ANALYSIS OF FULLY DIFFERENTIAL AMP
BY JIM KARKI OF TI USING SUPER POSITION ON V_P & V_M 12/17/16

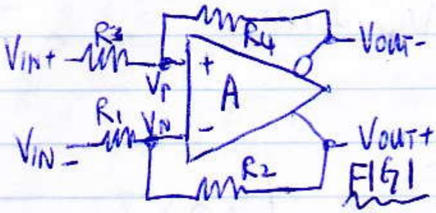


FIG 1

$$V_{ID} = V_{IN+} - V_{IN-} \quad (1) \qquad V_{IC} = \frac{V_{IN+} + V_{IN-}}{2} \quad (2)$$

$$V_{OD} = V_{OUT+} - V_{OUT-} \quad (3) \qquad V_{OC} = \frac{V_{OUT+} + V_{OUT-}}{2} \quad (4)$$

$$V_{OD} = V_{OUT+} - V_{OUT-} = A(V_P - V_N) \quad (5)$$

$$V_P = V_{IN+}\left(\frac{R_4}{R_3+R_4}\right) + V_{OUT-}\left(\frac{R_3}{R_3+R_4}\right) = V_{IN+}(1-\beta_1) + V_{OUT-}\beta_1, \quad \beta_1 = \frac{R_3}{R_3+R_4} \quad (8)$$

$$V_N = V_{IN-}\left(\frac{R_2}{R_1+R_2}\right) + V_{OUT+}\left(\frac{R_1}{R_1+R_2}\right) = V_{IN-}(1-\beta_2) + V_{OUT-}\beta_2, \quad \beta_2 = \frac{R_1}{R_1+R_2} \quad (7)$$

$$(5) \Rightarrow V_{OUT+} - V_{OUT-} = A(V_P - V_M) = A\left[(V_{IN+})(1-\beta_1) + (V_{OUT-})\beta_1 - (V_{IN-})(1-\beta_2) - (V_{OUT+})\beta_2\right]$$

$$\Rightarrow (V_{OUT+})(1+A\beta_2) - (V_{OUT-})(1+A\beta_1) = A\left[(V_{IN+})(1-\beta_1) - (V_{IN-})(1-\beta_2)\right] \quad (9)$$

$$\frac{(V_{OUT+}) + (V_{OUT-})}{2} = V_{OC} \Rightarrow V_{OUT-} = 2V_{OC} - V_{OUT+}$$

$$(9) \Rightarrow (V_{OUT+})(1+A\beta_2) - (2V_{OC} - V_{OUT+})(1+A\beta_1) = A\left[(V_{IN+})(1-\beta_1) - (V_{IN-})(1-\beta_2)\right]$$

$$\Rightarrow (V_{OUT+})\left[2 + A(\beta_1+\beta_2)\right] = A(\beta_1+\beta_2)(V_{OUT+})\left[\frac{2}{A(\beta_1+\beta_2)} + 1\right]$$

$$= A\left[(V_{IN+})(1-\beta_1) - (V_{IN-})(1-\beta_2) + \frac{2V_{OC}}{A}(1+A\beta_1)\right]$$

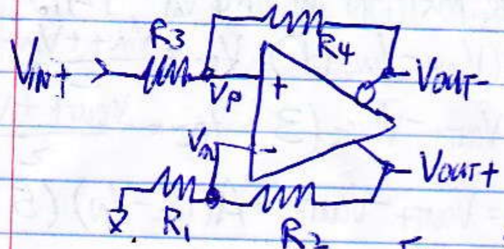
$$\Rightarrow V_{OUT+} = \left(\frac{1}{\beta_1+\beta_2}\right)\left[\frac{(V_{IN+})(1-\beta_1) - (V_{IN-})(1-\beta_2) + 2V_{OC}\left(\frac{1}{A} + \beta_1\right)}{\left(1 + \frac{2}{A(\beta_1+\beta_2)}\right)}\right] \quad (10)$$

$$\therefore V_{OUT-} = \left(\frac{1}{\beta_1+\beta_2}\right)\left[\frac{-(V_{IN+})(1-\beta_1) + (V_{IN-})(1-\beta_2) + 2V_{OC}\left(\frac{1}{A} + \beta_2\right)}{\left(1 + \frac{2}{A(\beta_1+\beta_2)}\right)}\right] \quad (12)$$

$$V_{OD} = V_{OUT+} - V_{OUT-} = \left(\frac{1}{\beta_1+\beta_2}\right)\left[\frac{2\left[(V_{IN+})(1-\beta_1) - (V_{IN-})(1-\beta_2)\right] + 2V_{OC}(\beta_1 - \beta_2)}{\left(1 + \frac{2}{A(\beta_1+\beta_2)}\right)}\right] \quad (14)$$

SINGLE END INPUT FULL DIFFERENTIAL AMP

12/19/17



$\Rightarrow V_{IN-} = 0V$

FIG2

$$(10) \Rightarrow V_{OUT+} = \left(\frac{1}{(\beta_1+\beta_2)}\right)\left[\frac{(V_{IN+})(1-\beta_1)+2V_{OC}\left(\frac{1}{A}+\beta_1\right)}{\left(1+\frac{2}{A(\beta_1+\beta_2)}\right)}\right] \quad (10a)$$

$$(12) \Rightarrow V_{OUT-} = \left(\frac{1}{(\beta_1+\beta_2)}\right)\left[\frac{(-V_{IN+})(1-\beta_1)+2V_{OC}\left(\frac{1}{A}+\beta_2\right)}{1+\frac{2}{A(\beta_1+\beta_2)}}\right] \quad (12a)$$

$$(14) \Rightarrow V_{OD} = \frac{1}{(\beta_1+\beta_2)}\left[\frac{2[(V_{IN+})(1-\beta_1)+2V_{OC}(\beta_1-\beta_2)}{\left(1+\frac{2}{A(\beta_1+\beta_2)}\right)}\right] \quad (14a)$$

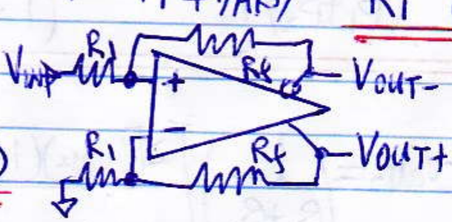
CIRCUIT GREATLY SIMPLIFIED IF $R_1 = R_3$ & $R_2 = R_4 \Rightarrow \beta_1 = \beta_2 = \beta$

$$(10a) \Rightarrow V_{OUT+} = \frac{1}{2\beta}\left[\frac{V_{IN+}(1-\beta)+2V_{OC}(1/A+\beta)}{1+1/A\beta}\right] \quad (10b)$$

$$(12a) \Rightarrow V_{OUT-} = \frac{1}{2\beta}\left[\frac{-V_{IN+}(1-\beta)+2V_{OC}(1/A+\beta)}{1+1/A\beta}\right] \quad (12b)$$

$$(14a) \Rightarrow V_{OD} = V_{OUT+} - V_{OUT-} = \frac{1-\beta}{\beta}\left(\frac{V_{IN+}}{1+1/A\beta}\right) = \frac{R_f}{R_1}\,\frac{(V_{IN+})A\beta}{(1+A\beta)}, \; R_f = R_2 = R_4 \quad (14b)$$

$$GAIN = \frac{V_{OD}}{V_{IN+}} = \frac{R_f}{R_1}\,\frac{A\beta}{(1+A\beta)} \quad (1)$$



SINGLE ENDED INPUT FULL DIFFERENTIAL AMP
DRIVEN BY TRIODE WITH PLATE RESISTANCE r_{P1} 12/22/17

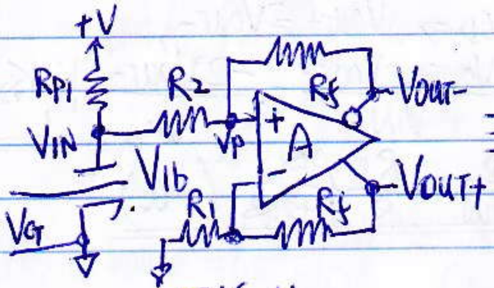


FIG 4

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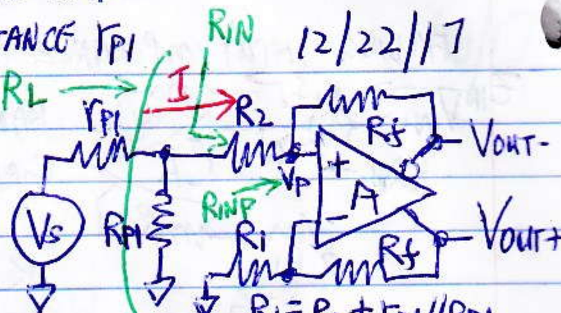
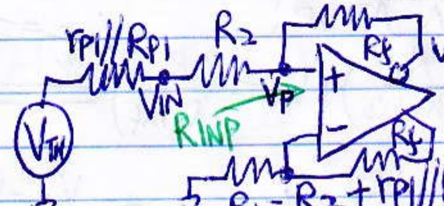


$R_1 = R_2 + r_{P1} // R_{P1}$

FIG 5

THEVENIN OF FIG 5 => EQ



$R_1 = R_2 + r_{P1} // R_{P1}$ FIG 6

$V_{TH} = V_S \frac{R_{P1}}{r_{P1} + R_{P1}}$

→ FINDING R_{INP}, USE SUPER POSITION AT V_P

$$(12) \Rightarrow V_{OUT-} = \left(\frac{1}{\beta_+ + \beta_-}\right) \frac{-V_{IN}(1-\beta_+)}{1 + 2/A(\beta_+ + \beta_-)}$$

FOR BALANCED, SINGLE ENDED $\beta_+ = \frac{R_2}{R_2 + R_f}$, $\beta_- = \frac{R_2 + (r_{P1} // R_{P1})}{R_2 + R_f + (r_{P1} // R_{P1})}$

$$\text{FOR } A(\beta_+ + \beta_-) \gg 2 \Rightarrow V_{OUT-} = \frac{-V_{IN}(1-\beta_-)}{\beta_+ + \beta_-}$$

$$V_P = V_{IN} \frac{R_f}{R_2 + R_f} + V_{OUT-} \frac{R_2}{R_2 + R_f} = \frac{V_{IN}}{R_2 + R_f}\left(R_f - \frac{R_2(1-\beta_+)}{\beta_+ + \beta_-}\right)$$

$$I_{R2} = \frac{V_{IN} - V_{OUT-}}{R_2 + R_f} = \frac{V_{IN}}{R_2 + R_f}\left(1 + \frac{(1-\beta_+)}{\beta_+ + \beta_-}\right)$$

$$R_{INP} = \frac{V_P}{I_{R2}} = \frac{\left(R_f - \frac{R_2(1-\beta_+)}{\beta_+ + \beta_-}\right)}{\left(1 + \frac{(1-\beta_+)}{\beta_+ + \beta_-}\right)} = \frac{R_f(\beta_+ + \beta_-) - R_2(1-\beta_+)}{(\beta_+ + \beta_- + 1 - \beta_+)}$$

$$\rightarrow R_{INP} = \frac{(R_f\beta_+ + R_f\beta_- - R_2 + R_2\beta_+)}{1 + \beta_-} \quad (5)$$

$$\rightarrow R_{IN} = R_2 + R_{INP} = \frac{(R_2 + R_f)(\beta_+ + \beta_-)}{1 + \beta_-} \quad (6)$$

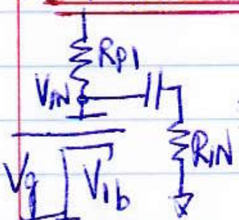
12/25/17

→ PLATE LOAD RESISTANCE FOR V_{1b} $\quad R_L = R_{IN} // R_{P1}$

$$R_{IN} = \frac{(R_2+R_f)(\beta_+ + \beta_-)}{1+\beta_-} \Rightarrow R_L = \frac{R_{P1}\left(\frac{(R_2+R_f)(\beta_+ + \beta_-)}{1+\beta_-}\right)}{\left(\frac{(R_2+R_f)(\beta_+ + \beta_-)}{1+\beta_-} + R_{P1}\right)}$$

$$R_L = \frac{R_{P1}(R_G+R_f)(\beta_+ + \beta_-)}{\left[(R_2+R_f)(\beta_+ + \beta_-) + R_{P1}(1+\beta_-)\right]} = \frac{R_{P1}(R_2+R_f)}{R_2+R_f+R_{P1}\frac{(1+\beta_-)}{(\beta_+ + \beta_-)}} \quad (7)$$

→ TUBE V_{1b}



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$$\text{GAIN } V_{1b} = \frac{V_{IN}}{V_g} = g_m \frac{r_{P1} R_L}{r_{P1}+R_L} = \mu \frac{R_L}{r_{P1}+R_L} \quad (8)$$