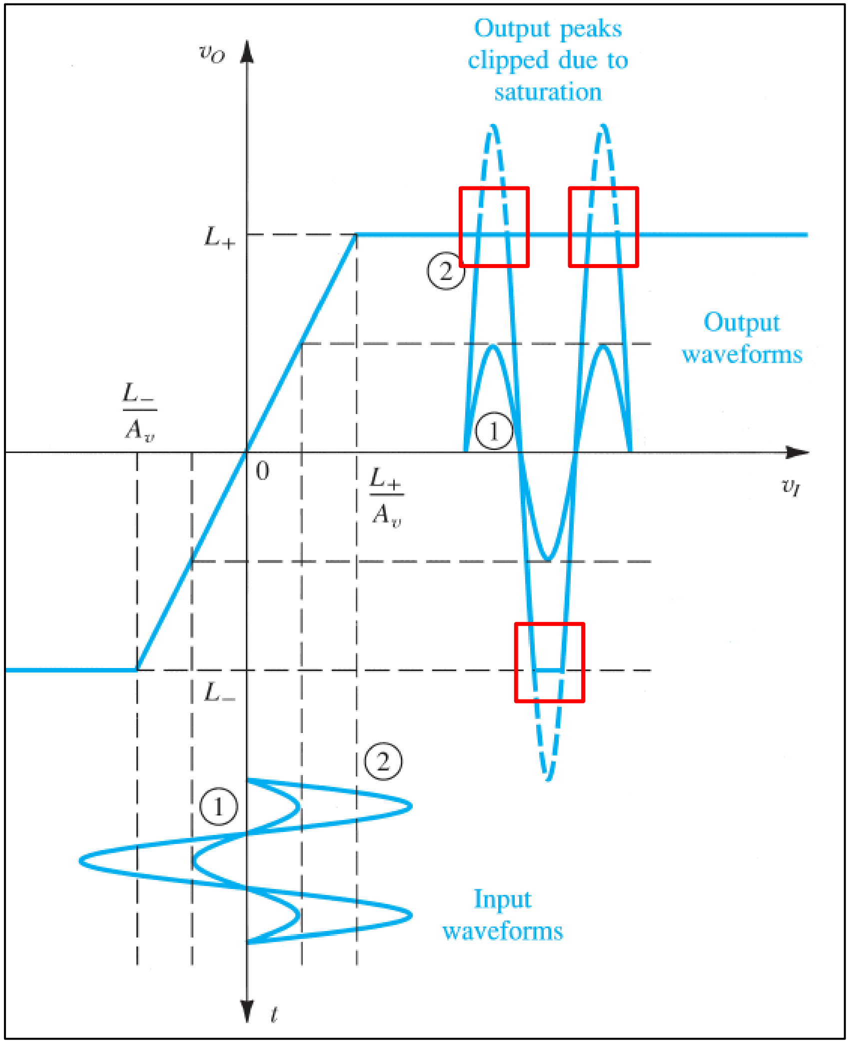
Op Amp Imperfections

- Large-Signal Operation
- Output Current Limits
- Slew Rate

Large-Signal Operation of Op Amps

Output Voltage Saturation

Similar to all other amplifiers, op amps operate linearly over a limited range of output voltages. Specifically, **the op-amp output saturates in the manner shown below with *L*+ and *L*– within 1 V or so of the positive and negative power supplies**, respectively. Thus, to avoid clipping off the peaks of the output waveform, and the resulting waveform distortion, the input signal must be kept correspondingly small.



An amplifier transfer characteristic that is linear except for output saturation

Output Current Limits

Another limitation on the operation of op amps is that their output current is limited to a specified maximum. For instance, **the popular 741 op amp is specified to have a maximum output current of ± 20mA**.

Thus, in designing closed-loop circuits utilizing the 741, the designer has to ensure that under no condition will the op amp be required to supply an output current, in either direction, exceeding 20 mA. **This, of course, has to include both the current in the feedback circuit as well as the current supplied to a load resistor**.

If the circuit requires a larger current, the op-amp output voltage will saturate at the level corresponding to the maximum allowed output current !

Slew Rate

1 Another phenomenon that can cause nonlinear distortion when large output signals are present is slew-rate limiting. The name refers to the fact that there is a specific **maximum rate of change possible at the output** of a real op amp. This maximum is known as the **slew rate** (**SR**) of the op amp and is defined as

$$\mathrm{SR} = \left.\frac{dv_O}{dt}\right|_{\max}$$

and is **usually specified on the op-amp data sheet in units of V/μs**. It follows that if the input signal applied to an op-amp circuit is such that it demands an output response that is faster than the specified value of SR, the op amp will not comply. Rather, its output will change at the maximum possible rate, which is equal to its SR.

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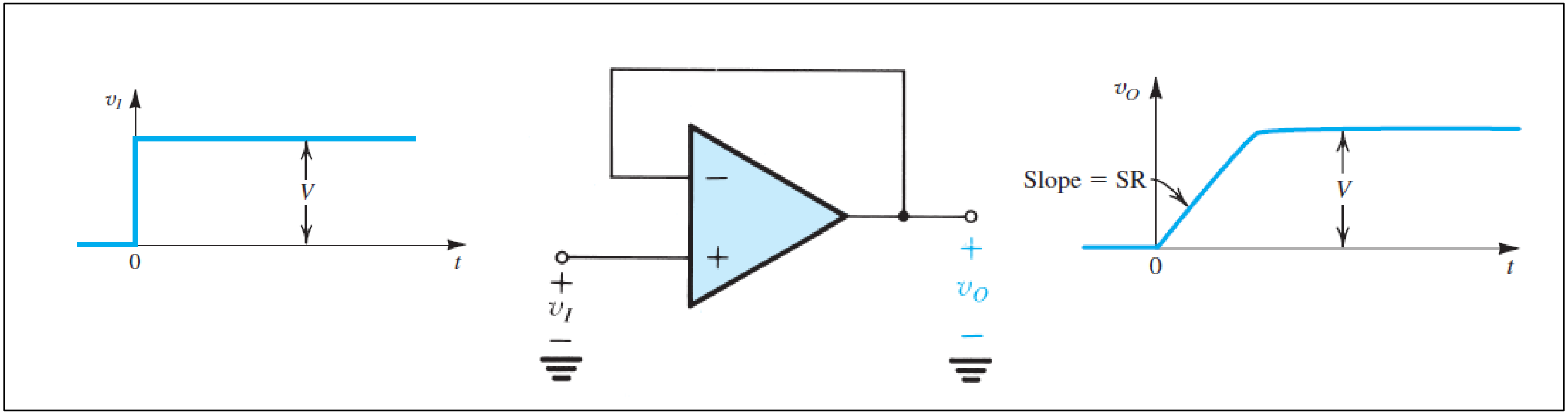
As an example, consider an op amp connected in the unity-gain voltage-follower configuration shown below, and let the input signal be the step voltage shown in the figure.

The output of the op amp will not be able to rise instantaneously to the ideal value *V*; rather, the output will be the linear ramp of slope equal to SR, as shown. The amplifier is then said to be **slewing**, and its output is **slew-rate limited**.



Full-Power Bandwidth

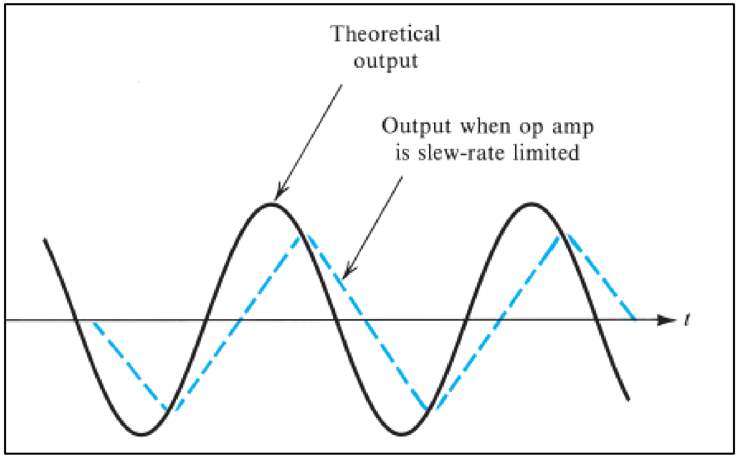
Op-amp slew-rate limiting can cause nonlinear distortion in sinusoidal waveforms. Consider once more the unity-gain follower with a sine-wave input given by

$$v_I = \hat{V}_i \sin \omega t$$

The **rate of change** of this waveform is given by

$$\frac{dv_I}{dt} = \omega \hat{V}_i \cos \omega t$$

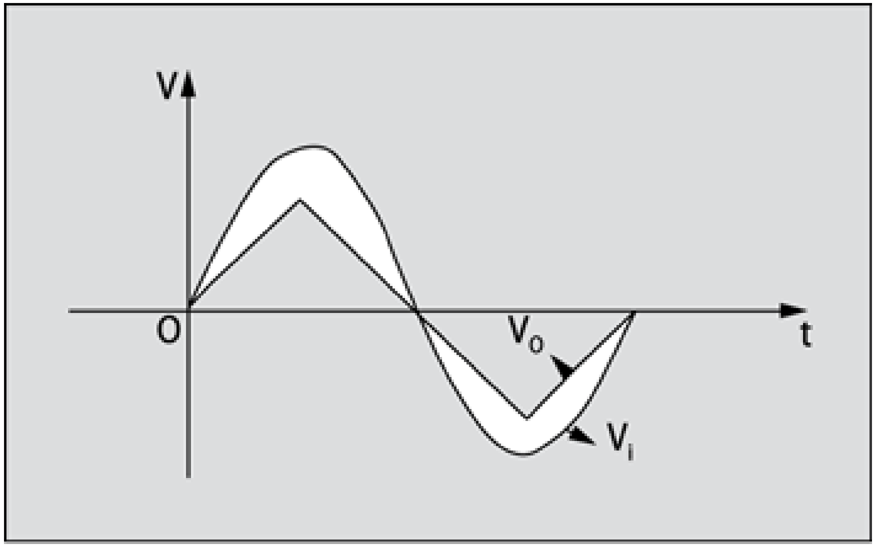
with a **maximum value of wV_i. This maximum occurs at the zero crossings of the input sinusoid**. Now if wV_i exceeds the slew rate of the op amp, the output waveform will be distorted in the manner shown below. Observe that the output cannot keep up with the large rate of change of the sinusoid at its zero crossings, and the op amp slews.



The op-amp data sheets usually specify a frequency f_M called the **full-power bandwidth**. It is the frequency at which an output sinusoid with amplitude equal to the rated output voltage of the op amp begins to show distortion due to slew-rate limiting.

If we denote the rated output voltage V_{omax} then f_M is related to SR as follows:

$$\omega_M V_{omax} = SR \longrightarrow f_M = \frac{SR}{2\pi V_{omax}}$$



CA741

SR = 0,5 X 10^6 V/s, V_{out} = 12V

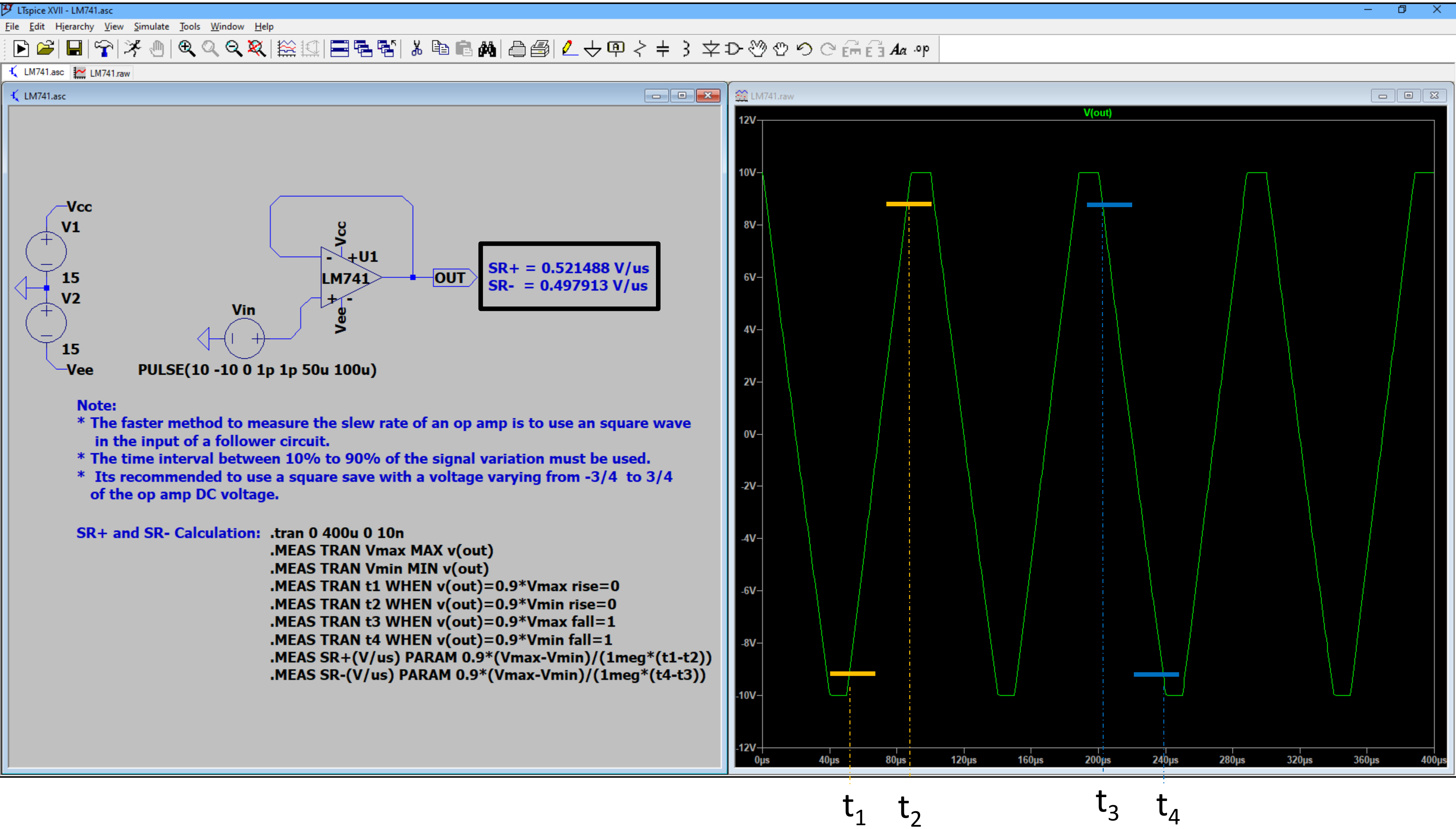
f ≈ 6.63 KHz

LM318

SR = 55 X 10^6 V/s, V_{out} = 12V

f ≈ 730 KHz

Measurement of SR with the LTSPice



$$SR^{+} = \frac{0.9(V_{max} - V_{min})}{(t_2 - t_1)}$$

$$SR^{-} = \frac{0.9(V_{max} - V_{min})}{(t_4 - t_3)}$$