Including R in FDTD as per equations (6a,6b,10a,10b,10c, and 10d)

For k = 1

$$V_1^{n+1} = \frac{(R_s \frac{C}{2}\frac{\Delta z}{\Delta t} - \frac{1}{2})V_1^n - R_s\left(I_1^{n+\frac{1}{2}}\right) + \frac{(V_s^{n+1} + V_s^n)}{2}}{R_s \frac{C}{2}\frac{\Delta z}{\Delta t} + \frac{1}{2}}$$

For k = 2, ..,NDZ, if G = 0 , so this will be the same.

$$V_k^{n+1} = V_k^n - \frac{\Delta t}{\Delta z C}\left(I_k^{n+\frac{1}{2}} - I_{k-1}^{n+\frac{1}{2}}\right) - \frac{G\Delta t}{C}V_k^n.$$

At K = NDZ+1. This depends on $R_L$should be the same.

$$V_{NDZ+1}^{n+1} = \frac{(R_L \frac{C}{2}\frac{\Delta z}{\Delta t} - \frac{1}{2})V_{NDZ+1}^n - R_L\left(I_{NDZ}^{n+\frac{1}{2}}\right) + \frac{(V_L^{n+1} + V_L^n)}{2}}{R_L \frac{C}{2}\frac{\Delta z}{\Delta t} + \frac{1}{2}}$$

Current update for all nodes (K=1,…,NDZ):

$$I_k^{n+\frac{3}{2}} = I_k^{n+\frac{1}{2}} - \frac{\Delta t}{\Delta z l}\left(V_{k+1}^{n+1} - V_k^{n+1}\right) - \frac{r\Delta t}{l}I_k^{n+\frac{1}{2}}$$

Code:

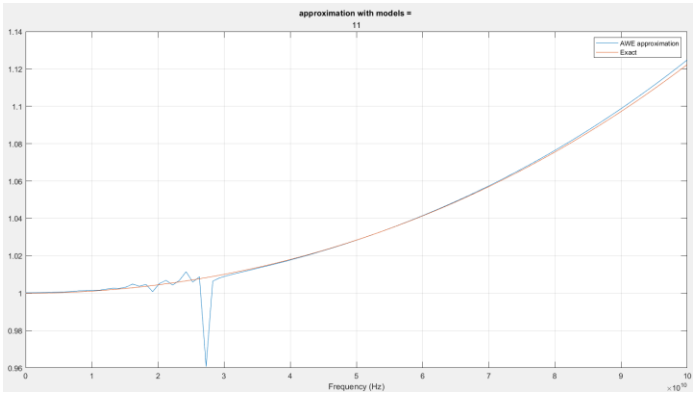
```
%FDTD
clear
clc
L_total = 150e-6;  % Total length of the line (m)
R = 1200;
L = 250e-9;
C = 1e-10;
Rs = 10;
NDZ = 50;  % Number of spatial steps
dz = L_total / NDZ;  % Spatial step delta z
v = 1/sqrt(L*C); % Phase velocity (m/s)
%dt = dz/v;   % Magic time step (dt = dz/v)
dt = 1e-16;  % Time step delta t
t_max = 10e-12;
t_steps = round(t_max / dt);  % Number of time steps
% allocate voltage and current arrays
time = (0:t_steps-1)*dt;
V = zeros(NDZ+1, t_steps);
I = zeros(NDZ, t_steps);
% 1.Step input (1V source)
Vs = 1 * ones(1, t_steps);
% 2. Sine wave (100 GHz)
%freq = 100e9; % Frequency in Hz
%Vs = sin(2*pi*freq * time);
% 3. Trapezoidal pulse (custom function)
%for i=1:length(time)
    %Vs(i) = trapezoidalPulse(time(i));
%end

% FDTD Loop for Time Stepping
for n = 1:t_steps-1
```

```
     V(1, n+1) = (Rs*C/2*dz/dt+0.5)^-1*((Rs *C/2 *dz/dt-0.5)*V(1,n)-Rs*I(1,n)+0.5*(Vs(n+1)+Vs(n)));
    for k = 1:NDZ
    if k>1
        V(k,n+1) = V(k,n) + dt/(dz *C)* (I(k-1,n) - I(k,n));  % Update voltag
        I(k-1,n+1) = I(k-1,n)-(dt/(L*dz))*(V(k,n+1)-V(k-1,n+1))-(R*dt/L)*I(k-1,n);% Update current
    end
    end
    V(NDZ,n+1) =V(NDZ,n)+dt*(I(NDZ-1,n)/(C*dz));
end
y_FDTD = V(NDZ,:);
% Plot the results for the voltage at the load
figure(1)
plot(time/1e-12, V(NDZ,:));
xlabel('Time (ps)');
ylabel('V Load (Volts)');
title('FDTD Simulation of Transmission Line with unit step input');
%title('FDTD Simulation of Transmission Line with 100 GHz Sine Wave Input');
%title('FDTD Simulation of Transmission Line with Trapezoidal Pulse Input');
grid on
```

THz model with AWE.

Due to the rounding issue at each model the following output is obtained.

Frequency response:



Unit step response: