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THE CENTER FOR POWER ELECTRONICS AND MIXED-SIGNAL IC, BEN-GURION UNIVERSITY

Analog Electronic Circuits

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Lesson #3 Outline

- Dynamic limitations of OpAmps
  - Open-loop response
  - Gain-Bandwidth product
- Drawing A_{OL} , $1/\beta$, βA_{OL}
- Closed-loop response
  - The GBW trade-off
    - Resistive circuits
    - Frequency-dependent circuits
- Transient response
  - Slew-rate

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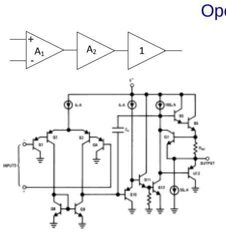
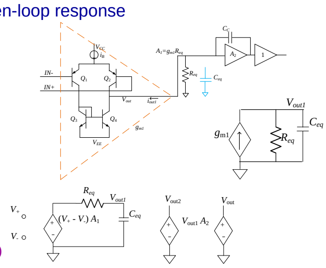
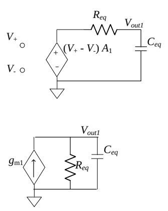
Open-loop response



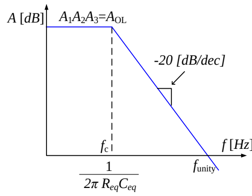


LM324 (Texas Instruments, National)

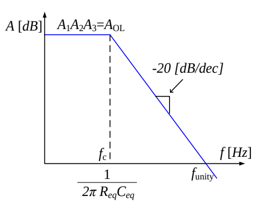
Open-loop response



$$A_{OL} = \frac{A}{1 + j\frac{f}{f_C}}$$



Gain-Bandwidth Product - GBW



$$A_{CL} = G\frac{A_{OL}}{1 + \beta A_{OL}}$$

$$\beta = 1, G = 1$$

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL}}$$

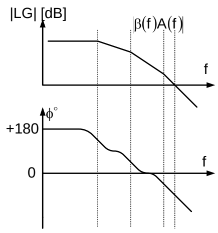
$$GBW = A_{OL} f_c = f_{unity}$$

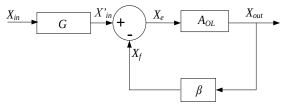
Loop-Gain
Nyquist Criterion

$$A_{CL} = G(s)\frac{A_{OL}(s)}{1 + \beta A_{OL}(s)}$$

- The system is unstable if the characteristic equation $\{1+\beta A_{OL}(s)\}$ has roots in the right half of the complex plane
- Nyquist criterion is a test for location of $\{1+\beta A_{OL}(s)\}$ roots
- Nyquist criterion can be viewed on the frequency domain (Bode)

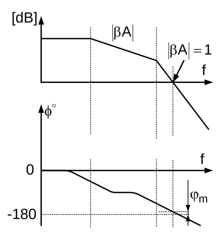
Loop-gain on the frequency domain





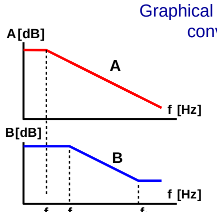
In negative feedback systems $\phi = 180^{o}\,(-180^{o})$ At $f \rightarrow 0$

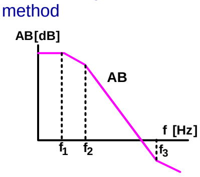
Bode plot
Phase margin



$$\varphi_m = \varphi_{|\beta A|=1} - (-180^{o}) = \varphi_{|\beta A|=1} + 180^{o}$$

Graphical representation of βA_{OL} conventional method





- Tedious – need to re-plot BA
- Analysis (not design) oriented
- Requires iterations

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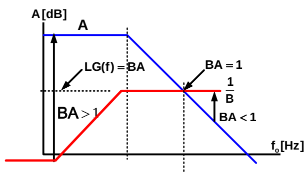
Graphical Representation of βA_{OL}

$$20\log A - 20\log\frac{1}{B} = 20\log(BA)$$

$$20\log A = 20\log\frac{1}{B} \Rightarrow B \cdot A = 1$$



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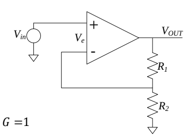
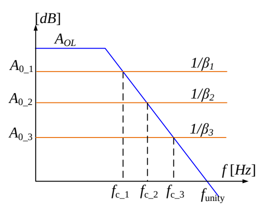
Closed-loop response
Non-inverting Amp



$G = 1$

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

$GBW = A_0 f_c = f_{unity}$



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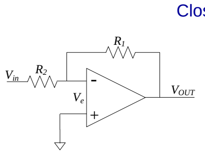
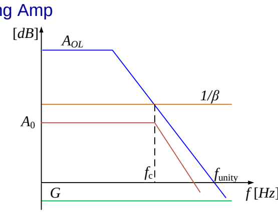
Closed-loop response
Inverting Amp



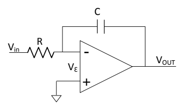
$G = \frac{R_1}{R_1 + R_2}$

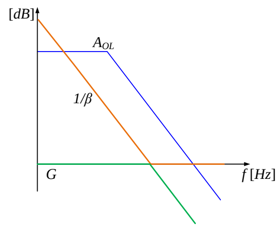
$\frac{1}{\beta} = \frac{R_1 + R_2}{R_2}$

$GBW = A_0 f_c = f_{unity}$



Closed-loop response
Integrator





$$G = \frac{1}{sCR + 1}$$

$$\frac{1}{\beta} = \frac{sCR + 1}{sCR}$$

$$GBW = A_0 f_c = f_{unity}$$

Transient response
Rise-time (ideal)