# 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 block diagram and circuit are shown in Figs. 1 and 2 respectively.

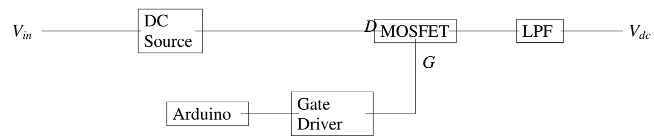


Fig. 1: Block Diagram

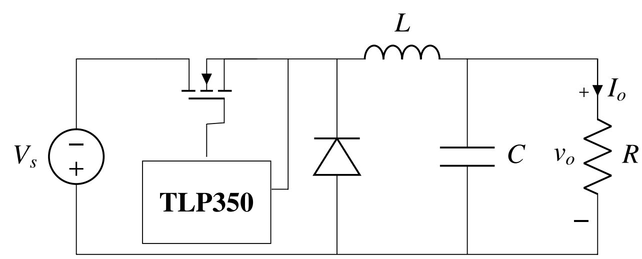


Fig. 2: DC-DC buck converter

**Problem 2.1.** When the switch is ON, 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 ON.

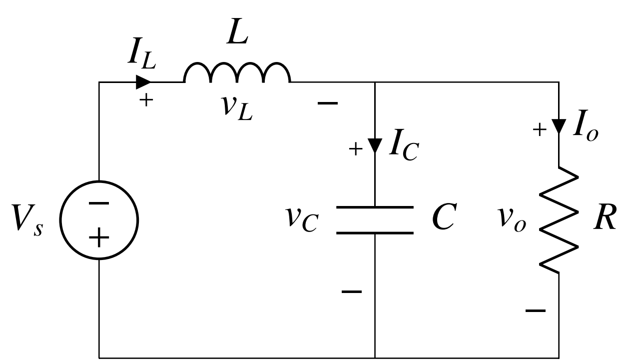


Fig. 3: Switch in ON state

**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. 4. Express the voltage across inductor interms of $V_s$ and $V_o$ and current

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passing through the capacitor interms of $I_L$ and $I_o$ when swich is OFF.

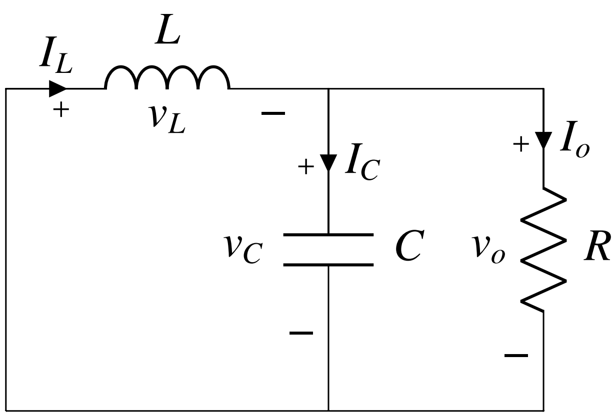


Fig. 4: Switch in OFF state

**Solution:**

$$
\begin{aligned}
V_L(OFF) + V_o &= 0 \\
V_L(OFF) &= -V_o \\
I_C(OFF) &= I_L - I_o
\end{aligned}
$$

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

**Solution:** From Volt-sec Balance

$$
\begin{aligned}
V_L(ON)T_{ON} + V_L(OFF)T_{OFF} &= 0 \\
(V_s - V_o)DT - V_o(1-D)T &= 0 \\
V_o &= DV_s
\end{aligned}
$$

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

$$
\begin{aligned}
(I_L - I_o)DT + (I_L - I_o)(1-D)T &= 0 \\
I_o &= I_L
\end{aligned}
$$

**Problem 2.4.** Express L interms 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:**

$$
\begin{aligned}
V_L(ON) &= V_s - V_o \\
L\frac{di_{ON}}{dt_{ON}} &= V_s - V_o \\
L\frac{\Delta I_L}{DT} &= V_s - DV_s \\
L &= \frac{D(1-D)V_s}{\Delta I_L f}
\end{aligned}
$$

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

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 interms of L,D,$\Delta V_o$ and $f = \frac{1}{T}$.

**Solution:** Charge on the capacitor

$$
\begin{aligned}
Q &= CV_C \\
\Delta Q &= C\Delta V_C = C\Delta V_o
\end{aligned}
$$

$\Delta Q$ =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 ($V_o$) = $5V$
$\Delta I_L = 11\%$ 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 Ω | | 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);

}
```

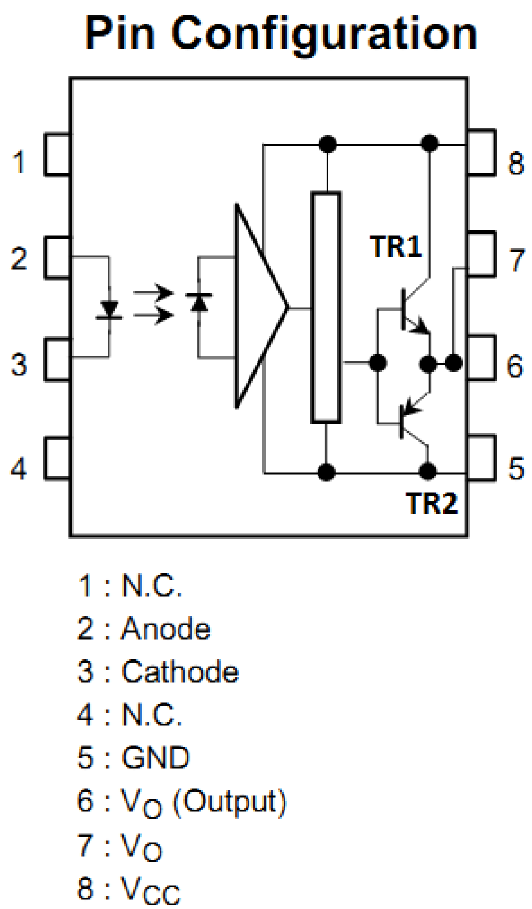


Fig. 5: TLP350

```
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()
```

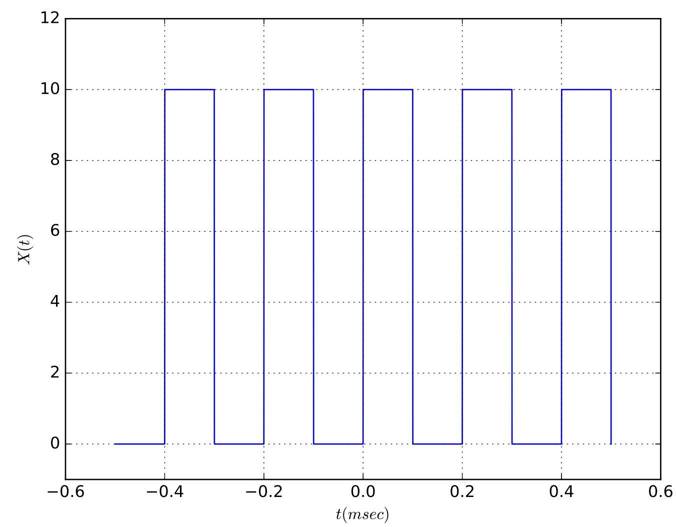


Fig. 6: Square Pulse

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

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

**Problem 4.3.** Compute and sketch the frequency response for the L-C-R part of Fig. 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.

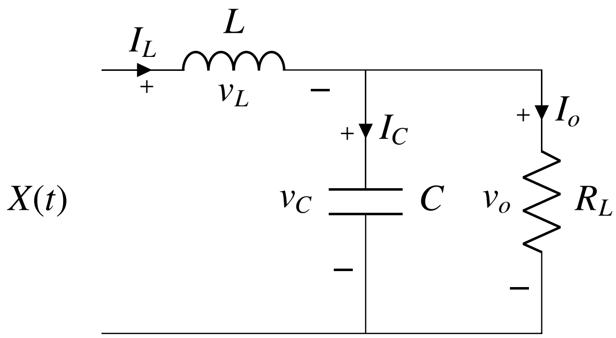


Fig. 7: Filter

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

**Problem 4.6.** Explain your results through a Python script.