# Full-Power Bandwidth

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

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**:

$$V_o \leq L_+ \approx V^+ \qquad \text{and} \qquad -V_o \geq L_- \approx V^- .$$

# 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** $\omega$.

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,:

$$\left.\frac{d\, v_{out}(t)}{dt}\right|_{max} = \omega\, V_o$$

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

$$\left.\frac{d\, v_{out}(t)}{dt}\right|_{min} = -\omega V_o$$

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

# A simple way to determine you are slew rate limited

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

$$\omega V_o \leq S.R.$$

and

$$-\omega V_o \geq -S.R.$$

Note that:

**1)** These two equations are **equivalent**!

**2)** The conditions that cause slew-rate distortion depend on **both** the **magnitude** $V_o$ and the **frequency** $\omega$ of the output signal!

# 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:

$$\omega V^+ < S.R.$$

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

$$\omega < \frac{S.R.}{V^+} \doteq \omega_M$$

# Full-Power bandwidth

The value:

$$\omega_M = SR/V^+$$

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

It eauals 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., $\omega > \omega_M$).

# I'll find out from the exam 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 $\omega$. 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**.