TI DSP, MCU 및 Xilinx Zynq FPGA 프로그래밍 전문가 과정

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BUCK CONVERTER 12V 1A

<TL494 + IR2110>

Represented by 박현우
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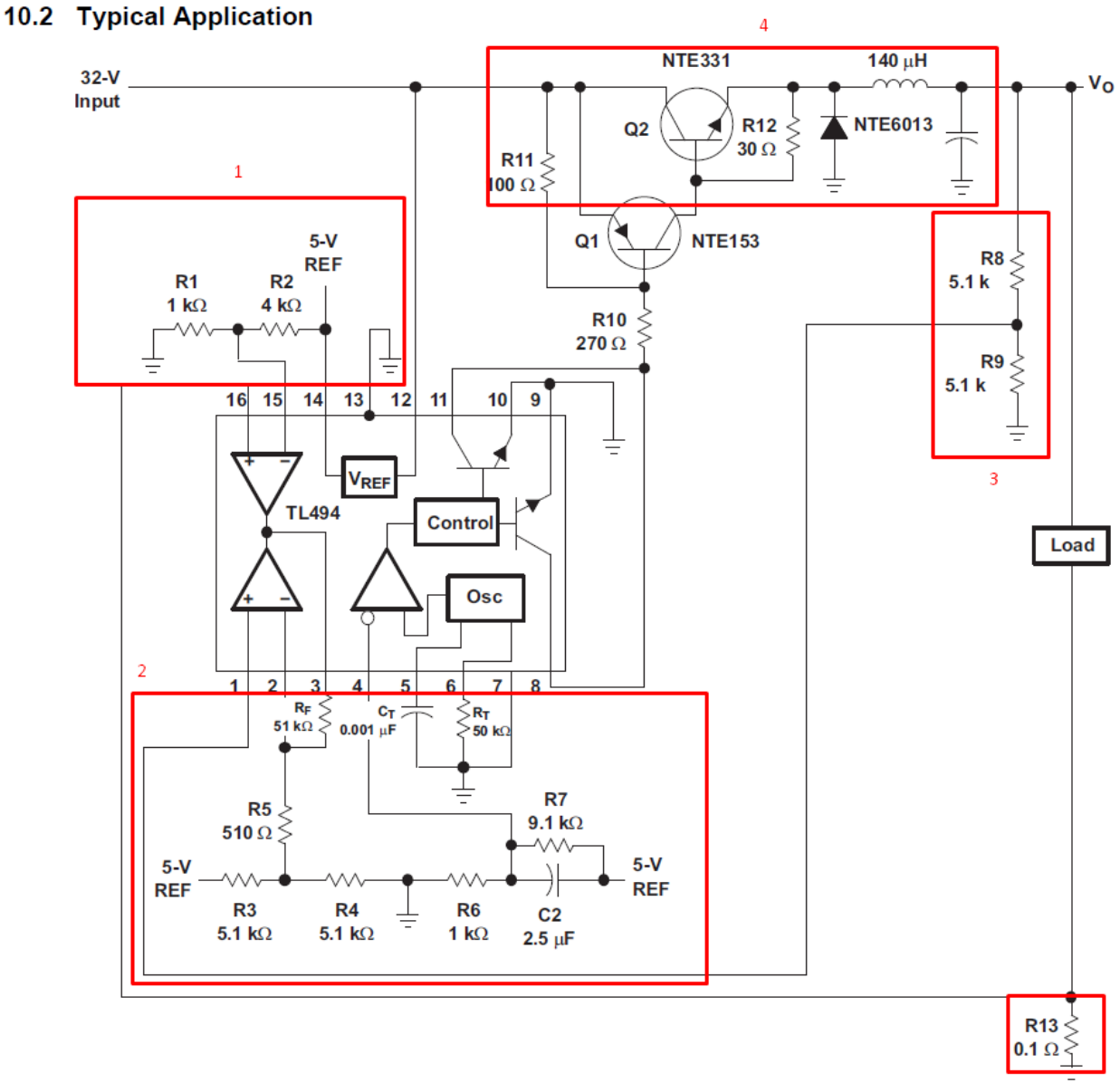
목차

BUCK CONVERTER 12V 1A

1) TL494 소자 값 구하기 및 회로도 연결



왼쪽 사진에 보이는 1, 2, 3, 4 번의 소자 선정을 위해

TL494의 데이터시트를 보고

12V_1A BUCK에 필요한 소자의 용량을 계산해보자.

1) TL494 소자 값 구하기 및 회로도 연결

4.2.4 Fail-Safe Operation

With the modulation scheme employed by the TL494 and the structure of the oscillator, the TL494 inherently turns off if either timing component fails. If timing resistor R_T opens, no current is provided by the oscillator to charge C_T. The addition of a bleeder resistor (see Figure 22) ensures the discharge of C_T. With the C_T input at ground, or if C_T short circuits, both outputs are inhibited.

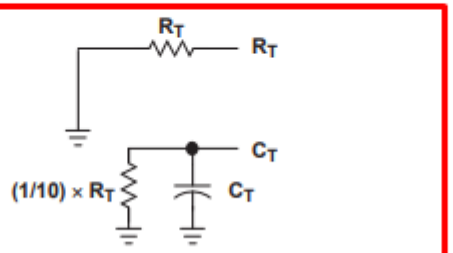


Figure 22. Fail-Safe Protection

TL494는 선천적으로 타이밍 소자가 망가지면 꺼지기 때문에

Bleeder resistor 용도로 $\frac{1}{10} \times R_t$을 캐패시터 에 병렬로 달아두면

이 부분의 회로가 쇼트가 나더라도 캐패시터의 방전을 보호를 할 수 있다.

1) TL494 소자 값 구하기 및 회로도 연결

4.3 *Error-Amplifier-Bias Configuration*

The design of the TL494 employs both amplifiers in a noninverting configuration. Figure 23 shows the proper bias circuits for negative and positive output voltages. The gain control circuits, shown in Figure 11, can be integrated into the bias circuits.

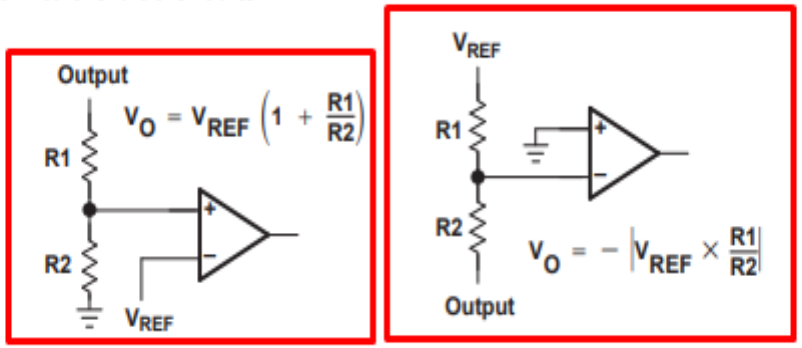


Figure 23. Error-Amplifier-Bias Configurations

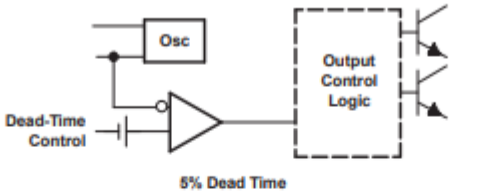
게인 값을 이용하여

설정한 출력 전압이 제대로 나오는지 확인하는 에러 증폭기

1) TL494 소자 값 구하기 및 회로도 연결

4.5 *Applications of the Dead-Time Control*

The primary function of the dead-time control is to control the minimum off time of the output of the TL494. The dead-time control input provides control from 5% to 100% dead time (see Figure 28).



5% Dead Time

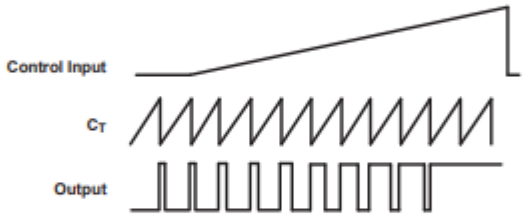


Figure 28. Dead-Time Control Characteristics

Therefore, the TL494 can be tailored to the specific power transistor switches that are used to ensure that the output transistors never experience a common on time. The bias circuit for the basic function is shown in Figure 29. The dead-time control can be used for many other control signals.

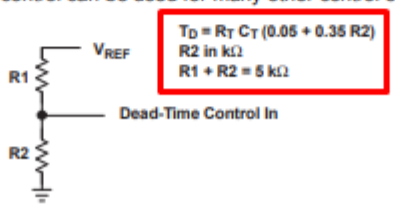
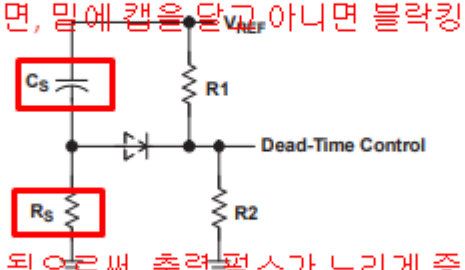


Figure 29. Tailored Dead Time

4.5.1 Soft Start

With the availability of the dead-time control, input implementation of a soft-start circuit is relatively simple; Figure 30 shows one example. Initially, capacitor C_S forces the dead-time control input to follow the 5-V reference regulator that disables both outputs, i.e., 100% dead time. As the capacitor charges through R_S, the output pulse slowly increases until the control loop takes command. If additional control is to be introduced at this input, a blocking diode should be used to isolate the soft-start circuit. If soft start is desired in conjunction with a tailored dead time, the circuit in Figure 29 can be used with the addition of capacitor C_S across R1.

소프트 스타트를 하고 싶다면, 밑에 캡을 달고 아니면 블락킹 다이오드를 달아줘야 한다.



이 저항을 통해 캡이 충전됨으로써, 출력펄스가 느리게 증가된다.

Figure 30. Soft-Start Circuit

The use of a blocking diode for soft-start protection is recommended. Not only does such circuitry prevent large current surges during power up, it also protects against any false signals that might be created by the control circuit as power is applied.

1) TL494 소자 값 구하기 및 회로도 연결

5.2.1 Oscillator

Connecting an external capacitor and resistor to pins 5 and 6 controls the TL494 oscillator frequency. The oscillator is set to operate at 20 kHz, using the component values calculated by Equation 8 and Equation 9:

$$f_{OSC} = \frac{1}{R_T \times C_T} \quad (8)$$

Choose C_T = 0.001 µF and calculate R_T:

$$R_T = \frac{1}{f_{OSC} \times C_T} = \frac{1}{(20 \times 10^3) \times (0.001 \times 10^{-6})} = 50\ k\Omega \quad (9)$$

$$f_{osc} = \frac{1}{R_T \times C_T}$$

$$C_T = 0.001uF$$

$$R_T = \frac{1}{100 \times 10^3 \times (0.001 \times 10^{-6})} = 10k\Omega$$

$$f_{osc} = 100kHz,\ R_T = 10k,\ C_T = 0.001uF$$

1) TL494 소자 값 구하기 및 회로도 연결

5.2.4 Soft Start and Dead Time

To reduce stress on the switching transistors at start-up, the start-up surge that occurs as the output filter capacitor charges must be reduced. The availability of the dead-time control makes implementation of a soft-start circuit relatively simple (see Figure 38).

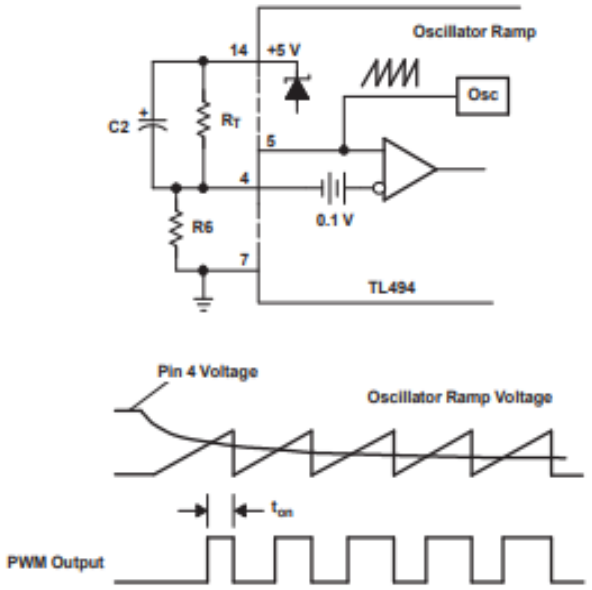


Figure 38. Soft-Start Circuit

The soft-start circuit allows the pulse width at the output to increase slowly (see Figure 38) by applying a negative slope waveform to the dead-time control input (pin 4).

Initially, capacitor C2 forces the dead-time control input to follow the 5-V regulator, which disables the outputs (100% dead time). As the capacitor charges through R6, the output pulse width slowly increases until the control loop takes command. With a resistor ratio of 1:10 for R6 and R7, the voltage at pin 4 after start-up is 0.1 × 5 V, or 0.5 V.

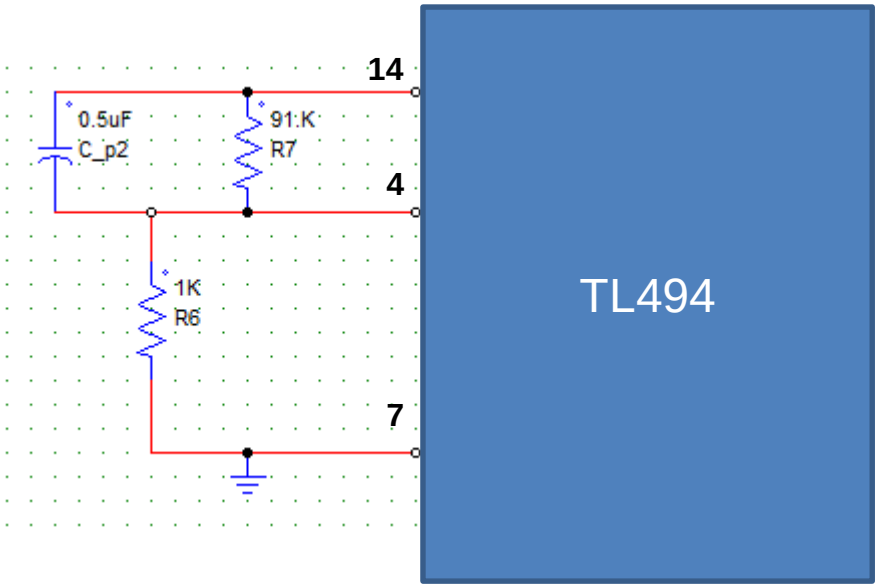
The soft-start time generally is in the range of 25 to 100 clock cycles. If 50 clock cycles at a 20-kHz switching rate is selected, the soft-start time is:

$$t = \frac{1}{f} = \frac{1}{20\ \text{kHz}} = 50\ \mu\text{s per clock cycle} \quad (12)$$

The value of the capacitor then is determined by:

$$C2 = \frac{\text{soft-start time}}{R6} = \frac{50\ \mu\text{s} \times 50\ \text{cycles}}{1\ \text{k}\Omega} = 2.5\ \mu\text{F} \quad (13)$$

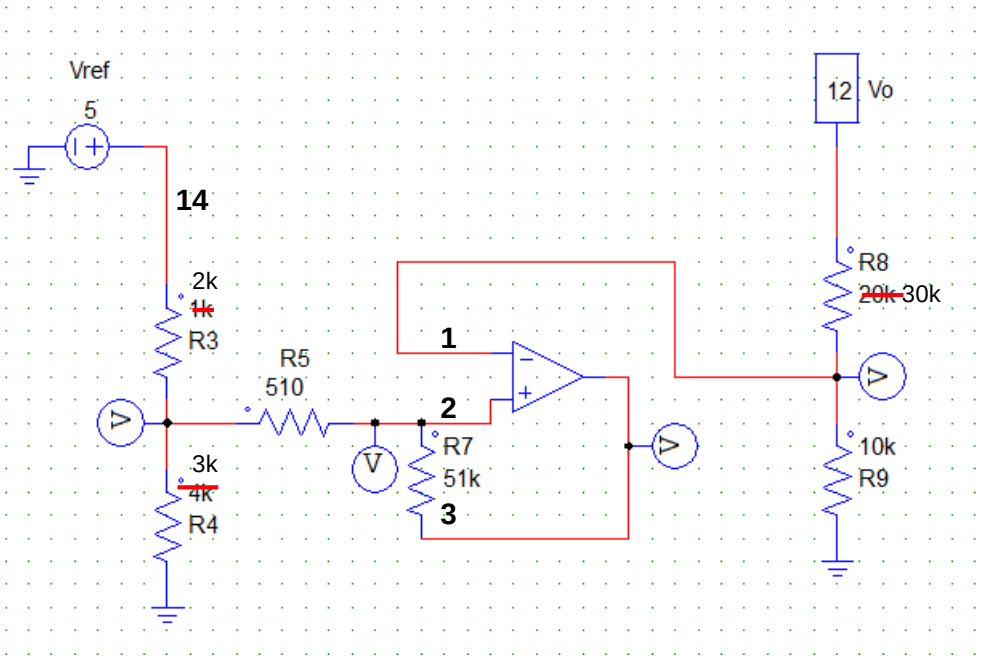
This helps eliminate any false signals that might be created by the control circuit as power is applied.

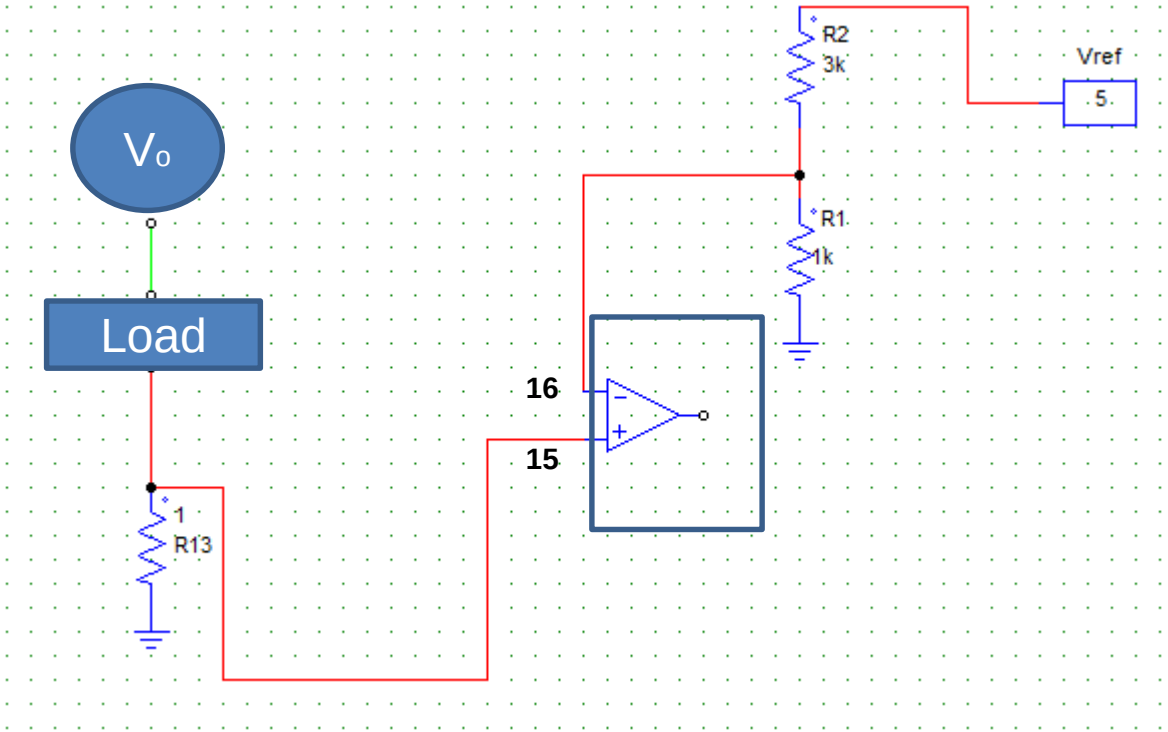


$$t = \frac{1}{f} = \frac{1}{100kHZ} = 0.00001$$

$$C2 = \frac{soft\text{-}start\ time}{R} = \frac{0.00001 \times 50\ cycles}{1K\Omega} = 0.5\text{uF}$$

1) TL494 소자 값 구하기 및 회로도 연결





$$R_{13} = \frac{1V}{1A} = 1\Omega$$

2) 수식으로 구해본 L과 C

7. CCM Buck converter : Design

- Specifications
  - V_{in}:24V
  - V_o=5V (output voltage ripple (ROV) V_{o_ripple}/V_o=+-2%)
  - I_o=10A (Ripple ratio (ROA) =20%)
  - Switching frequency fsw=50kHz(=20usec)

1. Determining Max Duty Ratio
   - From $V_o=DV_{in}$, D=5/24=0.2083

2. Determining L_o:
   - $i_{Lo\_ripple}= I_o \cdot ROA \rightarrow I_{o\_ripple}= I_o \cdot 0.2 =2(A)$
   - $(1-D)T_sV_o/L_o= I_{o\_ripple} \rightarrow L_o= (1- 0.2083)x20x10^{-6}x5/2=39.58(uH)$

3. Determining C_o:
   - From spec., $V_{o\_ripple}=V_o x4\% \rightarrow V_{o\_ripple}=5x0.04=0.2(V)$
   - From $V_{o\_ripple} = \frac{T_s^2}{8L_oC_o}V_o(1-D)$, $C_o = \frac{T_s^2}{8L_oV_{o\_ripple}}V_o(1-D)$
   - $C_o=(20x10^{-6})^2x(24x\ 0.2083\ ^2-2x5x\ 0.2083\ +5)/(8x39.58x10^{-6}x0.2)=25(uF)$

BUCK (Step Down)

The Transfer Function of a Buck Converter:

$(V_{OUT}+V_F)/(V_{IN}-V_{RDSon}) = D$

Requirements:	Fill in shaded regions:		
The output voltage of the converter:	V_{OUT} =	12	V
The input voltage of the converter:	V_{IN} =	22.2	V
The nominal output current:	I_{OUT} =	1	A
Output power of the converter:	P_{OUT} =	12	W
The minimum output current:	I_{OUTMIN} =	0.1	A, assumed to be 10% of I_{OUT}
The switching frequency of the converter:	f_{SW} =	100	kHz
Maximum allowable peak-to-peak ripple:	V_{pp_ripple}=	0.12	V, assumed to be 1% of V_{OUT}
Forward voltage drop across diode:	V_F =	0.25	V
R_{DSon} of switch at operating point:	R_{DSon} =	0.1	Ω
Voltage drop across R_{DSon}:	V_{RDSon} =	0.1	V
Conduction losses of switch:	P_{COND} =	0.056	W
Duty Cycle:	D =	0.554	
Switching Period:	T =	10	µs
On-time of the switch:	t_{ON} =	5.543	µs

2) 수식으로 구해본 L과 C

The minimum inductor value is calculated assuming the minimum output current is equal to 10% of the nominal current. The inductor is sized such that the converter will remain in the continuous current mode through this range.

Minimum inductor value:	L =	279.92	µH
Inductor stored energy:	E =	169.35	µJ

The drain current waveform is a ramp on a step. The value of the current at the center of the ramp is equal to the output DC current. The peak inductor current is equal to the output current added to half the peak to peak ripple.

Peak-to-peak ripple current:	$I_{ppRIPPLE}$ =	0.2	A
Peak switch current:	I_{PEAK} =	1.1	A
RMS current:	I_{RMS} =	0.746	A

A Schottky rectifier is chosen because of its low forward voltage, V_F, and its excellent reverse recovery characteristics. Replacing this diode with a FET and using synchronous rectification will give even more efficiency benefits. This rectifier must meet the following criteria:

DC blocking voltage:	V_R =	22.2	V
Average rectified output current:	I_{AVE} =	0.446	A

The switch must be selected to meet the above current requirements. The major Drain to Source voltage stress occurs at switch turn-off when the Source could possibly ring up to 5V below ground.

Minimum rated Drain to Source voltage:	V_{DS} =	27.45	V

The output capacitor is chosen such that it provides significant filtering of the switching ripple. The selected capacitor must be large enough so that its impedance is much smaller than the load at the switching frequency, allowing most of the ripple current to flow through the capacitor, not the load. The ripple current flowing through the output capacitor is equal to the inductor current waveform with the dc component removed. The output capacitor's ESR must also be taken into account because this parasitic resistance, which is out of phase with its capacitance, will cause additional voltage ripple. Be sure to select capacitors based upon their maximum ripple current and ESR ratings at the temperature and frequency of the application.

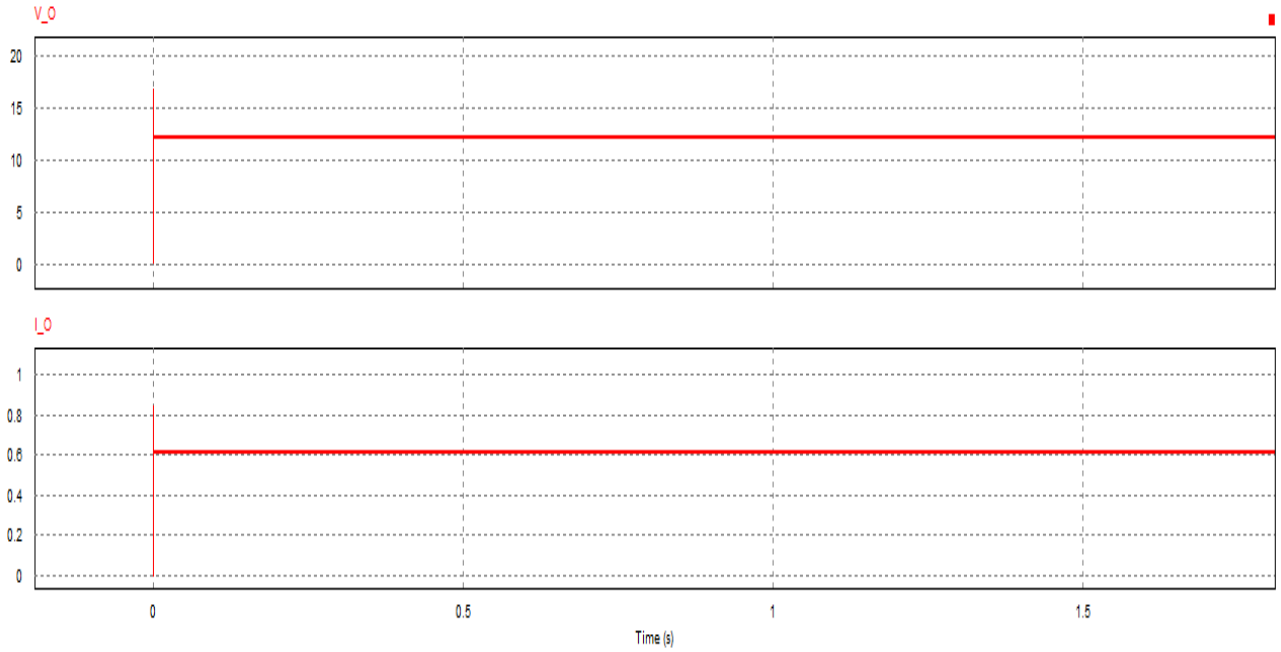
Output capacitor RMS ripple current:	I_{RMScap} =	0.058	A
Minimum output capacitance:	C_{OUT} =	2.08	µF
Chances are, a bank of capacitors will be required to handle the output ripple current. This capacitance will have an ESR associated with it:			
Total capacitance of output bank used:	$C_{OUTbank}$ =	82	µF
Maximum ESR required:	ESR_{MAX} =	0.5998	Ω
Actual ESR of output capacitor bank used:	ESR =	0.015	Ω

수식을 바탕으로 직접 계산해서 얻음 인덕터와 캐패시퍼의 값

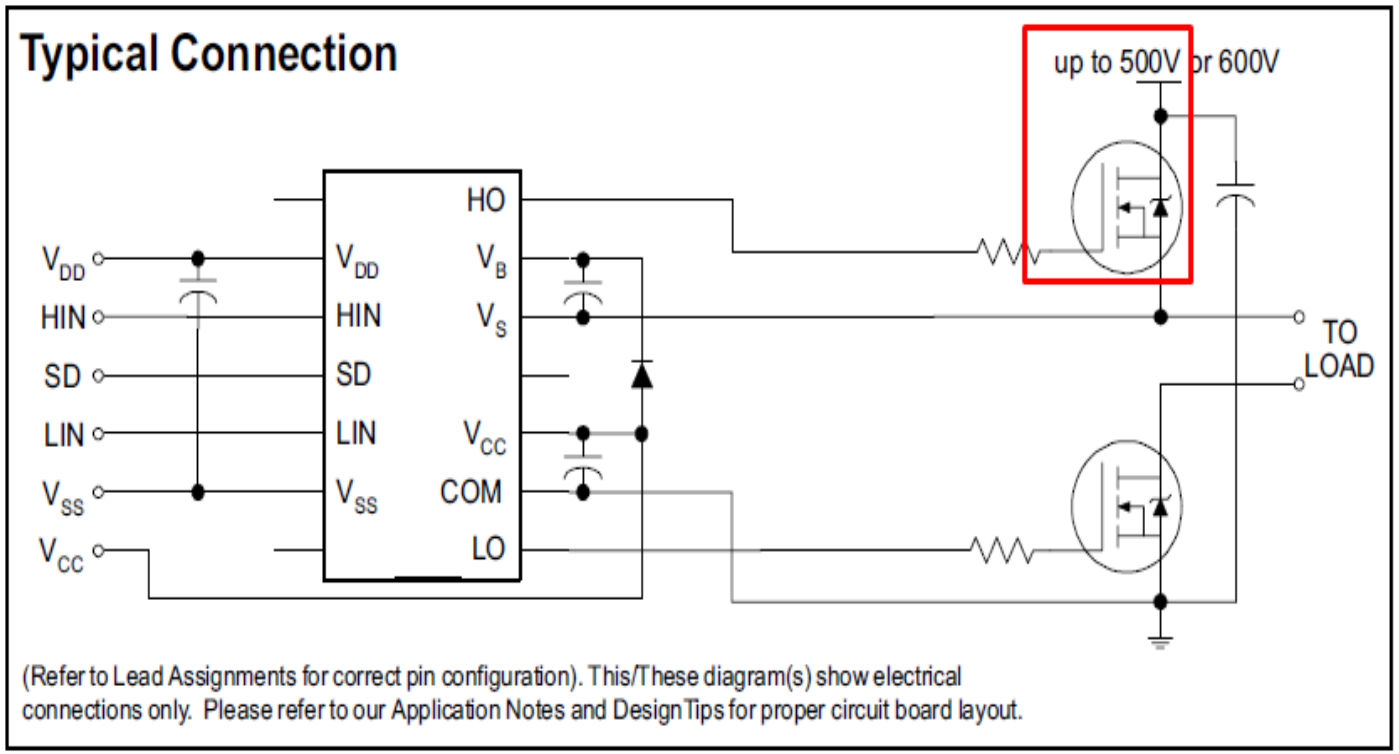
$$L_o = \frac{10^{-5} \times 12 \times (1-0.540540)}{0.2} = 275.676uH$$

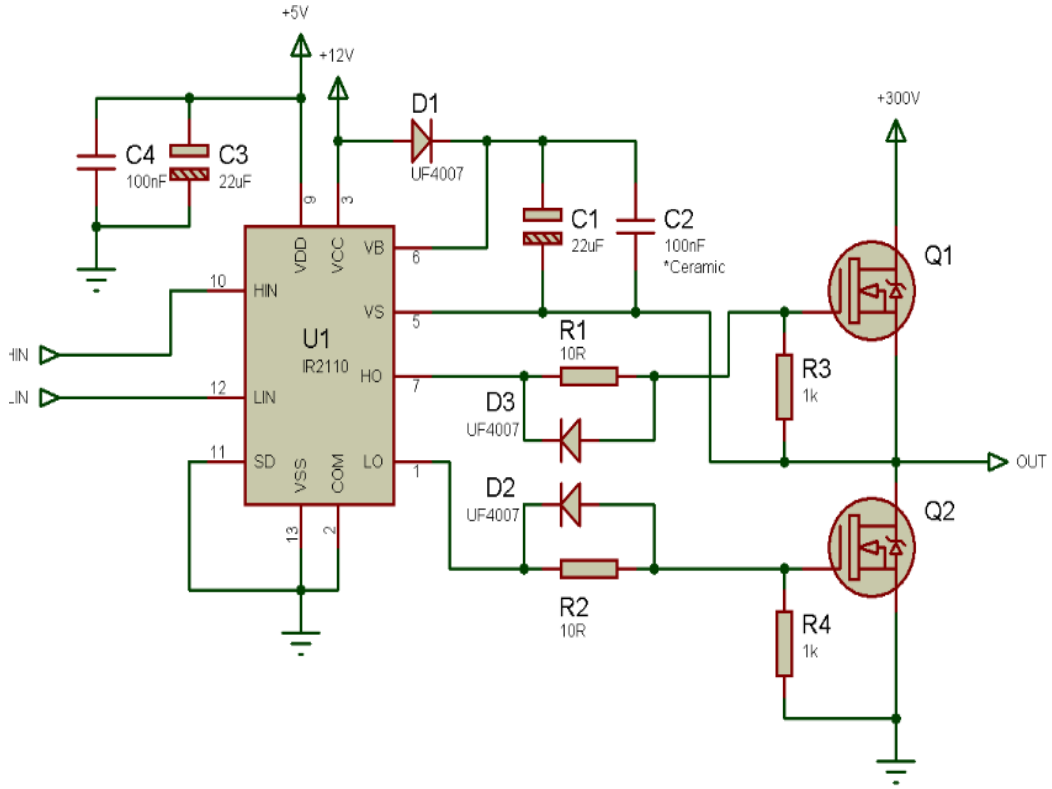
$$C_o = \frac{(10^{-5})^2 \times 22.2 \times (1-0.540540)}{8 \times 275.676 \times 10^{-6} \times 0.24} = 1.85uF$$

Psim simulation 을 통해서 간단히 검증해본 결과물

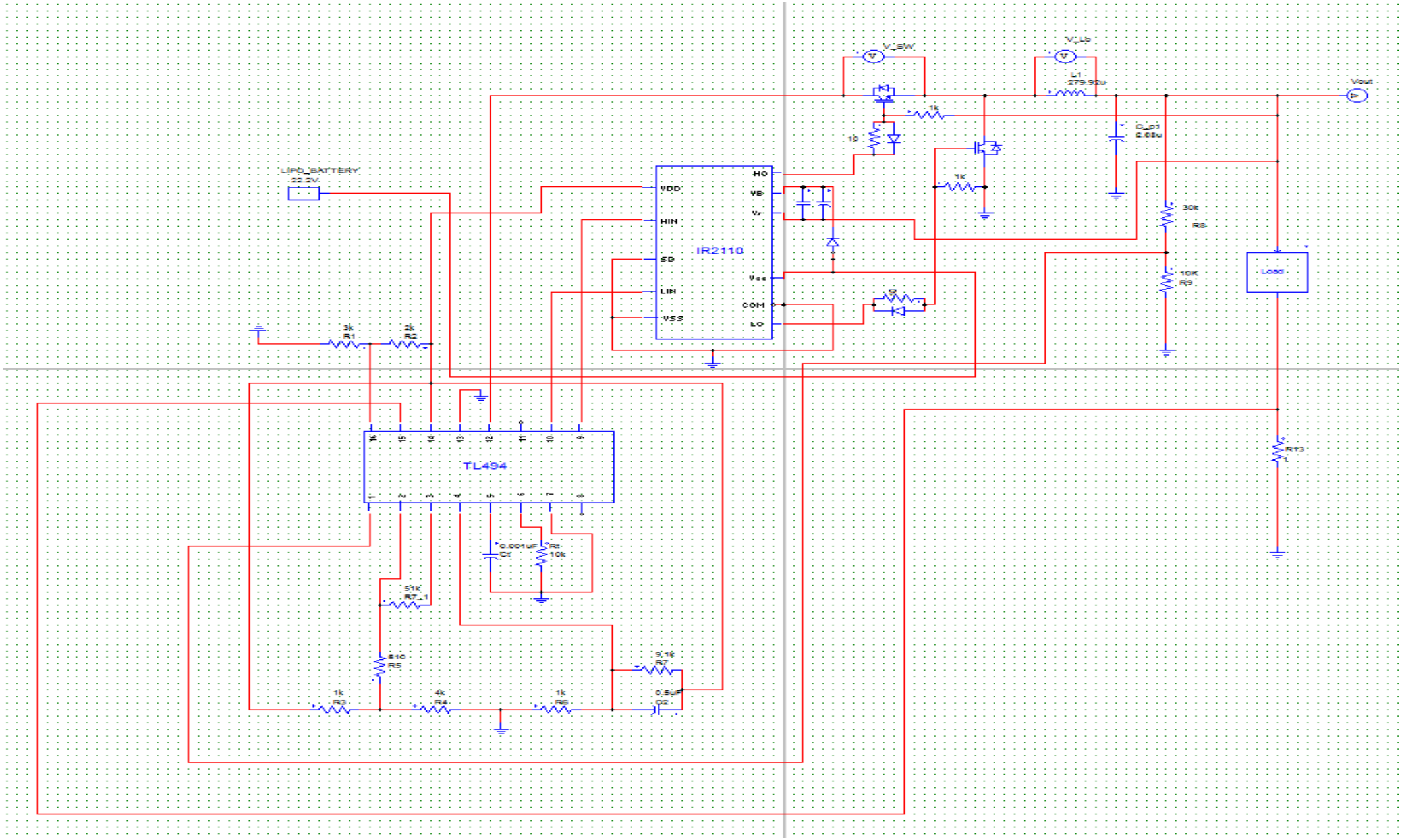


3) IR2110 회로도 연결





4) BUCK 최종 회로도 연결 모델



5) 소자 선정 팁

4. Calculating voltage and current stresses of Semiconductors
   - MOSFET switch:
     1. Voltage stress: 24(V)
     2. Current stress: $I_o+0.5I_{o\_ripple}=10+1=11$(A)
   - Diode:
     1. Voltage stress: 24(V)
     2. Current stress:$I_o+0.5I_{o\_ripple}=10+1=11$(A)
5. Selecting MOSFET and Diode
   - Voltage ratings of MOSFET and Diode: **50~100% Margin**
     1. Voltage rating: (max voltage stress)x2 → over 48(V)
   - Current ratings of MOSFET and Diode: **100% Margin**
     1. Current rating: (max current stress)x2 → over 22 (A)

     → MOSFET: STD30NF06 (60V, 28A, Coss=290pF, Rds=0.020hm)
     → Diode: MBR3050PT (50V, 30A, VF=0.75V)
   - Related Web site:
     1. www.irf.com
     2. www.fairchildsemi.com
     3. www.st.com
     4. www.alldatasheet.com