Full-Power Bandwidth

Consider now the case where the input to an op-amp circuit is sinusoidal, with frequency $\boldsymbol{\omega}$.

The output will thus likewise be sinusoidal, e.g.:

 $v_{out}(t) = V_o \sin \omega t$

where V_o is the magnitude of the output sine wave.

Q: Under what conditions is this output signal possible? In other words, might this output signal be **distorted**?

A: First, the output will not be saturated if:

$$V_o \leq L_+ \approx V^+$$
 and $-V_o \geq L_- \approx V^-$.

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The time derivative

Q: So, the output will not be distorted if the above statement is true?

A: Be careful!

It **is** true that the output will **not** saturate if magnitude of the sinewave is smaller than the saturation limits.

However, this is not the only way that the signal can be distorted!

Q: I almost forgot! A signal can **also** be distorted by **slew-rate limiting**. Could this problem possibly affect a sine wave output?

A: Recall that the **slew rate** is a limit on the **time derivative** of the output signal.

The time derivative of our sine wave **output** is:

 $\frac{d v_{out}(t)}{dt} = \omega V_o \cos \omega t$

The max and min

Note that the time derivative is proportional to the signal frequency ω .

Makes sense!

As the output signal frequency **increases**, the output voltage changes more **rapidly** with time.

Also note however, that this derivative is a likewise a function of time. The maximum value occurs when $\cos \omega t = 1$, i.e.:

$$\frac{d v_{out}(t)}{dt} \bigg|_{\max} = w V_o$$

while the **minimum** value occurs when $\cos \omega t = -1$, i.e.,:

$$\frac{d v_{out}(t)}{dt}\Big|_{\min} = -\omega V_o$$

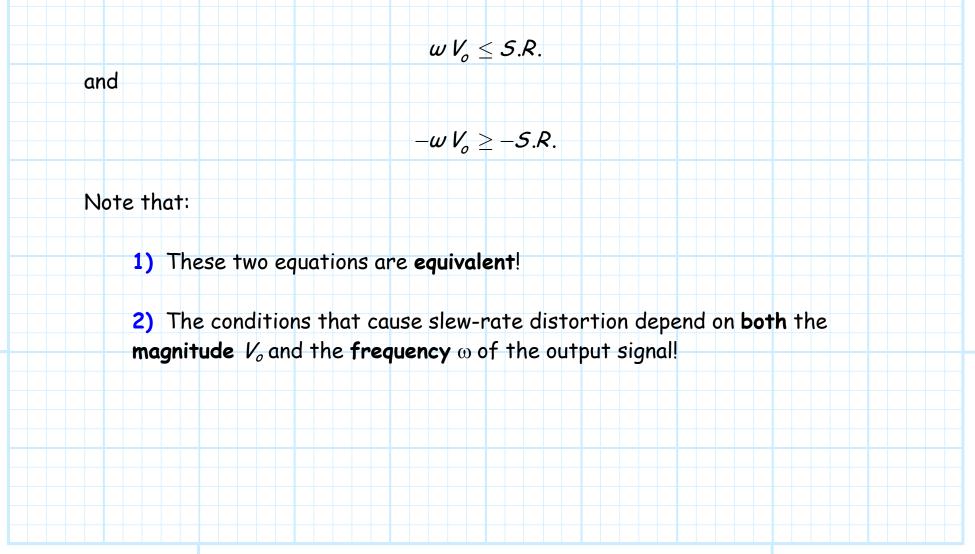
Thus, we find that the output signal will **not** be distorted if these values are within the **slew rate limits** of the op-amp.

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<u>A simple way to determine</u> you are slew rate limited

In other words, to avoid distortion by slew rate limiting, we find:



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The frequency can only be so large

Now, recall that there are limits on the magnitude alone, that is:

$$V_o \leq L_+ \approx V^+$$

to avoid saturation.

Let's assume that the output sine wave is as large as it can be without saturating, i.e., $V_o = V^+$ and thus:

$$v_{out}(t) = V^+ \sin \omega t$$

We then find to avoid slew-rate limiting:

$$wV^+ < S.R.$$

Rearranging, a limit on the **maximum frequency** for this sine wave output (one with maximum amplitude) is:

 $w < \frac{S.R.}{V^+} \doteq w_M$

Full-Power bandwidth

The value:

$$w_{M} = SR/V^{+}$$

is called the **full-power bandwidth** of the op-amp (given a DC supply V^+).

It equals the largest frequency a full-power (i.e., $V_o = V^+$) sine wave can obtain without being distorted by slew rate limiting!

Thus, if the input signal to $\omega V^+ < S.R.$ an op-amp circuit is a sine wave, we **might** have to worry about slew rate limiting, **if** the signal frequency is greater than the full-power bandwidth (i.e., $\omega > \omega_M$).

<u>I'll find out from the exam</u> if you read this page

Please note these important facts about full-power bandwidth:

- 1) The analysis above was performed for a sine wave signal. It is explicitly accurate only for a sine wave signal. For some other signal, you must determine the time derivate, and then determine its maximum (or minimum) value!
- 2) Full-power bandwidth is completely different than the closed-loop amplifier bandwidth. For example, a signal with a frequency greater than the closed-loop amplifier bandwidth will not result in a distorted signal!
- 3) Distortion due to slew-rate limiting depends **both** on signal amplitude V^+ and signal frequency ω . Thus, as sine wave whose frequency is much greater than the full-power bandwidth (i.e., $\omega \gg \omega_M$) may be undistorted
 - if its amplitude V^+ is sufficiently small.