Lecture #7
Voltage Regulators

Instructor:
Dr. Ahmad El-Banna
Agenda

- Voltage Regulation
- Basic Linear Series Regulators
- Basic Linear Shunt Regulators
- Intro. to Switching Regulators
VOLTAGE REGULATION
Intro.

- **Two** basic categories of voltage regulation are:
  - Line regulation
  - Load regulation

- The **purpose** of line regulation is to maintain a nearly constant output voltage **when** the input voltage **varies**.
- The **purpose** of load regulation is to maintain a nearly constant output voltage **when** the load **varies**.
Line Regulation

- When the ac input (line) voltage of a power supply changes, an electronic circuit called a regulator maintains a nearly constant output voltage.
- Line regulation can be defined as the percentage change in the output voltage for a given change in the input voltage.

\[
\text{Line regulation} = \left( \frac{\Delta V_{\text{OUT}}}{\Delta V_{\text{IN}}} \right) \times 100\%
\]

- Line regulation can also be expressed in units of \(\%/V\)

\[
\text{Line regulation} = \frac{(\Delta V_{\text{OUT}}/V_{\text{OUT}}) \times 100\%}{\Delta V_{\text{IN}}}
\]
Load Regulation

- Load regulation can be defined as the percentage change in output voltage for a given change in load current.
- One way to express load regulation is as a percentage change in output voltage from no-load (NL) to full-load (FL).

\[
\text{Load regulation} = \left( \frac{V_{\text{NL}} - V_{\text{FL}}}{V_{\text{FL}}} \right) \times 100\%
\]

- The load regulation can be expressed as a percentage change in output voltage for each mA change in load current.

- Using \( R_{\text{OUT}} \), Thevenin equivalent circuit for a power supply with a load resistor.

\[
V_{\text{TH}} = V_{\text{NL}}
\]

\[
R_{\text{TH}} = R_{\text{OUT}}
\]

\[
V_{\text{OUT}} = V_{\text{NL}} \left( \frac{R_L}{R_{\text{OUT}} + R_L} \right)
\]

\[
\text{Load regulation} = \left( \frac{R_{\text{OUT}}}{R_{\text{FL}}} \right) \times 100\%
\]
BASIC LINEAR SERIES REGULATORS
Regulators Classification

• The fundamental classes of voltage regulators are:
  • linear regulators
  • switching regulators
• Both of these are available in integrated circuit form.
• Two basic types of linear regulator are
  • series regulator
  • shunt regulator
Series Voltage Regulator

Basic op-amp series regulator
Regulating Action

- Illustration of series regulator action that keeps $V_{OUT}$ constant when $V_{IN}$ or $R_L$ changes.

\[ V_{OUT} \approx \left(1 + \frac{R_2}{R_3}\right)V_{REF} \]

(a) When $V_{IN}$ or $R_L$ decreases, $V_{OUT}$ attempts to decrease. The feedback voltage, $V_{FB}$, also attempts to decrease, and as a result, the op-amp’s output voltage $V_B$ attempts to increase, thus compensating for the attempted decrease in $V_{OUT}$ by increasing the $Q_1$ emitter voltage. Changes in $V_{OUT}$ are exaggerated for illustration.

When $V_{IN}$ (or $R_L$) stabilizes at its new lower value, the voltages return to their original values, thus keeping $V_{OUT}$ constant as a result of the negative feedback.

(b) When $V_{IN}$ or $R_L$ increases, $V_{OUT}$ attempts to increase. The feedback voltage, $V_{FB}$, also attempts to increase, and as a result, $V_B$, applied to the base of the control transistor, attempts to decrease, thus compensating for the attempted increase in $V_{OUT}$ by decreasing the $Q_1$ emitter voltage.

When $V_{IN}$ (or $R_L$) stabilizes at its new higher value, the voltages return to their original values, thus keeping $V_{OUT}$ constant as a result of the negative feedback.
Short-Circuit or Overload Protection

- If an **excessive** amount of **load current** is drawn, the series-pass **transistor** can be quickly damaged or **destroyed**.
- Most regulators use some type of excess **current protection** in the form of a current-limiting mechanism.
- One method of current limiting to prevent overloads called **constant-current limiting**.

\[ I_{L_{\text{max}}} = \frac{0.7 \, V}{R_4} \]
BASIC LINEAR SHUNT REGULATORS
Shunt Regulator

- In the shunt regulator, the control element is a transistor in parallel (shunt) with the load.
Regulating Action

- Sequence of responses when $V_{OUT}$ tries to decrease as a result of a decrease in $R_L$ or $V_{IN}$ (opposite responses for an attempted increase)

- It offers inherent short-circuit protection

\[ \Delta I_S = \frac{\Delta V_{IN}}{R_1} \]
\[ I_{L(max)} = \frac{V_{IN}}{R_1} \]
INTRO. TO SWITCHING REGULATORS
Switching Regulators

• The two types of linear regulators, series and shunt, have control elements (transistors) that are conducting all the time, with the amount of conduction varied as demanded by changes in the output voltage or current.

• The switching regulator is different because the control element operates as a switch.

• A much greater efficiency can be realized with a switching type of voltage regulator than with the linear types because the transistor switches on and off and dissipates power only when it is on.

• Efficiencies can be greater than 90%.

• Three basic configurations of switching regulators are step-down, step-up, and inverting.

• In some cases, such as a laptop computer, all three types may be employed for various parts of the system.

• For example, the display typically will use an inverting type, the microprocessor would use a step-down type, and the disk drive may use a step-up type.
• For more details, refer to:
• The lecture is available online at:
  • [http://bu.edu.eg/staff/ahmad.elbanna-courses/12135](http://bu.edu.eg/staff/ahmad.elbanna-courses/12135)
• For inquiries, send to:
  • [ahmad.elbanna@feng.bu.edu.eg](mailto:ahmad.elbanna@feng.bu.edu.eg)