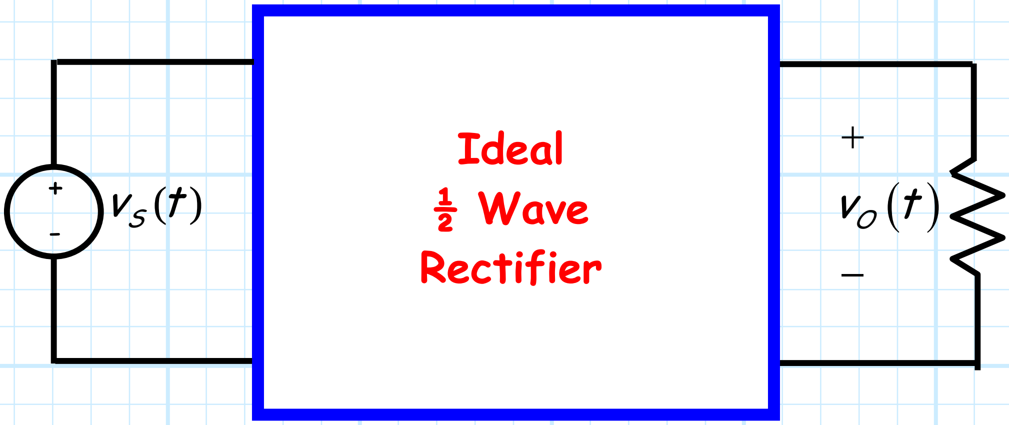
Signal Rectification

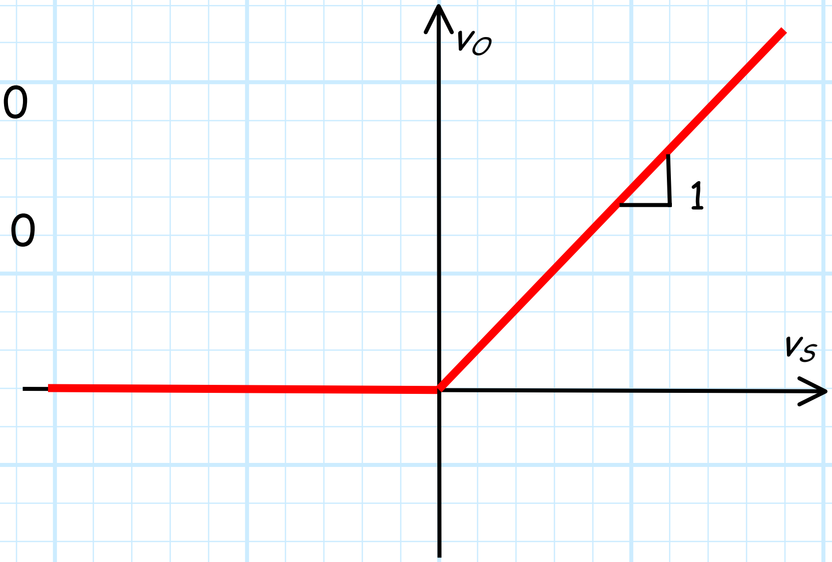
An important application of junction diodes is **signal rectification**.

There are **two** types of signal rectifiers, **half-wave** and **full-wave**.

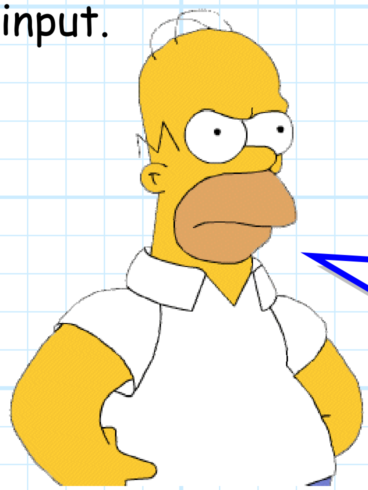
Let's first consider the **ideal half-wave rectifier**. It is a circuit with the transfer function $v_O = f(v_S)$:



$$v_O = \begin{cases} 0 & \text{for} \quad v_S < 0 \\ v_S & \text{for} \quad v_S > 0 \end{cases}$$

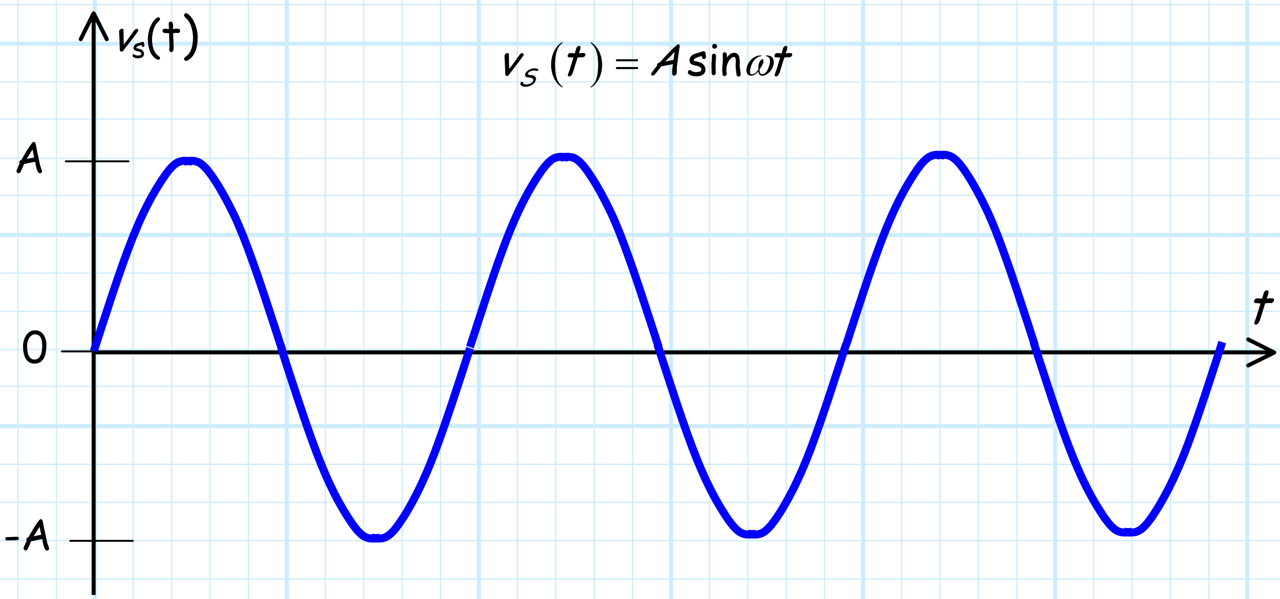


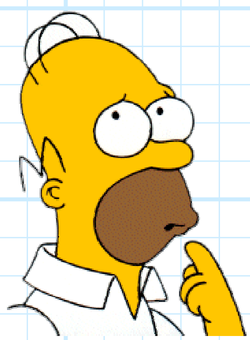
Pretty simple! **When** the input is negative, the output is **zero**, whereas **when** the input is positive, the output is the **same** as the input.



Q: *Pretty simple and pretty **stupid** I'd say! This might be your most **pointless** circuit yet. How is **this** circuit even remotely useful??*

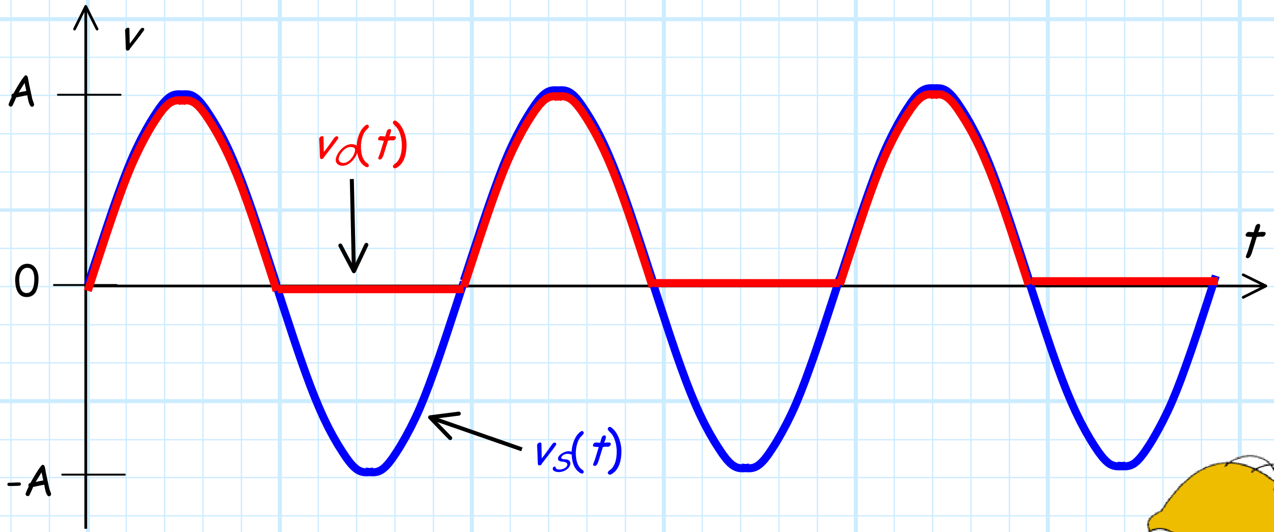
A: To see **why** a half-wave rectifier is useful, consider the **typical** case where the input source voltage is a **sinusoidal** signal with **frequency** ω and peak **magnitude** A:



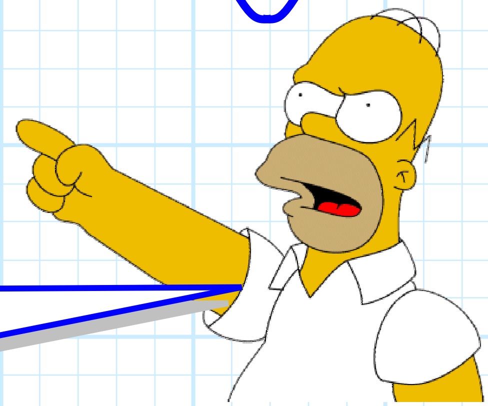


Think about what the **output** of the half-wave rectifier would be! Remember the rule: when $v_S(t)$ is **negative**, the output is **zero**, when $v_S(t)$ is **positive**, the output is **equal** to the input.

The **output** of the half-wave rectifier for **this** example is therefore:



Q: *That's the **lamest** result I've ever seen. What good is **half** a sine wave? Why even bother?*



A: Although it may appear that our rectifier had **little** useful effect on the input signal $v_S(t)$, in fact the difference between input $v_S(t)$ and output $v_O(t)$ is both **important** and **profound**.

To see how, consider first the **DC component** (i.e. the time-averaged value) of the **input** sine wave:

$$
\begin{aligned}
V_S &= \frac{1}{T}\int_0^T v_S(t)\,dt \\
&= \frac{1}{T}\int_0^T A \sin \omega t \, dt = 0
\end{aligned}
$$

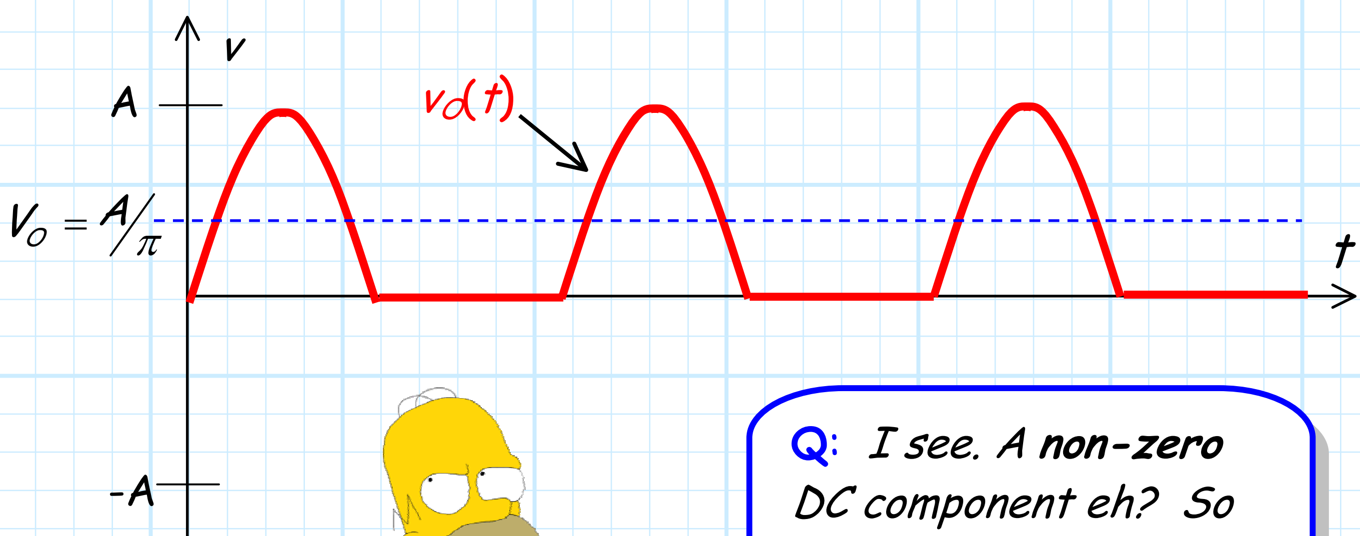
Thus, (as you probably already knew) the **DC component** of a sine wave is **zero**—a sine wave is an **AC signal**!

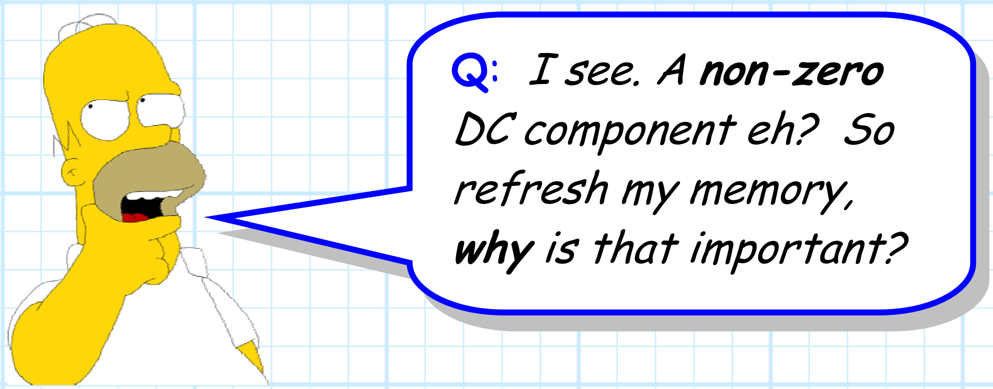
Now, contrast this with the **output** $v_O(t)$ of our half-wave rectifier. The **DC component** of the **output** is:

$$V_O = \frac{1}{T}\int_0^T v_O(t)\,dt$$

$$= \frac{1}{T}\int_0^{T/2} A\sin\omega t\,dt + \frac{1}{T}\int_{T/2}^{T} 0\,dt = \frac{A}{\pi}$$

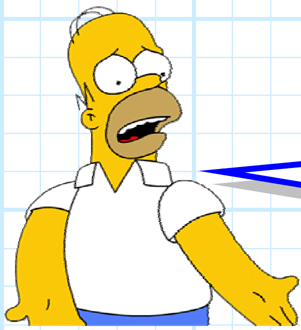
Unlike the input, the **output** has a **non-zero** (positive) **DC component** ($V_O = A/\pi$)!





A: Recall that the **power distribution** system we use is an ***AC*** system. The source voltage $v_S(t)$ that we get when we plug our "**power cord**" into the wall socket is a 60 Hz **sinewave**—a source with a **zero DC component**!

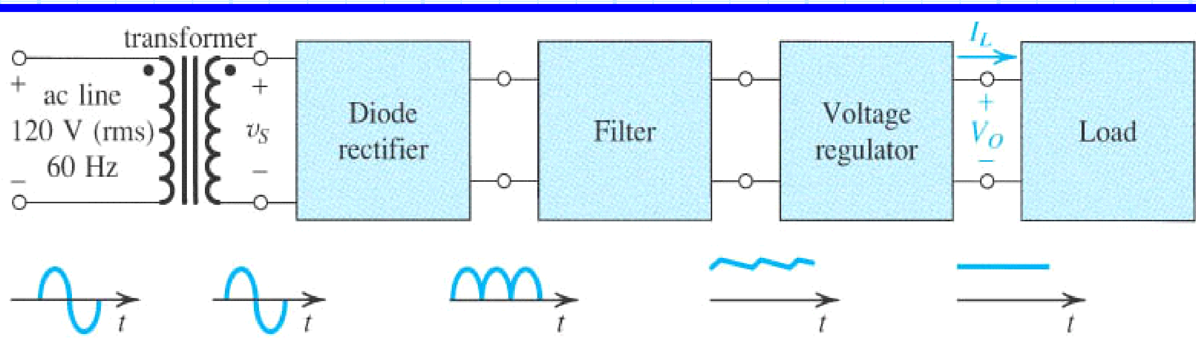
The **problem** with this is that most **electronic devices** and systems, such as TVs, stereos, computers, etc., require a **DC voltage(s)** to operate!



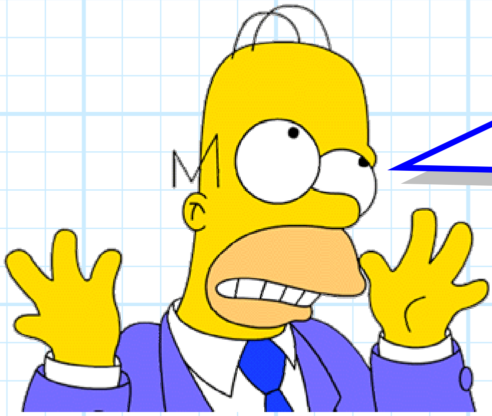
Q: *But, how can we create a* ***DC*** *supply voltage if our power source* $v_S(t)$ *has* ***no*** *DC component??*

A: That's **why** the half-wave rectifier is so **important**! It takes an AC source with **no** DC component and creates a signal with **both** a DC and AC component.

We can then pass the output of a half-wave rectifier through a **low-pass filter**, which **suppresses** the AC component but lets the **DC** value ($V_O = A/\pi$) pass through. We then **regulate** this output and form a **useful DC voltage source**—one suitable for powering our electronic systems!

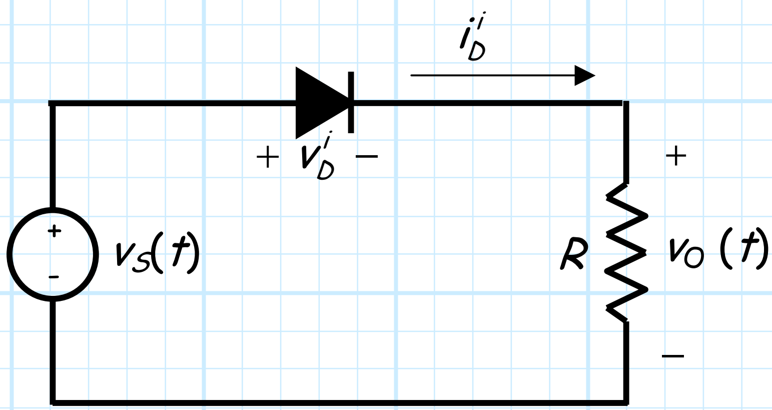


A Power Supply



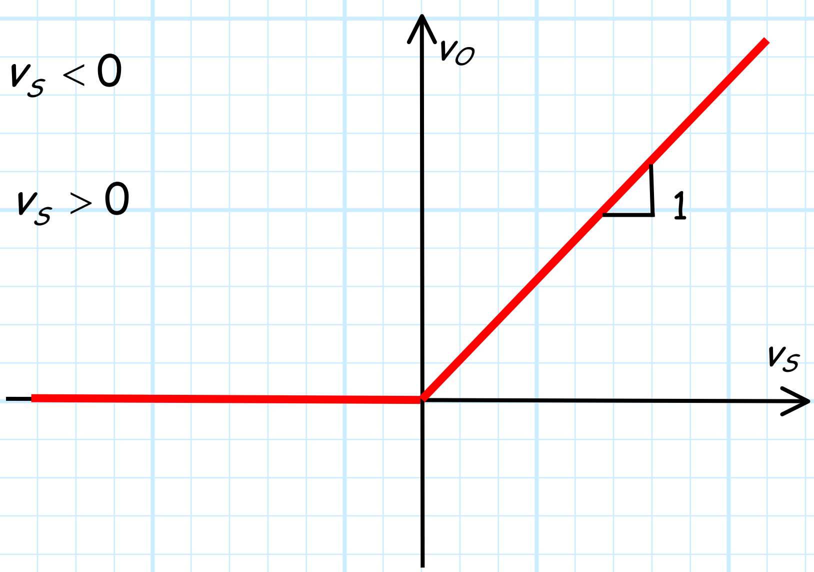
Q: *OK, now I see **why** the **ideal** half-wave rectifier might be useful. But, is there any way to actually **build** this magical device?*

A: An **ideal** half-wave rectifier can be "built" if we use an **ideal** diode.

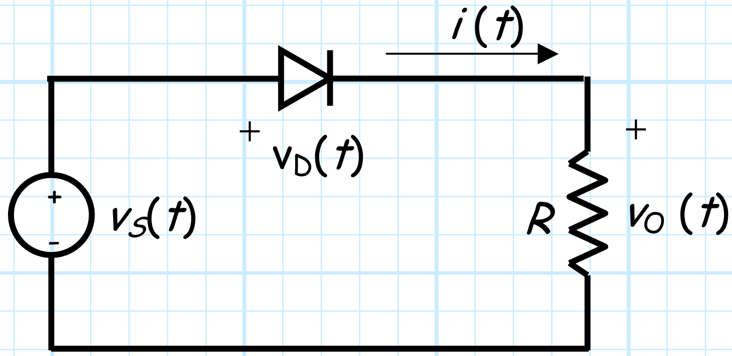


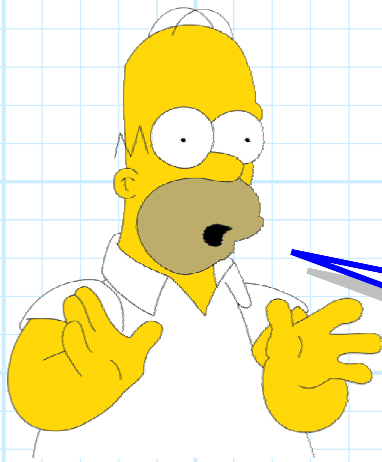
If we follow the transfer function **analysis steps** we studied earlier, then we will find that this circuit is indeed an **ideal half-wave rectifier**!

$$v_O = \begin{cases} 0 & \text{for} \quad v_S < 0 \\ v_S & \text{for} \quad v_S > 0 \end{cases}$$



Of course, since **ideal** diodes do **not** exist, we must use a **junction** diode instead:

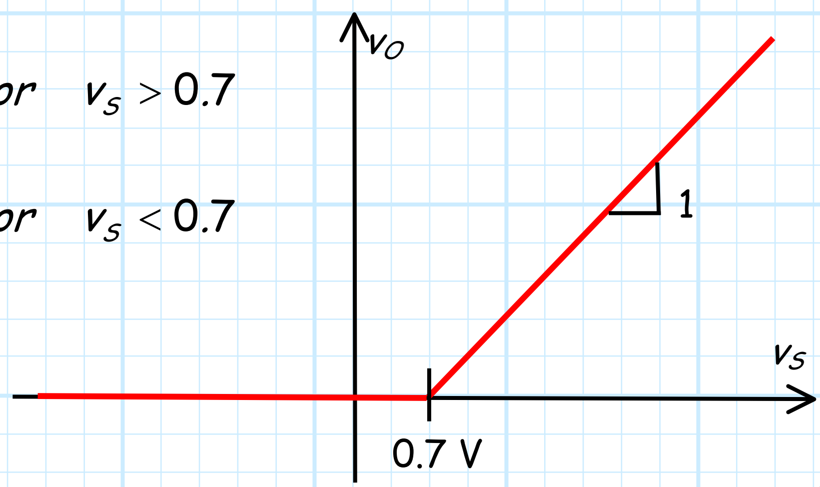




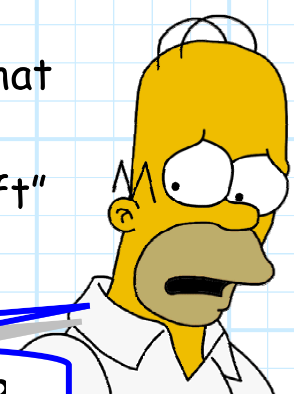
Q: *This circuit looks so **familiar**! Haven't we studied it before?*

A: Yes! It was an **example** where we determined the junction diode circuit transfer function. Recall that the **result** was:

$$v_O = \begin{cases} v_S - 0.7 & for \quad v_S > 0.7 \\ 0 & for \quad v_S < 0.7 \end{cases}$$



Note that this result is **slightly different** from that of the **ideal** half-wave rectifier! The **0.7 V drop** across the junction diode causes a horizontal "shift" of the transfer function from the ideal case.



Q: *So then this junction diode circuit is **worthless**?*

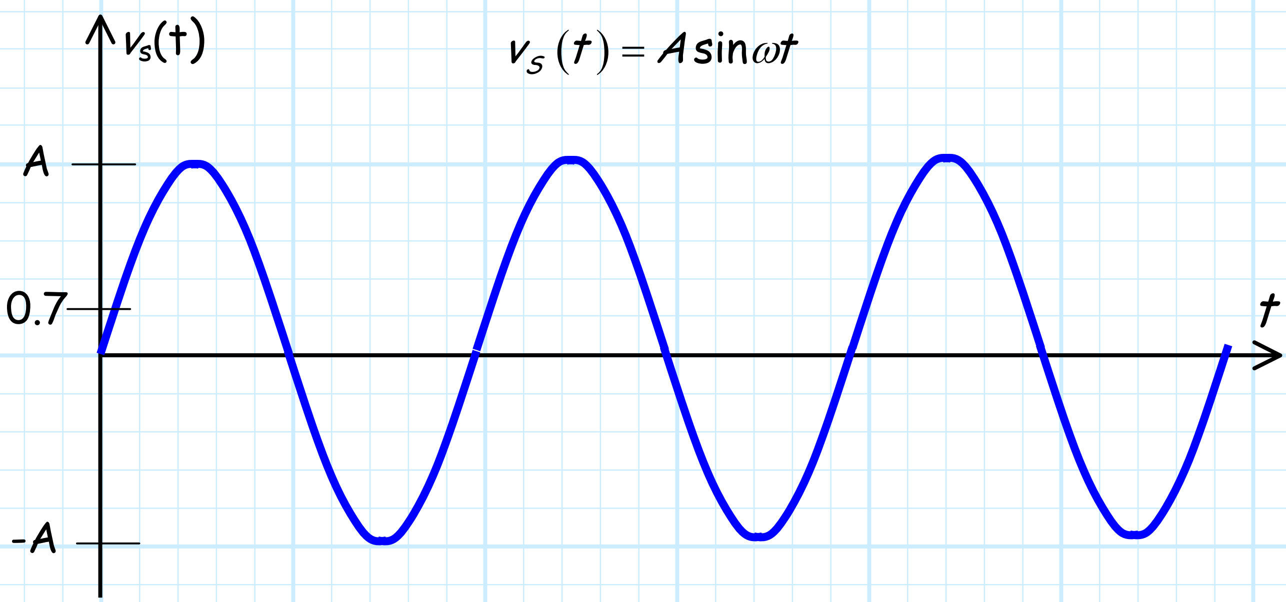
A: Hardly! Although the transfer function is **not quite** ideal, it works **well enough** to achieve the goal of signal rectification—it takes an input with **no** DC component and creates an output with a **significant** DC component!

Note what the transfer function "**rule**" is now:

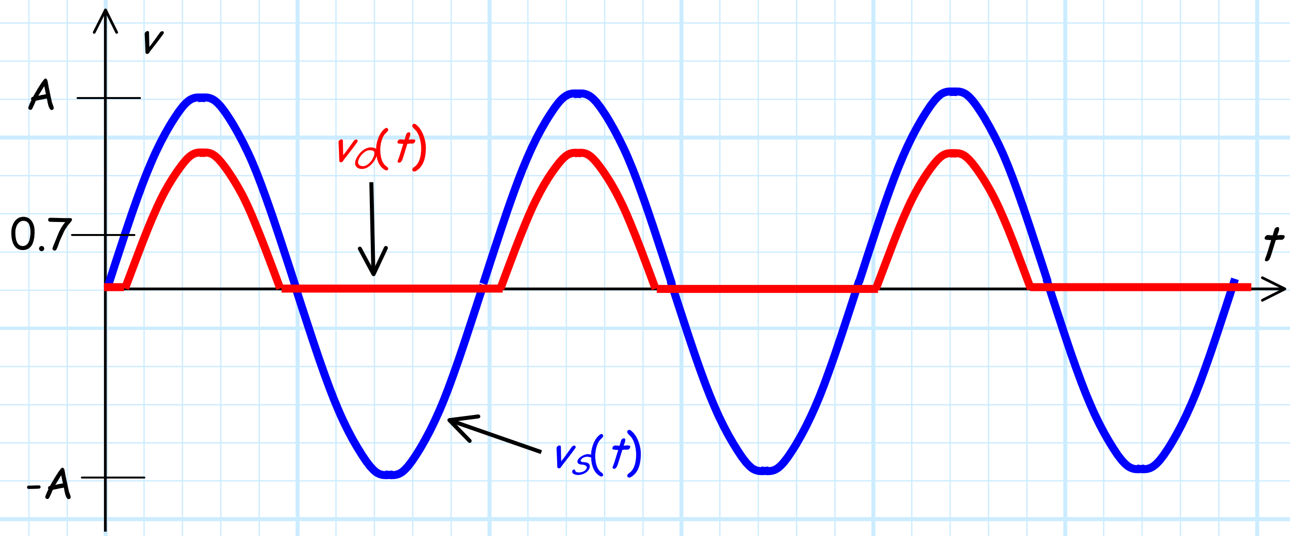
1. When the input is **greater** than 0.7 V, the output voltage is **equal** to the input voltage minus 0.7 V.

2. When the input is **less** than 0.7 V, the output voltage is **zero**.

So, let's consider **again** the case where the **source** voltage is **sinusoidal** (just like the source from a "wall socket"!):



The output of our **junction diode** half-wave rectifier would therefore be:



Although the output is **shifted downward** by 0.7 V (note in the plot above this is **exaggerated**, typically A >>0.7V), it should be apparent that the **output** signal $v_O(t)$, unlike the input signal $v_S(t)$, has a **non-zero** (positive) **DC component**.

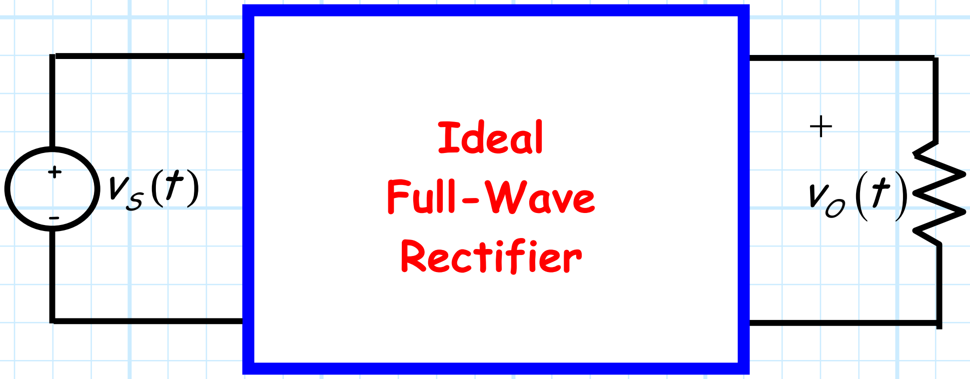
Because of the 0.7 V shift, this DC component is **slightly smaller** than the **ideal** case. In fact, we find that if A>>0.7, this **DC component** is approximately:

$$V_O \approx \frac{A}{\pi} - 0.35 \text{ V}$$

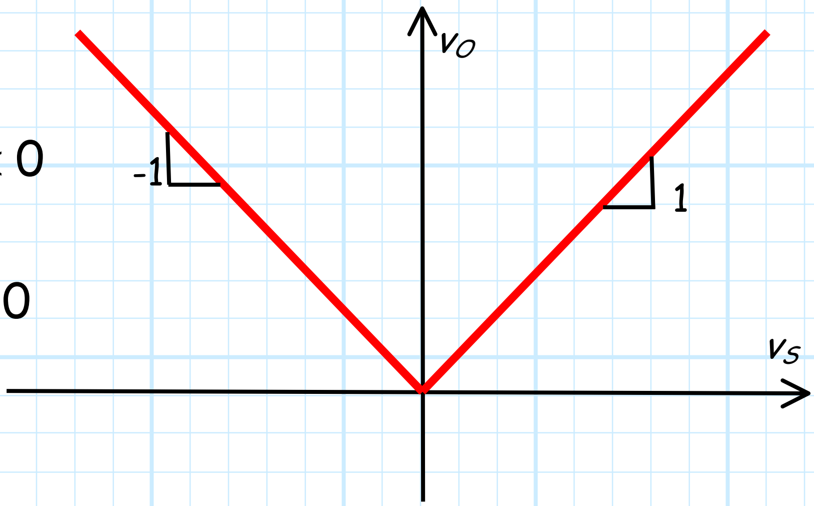
In other words, **just** 350 mV less than **ideal**!

Q: *Way back on the first page you said that there were* ***two*** *types of rectifiers. I now understand* ***half-wave*** *rectification, but what about these so-called* ***full-wave*** *rectifiers?*

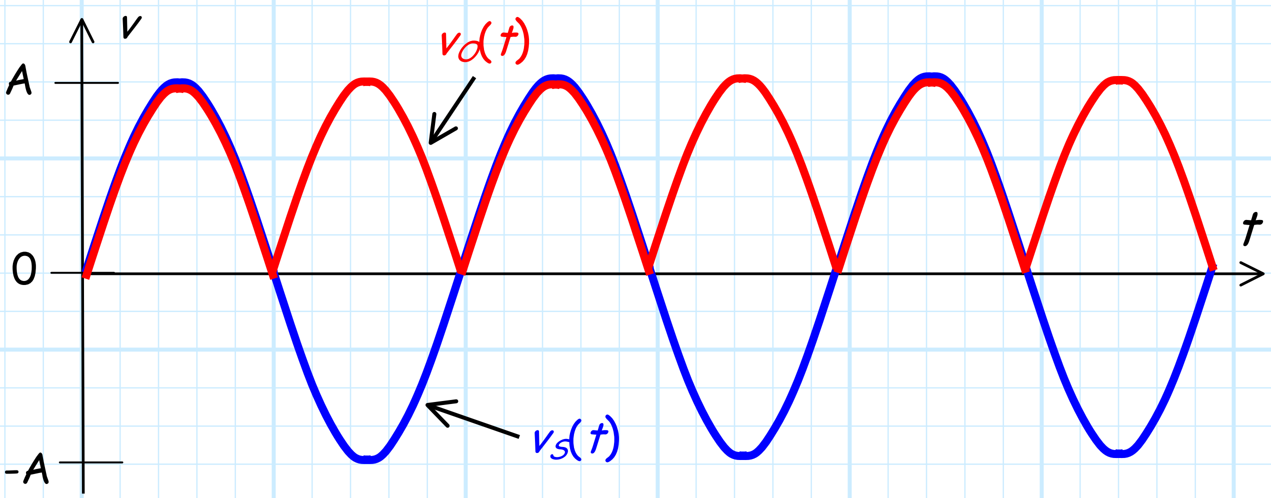
A: Almost forgot! Let's examine the transfer function of an **ideal full-wave rectifier**:



$$v_O = \begin{cases} -v_s & for \quad v_s < 0 \\ v_s & for \quad v_s > 0 \end{cases}$$

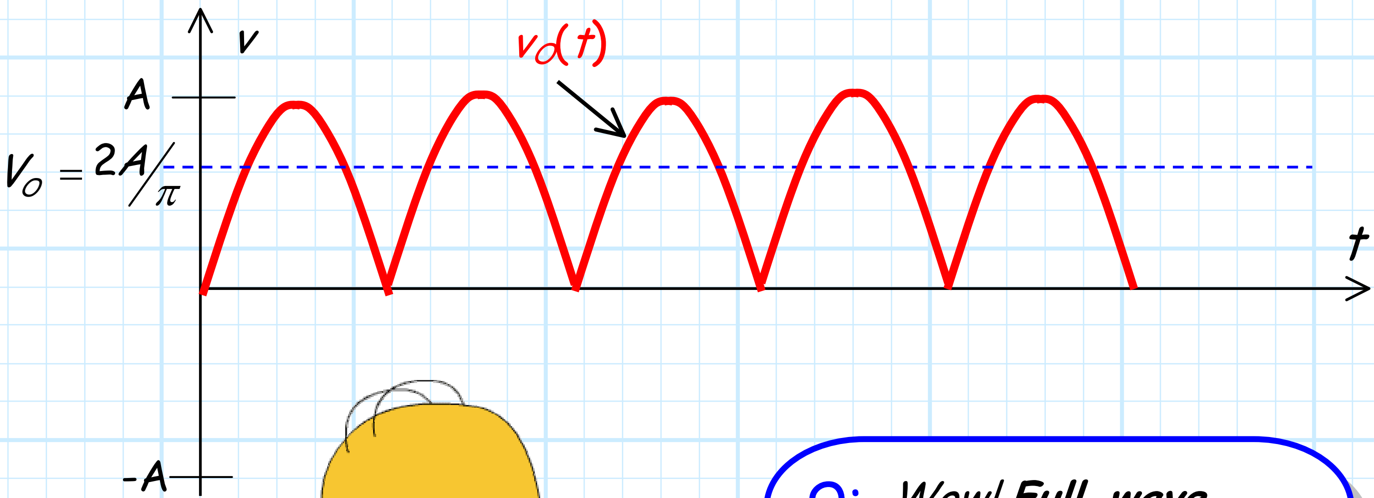


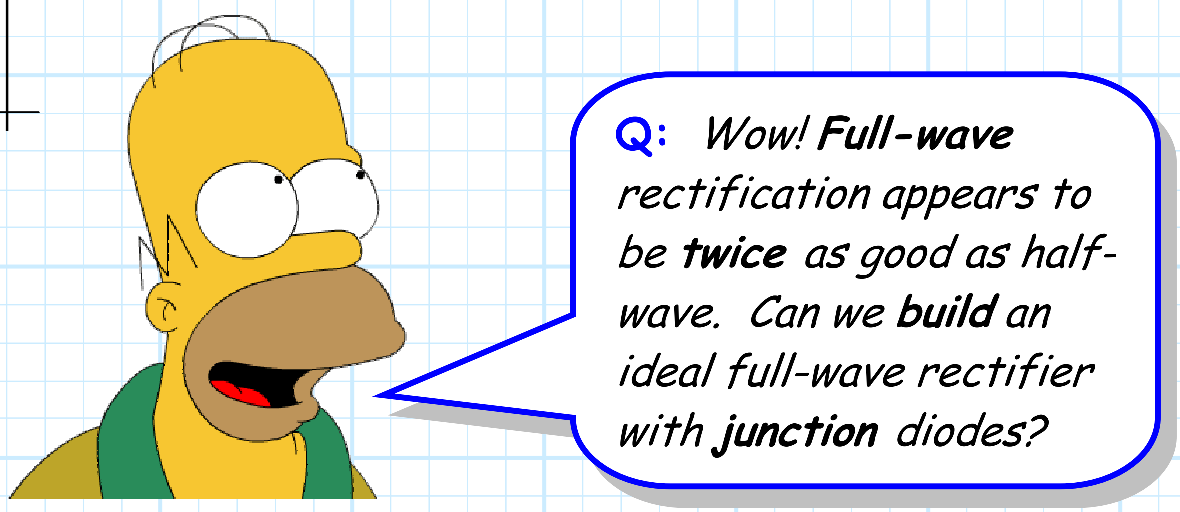
If the ideal half-wave rectifier makes **negative** inputs **zero**, the ideal full-wave rectifier makes **negative** inputs—**positive**! For **example**, if we again consider our **sinusoidal** input, we find that the output will be:



The result is that the output signal will have a DC component **twice** that of the ideal half-wave rectifier!

$$
\begin{aligned}
V_O &= \frac{1}{T}\int_0^T v_O(t)\,dt \\
&= \frac{1}{T}\int_0^{T/2} A\sin\omega t\,dt - \frac{1}{T}\int_{T/2}^{T} A\sin\omega t\,dt = \frac{2A}{\pi}
\end{aligned}
$$





A: Although we cannot build an **ideal** full-wave rectifier with **junction** diodes, we can build full-wave rectifiers that are **very close** to ideal with junction diodes!