# 1. Constructed the KLM model based through-transmission model

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close all

%%%%%%%%%%%%%%%%%%%%%%%%%%%%  Input axis setting
%%%%%%%%%%%%%%%%%%%%%%%%%%%%

N = 2^12;                    % Sampling Number
t = linspace(0, 8, N);      % Sampling Time          [us]
dt = t(2) - t(1);            % Time step              [T/N]
f = linspace(eps, 1/dt, N);   % Sampling Frequency    [MHz] ∴ Fs = N/t

% eps = 2.220446049250313e-16

%%%%%%%%%%%%%%%%%%%%%%%%%%%%   Transfer Function
%%%%%%%%%%%%%%%%%%%%%%%%%%%%

w=f*(2*pi)*1e6;            % Sampling Frequency [rad/s] (Synchronized)
w0_in=3e6*2*pi;          % input  frequency Resonance frequency [rad/s]
ww_in=w/w0_in;

w0_out=1.3e6*2*pi;         % output  frequency
ww_out=w/w0_out;

Zt=45e6;         % load impedance
ohm=50;             % Impedance Matching

%%%%%%%%%%%%%%%%%%%%%  N1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n=2;             % turn relationship

% electric matching matrix - turn relationship n
N1_11=n*ones(1, length(w));
N1_12=0*ones(1, length(w));
N1_21=0*ones(1, length(w));
N1_22=1/n*ones(1, length(w));

N1_in = cell2mat({N1_11; N1_12; N1_21; N1_22});
N1_out = cell2mat({N1_11; N1_12; N1_21; N1_22});

%%%%%%%%%%%%%%%%%%%%%%%%   N2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

c0=3600e-12;          % Capacitance
L_in=1/(w0_in^2*c0);     % Serial Inductance
L_out=1/(w0_out^2*c0);     % Serial Inductance

% electric matching matrix - Serial Inductance
N2_11=1*ones(1, length(w));
N2_12=(-i*w*L_in);
N2_21=0*ones(1, length(w));
N2_22=1*ones(1, length(w));

N2_in = cell2mat({N2_11; N2_12; N2_21; N2_22});

N2_11=1*ones(1, length(w));
N2_12=(-i*w*L_out);
N2_21=0*ones(1, length(w));
N2_22=1*ones(1, length(w));

N2_out = cell2mat({N2_11; N2_12; N2_21; N2_22});
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%%%%%%%%%%%%%%%%%%%%%%%%%   N3
%%%%%%%%%%%%%%%%%%%%%%%%%%%%

kt=0.5;             % 전기-기계결합상수

cc_in=-c0./(kt^2*(sin(pi*ww_in)./(pi*ww_in)));            % C`_in
cc_out=-c0./(kt^2*(sin(pi*ww_out)./(pi*ww_out)));         % C`_out

% Matrix that characterizes capacitances C and C`
N3_11=1*ones(1, length(w));
N3_12=(i*(1./(w*c0)+1./(w.*cc_in)));
N3_21=0*ones(1, length(w));
N3_22=1*ones(1, length(w));

N3_in = cell2mat({N3_11; N3_12; N3_21; N3_22});

% Matrix that characterizes capacitances C and C`
N3_11=1*ones(1, length(w));
N3_12=(i*(1./(w*c0)+1./(w.*cc_out)));
N3_21=0*ones(1, length(w));
N3_22=1*ones(1, length(w));

N3_out = cell2mat({N3_11; N3_12; N3_21; N3_22});

%%%%%%%%%%%%%%%%%%%%%%%%%%%%    N4
%%%%%%%%%%%%%%%%%%%%%%%%%%%%

zc=34e6;            % piezelectric impedance
tr_in=kt*(pi/(w0_in*c0*zc)^(1/2))*sin(pi*ww_in/2)./(pi*ww_in/2);          % Ψ
tr_out=kt*(pi/(w0_out*c0*zc)^(1/2))*sin(pi*ww_out/2)./(pi*ww_out/2);          % Ψ

% Matrix of the elements of the transformer Ψ
N4_11=1./tr_in;
N4_12=0*ones(1, length(w));
N4_21=0*ones(1, length(w));
N4_22=tr_in;

N4_in = cell2mat({N4_11; N4_12; N4_21; N4_22});

% Matrix of the elements of the transformer Ψ
N4_11=1./tr_out;
N4_12=0*ones(1, length(w));
N4_21=0*ones(1, length(w));
N4_22=tr_out;

N4_out = cell2mat({N4_11; N4_12; N4_21; N4_22});

%%%%%%%%%%%%%%%%%%%%%%%%%   N5
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

zb=34e6;              % backing impedance

zz_in=pi*ww_in/2;                                                      % pτ
zib_in=zc*((zb+i*zc*tan(zz_in))./(zc+i*zb*tan(zz_in)));   % ZL : net impedance

zz_out=pi*ww_out/2;                                                      % pτ
zib_out=zc*((zb+i*zc*tan(zz_out))./(zc+i*zb*tan(zz_out)));   % ZL : net impedance

% Matching matrix between the backing and the piezoceramic
N5_11=1*ones(1, length(w));
N5_12=0*ones(1, length(w));
N5_21=-1./zib_in;
N5_22=1*ones(1, length(w));

N5_in = cell2mat({N5_11; N5_12; N5_21; N5_22});
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% Matching matrix between the backing and the piezoceramic
N5_11=1*ones(1, length(w));
N5_12=0*ones(1, length(w));
N5_21=-1./zib_out;
N5_22=1*ones(1, length(w));

N5_out = cell2mat({N5_11; N5_12; N5_21; N5_22});

%%%%%%%%%%%%%%%%%%%%%%  N6
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Piezoceramic matrix connected to the backing
N6_11=cos(zz_in);
N6_12=(-i*zc*sin(zz_in));
N6_21=(-i*(1/zc)*sin(zz_in));
N6_22=cos(zz_in);

N6_in = cell2mat({N6_11; N6_12; N6_21; N6_22});

% Piezoceramic matrix connected to the backing
N6_11=cos(zz_out);
N6_12=(-i*zc*sin(zz_out));
N6_21=(-i*(1/zc)*sin(zz_out));
N6_22=cos(zz_out);

N6_out = cell2mat({N6_11; N6_12; N6_21; N6_22});

%%%%%%%%%%%%%%%%%%%%%%   N7
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

z1=2.74e6;          % epoxy impedance
l1=0.000001;        % epoxy 두께
v1=2800;            % velocity

% Piezoceramic matrix connected to the load through layers.(epoxy)
zz1=l1*w/v1;                            % pτ(epoxy)

N7_11=cos(zz1);
N7_12=(-i*z1*sin(zz1));
N7_21=(-i*(1/z1)*sin(zz1));
N7_22=cos(zz1);

N7_in = cell2mat({N7_11; N7_12; N7_21; N7_22});

N7_11=cos(zz1);
N7_12=(-i*z1*sin(zz1));
N7_21=(-i*(1/z1)*sin(zz1));
N7_22=cos(zz1);

N7_out = cell2mat({N7_11; N7_12; N7_21; N7_22});

%%%%%%%%%%%%%%%%%%%%%%   N8
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

zf_in=41.34e6;         %  input wear plate impedance
lf_in=0.7e-3;          % input wear plate 두께
vf_in=10600;           % input velocity

% Matrix of the 1st matching layer.(Front Matrial)
zzf_in=lf_in*w/vf_in;                          % pτ(Front Mat)

zf_out=41.34e6;        % output wear plate impedance
lf_out=1.5e-3;         % output wear plate 두께
vf_out=10600;          % output velocity
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% Matrix of the 1st matching layer.(Front Matrial)
zzf_out=lf_out*w/vf_out;                                   % pτ(Front Mat)

N8_11=cos(zzf_in);                    %   input wear plate matrix
N8_12=(-i*zf_in*sin(zzf_in));
N8_21=(-i*(1/zf_in)*sin(zzf_in));
N8_22=cos(zzf_in);

N8_in = cell2mat({N8_11; N8_12; N8_21; N8_22});

N8_11=cos(zzf_out);               %   output wear plate matrix
N8_12=(-i*zf_in*sin(zzf_out));
N8_21=(-i*(1/zf_in)*sin(zzf_out));
N8_22=cos(zzf_out);

N8_out = cell2mat({N8_11; N8_12; N8_21; N8_22});

%%%%%%%%%%%%%%%%%%%%     N9
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

z2=1.5e6;             % couplalnt
l2=0.000001;          % 두께
v2=1500;               % velocity

% Matrix of the 2nd matching layer.(Couplant)
zz2=-l2*w/v2;                               % pτ(Couplant)

N9_11=cos(zz2);
N9_12=(-i*z2*sin(zz2));
N9_21=(-i*(1/z2)*sin(zz2));
N9_22=cos(zz2);

N9_in = cell2mat({N9_11; N9_12; N9_21; N9_22});

N9_11=cos(zz2);
N9_12=(-i*z2*sin(zz2));
N9_21=(-i*(1/z2)*sin(zz2));
N9_22=cos(zz2);

N9_out = cell2mat({N9_11; N9_12; N9_21; N9_22});

%%%%%%%%%%%%%%%%%%%%     N10
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

zm=45.74e6;            % metal impedance
lm=30e-3;              % 두께
vm=5900;                % velocity

% Matrix of the metal matching layer.
zzm=lm*w/vm;                                % pτ(metal)

N10_11=cos(zzm);
N10_12=(-i*zm*sin(zzm));
N10_21=(-i*(1/zm)*sin(zzm));
N10_22=cos(zzm);

N10 = cell2mat({N10_11; N10_12; N10_21; N10_22});

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%

% Transfer Matrix.(Nt = )
Nt = cell2mat({ones(1, length(w)); zeros(1, length(w)); zeros(1, length(w)); ones(1,
length(w))});
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```
 Nt = Matrices_Product(Nt,N1_out);
 Nt = Matrices_Product(Nt,N2_out);
 Nt = Matrices_Product(Nt,N3_out);
 Nt = Matrices_Product(Nt,N4_out);
 Nt = Matrices_Product(Nt,N5_out);
 Nt = Matrices_Product(Nt,N6_out);
 Nt = Matrices_Product(Nt,N7_out);
 Nt = Matrices_Product(Nt,N8_out);
 Nt = Matrices_Product(Nt,N9_out);
 Nt = Matrices_Product(Nt,N10);
 Nt = Matrices_Product(Nt,N9_in);
 Nt = Matrices_Product(Nt,N8_in);
 Nt = Matrices_Product(Nt,N7_in);
 Nt = Matrices_Product(Nt,N6_in);
 Nt = Matrices_Product(Nt,N5_in);
 Nt = Matrices_Product(Nt,N4_in);
 Nt = Matrices_Product(Nt,N3_in);
 Nt = Matrices_Product(Nt,N2_in);
 Nt = Matrices_Product(Nt,N1_in);

%%%%%%%%%%%%%%%%%%%%  Eletric Supply impedance Ze
%%%%%%%%%%%%%%%%%%%%

zg=(zc^(1/2))*(Zt^(1/2));
Rm=((4*kt^2)/(pi*w0_in*c0))*(zc/(zg+zb)).*((w0_in./(w)).^2).*(sin(pi*ww_in/2)).^2;
Xe=(ohm/w0_in*c0)*(2-kt^2-(2*kt^2)*((2*zc^2-zg^2-zb^2)/(zg+zb)^2));

Ze=Rm+i*Xe;

%%%%%%%%%%%%%%%%%%%%%%%%%%%  transfer function
%%%%%%%%%%%%%%%%%%%%%%%%%%

HT=2*Zt./(-Zt*Ze.*Nt(3,:)+Nt(1,:).*Ze-Nt(2,:)+Nt(4,:)*Zt);
%HT=2*Ze./(-Ze.*Ze.*Nt(3,:)+Nt(1,:).*Ze-Nt(2,:)+Nt(4,:).*Ze); % 1차 수정

ss=(Nt(3,:).*Ze*Zt-Nt(1,:).*Ze-Nt(4,:)*Zt+Nt(2,:)).^2;

%ss=(Nt(3,:).*Ze.*Ze-Nt(1,:).*Ze-Nt(4,:).*Ze+Nt(2,:)).^2;

HR=4*Ze*Zt./ss;                    % HR(w) - Frequency domain

HR_l=20*log(max(HR)./HR);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   spike Input
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% y = pulse_ref(0.35, 2.2, 2.8, t);  % Time domain [us]/ 볼트, 주파수(MHz), 대역폭,
% y = -exp(-(t-4).^2/2).*sin(w0.*t*1e-6);
% y = transpose(Importfile('Input_Signal.xlsx','Gaussian_1',2,4097));

V0=0.33;                          % input voltage (V)
t0=0.1;

a1=0.2;
a2=5000;

y=pulser(t0,a1,a2,V0,t);

yf1 = FourierT(y, dt);            % Frequency domain [MHz]
yt = IFourierT(yf1, dt);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   Output Signal
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
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Vout = yf1.*HT;                % Vin(f)、HR(w) - Frequency domain
Vout5 = Vout.*(f < 1/dt/2);

Vout_t = IFourierT(Vout5, dt);   % Vout(t) - Time domain

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     Plot
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

subplot(2,3,1);plot(f(1:1000),abs(yf1(1:1000)));  %% vin fre
subplot(2,3,1);ylabel('|Vin|');
subplot(2,3,1);xlabel('Frequency[MHz]');

subplot(2,3,2);plot(f(1:100),0.1*abs(HT(1:100)));   %% ht fre
subplot(2,3,2);ylabel('|HT|');
subplot(2,3,2);xlabel('Frequency[MHz]');

subplot(2,3,3);plot(f(1:50), abs(Vout(1:50)));   %% vout fre
subplot(2,3,3);ylabel('|Vout|');
subplot(2,3,3);xlabel('Frequency[MHz]');

subplot(2,3,4);plot(t, y);                 %% vin time
subplot(2,3,4);ylabel('|Vin|');
subplot(2,3,4);xlabel('time[us]');

subplot(2,3,5);plot(t, 2*real(Vout_t)*0.7e4);
subplot(2,3,5);
subplot(2,3,5);

subplot(2,3,6);plot(t(1:3000), 2*1e4*real(Vout_t(1:3000))*1e-3); %% time vout
subplot(2,3,6);ylabel('|Vout|');
subplot(2,3,6);xlabel('time[us]');

Voutt = 7*transpose(2*real(Vout_t));
```