# Lecture 6A – Rectification

Full wave rectifier (FWR) circuits (centre-tapped transformer, bridge). Capacitor filter. Zener regulator.

Due to the large (and ever increasing) amount of microelectronics used in electrical products, it is often desirable to have a steady DC supply that is derived from the AC "mains". To achieve this, it is necessary to somehow convert AC voltage into DC voltage. As a first step, we can convert the AC bipolar voltage into an AC unipolar voltage (one that still varies with time but always remains positive), a process known as rectification.

Centre-tapped Transformer FWR Circuit

Consider the following circuit:
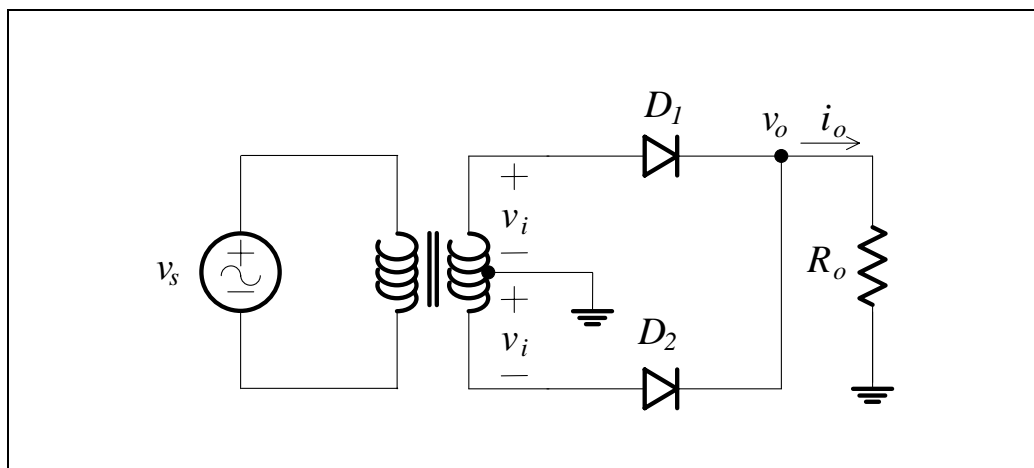
Figure 6A.1

The transformer steps down the supply voltage to the required value (e.g. from 240 V mains voltage to 9 V). The transformer is constructed so that the centre of the secondary winding is available as a terminal on the transformer. It is like two secondary windings joined in series. The two windings have a common terminal called the "centre tap".

We analyse the circuit in the usual way. Assume the diodes are ideal. Assume the diodes are acting like open circuits. We carry out an analysis. If the voltage across a diode is positive, then our assumption is incorrect.

6A.2

For a resistive circuit, there are two cases that have to be considered – the supply positive and the supply negative. If there were a capacitor in the circuit, then we would consider four cases – positive increasing, positive decreasing, negative decreasing and negative increasing.

Firstly, assume the supply is positive and both diodes are off. After analysis, D_1 is found to be forward biased and therefore in the conducting state. KVL around the output circuit then gives:

$$v_o = v_i \qquad \text{(6A.1)}$$

The output voltage equals the input voltage when the supply is positive. D_2 will remain in the off state, with a reverse bias voltage of magnitude $2v_i$.

Now assume the supply is negative and both diodes are off. D_2 should conduct in this case. KVL then gives us:

$$v_o = -v_i \qquad \text{(6A.2)}$$

In this case, v_i is a negative number, so the output voltage will still be positive. D_1 will remain in the off state.
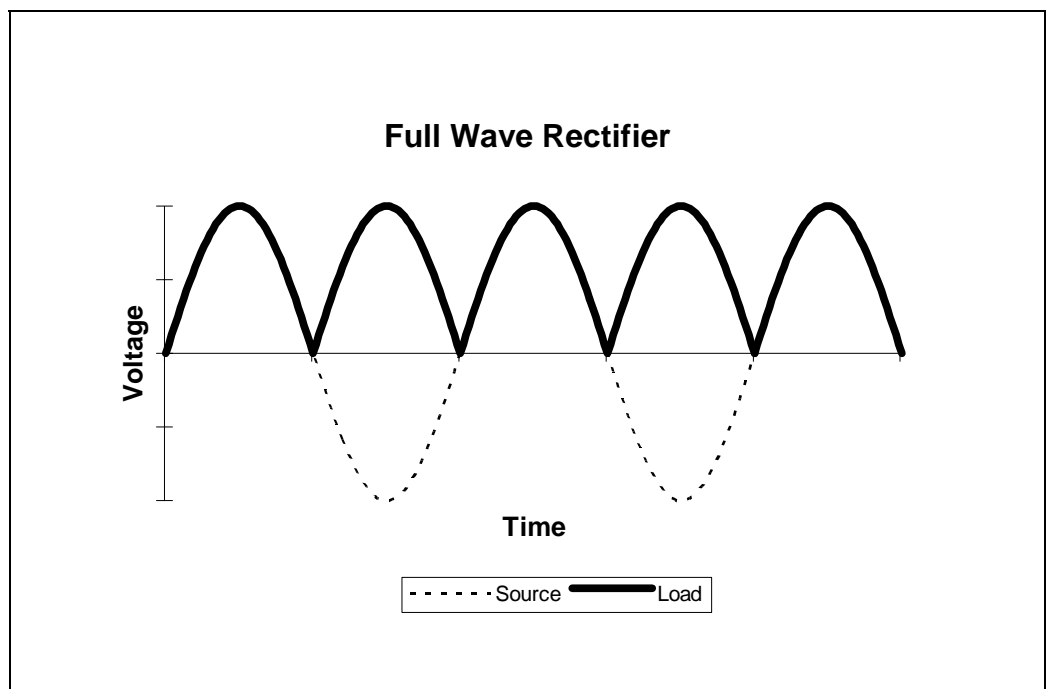
The result is a full wave rectifier:

Figure 6A. 2

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We can include the real effects of the diode, to a first approximation, by assuming a constant voltage drop model.

When a diode is off, the peak inverse voltage (PIV) it has to withstand can be obtained. This is important in selecting real diodes. In this case the PIV is $2\hat{v}_i$.

Bridge FWR Circuit

The following circuit also acts as a FWR:
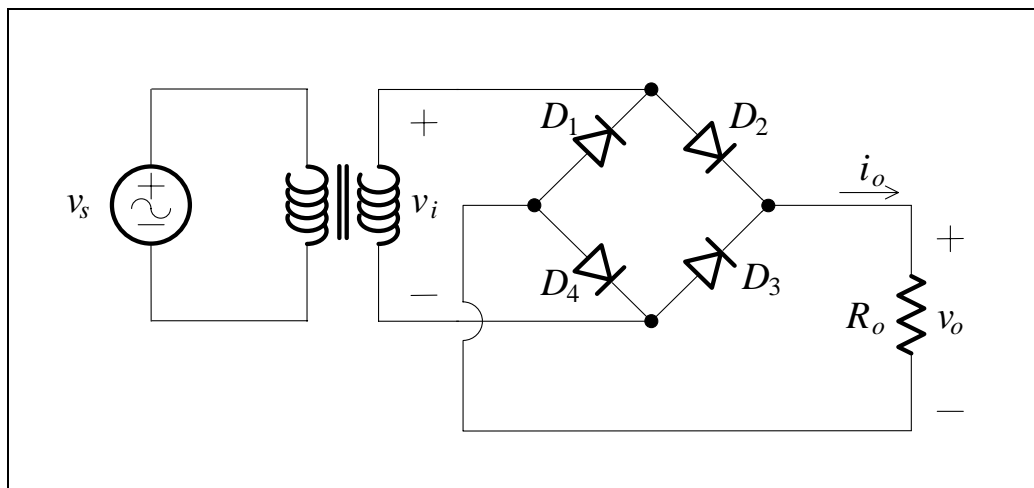
Figure 6A.3

We can perform the usual analysis quickly. In the positive half cycle D_2 and D_4 are on. D_1 and D_3 are effectively in parallel across the transformer secondary and are reverse biased. The PIV for each diode is $\hat{v}_i$. In the negative half cycle D_1 and D_3 are on, D_2 and D_4 are reverse biased. The output voltage is seen to be always positive.

The advantages of this configuration are: smaller transformer (no centre tap) and smaller PIV for each diode. The circuit is suitable for higher voltages.

6A.4

Capacitor Filter

The FWR voltage is not a good approximation to a DC voltage. The FWR waveform does have a steady DC value (the average of the waveform), but it still contains a large alternating component. To reduce this alternating component, we use a simple filter. We have seen the effect a switched capacitor makes on a varying voltage in Lecture 4A. It tends to smooth the waveform. If we connect a large capacitor across the output of the FWR, we get the following circuit:
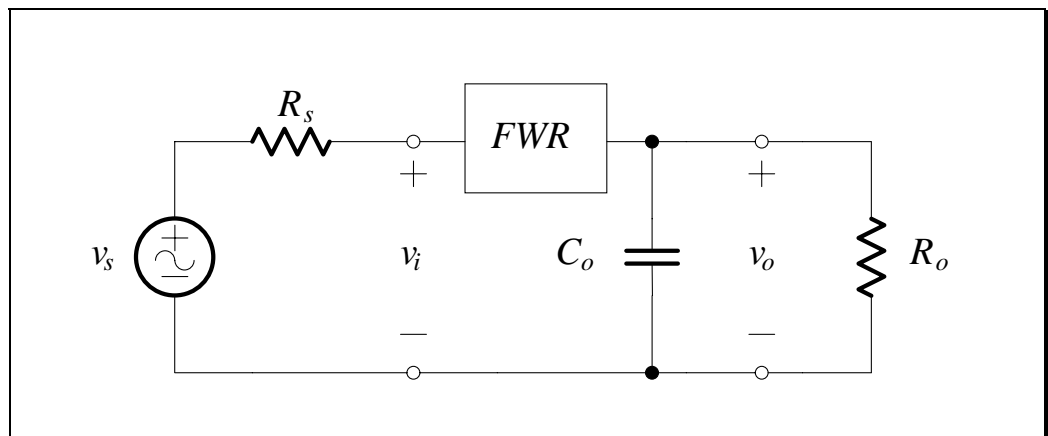

Figure 6A.4

An analysis of the above circuit (as was done in Lecture 4A) reveals that the output of the FWR with a capacitor is:
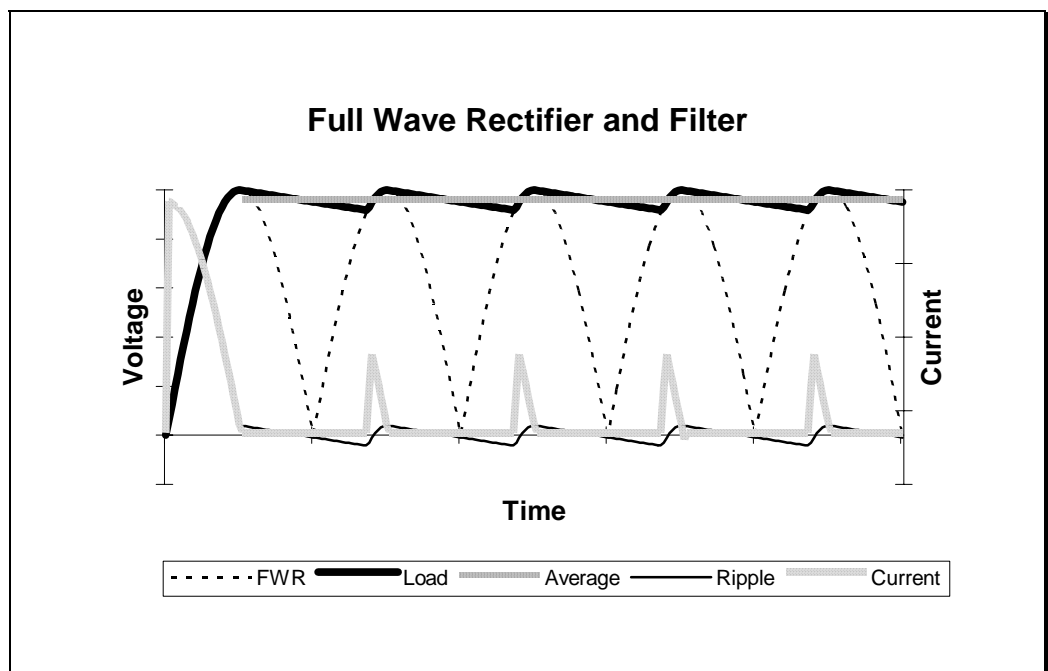

Full Wave Rectifier and Filter

Figure 6A.5

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If the time constant is large, then the exponential decay shown in the load voltage above can be approximated by:

$$v_o(t) \approx \hat{v}_o\left(1 - \frac{t}{R_o C_o}\right)$$

(6A.3)

which is the equation of a straight line.

Since the discharge time is much larger than the charging time, we can approximate this time by the period of the full wave rectified waveform, *T/2*.

The peak to peak excursions, or ripple, about the average value is then given by:

$$\delta v_o = \hat{v}_o - \hat{v}_o\left(1 - T/2R_o C_o\right)$$
$$= \frac{\hat{v}_o T}{2R_o C_o} = \frac{\hat{v}_o}{2fR_o C_o}$$

(6A.4)

The average or DC voltage is therefore:

$$V_{DC} = \hat{v}_o - \frac{\delta v_o}{2}$$
$$= \hat{v}_o - \frac{\hat{v}_o}{4fR_o C_o}$$
$$\approx \hat{v}_o - \frac{I_{DC}}{4fC_o}$$

(6A.5)

The ripple is reduced compared to the HWR, simply because the period of the waveform has halved. The output is now approaching DC. We can further smooth this wave using a regulator.

6A.6

Zener Regulator

A Zener diode is a diode that exhibits Zener breakdown when it is reverse biased. Zener breakdown occurs when the electric field in the depletion layer is strong enough to generate hole-electron pairs, which are accelerated by the field. This increases the reverse bias current. It gives rise to a sharper transition and steeper curve than forward biased conduction.

The definition of regulation is the percentage change in output for a given input:

$$\text{regulation} = \frac{\text{change in output}}{\text{change in input}} \times 100\% \tag{6A.6}$$

A reverse biased Zener diode can be added in parallel to the rectifier output.
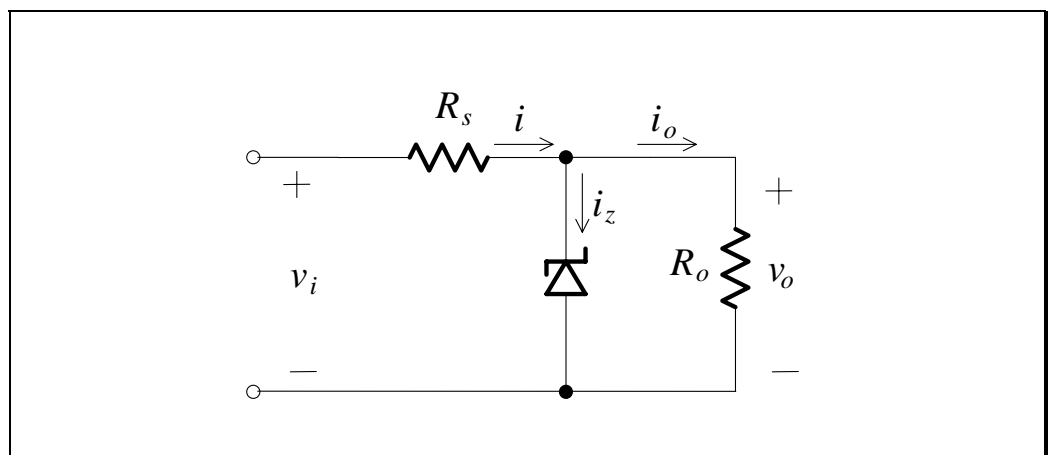
Figure 6A. 6

Large changes in input voltage or load current produce small voltage variations.

Describe how the vertical characteristic of the Zener achieves regulation. Demonstrate with 1 kΩ *resistors and* 5 mA *total current.*

Summary

- Rectification is the process of converting a bipolar waveform to a unipolar waveform. A rectified waveform can have both a DC and an AC component.

- A full-wave rectifier can be created using a centre-tapped transformer and two diodes, or by using an ordinary transformer and a diode bridge. Each circuit has advantages and disadvantages.

- A capacitor is placed on the output of a full-wave rectifier to increase the DC component whilst also reducing the AC component (or ripple).

- A Zener diode can be used as a simple regulator by operating the diode in the reverse breakdown region.

References

Sedra, A. and Smith, K.: *Microelectronic Circuits*, Saunders College Publishing, New York, 1991.
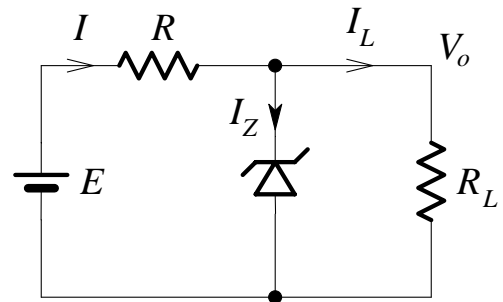
6A.8

Problems

1.

In the circuit shown, the Zener diode "regulates" at 50 V for $5 \le I_Z \le 40$ mA, and $E = 200$ V.

(i) Determine the value of R needed to allow voltage regulation $(V_o = V_Z)$ from a load current $I_L = 0$ to $I_{L\max}$.

(ii) With R = value determined in (i) and $I_L = 25$ mA, determine $E_{\min}$ and $E_{\max}$ for regulation to be maintained.