EE202 Lab Report 1

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In this lab the goal is to find two methods to measure Q(quality factor) of an inductor. In the LTspice I have used an imaginary Rin to mimic the internal resistance of the inductor. Q is equal to WL/Rl , Thus quality factor changes with frequency because of the w component in the equation. So Q is calculated for each different frequency.

Software Lab

First Method(Phase difference)

Inductors create a phase difference in the circuit. If we can measure the phase difference in the circuit we can find inductance and the resistance of the inductor. The phase difference can be measured by finding the time delays of the waveforms between Vin and Vout, Vin being the waveform before the inductor and Vout being waveform after the inductor.

$\Theta = 360 \times f \times \times \Delta t$

The gain ratio is :

Vout/Vin = Rext/(jwl+Rl+Rext)

The phase difference is

$\emptyset = tan$ ^−1 (ωL RL + $Rext$)

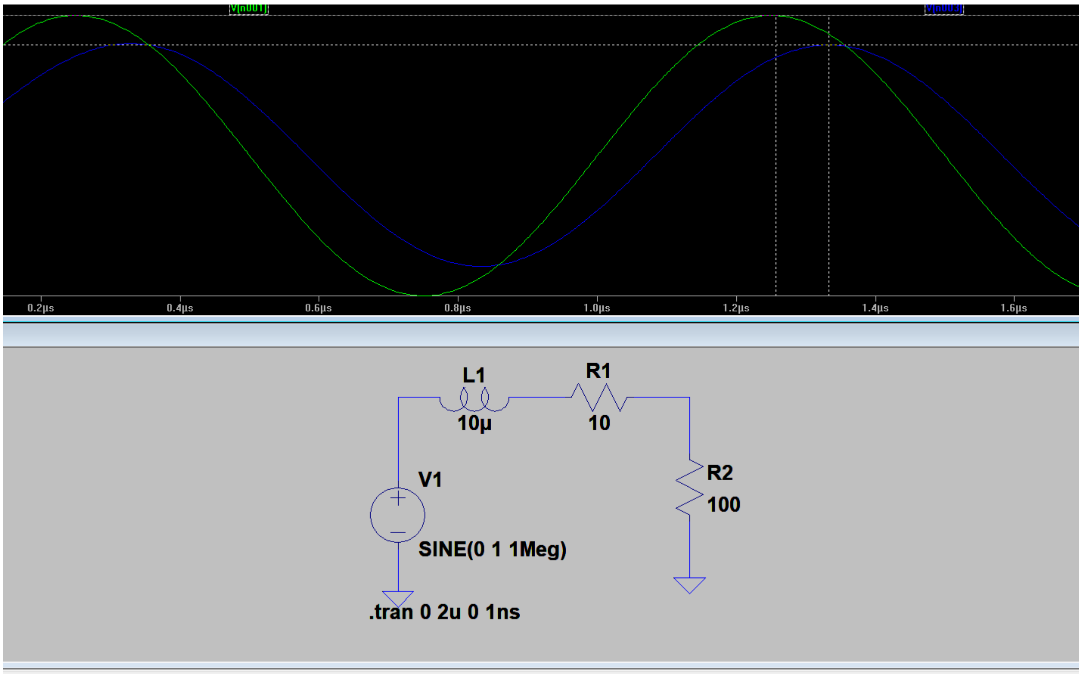
To solve two uknowns I have used two resistors for creating two equations and then solved. First Rexternal is R1 and second is R2.

$tan\emptyset =$ WL/ (RL+R1)

$tan\emptyset 2 =$ WL/ (RL+R2)

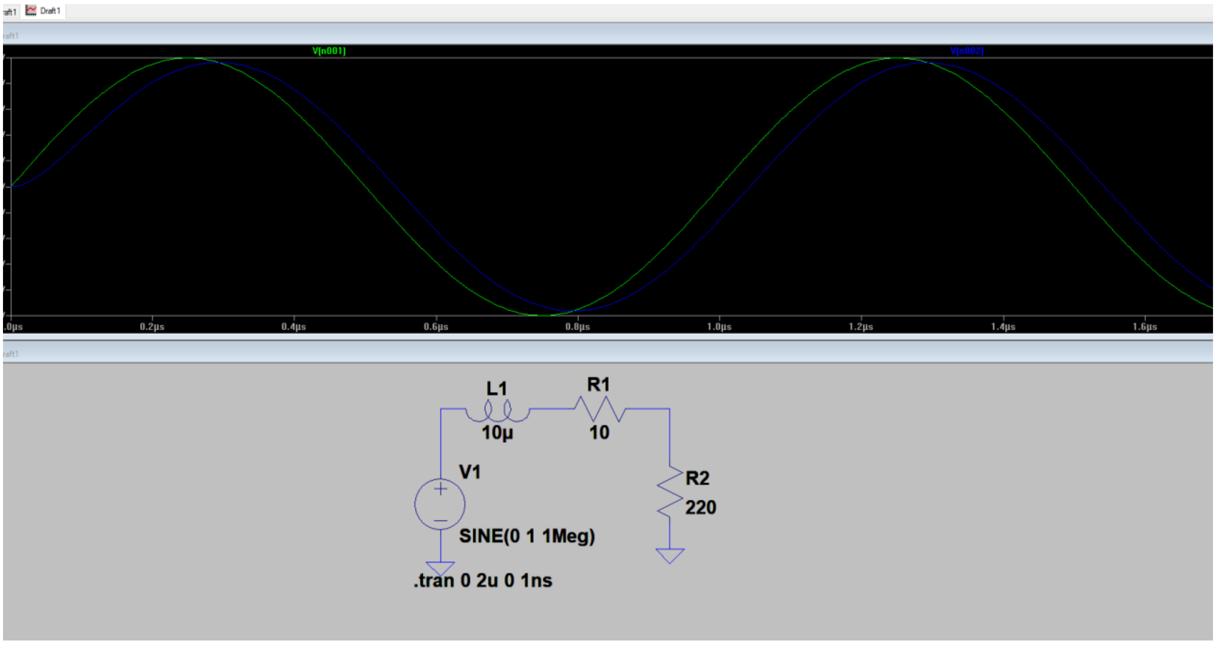
RL=($tan\emptyset 2$ X R2 - $tan\emptyset$ X R1)/ ($tan\emptyset 1 - tan\emptyset 2$)

L= (R1-R2)/w ($cot\emptyset 1 - cot\emptyset 2$)



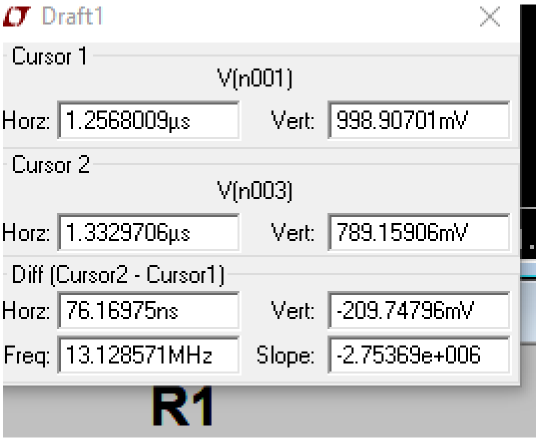
(a1)

First circuit which containing 100 ohm for R1 is in the figure a1. I have started my calculations from 1 MHZ. And I have used 10 ohms for internal resistance of the inductor thinking it is a good approximation.



(a2)

In figure a2 the circuit two is shown which I have used 220 ohm for Rexternal.



(a3)

I have used cursors in LT spice to measure the time difference between two signals which I have later used the phase difference. Horizintial difference gave me the time difference between two circuits.

f	Δt1(ns)	Δt2(ns)	Δ ϴ1	Δ ϴ2	Rl(ohm)	L(uh)
1	76.19	41.58	27.14	14.96	10.12	9.78
2	68.40	39.61	24.62	14.25	9.72	9.95
3	56.65	36.43	20.39	13.11	10.12	9.89
4	46.1	33.6	66.3	47.6	10.94	10.06

Qcalculated	Qexpected
6.06	6.28
12.64	12.35
18.41	18.84
23.1	25.13

My calculations showed me using phase difference to calculate quality factor is more reliable in lower frequency and as the frequency increases the error increases as well.

Java code I have written to make my calculations:

```
import java.util.Locale;
import java.util.Scanner;
public class Lab011
{
  public static void main(String args[])
  {
    Scanner scan = new Scanner(System.in).useLocale(Locale.US);
    double r1;
    double r2;
    double arl;
    double al;
    double f;
    double t1;
    double t2;
    System.out.print("R1: ");
    r1 = scan.nextDouble();
    System.out.println();
    System.out.print("R2: ");
    r2 = scan.nextDouble();
    System.out.println();
    System.out.print("AR1: ");
    arl = scan.nextDouble();
    System.out.println();
    System.out.print("AL: ");
    al = scan.nextDouble();
    System.out.println();
    System.out.print("t1: ");
    t1 = scan.nextDouble();
    System.out.println();
     System.out.print("t2: ");
    t2 = scan.nextDouble();
    System.out.println();
    System.out.print("F: ");
    f = scan.nextDouble();
```

```
    System.out.println();
    double dq1= -t1*360*0.001*f;
    double dq2= -t2*360*0.001*f;
    double q1= Math.toRadians(dq1);
    double q2= Math.toRadians(dq2);
    double L= -(r1-r2)/(6.28*((1/Math.tan(q1))-(1/Math.tan(q2))));
    double rl =((Math.tan(q2))*r2-Math.tan(q1)*r1)/(Math.tan(q1)-Math.tan(q2));
    double rerror = 100*(L-al)/(al);
    double rlerror = 100*(rl-arl)/arl;
    double qexpected = (6.28*al)/arl;
    double qcalculated = (6.28*L)/rl;
      System.out.println("L " + L);
      System.out.println("RL " + rl);
      System.out.println("rlerror " + rlerror);
      System.out.println("qexpected " + qexpected);
      System.out.println("qcalculated " + qcalculated);
  }
```

Second Method(Gain Ratio Method)

In this method the relation between Rexternal , Rinternal ,inductance and gain ratio is used to find quality factor.

(Vs/Vr)^2 =((WL)^2 + (Rl +Rext)^2)/Rext^2=x

From this calculation I have calculated to x: x1 and x2 with two different external resistors.

Rl= ((r1^2 * x1)- ((Rl+r1)^2/(w^2))

L= (x1*R1^2 – (Rl+ R1)^2/w^2) ^(1/2)

I have used the same circuit I have used for method 1 so signals can be referred to a1 and a2 figures mentioned above. Rexternals are also used as 100 and 220 same as the method 1.

f	Vs1	Vs0	Vs2	Vs02	Rl	L	Q
1	999.2	767.3	998.5	930.1	10.4	12.5	7.1
2	999.7	602.5	999.2	842.3	10.3	10.1	12.2
3	999.8	455.1	999.6	740.6	10.2	9.9	18.2
4	999.7	360.8	999.8	650.2	10.5	9.9	23.6

Java code I wrote for calculating method2

```
   import java.util.Scanner;
import java.lang.Math;
import java.util.Locale;
public class Lab012
{
  public static void main(String args[])
  {
    Scanner scan = new Scanner(System.in).useLocale(Locale.US);
    // Input
    double r1;
    double r2;
    double arl;
    double al;
    double vs1;
    double v01;
    double vs2;
    double v02;
    double f;
    // Output
    double x1;
    double x2;
    double rL;
    double l;
    double rLerror;
    double lError;
    double qExpec;
    double qCalculated;
    String selection = "";
    while(!selection.equals("e")){
    // Input
    System.out.print("R1: ");
    r1 = scan.nextDouble();
    System.out.println();
    System.out.print("R2: ");
    r2 = scan.nextDouble();
```

```
System.out.println();
System.out.print("AR1: ");
arl = scan.nextDouble();
System.out.println();
System.out.print("AL: ");
al = scan.nextDouble();
System.out.println();
System.out.print("VS1: ");
vs1 = scan.nextDouble();
System.out.println();
System.out.print("V01: ");
v01 = scan.nextDouble();
System.out.println();
System.out.print("VS2: ");
vs2 = scan.nextDouble();
System.out.println();
System.out.print("V02: ");
v02 = scan.nextDouble();
System.out.println();
System.out.print("F: ");
f = scan.nextDouble();
System.out.println();
// Output
x1 = Math.pow(vs1,2) / Math.pow(v01,2);
x2 = Math.pow(vs2,2) / Math.pow(v02,2);
rL = (Math.pow(r1,2)*(x1 - 1) - Math.pow(r2,2)*(x2 - 1))/(2*(r1 - r2));
l = Math.sqrt((Math.pow(r1,2)*x1-Math.pow(rL + r1,2))/Math.pow(2*Math.PI*f,2));
rLerror = -((rL - arl)/arl)*100;
lError = ((l - al)/al)*100;
qExpec = (2*Math.PI*f*al)/arl;
qCalculated = (2*Math.PI*f*l)/rL;
// Print Output
System.out.println("-------------------------------------------");
System.out.println("-------------------------------------------");
System.out.println("X1: "  + x1);
System.out.println("X2: "  + x2);
System.out.println("RL: "  + rL);
System.out.println("L: "  + l);
System.out.println("RLerror: "  + rLerror);
```

```
    System.out.println("Lerror: "  + lError);

    System.out.println("Qexpec: "  + qExpec);

    System.out.println("Qcalculated: "  + qCalculated);

    System.out.println("--------------------------------------------");

    System.out.println("--------------------------------------------");

    // Exit, continue

    System.out.println("for exit 'e' , for continue 'c'");

    selection = scan.next();

    }

  }

}
```

Hardware Lab

Toroidal Core

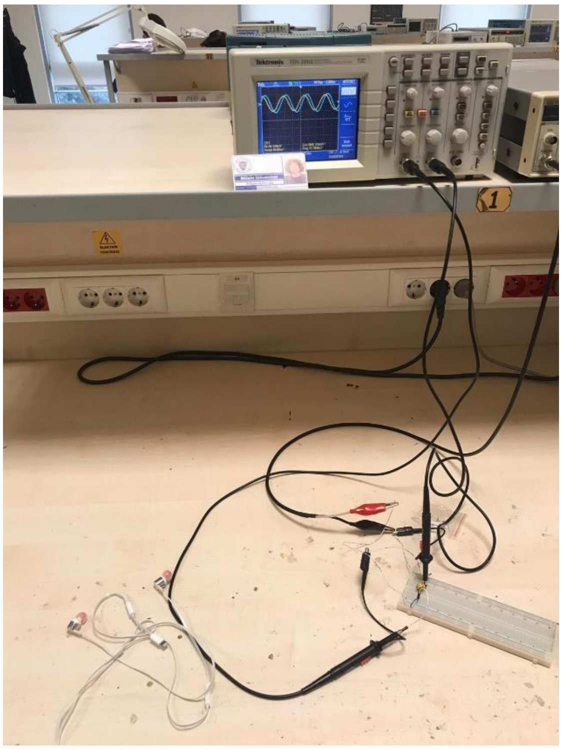
I have started the lab with Toroidal core because it was easier to find a fabricated inductor from the lab. After many tries I have made a toroidal inductor with the value of 4.35 uh and found a 10uh fabricated inductor from the lab.

b.1 my measurement of the toroidal inductor.

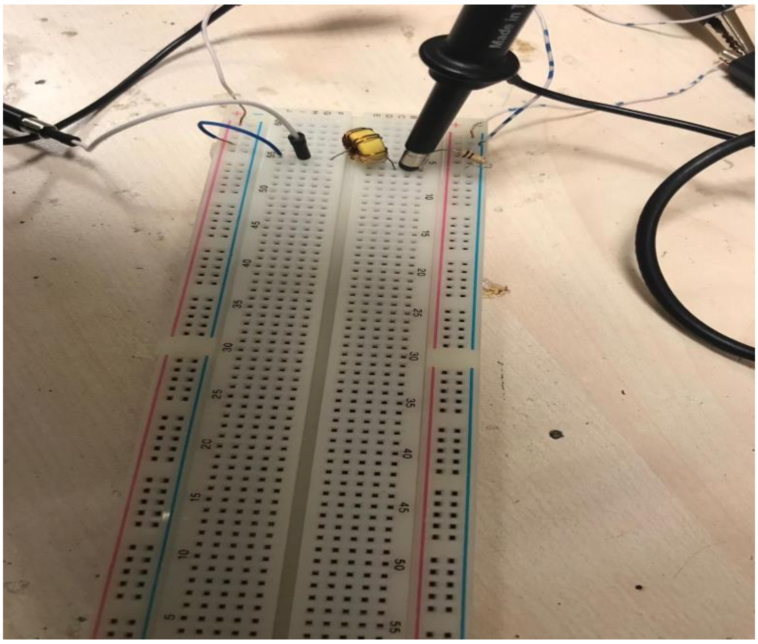
Toroid I have made. I have used core T-38 and 11 winding.

Below is given the measurement table for toroidal core method1

f	Δt1	Δt2	Rl	L	Q
1	76.3	27.5	3.95	5.0	7.6
2	56.3	16.7	4.2	5.4	15.9
3	40.7	11.2	4.0	5.2	24.4
4	32.5	8.3	4.4	5.0	28.5

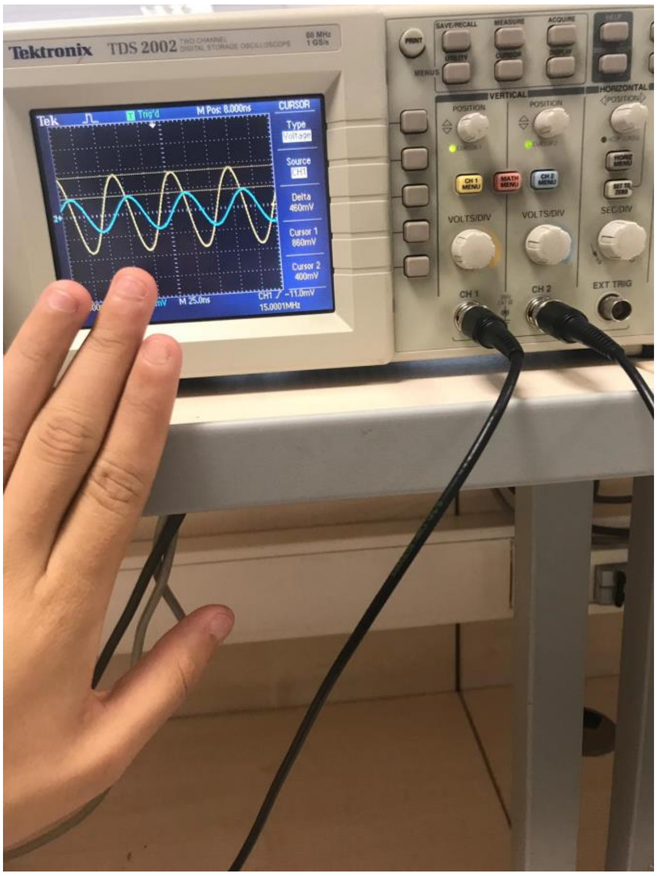


b.2 experiment set up for toroidal inductor



b.3 circuit set up for toroidal inductor

Then I used gain ratio method for the same circuit this time using peak voltage values of the signals. I turned cursor to voltage mode and noted the peak voltages.



b.4 Gain Ratio method oscilloscope result

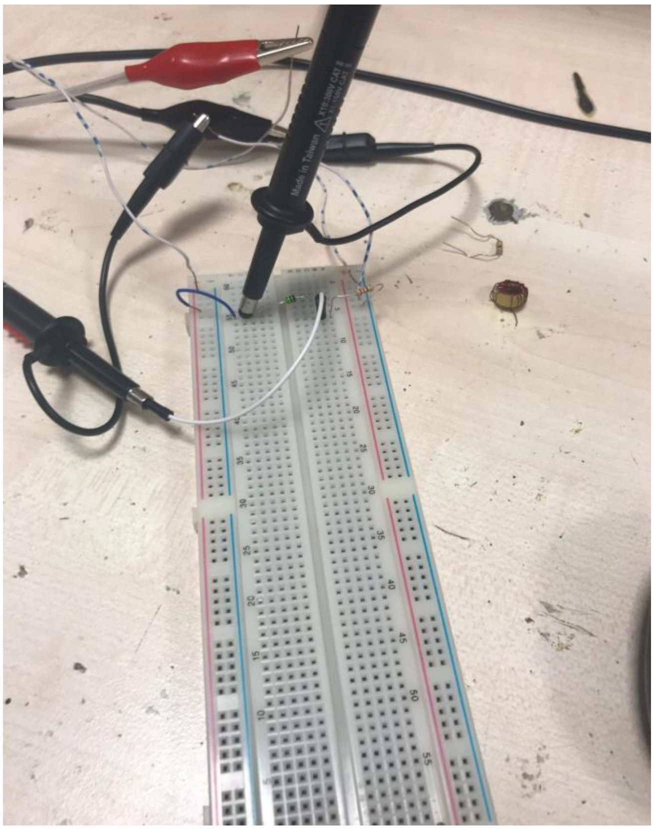
f	Vs1	Vs0	Vs2	Vs02	Rl	L	Q
1	860,2	400,1	920,8	340,4	4.2	4.6	6.87
2	900,3	364,3	912,6	322.9	3,9	5,1	16.32
3	906.4	403.2	934.6	398.4	3.2	4.9	28.8
4	922.5	320.2	930.2	560.9	3.6	4.2	29.3

Fabricated Inductor Experiment

After I was finished with the toroidal core experiment I used fabricated inductor with 10uH and it gave more reliable results compared to toroidal core inductor.

Below are given the measurements which had been taken for 10uh inductor and method 1 (phase difference) used to calculations.

f	Δt1	Δt2	Rl	L	Q
1	96.2	50.1	2.1	10.9	32.5
2	75.3	48.4	2.6	11.4	55.6
3	61.1	43.7	1.8	11.3	118.27
4	48.3	37.1	2.1	11.6	138.7



b.4 circuit setup for fabricated inductor

I used the same circuit for method2(Gain ratio method). Below are my result table for fabricated inductor circuit and gain ratio method.

f	Vs1	Vs0	Vs2	Vs02	Rl	L	Q
1	716	538	1550	1480	2.4	11.3	29.5
2	840	460	870	726	2.9	11.5	49.4
3	910	380	920	654	2.5	9.4	70.8
4	930	300	910	550	1.6	10.6	166.4

Conclusion

In this lab two methods was needed to calculate quality factor (Q) thus inductance and internal resistance needed to be find in order to calculate Q because of the Q= w*L/Rl. Gain ratio method used voltage relationship between input and output signals of the inductor. Phase difference method used time difference between the input and output signals of the inductor. Because of the variable insufficiency two resistors are used to create two equations and solve it for two unknowns. In software lab I used Ltspice and java. Ltspice is used for simulating the circuit which I have designed then java is used to make the calculations easier for both methods. In hardware lab I used breadboard , fabricated inductor with 10uh and toroidal core inductor with 4.5uh. I have used the methods with on my circuit and it was successful. Toroidal core error rate was higher I think it was because of the hand winding is not reliable compared to fabricated inductor. Lab goals which was assigned was completed.