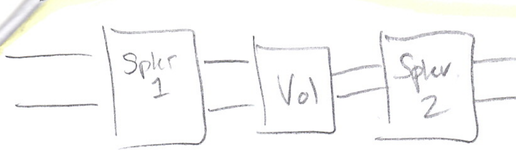

$$\begin{bmatrix}V_1\\ I_1\end{bmatrix} = \overbrace{\underbrace{\begin{bmatrix}A & B\\ C & D\end{bmatrix}}_{T}\underbrace{\begin{bmatrix}1 & 0\\ sC_v & 1\end{bmatrix}}_{Vol}\underbrace{\frac{1}{\Delta_T}\begin{bmatrix}D & B\\ C & A\end{bmatrix}}_{T_{rev}}}^{\begin{bmatrix}\bar{A} & \bar{B}\\ \bar{C} & \bar{D}\end{bmatrix}}\begin{bmatrix}V_2\\ -I_2\end{bmatrix}$$

$\Delta_T = -1$ (reciprocal)

$$\begin{bmatrix}F_1\\ U_1\end{bmatrix} = \underbrace{\begin{bmatrix}A_0 & 0\\ 0 & 1/A_0\end{bmatrix}\begin{bmatrix}1 & 0\\ s\frac{V}{\gamma P_0} & 1\end{bmatrix}\begin{bmatrix}1/A_0 & 0\\ 0 & A_0\end{bmatrix}}\begin{bmatrix}F_2\\ -U_2\end{bmatrix}$$

$$= \begin{bmatrix}1 & 0\\ \frac{sV}{\gamma P_0 A_0^2} & 1\end{bmatrix}$$

where $C_v = \frac{V}{\gamma P_0 A_0^2}$ where A_0 = speaker cone area, V = volume of chamber between speakers

Note $\frac{1}{sC_v}$ is a mechanical impedance

$A = Z_e/T_0 \quad B = (Z_eZ_m + T_0^2)/T_0$

$C = 1/T_0 \quad D = Z_m/T_0$

$\bar{A} = -DA - sC_vBD - BC$

$\bar{B} = -2BA - sC_vB^2$

$\bar{C} = -2DC - sC_vD^2$

$\bar{D} = -BC - sC_vBD - DA = \bar{A}$

$\Delta_T = -1$

$\Delta_{\bar{T}} = 1$

Note: If the diaphragm interfaces directly to load, then

$$\begin{bmatrix}V_1\\ I_1\end{bmatrix} = \underbrace{\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}A_0 & 0\\ 0 & 1/A_0\end{bmatrix}}\begin{bmatrix}P_2\\ -U_2\end{bmatrix} \qquad \begin{bmatrix}V_1\\ I_1\end{bmatrix} = \begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}F_2\\ -U_2\end{bmatrix}$$

$$= \begin{bmatrix}A_0A & B/A_0\\ A_0C & D/A_0\end{bmatrix} = \begin{bmatrix}A' & B'\\ C' & D'\end{bmatrix}$$

$A' = A_0A = A_0Z_e/T_0 = Z_e/(T_0/A_0)$

$B' = B/A_0 = \frac{Z_eZ_m + T_0^2}{A_0T_0} = \frac{Z_e(Z_m/A_0^2) + (T_0/A_0)^2}{T_0/A_0}$

$C' = A_0/T_0 = 1/(T_0/A_0) \quad D' = Z_m/T_0A_0 = (Z_m/A_0^2)/(T_0/A_0)$

$\therefore T_a = T_0/A_0,\ Z_e = Z_e,\ Z_a = Z_m/A_0^2$

Open circuit Transfer function

$$V_1 = \left[\bar{A}V_2 - \bar{B}I_2\right]_{I_2=0} = \bar{A}V_2 \Rightarrow \frac{V_2}{V_1} = \frac{1}{\bar{A}} = \frac{-1}{DA + sC_vBD + BC} = \boxed{\frac{-T_0^2}{Z_eZ_m + sC_v(Z_eZ_m + T_0^2)Z_m + (Z_eZ_m + T_0^2)}}$$

Input Impedance w/ $V_2 = 0$ (short circuit)

$$\left.\frac{V_1}{I_1}\right|_{V_2=0} = \frac{\bar{B}}{\bar{D}} = \frac{-2BA - sC_vB^2}{-DA - sC_vBD - BC} = \frac{2BA + sC_vB^2}{DA + sC_vBD + BC} = \boxed{\frac{2Z_e(Z_eZ_m + T_0^2) + sC_v(Z_eZ_m + T_0^2)}{Z_eZ_m + sC_v(Z_eZ_m + T_0^2)Z_m + (Z_eZ_m + T_0^2)}}$$

Input Impedance w/ $I_2 = 0$ (open circuit)

$$\left.\frac{V_1}{I_1}\right|_{I_2=0} = \frac{\bar{A}}{\bar{C}} = \frac{-DA - sC_vBD - BC}{-2DC - sC_vD^2} \qquad \frac{DA + sC_vBD + BC}{2DC + sC_vD^2} = \boxed{\frac{Z_eZ_m + sC_v(Z_eZ_m + T_0^2)Z_m + (Z_eZ_m + T_0^2)}{Z_m + sC_vZ_m^2}}$$

Can $\bar{A}, \bar{B}, \bar{C}, \bar{D}$ be simplified at all?

$$\bar{A} = -(DA + sC_vBD + BC) = -\left(\frac{Z_eZ_m}{T_0^2} + \frac{sC_v(Z_eZ_m + T_0^2)Z_m}{T_0^2} + \frac{(Z_eZ_m + T_0^2)}{T_0^2}\right)$$

$$= -\frac{Z_eZ_m}{T_0^2}\left(2 + sC_vZ_m\right) - 1 - sC_vZ_m$$