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TECHNICAL NOTE

VOLTAGE CONTROLLED AMPLIFIER ANALYSIS

1.0 Circuit

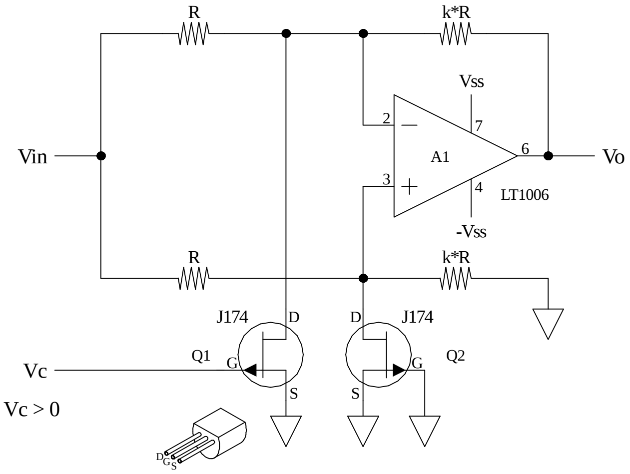

Figure 1.0-1

1.1 Analysis model

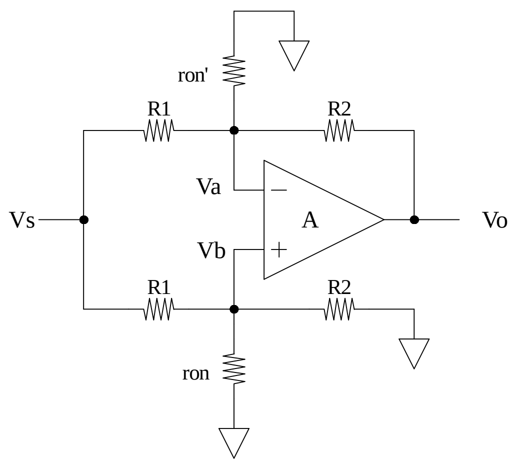

Figure 1.1-1

r_{on}' is the controlled FET on resistance with non-zero gate to source voltage,	Ohms
r_{on} is the reference FET on resistance with zero gate to source voltage,	Ohms
A is the operational amplifier open loop gain,	V/V

1.2 Analysis

Define α, the attenuation factor from the signal input terminal to the amplifier inverting input, and β, the attenuation factor from the output terminal to the amplifier inverting input;

$$\alpha = \frac{R_2 \cdot r_{on}'}{R_1 \cdot r_{on}' + R_1 \cdot R_2 + R_2 \cdot r_{on}'} \qquad \text{Eq:1.2-1}$$

$$\beta = \frac{R_1 \cdot r_{on}'}{R_1 \cdot r_{on}' + R_1 \cdot R_2 + R_2 \cdot r_{on}'} \qquad \text{Eq:1.2-2}$$

Define σ, the attenuation factor from the signal input terminal to the amplifier non-inverting input.

$$\sigma = \frac{R_2 \cdot r_{on}}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}} \qquad \text{Eq:1.2-3}$$

solving for V_o,

$$V_O = A \cdot (V_a - V_b) \qquad \text{Eq:1.2-4}$$

$$V_a = \sigma \cdot V_S$$
$$V_b = \alpha \cdot V_S + \beta \cdot V_O$$

$$V_O = A \cdot \sigma \cdot V_S - A \cdot \alpha \cdot V_S - A \cdot \beta \cdot V_O$$

$$V_O = \frac{A \cdot (\sigma - \alpha) \cdot V_S}{1 + A \cdot \beta}$$

solving for voltage gain,

$$A_V = \frac{V_O}{V_S} = \frac{A \cdot (\sigma - \alpha)}{1 + A \cdot \beta} \qquad \text{Eq:1.2-5}$$

if A→∞,

$$A_V = \frac{\sigma - \alpha}{\beta}$$

$$A_V = \frac{\sigma}{\beta} - \frac{\alpha}{\beta}$$

using Eq:1.2-1 and Eq:1.2-2,

$$A_V = \sigma \cdot \left(\frac{R_1 \cdot r_{on}' + R_1 \cdot R_2 + R_2 \cdot r_{on}'}{R_1 \cdot r_{on}'} \right) - \frac{R_2}{R1}$$

$$A_V = \sigma \cdot \left(1 + \frac{R_2}{r_{on}'} + \frac{R_2}{R_1} \right) - \frac{R_2}{R_1}$$

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$$A_V = \sigma \cdot \left(1 + \frac{R_2}{R_1}\right) + \sigma \cdot \frac{R_2}{r'_{on}} - \frac{R_2}{R_1}$$

from FET Junction Transistors, Carl David Todd, Wiley, p.122

$$r'_{on} = r_{on} \cdot \left(1 - \frac{V_{GS}}{V_P}\right)^{-1} \qquad \text{Eq:1.2-6}$$

V_{GS} = Gate to source voltage
V_P = Pinch-off voltage of JFET

$$A_V = \sigma \cdot \left(1 + \frac{R_2}{R_1}\right) + \sigma \cdot \frac{R_2}{r_{on}} \cdot \left(1 - \frac{V_{GS}}{V_P}\right) - \frac{R_2}{R_1}$$

from Eq:1.2-3,

$$\sigma = \frac{R_2 \cdot r_{on}}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}}$$

$$A_V = \frac{R_2 \cdot r_{on}}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}} \cdot \left(1 + \frac{R_2}{R_1}\right) + \frac{R_2^2}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}} \cdot \left(1 - \frac{V_{GS}}{V_P}\right) - \frac{R_2}{R_1}$$

now if r_{on} is very small,

$$\frac{R_2 \cdot r_{on}}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}} \to 0$$

$$\frac{R_2^2}{R_1 \cdot r_{on} + R_1 \cdot R_2 + R_2 \cdot r_{on}} \to \frac{R_2}{R_1}$$

then,

$$A_V = \frac{R_2}{R_1} \cdot \left(1 - \frac{V_{GS}}{V_P}\right) - \frac{R_2}{R_1}$$

$$A_V = -\frac{R_2}{R_1} \cdot \frac{V_{GS}}{V_P} \qquad \text{Eq:1.2-7}$$

for $R_2 = k \cdot R_1$,

$$A_V = -k \cdot \frac{V_{GS}}{V_P} \qquad \text{Eq:1.2-8}$$

$V_{GS} \to V_C$

$$\boxed{A_V = -k \cdot \frac{V_C}{V_P}} \qquad \text{Eq:1.2-9}$$