ECE 4445 Audio Engineering Formula Sheet

$$\frac{dF}{dt} \to j\omega F \quad \int F dt \to \frac{F}{j\omega} \quad \omega = 2\pi f \quad j = \sqrt{-1} \quad S = \text{Area} \quad V = \text{Volume}$$

$$c = \sqrt{\frac{\gamma P_0}{\rho_0}} = 345\,\text{m/s} = 1131\,\text{ft}\,\text{s}^{-1} \quad \gamma = 1.4 \quad P_0 = 1.013 \times 10^5\,\text{Pa} \quad \rho_0 = 1.18\,\text{kg}\,\text{m}^{-3} \quad \frac{f_2}{f_1} = 2^{1/q}$$

$$f_n = 1000 \times 2^{n/q} \quad f_c = \sqrt{f_\ell f_u} \quad p(t) = P(t) - P_0 \quad SPL = 20 \log\left(\frac{p_{rms}}{p_{ref}}\right) \text{dB} \quad p_{ref} = 2 \times 10^{-5}\,\text{Pa}$$

$$SPL_{total} = 10 \log\left[\sum_i 10^{SPL_i/10}\right] \text{dB} \quad S = 2^{(P-40)/10} \quad P_{total} = 10 \log\left(\sum_i 10^{P_i/10}\right)$$

$$S_{total} = \frac{1}{16}\left(\sum_i 10^{P_i/10}\right)^{\log 2} \quad S(f) = \frac{V_0^2}{f}\,\text{V/Hz} \quad V_{rms}^2 = V_0^2 \int_{f_1}^{f_2} \frac{df}{f} = V_0^2 \ln\left(\frac{f_2}{f_1}\right) \text{V}$$

$$p(z) = p_0 e^{-jkz} \quad k = \frac{\omega}{c} \quad u_z(z) = \frac{p(z)}{\rho_0 c} \quad Z_s = \frac{p(z)}{u_z(z)} = \rho_0 c = 407\,\text{mks rayls}$$

$$I_{ave} = \frac{p_{rms}^2}{\rho_0 c} = u_{rms}^2 \rho_0 c \quad P_{AR} = I \times S \quad \lambda = \frac{c}{f} = \frac{2\pi c}{\omega} = \frac{2\pi}{k} \quad \xi = \frac{u}{j\omega} = \frac{p}{j\omega\rho_0 c} \quad p(r) = K\frac{e^{-jkr}}{r}$$

$$u_r(r) = \frac{1}{j\omega\rho_0}\left(\frac{1}{r} + jk\right) K\frac{e^{-jkr}}{r} \quad Z_s = \frac{p(r)}{u_r(r)} = \frac{\rho_0 c}{1 + c/j\omega r} \quad U = \frac{dV}{dt} = S_D\frac{dx}{dt} = S_D u$$

$$p(r) = \frac{j\omega\rho_0 U}{1 + j\omega r_1/c}\,\frac{e^{-jk(r-r_1)}}{4\pi r} \quad p(r) \simeq j\omega\rho_0 U\frac{e^{-jkr}}{4\pi r} \quad P_{AR} = U_{rms}^2 R_{AR} \quad R_{AR} = \frac{\omega^2\rho_0}{4\pi c} \overset{\text{or}}{=} \frac{\omega^2\rho_0}{2\pi c}$$

$$p(r,\theta) = j\omega\rho_0 U\left[\frac{2J_1(ka\sin\theta)}{ka\sin\theta}\right]\frac{e^{-jkr}}{2\pi r} \quad p(r,0) = j\omega\rho_0 U\frac{e^{-jkr}}{2\pi r} \quad r \ge \frac{8a^2}{\lambda} = \frac{2D^2}{\lambda} \quad R_A = \frac{\rho_0 c}{S}$$

$$M_A = \frac{\rho_0 \ell_{eff}}{S} \quad \ell_{eff} = \ell + \ell_f + \ell_{uf} \overset{\text{or}}{=} \ell + 2\ell_f \overset{\text{or}}{=} \ell + 2\ell_{uf} \quad \ell_f = 0.8488\sqrt{\frac{S}{\pi}} \quad \ell_{uf} = 0.6132\sqrt{\frac{S}{\pi}}$$

$$C_A = S^2 C_M = \frac{V}{\rho_0 c^2} \quad p = p_1 - p_2 = UZ_A \quad Z_A = R_A \quad Z_A = j\omega M_A \quad Z_A = \frac{1}{j\omega C_A} \quad f_0 = \frac{1}{2\pi\sqrt{M_A C_A}}$$

$$u = j\omega x \quad f = j\omega M_M u \quad f = R_M(u_1 - u_2) \quad f = \frac{u_1 - u_2}{j\omega C_M} \quad e = B\ell u \quad f = B\ell i \quad f = \tau q - \frac{x}{C_M}$$

$$e = -\tau x + \frac{q}{C_E} \quad e = \frac{i}{C_{E0}s} + \frac{uE}{x_0 s} \quad f = -\frac{qQ}{x_0 C_{E0}} - \frac{x}{C_M} = -\frac{iE}{x_0 s} - \frac{u}{C_M s} \quad H_{prox}(s) = 1 + \frac{c}{sr}$$

$$f = S(p_F - p_B) = Sp \quad U = Su \quad M_{AD} = \frac{M_{MD}}{S_D^2} \quad R_{AS} = \frac{R_{MS}}{S_D^2} \quad C_{AS} = S_D^2 C_{MS} \quad R_{AE} = \frac{(B\ell)^2}{S_D^2 R_E} \quad M_{A1} = \frac{8\rho_0}{3\pi^2 a}$$

$$M_{AS} = M_{AD} + 2M_{A1} = \frac{M_{MD}}{S_D^2} + 2\frac{8\rho_0}{3\pi^2 a} \quad C_{AE} = \frac{S_D^2 L_E(\omega)}{(B\ell)^2} \quad R'_{AE} = \frac{(B\ell)^2}{S_D^2 R'_E(\omega)}$$

$$M_{MS} = S_D^2 M_{AS} \quad U_D = \frac{S_D e_g}{B\ell}\,\frac{R_{AE}}{R_{AT}}\,\frac{R_{AT}C_{AS}s}{M_{AS}C_{AS}s^2 + R_{AT}C_{AS}s + 1} = \frac{S_D e_g}{B\ell}\,\frac{R_{AE}}{R_{AT}}\,\frac{(1/Q_{TS})(s/\omega_S)}{(s/\omega_S)^2 + (1/Q_{TS})(s/\omega_S) + 1}$$

$$R_{AT} = R_{AE} + R_{AS} = \frac{(B\ell)^2}{S_D^2 R_E} + \frac{R_{MS}}{S_D^2} \quad \omega_S = 2\pi f_S = \frac{1}{\sqrt{M_{AS}C_{AS}}} = \frac{1}{\sqrt{M_{MS}C_{MS}}} \quad V_{AS} = \rho_0 c^2 S_D^2 C_{MS} = \rho_0 c^2 C_{AS}$$

$$Q_{TS} = \frac{Q_{MS}Q_{ES}}{Q_{MS} + Q_{ES}} \quad Q_{MS} = \frac{1}{R_{AS}}\sqrt{\frac{M_{AS}}{C_{AS}}} = \frac{1}{R_{MS}}\sqrt{\frac{M_{MS}}{C_{MS}}} \quad Q_{ES} = \frac{1}{R_{AE}}\sqrt{\frac{M_{AS}}{C_{AS}}} = \frac{R_E}{(B\ell)^2}\sqrt{\frac{M_{MS}}{C_{MS}}}$$

$$p = \frac{\rho_0}{2\pi}sU_D = \frac{\rho_0}{2\pi}\,\frac{B\ell e_g}{S_D R_E M_{AS}}G(s)\,T_{u1}(s) \quad G(s) = \frac{(s/\omega_S)^2}{(s/\omega_S)^2 + (1/Q_{TS})(s/\omega_S) + 1} \quad T_{u1}(s) = \frac{1}{1 + s/\omega_{u1}}$$

$$\omega_{u1} = 2\pi f_{u1} = \frac{M_{AS}}{M_{AD} R_{AE} C_{AE}} = \frac{R_E M_{AS}}{M_{AD} L_E} = \frac{M_{MS} R_E}{M_{MD} L_E} \quad Q'_{ES} = \left(1 + \frac{R_g}{R_E}\right) Q_{ES}$$

$$f'_{u1} = \frac{\omega'_{u1}}{2\pi} = \frac{(R_E + R_g) M_{AS}}{2\pi L_E M_{AD}} = \left(1 + \frac{R_g}{R_E}\right) f_{u1} \quad f_\ell = f_{S,C}\left[X + \sqrt{X^2 + 1}\right]^{1/2} \quad X = \left(\frac{1}{2Q^2_{TS,TC}} - 1\right)$$

$$Z_{VC}(s) = R_E + Z_e(j\omega) + R_{ES} \frac{(1/Q_{MS})(s/\omega_S)}{(s/\omega_S)^2 + (1/Q_{MS})(s/\omega_S) + 1}$$

$$R_{ES} = R_E \frac{Q_{MS}}{Q_{ES}} \quad Z_e(j\omega) = (j\omega)^n L_e \quad n = \frac{1}{90} \arctan\left[\frac{\mathrm{Im}(Z_e)}{\mathrm{Re}(Z_e)}\right] \quad L_e = \frac{|Z_e|}{\omega^n}$$

$$p^{1V}_{sens} = \frac{\rho_0}{2\pi} \frac{B\ell S_D}{R_E M_{MS}} = \frac{\sqrt{2\pi\rho_0}}{c} f_S^{3/2} \left(\frac{V_{AS}}{R_E Q_{ES}}\right)^{1/2} \quad SPL^{1V}_{sens} = 20\log\left(\frac{p^{1V}_{sens}}{p_{ref}}\right) \quad SPL^{1W}_{sens} = 20\log\left(\frac{p^{1V}_{sens}\sqrt{R_E}}{p_{ref}}\right)$$

$$\eta_0 = \frac{P_{AR}}{P_E} = \frac{4\pi^2}{c^3} \frac{f_S^3 V_{AS}}{Q_{ES}} \quad x_D = e_g \left(\frac{V_{AS}}{\rho_0 c^2 S_D^2 R_E \omega_S Q_{ES}}\right)^{1/2} \frac{1}{(s/\omega_S)^2 + (1/Q_{TS})(s/\omega_S) + 1}$$

$$C_{AB} = \frac{V_{AB}}{\rho_0 c^2} \quad M_{AB} = \frac{B\rho}{\pi a} \quad M_{AC} = M_{AD} + M_{AB} + M_{A1} \quad R_{AC} = R_{AS} + R_{AB} \quad C_{AT} = \frac{C_{AS}}{1+\alpha} = \frac{\alpha C_{AB}}{1+\alpha}$$

$$\alpha = \frac{C_{AS}}{C_{AB}} = \frac{V_{AS}}{V_{AB}} \quad V_{AT} = \frac{V_{AS}}{1+\alpha} = \frac{\alpha V_{AB}}{1+\alpha} \quad Q_{TC} \overset{M_{AC} = M_{AS}}{=} \frac{1}{R_{ATC}} \sqrt{\frac{M_{AS}}{C_{AT}}}$$

$$R_{ATC} = R_{AE} + R_{AC} \quad \omega_C = 2\pi f_C \overset{M_{AC} = M_{AS}}{=} \frac{1}{\sqrt{M_{AS} C_{AT}}} = \sqrt{1+\alpha}\,\omega_S \quad Q_{TC} = \frac{Q_{MC} Q_{EC}}{Q_{MC} + Q_{EC}}$$

$$Q_{MC} \overset{M_{AC} = M_{AS}}{=} \frac{1}{R_{AC}} \sqrt{\frac{M_{AS}}{C_{AT}}} = \frac{R_{AS}}{R_{AS} + R_{AB}} \sqrt{1+\alpha}\, Q_{MS} \quad Q_{EC} \overset{M_{AC} = M_{AS}}{=} \frac{1}{R_{AE}} \sqrt{\frac{M_{AS}}{C_{AT}}} = \sqrt{1+\alpha}\, Q_{ES}$$

$$p = \frac{\rho_0}{2\pi} \frac{B\ell e_g}{S_D R_E M_{AC}} G_C(s) \quad G_C(s) = \frac{(s/\omega_C)^2}{(s/\omega_C)^2 + (1/Q_{TC})(s/\omega_C) + 1} \quad T_{u1}(s) = \frac{1}{1 + s/\omega_{u1}} \quad \omega_{u1} = \frac{R_E M_{AC}}{L_E M_{AD}}$$

$$\omega_B = 2\pi f_B = \frac{1}{\sqrt{M_{AP} C_{AB}}} \quad p = \frac{\rho_0}{2\pi} \frac{B\ell e_g}{S_D R_E M_{AS}} G_V(s) \quad G_V(s) = \frac{(s/\omega_0)^4}{(s/\omega_0)^4 + a_3 (s/\omega_0)^3 + a_2 (s/\omega_0)^2 + a_1 (s/\omega_0) + 1}$$

$$|G_V(j2\pi f)|^2 = \frac{(f/f_0)^8}{(f/f_0)^8 + A_3 (f/f_0)^6 + A_2 (f/f_0)^4 + A_1 (f/f_0)^2 + 1} \quad L_P = \left(\frac{c}{2\pi f_B}\right)^2 \frac{S_P}{V_{AB}} - 1.463\sqrt{\frac{S_P}{\pi}}$$

$$h = \frac{f_B}{f_S} \quad q = \frac{f_\ell}{f_S} \quad L_w = \frac{R_{Ew}}{2\pi f_w} \quad C_m = \frac{1}{2\pi f_{m1} R_{Em}} \quad L_m = \frac{R_{Em}}{2\pi f_{m2}} \quad C_t = \frac{1}{2\pi f_t R_{Et}}$$

$$L_w = \frac{R_{Ew}}{2\pi f_w Q_w} \quad C_w = \frac{Q_w}{2\pi f_w R_{Ew}} \quad L_{m1} = \frac{R_{Em}}{2\pi f_{m1} Q_{m1}} \quad C_{m1} = \frac{Q_{m1}}{2\pi f_{m1} R_{Em}}$$

$$C_1 = \frac{1}{3\pi f_c R_E} \quad C_2 = 3C_1 \quad L = \frac{3R_E}{8\pi f_c} \quad L_2 = \frac{R_E}{4\pi f_c} \quad L_1 = 3L_2 \quad C = \frac{2}{3\pi f_c R_E}$$

$$R_2 = \frac{R_{in} R_E}{(R_E/k_{pad}) - R_{in}} \quad R_1 = R_{in} - R_2 \| R_E$$

$$R_1 = R_E \quad C_1 = \frac{L_e}{(2\pi)^{(1-n)} R_E^2 \left[f_1^n f_2^{(2+n)}\right]^{\frac{(1-n)}{2(1+n)}}} \quad C_2 = \frac{L_e}{(2\pi)^{(1-n)} R_E^2 \left[f_1^{(2+n)} f_2^n\right]^{\frac{(1-n)}{2(1+n)}}} - C_1$$

$$R_2 = \frac{1}{2\pi f_1^{\frac{1}{(1+n)}} f_2^{\frac{n}{(1+n)}} C_2} \quad R_3 = R_E \left(1 + \frac{Q_{EC}}{Q_{MC}}\right) \quad L_1 = \frac{R_E Q_{EC}}{2\pi f_C} \quad C_3 = \frac{1}{2\pi f_C R_E Q_{EC}}$$

$$P_{L(ave)} = \frac{V_P^2}{2R_L} = \frac{V^2_{o(rms)}}{R_L} \quad P_{L(ave)} = P_{L(peak)} = \frac{V_P^2}{R_L} \quad \frac{v_O}{v_I} = \frac{A}{1+bA} \simeq \frac{1}{b}$$

$$v_O = \frac{A_1 A_2}{1+bA} v_I + \frac{A_2}{1+bA} v_N \quad R_{out} = \frac{R_o}{1+bA} \quad DF = \frac{R_L}{R_{out}} \quad \varphi_m = 180^\circ + \varphi(\omega_x) \quad \omega_x = bA\omega_1$$

$$A' = \frac{1}{b} \frac{\omega_2}{\omega_1} \quad \omega'_1 = \frac{\omega_2}{bA} \quad \omega'_2 = bA\omega_1$$