4.1 Linear Dependent Sources

- basis of the operational amplifier
- basis of feedback control

There are four basic types — these are all linear:

1. Current controlled voltage source
   - $r$ has units of ohms
   - $r$ transresistance

2. Voltage controlled voltage source
   - $\mu$ is voltage gain

3. Current controlled current source
   - $\beta$ is current gain

4. Voltage controlled current source
   - $g$ has units of siemens
   - $g$ transconductance

1. Dependent sources are not in catalogs
2. Cannot be turned on/off individually — always a source and a controlling voltage/current
\[
i_x = \frac{50}{50 + 25} i_s = \frac{2}{3} i_s
\]
\[
V_o = -48i_x \left( \frac{300}{300 + 500} \right) = -48 \left( \frac{2}{3} i_s \right) (18.75) = -6000 i_s
\]

1. can amplify very small currents
2. signal is inverted. This is common in many amplifiers.

\[
i_o = \frac{V_o}{R_L} = \frac{-6000 i_s}{500} = -12 i_s
\]

\[
P_o = V_o i_o = (-6000 i_s)(-12 i_s) = 72,000 i_s^2
\]

Exercise 4-1: Determine output

\[
i_x = \frac{V_s}{R_C + R_p}
\]

\[
V_o = \frac{R_L}{R_L + R_C} (-R_i x) = \left( \frac{R_L}{R_L + R_C} \right) \left( - \frac{R_s V_s}{R_s + R_p} \right)
\]
\( V_A, V_B \) are known

find \( V_C, V_D \) using KCL

\[ \Sigma i = 0 \]
\[ \frac{V_{s1} - V_C}{R_1} + \frac{V_{s2} - V_C}{R_2} - \frac{V_C - V_D}{R_B} - \frac{V_C - V_D}{R_P} = 0 \]

\[ \sum \text{in} \]
\[ \frac{V_C - V_D}{R_P} + \beta_i B - \frac{V_D}{R_E} = 0 \]

Don't use \( i_B \) here

\[ \left( -\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_B} - \frac{1}{R_P} \right) V_C + \left( \frac{1}{R_P} \right) V_D = \frac{V_{s1}}{R_1} + \frac{V_{s2}}{R_2} \]

\[ \left( \frac{1}{R_P} \right) V_C \]

\[ \left( -\frac{1}{R_P} - \frac{1}{R_E} \right) V_D = -\beta_i B \]

Now use controlling connection \( \frac{V_C - V_D}{R_P} = \beta_i B \)

\[ \left( \frac{1}{R_P} \right) \left( V_C \right) \]

\[ \left( -\frac{1}{R_P} - \frac{1}{R_E} \right) V_D = -\beta \frac{V_C}{R_P} + \beta \frac{V_D}{R_P} \]

\[ \left( \frac{1}{R_P} + \frac{\beta}{R_P} \right) V_C + \left( -\frac{1}{R_P} - \frac{\beta}{R_P} - \frac{1}{R_E} \right) V_D = 0 \]

\[ \left( \frac{\beta + 1}{R_P} \right) V_C - \left( \frac{\beta + 1}{R_P} + \frac{1}{R_E} \right) V_D = 0 \]

Solve 1 & 2 simultaneously.

MAY WANT TO MENTION CAN'T SUPERIMPOSE.
do source transformation

only one independent node ⇒ one equation

\[ \frac{\sum I}{R_1} + \frac{\nu_s}{R_1} - \frac{\nu_A}{R_2} - \frac{\nu_A - \nu_B}{R_3} = 0 \]

control constraint \[ \nu_A = \nu_x \quad \nu_B = \nu_0 \]
- \[ \nu_0 = \mu \nu_x = \mu \nu_A \]
- \[ \nu_A = \nu_x = -\frac{\nu_0}{\mu} \]

\[ \frac{\nu_s}{R_1} - \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \nu_A + \frac{\nu_B}{R_3} = 0 \]

\[ \frac{\nu_s}{R_1} - \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \left( -\frac{\nu_0}{\mu} \right) + \frac{\nu_B}{R_3} = 0 \]

\[ \frac{\nu_s}{R_1} = - \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \frac{1}{\mu} + \frac{1}{R_3} \nu_0 \]

\[ \frac{\nu_s}{\nu_0} = - \frac{1}{\frac{R_1}{R_0} + \frac{1}{R_2} + \frac{1}{R_3} + \mu} \]

output independent of \( R_4 \)

signal inversion

consider situation where \( \mu >> 1 \)

\[ \frac{\nu_s}{\nu_0} \approx - \frac{\frac{R_1}{R_0}}{\frac{R_1}{R_3}} = - \frac{R_3}{R_1} \]