DC-DC Converter

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Contents

***Abstract*—This manual provides the design of a 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

2 Circuit Operation

The buck converter circuit is shown in Fig. 1.

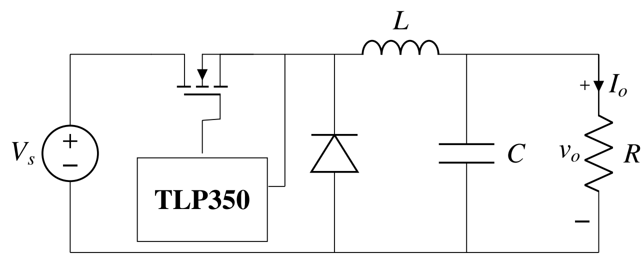

Fig. 1: DC-DC buck converter

Problem 2.1. When the switch is ON, the circuit diagram is shown in Fig. 2. Express the voltage across inductor interms of V_s and V_o and current passing through the capacitor interms of I_L and I_o when swich is ON.

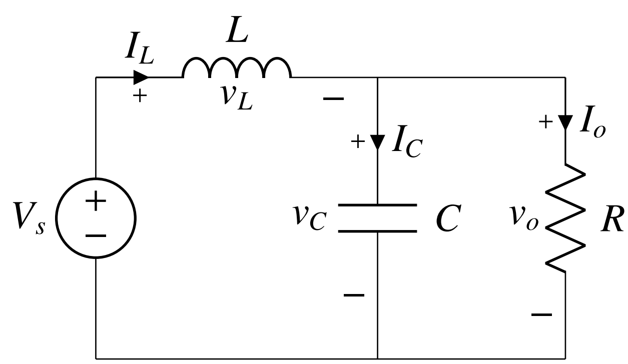

Fig. 2: Switch in ON state

Solution:

$$V_L(ON) = V_s - V_o$$
$$I_C(ON) = I_L - I_o$$

Problem 2.2. When the switch is OFF, the circuit diagram is shown in Fig. 3. Express the voltage across inductor interms of V_s and V_o and current passing through the capacitor interms of I_L and I_o when swich is OFF.

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.

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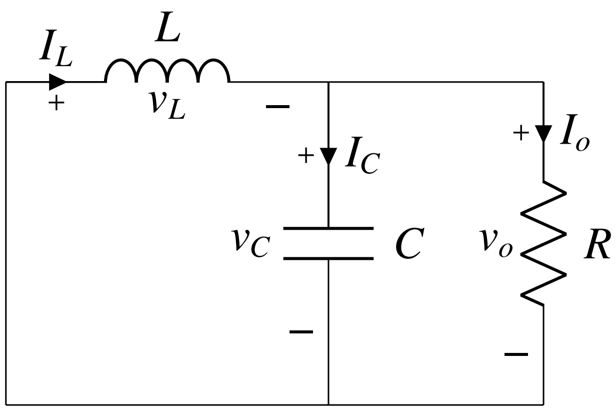

Fig. 3: Switch in OFF state

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 interms of D,V_o , $f = \frac{1}{T}$ and ΔI_L where ΔI_L is Ripple in the inductor current i.e maximum change in the inductor current from ON state to OFF state .

Solution:

$$V_L(ON) = V_s - V_o$$
$$L\frac{di_{ON}}{dt_{ON}} = V_s - V_o$$
$$L\frac{\Delta I_L}{DT} = V_s - DV_s$$
$$L = \frac{D(1 - D)V_s}{\Delta I_L f}$$
$$L = \frac{(1 - D)V_o}{f\Delta I_L} \tag{2.4.1}$$

Where ΔI_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 interms of L,D,ΔV_o and $f = \frac{1}{T}$.

Solution: Charge on the capacitor

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

ΔQ =Area under the capacitor current will

$$\Delta Q = \frac{1}{2}\frac{\Delta I_L}{2}\frac{T}{2} = \frac{\Delta I_L}{8f}$$
$$C = \frac{\Delta I_L}{8f\Delta V_o} \tag{2.5.1}$$

Problem 2.6. Assume,
Input Voltage (V_s) = $10V$
Output Voltage (V_o) = $5V$
ΔI_L = 11% of I_L
ΔV_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. 1 and measure I_o and V_o.

3 Circuit Assembly

Problem 3.1. Assemble the Buck converter circuit according to Figs. 1, 4 and Table II.

TLP350	1	2	3	4	5	6	7	8
ARDUINO	NA	13	GND	NA			NA	
					GND			15V
						22 Ω		

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);

}

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

}
```

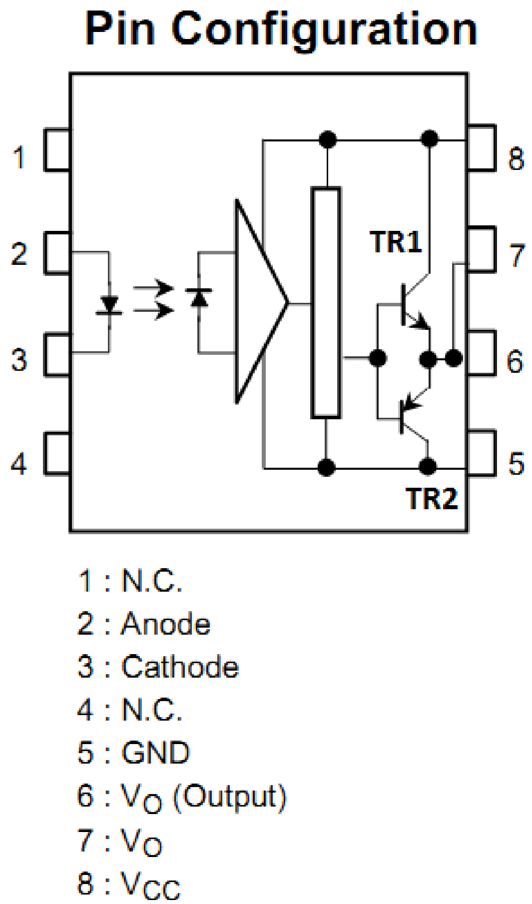

Fig. 4: TLP350

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. 5

```
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()
```

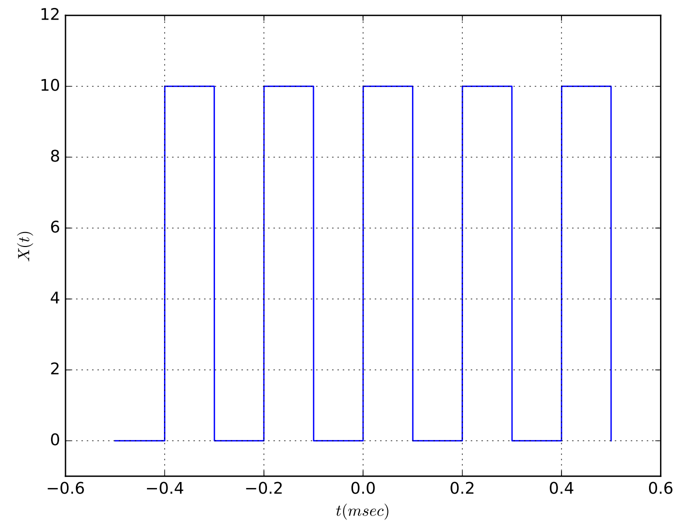

Fig. 5: Square Pulse

Problem 4.2. Show that the voltage across the diode in Fig. 1 is

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

Problem 4.3. Compute and sketch the frequency response for the L-C-R part of Fig. 1 shown in Fig. 6 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. 6.

Problem 4.5. Find V_o.

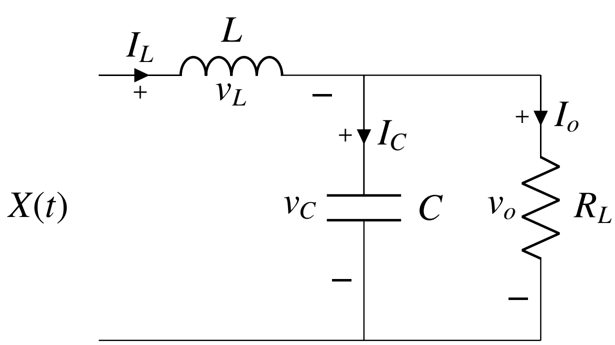

Fig. 6: Filter