ELEC2216

Advanced Electronic Systems

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1 Power Supplies

Power Supplies 1

1.1 What *is* power?

Power is the rate of disapation of energy. You can express power in terms of voltage and current using the chain rule.

$$P = \frac{dE}{dt}, V = \frac{dP}{dQ}, I = \frac{dQ}{dt}$$

$$P = I \cdot V = \frac{dP}{dQ} \cdot \frac{dQ}{dt} = \frac{dE}{dt}$$

Losses are often expressed in terms of power. Ohmic loss is the power lost though resistance.

$$P = I^2 R$$

This means that to decrease Ohmic loss you can increase the voltage while decreasing the current. This is easy to do for AC with a transformer, but harder to achieve for DC.

1.2 Quantifying Time-dependent Voltage

- Instantaneous value
- Peak value
- Peak to peak value
- Average value
- Effective value or RMS

1.2.1 Effective Voltage and Power

$$\text{At DC: } P = IV = \frac{V^2}{R}$$
$$\text{At AC: } P_{AV} = \frac{1}{T}\int_0^T \frac{v^2(t)}{R} dt$$

V_{RMS} is a voltage that will cause the same loss in a resistance R as a DC voltage V.

$$P_{AV} = \frac{V_{RMS}^2}{R} = \frac{1}{T}\int_0^T \frac{v^2(t)}{R} dt$$
$$\downarrow$$
$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T v^2(t) dt}$$

For a generic AC voltage $V_m \sin(\omega t)$ this solves to the following.

$$\begin{aligned} V_{RMS} &= \frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t) d(\omega t) \\ &= \frac{V_m^2}{4\pi}\int_0^{2\pi} (1-\cos(\omega t)) d(\omega t) \\ V_{RMS} &= \frac{V_m}{2} \end{aligned}$$

1.3 Transformers

Transformers convert AC voltages. This conversion is done in the ratio of turns in each coil: the turn ratio a.

$$a = \frac{n_1}{n_2} = \frac{v_1}{v_2}$$

1.4 Rectification

Rectification is the process of converting AC $\rightarrow$ DC voltages.

1.4.1 Half Wave Rectifier

In a half wave rectifier a diode is used to remove the negative part of the signal over a load

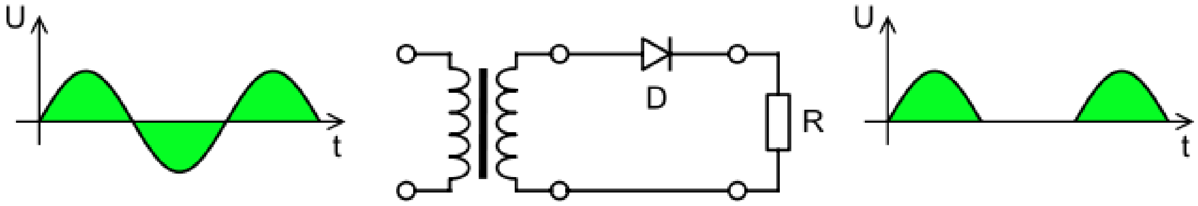

Figure 1: Circuit, input and output diagrams for a half-wave rectifier.

You can then put a capacitor across the output to smoothen the output waveform.

1.4.2 Full Wave Rectifier

Using a center tap on the transformer you can do full wave rectification.

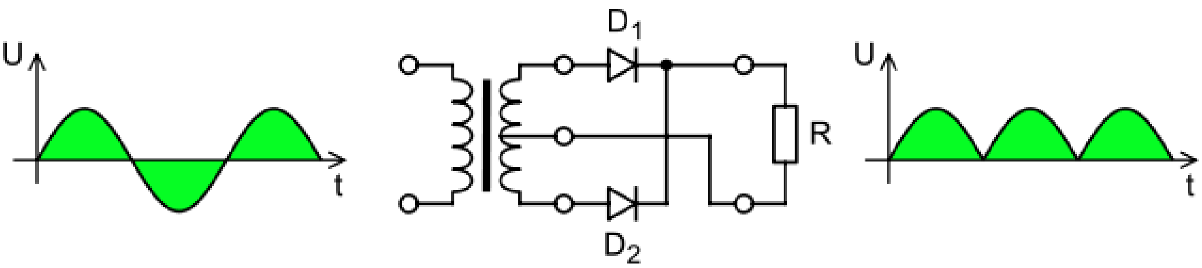

Figure 2: Circuit, input and output diagrams for a full-wave rectifier.

1.4.3 Bridge Rectifier

A bridge rectifier doesn't require a center tap on the transformer, and has half the current though the diodes, but has twice the voltage drop though the resistors.

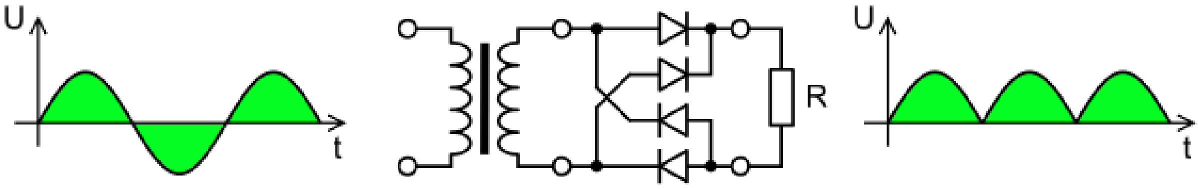

Figure 3: Circuit, input and output diagrams for a bridge rectifier.

1.5 Quantifying and Calculating Ripple Voltage

Ripple voltage is the deviation from the ideal DC voltage at the output. The voltage decay from the maximum voltage can be expressed as the following:

$$v_0(t) = v_p e^{-\frac{t}{RC}}$$

Then using the fact that for small t, $e^{-x} \approx 1 - x$:

$$v_{min} = v_p \left(1 - \frac{t}{RC}\right)$$

Then if $RC >> T$:

$$v_r \approx \frac{v_p T}{RC}$$

What capacitance is required for a less then 5% ripple in a Half Wave Rectifier over a load of 16kΩ?

$$\begin{aligned} v_r &= \frac{v_p T}{RC} \\ \frac{v_r}{v_p} &= \frac{T}{RC} \\ \frac{T}{RC} &= 5\% \\ C = \frac{T}{0.05 \cdot R} &= 25\mu\text{F} \end{aligned}$$

From the above example you can see that a larger capacitance gives a smaller ripple. But large capacitors get expensive. It might be work trying a regulator...

1.6 Regulators

- Line Regulation - keeping a constant output voltage with a varying input voltage.
- Load Regulation - keeping a constant output voltage with a varying output load.
- Ripple Rejection

1.6.1 Quantifying Power Supply Efficiency

- Quiescent Current is the current used by the supply at idle.
- Efficiency, P_{out}/P_{in}, is normally a large percentage.

1.6.2 Linear vs Switching Regulators

Table 1: Tabulated differences between Linear and Switching regulators.

Linear	Switching
Operates in linear region	Operates as a switch
Simple	Complex
Inefficient	Efficient

Additionally to the table above:

- Linear regulators are stable, resulting in a small v_r, but are step-down only.
- Switching regulators are more flexible then linear ones are they can be both boost (step-up) and buck (step-down) or boost-buck, however, they produce a lot of noise due to their switching nature.

1.7 Types of Linear Regulator

1.7.1 Series Regulator

A series regulator is (shock) placed in series with the voltage source. It has three pins, v_{in}, v_{out} and `GND`.

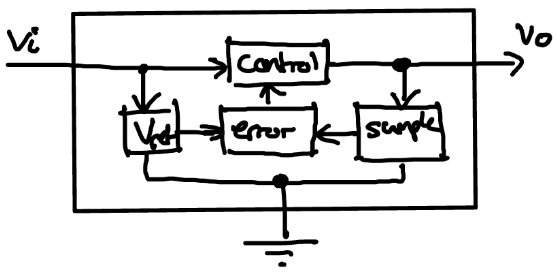

Figure 4: Block diagram for a series linear regulator.

Inside the regulator are four main components.

- v_{ref}, a voltage reference, normally a Zener diode.
- An error block, which is physically an op-amp.
- A sample stage, which is just a voltage divider.
- A Control element, physically a transistor.

1.7.2 Shunt Regulator

A shunt regulator is similar to a series regulator but is placed in parallel with the load.

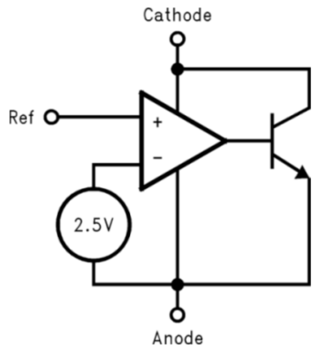

Figure 5: Schematic of TI's LM431 shunt voltage regulator.

1.8 Heat Flow in Linear Regulators

In a linear regulator dropping from 8V to 3V with a current of 1A, how much power must be dissipated in the regulator?

$$P = IV$$
$$P = 1 \cdot (8 - 5)$$
$$P = 3\text{W}$$

As shown in the above example, a lot of power, and therefore heat is generated in a linear regulator. To remove this heat from the board we use a heat sink.

The maximum temperature a silicon semiconductor will work at is roughly 150 to 200 °C.

1.9 Modeling Heat Flow

$$\Delta T = P_j \theta$$

Where:

ΔT	is the temperature difference.
P_j	is the power dissipated at the junction.
θ	is the thermal resistance, in kelvin per watt, $\frac{K}{W}$.

Normally the heat will flow though several boundaries. This requires you to equate several thermal resistances, for example the junction to case, θ_{jc} and case to ambient, θ_{ca}.

$$
\begin{gathered}
T_j - T_c = \theta_{jc} P_j \\
T_c - T_a = \theta_{ca} P_j \\
\downarrow \\
T_j = T_a + (\theta_{jc} + \theta_{ca}) P_j
\end{gathered}
$$

This can be concidered a general form, so adding a heat sink on the case would lead to the following:

$$T_j = T_a + (\theta_{jc} + \theta_{cs} + \theta_{sa}) P_j$$

For a 3W transistor with the following thermal resistances, what is the junction temperature in a 25°C room?

θ_{jc}	of 5 K/W
θ_{cs}	of 2 K/W
θ_{sa}	of 10 K/W

$$
\begin{aligned}
T_j &= T_a + (\theta_{jc} + \theta_{cs} + \theta_{sa}) P_j \\
&= 25 + (5 + 2 + 10) \times 3 \\
&= 25 + 17 \times 3 \\
T_j &= 76^{\circ} C
\end{aligned}
$$