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Homework 5
EE 363N
November 4, 2000

An expression was derived in class for the velocity of the cone in a moving-coil loudspeaker. The corresponding acceleration $A(\omega)e^{j\omega t}$ is simply $j\omega$ times this velocity, such that for input voltage $V_0 e^{j\omega t}$ the complex acceleration amplitude is

$$A(\omega) = \frac{j\omega V_0 / \phi}{1 + Z_E / Z_{MA}}$$

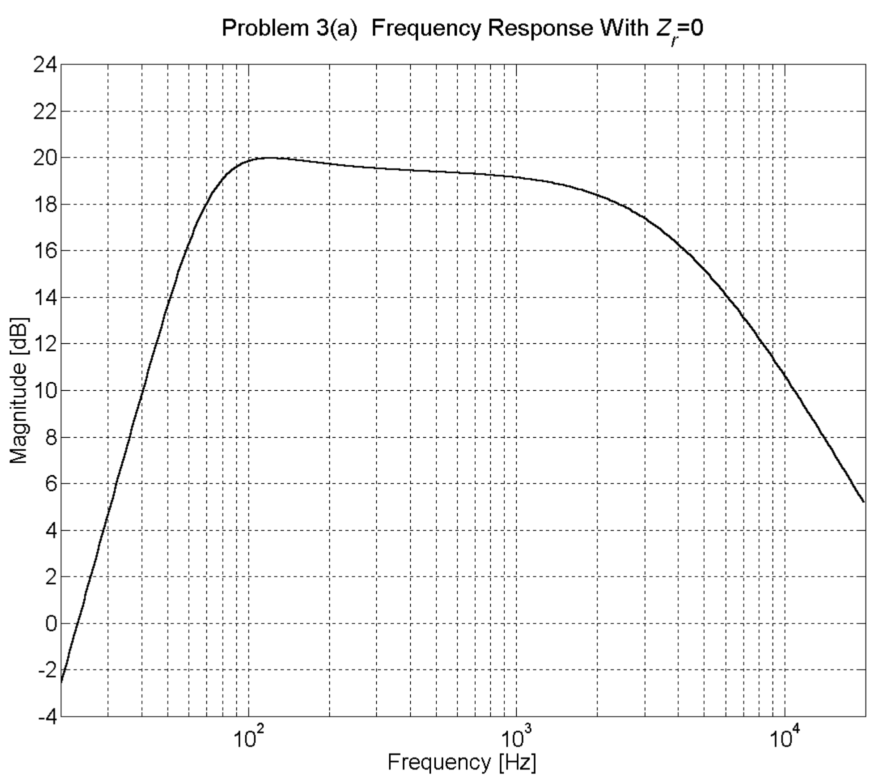
where $Z_E = R_0 + j\omega L_0$ is the electrical impedance,

$$\frac{1}{Z_{MA}} = \frac{1}{Z_M} + \frac{1}{Z_A} = \frac{1}{\phi^2}\left(R_m + j\omega m + \frac{s}{j\omega} + 2Z_r\right)$$

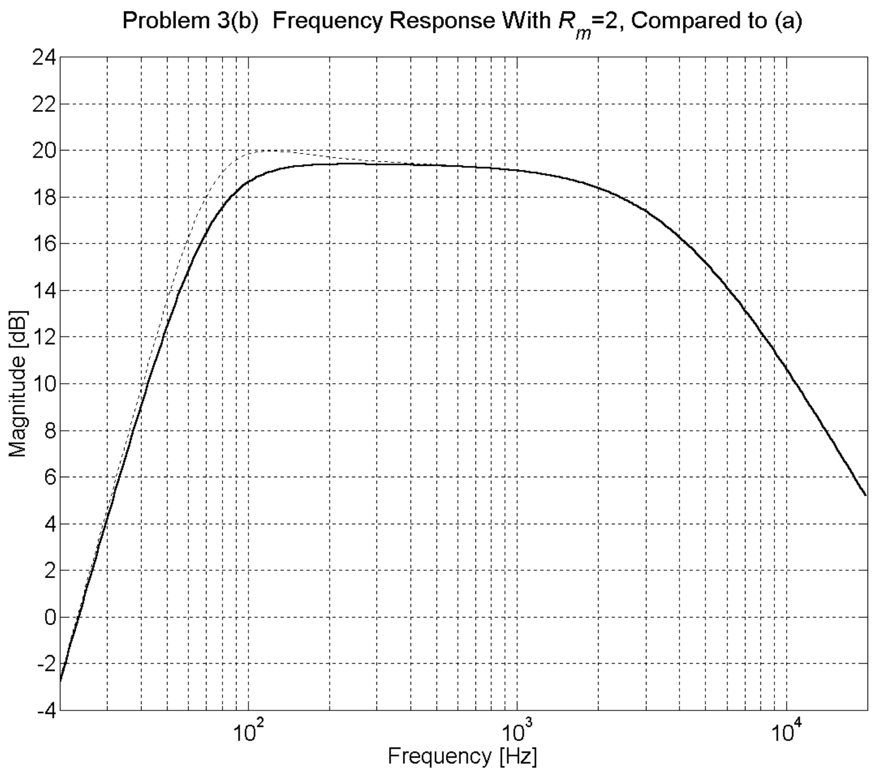
and Z_r is the radiation impedance. The reason for considering the acceleration is that the axial sound pressure at distances $r > \frac{1}{2} ka^2$ is proportional to this quantity and therefore exhibits the same frequency dependence, i.e., $|p| = (\rho_0 a^2/2r)|A(\omega)|$. We consider here the loudspeaker described by the parameters on page 407. Plot the frequency responses requested below in dB defined by $20 \log_{10}|A(\omega)/g|$, where $g = 9.81$ m/s^2 is the gravitational constant. Show frequency $f = 20$ Hz to $f = 20$ kHz. Let $V_0 = 1$ volt.

Speaker Parameters		**Transition Frequencies**
$m = 10$ g $= 0.01$ kg	$l = 5$ m	$\sqrt{\frac{S}{m}} = 71.2$ Hz
$a = 0.1$ m	$B = 0.9$ T	
$S = 2000$ N/m	$\phi = Bl = 4.5$ N/A	
$R_m = 1$ N·s/m	$R_r = \pi a^2 \rho_0 c R_1(2ka)$ N·s/m	$\frac{R_o}{L_o} = 3979$ Hz
$L_o = 0.2$ mH $= 0.0002$ H	$X_r = \pi a^2 \rho_0 c X_1(2ka)$ N·s/m	
$R_o = 5\ \Omega$		

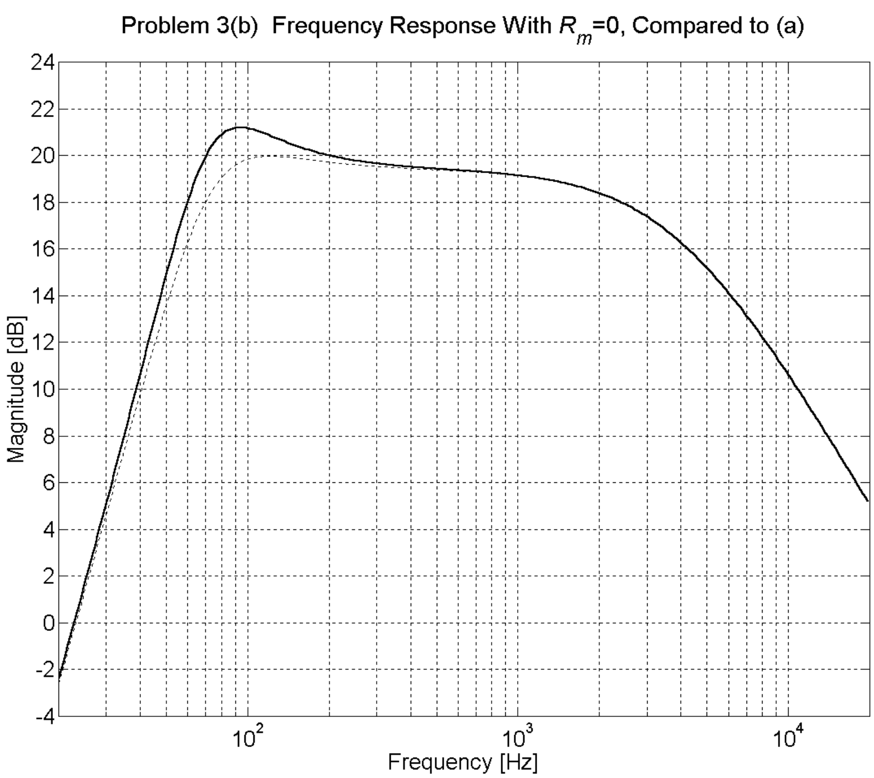
Homework 5, Problem 3(a)



Homework 5, Problem 3(b)



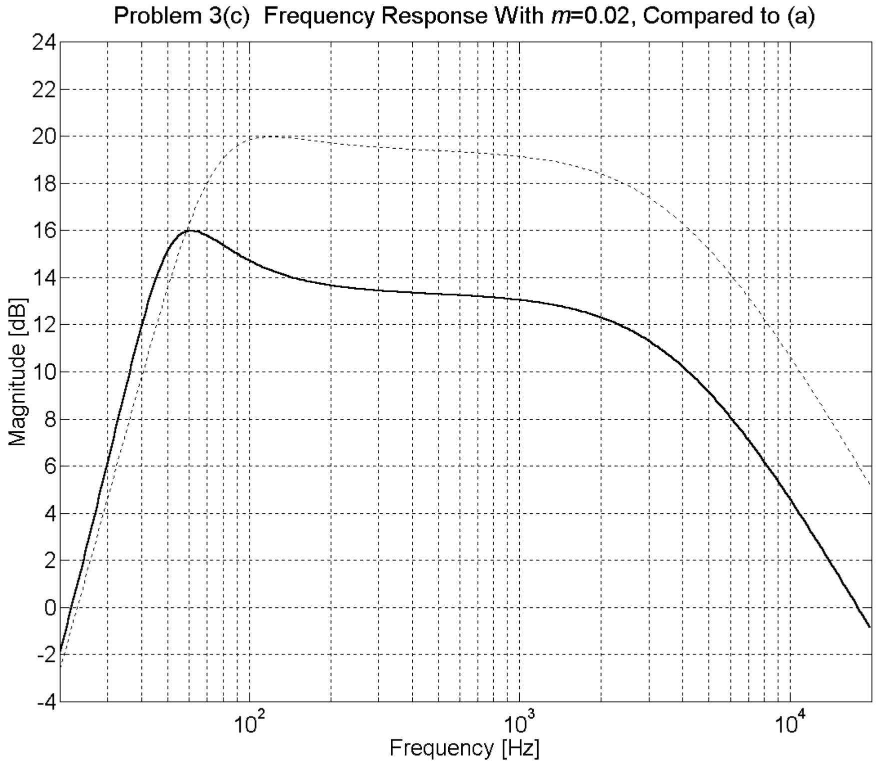
When the mechanical resistance is doubled, the resonant peak is removed and there is a loss of low frequency response (~1.7 dB max) at frequencies near the mechanical transition frequency.



When the mechanical resistance is removed, the resonant peak increases in amplitude and shifts to a lower frequency, closer to mechanical transition $\sqrt{S/m}$.

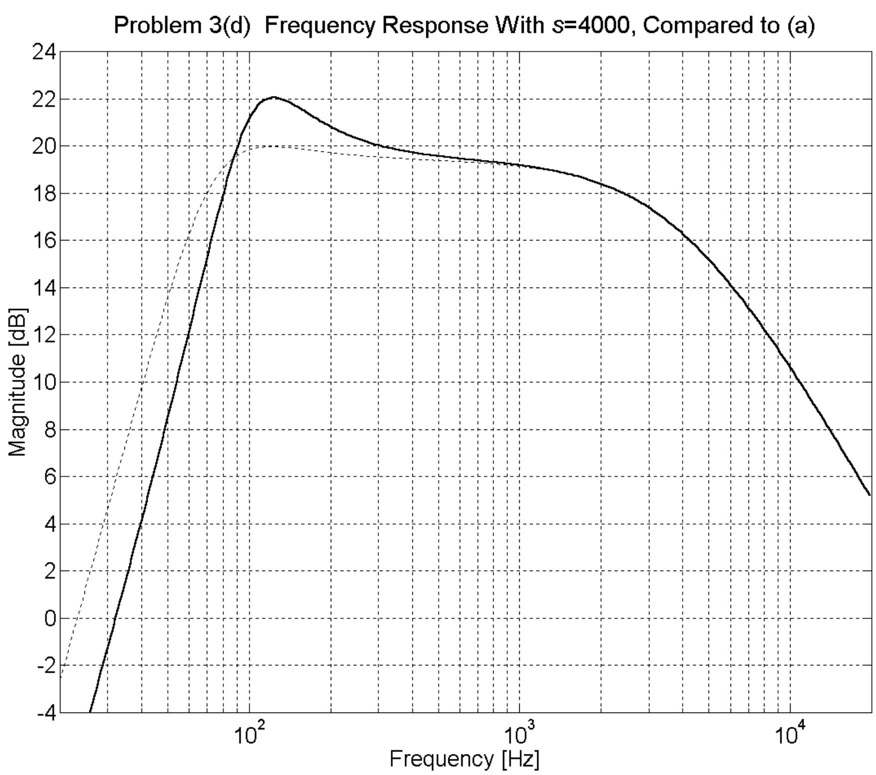
Low frequency response is increased at frequencies near $\sqrt{S/m}$ (2 dB max).

Homework 5, Problem 3(c)



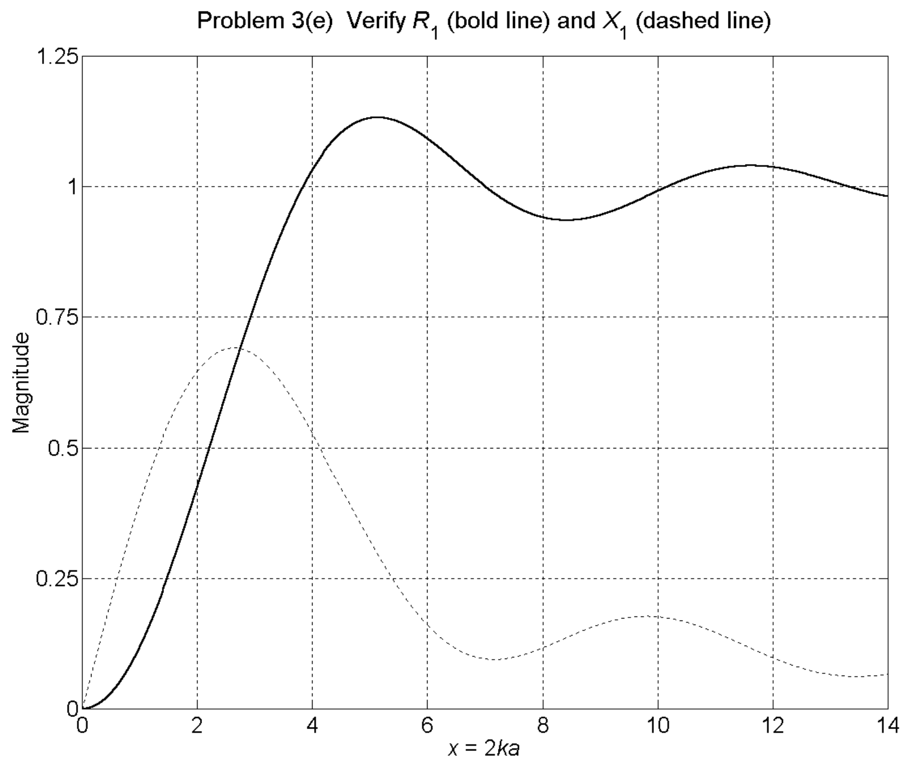
The mass is doubled. There is a flat 6 dB loss above 150 Hz. The resonant peak is shifted to a lower frequency and becomes more pronounced. Frequency response increases below resonance (2 dB max) with steeper low frequency rolloff (14 dB/octave).

Homework 5, Problem 3(d)

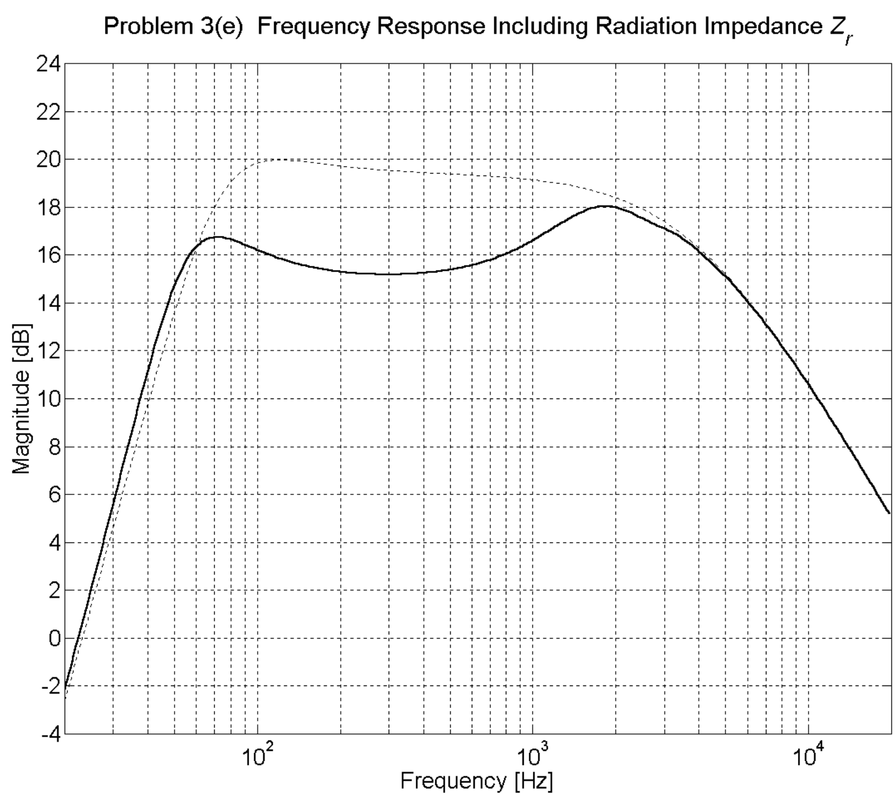


The stiffness is doubled. Only frequencies below 1 kHz are affected. 2 dB gain at resonance with up to 6 dB loss at frequencies below resonance. Slightly steeper low-frequency rolloff (12.5 dB/octave).

Homework 5, Problem 3(e)

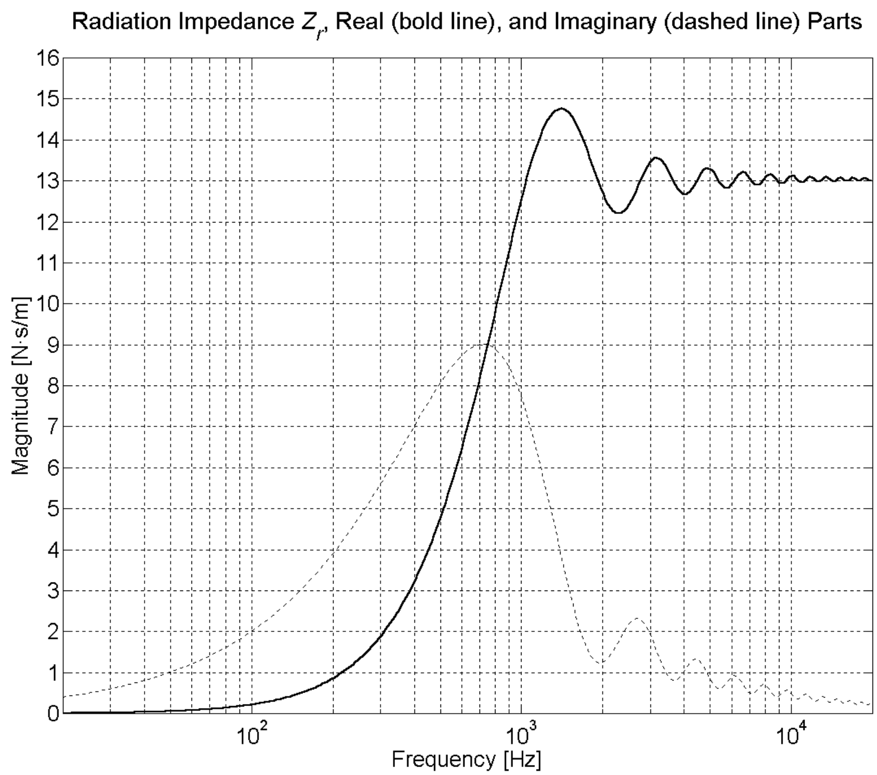


This is a recreation of Figure 7.5.2 from the textbook as a check for the coding of R_1 and X_1.

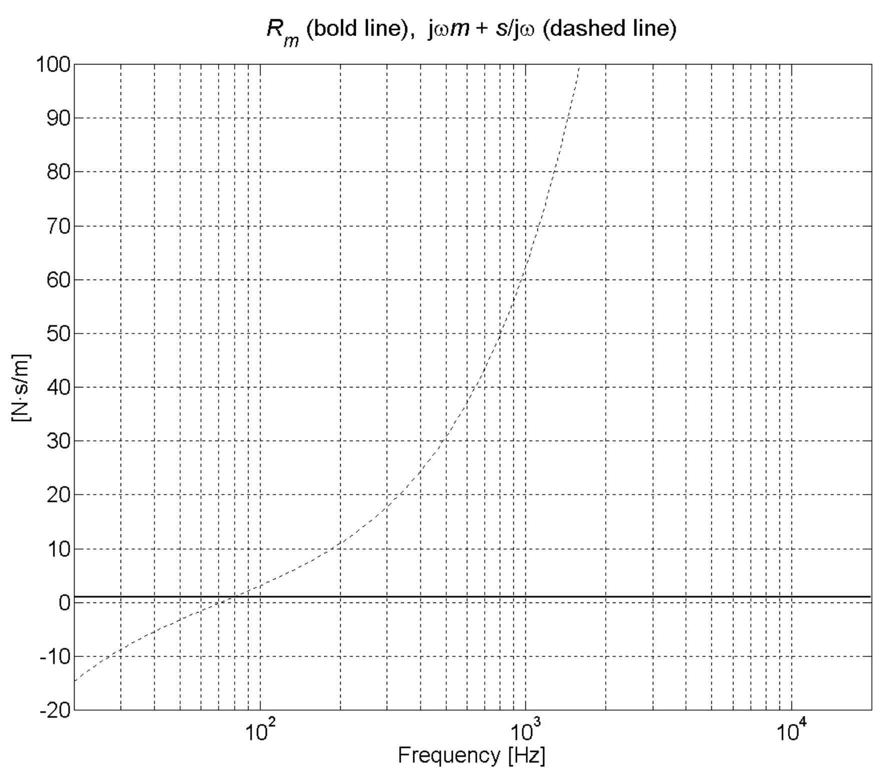


Z_r has the greatest effect on the midrange frequencies since Z_r is small at low frequencies and $j\omega m$ becomes much larger at high frequencies.

Homework 5, Problem 3(e) – Radiation Impedance Z_r and other factors



Z_r has the most influence where its magnitude is significant compared to $j\omega m + S/j\omega$.



The imaginary part becomes very large above R_o/L_o compared to Z_r.

Homework 5, Problem 3(e)

Complex Acceleration Amplitude for an input voltage $V_0 e^{jwt}$

$$20\log_{10}\frac{\left|\dfrac{j\omega V_0/\phi}{1+\dfrac{R_0+j\omega L_0}{\phi^2\left\{R_m+j\omega m+\dfrac{s}{j\omega}+2\pi a^2\rho_0 c\left[1-\dfrac{2J_1(2ka)}{2ka}+j\dfrac{2H_1(2ka)}{2ka}\right]\right\}}}\right|}{g}$$

Electrical Impedance

$$Z_E = R_0 + j\omega L_0$$

Radiation Impedance

$$Z_r = \pi a^2\rho_0 c\left[1-\frac{2J_1(2ka)}{2ka}+j\frac{2H_1(2ka)}{2ka}\right]$$

$$R_1 = 1-\frac{2J_1(2ka)}{2ka}$$

$$X_1 = \frac{2H_1(2ka)}{2ka}$$

First order Bessel J Function

$$J_1(2ka)$$

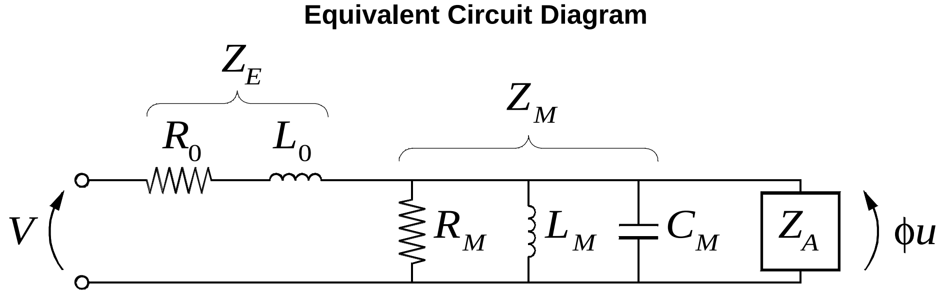
Struve Function

$$H_1(2ka)$$

Total Mechanical Impedance $Z_M \parallel Z_A$

$$Z_{MA} = \phi^2\left\{R_m+j\omega m+\frac{s}{j\omega}+2\pi a^2\rho_0 c\left[1-\frac{2J_1(2ka)}{2ka}+j\frac{2H_1(2ka)}{2ka}\right]\right\}$$

Equivalent Circuit Diagram



$$Z_A = \frac{\phi^2}{Z_r}, \qquad Z_r = \pi a^2\rho_0 c\,(R_1 + j X_1)$$

Matlab code for 3(e):

```
function graphlog()
%   This function graphs a function with a logarithmic x-axis.  Edit the
%   first section to determine the expression to be plotted, domain, range,
%   resolution, line width, labels, etc.  Expression1 is plotted with a
%   heavy line and expression 2 is plotted with a light dashed line.



% ****************  USER-EDITABLE SECTION  ******************************************

N=1; Ro=5; Lo=0.0002; a=.1; Rm=1; Zr=0; m=0.01; s=2000;     % constants
g=9.81; m=0.01; B=0.9; l=5; Fee=B*l; Vo=1; poc=415;         % constants
                                            % the expression to be plotted, x in radians
expression1 = 'w=x*2*pi; k=w/343; Ze=Ro+j*w*Lo; R1=1-2*besselj(1,2*k*a)/(2*k*a); X1=struve(2*k*a);
Zr=pi*a^2*poc*(R1+j*X1); Zma=Fee^2/(Rm+j*w*m+s/(j*w)+2*Zr); Aw=j*w*Vo/Fee/(1+Ze/Zma); y=20*log10(abs(Aw/g));';
expression2 = 'Zr=0; Zma=Fee^2/(Rm+j*w*m+s/(j*w)+2*Zr); Aw=j*w*Vo/Fee/(1+Ze/Zma); z=20*log10(abs(Aw/g));';
PlotWindowSize = [1100,900];               % plot window size in pixels
NumberOfPlots = 2;                          % 1 or 2 plots
Domain = [20 10 20e3]; Range = N*[-4 2 24]; % domain & range [min spacing max]
Resolution = 50;                            % Higher values makes finer plot
Line_Width = 2;                             % width of the plot line
tTXT = 'Problem 3(e)  Frequency Response Including Radiation Impedance {\itZ{_r}}';      % Title
xTXT = 'Frequency [Hz]';                    % the X-axis label
yTXT = 'Magnitude [dB]';                    % the Y-axis label
Fnt  = [22 20 20];                          % fontsize for [title labels grid#s]



% ****************  EVALUATE THE EXPRESSIONS  ***************************************

X=[]; Y=[]; Z=[]; x=Domain(1);              % initialize variables
while x < Domain(3),                        % fill the matrices
   eval(expression1); X = [X,x]; Y = [Y,y]; % evaluate the expression
   if NumberOfPlots==2
      eval(expression2); Z = [Z,z];         % evaluate second expression
   end
    x = x*(1+Resolution^-1);                 % controls the resolution of the plot
end                                         % end of "while" statements

% ****************  PLOT THE EXPRESSION  ********************************************

figure('Position',[-10 -210 PlotWindowSize(1) PlotWindowSize(2)])
semilogx(X,Y,'LineWidth',Line_Width);       % create plot, set linewidth
if NumberOfPlots==2
   hold on, semilogx(X,Z,'LineStyle',':');  % second plot, dashed line
   hold off
end

% ****************  APPLY TEXT AND GRID SETTINGS  ***********************************

cnt=1; Ytk=[Range(1)];                       % y-axis tick marks/grid lines
while cnt*Range(2)<=Range(3)-Range(1)
   Ytk = [Ytk,Ytk(cnt)+Range(2)]; cnt=cnt+1;
end

set(gca,'FontSize',Fnt(3)), grid on         % set grid fontsize, make the grid visible
set(gca,'Ytick',Ytk);
xlimits = [Domain(1) Domain(3)];            % set the X axis limits to the range specified
set(gca,'Xlim',xlimits);                    % apply the specified range
ylimits = [Range(1) Range(3)];              % set the Y axis limits to the range specified
set(gca,'Ylim',ylimits);                    % apply the specified range
title(tTXT, 'FontSize',Fnt(1), 'Color',[0 0 0])
xlabel(xTXT,'FontSize',Fnt(2), 'Color',[0 0 0])
ylabel(yTXT,'FontSize',Fnt(2), 'Color',[0 0 0])


function PP=struve(pp)
if pp<=4.32
   PP = 4/pi*(pp/3-pp^3/45+pp^5/1600-pp^7/10^5+pp^9/10^7);
else
   PP = 4/pi/pp+(8/pi/pp^3)^.5*sin(pp-3*pi/4);
end
```

Matlab code for Figure 7.5.2, problem 3(e):

```
function fig752()
%   This function reproduces Figure 7.5.2 on page 187.



% ****************  USER-EDITABLE SECTION  *****************************************

                                            % the expression to be plotted, x in radians
expression1 = 'R1=1-2*besselj(1,x)/(x); y=R1;';
expression2 = 'X1=struve(x); z=X1;';
PlotWindowSize = [1100,800];                % plot window size in pixels
NumberOfPlots = 2;                          % 1 or 2 plots
Domain = [0 2 14]; Range = [0 .25 1.25];    % domain & range [min spacing max]
Resolution = 1000;                          % Higher values makes finer plot
Line_Width = 2;                             % width of the plot line
tTXT = 'Problem 3(e)  Verify {\itR}{_1} (bold line) and {\itX}{_1} (dashed line)';  % Title
xTXT = '{\itx} = 2{\itka}';                 % the X-axis label
yTXT = 'Magnitude';                         % the Y-axis label
Fnt  = [20 16 16];                          % fontsize for [title labels grid#s]



% ****************  EVALUATE THE EXPRESSIONS  **************************************

X=[]; Y=[]; Z=[]; x=Domain(1);              % initialize variables
while x < Domain(3),                        % fill the matrices
   eval(expression1); X = [X,x]; Y = [Y,y]; % evaluate the expression
   if NumberOfPlots==2
      eval(expression2); Z = [Z,z];         % evaluate second expression
   end
    x = x+(Domain(3)-Domain(1))/Resolution;  % controls the resolution of the plot
end                                         % end of "while" statements

% ****************  PLOT THE EXPRESSION  *******************************************

figure('Position',[-10 -110 PlotWindowSize(1) PlotWindowSize(2)]) % figure window position and size
plot(X,Y,'LineWidth',Line_Width);           % create plot, set linewidth
if NumberOfPlots==2
   hold on, plot(X,Z,'LineStyle',':');      % second plot, dashed line
   hold off
end

% ****************  APPLY TEXT AND GRID SETTINGS  **********************************

Xtk=[Domain(1)]; Unit=Domain(1)+Domain(2);  % x-axis tick marks/grid lines
while Unit <= Domain(3)
   Xtk = [Xtk,Unit]; Unit=Unit+Domain(2);
end
cnt=1; Ytk=[Range(1)];                      % y-axis tick marks/grid lines
while cnt*Range(2)<=Range(3)-Range(1)
   Ytk = [Ytk,Ytk(cnt)+Range(2)]; cnt=cnt+1;
end

set(gca,'FontSize',Fnt(3)), grid on         % set grid fontsize, make the grid visible
set(gca,'Xtick',Xtk); set(gca,'Ytick',Ytk); % set the X&Y tick marks/grid lines
xlimits = [Domain(1) Domain(3)];            % set the X axis limits to the range specified
set(gca,'Xlim',xlimits);                    % apply the specified range
ylimits = [Range(1) Range(3)];              % set the Y axis limits to the range specified
set(gca,'Ylim',ylimits);                    % apply the specified range
title(tTXT, 'FontSize',Fnt(1), 'Color',[0 0 0])
xlabel(xTXT,'FontSize',Fnt(2), 'Color',[0 0 0])
ylabel(yTXT,'FontSize',Fnt(2), 'Color',[0 0 0])


function PP=struve(pp)                      % approximation for X1 given by Dr. Hamilton
if pp<=4.32
   PP = 4/pi*(pp/3-pp^3/45+pp^5/1600-pp^7/10^5+pp^9/10^7);
else
   PP = 4/pi/pp+(8/pi/pp^3)^.5*sin(pp-3*pi/4);
end
```