ECE 6416 Formula Sheet

$$v_{thermal}^2 = 4kTR\Delta f \quad i_{thermal}^2 = \frac{v_t^2}{R^2} = \frac{4kT\Delta f}{R} \quad v_{thermal}^2 = 4kT\,\mathrm{Re}\,(Z)\,\Delta f \quad i_{thermal}^2 = 4kT\,\mathrm{Re}\,(Y)\,\Delta f$$

$$i_{shot}^2 = 2qI_{DC}\Delta f \quad i_{flicker}^2 = \frac{K_f I_{DC}\Delta f}{f} \quad v_{excess}^2 = i_{ex}^2 R^2 = \frac{K_f I_{DC}^2 R^2 \Delta f}{f} = \frac{K_f V_{DC}^2 \Delta f}{f}$$

$$v_{excess}^2 = 10^{NI/10} \times V_{DC}^2 \times \log\left(\frac{f_2}{f_1}\right) \mu\mathrm{V}^2 \quad i_{excess}^2 = 10^{NI/10} \times I_{DC}^2 \times \log\left(\frac{f_2}{f_1}\right) \mu\mathrm{A}^2$$

$$\text{Correlation: } \rho = \frac{\overline{v_a(t)\,v_b(t)}}{v_a v_b} \quad \gamma = \gamma_r + j\gamma_i = \frac{\overline{V_a V_b^*}}{v_a v_b}$$

$$\text{Noise Bandwidth: } B_n = \frac{1}{A_0^2}\int_0^\infty |A(j2\pi f)|^2 df \quad B_n = \frac{\pi}{2}B_3$$

$$\text{Signal-to-Noise Ratio: } SNR = \frac{v_s^2}{v_{ni}^2}$$

$$\text{Noise Resistance and Conductance: } R_n = \frac{v_n^2}{4kT_0\Delta f} \quad G_n = \frac{i_n^2}{4kT_0\Delta f}$$

$$\text{Noise Factor and Noise Figure: } F = \frac{v_{ni}^2}{v_{ts}^2} \quad NF = 10\log(F)$$

$$\text{Equivalent Noise Input Voltage: } v_{ni}^2 = 4kT\,\mathrm{Re}\,(Z_s)\,\Delta f + v_n^2 + 2v_n i_n \,\mathrm{Re}\,(\gamma Z_s^*) + i_n^2 |Z_s|^2$$

$$\text{Correlation Impedance: } Z_\gamma = R_\gamma + jX_\gamma = (\gamma_r + j\gamma_i)\frac{v_n}{i_n}$$

$$\text{Optimum Source Impedance: } Z_{opt} = \left[\sqrt{1-\gamma_i^2} - j\gamma_i\right]\frac{v_n}{i_n} = \sqrt{\frac{R_n}{G_n} - X_\gamma^2} - jX_\gamma$$

$$\text{Minimum Noise Factor: } F_{min} = 1 + \frac{v_n i_n}{2kT_0\Delta f}\left(\gamma_r + \sqrt{1-\gamma_i^2}\right) = 1 + 2G_n(R_\gamma + R_{opt})$$

$$\text{Noise Factor as a Function of } F_{min}\text{: } F = F_{min} + \frac{G_n}{R_s}|Z_s - Z_{opt}|^2$$

$$\text{Noise Factor of Multi-Stage Amplifier: } F = F_1 + \frac{F_2 - 1}{G_{a1}} + \cdots + \frac{F_N - 1}{G_{a1}G_{a2}\cdots G_{a(N-1)}}$$

$$\text{Noise Temperature: } T_n = (F-1)\,T_0 = T_{n1} + \frac{T_{n2}}{G_{a1}} + \cdots + \frac{T_{nN}}{G_{a1}G_{a2}\cdots G_{a(N-1)}}$$

$$\text{Diode: } i_n^2 = 2q(I_D + 2I_S)\,\Delta f \quad r_d = \frac{\eta V_T}{I_D + I_S} = \frac{\eta kT}{q(I_D + I_S)}$$

$$\text{BJT: } i_c = i_c' + \frac{v_{ce}}{r_0} \quad i_c' = g_m v_\pi = \beta i_b = \alpha i_e' \quad g_m = \frac{I_C}{V_T} \quad r_\pi = \frac{V_T}{I_B} \quad r_e = \frac{V_T}{I_E}$$

$$\text{BJT: } r_0 = \frac{V_A + V_{CE}}{I_C} \quad V_A = \infty \text{ unless given}$$

$$\text{BJT: } i_{c(sc)} \overset{r_0 \text{ approx}}{=} G_m(v_{tb} - v_{te}) \quad G_m = \frac{\alpha}{r_e' + R_{te}} \quad r_e' = \frac{R_{tb} + r_x}{1+\beta} + r_e$$

$$\text{BJT: } v_{tx}^2 = 4kTr_x\Delta f \quad i_{shb}^2 = 2qI_B\Delta f \quad i_{fb}^2 = \frac{K_f I_B \Delta f}{f} \quad i_{shc}^2 = 2qI_C\Delta f$$

$$\text{BJT: } v_{ni}^2 = 4kT(R_1 + r_x + R_2)\,\Delta f + \left(2qI_B\Delta f + \frac{K_f I_B\Delta f}{f}\right)(R_1 + r_x + R_2)^2 + 2qI_C\Delta f\left(\frac{R_1 + r_x + R_2}{\beta} + \frac{V_T}{I_C}\right)^2$$

BJT: $v_{n1}^2 = 4kTr_x\Delta f + 2kT\frac{V_T}{I_C}\Delta f \quad i_{n1}^2 = 2qI_B\Delta f + \frac{K_f I_B \Delta f}{f} + 2q\frac{I_C}{\beta^2}\Delta f \quad \rho_1 = \frac{2kT\Delta f}{\beta v_n i_n}$

BJT: $v_{n2}^2 = 4kTr_x\Delta f + \left(2qI_B\Delta f + \frac{K_f I_B \Delta f}{f}\right) r_x^2 + 2qI_C\Delta f \left(\frac{r_x}{\beta} + \frac{V_T}{I_C}\right)^2$

BJT: $i_{n2}^2 = 2qI_B\Delta f + \frac{K_f I_B \Delta f}{f} + 2q\frac{I_C}{\beta^2}\Delta f$

BJT: $\rho_2 = \frac{1}{v_n i_n}\left[\left(2qI_B\Delta f + \frac{K_f I_B \Delta f}{f}\right) r_x + 2q\frac{I_C}{\beta}\Delta f \left(\frac{r_x}{\beta} + \frac{V_T}{I_C}\right)\right]$

BJT: $I_{C(opt)} = \frac{V_T}{R_1 + r_x + R_2} \times \frac{\beta}{\sqrt{1+\beta}} \quad v_{ni(min)}^2 = 4kT\left(R_1 + r_x + R_2\right)\Delta f \times \frac{\sqrt{1+\beta}}{\sqrt{1+\beta} - 1}$

JFET: $i_d = g_m v_{gs} + \frac{v_{ds}}{r_0} = \frac{v_{gs}}{r_s} + \frac{v_{ds}}{r_0} \quad g_m = 2\sqrt{\beta I_D} \quad r_s = \frac{1}{g_m}$

JFET: $r_0 = \frac{\lambda^{-1} + V_{DS}}{I_D} \quad i_{d(sc)} \overset{r_0 \text{ approx}}{=} G_m\left(v_{tg} - v_{ts}\right) \quad G_m = \frac{1}{r_s + R_{ts}}$

JFET: $i_{shg}^2 = 2qI_G\Delta f \quad i_{td}^2 = 4kT\left(\frac{2g_m}{3}\right)\Delta f \quad i_{fd}^2 = \frac{K_f I_D^m \Delta f}{f^n}$

JFET: $v_n^2 = \frac{4kT\Delta f}{3\sqrt{\beta I_D}} + \frac{K_f \Delta f}{4\beta f} \quad i_n^2 = i_{shg}^2 = 2qI_G\Delta f$

MOSFET: $i_d = g_m v_{gs} + g_{mb} v_{bs} + \frac{v_{ds}}{r_0} = \frac{v_{gs}}{r_s} + \frac{v_{bs}}{r_{bs}} + \frac{v_{ds}}{r_0}$

MOSFET: $g_m = 2\sqrt{KI_D} \quad g_{mb} = \chi g_m \quad r_s = \frac{1}{g_m} \quad r_s' = \frac{r_s}{1+\chi}$

MOSFET: $K = K_0\left(1 + \lambda V_{DS}\right) \quad K_0 = \frac{\mu C_{ox}}{2}\frac{W}{L} \quad \lambda = 0 \text{ unless given}$

MOSFET: $r_0 = \frac{V_{DS} + 1/\lambda}{I_D} \quad i_{d(sc)} \overset{r_0 \text{ approx}}{=} G_{mg} v_{gs} - G_{ms} v_{bs} \quad G_{mg} = \frac{1}{1+\chi}\frac{1}{r_s' + R_{ts}} \quad G_{ms} = \frac{1}{r_s' + R_{ts}}$

MOSFET: $i_{td}^2 = 4kT\left(\frac{2g_m}{3}\right)\Delta f \quad i_{fd}^2 = \frac{K_f I_D \Delta f}{L^2 C_{ox} f} \quad v_n^2 = \frac{4kT\Delta f}{3\sqrt{KI_D}} + \frac{K_f \Delta f}{4KL^2 C_{ox} f} \quad i_n^2 = 0$