Content

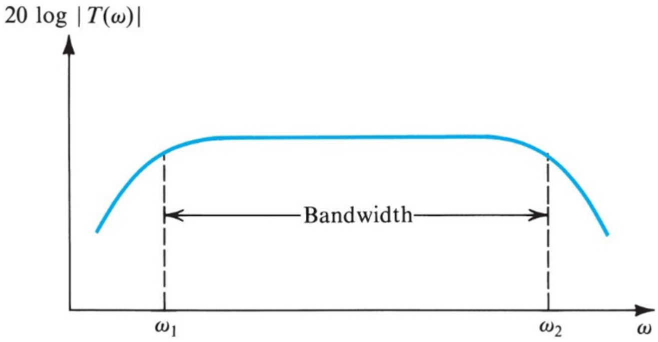
Signals and Spectra (book 1.1-1.3)

Amplifiers (book 1.4-1.6)

- Frequency Response

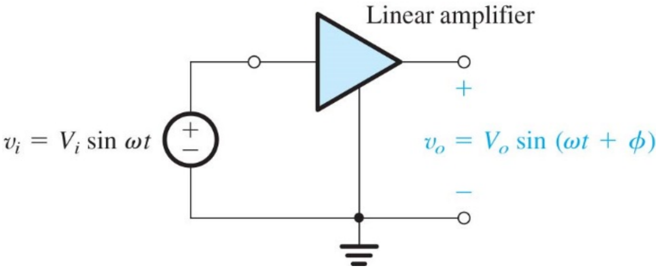
Frequency Response

(This behaviour is not explained by the simple model! Capacitors and/or inductors are needed.)

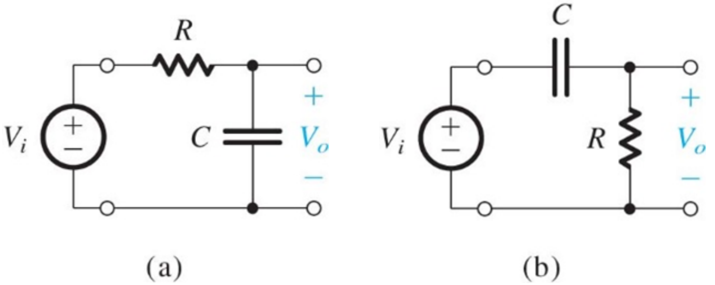


Linear Amplifier

Linear here means that there is no distortion of a fixed frequency sinusoid. Equivalet in math-speak: the amplifier/filter output can be modelled as a linear differential equation of the input signal. An amplifier composed of but linear elements will behave like that, including somewhat more complicated models than our first purely resistive model ...



Single Time Constant Networks



STC netwoks are circuits that can be expressed as a first order linear differential equation of the input. When the input voltage source provides a signal the STC network is a *filter* with a specific *transfer function*, i.e. a frequency dependent complex number that describes how the *spectrum* of the input is modified at each frequency, i.e. it is a *frequency* (ω) *dependent gain* expressed as function $T(j\omega) = \frac{y(j\omega)}{x(j\omega)}$ for a filter projecting signal x onto signal y. Often the abreviation $s = j\omega$ is used.

Transfer Function

The Transfer function $T(s) = \frac{y(s)}{x(s)}$ for linear electronic circuits can be written as dividing two polynomials of s (for us s is simply short for $j\omega$).

$$T(s) = \frac{a_0 + a_1 s + ... + a_m s^m}{1 + b_1 s + ... + b_n s^n}$$

$T(s)$ is often written as products of first order terms in both nominator and denominator in the following *root form*, which is conveniently showing some properties of the Bode-plots. More of that later.

$$T(s) = a_0 \frac{(1 + \frac{s}{z_1})(1 + \frac{s}{z_2})...(1 + \frac{s}{z_m})}{(1 + \frac{s}{\omega_1})(1 + \frac{s}{\omega_2})...(1 + \frac{s}{\omega_n})}$$

Transfer Function

The transfer function $T(s)$ of a linear filter is

- the Laplace transform of its impulse reponse $h(t)$.
- the Laplace transform of the differential equation describing the I/O realtionship that is then solved for $\frac{V_{out}(s)}{V_{in}(s)}$
- (easiest!!!) the circuit diagram solved quite normally for $\frac{V_{out}(s)}{V_{in}(s)}$ by putting in impedances $Z(s)$ for all linear elements according to some simple rules (next page).

Impedances of Linear Circuit Elements

resistor:	R
capacitor:	$\frac{1}{sC}$
inductor:	sL

Ideal linearly dependent sources (e.g. the $i_d = g_m v_{gs}$ sources in small signal models of FETs) are left as they are.

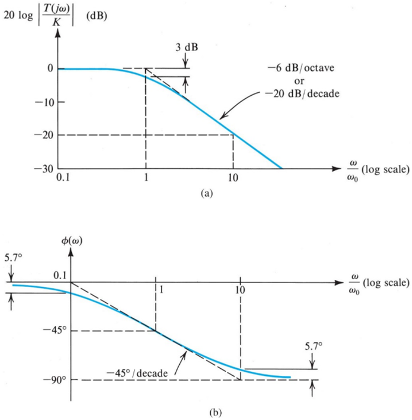
Single Time Constant Transfer Functions

Table 1.2 Frequency Response of STC Networks

	Low-Pass (LP)	High-Pass (HP)
Transfer Function $T(s)$	$\frac{K}{1+(s/\omega_0)}$	$\frac{Ks}{s+\omega_0}$
Transfer Function (for physical frequencies) $T(j\omega)$	$\frac{K}{1+j(\omega/\omega_0)}$	$\frac{K}{1-j(\omega_0/\omega)}$
Magnitude Response $\lvert T(j\omega)\rvert$	$\frac{\lvert K\rvert}{\sqrt{1+(\omega/\omega_0)^2}}$	$\frac{\lvert K\rvert}{\sqrt{1+(\omega_0/\omega)^2}}$
Phase Response $\angle T(j\omega)$	$-\tan^{-1}(\omega/\omega_0)$	$\tan^{-1}(\omega_0/\omega)$
Transmission at $\omega = 0$ (dc)	K	0
Transmission at $\omega = \infty$	0	K
3-dB Frequency	$\omega_0 = 1/\tau$; $\tau \equiv$ time constant $\tau = CR$ or L/R	
Bode Plots	in Fig. 1.23	in Fig. 1.24

Bode Plot

1^{st} Order Low-Pass Filter



Content

The Ideal Opamp (book: 2.1)

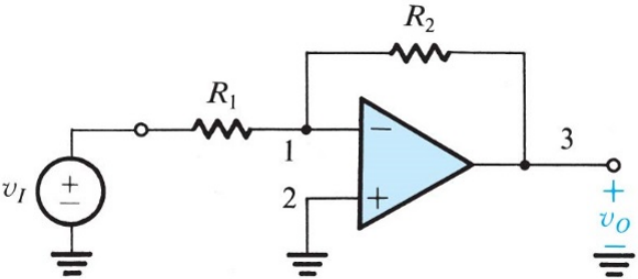
Some Circuits with OpAmps (book:2.2-2.5)

DC Imperfections (book:2.6)

Closed Loop Frequency Response (book:2.7)

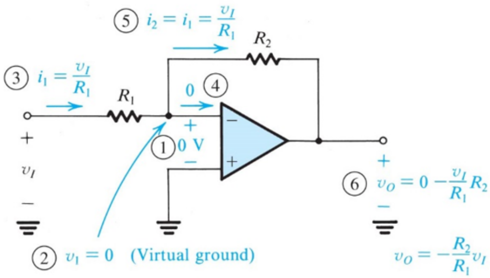
Large Signal (Non-Linear) Effects (book:2.8)

Basic Inverting Amplifier



$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} \quad \text{(page 101)}$$

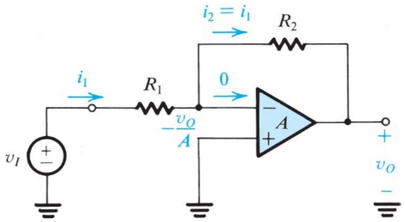
Basic Inverting Amplifier Analysis



(b)

$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} \quad (2.9)$$

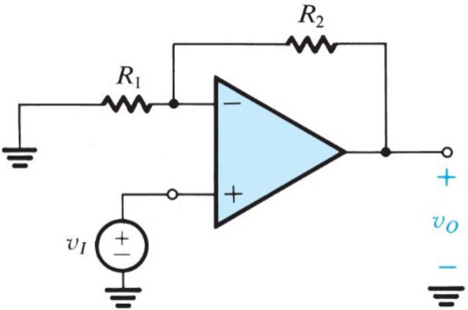
Finite Open Loop Gain



$$\frac{v_O}{v_I} = -\frac{R_2}{R_1} * \frac{1}{1 + (1 + R_2/R_1)/A} \quad (2.5)$$

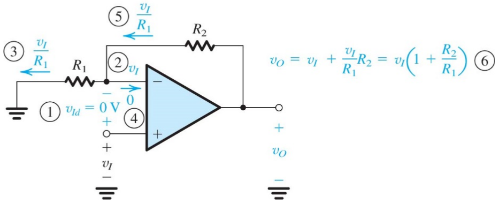
For negligible *gain error*: $1 + R_2/R_1 << A$ (page 104)

Basic Non-Inverting Amplifier



$$\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1} \quad (2.9)$$

Analysis



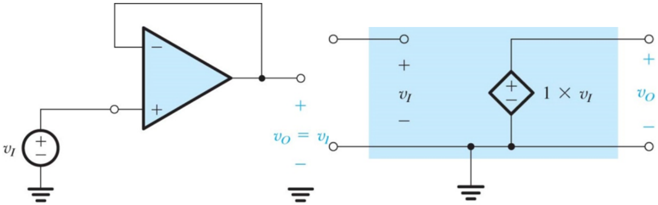
5
$\frac{v_I}{R_1}$
R_2
3
$\frac{v_I}{R_1}$
R_1
2
v_I
$v_O = v_I + \frac{v_I}{R_1}R_2 = v_I\left(1 + \frac{R_2}{R_1}\right)$
6
0
1
$v_{Id} = 0$ V
4
+
v_I
−
+
v_O
−

Finite open loop gain

$$\frac{v_O}{v_I} = (1 + \frac{R_2}{R_1})\frac{1}{1 + (1 + R_2/R_1)/A} \quad (2.11)$$

For negligible *gain error*: $1 + R_2/R_1 << A$ (page 111)

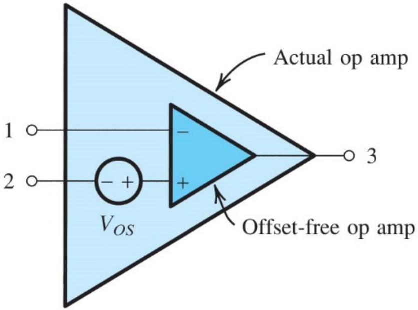
Special Case: The Follower



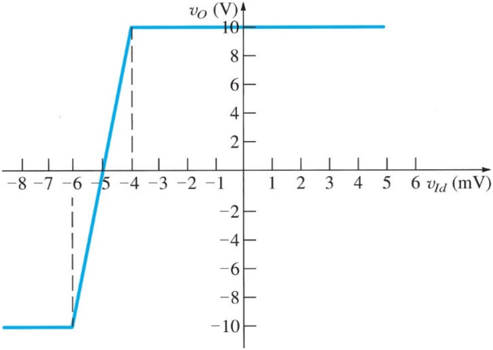
(a) (b)

Content

Input Offset Voltage



Input Offset Effect



Content

General Concept

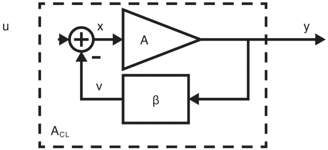


Figure 5.1

$$A_{CL} = \frac{y}{u} = \frac{A}{1 + A\beta} = \frac{A}{1 + L}$$

where $L := A\beta$

$$A_{CL} \approx \frac{1}{\beta} \quad \text{for large } L$$

β in inverting and non-inverting amp

non-inverting:

$$\beta = \frac{R_1}{R_1 + R_2} \; , \; \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

inverting:

$$\beta = \frac{R_1}{R_1 + R_2} / \frac{R_2}{R_1 + R_2} \; , \; \frac{1}{\beta} = \frac{R_2}{R_1}$$

Closed Loop Bandwidth Illustration

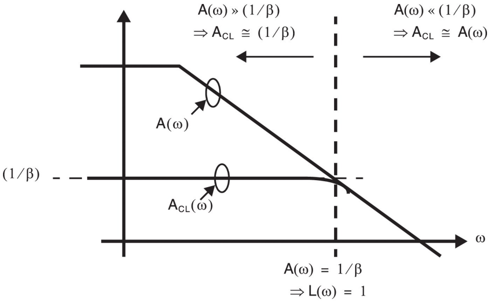
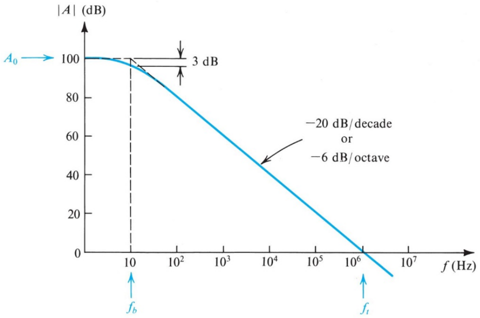


Figure 5.2

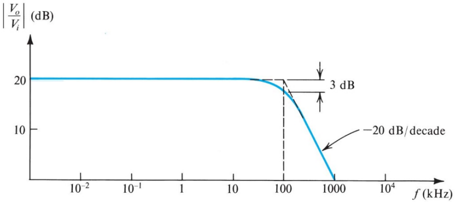
Provided the feedback loop is purely resistive, i.e. no time constant in the feedback loop.

Example Open Loop Gain



Non-Inverting Example

$$R_2/R_1 = 9\ ,\ \beta = 1/10 \Rightarrow \omega_{3dB} = \frac{\omega_t}{\beta} = 100kHz$$

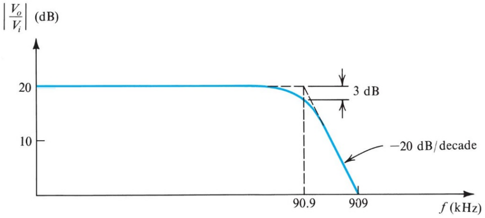


Inverting Example

$$R_2/R_1 = 10\ ,\ \beta = 1/10 \Rightarrow \omega_{3\text{dB}} = \frac{\omega_t}{\beta} = 100kHz$$

However, the open loop gain with respect to v_I:

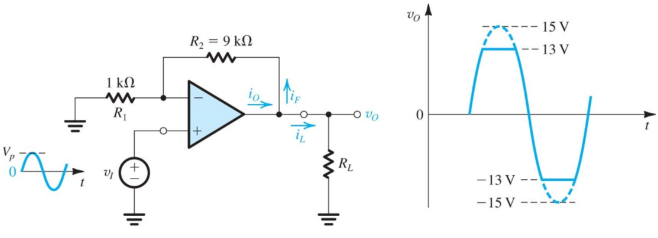
$$\omega_t' = \omega_t \left(\frac{1}{1 + R_1/R_2} \right)$$



Wait for chapter 10 for an explanation!

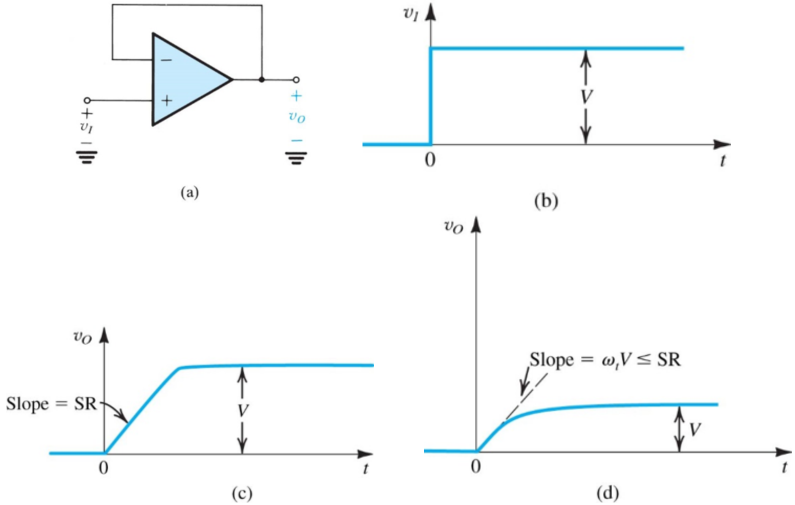
Content

Power Rail Clipping



(a) (b)

Slew Rate Effect On Step



(similar effect by absolute output current limit)

Slew Rate Effect On Sine