



電子回路論第5回

Electric Circuits for Physicists

東京大学理学部・理学系研究科
物性研究所
勝本信吾

Shingo Katsumoto

Outline

Introduction of a freeware “Scilab”

Ch.4 Amplification circuit

4.1 Amplification and system stability

4.1.1 What is amplifier?

4.1.2 Feedback

4.1.3 Stability of feedback

4.2 Operational amplifier (OP-amp)

4.2.1 Linear model of OP-amp

4.2.2 Package

4.2.3 Circuit examples

4.2.4 Datasheet

4.2.5 Stability

A convenient freeware: Scilab

Home - Scilab

www.scilab.org

Scilab Download Resources Community Projects Development

Download Scilab
Scilab 5.5.1 - 32-bit Windows • 127.92 MB
Other Systems

Open source software for numerical computation

Scilab Console

File Edit Control Applications ?

File Browser C:\

Name

- Perflogs
- Program Files
- Users
- Windows
- autexec.bat
- config.sys


Startup execution:
loading initial environment
-->a=rand(4,4)
a =

column 1 to 2

Name	Dimen...	Type	Visib
a	4x4	Double	
ans	1x1	Boolean	
home	1x1	String	
WSCI	1x1	String	
PWD	1x1	String	
%k	1x1	Boolean	
%F	1x1	Boolean	
%T	1x1	Boolean	
%nan	1x1	Double	
%nanf	1x1	Double	

News : 10/16/2014 - Windows users, reinstall Scilab 5.5.1 10/6/2014 - Scilab at C.

Professional Solutions



Scilab Enterprises, official publisher of Scilab software, also offers dedicated services for all its users: support, consulting, migration, training, development and implementation of specific applications...

Open Source

Scilab is open source software distributed under [CeCILL license](#). Many other [third-party projects](#) are also available.

Education

Scilab is widely used in secondary and higher education institutions for teaching [mathematics](#), [engineering sciences](#) and [automatic control engineering](#).

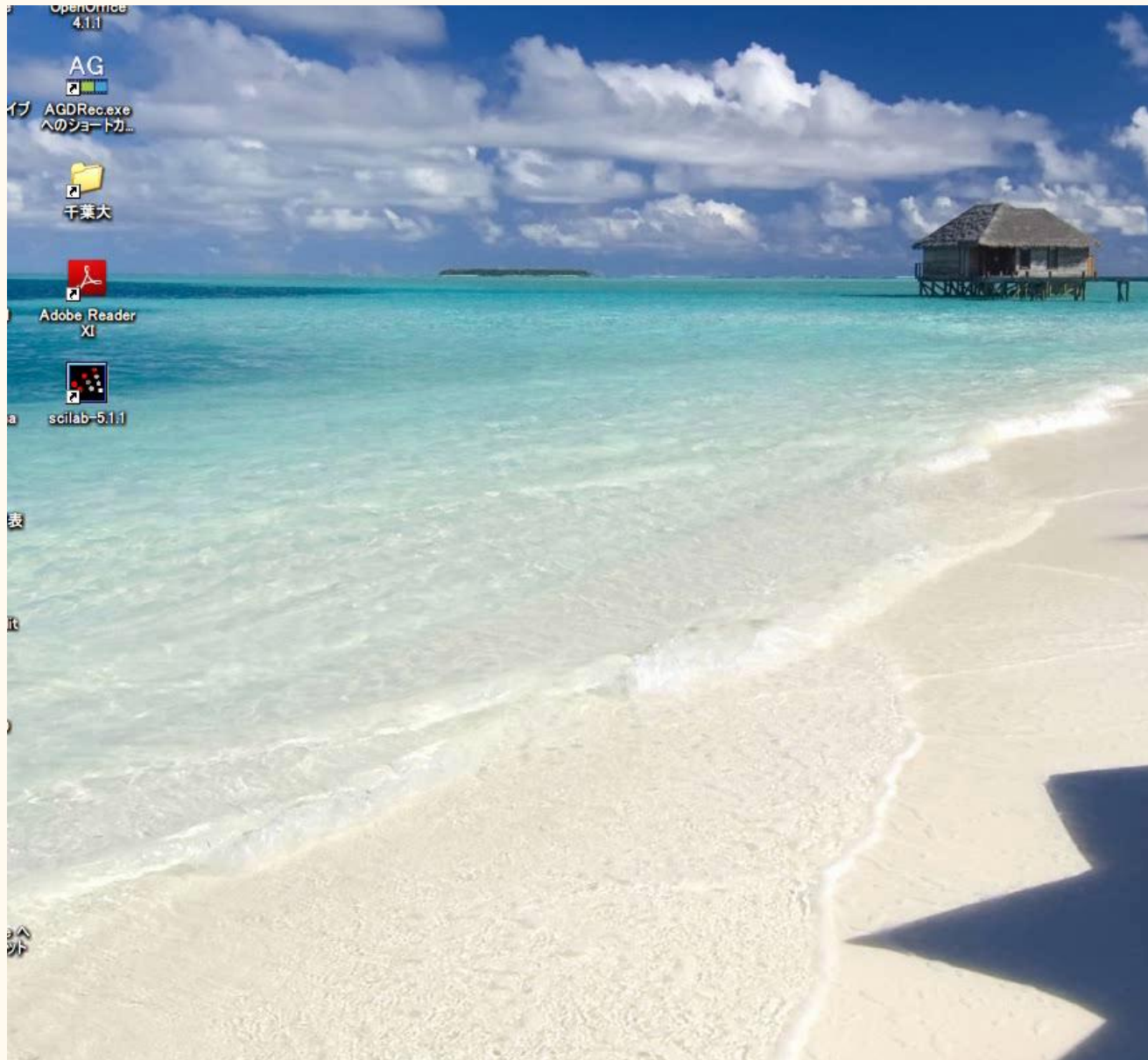
To donate

Scilab

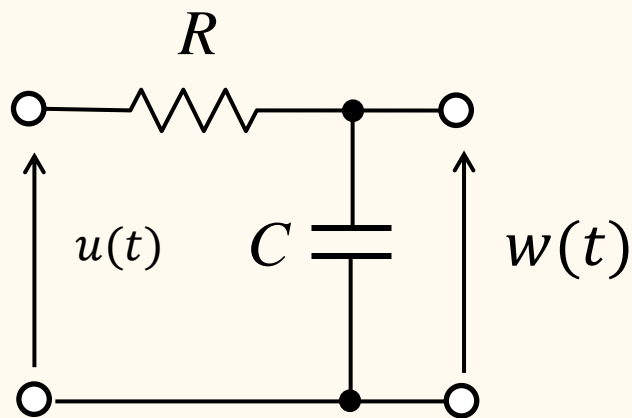
- Overview
- New in Scilab 5.5.0
- New in Scilab 5.5.1
- Xcos
- Features
- Gallery
- System requirements
- Quality



Transfer function analysis with Scilab



Simple application

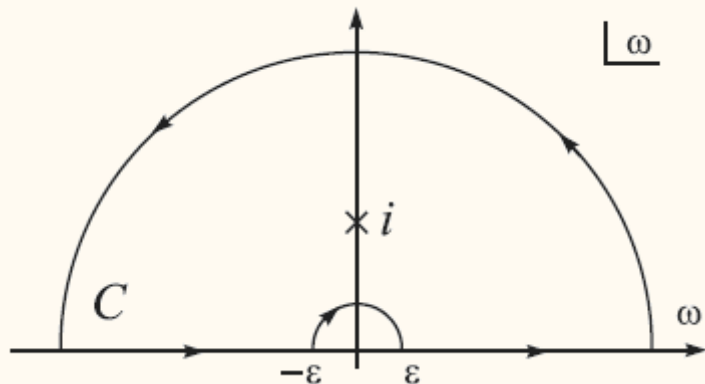


$$V = V_0 \left[1 - \exp \left(-\frac{t}{CR} \right) \right]$$

$$g(t) = \int_{-\infty}^{\infty} \frac{1}{1+i\omega} \left[\frac{1}{i\omega} + \pi\delta(\omega) \right] e^{i\omega t} \frac{d\omega}{2\pi}$$

$$= \int_{-\infty}^{\infty} \frac{e^{i\omega t}}{(i-\omega)\omega} \frac{d\omega}{2\pi} + \frac{1}{2}$$

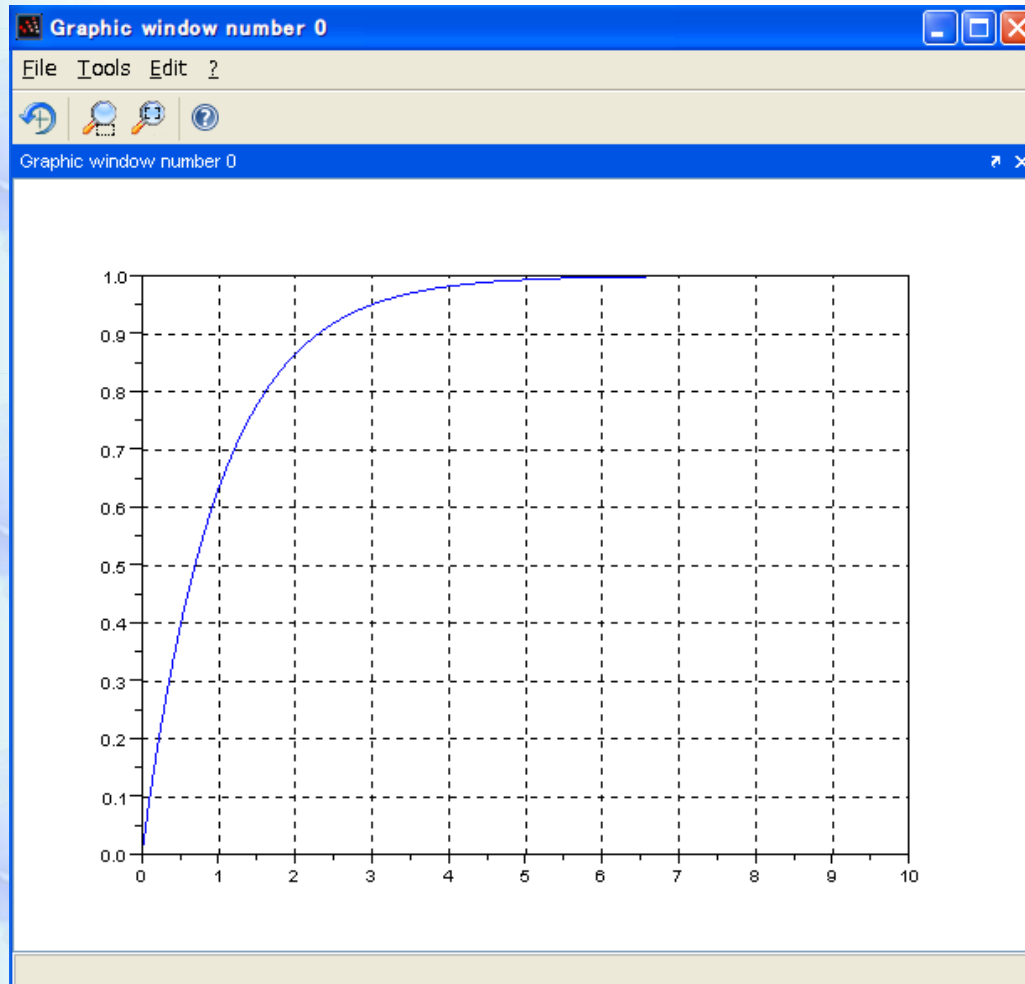
$$-2\pi i \frac{e^{-t}}{2\pi i} - \lim_{\epsilon \rightarrow 0} \left[\int_{\pi}^0 \frac{e^{i\epsilon e^{i\theta} t}}{\epsilon e^{i\theta} (\epsilon e^{i\theta} - i)} \frac{i\epsilon e^{i\theta} d\theta}{2\pi} \right] = -e^{-t} - \frac{1}{2}$$



$$g(t) = -e^{-t}$$

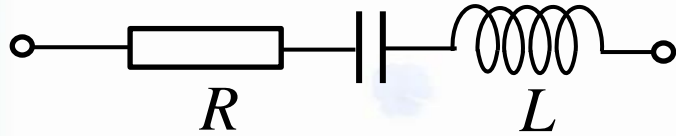
Transient response: Use of Scilab

$$\Xi(s) = \frac{1}{1+s}$$

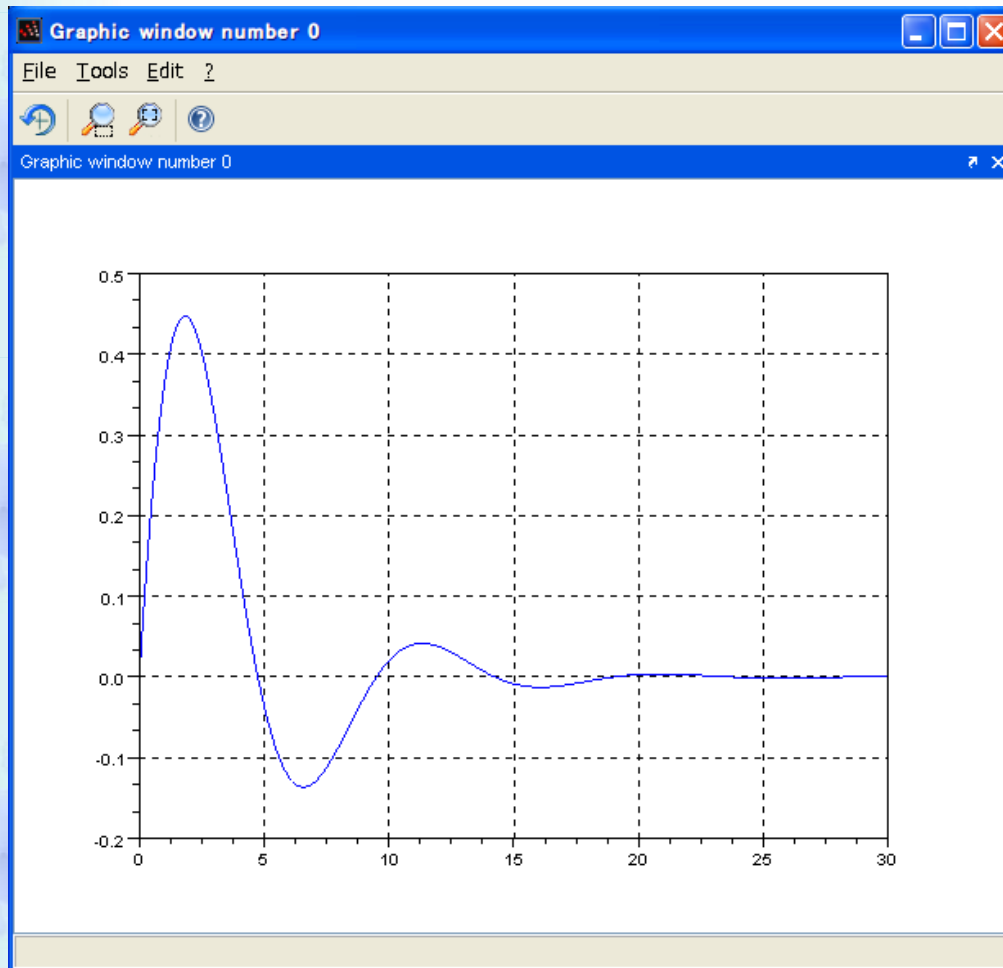


```
-->s=poly(0,'s');  
-->G=1/(1+s);  
-->sys=syslin('c',G);  
-->t=linspace(0,10,100);  
-->y=csim('step',t,sys);  
-->plot(t,y)  
-->xgrid()
```

Transient response: Use of Scilab



$$Y(s) = \frac{Cs}{LCs^2 + CRs + 1}$$



```
-->G=s/(1+s+2*s*s);  
-->sys=syslin('c',G);  
-->y=csim('step',t,sys);  
-->plot(t,y)
```

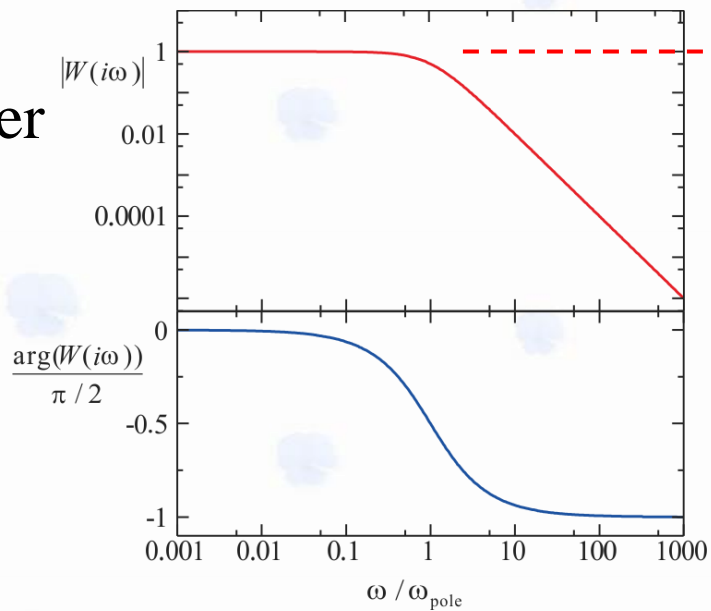


Chapter 4

Amplification circuits

Linear amplifier

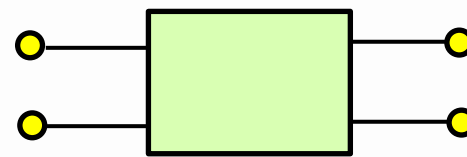
passive filter



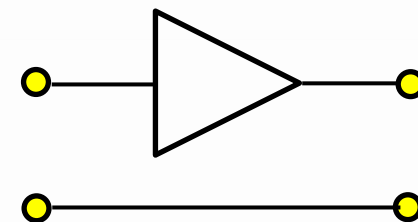
gain = 1

gain > 1 → amplifier

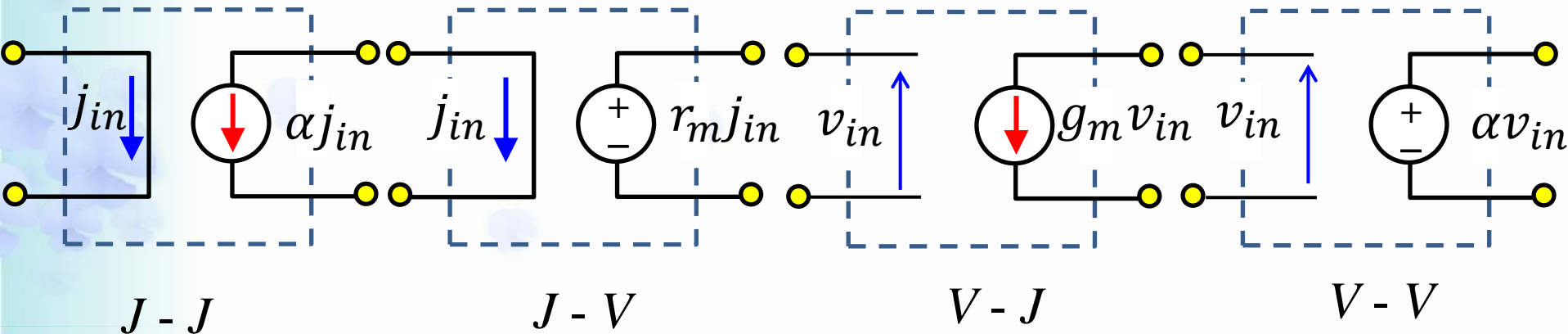
four terminal circuit model



Circuit symbol



Controlled power source models



Gain, and “Unit” for gain

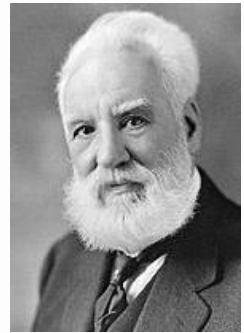
$$\text{Voltage gain: } \left| \frac{v_{out}}{v_{in}} \right| \quad \text{Current gain: } \left| \frac{j_{out}}{j_{in}} \right| \quad \text{Power gain: } \left| \frac{v_{out}j_{out}}{v_{in}j_{in}} \right|$$

When we say “the gain of the amplifier ...”, the gain means power gain.

$$\text{quantity } Q, \text{ unit } Q_0 : Q \text{ in log scale: } L = \log_{10} \frac{Q}{Q_0} \quad (\text{B, bel})$$

cf. deca- 10
1/10 dB : (decibel)
From: G. Bell

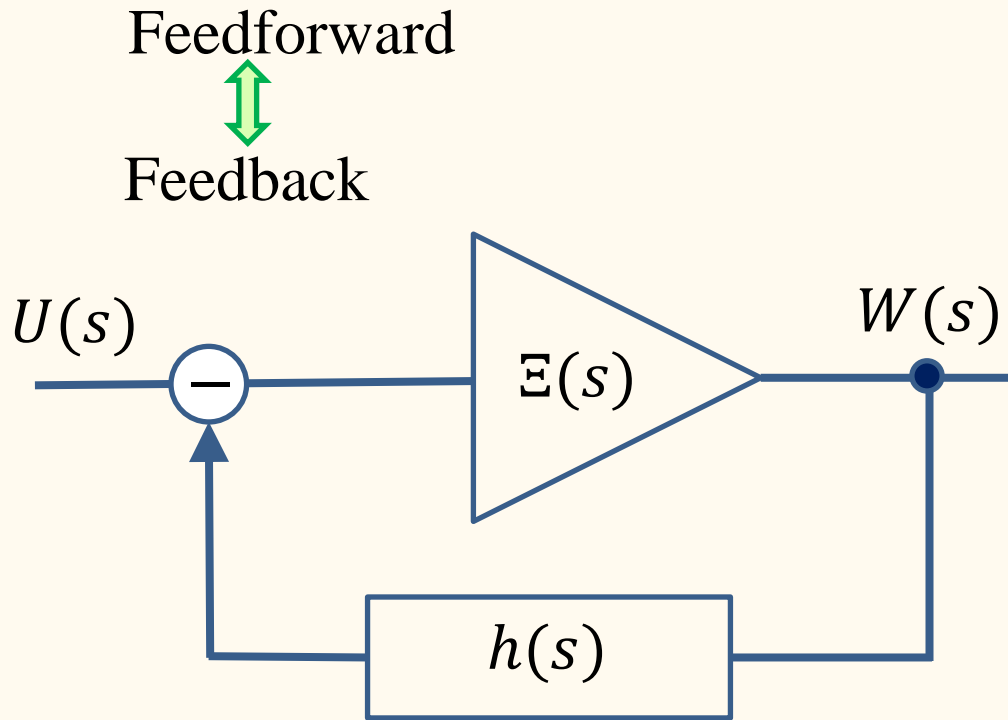
Alexander Graham Bell
1847 - 1922



$$G = 10 \times \log_{10} \left(\frac{v_{out}}{v_{in}} \right)^2 = 20 \log_{10} \frac{v_{out}}{v_{in}}$$

dB units: dBm (1mW: 0dBm), dBv (1V: 0dBv), etc.

Feedback circuit



$$W(s) = E(s)U(s)$$

$$W(s) = E(s)[U(s) - h(s)W(s)]$$

$$W(s) = \frac{E(s)}{1 + E(s)h(s)} U(s)$$

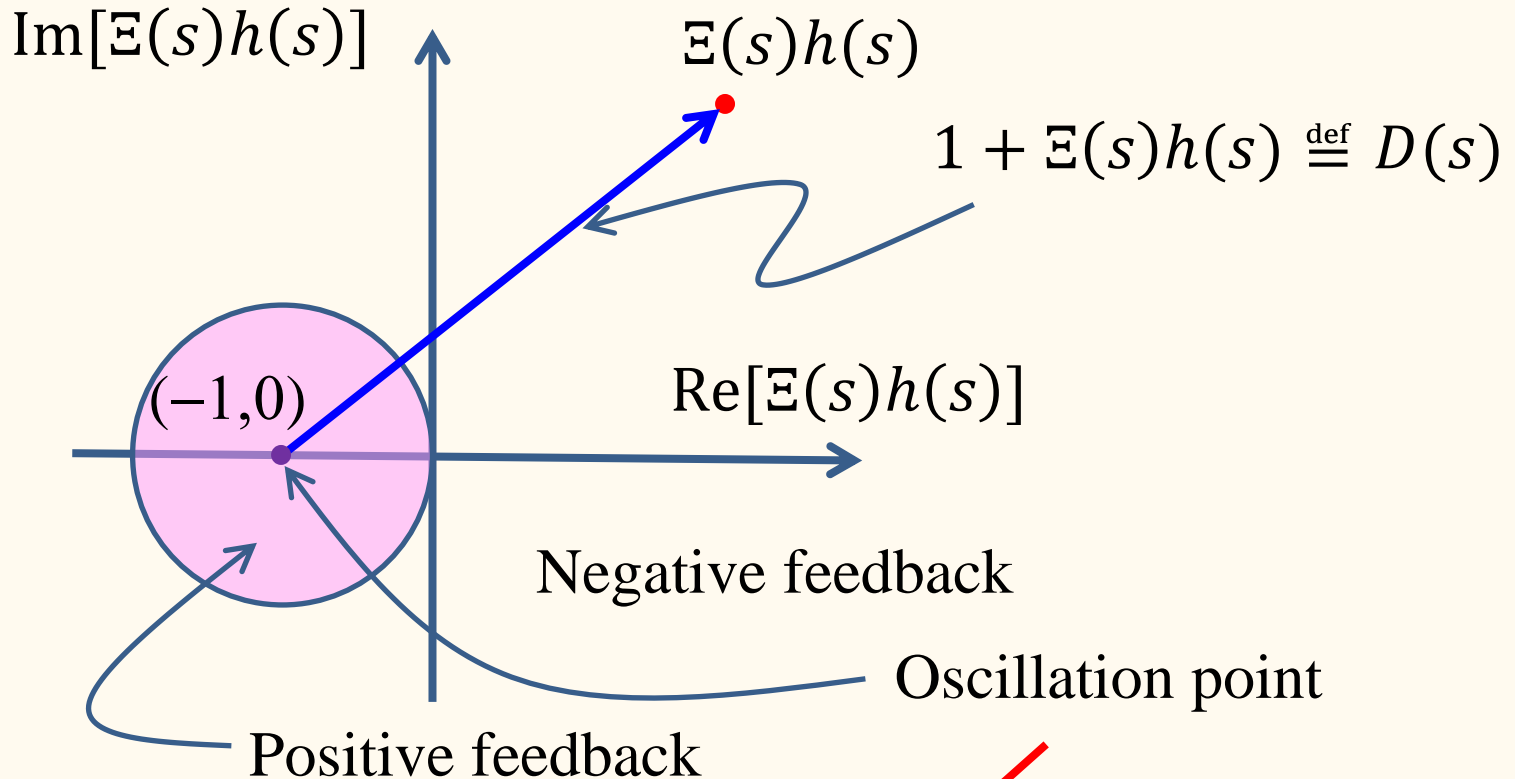
$$\stackrel{\text{def}}{=} G(s)U(s)$$

$|1 + E(s)h(s)| > 1$: Negative feedback, < 1 : Positive feedback

$$|E(s)| \gg 1 \rightarrow G(s) \approx \frac{1}{h(s)}$$

Condition for negative feedback

$|1 + \Xi(s)h(s)| > 1$: Negative feedback, < 1 : Positive feedback



If $\Xi(s)h(s) = -1$ has solutions, the circuit may be unstable.

How can we judge?



Criteria

(Routh-Hurwitz, **Nyquist**,
Liapunov, ...)

Zeros and poles of $D(s)$

Assumption 1: $\Xi(s), \Xi(s)h(s)$ are stable

→ Poles are on the left half plane of s .

Assumption 2: $\Xi(i\omega), \Xi(i\omega)h(i\omega) \rightarrow 0$ for $|\omega| \rightarrow \infty$

$\Xi(s) = \frac{Q(s)}{P(s)}, h(s) = \frac{q(s)}{p(s)}$: $P(s), Q(s), p(s), q(s)$ polynomials

$\deg(P) > \deg(Q), \deg(p) \geq \deg(q)$

$$D(s) = 1 + \Xi(s)h(s) = \frac{P(s)p(s)}{P(s)p(s) + Q(s)q(s)}$$

$$D(s) = D_0 \frac{(s - \beta_1) \cdots (s - \beta_n)}{(s - \alpha_1) \cdots (s - \alpha_n)} \quad \begin{array}{l} \curvearrowright \\ \curvearrowleft \end{array} \text{The same order}$$

Zeros and poles of $D(s)$

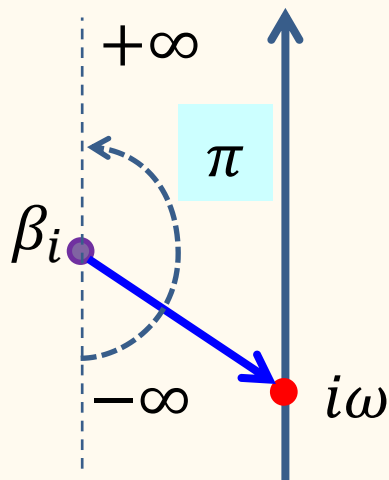
$$D(s) = D_0 \frac{(s - \beta_1) \cdots (s - \beta_n)}{(s - \alpha_1) \cdots (s - \alpha_n)}$$

$\{\beta_i\}$: Zeros of $D(s)$ \rightarrow Poles of $G(s)$

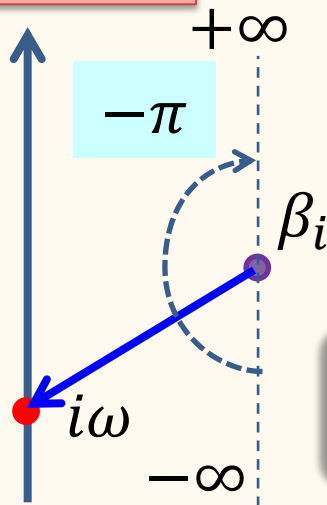
$\exists \beta_i \in$ right half plane of $s \rightarrow$ The circuit is unstable.

$$\arg(D) = \sum_{i=1}^n \arg(s - \beta_i) - \sum_{i=1}^n \arg(s - \alpha_i)$$

Left half plane



Right half plane



$s = i\omega$ (on imaginary axis)

$\omega: -\infty \rightarrow +\infty$

Number of zeros on the right half plane: m

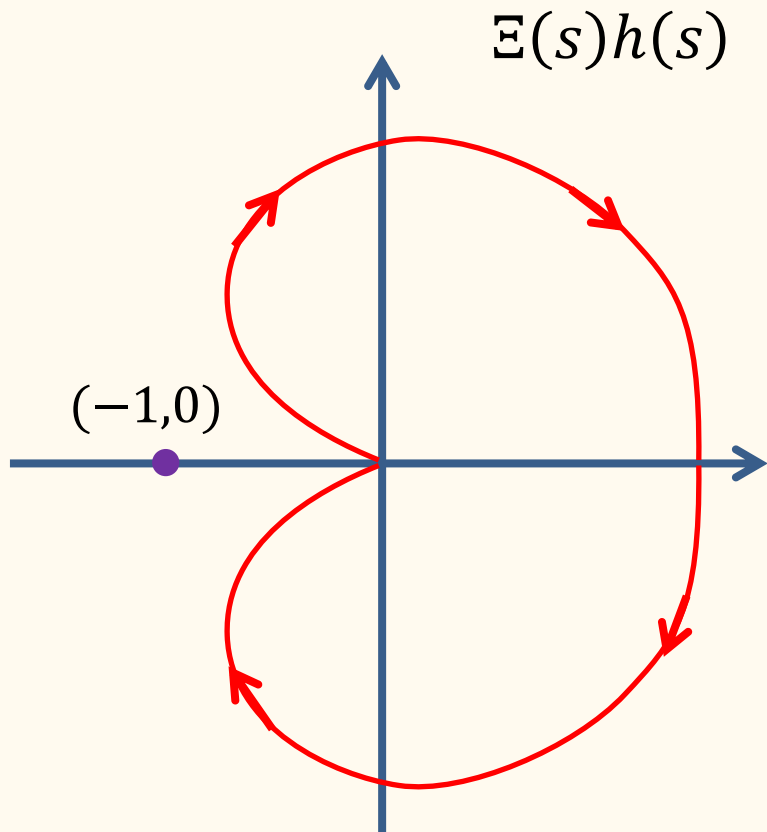
$$\Delta \arg(D) = (n - m)\pi - m\pi$$

$$-n\pi = -2m\pi$$

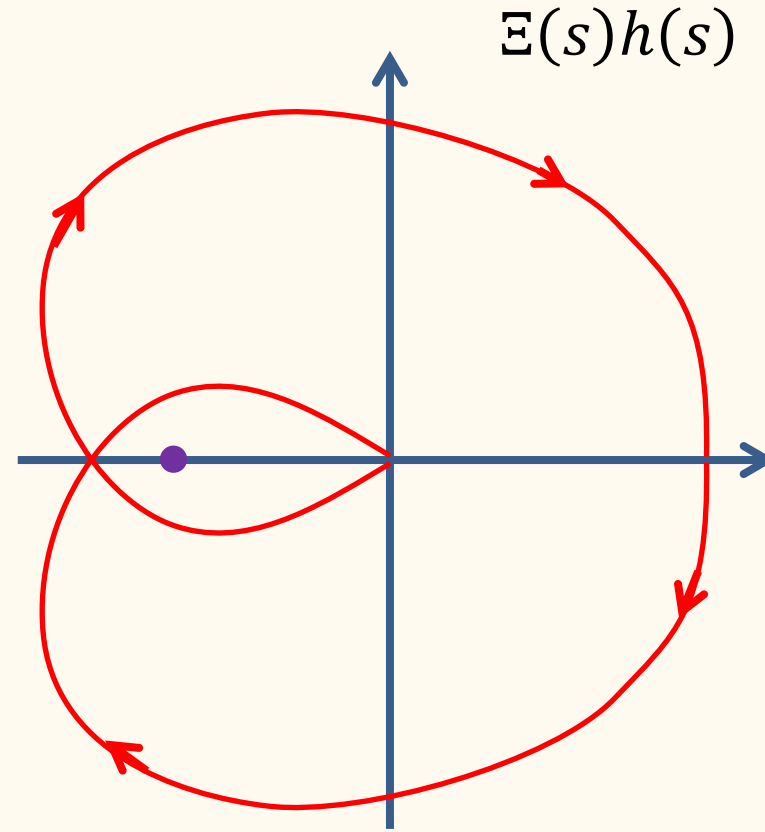
Nyquist Plot and Criterion



Harry Nyquist
(1889–1976)

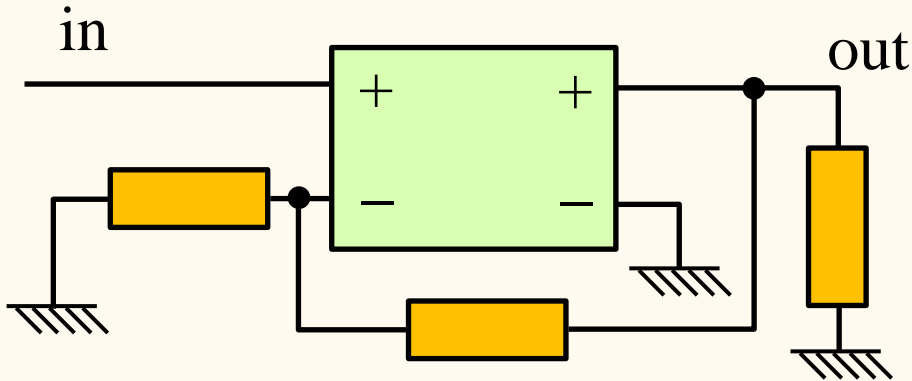
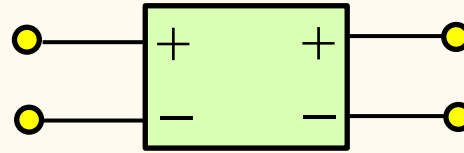


$\Delta \arg(D) = 0$
Stable

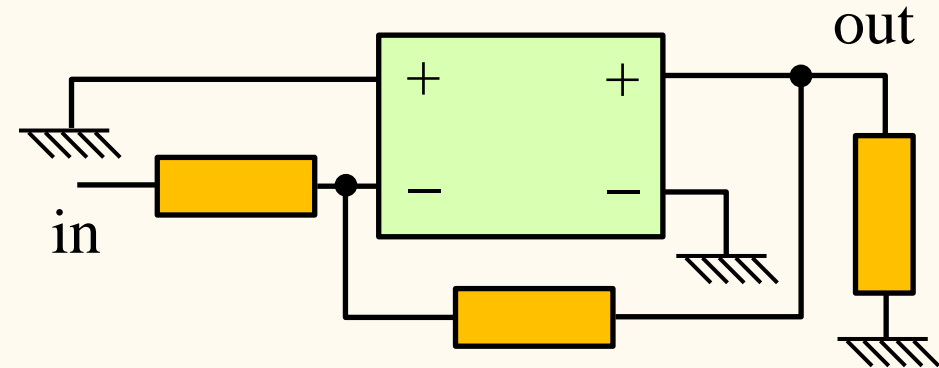


$\Delta \arg(D) = -4\pi$
Unstable

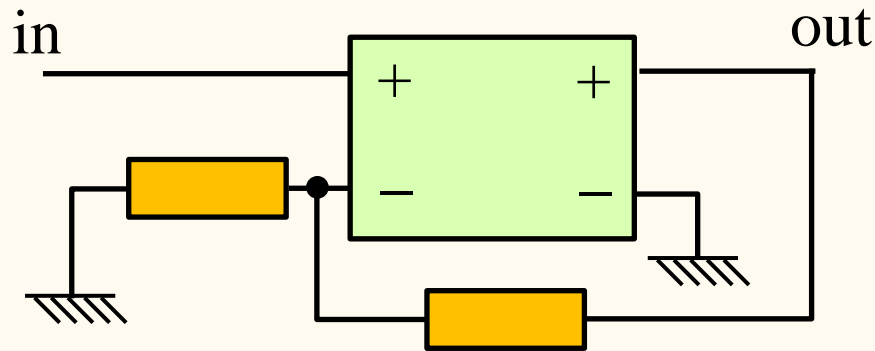
Feedback in terminal-pair circuits with resistors



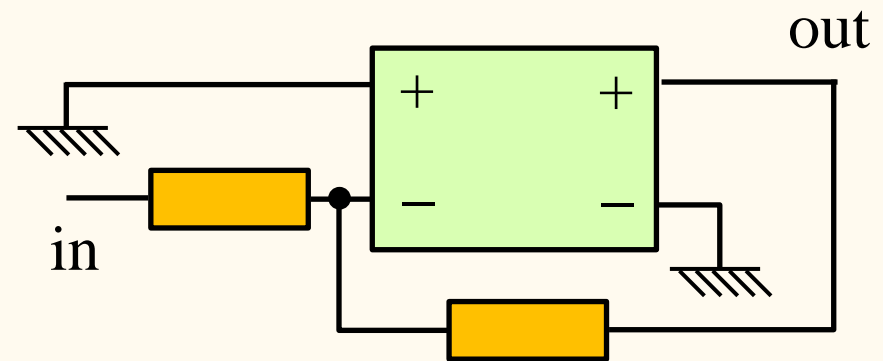
(i) input: parallel, output: parallel



(ii) input: series, output: parallel

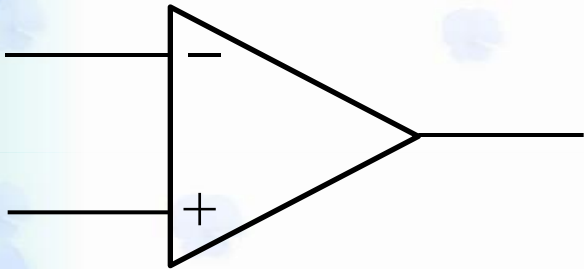


(iii) input: parallel, output: series



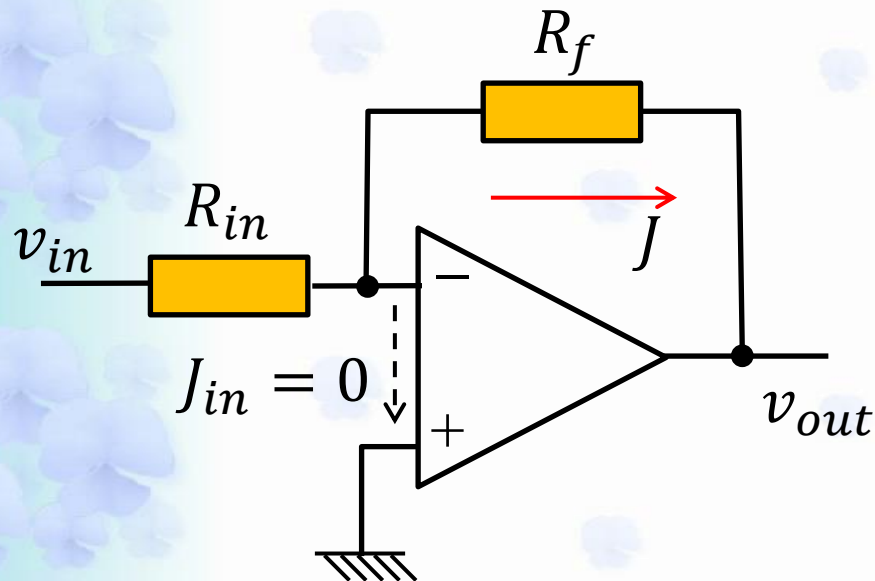
(iv) input: series, output: series

Operational amplifier (OP amp.)



- Differential amplifier
- Input impedance $\sim \infty$
- Open loop gain $A_o \gg 1$
- Output resistance ≈ 0

Case (iv)



$$A_o \gg 1 \therefore \underline{V_- \approx V_+ = 0}$$

Virtual short circuit

$$J = -\frac{v_{out}}{R_f} = \frac{v_{in}}{R_{in}}$$

$$\therefore v_{out} = -\frac{R_f}{R_{in}} v_{in}$$

Inverting amplifier

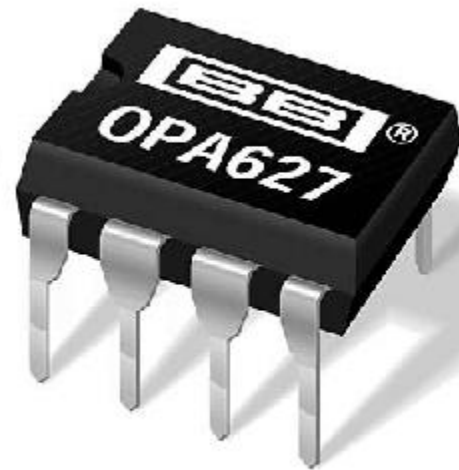
Opamp packages



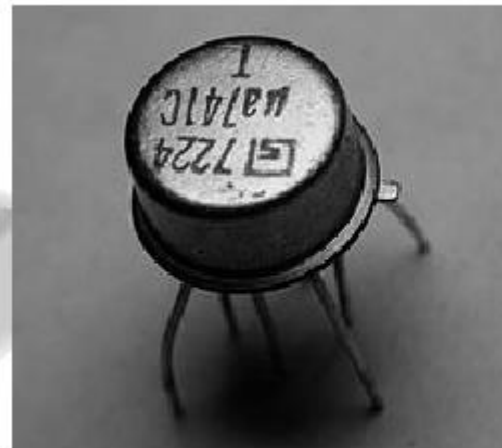
(a)



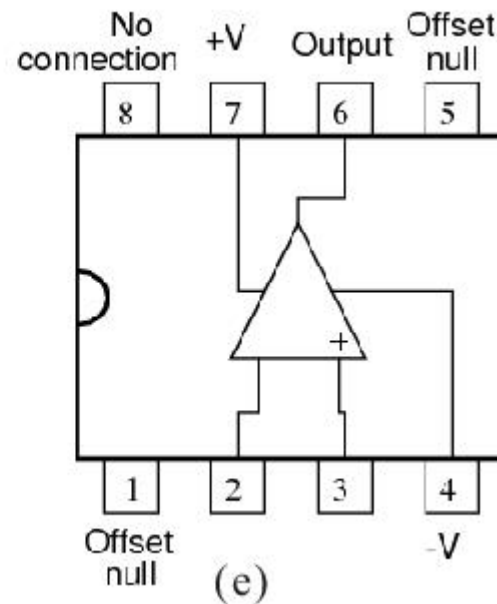
(b)



(c)

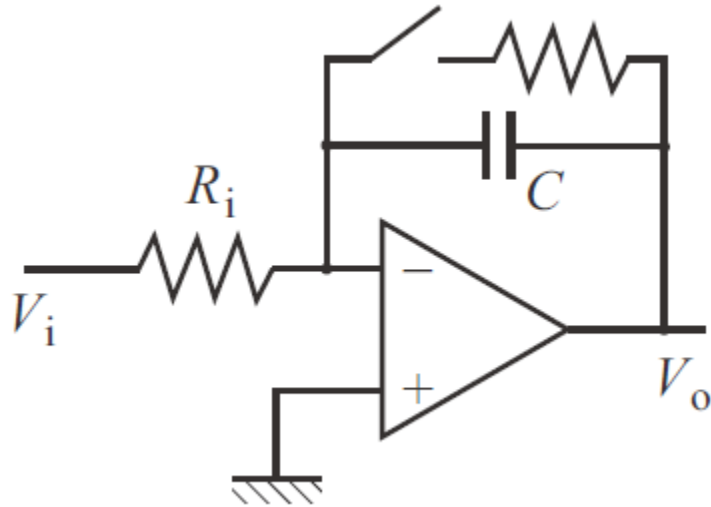


(d)



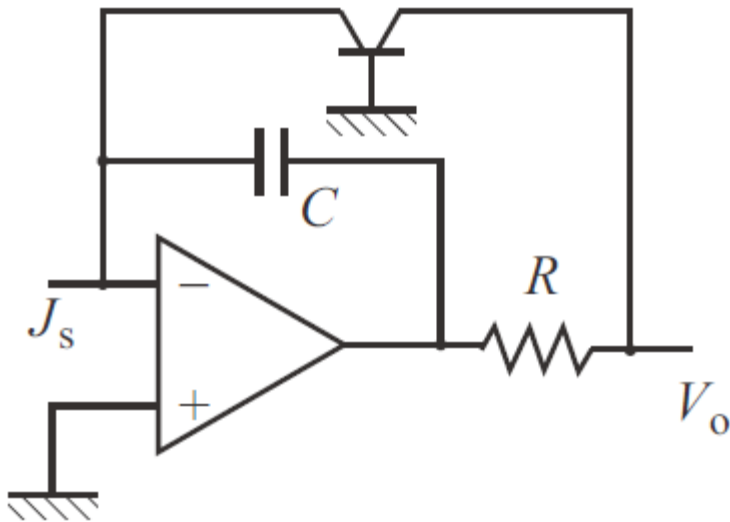
(e)

Various applications of OP amps



$$V_{\text{out}}(t) = -\frac{Q}{C} = -\frac{1}{C} \int_0^t \frac{V_i(\tau)}{R_i} d\tau$$
$$= -\frac{1}{CR_i} \int_0^t V_i(\tau) d\tau$$

Integration circuit



$$V_{\text{out}} = -V_{\text{BE}} = -\frac{k_{\text{B}}T}{e} \ln \left(\frac{J_s}{J_0} + 1 \right)$$

Logarithmic amplifier

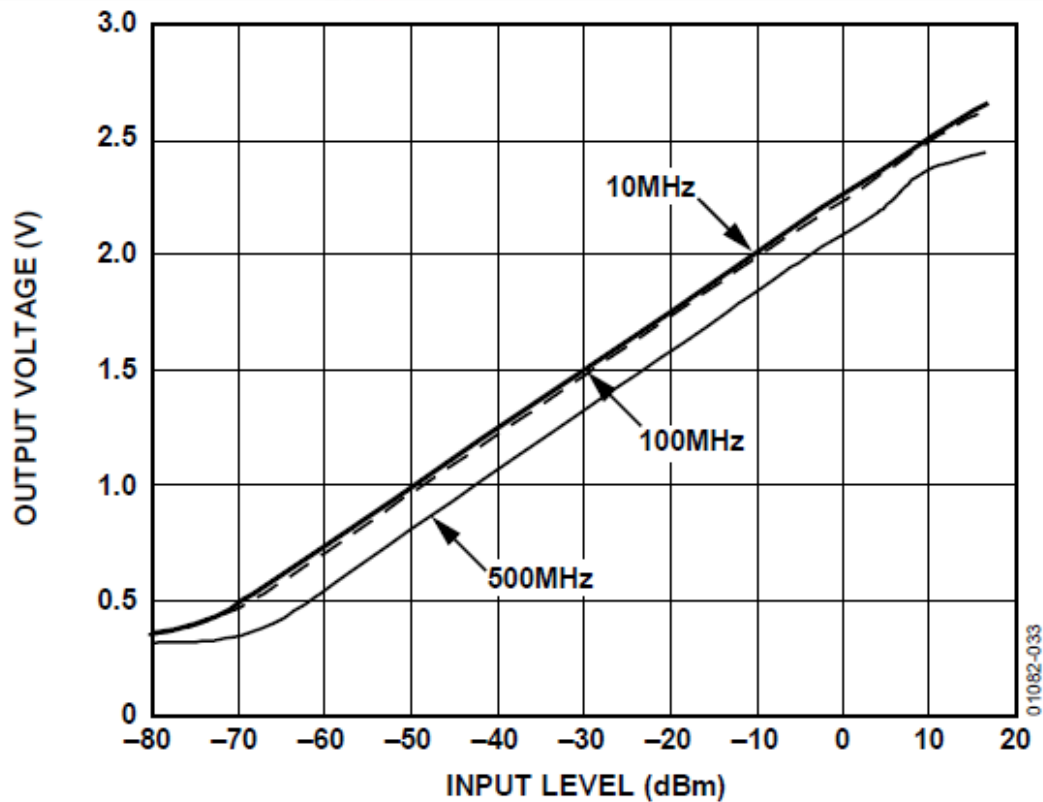
Logarithmic Amplifier



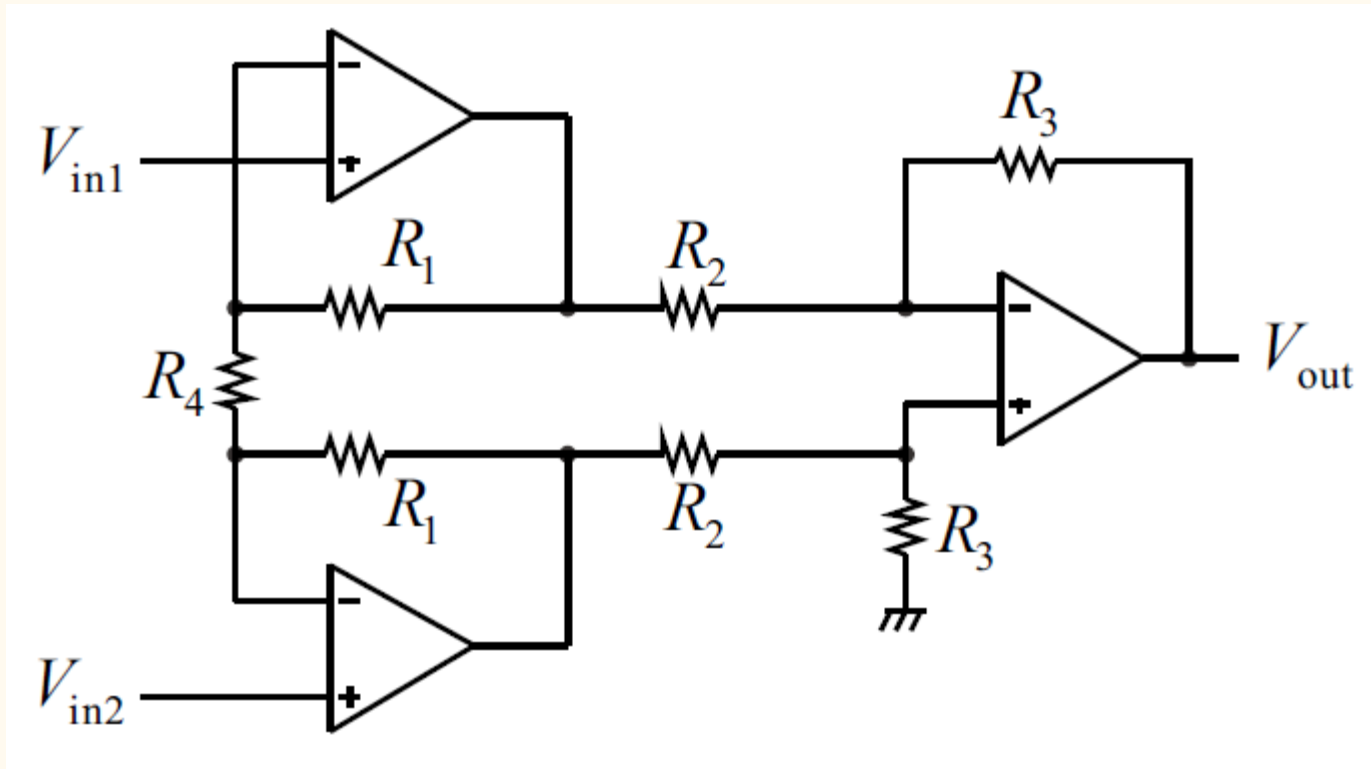
Low Cost, DC to 500 MHz, 92 dB
Logarithmic Amplifier

Data Sheet

AD8307

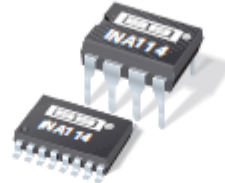


Instrumentation amplifier



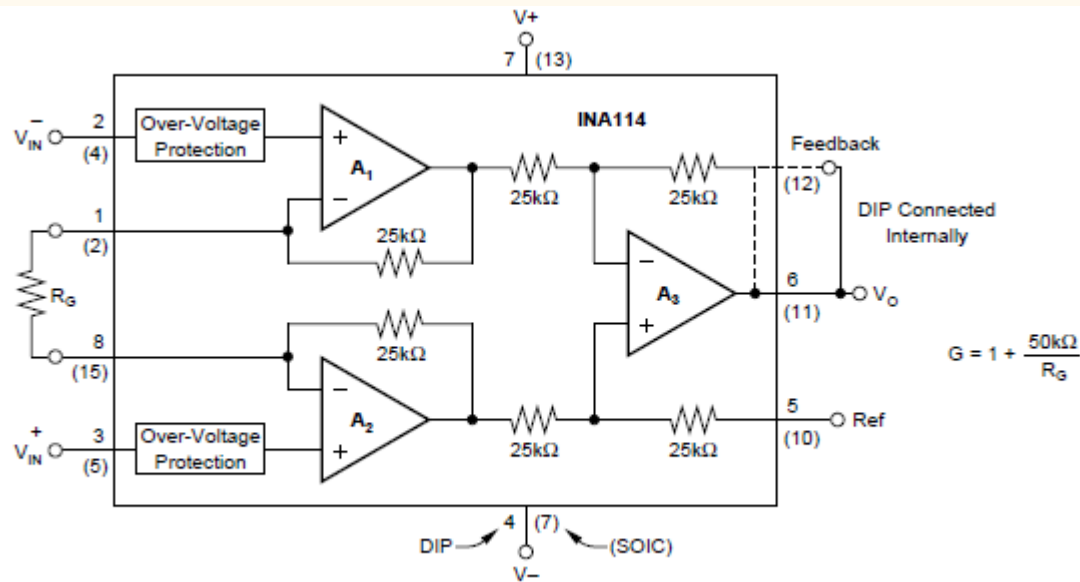
$$V_{out} = -\frac{R_3}{R_2} \left(\frac{2R_1 + R_4}{R_4} \right) (V_{in1} - V_{in2})$$

Instrumentation amplifier



INA114

Precision INSTRUMENTATION AMPLIFIER





Ultralow Offset Voltage Operational Amplifier

Data Sheet

OP07

FEATURES

- Low V_{os} : 75 μV maximum
- Low V_{os} drift: 1.3 $\mu\text{V}/^\circ\text{C}$ maximum
- Ultrastable vs. time: 1.5 μV per month maximum
- Low noise: 0.6 μV p-p maximum
- Wide input voltage range: $\pm 14\text{ V}$ typical
- Wide supply voltage range: $\pm 3\text{ V}$ to $\pm 18\text{ V}$
- 125 $^\circ\text{C}$ temperature-tested dice

PIN CONFIGURATION

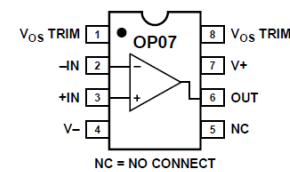
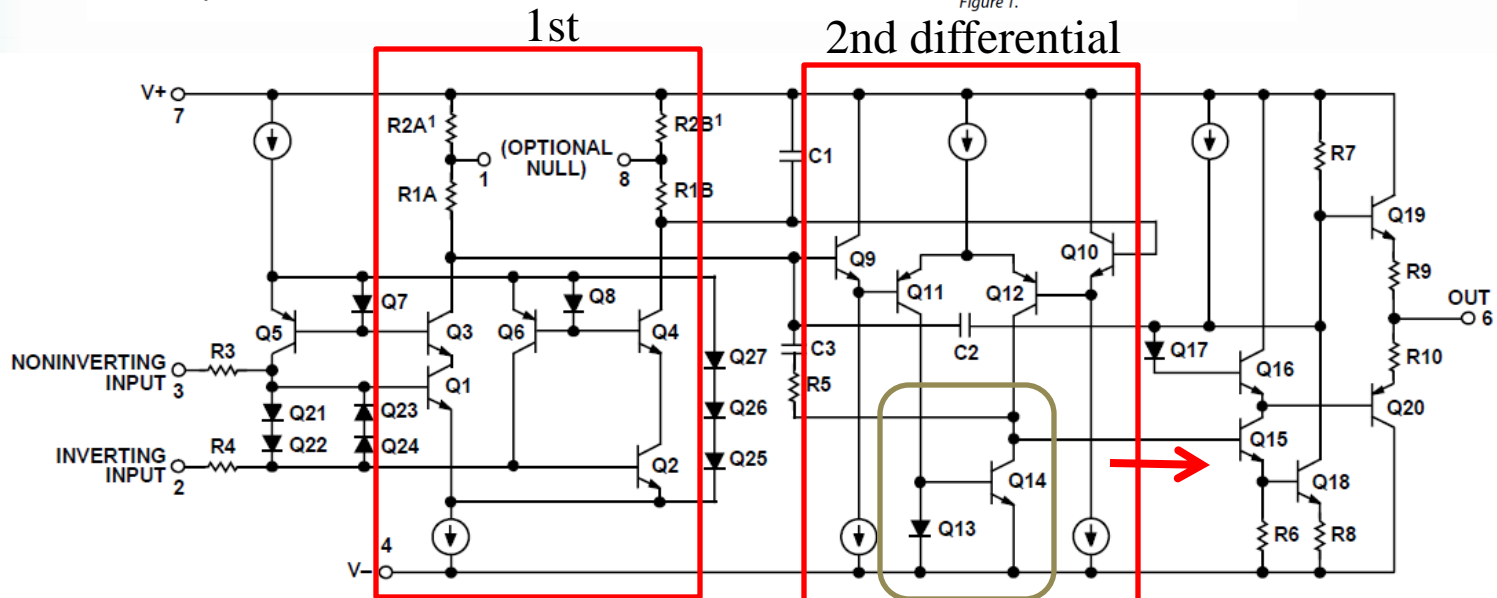


Figure 1.



¹R2A AND R2B ARE ELECTRONICALLY ADJUSTED ON CHIP AT FACTORY FOR MINIMUM INPUT OFFSET VOLTAGE.

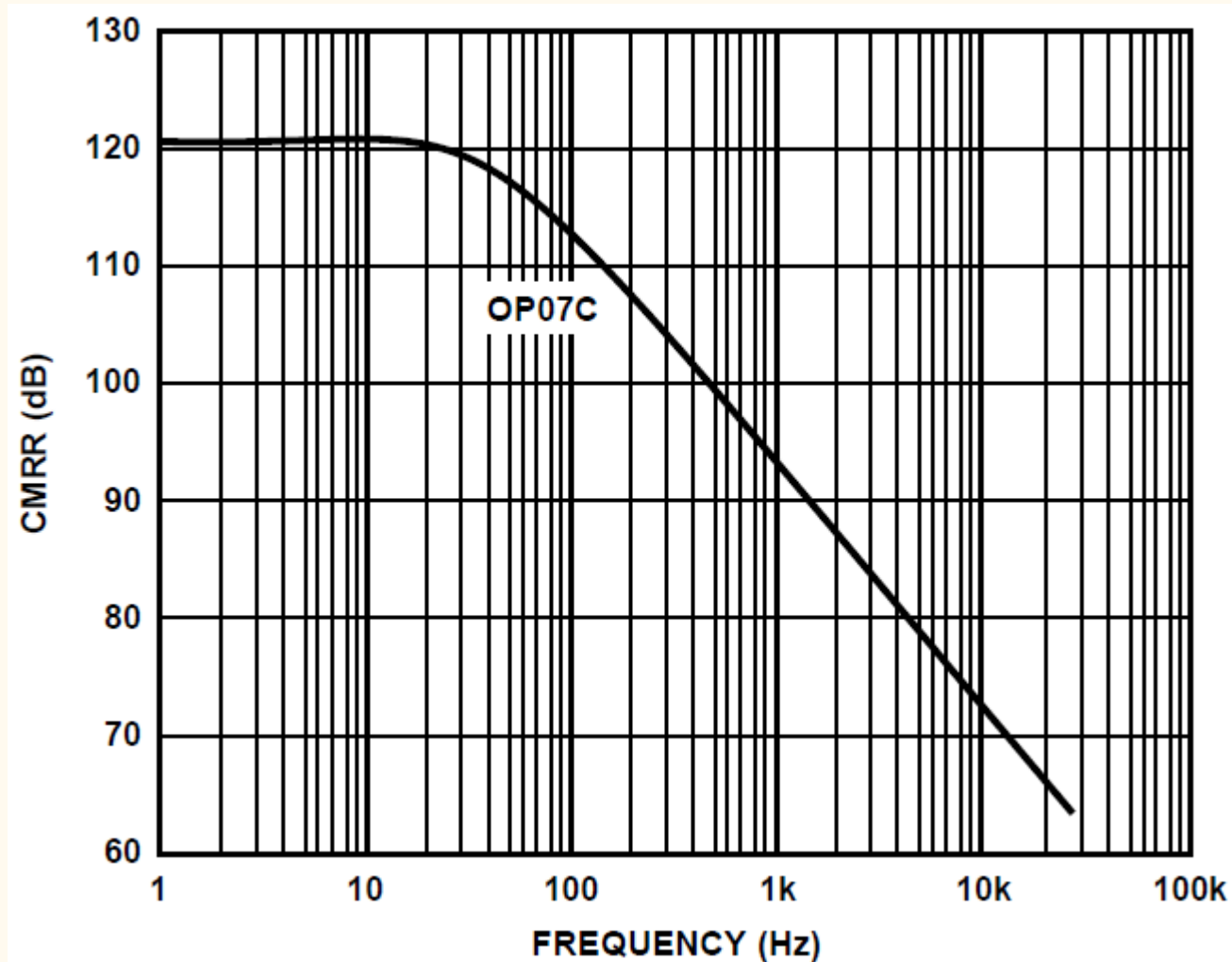
Figure 2. Simplified Schematic

OP-amp data sheet

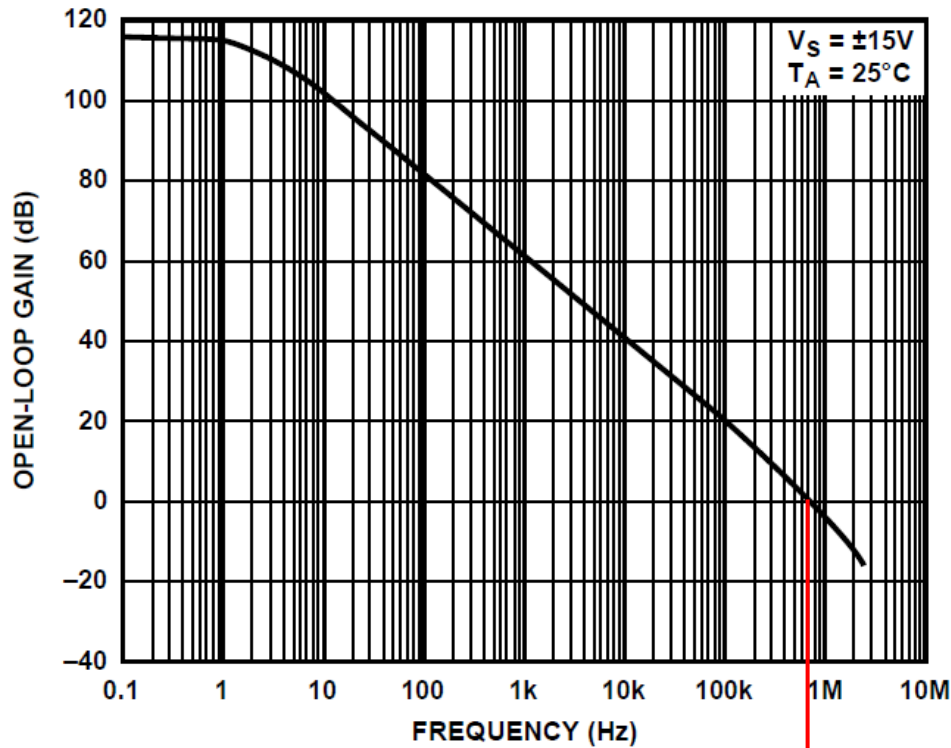
Parameters

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
$T_A = 25^\circ\text{C}$						
Input Offset Voltage ¹	V_{OS}			60	150	μV
Long-Term V_{OS} Stability ²	V_{OS}/Time			0.4	2.0	$\mu\text{V}/\text{Month}$
Input Offset Current	I_{OS}			0.8	6.0	nA
Input Bias Current	I_B			± 1.8	± 7.0	nA
Input Noise Voltage	e_n p-p	0.1 Hz to 10 Hz ³		0.38	0.65	μV p-p
Input Noise Voltage Density	e_n	$f_0 = 10$ Hz		10.5	20.0	nV/ $\sqrt{\text{Hz}}$
		$f_0 = 100$ Hz ³		10.2	13.5	nV/ $\sqrt{\text{Hz}}$
		$f_0 = 1$ kHz		9.8	11.5	nV/ $\sqrt{\text{Hz}}$
Input Noise Current	I_n p-p			15	35	pA p-p
Input Noise Current Density	I_n	$f_0 = 10$ Hz		0.35	0.90	pA/ $\sqrt{\text{Hz}}$
		$f_0 = 100$ Hz ³		0.15	0.27	pA/ $\sqrt{\text{Hz}}$
		$f_0 = 1$ kHz		0.13	0.18	pA/ $\sqrt{\text{Hz}}$
Input Resistance, Differential Mode ⁴	R_{IN}		8	33		M Ω
Input Resistance, Common Mode	R_{INCM}			120		G Ω

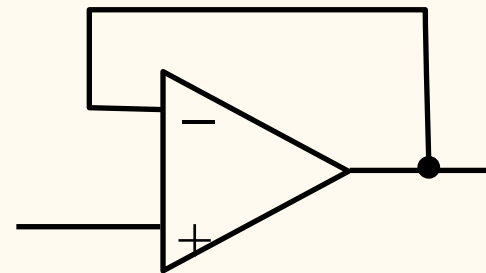
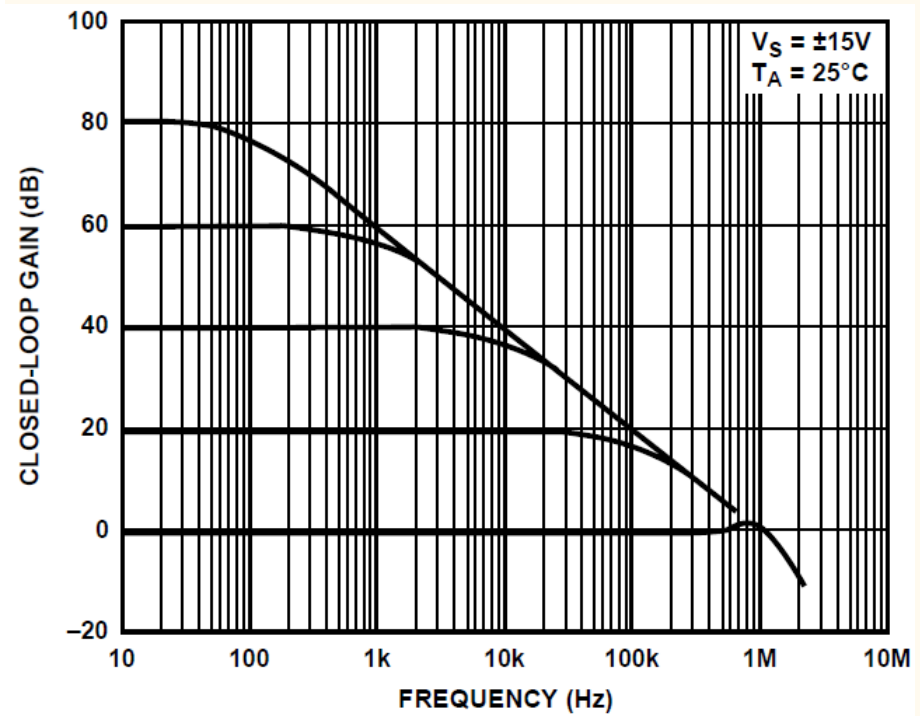
Common mode rejection ratio (CMRR)



OP-amp data sheet

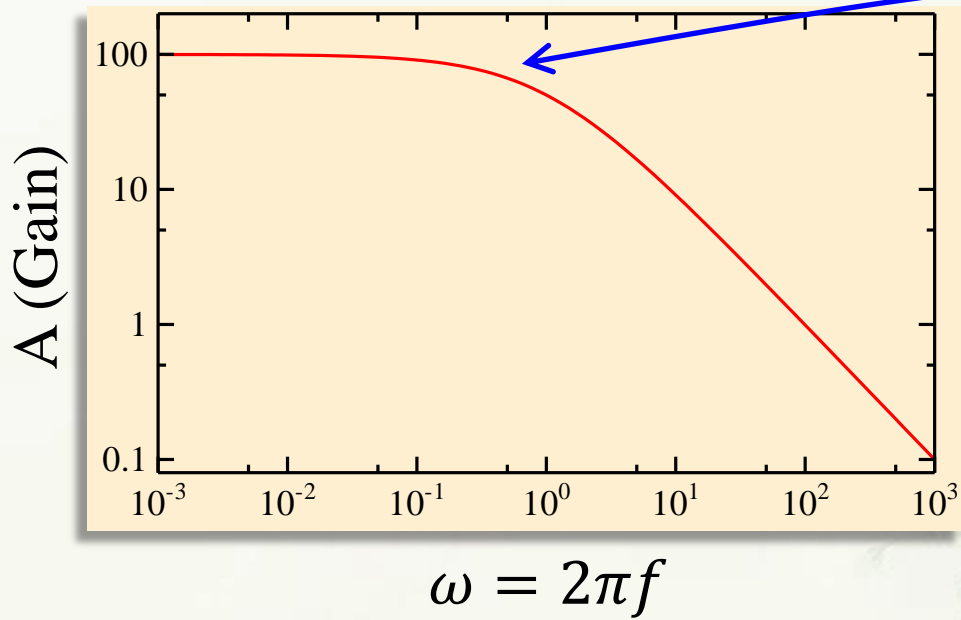


Unity gain frequency



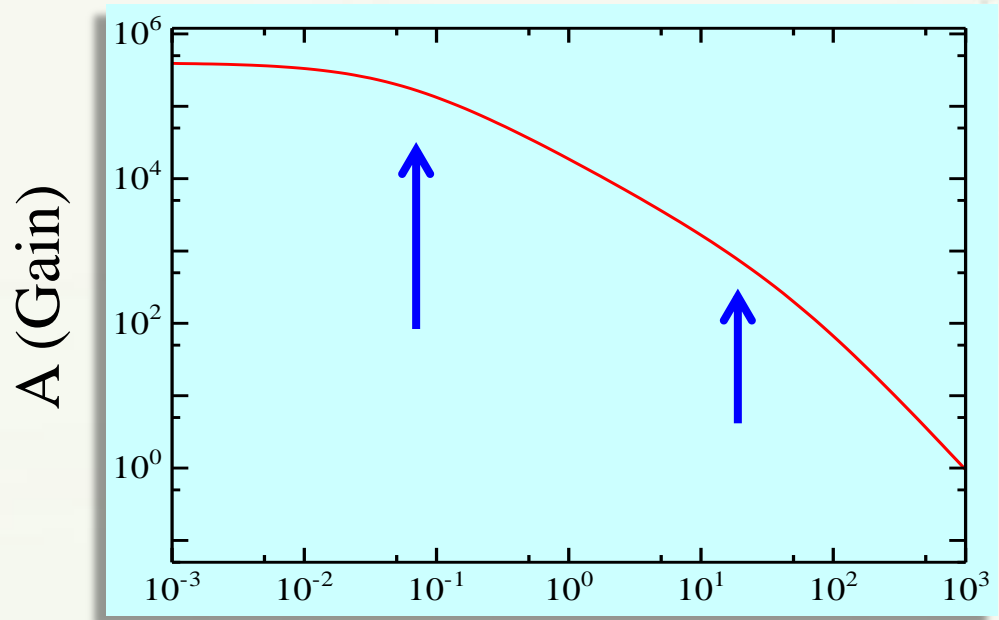
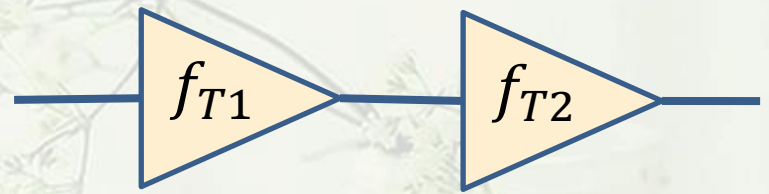
Voltage follower

Frequency Dependent Characteristics of OP-Amps



Cut-off frequency
 $\omega_T = 2\pi f_T$

Phase rotates by $\pi/2$



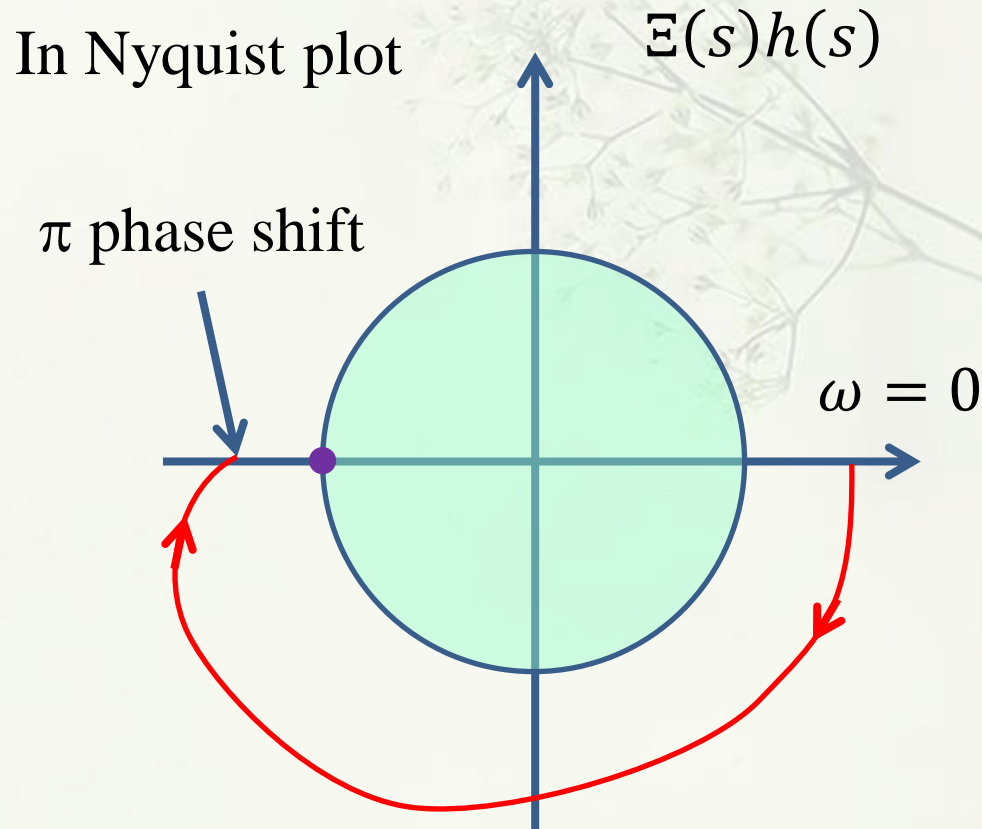
Multiple cut-off frequency:
Phase rotates more than π

If gain is larger than 1 at
phase shift π :
Dangerous!

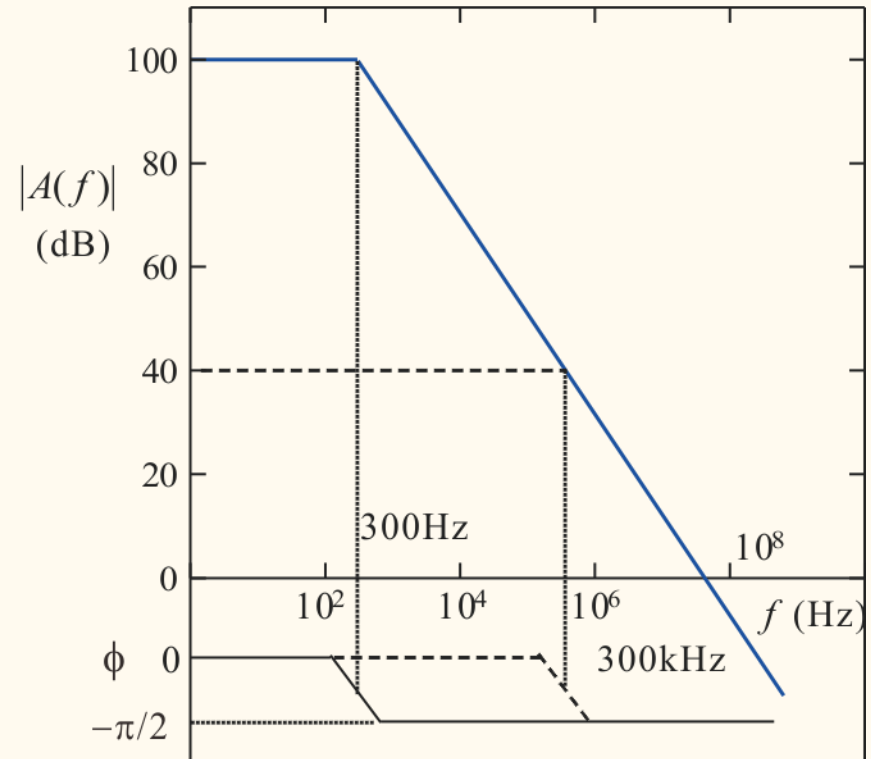
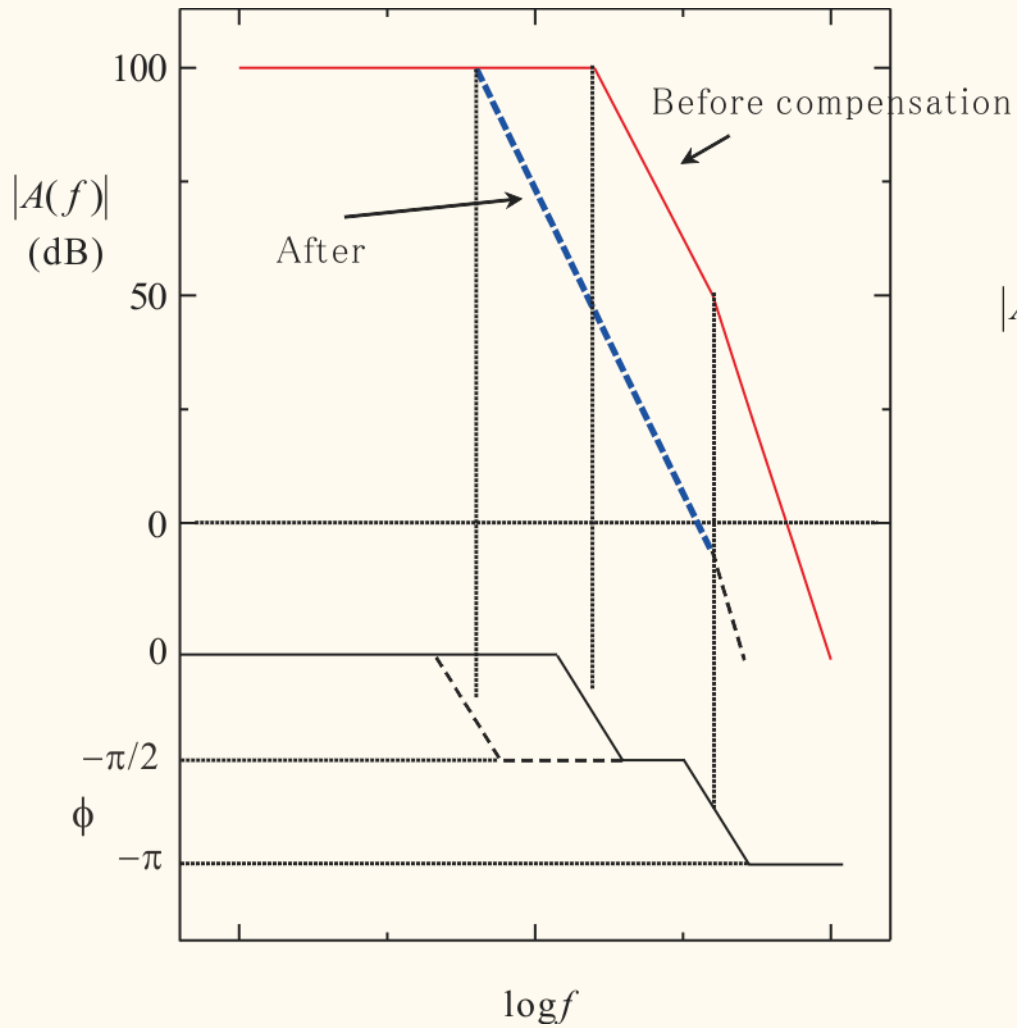
Phase compensation

Why dangerous?

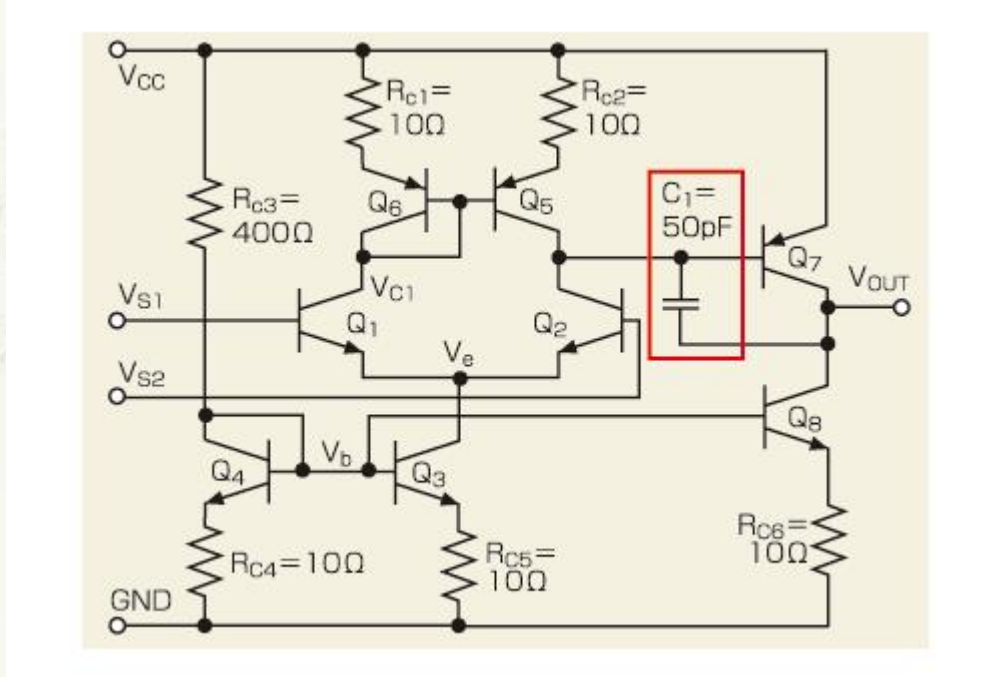
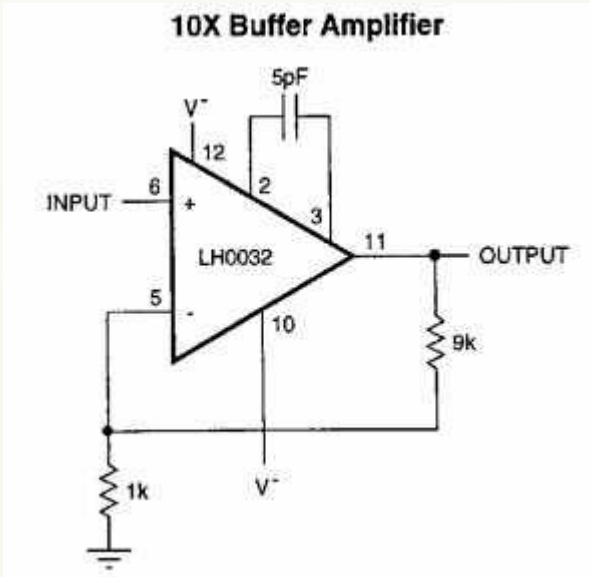
π phase shift: negative feedback \rightarrow positive feedback



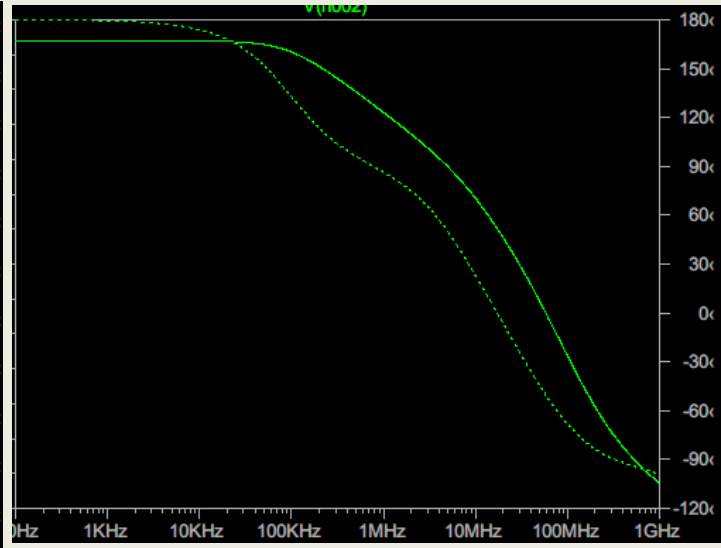
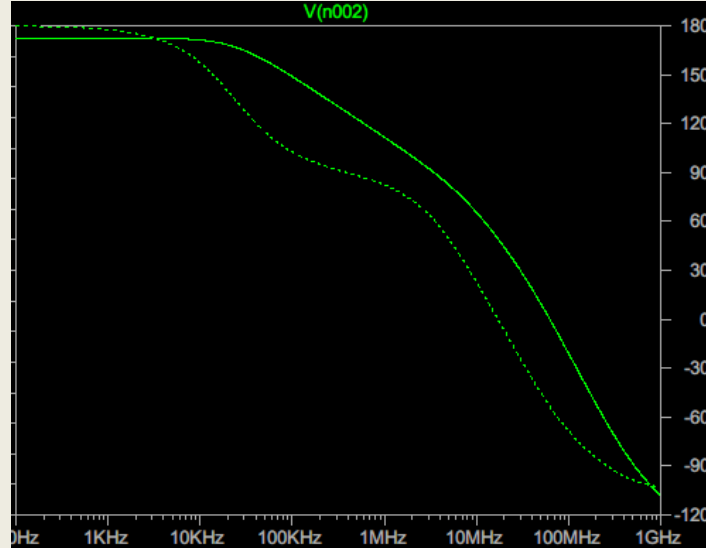
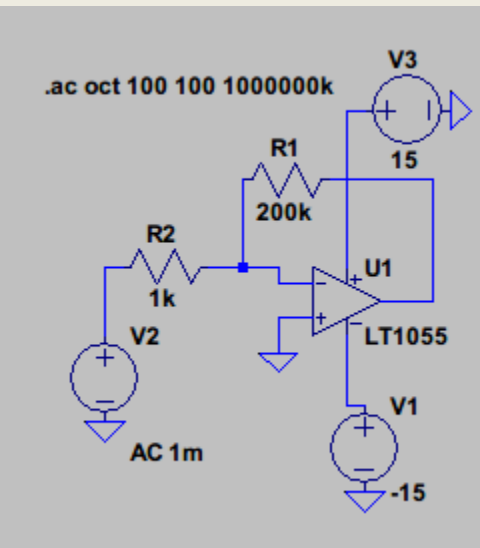
Phase compensation



Phase compensation

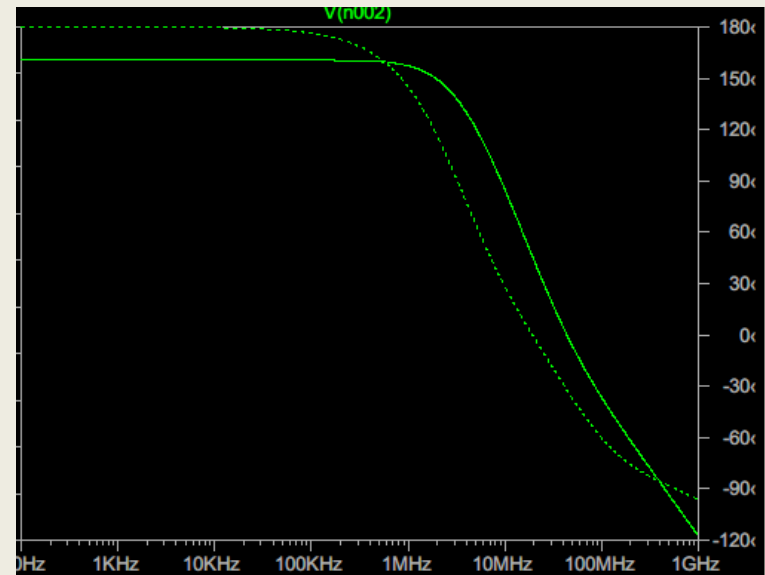
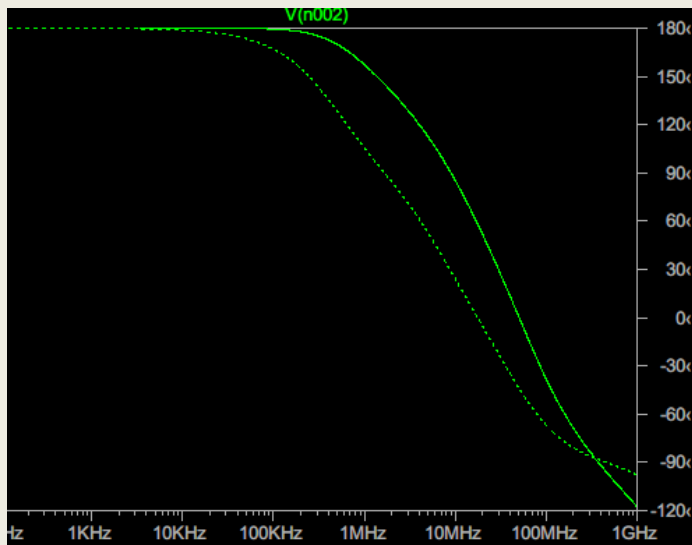


Inverting amplifier and cut-off frequency



$$A = 200 f_T = 30\text{kHz}$$

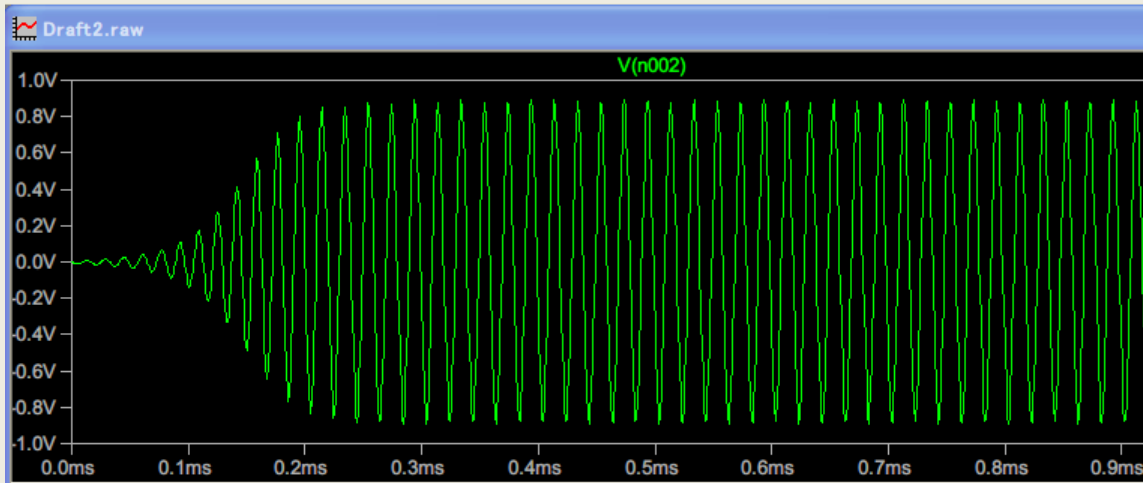
$$A = 50 f_T = 90\text{kHz}$$



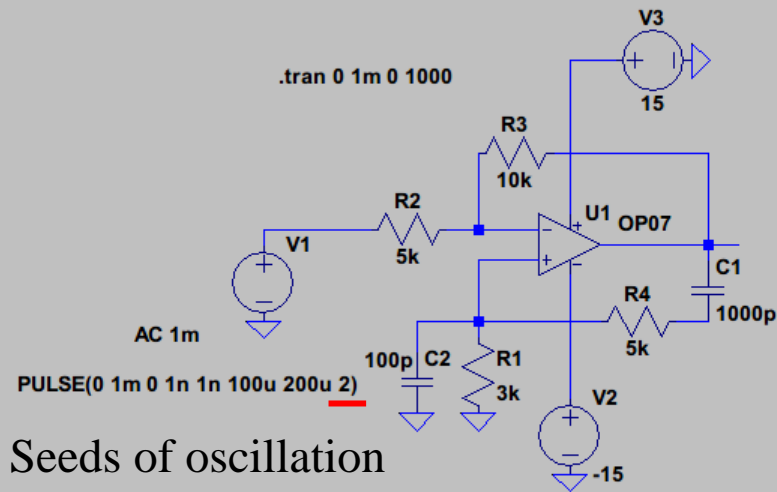
$$A = 10 f_T = 300\text{kHz}$$

$$A = 2 f_T = 2\text{MHz}$$

Oscillation of OPamp



Draft2.asc



Seeds of oscillation

