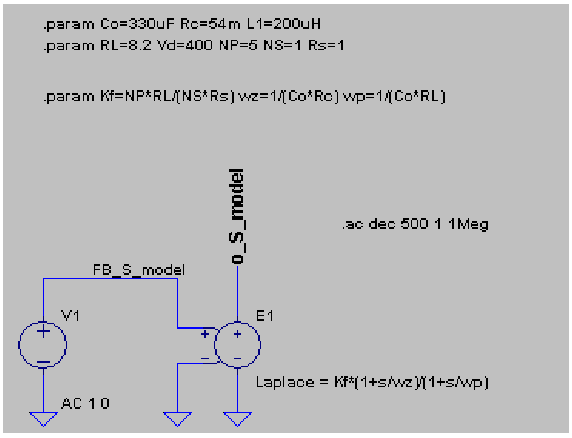


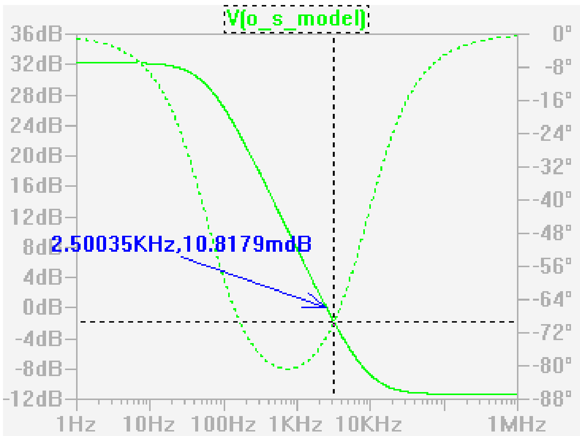
Rc = 54mOhm

Rs: Shunt resistor value used to measure the current of the transistor is selected to be:

Rs = 1 ohm

Forward converter model implemented in LT spice $G_{vc} = \tilde{v}_o / \tilde{v}_{FB}$:





At 1 Hz the gain is 32.2 dB and at 2.5kHz (15707 rad/s) the gain is ~0 dB.

At w_c = 3.183 kHz (20000 rad/s) the gain is -1.9 dB and the phase is -70 deg.

Answer 1: Find R1 and R2

We know that Vref inside the TL431 is 2.5 V and the output voltage is Vo = 24 V. R2 is selected to be **R2=1kOhm** and the current of R2 is then 2.5 mA. From the voltage divider equation R1 is determined:

$$2.5V = 24V \frac{R_2}{R_1 + R_2}$$

R1 is found to be **R1 = 8.6 kOhm**.

Answer 2: Find desired gain at w_{cross}

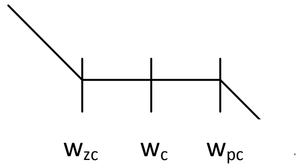
Compensator design type II.

The compensator function is:

$$G_c = \frac{\tilde{v}_{FB}}{\tilde{v}_o} = -\frac{w_i}{s} \frac{1 + s / w_{zc}}{1 + s / w_{pc}}$$

$$w_i = \frac{K_{op} R_B}{R_D R_1 C_F} \qquad w_{zc} = \frac{1}{(R_1 + R_F) C_F} \qquad w_{pc} = \frac{1}{R_B C_B}$$

The gain of G_c is sketched in the below plot and location of w_{zc}, w_c w_{pc} is indicated:



Here w_c is locacted at the center so $w_c = \sqrt{w_{zc} w_{pc}}$ and from specifications w_c = 20000 rad/s and from forward converter transfer function the gain at w_c = 20000 rad/s calculated to be -1.9 dB. The gain of the compensator must then be $G_c(w_c)$ = 1.9 dB to obtain an open loop gain G_{op} = 1 dB at w_c= 20000 rad/s.

Now we need to know what the gain of $G_c(w)$ at $w=w_c$ is and therefore $s = jw_c = j\sqrt{w_{zc} w_{pc}}$ is substituted into the G_c function.

$$G_c(w_c) = -\frac{w_i}{j\sqrt{w_{zc} w_{pc}}} \frac{1 + j\sqrt{\frac{w_{pc}}{w_{zc}}}}{1 + j\sqrt{\frac{w_{zc}}{w_{pc}}}}$$

$$\left\| G_c(w_c) \right\| = \frac{w_i}{\sqrt{w_{zc} w_{pc}}} \frac{\sqrt{1 + \frac{w_{pc}}{w_{zc}}}}{\sqrt{1 + \frac{w_{zc}}{w_{pc}}}}$$

And this is reduced to the result:

$$\left\| G_c(w_c) \right\| = \frac{w_i}{w_{zc}}$$

If RF << R1 then

$$\left\| G_c(w_c) \right\| = \frac{w_i}{w_{zc}} = \frac{K_{op} R_B}{R_D}$$

We need to find K_{op} R_B and R_D, remember $\left\| G_c(w_c) \right\|$ = 1.9 dB $\left\| G_c(w_c) \right\|$ = 1.244

Answer 3: Find $w_{zc} = w_{cross}/3$ select R_F and C_F

Select **R_F = 100** Ohm and with $w_{zc} = w_c/3$ and $w_{zc} = 1/((R_F+R_1)*C_F)$ then $C_F = 3/(w_c(R_F+R_1))$ and C_F is found to be **C_F = 17nF**.

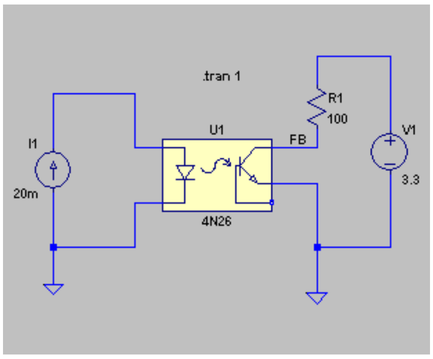
Answer 4: Find $w_{pc} = 3w_{cross}$ select R_D, R_B and C_B

We use: $\|G_c(w_c)\| = \frac{w_i}{w_{zc}} = \frac{K_{op}R_B}{R_D}$

And need to find K_{op}, R_B and R_D:

Finding K_{op}

Select opto coupler 4N26 and make a small test circuit in LTspice shown on figure



$$Gain = \frac{i_C}{i_F}$$

I_c = transistor collector current and i_F is diode current

The test results are:

i_F current ->	1mA	10 mA	20 mA
V1=10V, R1=1k : Gain = i_C/i_F	0.8	0.67	0.49
V1=3.3 V, R1=100: Gain= i_C/i_F	0.8	0.67	0.56

So for an I_F in the range of 1mA to 10 mA the Gain is 0.7 and **K_{op} =0.7**

NOTICE: R1 is here identical with RB so RB must be in the range of 100 ohm….. when V1 = 3.3 V, If R1 is chosen larger ex. In the kohm range the Gain are much more dependent of i_F.

Finding R_D

Here is assumed that the TL341 cathode voltage must be higher than 2.5 V and during this condition the current must be minimum 1 mA. So V_{Kmin} = 2.5 V at i_F = 1mA assuming an opto coupler voltage of 1.1 V so V_{opto}= 1.1 V.

Then R_D can be calculated

$$R_D \leq (V_o - V_{opto} - V_{K\min}) / i_{F\min}$$

$$R_D \leq (24 - 1.1 - 2.5) / 1mA$$

R_D< 20 kOhm, but since R_B are selected next and and it has to be in the 100 ohm region range to obtain a stabile gain of the opto coupler, R_D=200 ohm – see next paragraph where R_B is found:

Finding R_B

$$R_B = \frac{\|G_c(w_c)\| R_D}{K_{op}}$$

$$R_B = \frac{1.244 \cdot 200}{0.7}$$

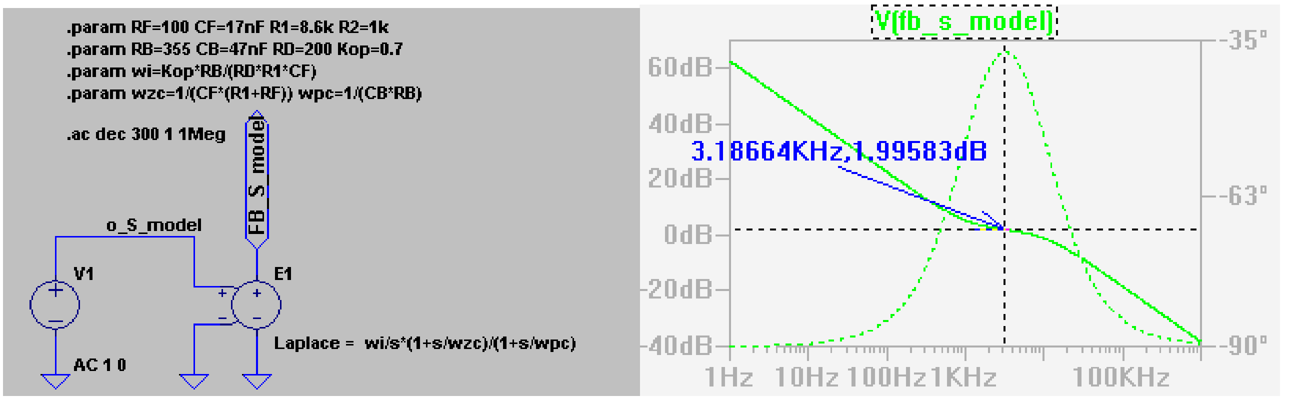
R_B = 355 Ohm

In literature reference 'Designing with the TL431' paragraph 6. is it stated that $w_{zc}=w_c/3$ and it is selected that $w_{pc} = 3{*}w_c$

Find C_B

Select w_{pc} = 3 w_c and w_{pc} = 1/(C_B R_B). Here R_B was calculated to **R_B=355 Ohm** with w_c = 20000 rad/s C_B is found to be **C_B = 47nF**.

The compensator is now implemented in LT spice $\tilde{v}_{FB} / \tilde{v}_o$:



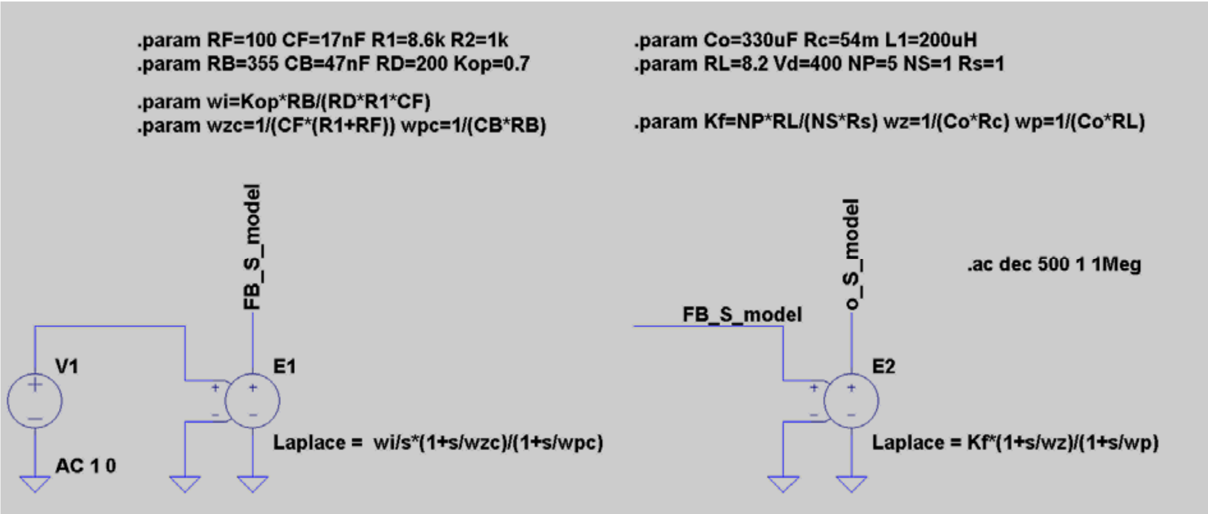
The function shows the desired Gain of 2dB at the cross over frequency 3.187 kHz.

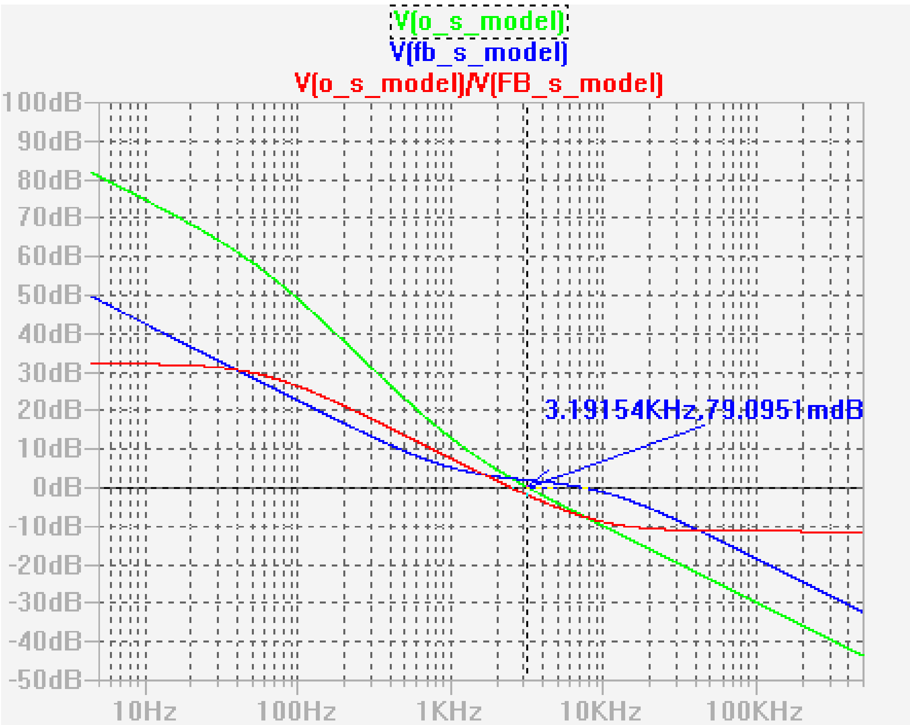
Summary

So all capacitors and resistors and K_{op} are now found

R_F = 100 Ohm C_F = 17nF R1 = 8.6 kOhm R2=1kOhm R_B = 355 Ohm CB = 47nF R_D= 200 Ohm K_{op} =0.7

The total open loop T_{OL} function response is now modeled and calculated.



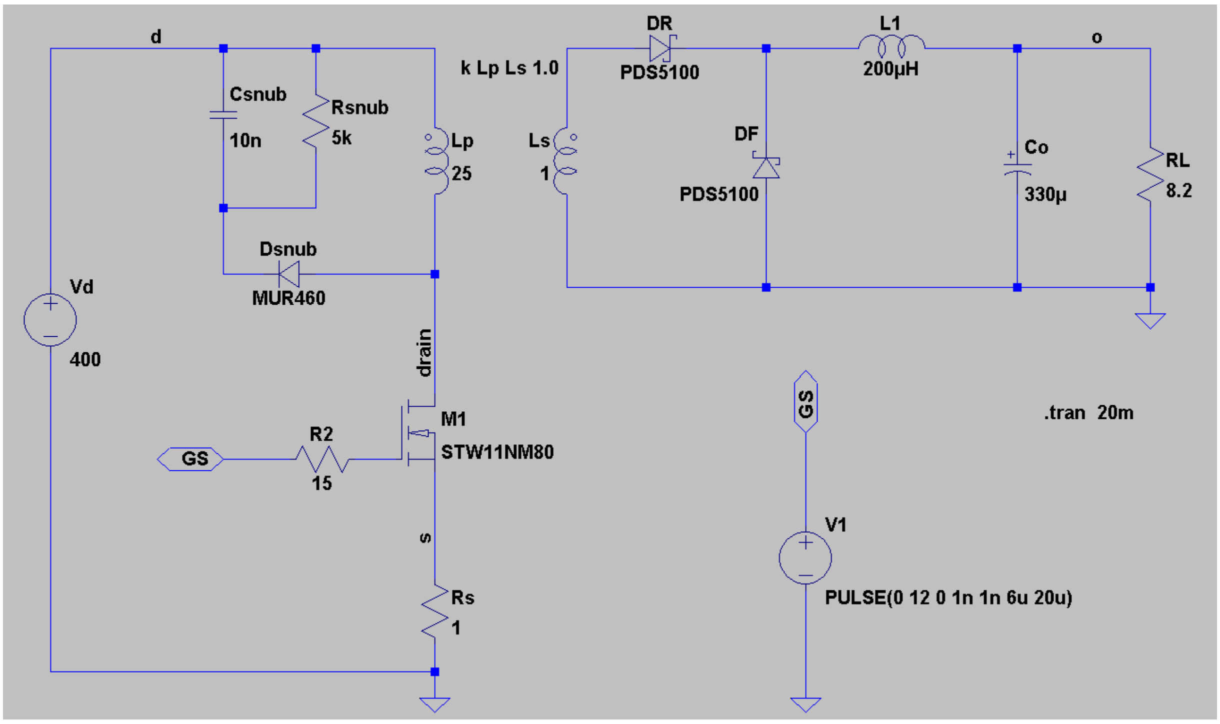


Green line: T_{OL} , Red line: Forward converter model, Blue line: Compensator model

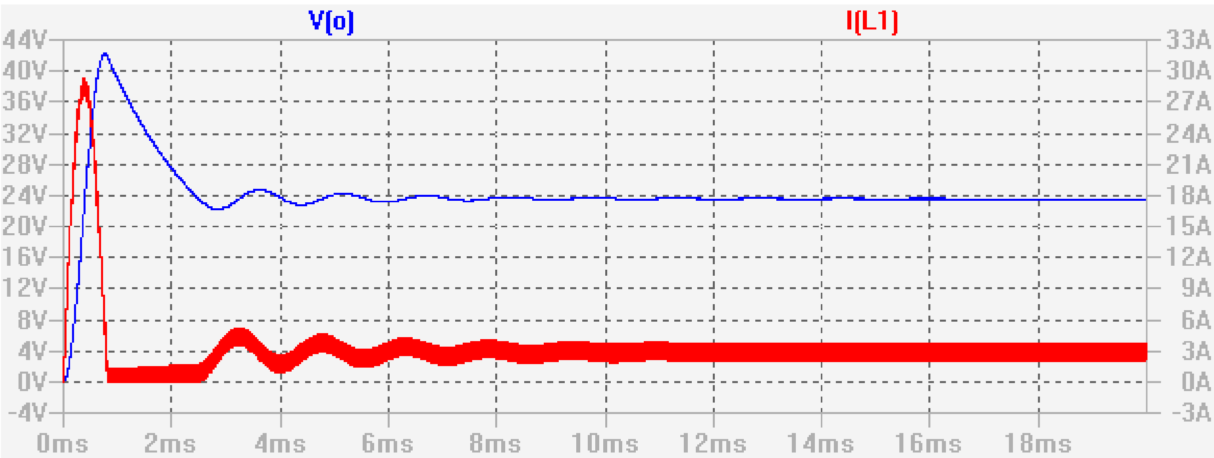
It is noticed that the green line showing the response of T_{OL} have a crossover frequency at 3.1915kHz close to the desired 20000 rad/s.

Answer 5: Simulate in LTspice

5a) Build Power circuit:

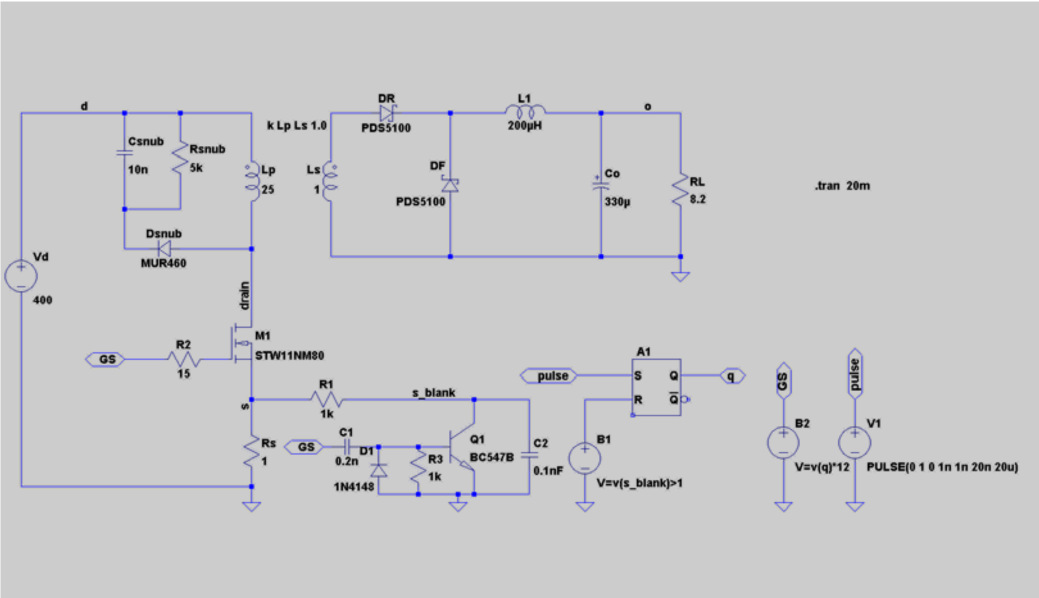


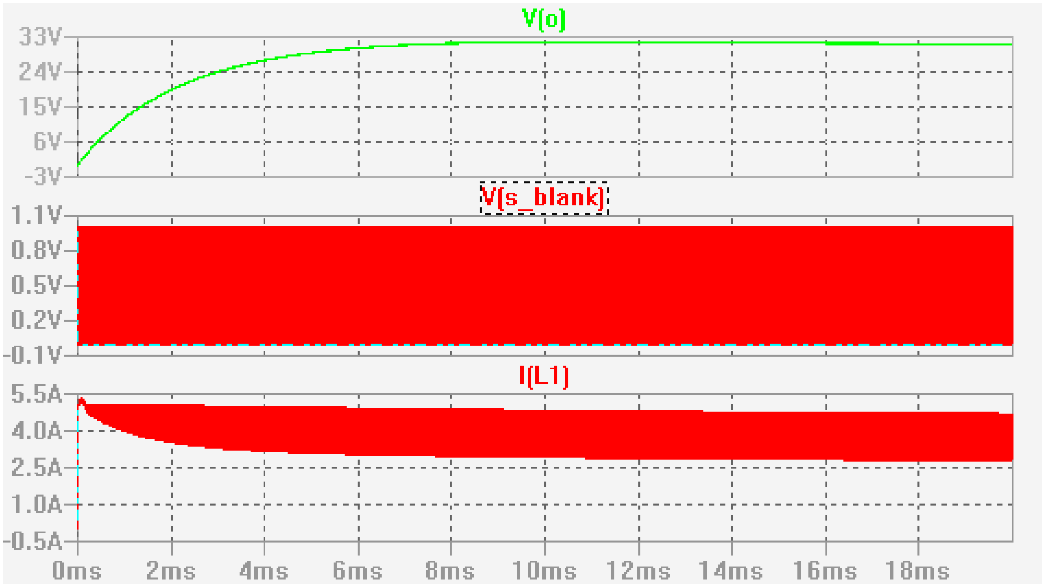
Simulation gives:



The non controlled behavior of converter is as expected and the V(o)~24 V at a duty cycle of D=0.3.

5b) Build current controller:

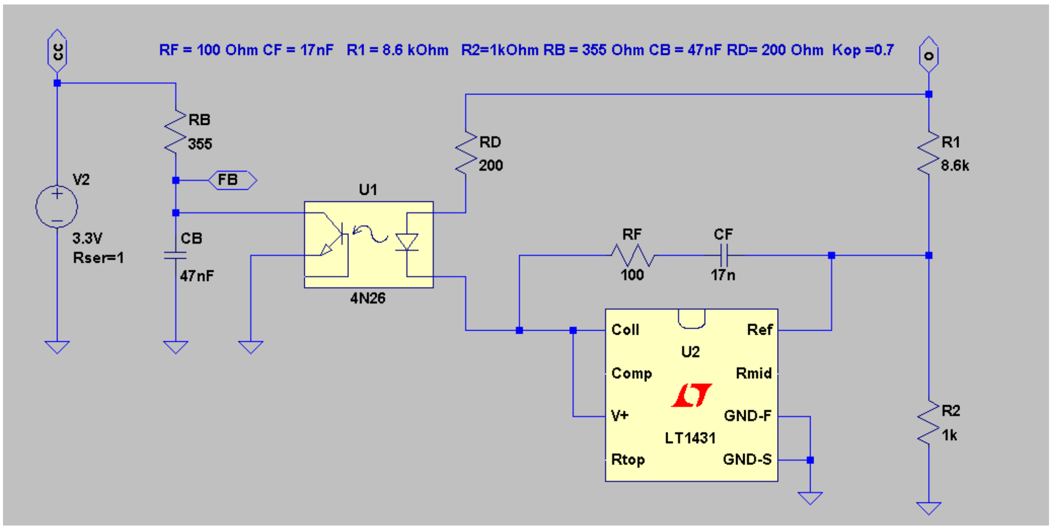




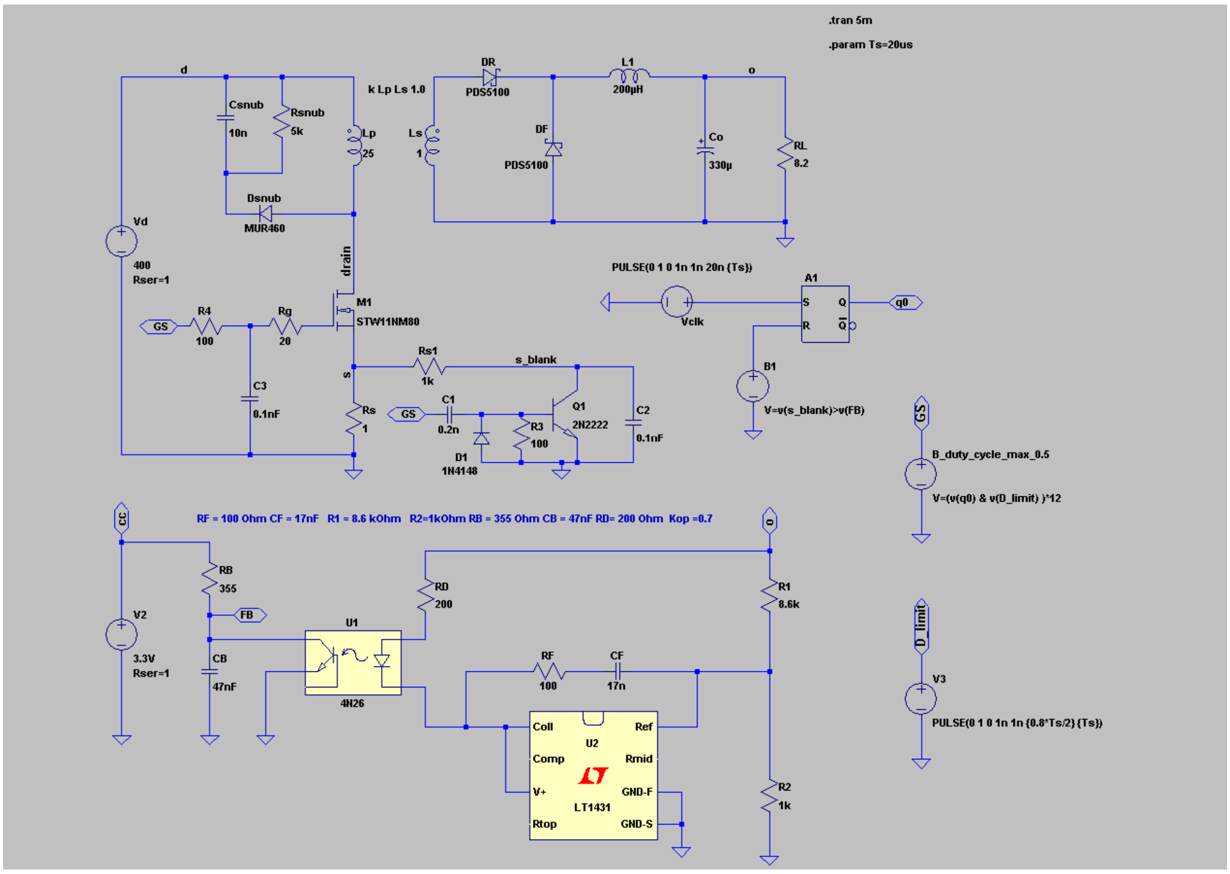
Notice: C1 = 0.2n, ESR=100 ohm Right click on capacitor C1 to add the value of ESR to capacitor.

Notice V(s_blank) is limited to the current reference voltage 1V. The inductor current is also well controlled.

5c) Build the controller:



5d) Simulate converter



Plots of v(o) and i(L1) and v(FB)