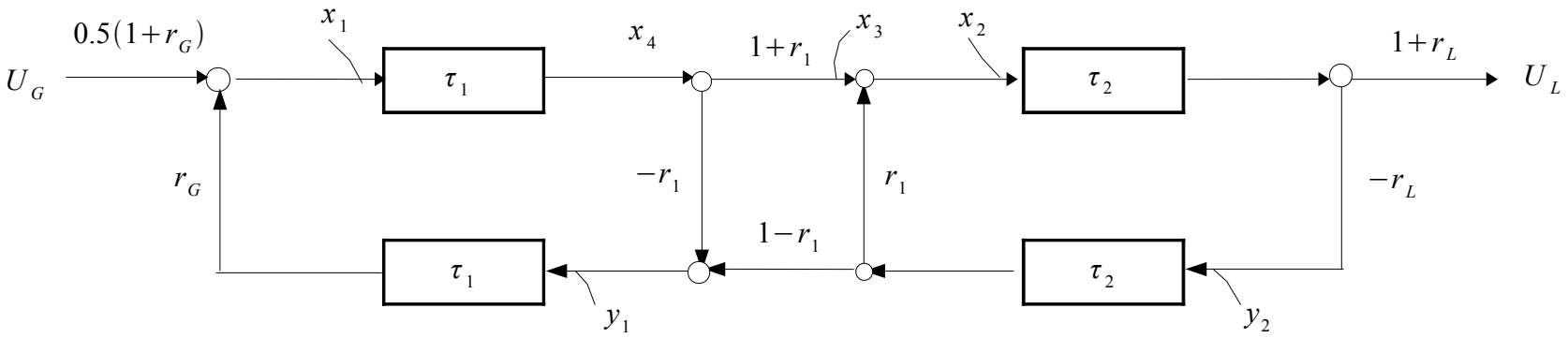
2管模型の入出力の関係の計算例

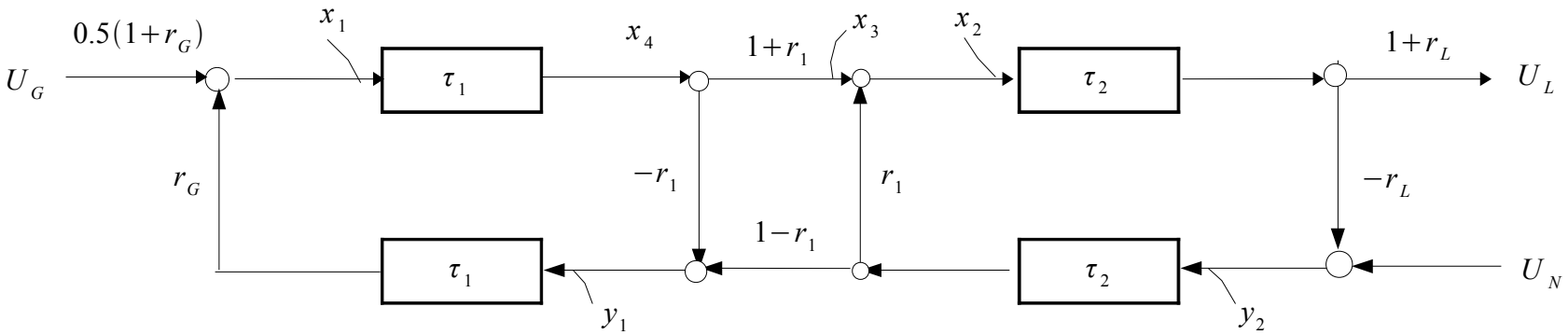


τ は τ 時間の遅延を示す
遅延時間は 管の長さを 音速で 割ったもの
$e^{-s\tau}=e^{-j\omega\tau}$ で置き換える
$s=j\omega$

$$x_1=0.5(1+r_G)U_G+r_G e^{-s\tau_1}y_1$$
$$x_2=(1+r_1)e^{-s\tau_1}x_1+r_1 e^{-s\tau_2}y_2$$
$$U_L=(1+r_L)e^{-s\tau_2}x_2$$
$$y_2=-\frac{r_L}{(1+r_L)}U_L$$
$$y_1=(1-r_1)e^{-s\tau_2}y_2-r_1 x_4$$
$$x_4=\frac{x_3}{(1+r_1)}$$
$$x_3=x_2-r_1 e^{-s\tau_2}y_2$$
$$x_2=\frac{1}{(1+r_L)}e^{+s\tau_2}U_L$$

$$0.5(1+r_G)(1+r_L)(1+r_1)e^{-s\tau_1}e^{-s\tau_2}U_G$$
=
$$(1+r_1 r_g e^{-s2\tau_1}+r_1 r_L e^{-s2\tau_2}+r_G r_L e^{-(s2(\tau_1+\tau_2))})U_L$$

2管模型にrlノイズ源がある場合の入出力の関係の計算例



$$x_1 = 0.5(1+r_G)U_G + r_G e^{-s\tau_1} y_1$$

$$x_2 = (1+r_1)e^{-s\tau_1} x_1 + r_1 e^{-s\tau_2} y_2$$

$$U_L = (1+r_L)e^{-s\tau_2} x_2$$

$$y_2 = -\frac{r_L}{(1+r_L)} U_L + U_N$$

$$y_1 = (1-r_1)e^{-s\tau_2} y_2 - r_1 x_4$$

$$x_4 = \frac{x_3}{(1+r_1)}$$

$$x_3 = x_2 - r_1 e^{-s\tau_2} y_2$$

$$x_2 = \frac{1}{(1+r_L)} e^{+s\tau_2} U_L$$

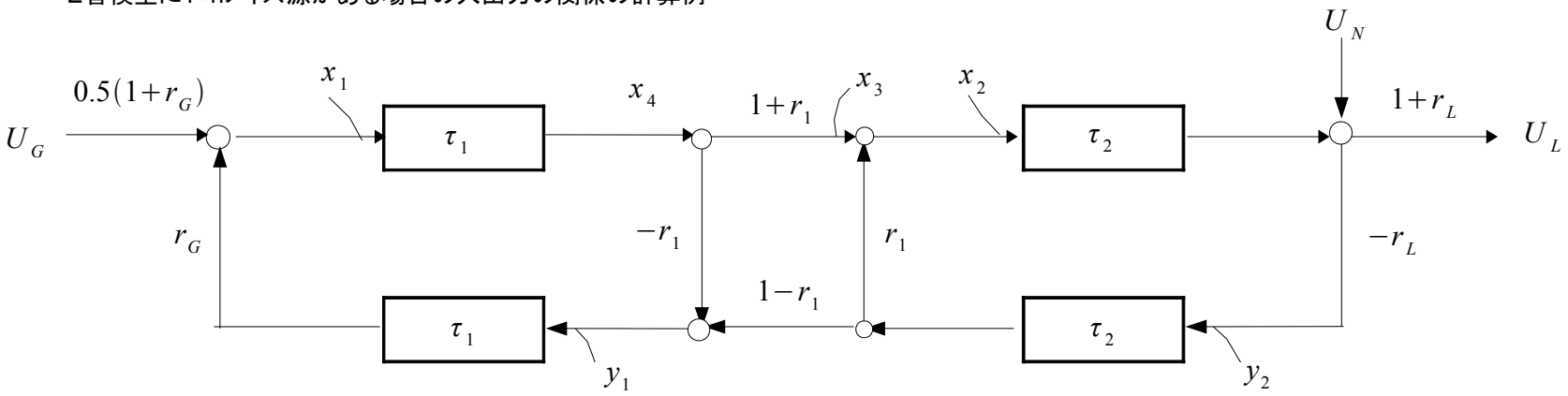
U_N はノイズ源を示す

$$0.5(1+r_G)(1+r_L)(1+r_1)e^{-s\tau_1}e^{-s\tau_2}U_G + (1+r_L)(r_1^2 r_G e^{-s2\tau_1} + r_1 e^{-s2\tau_2} + (1-r_1^2) r_G e^{-s2\tau_1} e^{-s2\tau_2}) U_N$$

=

$$(1 + r_1 r_g e^{-s2\tau_1} + r_1 r_L e^{-s2\tau_2} + r_G r_L e^{-(s2(\tau_1+\tau_2))}) U_L$$

2管模型に1+rlノイズ源がある場合の入出力の関係の計算例



$$x_1 = 0.5(1+r_G)U_G + r_G e^{-s\tau_1} y_1$$

$$x_2 = (1+r_1)e^{-s\tau_1} x_1 + r_1 e^{-s\tau_2} y_2$$

$$U_L = (1+r_L)(e^{-s\tau_2} x_2 + U_N)$$

$$y_2 = -\frac{r_L}{(1+r_L)} U_L$$

$$y_1 = (1-r_1)e^{-s\tau_2} y_2 - r_1 x_4$$

$$x_4 = \frac{x_3}{(1+r_1)}$$

$$x_3 = x_2 - r_1 e^{-s\tau_2} y_2$$

$$x_2 = \left(\frac{1}{(1+r_L)} U_L - U_N\right) e^{+s\tau_2}$$

$$0.5(1+r_G)(1+r_L)(1+r_1)e^{-s\tau_1}e^{-s\tau_2}U_G + (1+r_L)(1+r_G r_1 e^{-s2\tau_1})U_N$$

=

$$(1+r_1 r_g e^{-s2\tau_1} + r_1 r_L e^{-s2\tau_2} + r_G r_L e^{-(s2(\tau_1+\tau_2))})U_L$$

2管模型の出力に単にノイズ源をミックスしたもの