



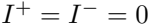








10-12-19











A horizontal sequence of eight grayscale images showing the progression of a handwritten digit '2' being drawn on a white background. The sequence starts with a single vertical stroke and gradually adds more strokes and curves until the digit is complete.

100%

100%











$$v_{out} = A_d(v^+ - v^-) + A_c \frac{1}{2}(v^+ + v^-) \approx A_d(v^+ - v^-)$$









$$CMRR = 20 \log_{10} \left(\frac{A_d}{A_c} \right) > 100 \text{ dB}, \quad (A_d > 10^5 A_c)$$



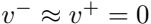


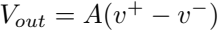


W + 1 = 1000







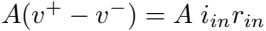


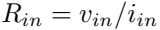




1994







$$v_n = i_n(r_n + r_{out}) + A(v^+ - v^-) = i_n(r_n + r_{out}) + A i_n r_n = i_n(A + 1)r_n + r_{out}$$

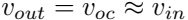


$$P_{in} = \frac{v_{in}}{v_{in}} = (A + 1) v_{in} + v_{out} \approx A v_{in}$$

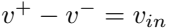
$$v_{out} = v_{oc} = A(v^{+} - v^{-}) + i_{in} r_{out} = A i_{in} r_{in} + i_{in} r_{out} = i_{in} (A r_{in} + r_{out})$$

$$G = \frac{v_{out}}{v_{in}} = \frac{Ar_{in} + r_{out}}{(A+1)r_{in} + r_{out}} \approx \frac{Ar_{in}}{(A+1)r_{in}} \approx 1$$

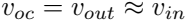








$$i_{sc} = \frac{v_{in}}{r_{in}} + \frac{A(v^{+} - v^{-})}{r_{out}} = \frac{v_{in}}{r_{in}} + \frac{Av_{in}}{r_{out}} = v_{in} \left(\frac{r_{out} + Ar_{in}}{r_{in}r_{out}} \right) \approx v_{in} \frac{A}{r_{out}}$$



$$R_{out} = \frac{v_{oc}}{i_{sc}} \approx \frac{v_{in}}{i_{sc}} = \left(\frac{r_{in} r_{out}}{r_{out} + A r_{in}} \right) \approx \frac{r_{out}}{A}$$





10101010

1999-2000

10-20









$$v_{out} = v_s \frac{R_L}{R_L + R_s} = v_s - \left(\frac{R_s}{R_L + R_s} \right) v_s < v_s$$

$$v_{out} = G_{oc} \left(\frac{R_L}{R_{out} + R_L} \right) \quad v_{in} = G_{oc} \left(\frac{R_{in}}{R_s + R_{in}} \right) \left(\frac{R_L}{R_{out} + R_L} \right) v_s$$



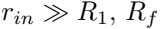
Prinzipien der Algebra 1

BRANDS + BRANDS 1

$$v_{out} = G_{oc} \left(\frac{R_{in}}{R_s + R_{in}} \right) \left(\frac{R_L}{R_{out} + R_L} \right) v_s \approx v_s$$

1990

1991







[illegible]

$$v_{in} = \frac{v_s - A(v_+ - v_-)}{R_1 + R_f} = \frac{v_s - A(i_{in}R_1 - v_s)}{R_1 + R_f}$$

$$v_{in} = \frac{(A+1)}{(A+1)R_1 + R_f} v_s$$

$$v_{out} = v_s - (R_1 + R_f)i_{in} = v_s \left[1 - \frac{(A+1)(R_1 + R_f)}{(A+1)R_1 + R_f} \right] = v_s \frac{-AR_f}{(A+1)R_1 + R_f}$$

$$G_{oc} = \frac{v_{out}}{v_s} = \frac{-AR_f}{(A+1)R_1 + R_f} \approx -\frac{R_f}{R_1}$$

$$\frac{v_s}{R_1} + \frac{v_{out}}{R_f} = 0,$$

$$G_{oc} = \frac{v_{out}}{v_s} = -\frac{R_f}{R_1}$$





$$\frac{v - v_s}{R_1} + \frac{v - (-Av)}{R_f} = 0$$

$$v_- = v_s \frac{R_f}{R_f + (A + 1)R_1}$$



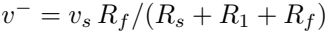


$$\frac{v_s - v^-}{R_1} = \frac{v_s}{R_1} \left[1 - \frac{R_f}{R_f + (A + 1)R_1} \right]$$

$$v_s \frac{1}{R_1} \frac{(A+1)R_1}{R_f + (A+1)R_1} = v_s \frac{A+1}{R_f + (A+1)R_1}$$

$$R_m = \frac{R_f + (A + 1)R_1}{A + 1} \approx R_1$$

$$i_{sc} = \frac{-Av^-}{r_{out}} + \frac{v^-}{R_f} = v^- \left(\frac{r_{out} - AR_f}{r_{out}R_f} \right)$$



$$i_{sc} = v_s \left(\frac{R_f}{R_s + R_1 + R_f} \right) \left(\frac{r_{out} - AR_f}{r_{out} R_f} \right) = v_s \frac{r_{out} - AR_f}{(R_s + R_1 + R_f) r_{out}}$$

$$\frac{v_s - v^-}{R_s + R_1} + \frac{(-Av^-) - v^-}{R_f + r_{out}} = 0$$

$$v_- = v_s \left(\frac{R_f + r_{out}}{(A+1)(R_s + R_1) + R_f + r_{out}} \right)$$



$$\left[v^- - (-Av^-) \right] \frac{r_{out}}{R_f + r_{out}} - Av^- = v^- \left(\frac{r_{out} - AR_f}{R_f + r_{out}} \right)$$

$$v_s = \frac{r_{out} - AR_f}{(A+1)(R_s + R_1) + R_f + r_{out}}$$

1994

$$\frac{v_{oc}}{i_{sc}} = \frac{(R_s + R_1 + R_f)r_{out}}{(A + 1)(R_s + R_1) + R_f + r_{out}}$$



$$\frac{(R_s + R_1 + R_f)r_{out}}{A(R_s + R_1)} \approx \left(\frac{R_1 + R_f}{R_1} \right) \frac{r_{out}}{A}$$

19

19

19

19

19

$$G_{oc} \approx -\frac{R_f}{R_1}$$



$$R_{out} \approx \left(\frac{R_1 + R_f}{R_1} \right) \frac{r_{out}}{A}$$

$$G_{oc} \approx \frac{R_1 + R_f}{R_1} > 1$$

$$R_{in} \approx \left(\frac{R_1}{R_1 + R_f} \right) A r_{in} \approx \frac{A}{G_{oc}} r_{in} < A r_{in}$$

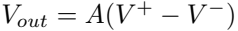
$$R_{out} \approx \left(\frac{R_1 + R_f}{R_1} \right) \frac{r_{out}}{A} \approx \frac{G_{oc}}{A} r_{out} > \frac{r_{out}}{A}$$















W + L = WA + O













$$\frac{V_{in}}{R_1} + \frac{V_{out}}{R_f} = 0,$$

$$V_{out} = -\frac{R_f}{R_1} V_{in}$$









$$H(j\omega) = \frac{V_{out}(j\omega)}{V_{in}(j\omega)} = -\frac{Z_2(j\omega)}{Z_1(j\omega)}$$



$$V_{in} = V_+ \approx V_- = V_{out} \frac{R_1}{R_1 + R_f},$$

$$V_{out} = \left(\frac{R_1 + R_f}{R_1} \right) V_{in}$$

$$\sum_{k=1}^n \frac{V_k}{R_k} + \frac{V_{out}}{R_f} = 0,$$

$$V_{out} = -R_f \sum_{k=1}^n \frac{V_k}{R_k} = - \sum_{k=1}^n \frac{R_f}{R_k} V_k$$

$$V_{out} = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2 + \left(\frac{R_f}{R_1} + \frac{R_f}{R_2} + 1\right)\left(\frac{R_4}{R_3 + R_4}V_3 + \frac{R_3}{R_3 + R_4}v_4\right)$$



$$\frac{V_1 - V}{R_1} + \frac{V_{out} - V}{R_2} = 0,$$

$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(1 + \frac{R_2}{R_1}\right)V$$

$$V \approx V + \frac{R_4}{R_3 + R_4} V_2$$

$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{R_1 + R_2}{R_1}\right)\frac{R_4}{R_3 + R_4}V_2$$





$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{R_1 + R_2}{R_1}\right)\frac{R_4}{R_3 + R_4}V_2 = \frac{R_2}{R_1}(V_2 - V_1)$$



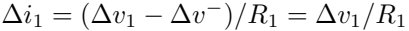
$V_1 = \frac{V_2}{2} + v$

$$V_{out} = \frac{R_2}{R_1} (V_2 - V_1) = \frac{R_2}{R_1} (V_2 - V_1)$$





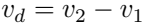




$$R_{in_1} = \frac{\Delta v_1}{\Delta i_1} = R_1$$







$$v_2 = i_2 R_2 + v_1 + i_2 R_1 + v_1 + i_2 R_1$$

$$R_{in_d} = \frac{v_d}{v_d} = R_1 + R_2$$

12345







$$V_{out} = -\frac{R_2}{R_1} V_1 + \left(1 + \frac{R_2}{R_1}\right) V_2$$





$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{R_1 + R_2}{R_1}\right)\frac{R_4}{R_3 + R_4}V_2 = V_2$$





$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{R_1 + R_2}{R_1}\right)\frac{R_4}{R_3 + R_4}V_2 = -\frac{R_2}{R_1}V_1$$





$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{R_1 + R_2}{R_3 + R_4}\right)\frac{R_4}{R_1}V_2 = \left(1 + \frac{R_2}{R_1}\right)V_2$$









$$V_{out} = -\frac{R_2}{R_1} V_1 + V_{shift};$$

$$V_{shift} = \left(\frac{R_1 + R_2}{R_1} \right) \frac{R_4}{R_3 + R_4} V_{ref}$$

V1

5

Verges



$$V_{out} = \left(\frac{R_1 + R_2}{R_1} \right) \frac{R_4}{R_3 + R_4} V_2 - V_{shift}$$

$$V_{shift} = \frac{R_2}{R_1} V_{ref}$$



$$v_1' = v_1 \left(1 + \frac{R_f}{R_1} \right), \quad v_2' = v_2 \left(1 + \frac{R_f}{R_1} \right)$$

$$V_{out} = \frac{R_4}{R_3} (V_2 - V_1) = \frac{R_4}{R_3} \left(1 + \frac{R_f}{R_1} \right) (V_2 - V_1)$$



11

$$V_{out} = \frac{R_4}{R_3} \left(1 + \frac{2R_f}{R_0} \right) (V_2 - V_1)$$







$$\frac{V_1 - V_1}{R_f} = \frac{V_1 - V_0}{R_1} = \frac{V_0 - V_2}{R_1} = \frac{V_2 - V_2}{R_f}$$

$$V_1 = \left(1 + \frac{R_f}{R_1} \right) V_1 - \frac{R_f}{R_1} V_0$$

$$v_2 = \left(1 + \frac{R_f}{R_1} \right) v_2 - \frac{R_f}{R_1} v_0$$

RESPONSE FOR

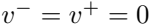


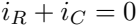






Input voltage	0	1	2	3
Op-amps Outputs	000	001	011	111
Binary Representation	00	01	10	11





$$iR + iC = \frac{v_i}{R} + C \frac{dv_{out}}{dt} = 0,$$

$$v_{out} = -\frac{1}{\tau} \int v_i dt$$



$$H(j\omega) = \frac{Z_2(j\omega)}{Z_1(j\omega)} = \frac{1/j\omega C}{R} = \frac{1}{j\omega RC} = \frac{1}{j\omega \tau}$$

$$iR + iC = \frac{v_{out}}{R} + C \frac{dv_i}{dt} = 0,$$

$$v_{out} = -RC \frac{dv_i}{dt} = -\tau \frac{dv_i}{dt}$$

$$H(j\omega) = -\frac{Z_2(j\omega)}{Z_1(j\omega)} = -\frac{R}{1/j\omega C} = -j\omega R$$

$$v_{out}(t) = c_p v_{in}(t) + c_i \int v_{in}(t) dt + c_d \frac{d v_{in}}{dt}$$

Practical

$$I_L = \frac{V_+ - V_-}{R_3} = \frac{V}{R_L}$$

over the course of the
over the last 10 years



