ANALYSIS OF REACTIVE MUFFLER BY EXPERIMENTAL AND NUMERICAL METHOD

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Abstract— A pollutant of concern to the mankind is the exhaust noise on the internal combustion engine. However this noise can be reduced by means of a well-designed muffler. The suitable design and development will help to reduce the noise level, but at the same time the performance of the engine should not be hampered by the back pressure caused by the muffler.
This paper describes predicted result of the Acoustic Transmission Loss.

Index Terms—Backpressure, Engine Noise, Muffler, Transmission Loss

I. INTRODUCTION

1.1 Muffler

A muffler is a passive noise control element in an automobile exhaust system that is designed to reduce the amount of noise that an engine produces due to combustion. Performance of mufflers is not only to reduce sound levels, but with reduced back pressure. Back pressure is created in the exhaust line because of restrictions of exhaust gases by muffler in the exhaust line. The back pressure must be minimal because they help to reduce the work done by the engine components, thereby increasing the performance of the engine. Muffler is a key part of the exhaust system which attenuates the unpleasant noise emitted by the engine after the combustion during the exhaust stroke.

1.2 Requirements of Mufflers

1. The muffler performance must not deteriorate with time.
2. Flow-generated noise within muffler element and at the tail pipe exit should be sufficiently low, particularly for mufflers with large insertion loss.
3. Spark-arresting capability is also a requirement occasionally (particularly for agricultural use).
4. Back pressure: It should be as minimum as possible.

1.3 Need of Mufflers

Mufflers are used to reduce the combustion noise present at the exit of the exhaust. As the noise norms becoming more stringent, it’s necessary for the entire automotive manufacturer to give more attention in the design of mufflers. Designing mufflers have been a challenging task for the designer for many years as it is not only reducing the noise but it also creates backpressure, which reduces the overall efficiency of the engine. Noise creates annoyance, sleep disturbance and if it is too loud then it can damage our hearing capability. Hence it is necessary to install muffler in every automotive so that noise emission can be controlled and remain within the noise norms.

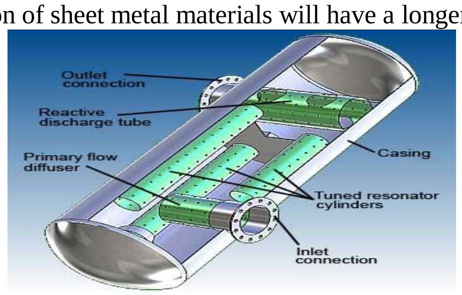
1.4 Types of Mufflers

1. Reflective/reactive mufflers
2. Dissipative / Absorptive muffler
3. Combination muffler/silencer

II. REACTIVE MUFFLER

1. Reactive Muffler

Reactive muffler consists of resonant chambers separated by series of baffle plates and pipes as shown in figure 1.The gas flow from the engine is directed by pipes of different lengths and with perforations. It distributes the exhaust gases in to the resonant chambers .the reactive muffler works by the principle of Helmholtz principle. The muffler reflects the pressure wave 180º out of phase back to the noise source which eventually cancels it by destructive interference. The reactive muffler works well in lower and mid range engine firing and harmonic frequencies the acoustic performance of reactive muffler is high in the frequency range of 30 to 600 Hz. the exhaust gases expands in the muffler chamber and thus reduces its pressure amplitude .the reactive muffler also reduces the high velocity gases to slow down and reduces the flow oriented noises, the only disadvantage of using reactive muffler is it creates high back pressure .Proper design of perforation in baffle plates and pipes and selection of pipe diameter will control the back pressure to the optimum. The volume of the muffler is selected based on the size of the engine generally the muffler volume should to 10 to 12 times the size of the engine can reduce the pressure amplitude effectively. The advantage of reactive muffler is the life time of the system will be longer since there are no non degradable materials inside it. Proper selection of sheet metal materials will have a longer run without rusting.



2.1 Fig. Reactive Muffler

Accurate prediction of sound radiation characteristics from reactive muffler is of significant importance in automotive exhaust system design. The most commonly used parameter to evaluate the sound radiation characteristics of muffler is transmission loss (TL). Transmission loss is one of the most frequently used criteria of muffler performance because it can be predicted very easily from the known physical parameters of the muffler. The transmission loss (TL) could be achieved by three methods analytical, numerical, and experimental. However, practical muffler configurations generally have large cross sectional dimensions as well as complex geometries. Analytical methods are cumbersome in the sense that the associated algebra is very complicated so, many times it is impossible to solve such problems by analytical methods. The numerical methods are completely general and allow the analysis of all types of mufflers. But the results achieved by numerical tool i.e. by FEM may not be correct due to many reasons such as modelling errors, meshing errors, assumptions while solving the partial differential equations (solution errors), specifications of approximate boundary conditions, insufficient constraints, selection of meshing elements, types of meshing. Irrespective of these drawbacks numerical methods can be used for optimization of model of complicated shapes and cost involved is less compared to experimental methods. So general practice is to optimize the model by numerical methods and validate the result by experimental methods. For the experimental validation ,experimental set up must be developed with due care and precautions. For the validation of experimental setup it is necessary to test the results of model of which analytical, numerical results are known. The measured transmission losses are compared with FEM method, demonstrating that transmission losses can be determined reliably with the setup which is prepared. In general, experimental results are required for verifying the analytical and numerical predictions and also for evaluating the overall performance of a system configuration so as to check if it satisfies the design requirements

In this research two load methods is used for measuring transmission loss by experimental method.

Theory

Two Load Method: In the two load method, two loads should be different to keep results stable. Generally, two loads can be two different length tubes, a single tube with and without absorbing materials. In this research two loads were achieved by outlet tube with and without absorbing material as shown in Figure 1.The two load methods are based on the transfer matrix approach. Using the transfer matrix method, one can readily obtain transmission loss of any muffler by using four pole equations from the four positions of microphones.

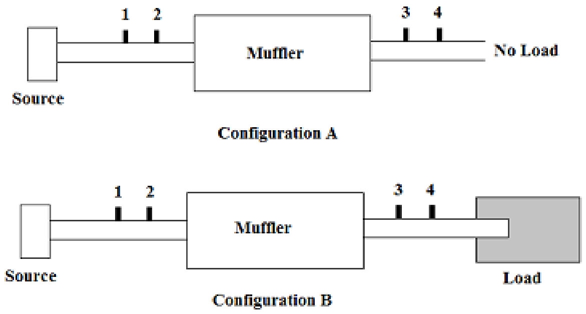


Fig .2.2. Two Configurations and Schematic Model of Muffler

Neglecting flow of air, the four poles for elements 1-2 can be

Expressed as

$$\begin{bmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{bmatrix} = \begin{bmatrix} \cos kl_{12} & j\rho c \sin kl_{12} \\ \frac{j \sin kl_{12}}{\rho c} & \cos kl_{12} \end{bmatrix}$$

The four poles for elements 2-3 can be expressed as

$$\begin{bmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{bmatrix}$$

Where

$$A_{23} = \frac{\Delta_{34}(H^{32}H^{34}b - H_{32}bH_{34}) + D_{34}(H^{32}b - H_{32a})}{\Delta_{34}(H_{34}b - H_{34a})}$$

$$B_{23} = \frac{B_{34}(H_{32a} - H_{32}b)}{\Delta_{34}(H_{34}b - H_{34a})}$$

$$C_{23} = \frac{H_{31a} - A_{12}H_{32a})(\Delta_{34}H_{33}b - D_{34}) - (H_{31}b - A_{12}H_{32}b)(\Delta_{34}H_{34a} - D_{34})}{B_{12}\Delta_{34}(H_{34}b - H_{34a})}$$

$$D_{23} = \frac{B_{34}(H_{31a} - H_{31}b) - A_{12}(H_{32}b - H_{32a})}{B_{12}\Delta_{34}(H_{34}b - H_{34a})}$$

$$TL = 20 \log_{10}(\frac{1}{2} \mid A^{23} + \frac{B_{23}}{\rho c} + \boldsymbol{\rho} c C_{23} + D_{23} \mid)$$

The term Hij, represents transfer function between Pi and Pj (Hij = Pj / Pi).The four poles for elements 3-4 can be expressed as

$$\begin{bmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{bmatrix} = \begin{bmatrix} \cos kl_{34} & j\rho c \sin kl_{34} \\ \frac{j \sin kl_{34}}{\rho c} & \cos kl_{34} \end{bmatrix}$$

By using two microphones with random excitation transmission loss can be calculated experimentally.

Experimental Setup

A schematic diagram of experimental set up for calculating TL of simple expansion muffler is shown in Fig.2.3. It consists of a noise generation system, noise propagation system and noise measurement system. The TL is measured by transfer function method. The setup has the following main components.

1. Impedance Tube
2. Data acquisition system
3. Noise source with amplifier
4. Sound pressure measuring microphones

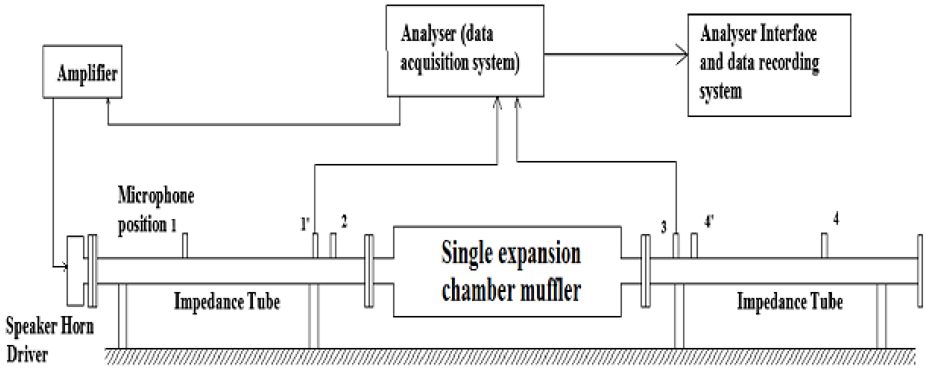


Fig 2.3. Schematic Diagram of Experimental Setup with Its Components

Impedance tube is a rigid tube through which sound propagates and reflects from test sample which results in creation of standing waves in it. It has measuring locations at specific distances from test sample where the acoustic pressure is measured. A sound source device is connected at the one end of impedance tube and test muffler at other end. As we are interested in incident and transmitted wave, two impedance tubes are used on either side of the muffler. The main purpose served by impedance tube is providing guidance to sound wave as required for plane wave propagation. The data acquisition system used is a four channel FFT analyzer with an interface for the control and setting of analyzer. It collects the pressure data from microphones and feed it to data recording storage system. It also has a single output channel which is fed to speaker through analyzer. A random noise signal is generated in same analyzer and directed to the speaker via amplifier. The reason behind using random noise (white noise) is that it contains equal power density of noise for each frequency. Sound source used is of high power to produce at least 120 dB of noise. Pressure field microphones are used for measurement. The two microphones are sufficient as transfer function method is used. Transfer function is evaluated for each set of reading. The actual test setup with required components is shown in Figure 2.3. Two configurations of set up are used with respect to boundary conditions.

Experimental Procedure

Experimentation for pressure measurement mainly consists of analyzer setting and data processing for TL calculation. The experiment is performed for frequency range of 50 to 3400 Hz. The measurements are taken in two slots with two locations 1-1' and 4-4' as shown in figure respectively to cover desired frequency range .The locations 1-2-3-4 are used for measuring pressure in frequency range 50-400 Hz, while the locations 1'-2-3-4' are used for measuring pressure in frequency range of 400-3400 Hz. The first set of readings is taken for no load condition with both frequency range and same procedure is repeated for with load condition. Two microphones are used for measurement, which are sufficient for measurement of transfer function between sound pressures measured at two locations. One microphone is placed at location 3 and other placed at location 1, 2 and 4 respectively to get transfer function H31, H32 and H34 with respected locations. All other locations except locations where microphone are inserted are sealed with pins to avoid sound leakage. The sound leakage is tested and wax is used to seal these leaks. The obtained transfer functions are then directly used in four -pole element calculations to get TL.

III. DESIGN OF REACTIVE MUFFLER

Many terms are used to define the working of any reflective mufflers. These terms are very important to completely understand the working of muffler.

1. Impedance:

The term impedance is used for the resistance of a system to an energy source.

1. Acoustic impedance (z):

It's a frequency dependent parameter and is very useful.

Mathematically,

$$Z = p/(V * S)$$

Where,

P = sound-pressure,

V = particle velocity,

S = Surface area.

2. Characteristic impedance (Z_o):

It's a material property of a medium such as air, rock or water.

Mathematically,

$$Z_o = \rho * C$$

Where,

ρ = Density of the medium

C = velocity of sound

A. Combination muffler

Some silencers combine both reactive and absorptive elements to extend the noise attenuation performance over a broader noise spectrum. Combination silencers are also widely used to reduce engine exhaust noise.

2. Muffler performance parameters

As per the literature and statistical survey, the required silencer volume for better performance is 8 –10 times the engine capacity. The use of an exhaust silencer is

Prompted by the need to reduce the engine exhaust noise. In most applications the final selection of an exhaust silencer is based on a compromise between the predicted acoustical, aerodynamic, mechanical and structural performance in conjunction with the cost of the resulting system.

Sound transmission characteristic of a structure can be measured in terms of the one of the following parameters

1. Insertion Loss, Il
2. Transmission Loss, Tl
3. Level Difference Ld, Or Noise Reduction, Nr

1) Insertion loss (IL)

Insertion loss is defined as the difference between the acoustic power radiated without the structure and that with the structure. Symbolically,

IL= 10 log W_1/W_2 dB

Where,

W_1 and W_2 denote the acoustic power without the structure and with the structure.

2) Transmission loss (TL)

Transmission loss is defined as the ratio of the incident power and transmitted power from the structure. Symbolically,

TL= 10 log W_i/W_t dB

Where ,

Wi and Wt denote the incident acoustic power and transmitted acoustic power.

TLis used in this work to evaluate the performance of the muffler wall.

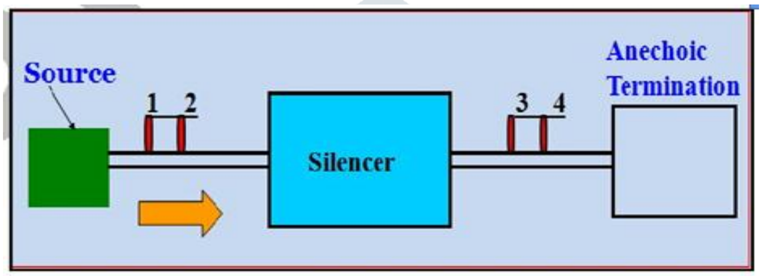


Figure 3.1 – Concept picture of Transmission Loss

3) Level difference (LD)

Level difference LD, or noise reduction, NR is the difference in sound pressure levels at two arbitrarily selected points inside the structure and outside the structure.

Symbolically,

LD= 20 log P_i/P_o dB

Where

P_i and P_o denote the pressure inside the structure and outside the structure.

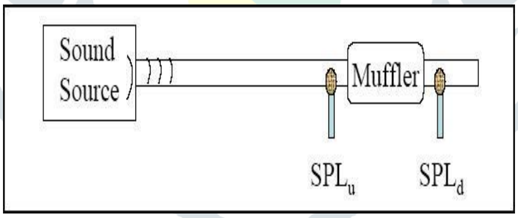


Figure 3.3 – Concept picture of Level difference

4) Back Pressure:

The average pressure in the exhaust pipe during the exhaust stroke is called the mean ambient pressure; and the term “back pressure” is used to denote the difference between this and the ambient pressure. This back pressure is due to loss in stagnation pressure in various tubular elements and across various junctions. When this back pressure is low enough (less than .1 bar), it simply represents a corresponding loss in the in brake mean effective pressure (BMEP) of the engine. Pressure drop across the complete muffler assembly: The most important detrimental effect in a muffler in a muffler with good insertion loss is the backpressure that it would exert on the engine. This back pressure is due to loss in stagnation pressure in various tubular elements and across various junctions. When this backpressure is low enough (less than 0.1 bar), it simply represents a corresponding loss in the brake Mean Effective pressure (BMEP) of the engine.

3. Design Of Expansion Chamber

As expansion chamber is of reactive type. It is most effective at low frequencies. I.e. less than 500 c/s and m=10

$$m = \frac{\text{Cross-sectional area of the expansion chamber}}{\text{Cross-sectional area of circular Pipe}}$$

$$m= \frac{\pi}{4}D^2/\frac{\pi}{4}d^2$$

Where,

D = Diameter of the expansion chamber

d = diameter of the inlet pipe.

Here the diameter of the inlet pipe = 0.0635. i.e.

d=0.0635m m = 10 (assumed)

$m = \frac{\pi}{4}D^2 / \frac{\pi}{4} d^2$

$D^2 = md^2$

$D = (10)^{1/2} * (0.0635) = 0.20m$

The normal practice is to adopt the length of the chamber 10 to 12 times the diameter of the exhaust pipe.

i.e. l = (10 to 12)d

Let us take l=2d , l=12*0.0635=0.762m

l=0.75m (approximately)

$$V_m = \frac{\pi}{4} D^2 \times l = 0.785 \times (0.2)^2 \times 0.75$$

Volume of the expansion chamber

$V_m = 0.02355 m^3$

Transmission Loss of the muffler:

$TL = 10 \log_{10} [1 + \frac{1}{4}(m - \frac{1}{m})^2 \sin^2 kl]$

$m = \frac{\pi}{4}D^2 / \frac{\pi}{4} d^2$

$m = (0.2)^2 / (0.635)^2$

$= 9.920019$

i.e. Adopt m=10

$k = 2\pi f l$

K = Sound Wave Number,

$k = 2\pi f / 345 * [295 / (t + 273)]^{1/2}$

$k = 2(3.14)(500) / 345 * [295 / (300 + 273)]^{1/2}$

k= 6.53

As this is reactive type muffler, it is effective up to 500c/s. Therefore f=500c/s is adopted. Substituting the values of k, l and m in

$TL = 10 \log_{10} [1 + \frac{1}{4}(m - \frac{1}{m})^2 \sin^2 kl]$

$TL = 10 \log_{10} [1 + \frac{1}{4}(10 - \frac{1}{10})^2 * \sin^2(6.53)(0.75)]$

we get

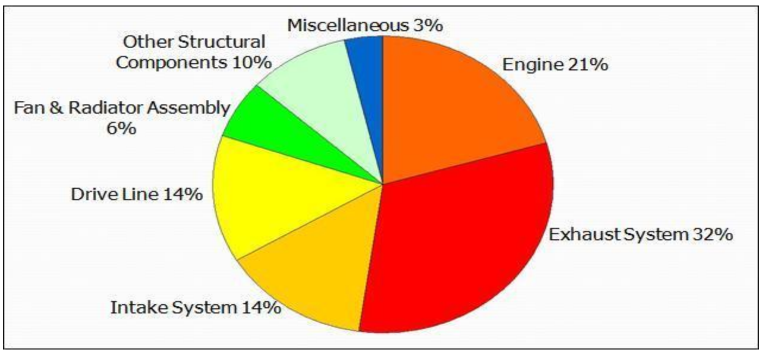
TL = 13 .92 dB

It is stated that commercial mufflers are design and developed empirically to fit particular engine and usually call for specific length of pipes before and after the muffler in order to minimize loss of engine power and minimize the insertion loss in those part of frequency range where the loudness contributions of the source are greatest.

IV. CASE STUDY

4.1 Noise Contributions From Various Automotive Systems

The vehicle noise comprises three major sources, viz., power unit, wind turbulence and tyre /road. The power unit consists of engine, cooling fan, exhaust and transmission. Main components of engine are injection system, intake system and cylinder block, particularly the sheet metal components. The best design practice is to design as well as vehicle for quietness. This requires knowledge of the mechanism of noise generation, propagation and radiation. The principle of impedance mismatch needs to be understood and made use of appropriately in design of exhaust system. The contributions of noise by various automotive systems are shown in fig.



Advantages of Reactive Muffler

1. High performance at low frequencies.
2. Typically give high insertion loss, IL, for stationary tones.
3. Useful in Harsh Conditions.

Disadvantages of Reactive Muffler

1. Poor performance at high frequencies
2. Not desirable characteristics for broadband noise.

V. CONCLUSION

The following conclusions are drawn:

1. Reduction of Oise level is around 15db compared to existing muffler
2. The fuel consumption is less compared to existing muffler

Three methods for measuring muffler TL have been discussed in this paper. The results indicated the limitations of the decomposition method in the absence of a good anechoic termination. Furthermore, the decomposition method does not lead to the four-pole parameters of the muffler; these are necessary for predicting the IL of the system. However, both the two source and two-load methods accurately measured the muffler TL without the use of an anechoic termination. Theoretically, any termination could be used, but termination with high revel action is not recommended. When the termination is highly reflective, the signal-to noise ratio is low, and random errors can be large, which may contaminate the experimental results. The two-load method is easier to employ than the two source method, since the sound source does not have to be moved. This assumes that the two loads are different enough. However, this study indicated that the two-source method might be the better choice for determining the four-pole parameters of a muffler. It is also possible to reverse the muffler, which may be easier than moving the sound source.

Future Work

The muffler which we are going to create that is little big in size. So, in future the size of muffler can be minimizing to a proper size which can be suitable for the motorcycle. Also there is scope to calculate back pressure. Also because of reduction in size of muffler the manufacturing cost of muffler can also be reduce. Due to reduction in the muffler the requirement of space is also less.

VI. MATLAB PROGRAM –

MATLAB PROGRAM FOR CALCULATING TL OF SEC BY TMM:

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% PROGRAM FOR CALCULATING THE TRANSMISSION LOSS OF SIMPLE %
% EXPANSION CHAMBER MUFFLER BY TRANSFER MATRIX METHOD     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clear;
close;
format;
Length_of_chamber=0.500;
Diameter_of_chamber=0.100;
ca=343;%m/s, speed of sound through air.
rhoa=1.21; %kg/m3, density of air.
f=5:5:3000;
w=2*pi*f; %w is the frequency in radians/sec
ka=w/ca; %wave number for air
p=1;

%for 1st pipe
l1=0.050; %m, length of the pipe
d1=0.030; %m, diameter of the pipe
s1=(pi/4)*(d1)^2; %cross sectional area of pipe
Y1=ca*rhoa/s1;


%for Expansion Chamber
l2=Length_of_chamber;
d2=Diameter_of_chamber;
s2=(pi/4)*(d2)^2;
Y2=ca*rhoa/s2;

%for end pipe
l3=0.05;
d3=0.030;
s3=(pi/4)*(d3)^2;
Y3=ca*rhoa/s3;

fp1(:,:,p)=[1 0;0 1];
fp2(:,:,p)=[1 0;0 1];
fp3(:,:,p)=[1 0;0 1];
Tm(:,:,p)=[1 0;0 1];
TM11(p)=1;
TM12(p)=1;
TM21(p)=1;
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```
TM22(p)=1;

for p=1:length(f)
fp1(:,:,p)=[cos(ka(p)*l1),1j*Y1*sin(ka(p)*l1);1j*sin(ka(p)*l1)/Y1,cos(ka(p)*l1)];
fp2(:,:,p)=[cos(ka(p)*l2),1j*Y2*sin(ka(p)*l2);1j*sin(ka(p)*l2)/Y2,cos(ka(p)*l2)];
fp3(:,:,p)=[cos(ka(p)*l3),1j*Y3*sin(ka(p)*l3);1j*sin(ka(p)*l3)/Y3,cos(ka(p)*l3)];
Tm(:,:,p)=fp1(:,:,p)*fp2(:,:,p)*fp3(:,:,p);
TM11(p)=Tm(1,1,p);
TM12(p)=(Tm(1,2,p))/Y1;
TM21(p)=(Tm(2,1,p))*Y3;
TM22(p)=Tm(2,2,p);
end

REAL=(TM11+TM22)/2;
IMG=(TM12+TM21)/2;
Complex=REAL+IMG;
mode=Complex.*conj(Complex);
TL=20*log10(sqrt(mode));

figure(1);
plot(f,TL,'-b');
xlabel('FREQUENCY in Hertz');
ylabel('TRANSMISSION LOSS IN dB');
title('Plot of TRANSMISSION LOSS Versus FREQUENCY');
```

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