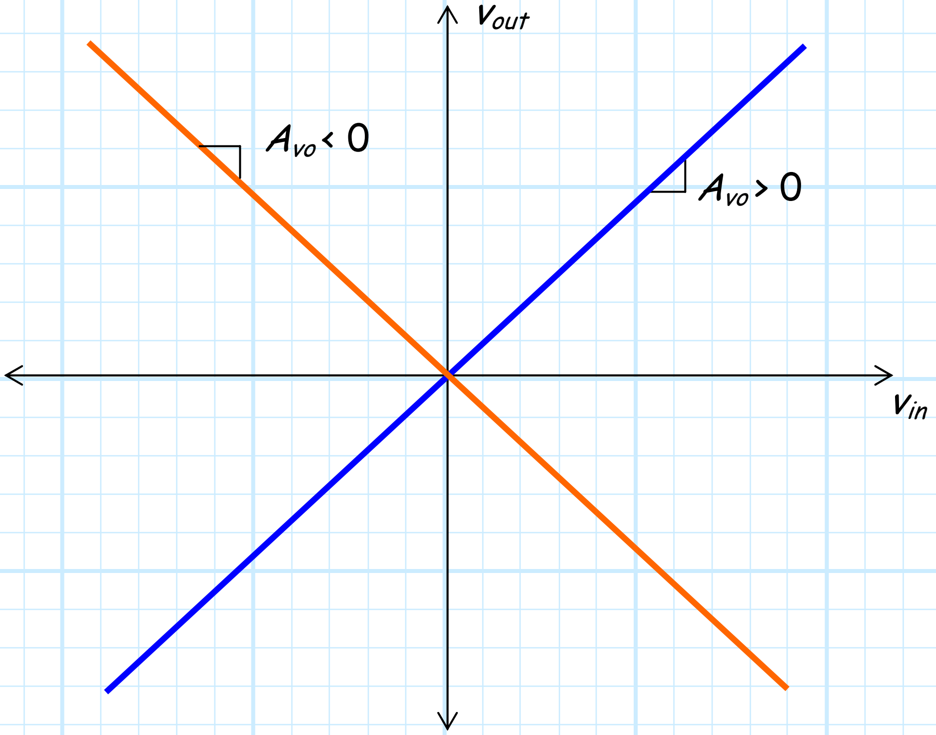
Output Voltage Saturation

Recall that the **ideal** transfer function implies that the **output voltage** of an amplifier can be **very** large, provided that the gain A_{vo} and the input voltage v_{in} are large.



The output voltage is limited

However, we found that in a "real" amplifier, there are **limits** on how large the output voltage can become.

The transfer function of an amplifier is more **accurately** expressed as:

$$v_{out}(t) = \begin{cases} L_+ & v_{in}(t) > L_+^{in} \\ A_{vo}\, v_{in}(t) & L_-^{in} < v_{in}(t) < L_+^{in} \\ L_- & v_{in}(t) < L_-^{in} \end{cases}$$

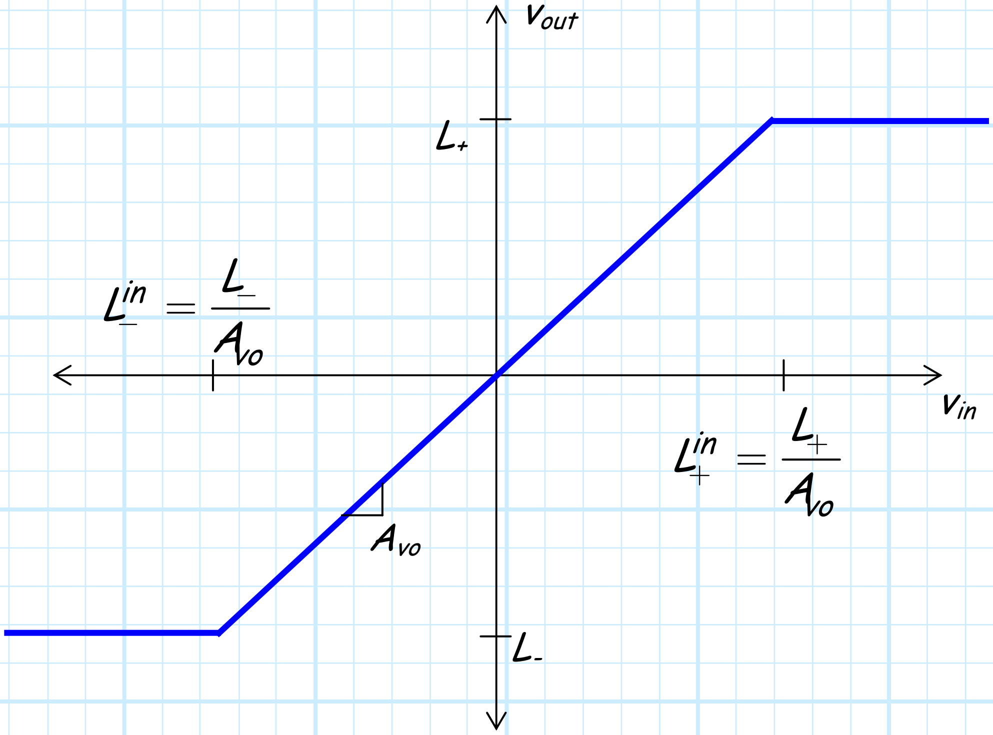
A non-linear behavior!

This expression is shown **graphically** as:

This expression (and graph) shows that electronic amplifiers have a **maximum** and **minimum** output voltage (L_+ and L_-).

If the **input** voltage is either too large or too small (too negative), then the amplifier **output** voltage will be equal to either L_+ or L_- .

If $v_{out} = L_+$ or $v_{out} = L_-$, we say the amplifier is in **saturation** (or compression).



Make sure the input isn't too large!

Amplifier saturation occurs when the **input** voltage is **greater** than:

$$v_{in} > \frac{L_+}{A_{vo}} \doteq L_+^{in}$$

or when the **input** voltage is **less** than:

$$v_{in} < \frac{L_-}{A_{vo}} \doteq L_-^{in}$$

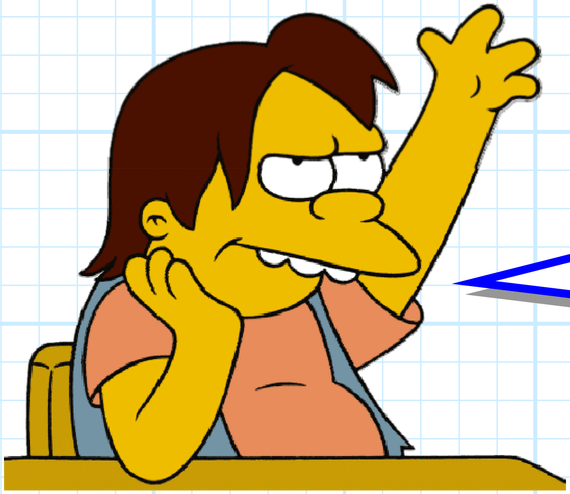
Often, we find that these voltage limits are **symmetric**, i.e.:

$$L_- = -L_+ \quad \text{and} \quad L_-^{in} = -L_+^{in}$$

For example, the output limits of an amplifier might be L_+ = 15 V and L_- = -15 V.

However, we find that these limits are also often **asymmetric** (e.g., L_+ = +15 V and L_- = +5 V).

Saturation: Who really cares?

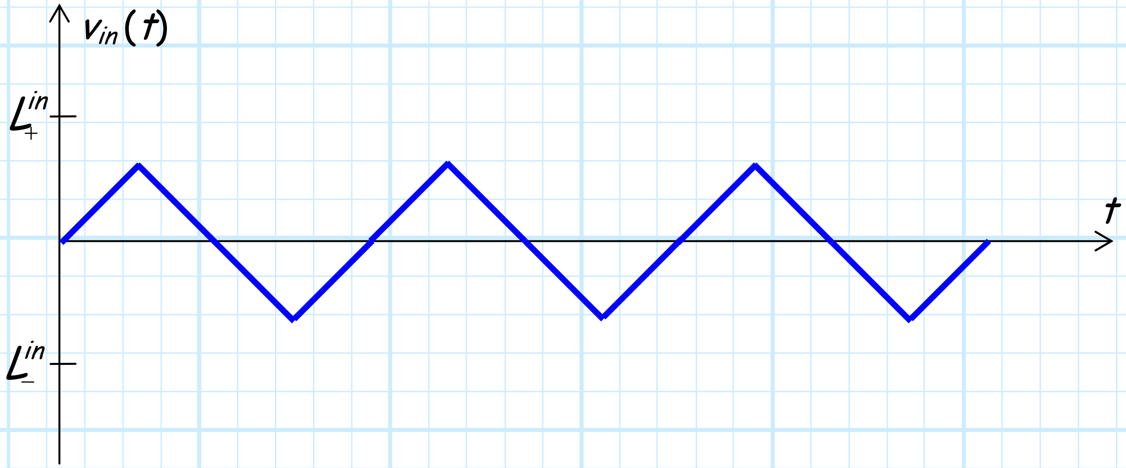


Q: *Why do we **care** if an amplifier saturates? Does it cause any **problems**, or otherwise result in performance **degradation**??*

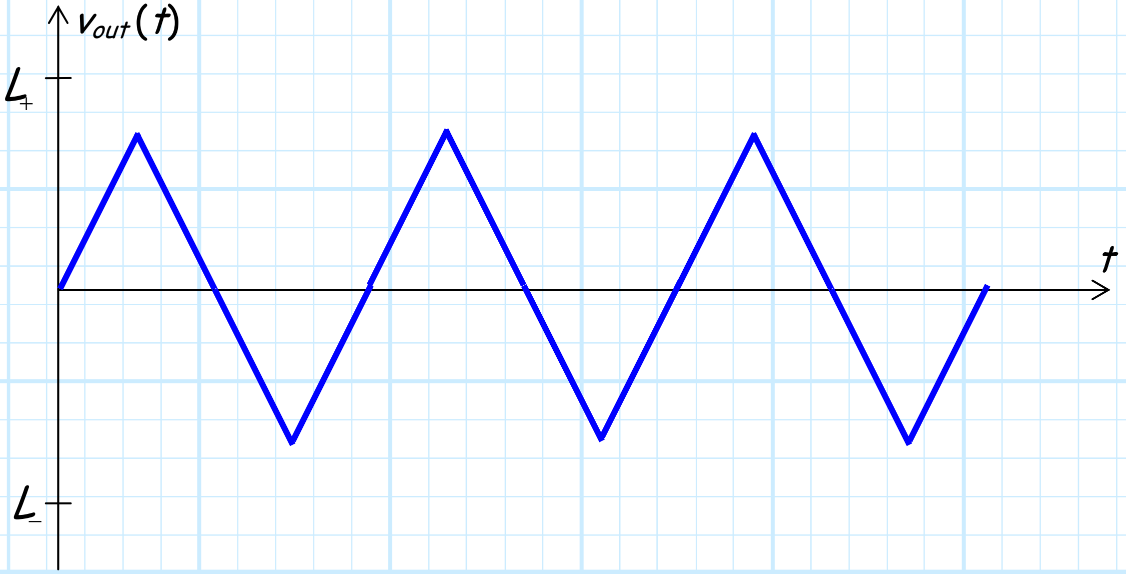
A: **Absolutely**! If an amplifier saturates—even momentarily—the unavoidable result will be a **distorted** output signal.

A distortion free example

For example, consider a case where the input to an amplifier is a **triangle** wave:

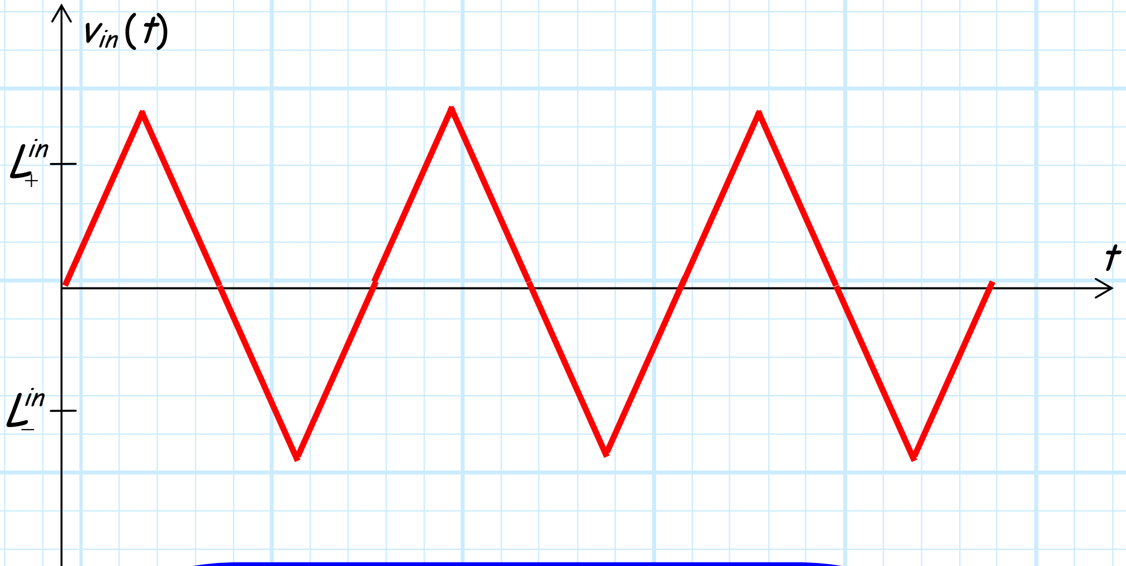


Since $L_-^{in} < v_{in}(t) < L_+^{in}$ for all time t, the **output** signal will be within the limits L_+ and L_- for all time t, and thus the amplifier output will be $v_{out}(t) = A_{vo}\, v_{in}(t)$:



The input is too darn big!

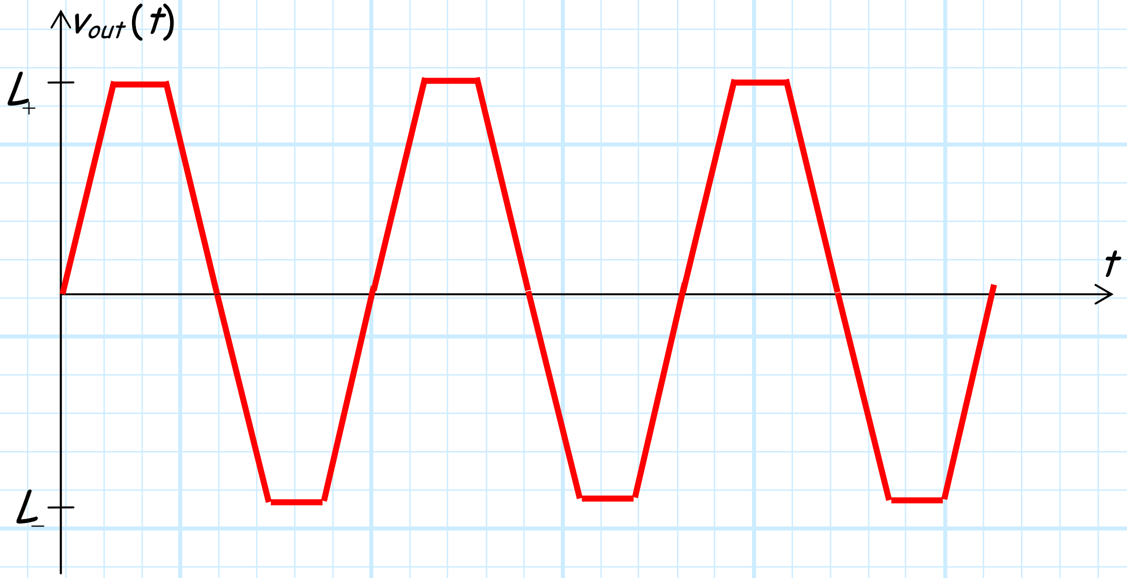
Consider now the case where the input signal is much **larger**, such that $v_{in}(t) > L_+^{in}$ and $v_{in}(t) < L_-^{in}$ for some time t (e.g., the input triangle wave **exceeds** the voltage limits L_+^{in} and L_-^{in} some of the time):



This is precisely the situation about which I earlier expressed ***caution****.*

We now must experience the palpable agony of ***signal distortion****!*

Palpable agony



Note that this output signal is **not** a triangle wave!

For time t where $v_{in}(t) > L_+^{in}$ and $v_{in}(t) < L_-^{in}$, the value $A_{vo}\, v_{in}(t)$ is greater than L_+ and less than L_-, respectively.

Thus, the output voltage is limited to $v_{out}(t) = L_+$ and $v_{out}(t) = L_-$ for these times.

As a result, we find that output $v_{out}(t)$ does **not** equal $A_{vo}\, v_{in}(t)$ —the output signal is **distorted**!

Amplifiers with op-amps

For amplifiers constructed with op-amps, the voltage limits L_+ and L_- are determined by the DC Sources V^+ and V^-:

$$L_+ \approx V^+ \quad \text{and} \quad L_- \approx V^-$$