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**Abstract**—This manual provides the design of a DC-DC Buck-Converter.

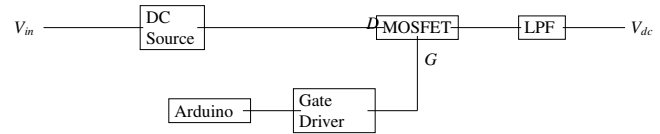


Fig. 1: Block Diagram

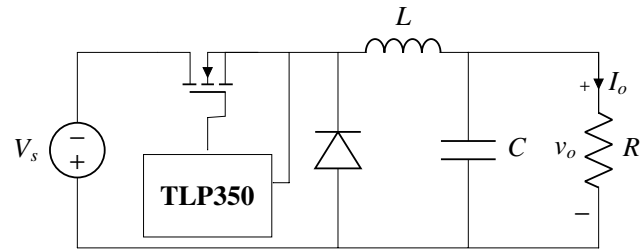


Fig. 2: DC-DC buck converter

## 1 COMPONENTS

Component	Value	Quantity
Arduino Uno		1
Inductor	5 mH	1
Capacitor	10 uF	1
n-MOS	IRF 540	1
Jumper Wires	M-M	20
Diode		1
Gate Driver	TLP350	1

TABLE I

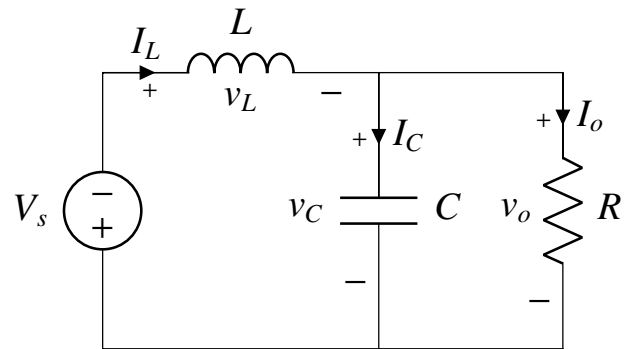


Fig. 3: Switch in ON state

## Solution:

$$V_L(ON) = V_s - V_o$$

$$I_C(ON) = I_L - I_o$$

The buck converter block diagram and circuit are shown in Figs. 1 and 2 respectively.

**Problem 2.1.** When the switch is ON, the circuit diagram is shown in Fig. 3. Express the voltage across inductor in terms of  $V_s$  and  $V_o$  and current passing through the capacitor in terms of  $I_L$  and  $I_o$  when switch is ON.

**Problem 2.2.** When the switch is OFF, the circuit diagram is shown in Fig. 4. Express the voltage across inductor in terms of  $V_s$  and  $V_o$  and current

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passing through the capacitor in terms of  $I_L$  and  $I_o$  when switch is OFF.

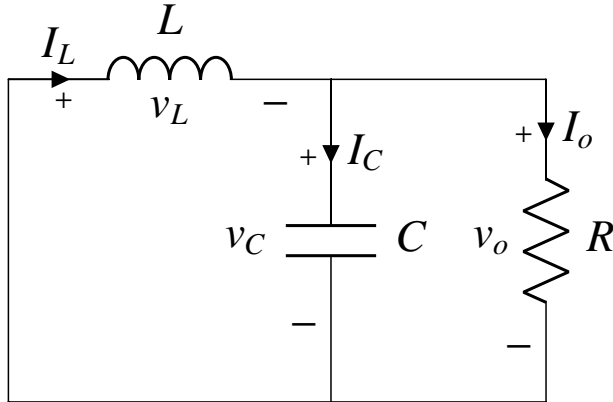


Fig. 4: Switch in OFF state

**Solution:**

$$V_L(OFF) + V_o = 0$$

$$V_L(OFF) = -V_o$$

$$I_C(OFF) = I_L - I_o$$

**Problem 2.3.** Find  $V_o$  and  $I_o$ .

**Solution:** From Volt-sec Balance

$$V_L(ON)T_{ON} + V_L(OFF)T_{OFF} = 0$$

$$(V_s - V_o)DT - V_o(1 - D)T = 0$$

$$V_o = DV_s$$

Where D is Duty cycle. From Amp-sec Balance,

$$(I_L - I_o)DT + (I_L - I_o)(1 - D)T = 0$$

$$I_o = I_L$$

**Problem 2.4.** Express L in terms of D,  $V_o$ ,  $f = \frac{1}{T}$  and  $\Delta I_L$  where  $\Delta I_L$  is Ripple in the inductor current i.e maximum change in the inductor current from ON state to OFF state .

**Solution:**

$$V_L(ON) = V_s - V_o$$

$$L \frac{di_{ON}}{dt_{ON}} = V_s - V_o$$

$$L \frac{\Delta I_L}{DT} = V_s - DV_s$$

$$L = \frac{D(1 - D)V_s}{\Delta I_L f}$$

$$L = \frac{(1 - D)V_o}{f \Delta I_L} \quad (2.4.1)$$

Where  $\Delta I_L$  is Ripple in the inductor current i.e maximum change in the inductor current from ON state to OFF state .

**Problem 2.5.** Express C in terms of L, D,  $\Delta V_o$  and  $f = \frac{1}{T}$ .

**Solution:** Charge on the capacitor

$$Q = CV_C$$

$$\Delta Q = C \Delta V_C = C \Delta V_o$$

$\Delta Q$  = Area under the capacitor current will

$$\Delta Q = \frac{1}{2} \frac{\Delta I_L T}{2} = \frac{\Delta I_L}{8f}$$

$$C = \frac{\Delta I_L}{8f \Delta V_o} \quad (2.5.1)$$

**Problem 2.6.** Assume,

Input Voltage ( $V_s$ ) = 10V

Output Voltage ( $V_o$ ) = 5V

$\Delta I_L$  = 11% of  $I_L$

$\Delta V_o$  = 6% of  $V_o$

Let  $R = 5\Omega$  (for  $I_o = 1A$ )

Calculate L and C.

**Problem 2.7.** Connect the circuit as per the Fig. 2 and measure  $I_o$  and  $V_o$ .

### 3 CIRCUIT ASSEMBLY

**Problem 3.1.** Assemble the Buck converter circuit according to Figs. 2, 5 and Table II.

TLP350	1	2	3	4	5	6	7	8
ARDUINO	NA	13	GND	NA			NA	
					-5 V	10 $\Omega$		12 V
MOSFET					S	G		

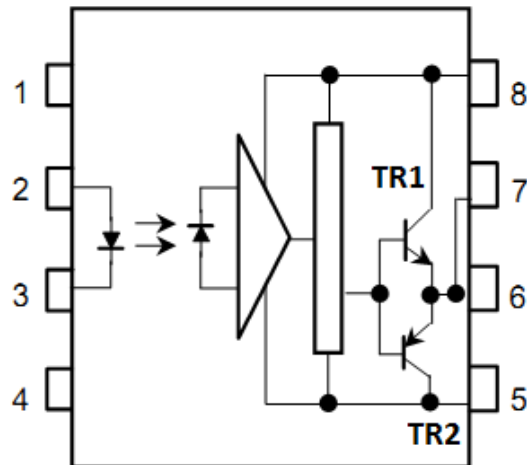
TABLE II: Pin Connections

**Problem 3.2.** Program the arduino to generate a square wave with Duty Cycle  $D = 0.5$  and frequency  $f = 5KHz$ .

**Solution:**

```
void setup() {
    pinMode(13, OUTPUT);
}
```

## Pin Configuration



- 1 : N.C.
- 2 : Anode
- 3 : Cathode
- 4 : N.C.
- 5 : GND
- 6 :  $V_O$  (Output)
- 7 :  $V_O$
- 8 :  $V_{CC}$

Fig. 5: TLP350

```
void loop() {
  digitalWrite(13,LOW);
  delayMicroseconds(10);
  digitalWrite(13,HIGH);
  delayMicroseconds(10);
}
```

### 4 FOURIER SERIES ANALYSIS OF BUCK-CONVERTER

**Problem 4.1.** Observe the output of the Source pin of the n-MOS on oscilloscope and write the python script to generate the same.

**Solution:** The output is shown in Fig. 6

```
import numpy as np
import matplotlib.pyplot as plt
from scipy import signal
A = 10 # wave amplitude
```

```
T = 0.2 # wave period

t = np.linspace(-2.5*T,2.5*T,int(1
e4))

plt.plot(t,A/2 *(1+signal.square
(2*np.pi*t/T,0.5)))

plt.ylim(-1,12)
plt.grid()
plt.xlabel('$t(msec)$')
plt.ylabel('$X(t)$')
plt.savefig('square.eps')
plt.show()
```

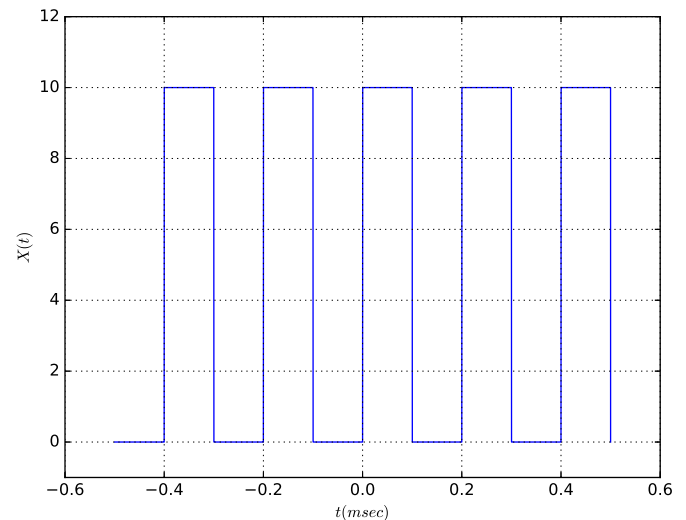


Fig. 6: Square Pulse

**Problem 4.2.** Show that the voltage across the diode in Fig. 2 is

$$V_D(t) = \begin{cases} \sum_{n=1}^{\infty} \frac{10}{n\pi} \sin(2\pi f t) & n \text{ odd} \\ 5 & n = 0 \\ 0 & n \text{ even} \end{cases} \quad (4.2.1)$$

**Problem 4.3.** Compute and sketch the frequency response for the L-C-R part of Fig. 2 shown in Fig. 7 for  $R = 5\Omega$  and L and C calculated using equation (2.4.1) and equation (2.5.1). What kind of filter is it?

**Problem 4.4.** Calculate the cut-off frequency for the filter in Fig. 7.

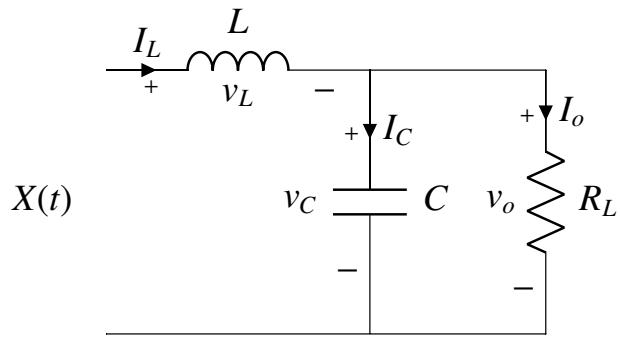


Fig. 7: Filter

**Problem 4.5.** Find  $V_o$ .