I. Diode and Diode Application

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1. Diodes

Some elements are **linear** (resistors, capacitors, inductors), which means that doubling the applied signal (let us say a voltage) produces a doubling of the response (let us say a current). They are also **passive** – they do not have built-in source of power. They are **two-terminal** devices, (which is self-explanatory).

Diode is also **two-terminal**, **passive** but **non-linear** a device. Figure 1 shows the diode.

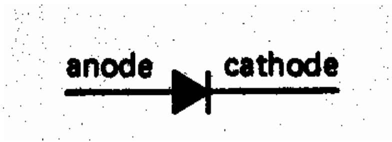

Fig.1. Diode.

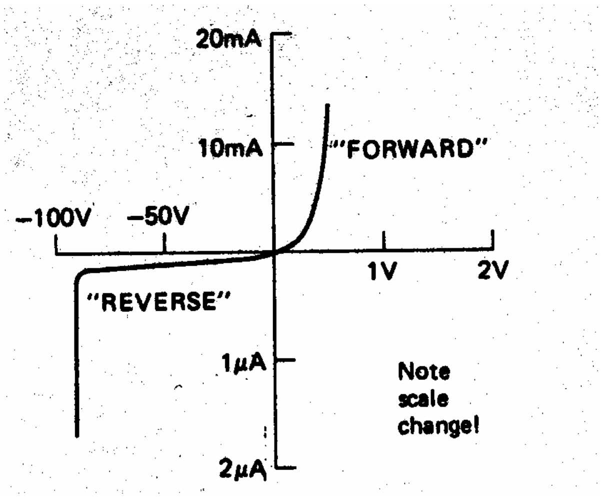

Fig.2. Diode voltage-current curve, U-I curve.

In Fig. 2 there is U-I (voltage-current) curve (characteristic). The diode arrow, anode terminal, shows the direction of forward current flow. If the diode is in a circuit in which a current of $10mA=10*10^{-3}A$ is flowing from anode to cathode, then the anode is approximately

0.5 volt more positive than cathode. We call it the **forward voltage drop**. The reverse current is measured in nanoampers and 1nA=1*10^{-9}A. It is so small in comparison to mA, that can be neglected until we reach the **reverse breakdown voltage.** Typically it is approximately 75V and normally we never subject a diode to voltage large enough to cause reverse breakdown.

Similarly, the **forward voltage drop,** which is about 0.5 or 0.8 V, is of little concern. For these reasons we treat the diode as a good approximation of an ideal **one-way conductor**.

Commercially available diodes are described also by other important characteristics, e.g.: maximum forward current, capacitance (measured in pF), leaking current, reverse recovery time (measured in nanoseconds, 0-2-4-5000).

2. Rectification

A rectifier changes ac (alternating current) to dc (direct current). This is the most important application of diodes. Diodes are sometimes called rectifiers.

The basic circuit is shown in Fig. 3.

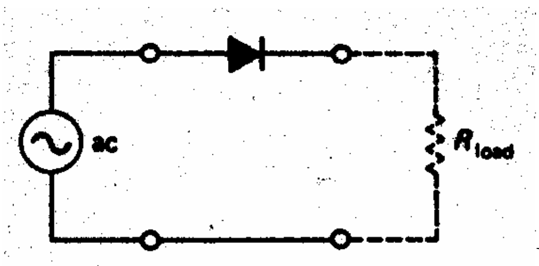

Fig.3. Half-wave rectifier.

The ac represents a source of ac voltage. It can be a transformer or just ac sine-wave power line. For sine-wave input, of amplitude much larger than forward voltage drop, the output will look like it is shown in Fig. 4.

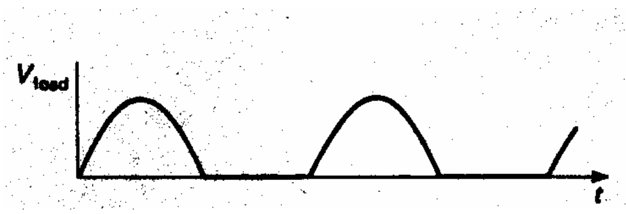

Fig.4. Voltage across R_{load} in Fig.3.

The process and the circuit we call a **half-wave rectifier**, because only half of the input waveform is used.

In Fig. 5 is shown a **full-wave rectifier** and Fig. 6 shows the voltage across the load. The small gaps across zero voltage occur because of the forward voltage drop.

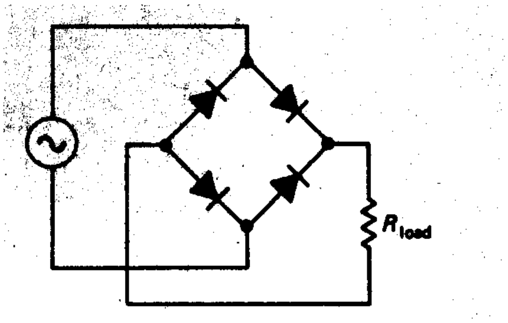

Fig.5. Full-wave bridge rectifier.

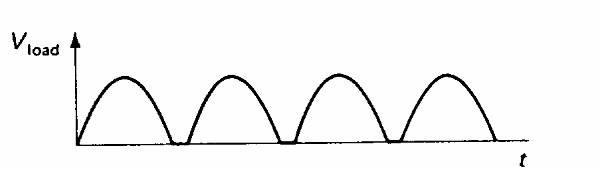

Fig.6. Voltage across R_{load} in Fig.5.

3. Power supply filtering

The rectified wave from Fig.6 is not good for application: it is dc only in the sense that it does not change polarity. But it does not have constant value and has plenty of ripples i.e. small waves or undulations (wave like forms). It has to be smoothed out in order to obtained authentic direct current. This can be done by means of a low-pass filter, which is shown in Fig. 7.

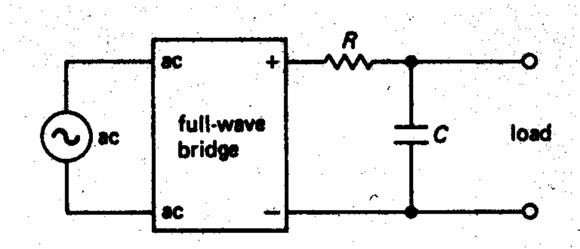

Fig.7. Full-wave bridge with RC filter.

The full-wave bridge diodes prevent flow of current back out of capacitor. The capacitor is an energy storage element. The energy stored in a capacitor is $\mathbf{E} = \frac{1}{2}\mathbf{C}\mathbf{U}^2$. For C in F (farads) and U in V (Volts), E comes out in J (jouls) and J=Watt/sek. The capacitor value is chosen so that $\mathbf{R}_{\mathbf{load}} >> 1/\mathbf{f}$, where f is the ripple frequency. For power line sine wave it is 2*50Hz=100Hz. It allows to ensure small ripples, by making the time constant for discharge much longer than the time between recharging (the capacitor is charging very quickly, while discharging is very slow).

It is quite easy to calculate the approximate ripple voltage (see Fig. 8). Let us assume that the load current stays constant (it will, for small ripples). The load causes the capacitor to discharge somewhat between cycles. The capacitor will loose some voltage, let us say $\Delta\mathbf{U}$. In this case, we have:

$$\Delta\mathbf{U} = \frac{\mathbf{I}}{\mathbf{C}}\Delta\mathbf{t}, \text{ (from } \mathbf{I} = \mathbf{C}\frac{\mathbf{dU}}{\mathbf{dt}}\text{)}$$

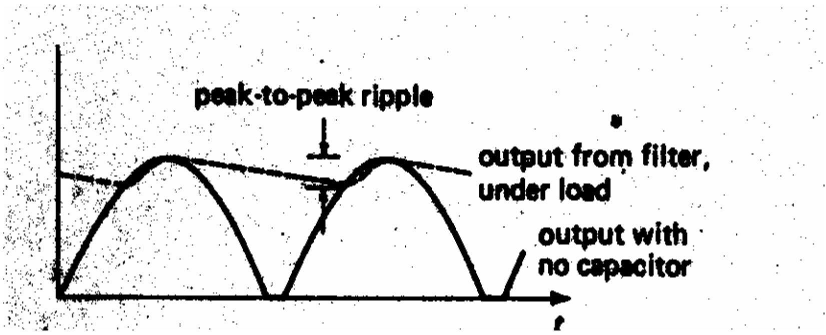

Fig.8. Power-supply ripple calculation.

Instead of $\Delta \mathbf{t}$ we use $1/\mathbf{f}$ or $1/2\mathbf{f}$ respectively for half-wave rectification and for full-wave rectification. Finally we obtain approximate ripple voltage:

- for halve-wave $\Delta \mathbf{U} = \frac{\mathbf{I_{load}}}{\mathbf{fC}}$,
- for full-wave $\Delta \mathbf{U} = \frac{\mathbf{I_{load}}}{2\mathbf{fC}}$.

If one wanted to do exact calculation (with no approximation), one would use the exact exponential formula (see lecture *Capacitors, RC circuits*). Sometimes it may be necessary.

A dc power supply using the bridge circuit looks (in the USA) as shown in Fig.9.

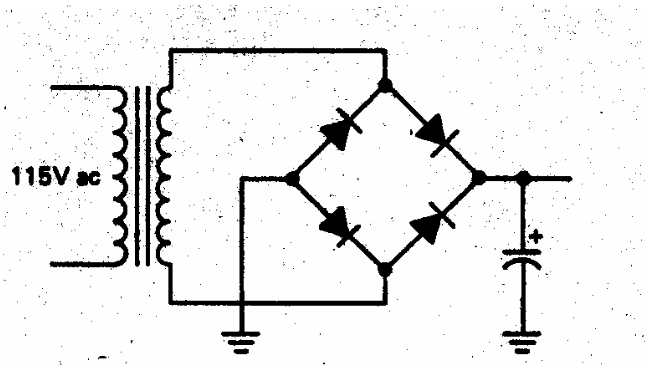

Fig.9. Bridge rectifier circuit. The curved electrode indicates a polarized capacitor, which must not be allowed the opposite polarity.

4. Applications of diodes

- **Signal rectifier**

If the input is not a sine wave, we usually do not think of it as a rectification in the sense as it was for power supply. For instance, we might want to have a series of pulses corresponding to **the rising edge** of a square wave (see Fig. 10, left hand side and right hand side of the capacitor C). While both, the rising and the falling, pulses are in the output after differentiation performed by CR circuit. The simplest way is to rectify the differentiated wave.

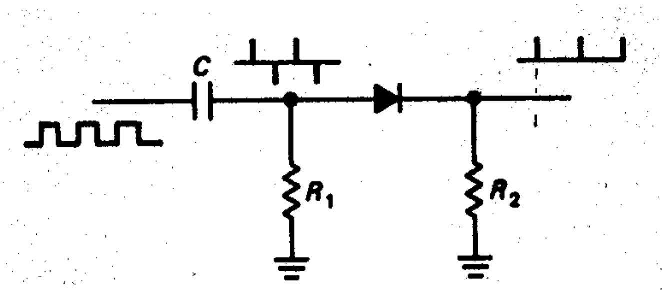

Fig.10. A series of pulses' rectifier.

We should remember about forward drop voltage of the diode: This circuit gives no output for signal for input smaller then, forward drop voltage, let us say 0.5 V pp (peak to peak). If this is a problem, there are various tricks that help to combat this limitation. For instance:

1. use Schottky diodes with smaller forward drop voltage (approximately 0.2V),
2. use so called circuit solution, which means modifying the circuit structure and compensating the drop,
3. use matched-pair compensation, use transistors, FETs.

◦ **Diode gates**

Another application of diode is to pass the higher of two voltages without affecting the lower. A good example is battery backup, a method of keeping s device running (for instance a precision electronic clock) in case of power failure. Figure 11 shows a circuit that does the job.

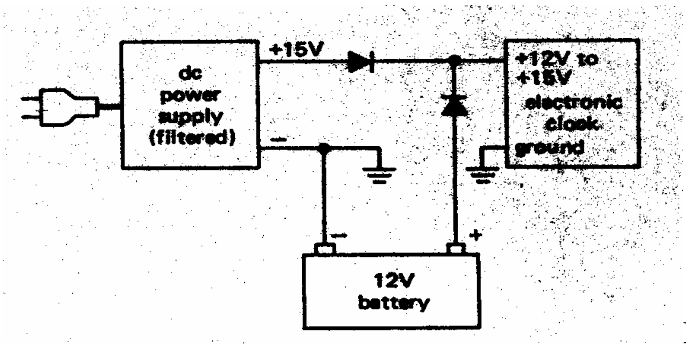

Fig.11. Diode OR gate, battery backup.

[**OR gate**: *The output of OR gate is HIGH if either input (or both) is HIGH. In general, gates can have any number of inputs. The output is LOW only if all inputs are LOW*].

1. The battery does nothing until the power fails.

2. Then the battery takes over the control, without interruption.

◦ **Diode clamps** (stabilizatory poziomu)

Sometimes it is necessary to limit the range of signal (for instance not to exceed certain voltage limit and not to destroy a device). The circuit in Fig. 12 will accomplish this.

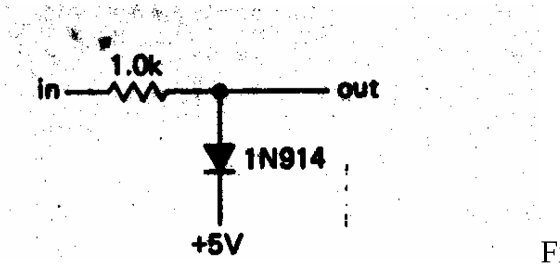

Fig.12. Diode voltage clamp.

The diode prevents the output from exceeding ≅ 5.6V, with no effect on voltages smaller than this, including negative voltages. The only limitation is that the input must not be so negative that the reverse breakdown voltage is exceeded. Diode clamps are the standard equipment on all inputs in the CMOS family of digital logic (Complementary Metal Oxide Semiconductor). Without them, the delicate input circuits are easily destroyed by static electricity.

◦ **Limiter**

The circuit in Fig.13 limits the **output swing** to one diode drop, roughly 0.6V.

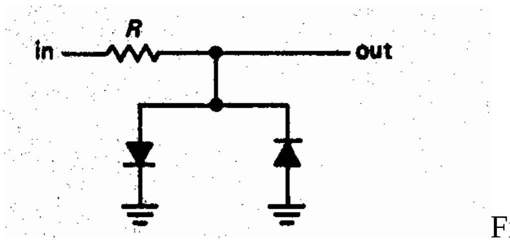

Fig.13. Diode limiter.

It might seem very small, but if the next device is an amplifier with large voltage amplification, its input has to be always near zero voltage. Otherwise the output is in state of saturation. For instance we have an op amp with a gain of 1000. The amplifier operates with supply voltage ±15V. Sometimes it can be ±12V or ±18V or something in between. It will never give output voltage bigger than the supply voltage, i.e. ±15V. It means that the input signal ±15mV (±15V/1000) or bigger will saturate the output. This particular amplifier gives the output proportional to the input (proportionality factor is 1000) only for input signals from the interval (-15mV,+15mV).

This diode limiter is often used as input protection for high-gain amplifiers.