The slewing-rate limitation will not only cause distortion of the output for square-wave inputs, but also distort the output for sine-wave inputs of sufficiently high frequency. The slew rate limits the maximum slope of the sinusoidal output, and by equating the sine wave's maximum slope to the slew-rate limit, the full-power bandwidth is found:

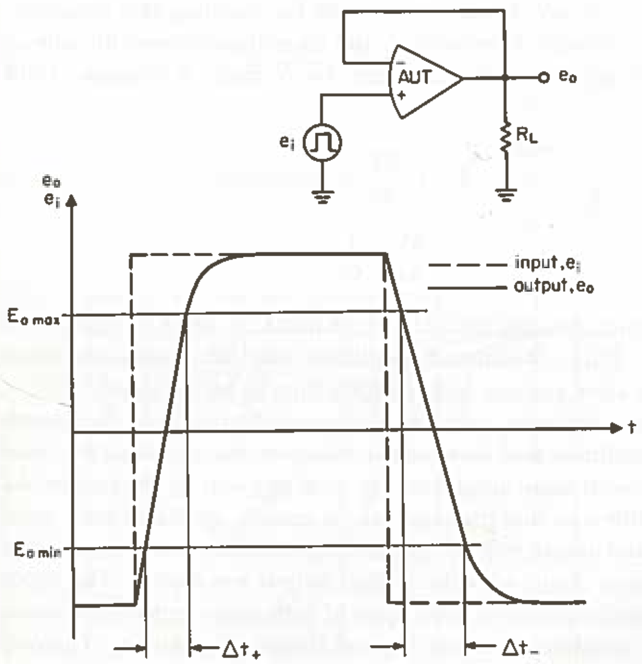
$$e = E_p \sin 2\pi f t$$

$$\left|\frac{de}{dt}\right| = 2\pi f E_p \cos 2\pi f t$$

$$S_R = \left|\frac{de}{dt}\right|_{\max} = 2\pi f_p E_p$$

$$f_p = \frac{S_R}{2\pi E_p} \qquad (1\text{–}24)$$

where E_p is the peak amplitude of the sine wave. Generally, the full-power bandwidth is specified for rated output, which is typically ±10 V.



$$S_{R+} = \frac{E_{o\,max} - E_{o\,min}}{\Delta t_+}, \quad S_{R-} = \frac{E_{o\,max} - E_{o\,min}}{\Delta t_-}$$

Fig. 1.24 The slew rate of practical operational amplifiers is frequently unsymmetrical, requiring testing for both positive and negative transitions.

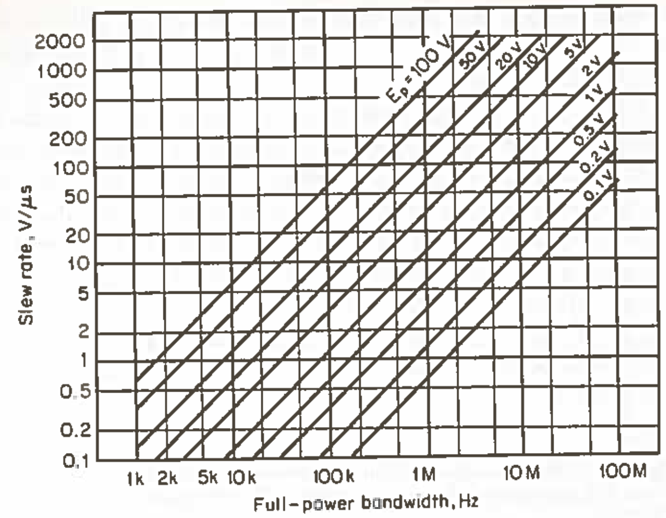


Fig. 1.25 Full-power bandwidth is theoretically related to slew rate, and is the primary frequency limitation when the output swing is large.

However, the full-power bandwidth for reduced output swing is frequently of most interest, and it can be found from Eq. (1–24), or from the graph in Fig. 1.25.

With the graphs in Figs. 1.23 and 1.25, the upper frequency limit of an operational amplifier circuit can be found. With the amplifier's slew-rate specification and the sine-wave amplitude required, the full-power bandwidth is determined from Fig. 1.25 or Eq. (1–24). Then, if the frequency of interest is less than the full-power bandwidth, the magnitude and vector errors can be found from Fig. 1.23. Note that if the frequency of interest is above the full-power bandwidth of the amplifier, the graph in Figure 1.23 does not apply, since it is generated for linear frequency response.

1.3.3 Settling time Settling time is the time required following application of an input step for the output to settle to within a specified error band of its final value. A complex output step response, containing overshoot and ring, is shown in Fig. 1.26. The settling time t_s is a strong function of the error-band η specified, particularly when there is output ring following a step input.

General-purpose amplifiers are usually phase-compensated to have a single-pole frequency response, as discussed previously in Sec. 1.3.1. Such an amplifier's output response to a step input $E_I u(t)$ can be found from the inverse Laplace transform of Eq. (1–23):

$$e_o(t) = A_{CL}\,(1 - e^{-t\beta\omega_T})E_I$$