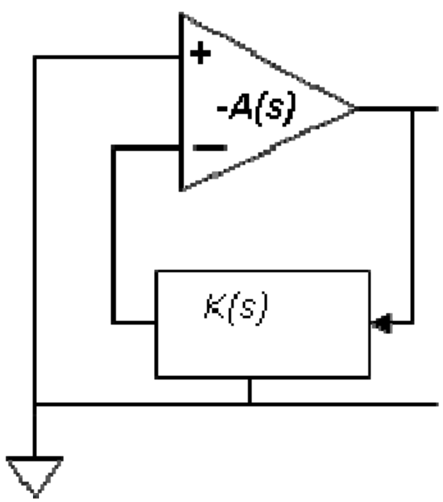
Quick Introduction to Phase Margin

Excess phase shift in an operational amplifier can cause oscillation in the user's application

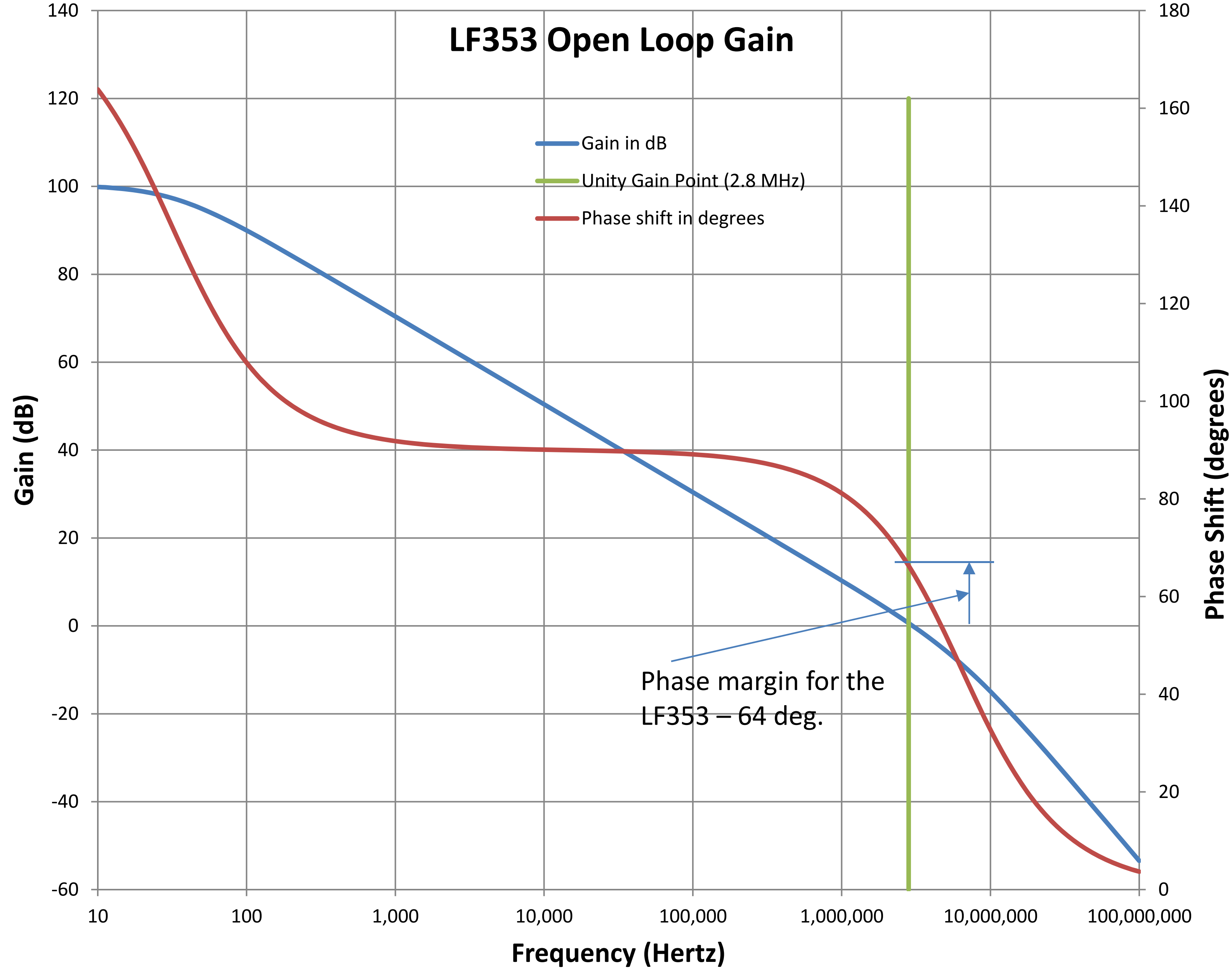
Defining Phase Margin

- Applies to feedback around an amplifier with negative gain at low frequency
- If |Gain| > 1 and phase shift > 180 degrees, the circuit oscillates
- If phase is too close to 180 degrees gives overshoot to step input
- Phase margin for the amplifier is how many degrees of phase shift could be added too the loop gain by the feedback block *K(s)* before oscillation would start



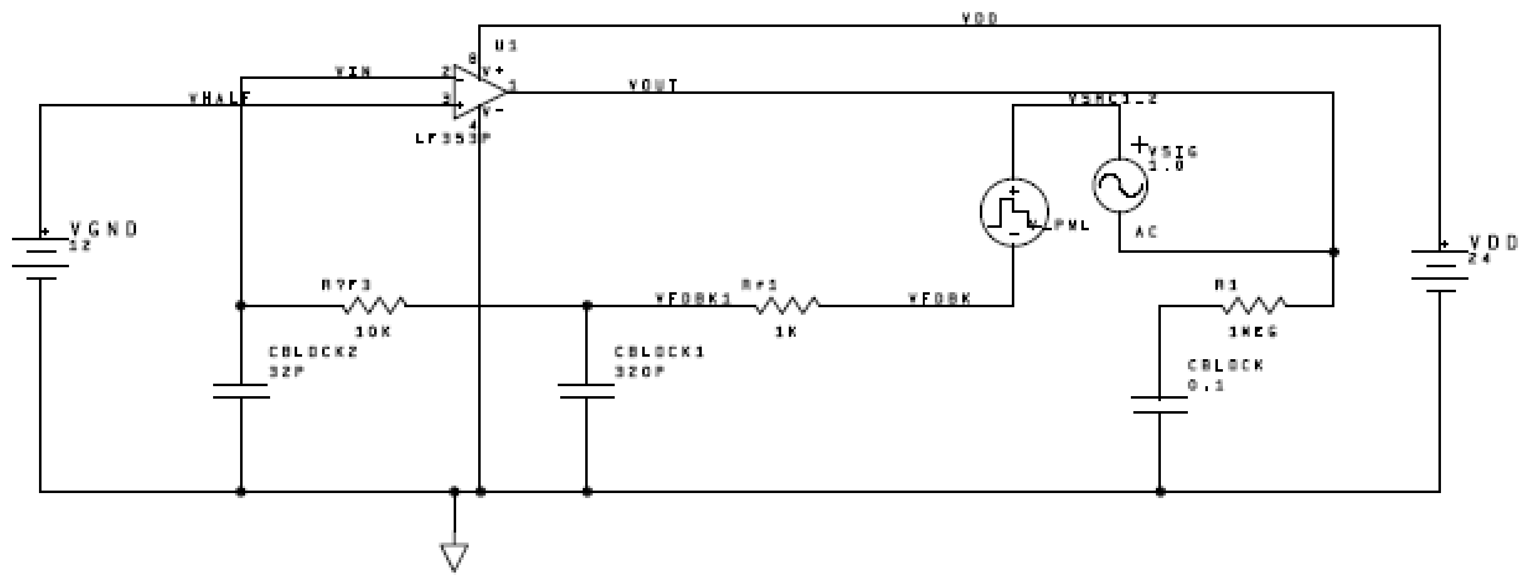
Open loop gain is defined as: $G_{OL} \equiv -A(s)K(s)$

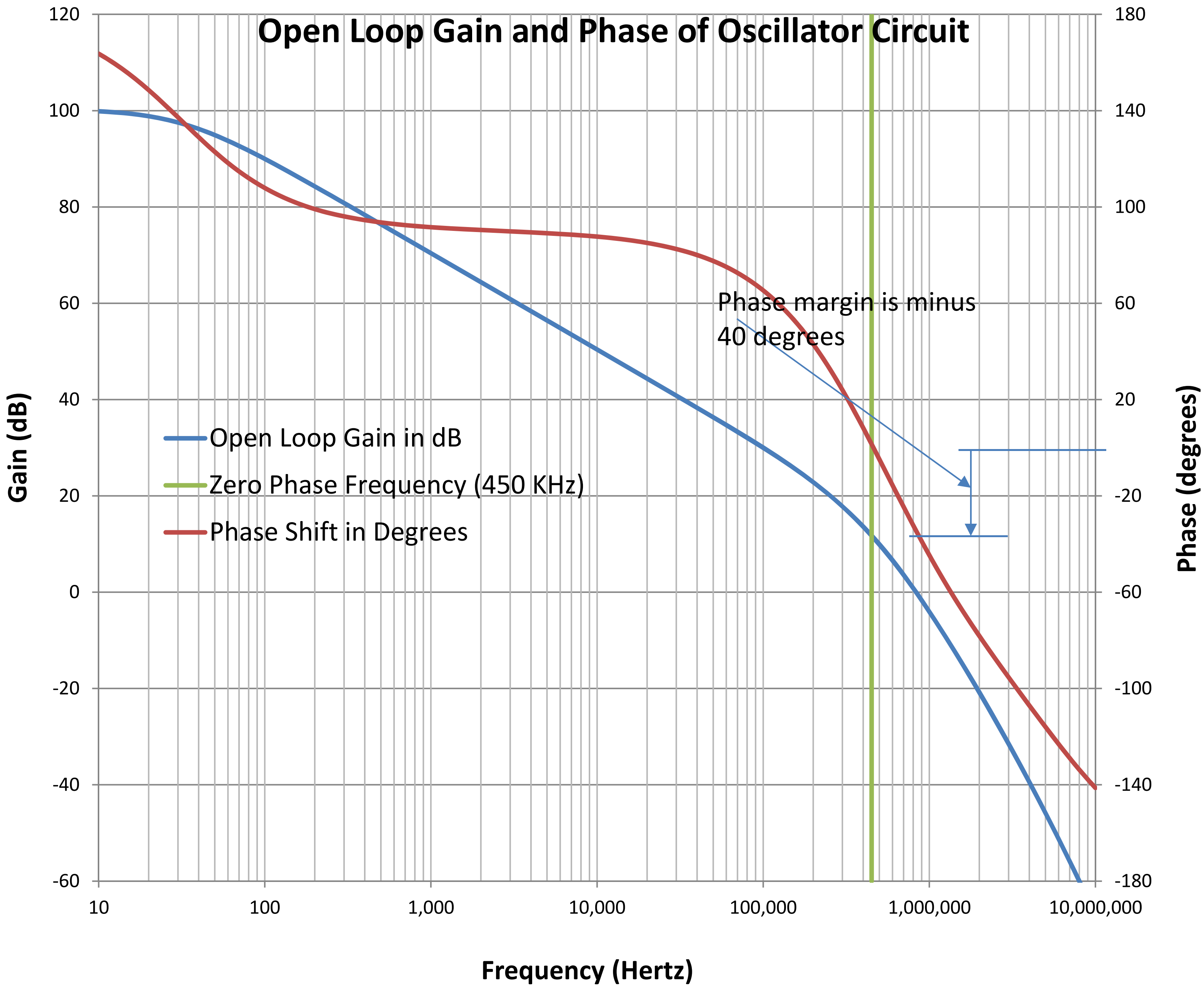
Usually phase is a monotonic function so the phase margin is 180 – Phase(A(s)) at frequency for which |A(s)| = 1X (0 dB)

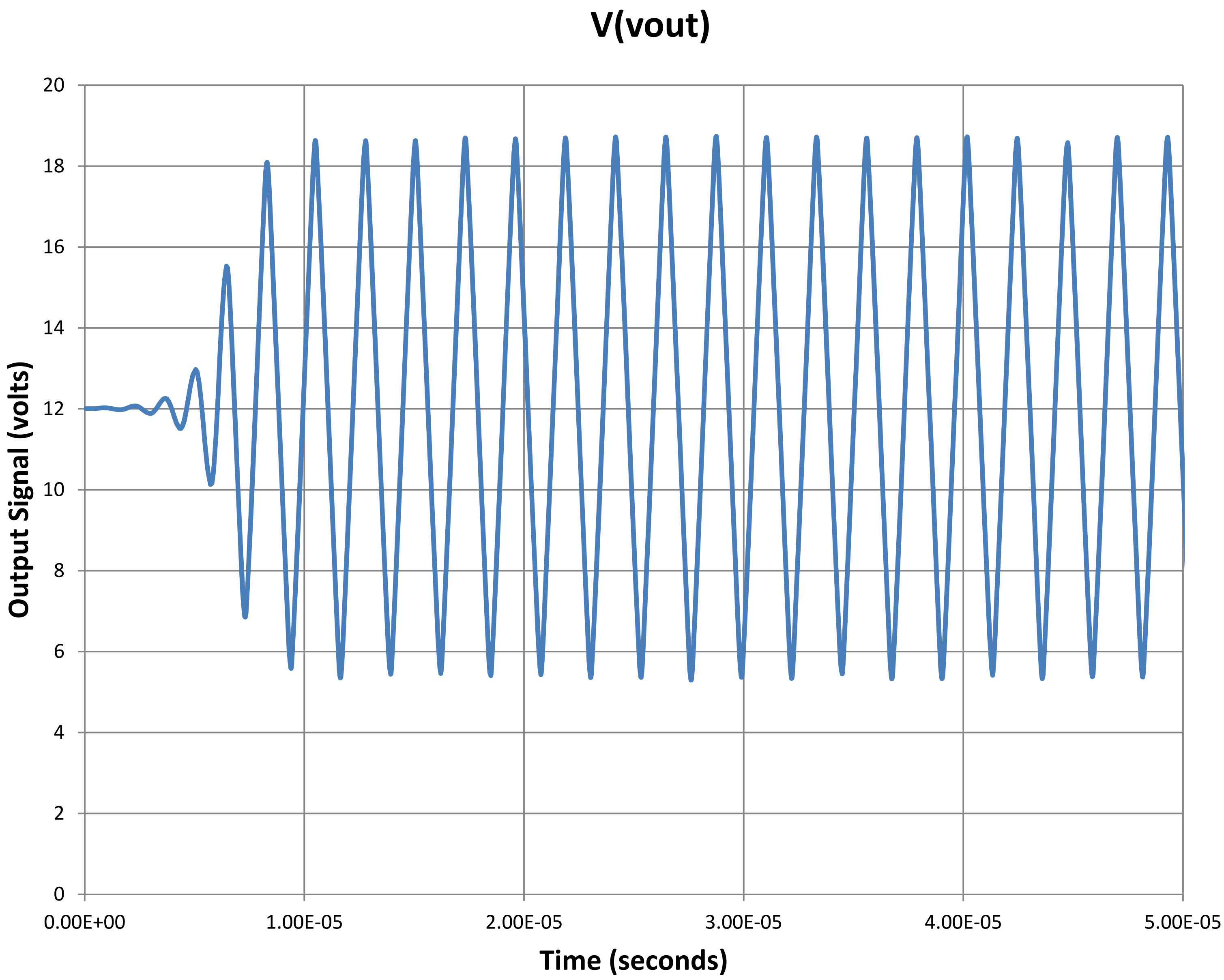


LF353 Open Loop Gain
Gain in dB
Unity Gain Point (2.8 MHz)
Phase shift in degrees
Phase margin for the
LF353 – 64 deg.
Gain (dB)
Phase Shift (degrees)
Frequency (Hertz)
140
120
100
80
60
40
20
0
-20
-40
-60
180
160
140
120
100
80
60
40
20
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000

Schematic of Phase Shift Oscillator

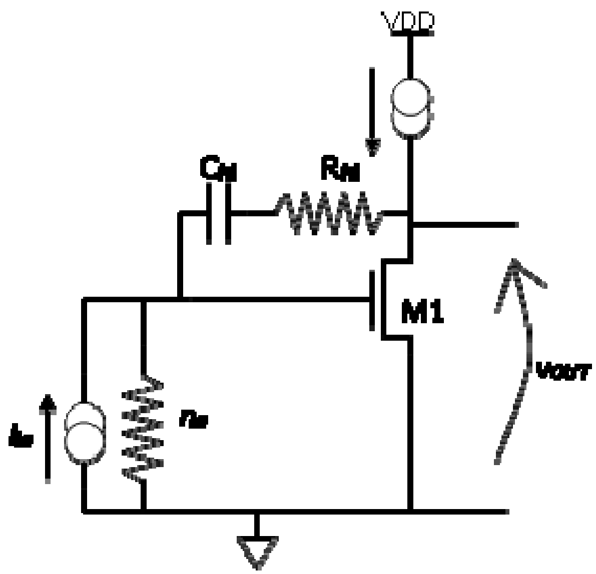



Open Loop Gain and Phase of Oscillator Circuit
Gain (dB)
120
100
80
60
40
20
0
-20
-40
-60
Phase (degrees)
180
140
100
60
20
-20
-60
-100
-140
-180
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Frequency (Hertz)
Open Loop Gain in dB
Zero Phase Frequency (450 KHz)
Phase Shift in Degrees
Phase margin is minus 40 degrees

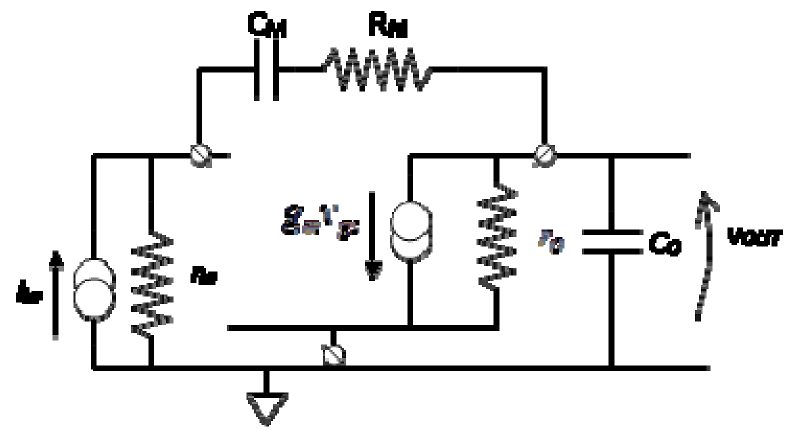

V(vout)
Output Signal (volts)
20
18
16
14
12
10
8
6
4
2
0
0.00E+00
1.00E-05
2.00E-05
3.00E-05
4.00E-05
5.00E-05
Time (seconds)

Common Source Stage with Miller Compensation

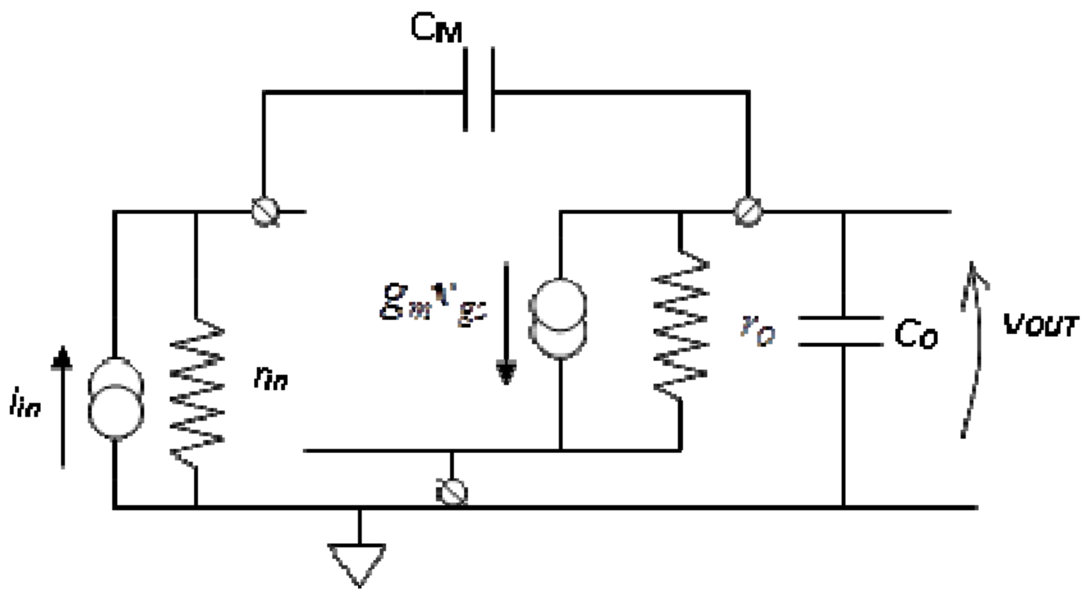
- Complete Circuit



- Small Signal Model
  - Omits CGS and CGD



Transfer Function with RM = 0



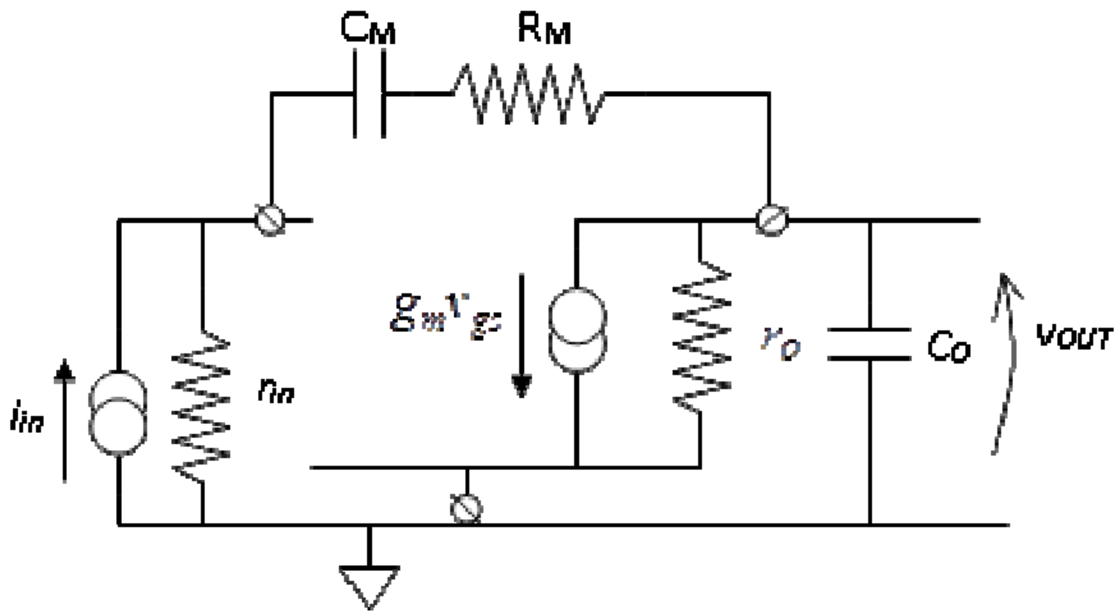
Zero – Bad for phase!!!

$$H(s)=\frac{-g_m r_O\left(1-sC_M/g_m\right)}{s^2C_Or_oC_Mr_i+s\left(\left(1+g_mr_o\right)C_Mr_i+C_Or_O+C_Mr_O\right)+1}$$

Second pole

Miller effect
Dominant pole

Transfer Function with RM in Place



Zero term bad for phase

Zero – New term good for phase
Make $R_M > 1/g_m$

$$H(s)=\frac{-g_m r_O\left(1-sC_M/g_m+sC_M R_M\right)}{s^2 C_O r_o C_M\left(r_i+R_M\right)+s\left(\left(1+g_m r_O\right)C_M r_i+C_O r_O+C_M r_O+C_M R_M\right)+1}$$