Review: In last lecture, we talked about AC power and how to transform AC to DC signal.

\[
\begin{align*}
&\Rightarrow \text{Transformer} \Rightarrow \text{Full-wave rectifier} \Rightarrow \text{Capacitor} \Rightarrow \\
&\Rightarrow \begin{array}{c}
\text{Voltage} \\
+1 \\
-1 \\
\end{array} \Rightarrow \begin{array}{c}
\text{Voltage} \\
\text{Fluctuations} \\
\text{Fluctuations} \\
\end{array} \Rightarrow \\
&\Rightarrow \begin{array}{c}
\text{Voltage} \\
\text{Smooth} \Rightarrow \text{Fluctuations} \\
\text{Smooth} \Rightarrow \\
\end{array}
\end{align*}
\]

The output is still not DC, because there are fluctuations.

In fact, such variation also occurs for a DC source like a battery.

In this lecture, we first talk about DC power and then see how we can remove the "fluctuations" to get an ideal DC signal.

1. DC Voltage Source (A battery).

   1) Ideal Case: \( V_s \begin{array}{c}
\Rightarrow \begin{array}{c}
\text{Voltage} \\
\text{Fluctuations} \Rightarrow \text{Fluctuations} \\
\end{array} \Rightarrow I-V \text{ characteristics} \\
\end{array} \)

   2) Real Case: \( V_s \begin{array}{c}
\Rightarrow \begin{array}{c}
\text{Voltage} \\
\text{Fluctuations} \Rightarrow \text{Fluctuations} \\
\end{array} \Rightarrow \begin{array}{c}
\text{Voltage} \\
\text{Fluctuations} \Rightarrow \text{Fluctuations} \\
\end{array}
\end{array} \)

   How will the voltage change for different \( I \)?
\[ V_L = V_s - R_s I \]

What is the \( I-V \) characteristics?

Obviously, it is a line. Now, if \( V_L = 0 \) \( \Rightarrow \) \( I = \frac{V_s}{R_s} \)

if \( I = 0 \) \( \Rightarrow \) \( V_L = V_s \)

Here, \( I = \frac{V_s}{R_s} \) \( \Rightarrow \) \( \text{short-circuit current } I_{sc} \)

\[ V_L = V_s \] \( \Rightarrow \) \( \text{open-circuit voltage } V_{oc} \)

Thus,

\[ V_L = V_{oc} \]

2. Power efficiency & Maximum power consumption.

Two questions:

1) What is the maximum power delivered to \( R_L \)?

2) ........ power efficiency?

percentage used by \( R_L \).
Power consumed by \( R_s \) and \( R_L \) respectively.

\[
I = \frac{V_s}{R_s + R_L}
\]

\[
P_s = I^2 R_s = \left( \frac{V_s}{R_s + R_L} \right)^2 R_s
\]

\[
P_L = I^2 R_L = \left( \frac{V_s}{R_s + R_L} \right)^2 R_L
\]

Question 1: \( \text{Max } P_L \)

\[
P_L (R_L) = \left( \frac{V_s}{R_s + R_L} \right)^2 R_L \]

To find the maximum of \( P_L \), we take the derivative of \( P_L \) with respect to \( R_L \).

\[
\frac{dP_L(R_L)}{dR_L} = \frac{d}{dR_L} \left( \frac{V_s^2}{R_s + R_L} \right)^2 R_L = \frac{d}{dR_L} \frac{V_s^2 R_L}{(R_s + R_L)^2} = \frac{V_s^2 (R_s + R_L)^2 - V_s^2 R_L (R_s + R_L)}{(R_s + R_L)^4}
\]

Let \( \frac{dP_L(R_L)}{dR_L} = 0 \) \( \Rightarrow \) \( V_s^2 (R_s + R_L) = V_s^2 R_L 2 (R_s + R_L) \)

\( \Rightarrow R_s + R_L = 2R_L \)

\( \Rightarrow R_L = R_s \)

It is referred to as load match.

\[
\begin{array}{c}
\text{Increasing function of } R_L \\
\end{array}
\]

Question 2: What is the highest efficiency?

\[
\text{Efficiency } \eta = \frac{P_L}{P_s + P_L} = \frac{I^2 R_L}{I^2 R_s + I^2 R_L} = \frac{R_L}{R_s + R_L} = \frac{1}{\frac{R_s}{R_L} + 1}
\]
\[ R_s = R_L \implies \eta = 0.5 \quad \text{Half of the energy wasted on } R_s. \]

In fact, the voltage across \( R_c \), \( \frac{R_c}{R_s + R_c} V_s \), is also an increasing function of \( R_L \).

3) Battery Characteristics

Battery voltage is not a constant (useful!)

How can we stabilize the voltage of a battery?

How can we stabilize the voltage output of the capacitor rectifier?

\[ V(t) \]

\[ t \quad \implies \quad \]

4) Regulator

1) Provide a constant voltage.

2) Provide different voltages for different parts of a system.

\[ 12V \implies \text{Motor} \]

\[ 12V \quad \implies \quad 5V \implies \text{ICs.} \]
1. For this purpose, we need Zener Diode.

Recall the I-V characteristics of a diode.

We use the circled part to build one-directional switch.

\[
\begin{align*}
& V \geq V_{on} \quad + \quad V_{on} = 0.7V \\
& V < V_{on} \quad \rightarrow \quad 0
\end{align*}
\]

On the other side, if \( V < V_{BO} \), the diode will work in the breakdown mode.

In the breakdown region, the diode is also a good conductor with very small resistance. Zener diode is designed to work in the breakdown region.

2. Circuit symbol

\[ V_{BO} = -5.7V \quad (\text{typical value}) \]

\[
\begin{align*}
& + \quad V \quad \{ \\
& \quad V > -5.7 \Rightarrow \quad 0
\end{align*}
\]

\[
\begin{align*}
& + \quad V' \quad \{ \\
& \quad V' < 5.7V \Rightarrow \quad 0
\end{align*}
\]

\[
\begin{align*}
& + \quad V' \quad \{ \\
& \quad V' > 5.7V \Rightarrow \quad 0
\end{align*}
\]

\[
\begin{align*}
& + \quad V' \quad \{ \\
& \quad V' < 5.7V \Rightarrow \quad 0
\end{align*}
\]

\[
\begin{align*}
& + \quad V' \quad \{ \\
& \quad V' > 5.7V \Rightarrow \quad 0
\end{align*}
\]
3. Regulator

What is the use?

On the other hand

4. In the lab, we use an IC regulator LM7805. ⇒ slide 11.

5. How good is the regulator?
We have two parameters to measure it

\[ \text{Line regulation} = \frac{\Delta V_o}{\Delta V_i} \]

How stable the output voltage is with the specified input range \(\Delta V_i\).

In the ideal case, it is 0.

\[ \text{Load regulation} = \frac{\Delta V_o}{\Delta I_o} \]

How stable the output voltage is with respect to the change of the output current?

In the ideal case, it is 0.

**Example:** The specified input is in the range \([7V, 25V]\)

The output is 5.0016 V for \(V_i = 7V\)

4.9976 V for \(V_i = 25V\)

What is the Line Regulation?

\[ LR = \frac{\Delta V_o}{\Delta V_i} = \frac{5.0016 - 4.9976}{25 - 7} = \frac{0.004}{18} \approx 0.00022. \]