

International Baccalaureate: Physics Extended essay

November 2017

Research Question: How does factors such as Distance between primary and secondary coil, frequency and number of turns affect the induced voltage in secondary coil.

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Word count: 3500

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Acknowledgement:

This Extended Essay would be incomplete without thanking Mr. Chirag Jhala and Mr. Sanjay Bhalara for their timely guidance.

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Abstract:

This essay mainly focuses on the phenomenon of wireless charging and tries to answer the question: "How does changing frequency, distance and number of turns affect the induced voltage in secondary coil?". The phenomenon of wireless charging is compared with the workings of a transformer because both the system works on induction.

The experiment is performed by using two different wave forms generated by an oscilloscope which have 4 different types of frequencies, 5 different measures of distances and 4 different number of turns in secondary coil. The coil is made up of 20-gauge wire, with a diameter of 5 to 6 cm. The wave type and frequency was supplied by an oscillator made up of a 555 timer chip with a variable frequency range from 100 Hz to 100 KHz and the distance was controlled by a scaled slider. The calculations showed that the efficiency of the system was about 40 to 50 %. A reason for this could be the spreading of magnetic field lines but in transformers, the magnetic field is conducted through a ferrite core that magnetizes and demagnetizes according to the wave function. Therefore, the efficiency of the transformer is up to 98 to 99 %, the remaining 1 or 2 % of its efficiency is lost in form of heat and the resistance. It could be concluded that 15 turns in secondary coil is the best optimum number of turns which can give the highest magnetic flux.

By analyzing the output wave, it is evident that the disturbance is greater when a square wave is supplied, in comparison to sine wave. The essay then concludes that in spite of disturbances in the output wave function, the square wave is proven to be the most efficient wave form.

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Research question:

1) How does the output of the secondary coil varies with distance between the coils, frequency of primary coil and number of turns in secondary coil?

Introduction and background information:

Everyday use of induction might seem very simple if translated to its meaning which says inducing current through a change in magnetic field. But the theory behind such simple term is very complex. Induction has many uses for example Detection metals, transformers which are normally used in ovens, induction heating etc. They all share a similar theory of induction. Nowadays the heat created from induction is used to melt metals as well.

A recent development in technology which uses induction as one of its main components, is wireless charging for mobile phones. This recent technology allows us to transfer power wirelessly without having multiple wires and making a mess. This simple technology has made our life simpler and comfortable. The first person to transfer power wirelessly was Nikola Tesla. He invented the transfer of power through air using coils. He dreamed about wireless lighting and wireless electric power stations.

1. Background information:

The term induction means inducing current in a coil by changing the magnetic field. The wireless charging also uses the phenomenon of change in magnetic field to induce a current in a coil. The system consists of two coils where one behaves as the power emitter known as primary coil and other behaves as the power generator known as the secondary coil. The same theory is explained by transformers. They use the change in magnetic field created by the Alternating current wave with an average frequency of 50 to 60 Hz per second, this change in magnetic field than induces a current in secondary coil.

The same phenomenon can be explained by using a coil attached with a small LED and a powerful magnet. To induce a current in the coil we just need to move the magnet into and out of the coil rapidly so that the coil induces a current. The amount of current generated is dependent on number of turns in the coil and the rate of change of magnetic field which means the speed at which the magnet is moved in and out of the coil. Therefore, we defined voltage induced as:

$$\text{Induced EMF (Electromotive force)} = -N \left[\frac{\phi}{\text{time}} \right]$$

N = number of turns in the secondary coil

ϕ = Rate of change of magnetic field

This simple expression defines Induction as a change in magnetic field over a period of time. The Equation above uses Lenz's Law and Faraday's Law to defined the induced EMF in the coil. $-N$ in the equation above shows the Lenz's law where he stated that the direction of induced EMF is such that it always opposes the cause of motion. Which further supports the claim that momentum is always conserved.

Transformer was first discovered by scientist Michael Faraday in 1831. Transformer uses a medium to transmit the change in magnetic field which is the ferrite core of the transformer. The presence of ferrite core reduces the loss of magnetic flux and therefore, gives a higher efficiency. When there is a change in polarity of the primary coil. It creates a varying magnetic field with varying magnetic directions. This changes the magnetic field and induces current in secondary coil. The diagram below shows the simple construction of transformer where the core is any ferrite core. Ferrite cores are the metals which acts as a magnet when electricity is applied and they do not form a permanent magnet when electricity is switched off. Changing frequency of primary coil also affect the output current generated in secondary coil. Number of turns, voltage and current in the system are interrelated. The equation below shows that how current, voltage and number of turns in secondary coil and primary coil are interrelated.

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

N = number of turns

V = voltage

I = Current

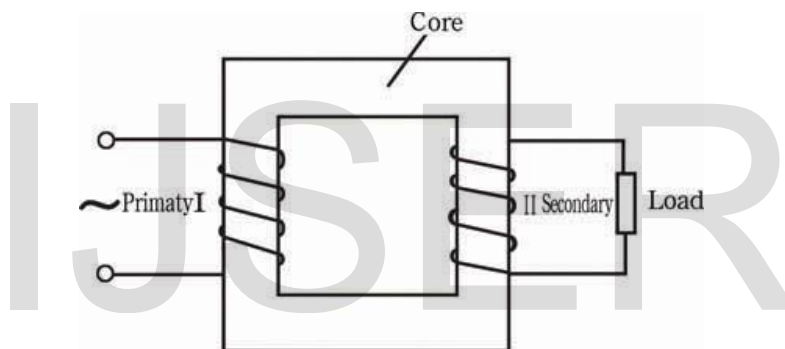


Figure 1: Shows the construction of transformers.

Wireless induction also uses the same principal as of transformer but they work without any core to transfer the magnetic field instead it uses air as a medium to change the magnetic field in secondary coil.

Sample Experiment:

The first step towards inducing current through air was initial conducted by using NPN transistor and a feedback loop. They both together creates a high frequency which will change the magnetic field at several rates inducing a current in secondary coil.

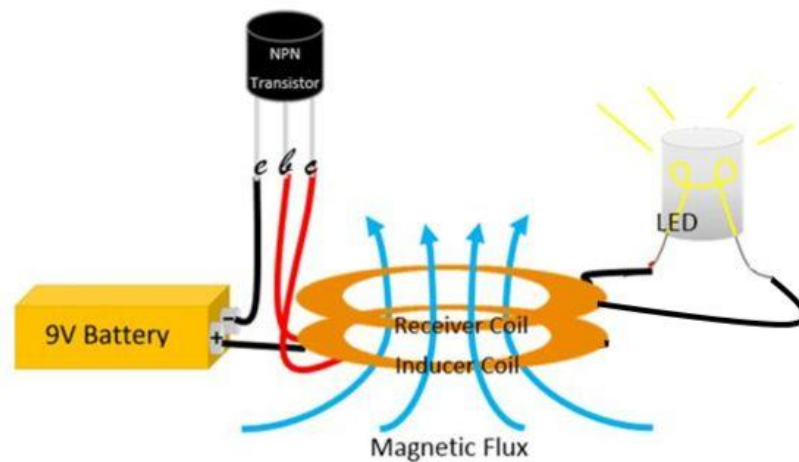


Figure 2: Circuit of simple wireless power transmission. (<https://tinyurl.com/y8oleppq>)

The diagram above is a perfect and simple construction of wireless induction system. This system uses a fixed frequency and is easy to create. The first sample coil that I made is shown below.

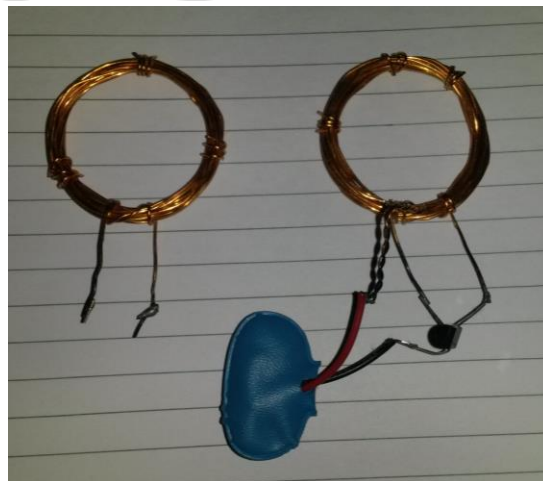


Figure 3: First system testing model.

This model made me prove the working of the system and understand the system well.

Variables:

Dependent variable:

- Voltage induced in secondary coil
- Current induced in secondary coil

Independent variable:

- Changing number of turns
- Changing distance between primary and secondary coils
- Changing the frequency of the wave form.
- Changing the type of the wave.

Controlled variable	Method of controlling	Units
Input Voltage	By using battery eliminator	Volts
Gauge of the wire	By using 20 gauge wire in the whole experiment	Gauge
Room temperature	By performing the experiment in an AC room	-

Safety instructions:

- Do not touch any electrical equipment because it contains AC to DC convertor.
- Wear plastic gloves before using any electrical equipment such as Voltage supplier etc.
- Keep your laptops and other devices away from Voltage supplier.
- Do not make a mess of wires because mess will cause a short circuit and may give you a shock or could destroy the equipment.
- Handle the electrical components such as 555 IC, Capacitor etc. First read the voltage range of these components and then only use it or else it may cause power overload which can even burn the IC or burst in case of capacitors.

Material:

Material needed for making coils:

- 20-gauge wire which is 10 meters in length.
- A pipe with 5 to 6 cm diameter
- Tape
- Wire cutter

Material needed for making coil holder:

- 1 large compressed foam sheet
- Hot glue gun to stick the parts
- A cutter
- Tape
- Ruler

Materials needed to make oscillator:

- 555 timer chip
- 1 M Ohms potentiometer (Depends on the range of frequency you want)
- 0.01 microfarad capacitor (× 2)
- 1 k Ohms resistor
- Bread board for making circuit
- Few jumper wires

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Method:

Schematic diagram of 555 timer variable oscillator:

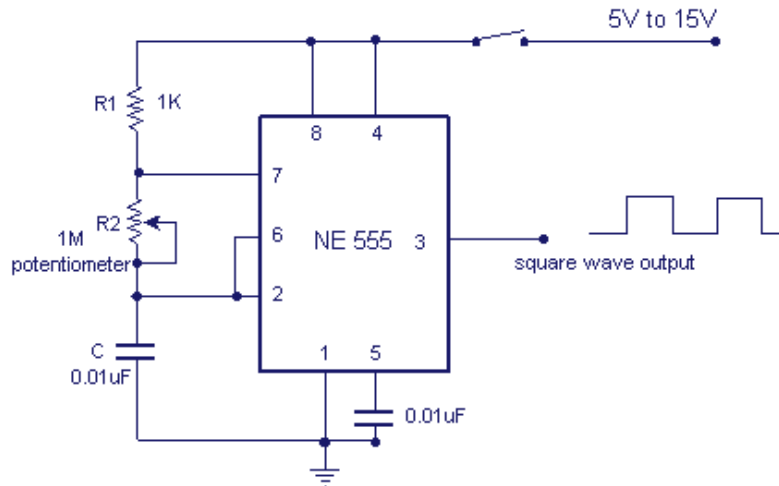


Figure 4: Schematic of 555 timer

The above diagram shows a schematic diagram of a 555 timer oscillator circuit gives variable frequency square wave as its output. The circuit uses the chip 555 as its core and 1 Million Ohms potentiometer as its variable transistor to create variable frequencies of square wave. The circuit above uses 5 to 6 volt input.

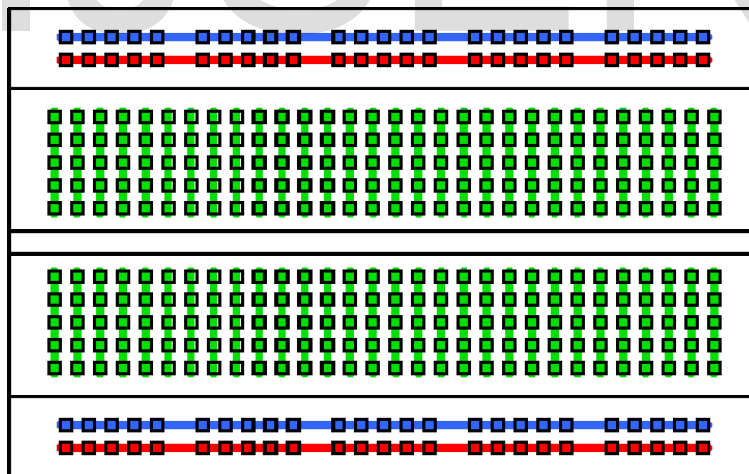


Figure 5: Channels of breadboard (<https://i.stack.imgur.com/mgQVL.png>)

The diagram above shows the arrangement of channels in breadboards and how the holes in the breadboard are connected internally. The red and blue lines indicate the power channel and the green line indicate the component channel where the components are to be placed. First make the circuit shown in Figure 2 in breadboard which will reduce the time and error in making such complicated circuits. The image below shows the same circuit as we saw in figure 2 but this shows the arrangement of components on breadboard.

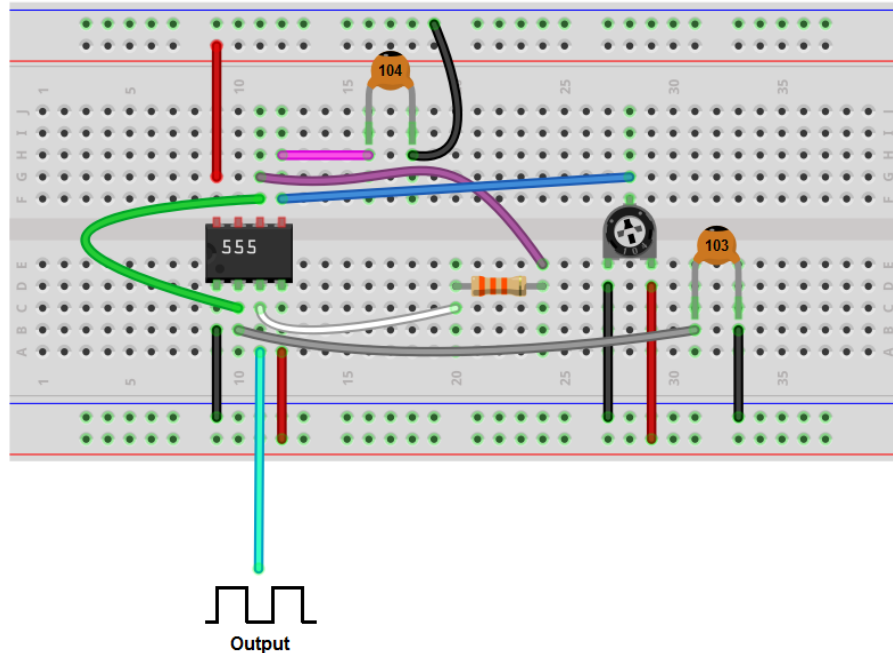


Figure 6: Schematic diagram on breadboard

Making coil:

- Take 5 to 6 cm Thick cylinder and attach one end copper wire to the cylinder with a tape.
- Than start winding the coil and count till 20.
- Make 4 different coils with 4 different turn. 20, 15, 10, 5 are the four different number of turns.
- Than use the tape and bind the coil so that all the turns are compressed together as shown in diagram below. Try to apply as less tape as possible because more tape might lead to change in permittivity.



Figure 7: shows the structure of coil and tapes used to make the coil

- Try not to destroy the shape of the coil because change in shape would lead to change in area of the coil which will further lead to errors in finding the Magnetic flux.

Method for making coil holder.

- Cut two squares from the sheet. Width of the squares should be slightly more than the diameter of the coil.
- Cut small triangles for using like rigid hinges.
- And stick the two squares in 90-degree angle with hot glue gun.
- And stick the small triangles as shown in diagram below.

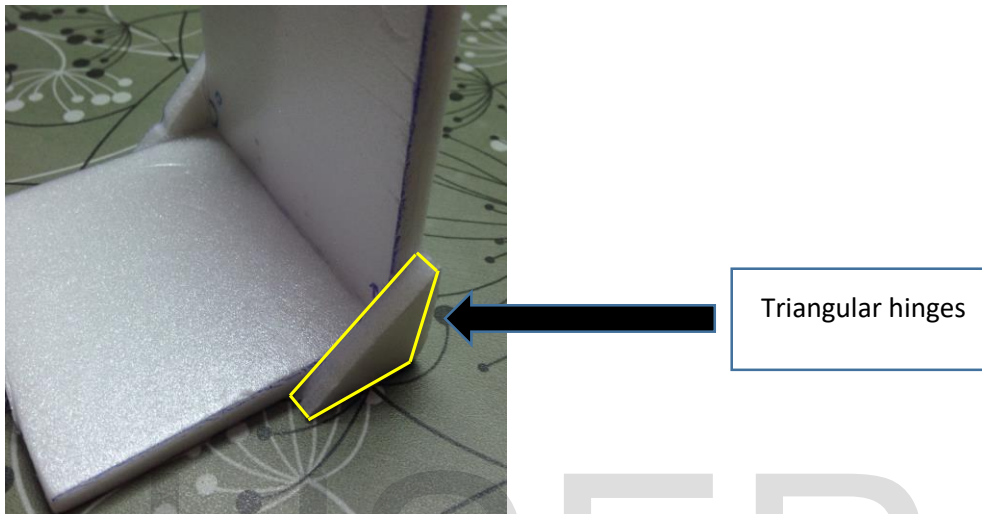


Figure 8: Shows how to attach the triangle hinge to the coil holder.

- Make sure to keep the angle as near to 90 degrees because this will reduce the movement of the two coils and help us take perfect readings.
- Repeat the following steps twice to create two holders one for primary coil and other for secondary coil.

Method for performing the experiment:

- Gather all the equipment. Place the coil in the coil holder as shown in the image below.

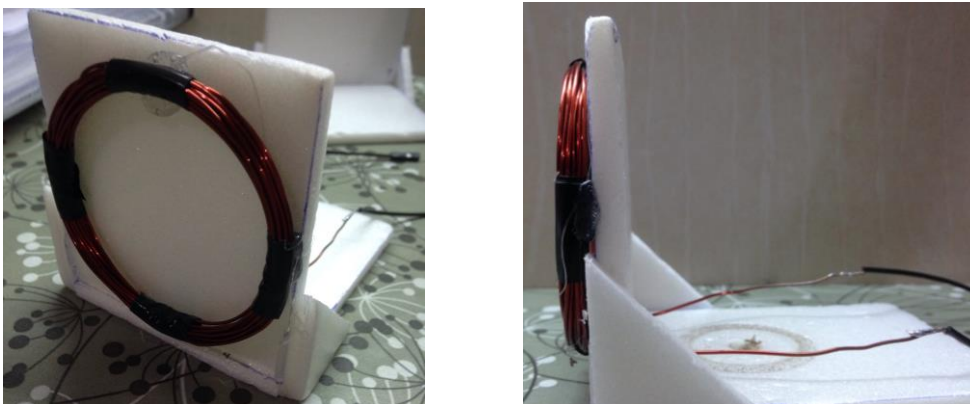


Figure 9: Coil and coil holder

- Now take a ruler and place each other at the distance 0 cm or can be use the scaled sliders shown in figure 8. Connect one coil to the oscillator and other to the oscilloscope. Set the oscillator to 110.0 KHz and record the reading. Change the distance between the coils and records the readings for multiple distances.
- Make sure that the wire is well insulated while measuring at 0 cm. If not so than the coils may shot each other and it may destroy your readings.
- Try to isolate the system from any magnetic or electrical interference for measuring perfect readings.
- I have used Hantek digital USB Oscilloscope for measuring the output. Try and use oscilloscope with higher resolution which will allow you to have more precise readings.



Figure 10: shows the scaled sliders for coil holders.

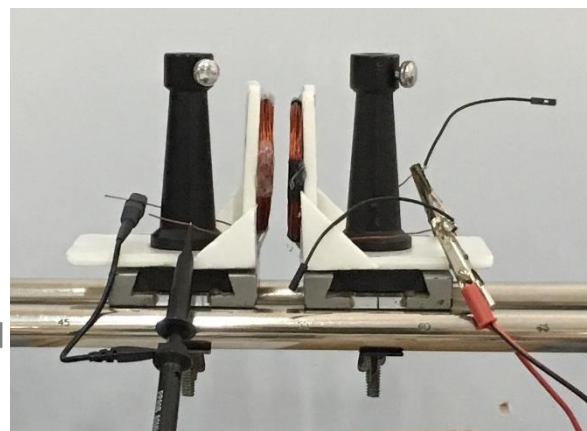
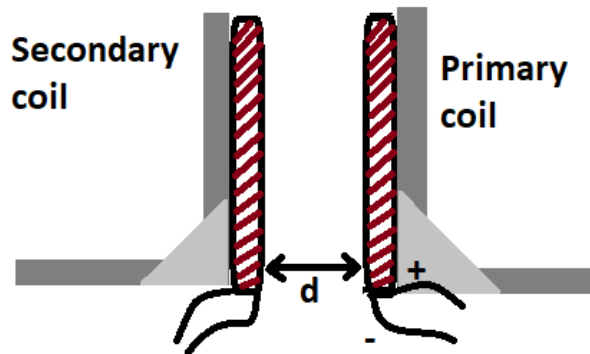


Figure 11: shows the construction of the setup and the distance between the two coils

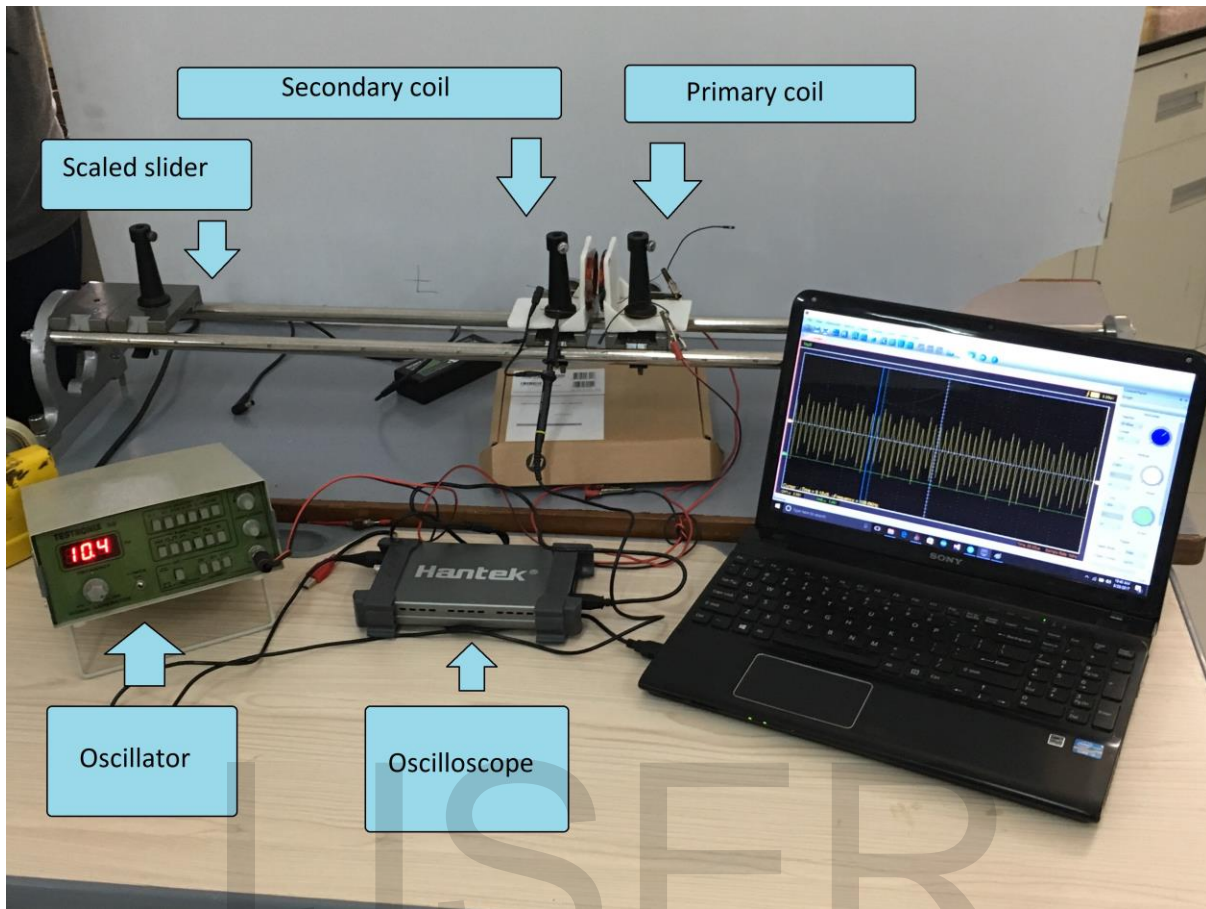


Figure 12: Experimental setup

Calculations:

$$\phi(\text{Magnetic flux}) = B(\text{Magnetic field}) \times A(\text{Area}) \dots\dots\dots [\text{Equation 1}]$$

Equation 1 shows the amount of magnetic field passing through a particular area.

$$\text{Turn density} = \frac{N(\text{Number of turns})}{\text{Length of coil}} \dots\dots\dots [\text{Equation 2}]$$

Equation 2 shows the number of turns per volume.

$$B(\text{Magnetic field}) = \mu_0 \times \text{Turn density} \times \text{Current} \dots\dots\dots [\text{Equation 3}]$$

Equation 3 shows the strength of magnetic field.

$$\text{Efficiency \%} = \frac{\text{Useful output voltage}}{\text{Total input voltage}} \times 100 \dots\dots\dots [\text{Equation 4}]$$

Equation 4 Efficiency of the system.

$$\text{Voltage} = \text{current}(I) \times \text{Resistance}(R) \dots\dots\dots [\text{Equation 5}]$$

Equation 5 Voltage and current relationship.

$$\text{Uncertainty in magnetic flux} = \sqrt{\left[\frac{U_{\text{voltage}}}{\text{Voltage output}}\right]^2 + \left[\frac{U_{\text{Resistance}}}{\text{Resistance}}\right]^2 + \left[\frac{U_{\text{Area}}}{\text{Area}}\right]^2} \dots\dots [\text{Equation 6}]$$

Equation 6 Percentage Uncertainty in magnetic flux.

Sample Calculation:

Input Voltage	6.50 V
Output Voltage (Square wave)	2.60 V
Frequency	110.9 KHz
Current in secondary coil	1.86 amps
Number of turns in Secondary coil	20 turns
Distance	0 cm
Resistance	1.4 Ohms

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \dots\dots\dots [\text{Equation 5}]$$

$$\text{Current} = \frac{2.6}{1.4}$$

$$\text{Current} = 1.86 \text{ amps}$$

$$\text{Turn density} = \frac{20}{0.5 \text{ cm}} \dots\dots\dots [\text{Equation 2}]$$

$$B = 4\pi \times 10^{-7} \times (40 \text{ turn}) \times (1.86 \text{ amps}) \dots\dots\dots [\text{Equation 3}]$$

$$B(\text{Magnetic field}) = 9.3 \times 10^{-5}$$

$$\Phi = (9.3 \times 10^{-5}) \times 95.0$$

$$\Phi(\text{Magnetic flux}) = 0.0088$$

$$\text{Efficiency \%} = \frac{2.6 (\text{Output voltage})}{6.5 (\text{Input voltage})} \times 100$$

$$\text{Efficiency \%} = 40 \%$$

$$\text{Percentage Uncertainty in Magnetic flux} = \sqrt{\left[\frac{0.01 \text{ v}}{2.60 \text{ v}}\right]^2 + \left[\frac{0.1 \text{ Ohms}}{1.4 \text{ Ohms}}\right]^2 + \left[\frac{0.1}{95.0}\right]^2}$$

$$\text{Uncertainty} = \sqrt{[1.48 \times 10^{-5}] + [5.1 \times 10^{-3}] + [1.1 \times 10^{-6}]} \times 100$$

$$\text{Uncertainty percentage} = 7.15 \%$$

(Sine wave):

Calculations of Distance Vs voltage:

Distance (Cm)	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
0.0	1.02	5.13×10^{-5}	4.8×10^{-3}	22.0 %	7.17 %
0.5	0.74	3.72×10^{-5}	3.5×10^{-3}	16.0 %	7.20 %
1.0	0.54	2.71×10^{-5}	2.6×10^{-3}	12.0 %	7.14 %
1.5	0.42	2.11×10^{-5}	2.1×10^{-3}	9.0 %	7.14 %
2.0	0.32	1.61×10^{-5}	1.5×10^{-3}	7.0 %	7.14 %

Calculations of Frequency Vs voltage (Sine wave):

Frequency	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
110.9 KHz	1.06	5.33×10^{-5}	5.1×10^{-3}	23.0 %	7.17 %
10.4 KHz	0.14	7.04×10^{-6}	6.7×10^{-4}	3.0 %	7.16 %
1 KHz	0.03	1.51×10^{-6}	1.4×10^{-4}	0.6 %	7.54 %
100 Hz	0.026	1.31×10^{-6}	1.3×10^{-4}	0.5 %	7.66 %

Calculations of Number of turns Vs voltage (Sine wave):

Number of turns	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
20	1.064	5.35×10^{-5}	5.08×10^{-3}	23.0 %	7.17 %
15	0.96	6.03×10^{-5}	5.73×10^{-3}	20.0 %	7.18 %
10	0.612	3.85×10^{-5}	3.65×10^{-3}	12.0 %	7.14 %
5	0.38	2.38×10^{-5}	2.27×10^{-3}	7.0 %	7.15 %

(Square wave):

Calculations of Distance Vs voltage (Square wave):

Distance (Cm)	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
0.0	1.86	9.3×10^{-5}	2.63×10^{-3}	40.0 %	7.15 %
0.5	1.32	6.6×10^{-5}	1.88×10^{-3}	28.3 %	7.16 %
1.0	0.95	4.8×10^{-5}	1.35×10^{-3}	20.3 %	7.18 %
1.5	0.69	3.5×10^{-5}	9.81×10^{-4}	14.8 %	7.14 %
2.0	0.32	1.6×10^{-5}	4.55×10^{-4}	11.4 %	7.14 %

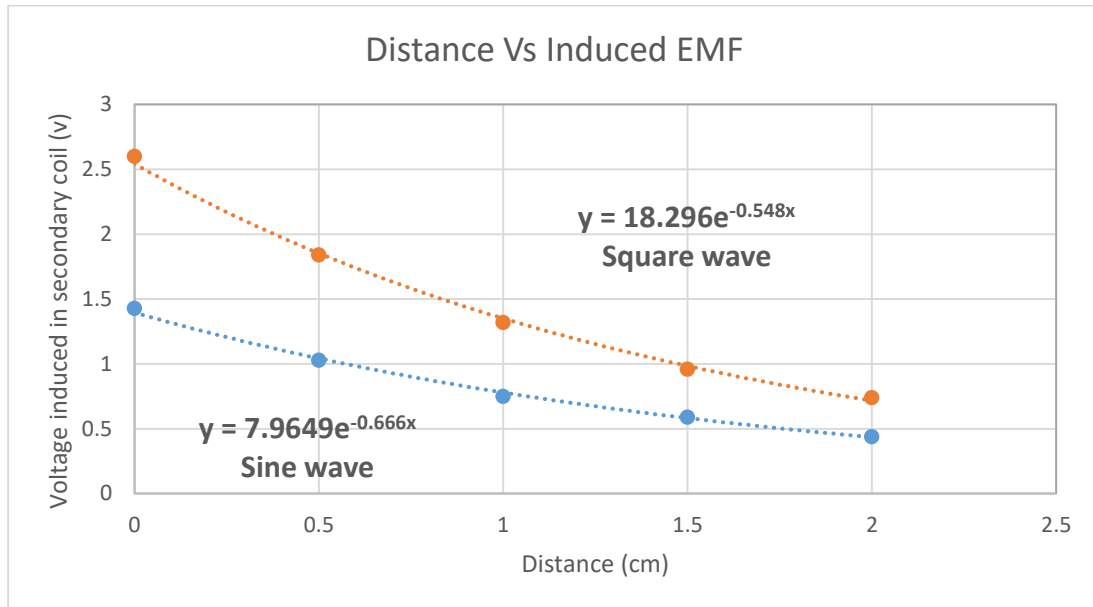
Calculations of Frequency Vs voltage (Square wave):

Frequency	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
110.9 KHz	1.85	9.3×10^{-5}	2.63×10^{-3}	40.0 %	7.15 %
10.4 KHz	0.57	2.9×10^{-5}	8.10×10^{-4}	12.3 %	7.14 %
1 KHz	0.18	9.0×10^{-6}	2.56×10^{-4}	3.9 %	7.15 %
100 Hz	0.063	3.2×10^{-6}	8.95×10^{-5}	1.35 %	7.23 %

Calculations of Number of turns Vs voltage (Square wave):

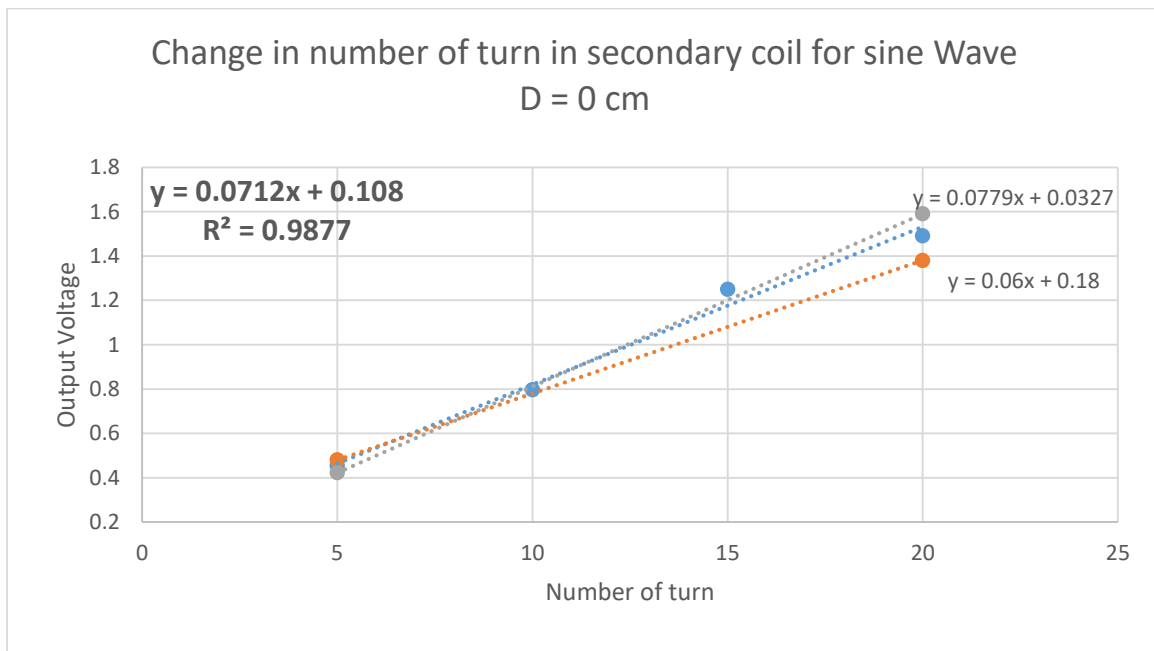
Number of turns	Current (amps)	Magnetic field (tesla)	Magnetic flux (tesla/cm ²)	Efficiency %	% Uncertainty
20	1.85	9.30×10^{-5}	8.83×10^{-3}	40.0 %	7.15 %
15	1.7	1.07×10^{-4}	1.01×10^{-2}	34.0 %	7.15 %
10	1.06	6.66×10^{-5}	6.33×10^{-3}	21.2 %	7.18 %
5	0.67	4.21×10^{-5}	4.00×10^{-3}	12.3 %	7.14 %

Data processing:



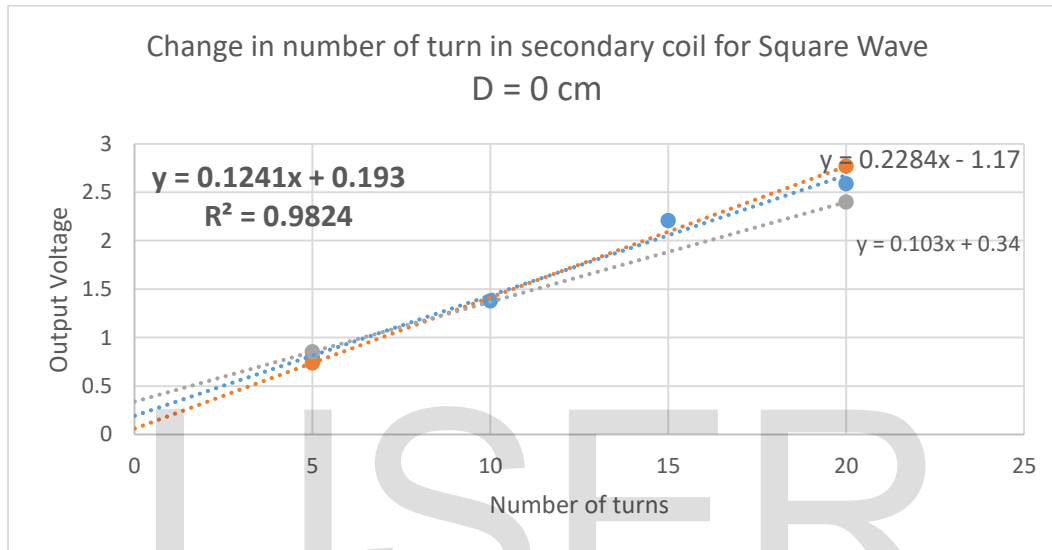
Graph 1: Relation between distance and Induced EMF

The graph above shows an exponential decay of Voltage when distance increases. It shows that voltage will never become zero because theoretically magnetic field lines stretch infinitely. The blue graph represents the voltage drop while using a sine wave, and the orange graph shows the voltage drop while using a square wave. The graph also shows that a square wave is more efficient because its graph (orange line) is higher than the sine wave's (blue line) while the input voltage was the same.



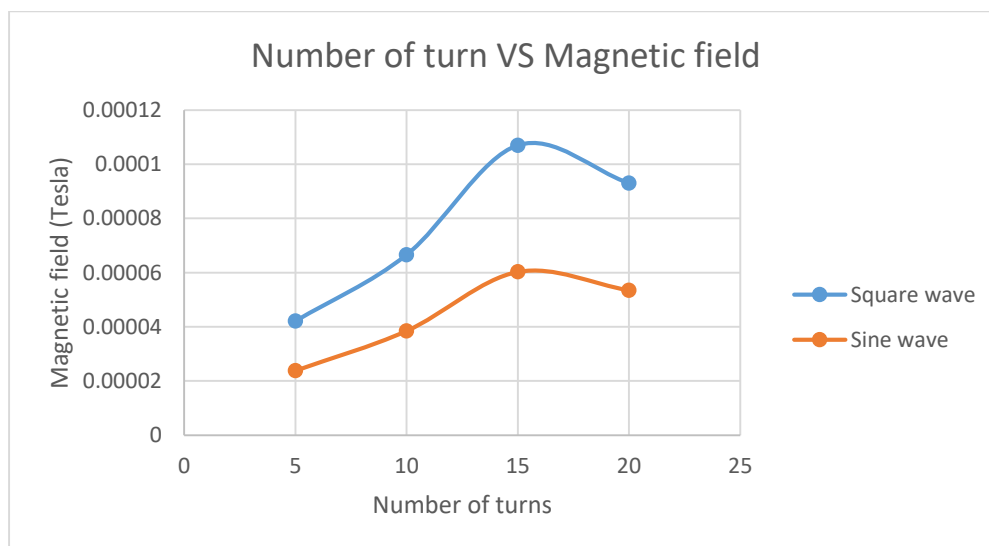
Graph 2: Relation between number of turn in secondary coil and Voltage of sine wave

The above graphs show the relation between voltage and number of turns in secondary coil while using Sine wave as the input wave form. Here the Blue line indicated the distance 0 between primary and secondary coil and the orange line indicates the distance to be 1 cm. Two different distances were taken to prove the reliability of the data. The graph shows that the value of R^2 of blue line is nearly same as of orange line. Both have the R^2 value near to 0.97 which shows the reliability of the equation related to the data. The graph related that as the number of turns are being increased we are able to see an increase in voltage induced.



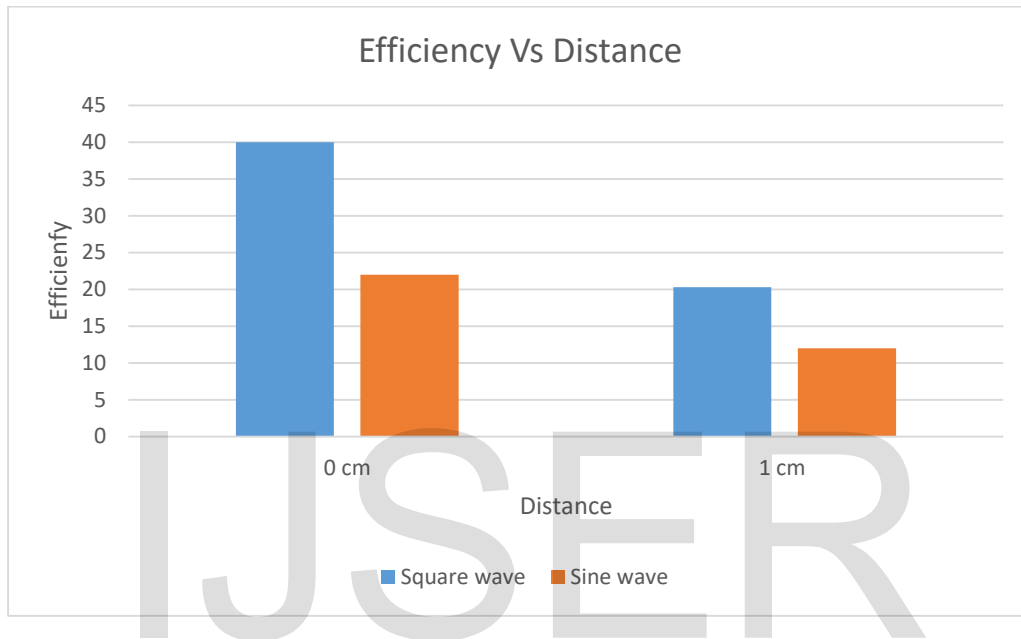
Graph 3: Relation between number of turn in secondary coil and Voltage of square wave

The graph above shows the same relation as we saw in graph 2 and here we can conclude that the reliability of data which is the value of R^2 which is near to the value 0.98. In the graph above we can notice that the relation between number of turns and voltage is linear and it always have a positive slope.



Graph 4: Relation between number of turn and magnetic field in secondary coil.

The graph explains that as the number of turns in secondary coil was increased there was an increase in magnetic field created by the secondary coil. But the increase is not linear by the bump at number of turns equals 15 we can conclude that 15 turns can be the maximum efficient combination because the showed that at 15 turns there was the maximum magnetic field created by the secondary coil due to its induced EMF. The orange graph represents the sine wave as an input function and the blue one represents the square wave as an input function. Both the waves in spite of the strength of the magnetic field shows the clear sudden increase in magnetic field at 15 turns. This shows that 20 turns in primary coil and 15 turns in secondary coil can become a best combination.



Graph 5: Relation between Efficiency and the type of waves.

The graph shows a clear representation of decrease in efficiency as the distance increase but the graph also shows that Square wave is proved as more efficient wave that can be used in wireless induction. The graph shows that at distance equals 0 the efficiency due to square wave is about 40 % but at the same time the efficiency due to sine wave is around 22 %. And when the distance is increased to 1 cm both have a decrease in efficiency but still at 1 cm square wave is proved to be more efficient than sine wave because of shape change in voltage.

Analysis of output wave:

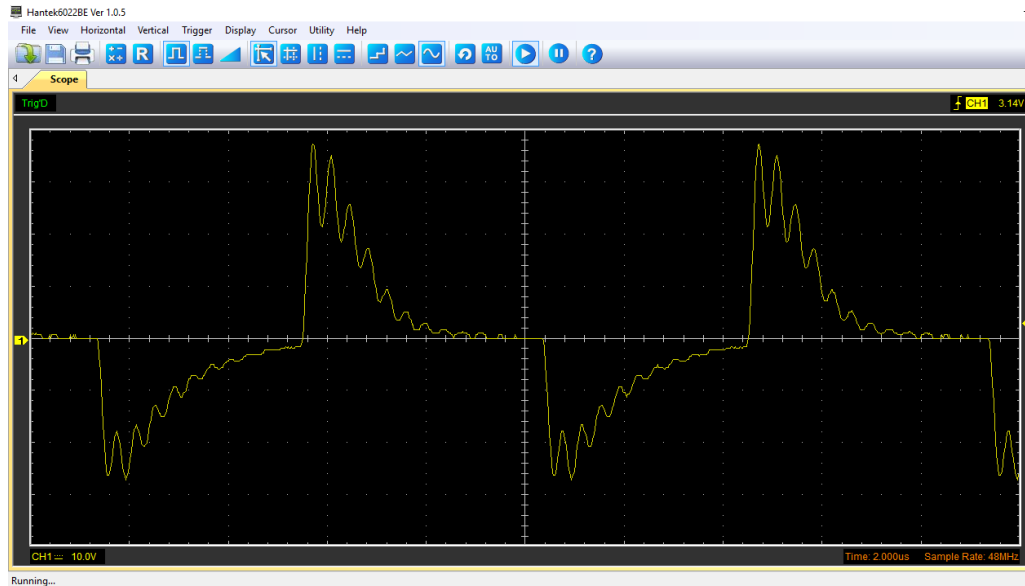


Figure 13: Output wave in secondary coil. Input wave was square wave

The image above shows the output wave form in secondary coil while input wave was square wave. We can see a disturbance in the output wave form. This might be because of self-induction but I was not able to prove the effect because the image below shows the output signal when sine wave was the wave form. We are not able to see the disturbed effect in the output wave. If taken the average than the wave form shown below can be taken as similar wave to the input wave but this is not the case in the wave form in the above image.

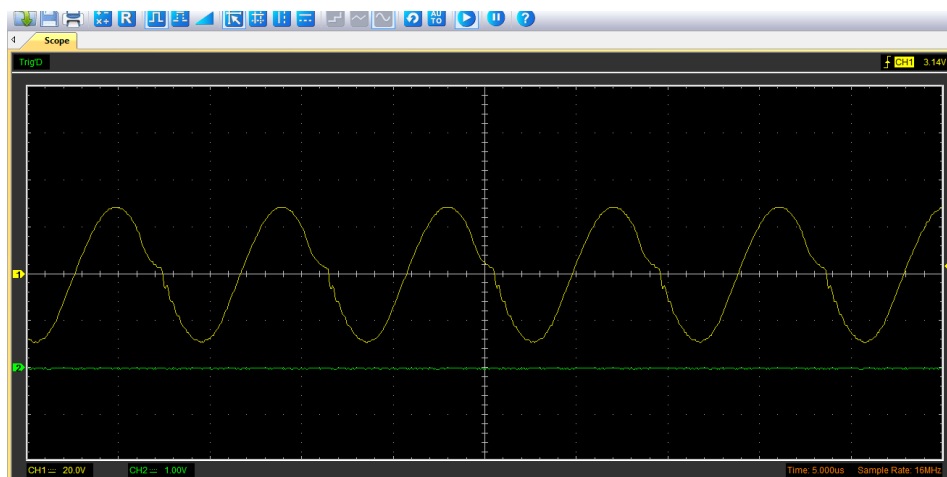


Figure 14: Output wave in secondary coil. Input wave was sine wave

When sine wave was applied and the output wave was also sine wave. But sine wave overall reduces the voltage induced in secondary coil. Due to its analogue property of the sine wave which does not create a sharp change in magnetic field therefore, reduces the rate of change of magnetic field inducing less output voltage.

Error analysis:

Random Error	Method of correction
Taking readings in an interval of two days will cause a temperature difference that can cause anomalous results	Avoid multiple day readings. Perform the experiment in one stretch
The diameter of every turn could differ from each other and this may cause error in calculating magnetic flux	Try to make the length of each turn equal by avoiding overlapping of turns.

Systematic Error	Method of correction
The amount of tape used in making coil changes the permeability of the coil	Prevent usage of excess tapes in making coil
Placement of the coils.	By making a coil holder

One of the main errors that can affect the readings is the error in Oscilloscope. Less tape should be used while making the coils as plastic has a higher permeability than air therefore, the amount of magnetic field induced in secondary coil may vary. To reduce the error one should use same amount of tapes in each of the coils. This will ensure that the permeability is constant. Another error that can affect the readings is the placement of the coils. If the coils are not facing exactly parallel to each other then it may change the rate of change of magnetic field which in turn will change the output in secondary coil. Slight change in the placement can change the readings up to several millivolts.

Conclusion:

As per the data examined we can conclude that distance and number of turns do affect the output in the secondary coil. I learned that using square waves, as an input waveform, can give higher efficiency to the system than sine wave. It was proved by comparing the output of both the waves. Square waves are more efficient because they cause a sudden change in voltage. This creates a sharp change in magnetic field which induces a large amount of voltage than sine waves. Sine waves are analog waves because they don't produce a sharp change in voltage. This sharp change in square wave increased the efficiency of the system up to 40 to 50 %.

The experiment also showed that using lower frequencies could also reduce the efficiency tremendously because there was a vast difference noticed between 100 KHz and 10 KHz. The efficiency reduced from 40 % to 12 % in reducing the frequency. The second variable - distance, showed us a decreasing relationship between distance and voltage induced. The function of the graph can be proved by the theory of magnetic field which says that a magnetic field can stretch infinitely long. However, increasing the distance will decrease the strength of the magnetic field. The same principle is seen in the results. Increasing the distance decreases the voltage induced. The number of turns also affected the induced voltage but in a wired manner. The results show that when using 15 number of turns the coil is experiencing more magnetic flux this could be either the error in constructing coil or error in measuring the output of the secondary coil.

Therefore, we can conclude that changing distance between the coils, changing frequency of input wave in the primary coil or changing number of turns in the secondary coil produces a change in the voltage measured in the secondary coil. By using a higher frequency of the input wave increases the induced voltage. This can also be done by increasing the number of turns or the distance between the coils.

Further extension:

To further extend this topic into deep research, the experiment can be conducted by using different gauge wires. This will also change the output voltage because magnetic field strength depends on current so if the resistance increases with increasing in gauge than current has to decrease to fulfil the equation $V = IR$. Therefore, gauge can be one of the factor that can affect the output voltage. Second extension could be of using three coils and check the output in each coils. we know by analyzing the graph of square wave which was distorted in secondary coil, that the secondary coil was also self-inducing. Thus the third coil is also the same effect. We can also keep multiple coils in a line and measure the voltage induced in each coil, by this experiment we would able to know the efficiency of the system and this would show that how effectively the power can be transmitted over a long distance. Number of coils experiencing the electromagnetic induction will show the distance between first (primary coil) and the last coil.

Personal connection:

I conducted this experiment because I was curious to know how the phenomenon of wireless charging worked. I had learned the working of a transformer in the 10th grade. I wanted to compare the working of a transformer and the working of a wireless charger. This was very different experiment compared to transformer experiment that we had experimented earlier. Air has a greater permeability than the ferrite core that is used in making transformer therefore the efficiency of the system that I assumed was correct. A greater permeability number will result in a bad conduction of the magnetic field. I assumed that this system will be less efficient because as air has permeability of 1, the magnetic field will be able to pass through one point to the other. In this experiment I learned how to use an oscilloscope and what other factors affect the output voltage. I used my skills in designing to design a model of my experiment. I used math and construction physics to construct a holder which is stable and strong. Which can hold the coil to nearly perfect to 90 degrees. This allowed me to take perfect readings and setup the experiment easily and also reduced the error in taking readings.

Sources:

- <https://tinyurl.com/ydbhztov>
- https://www.circuitspecialists.com/content/92615/Hantek6022be_Manual.pdf
- Simple Wireless Power CollinCoil1 –Instructables <http://www.instructables.com/id/Simple-Wireless-Power/>
- “Pardon Our Interruption.” *Pardon Our Interruption*, www.electronics-tutorials.ws/waveforms/555_oscillator.html. Accessed 19 Aug. 2017.
- Tsokos, K. A. *Physics for the IB Diploma*: Cambridge, Cambridge University Press, 2009. equations 1 to 6

Appendix 1:

Constants for table1:

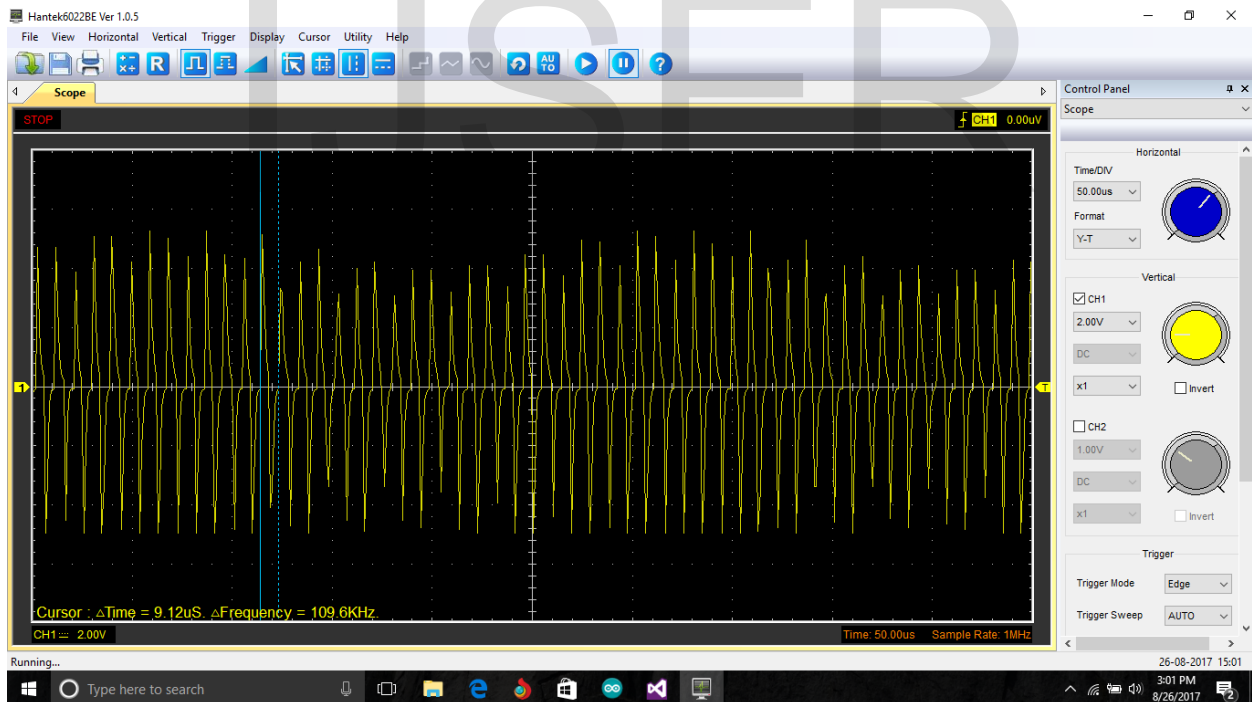
Input voltage	Number of turns in secondary coil	Frequency	Resistance
6.5 v	20	110.9 KHz	1.4 Ohms

Output voltage for Sine wave (V)	Output voltage for Square wave (V)	Distance (cm)
1.43	2.60	0
1.03	1.84	0.5
0.75	1.32	1.0
0.59	0.96	1.5
0.44	0.74	2.0

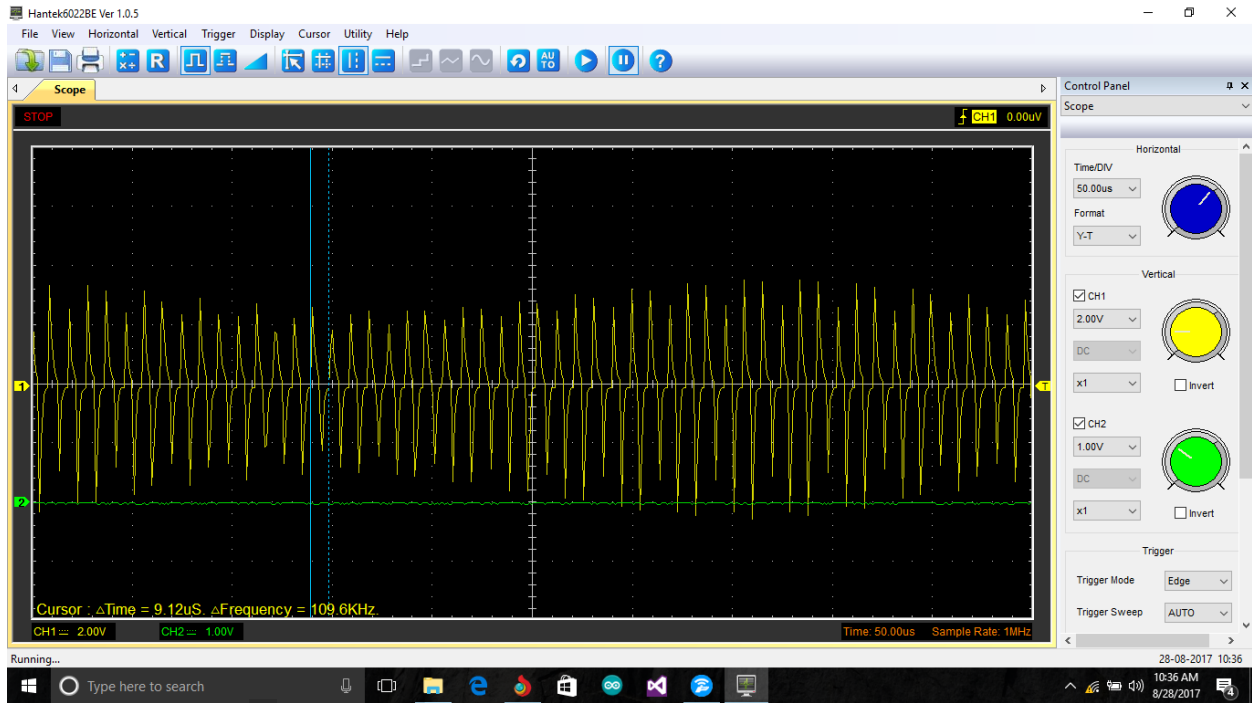
Data Table 1: Relation between Distance and Output voltage

Square wave

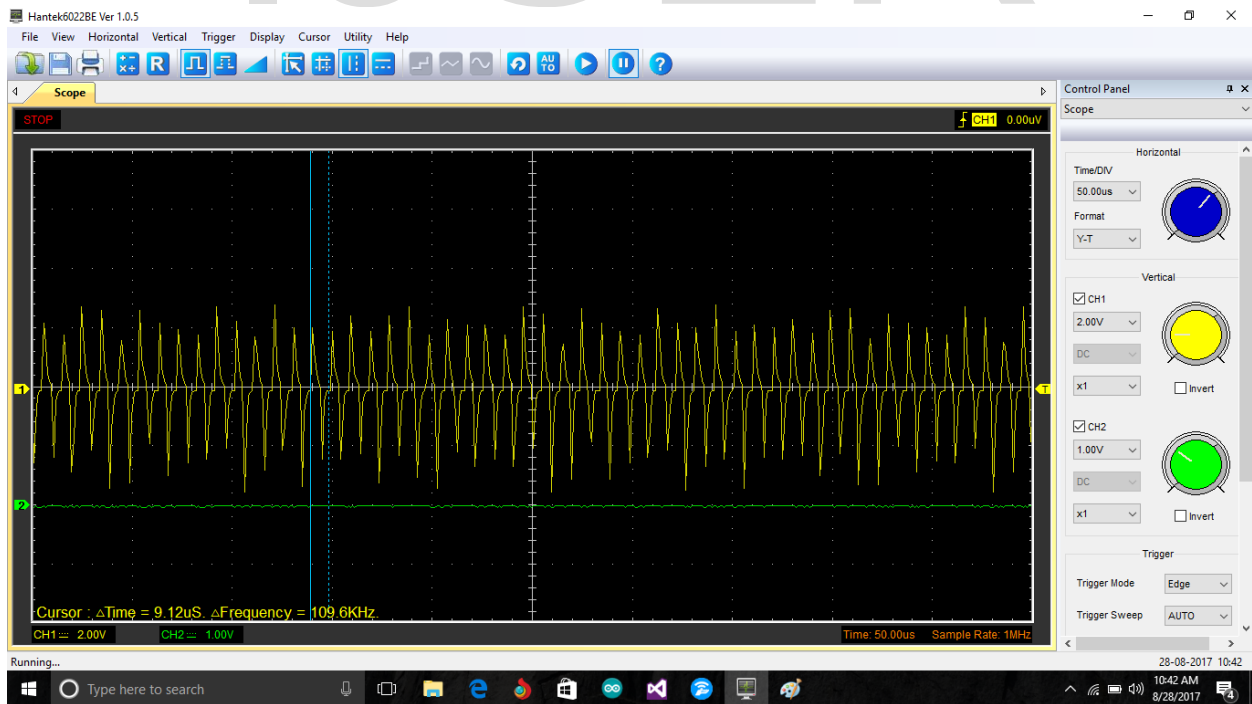
0 Cm 109 KHz 20 turns



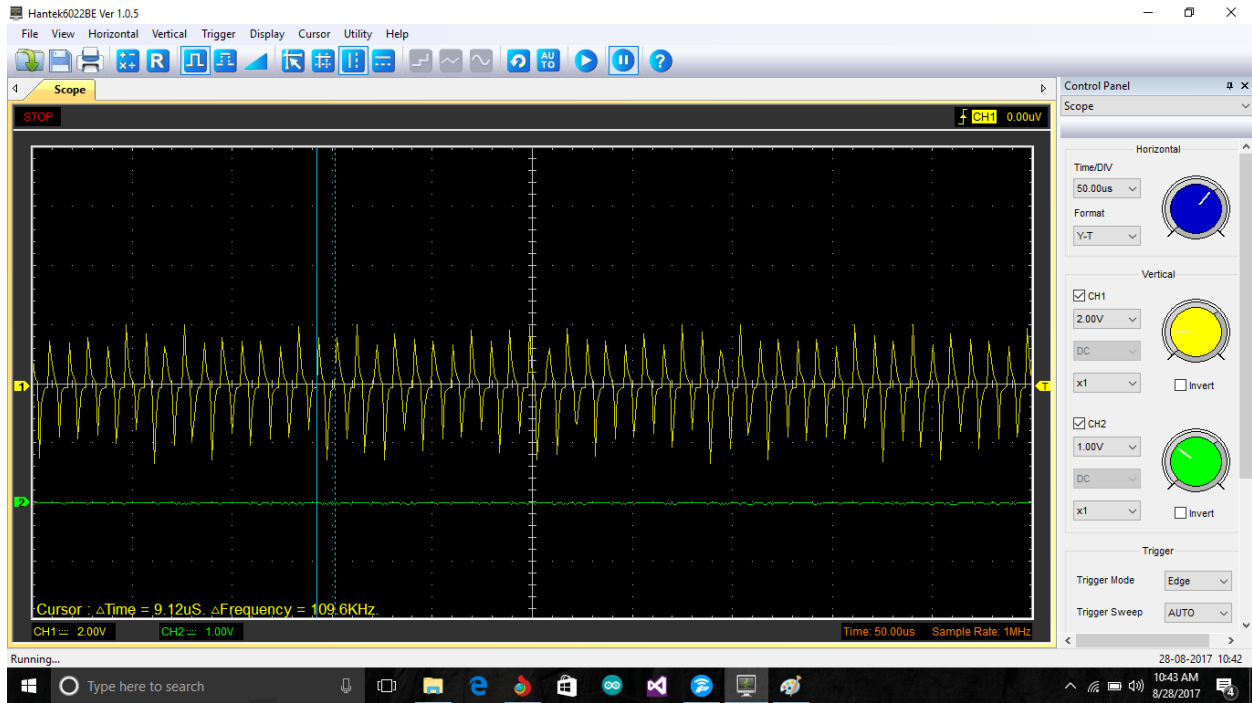
0.5 Cm 109 KHz 20 turns



1 Cm 109 KHz 20 turns

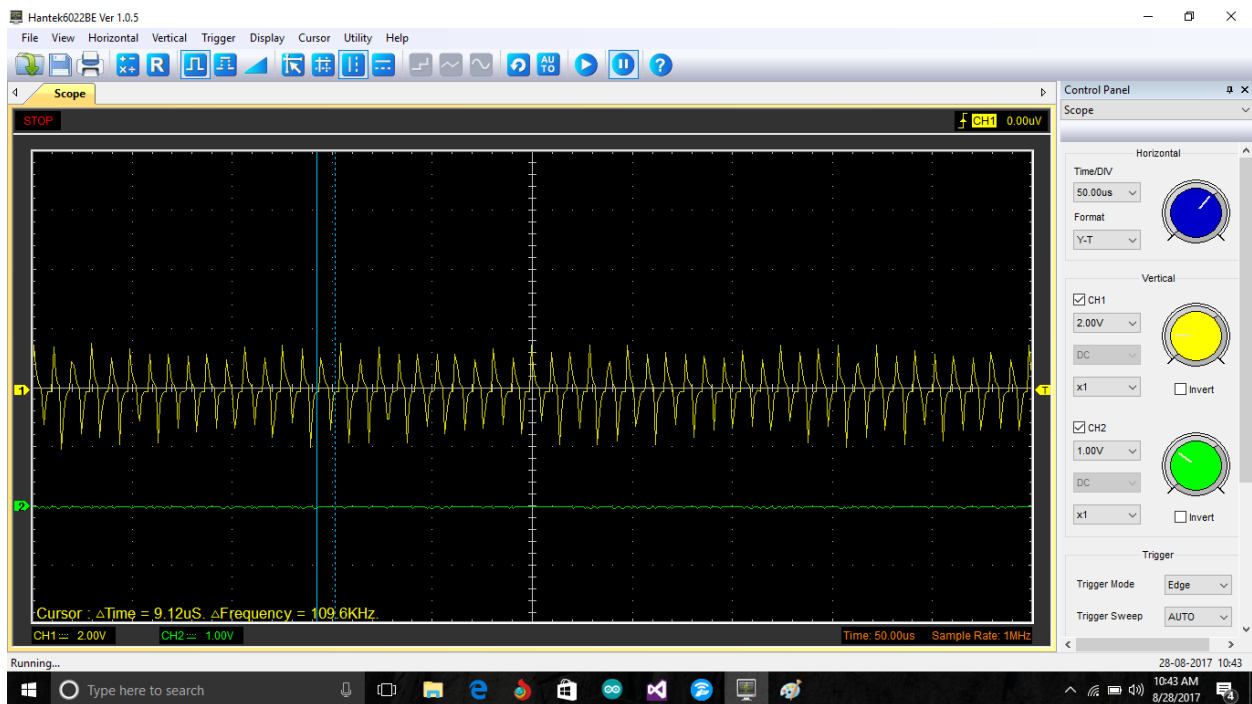


1.5 Cm 109 KHz 20 turns



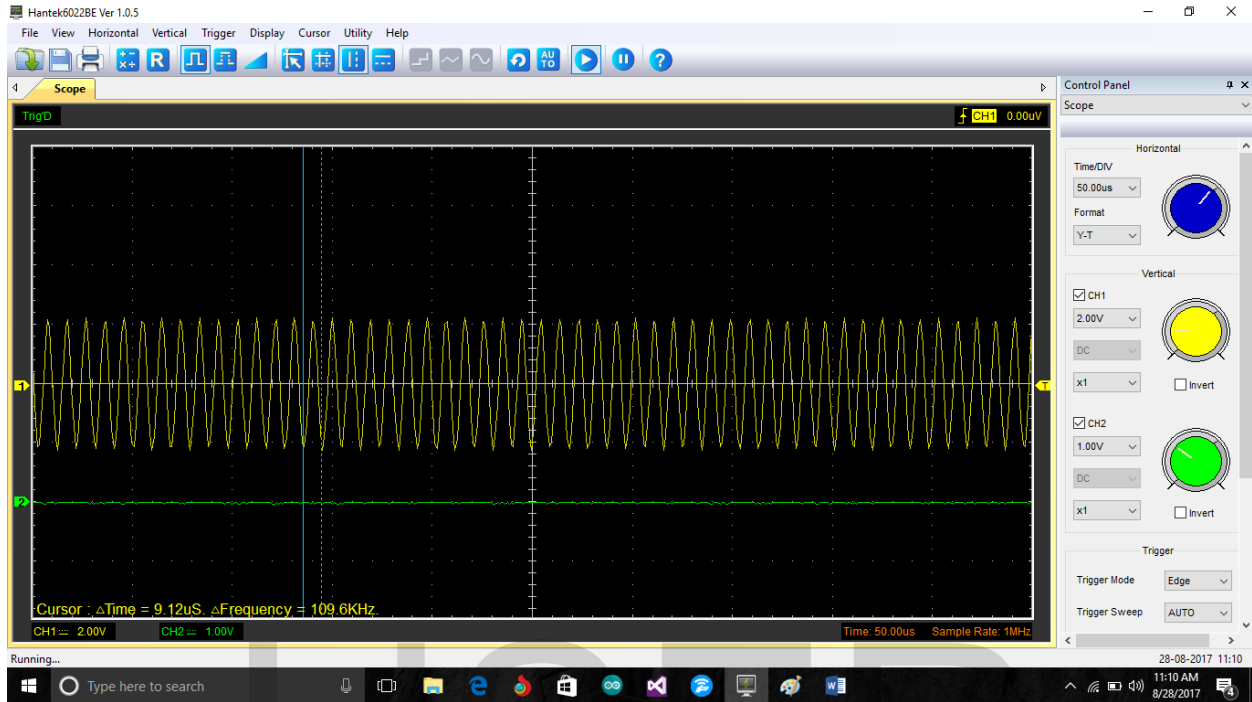
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2 Cm 109 KHz 20 turns

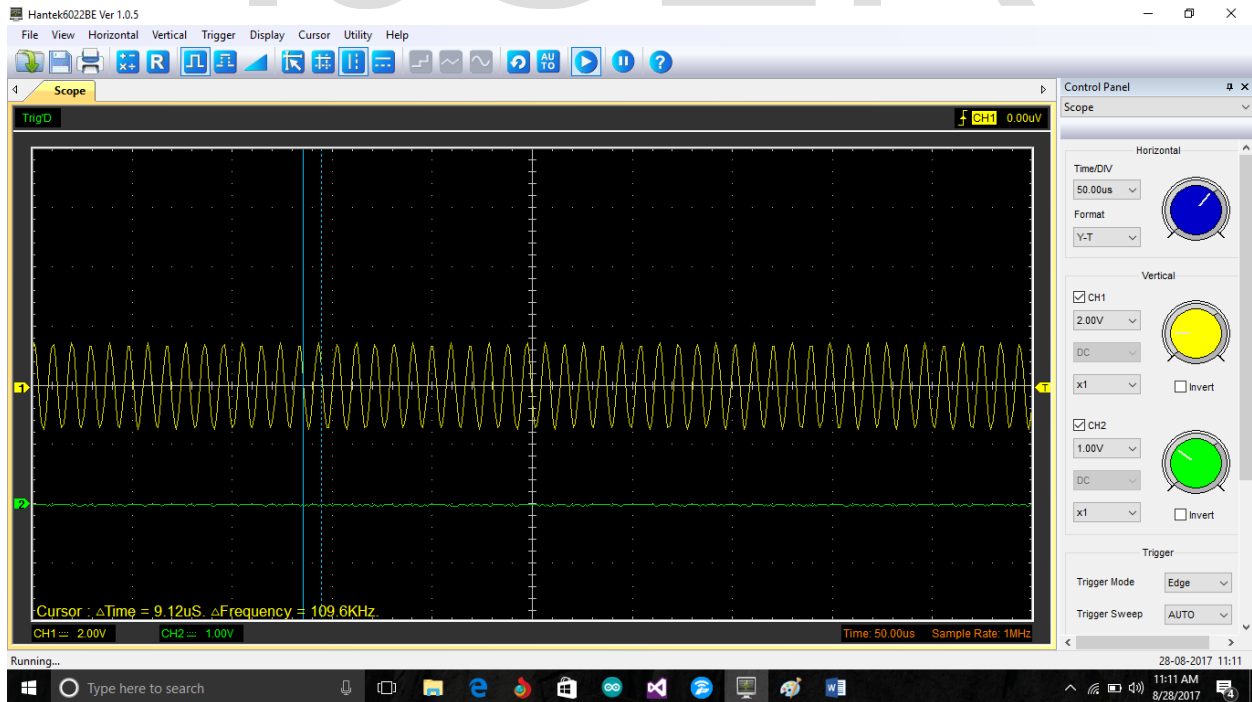


Sine wave

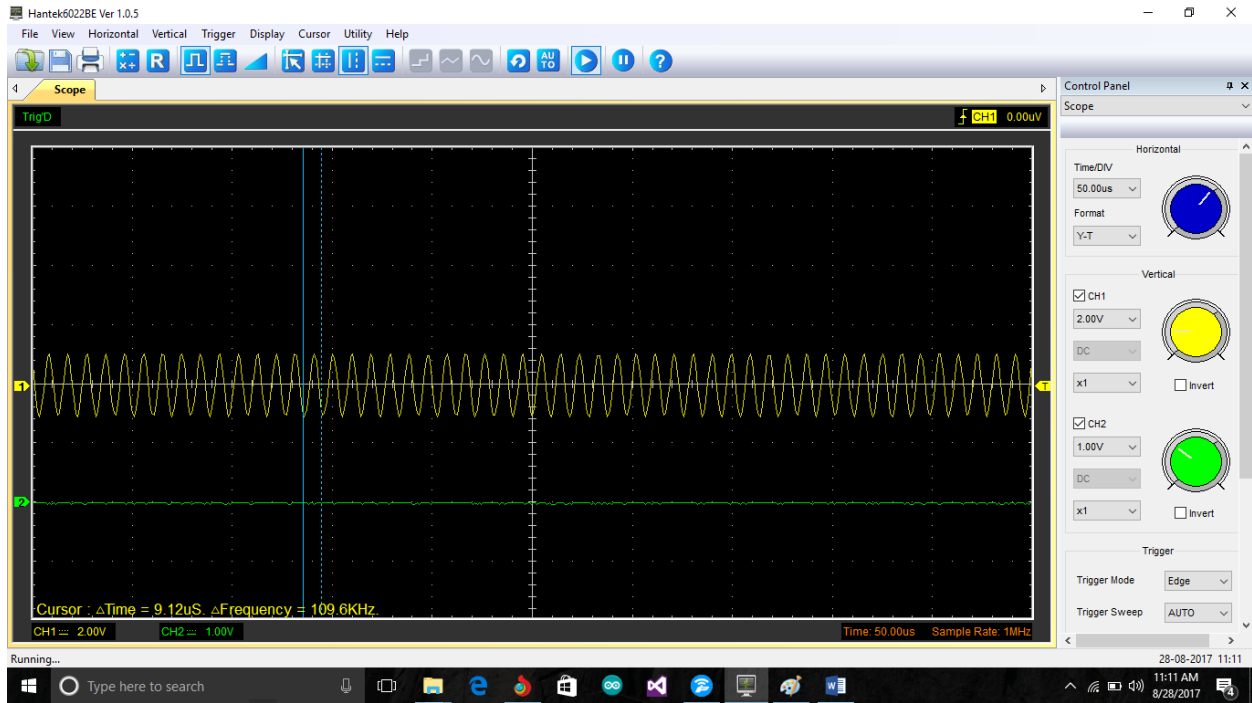
0 Cm 109 KHz 20 turns



0.5 Cm 109 KHz 20 turns

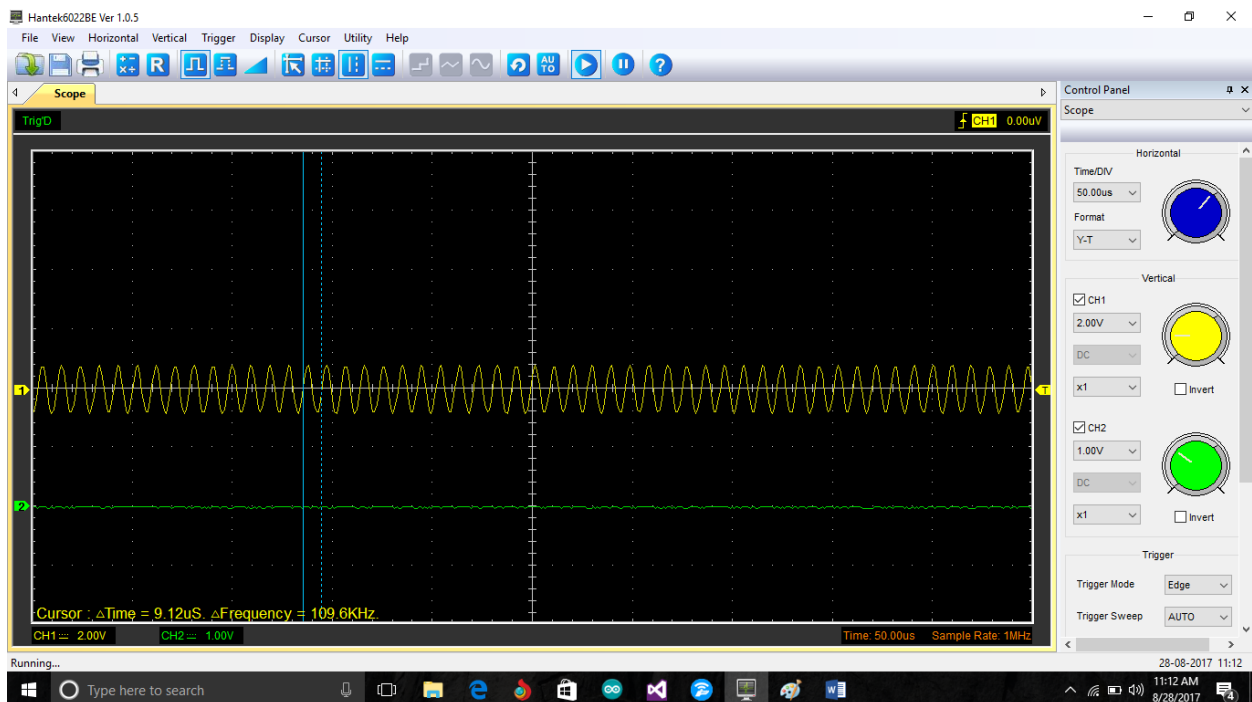


1 Cm 109 KHz 20 turns

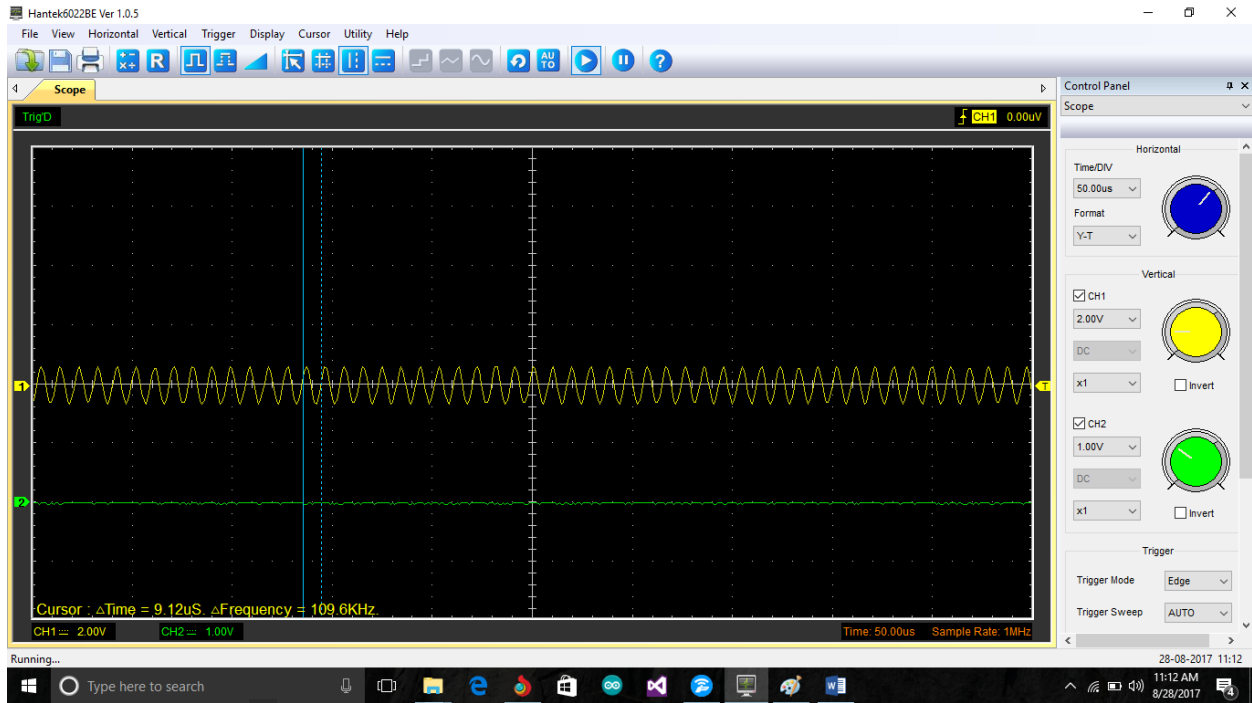


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1.5 Cm 109 KHz 20 turns



2 Cm 109 KHz 20 turns



Now keeping distance of coil fixed and changing the Frequency of the coil. The frequency will be 10 KHz, 1KHz, 0.1 KHz, 10 Hz and the distance will be 0 cm and 1 cm.

Constants for table 2:

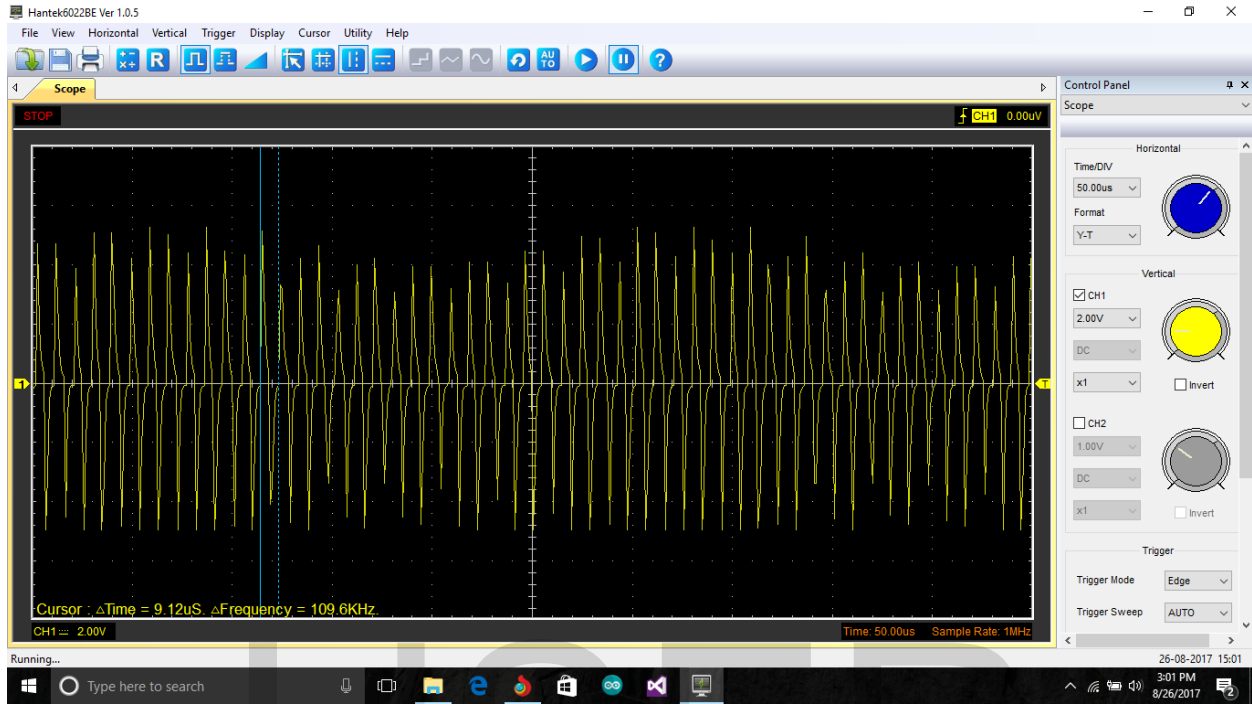
Input voltage	Number of turns in secondary coil	Resistance	Distance
6.5 v	20	1.4 Ohms	0 cm

Output voltage for Sine wave (V)	Output voltage for Square wave (V)	Frequencies
1.49	2.59	110.9 KHz
0.19	0.80	10.4 KHz
0.041	0.255	1 KHz
0.036	0.088	100 Hz

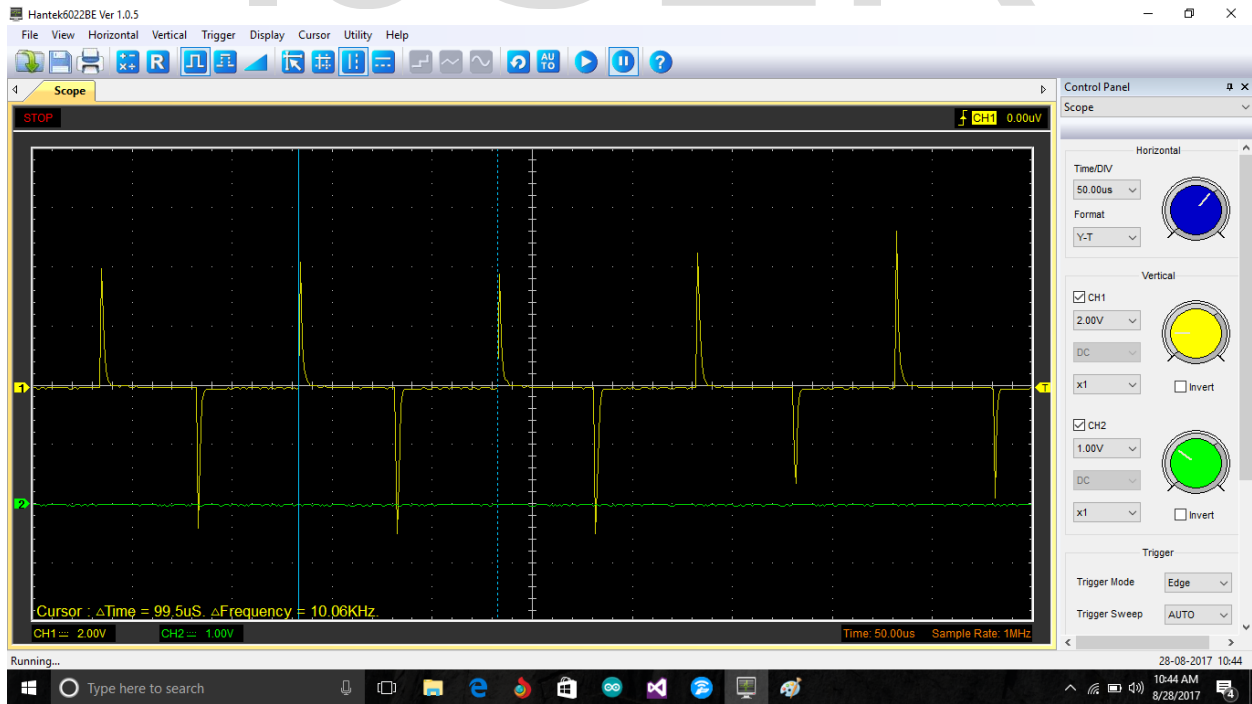
Data Table 2: Relation between Frequencies and Output voltage at 0 cm.

Square wave

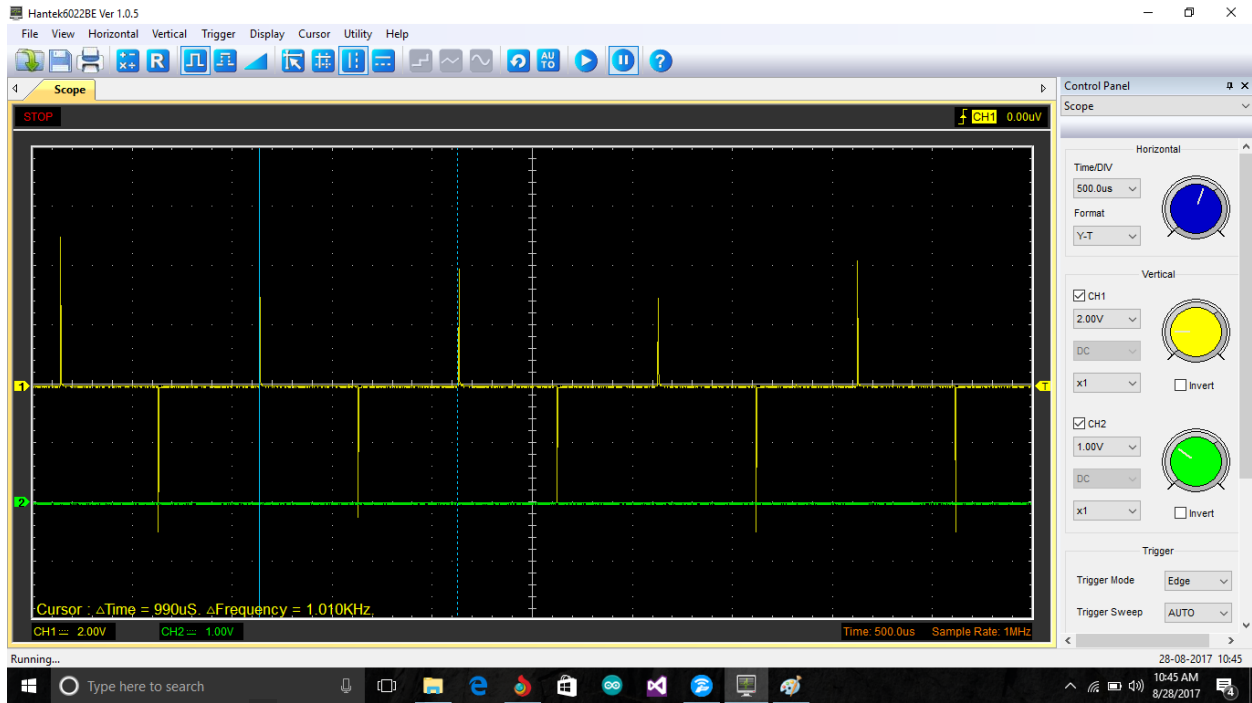
109 KHz 0 Cm 20 turns



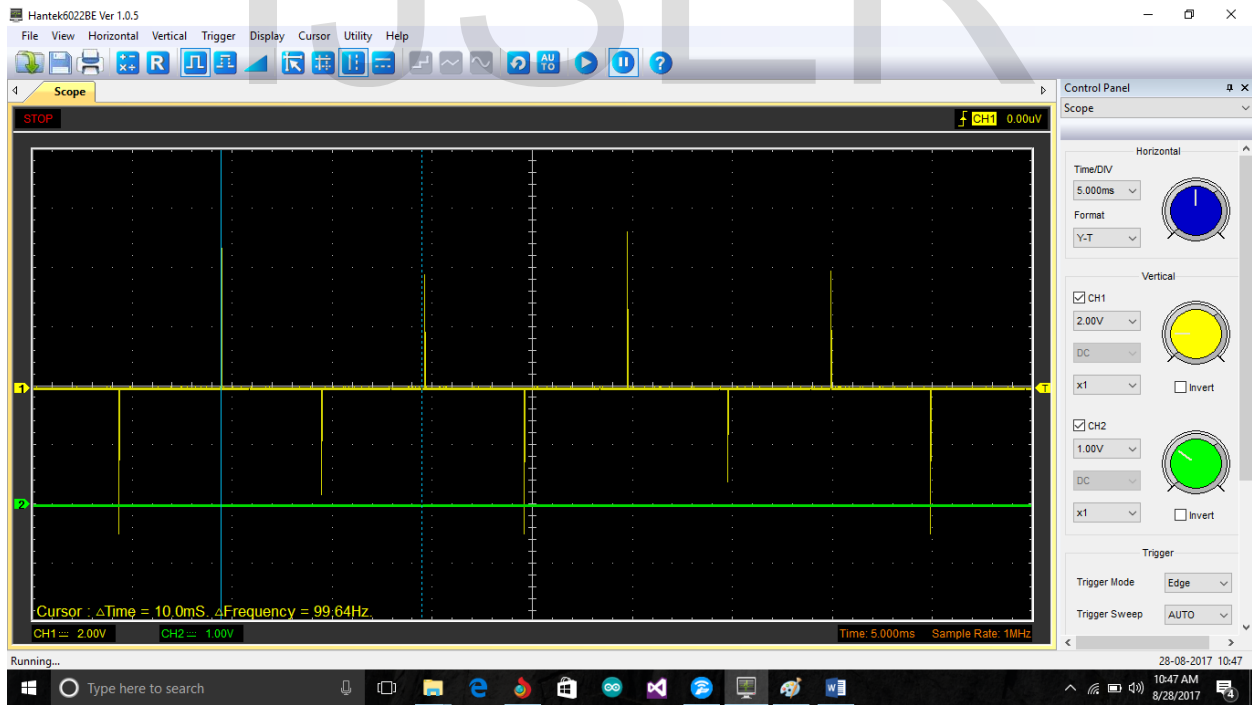
10 KHz 0 Cm 20 turns



1 KHz 0 Cm 20 turns

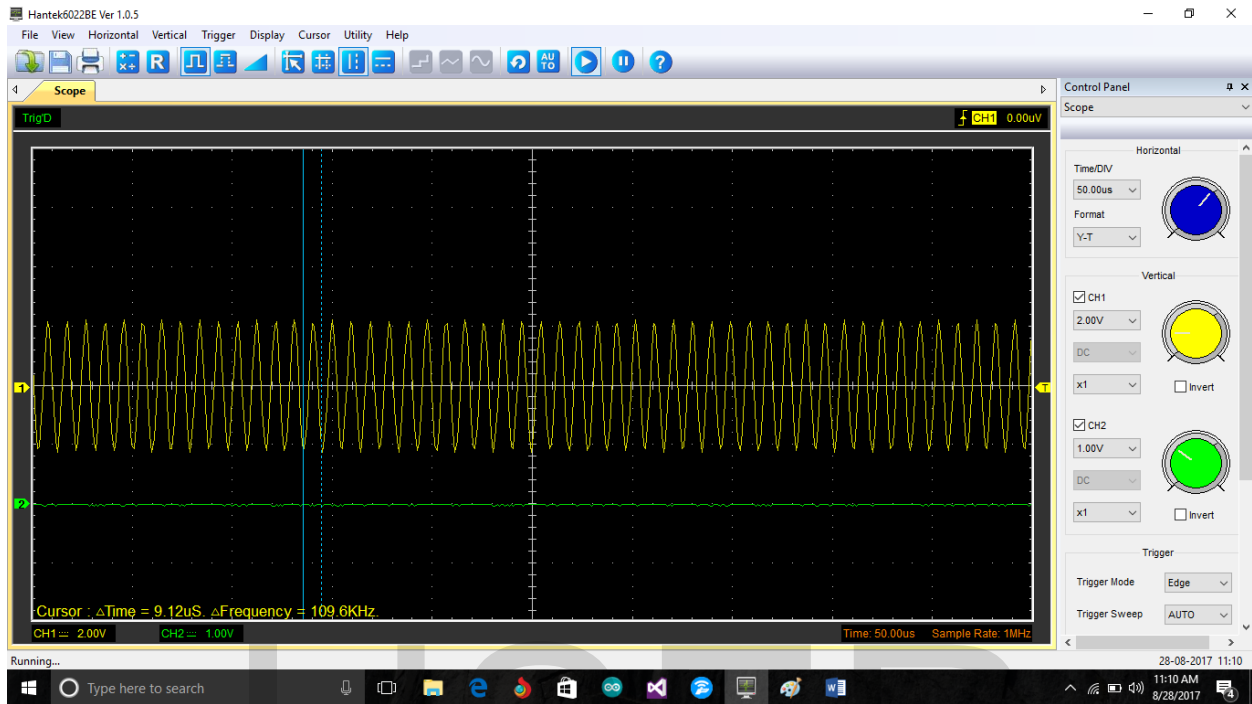


100 Hz 0 Cm 20 turns

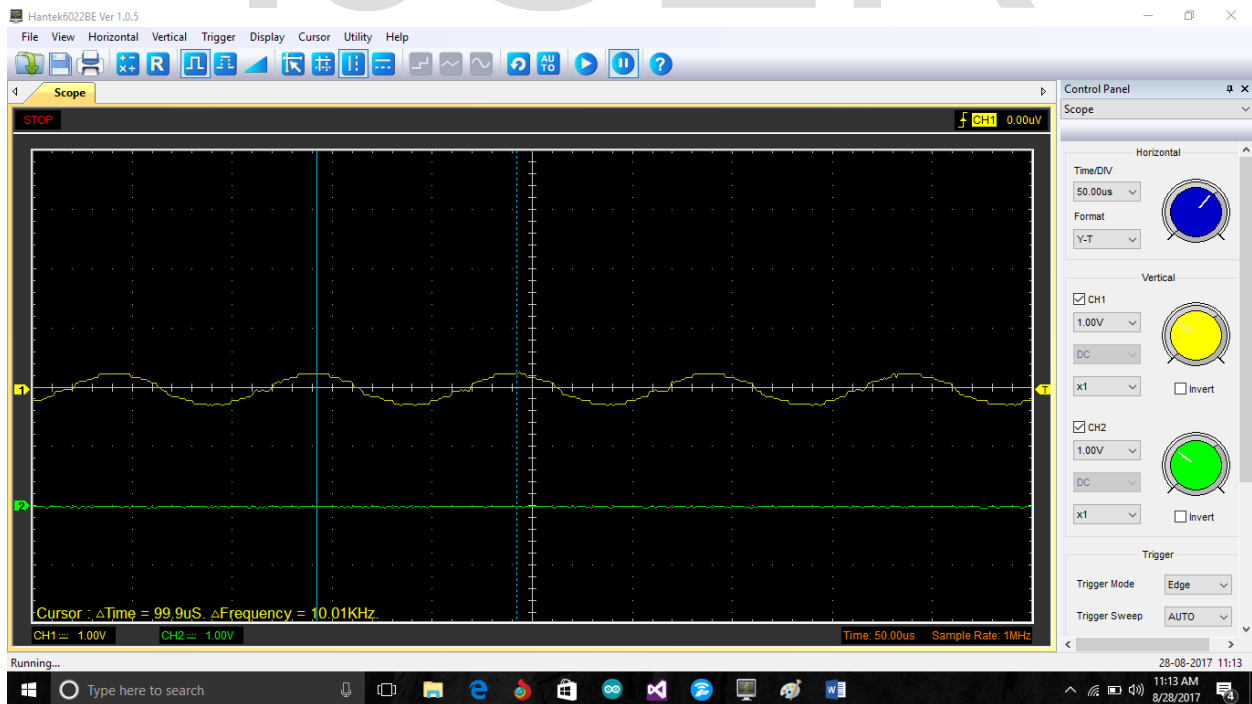


Sine wave

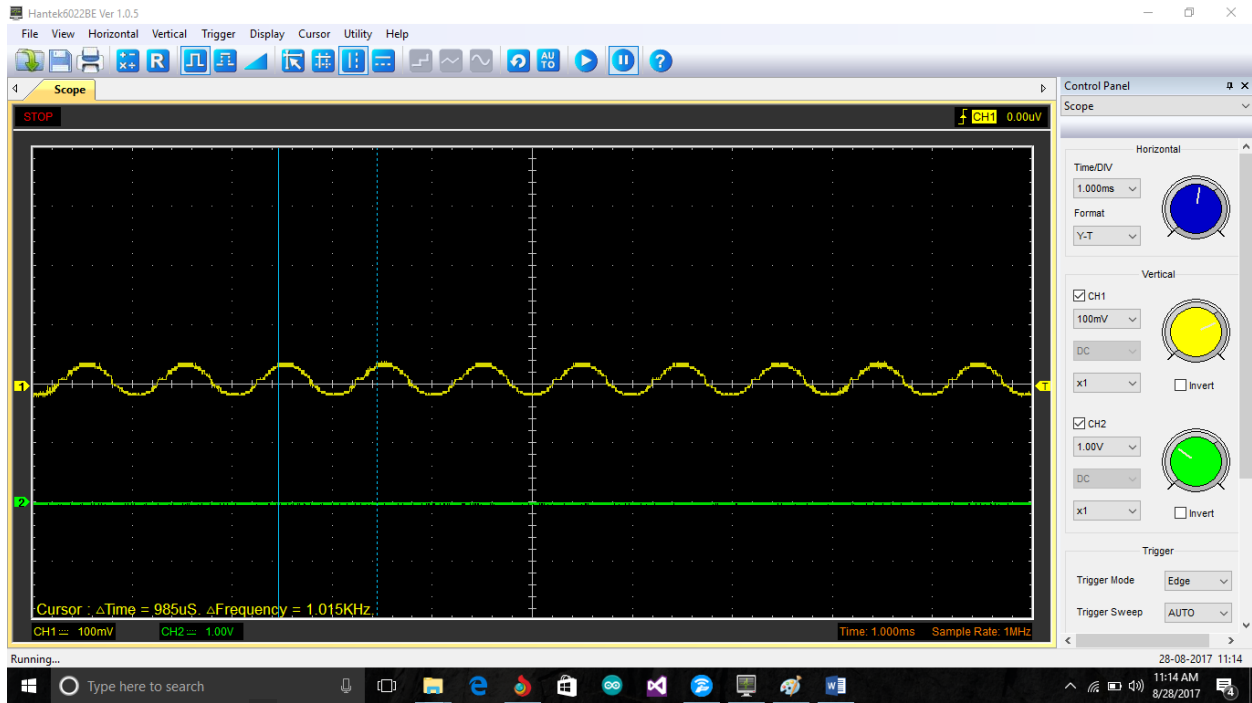
109 KHz 0 Cm 20 turns



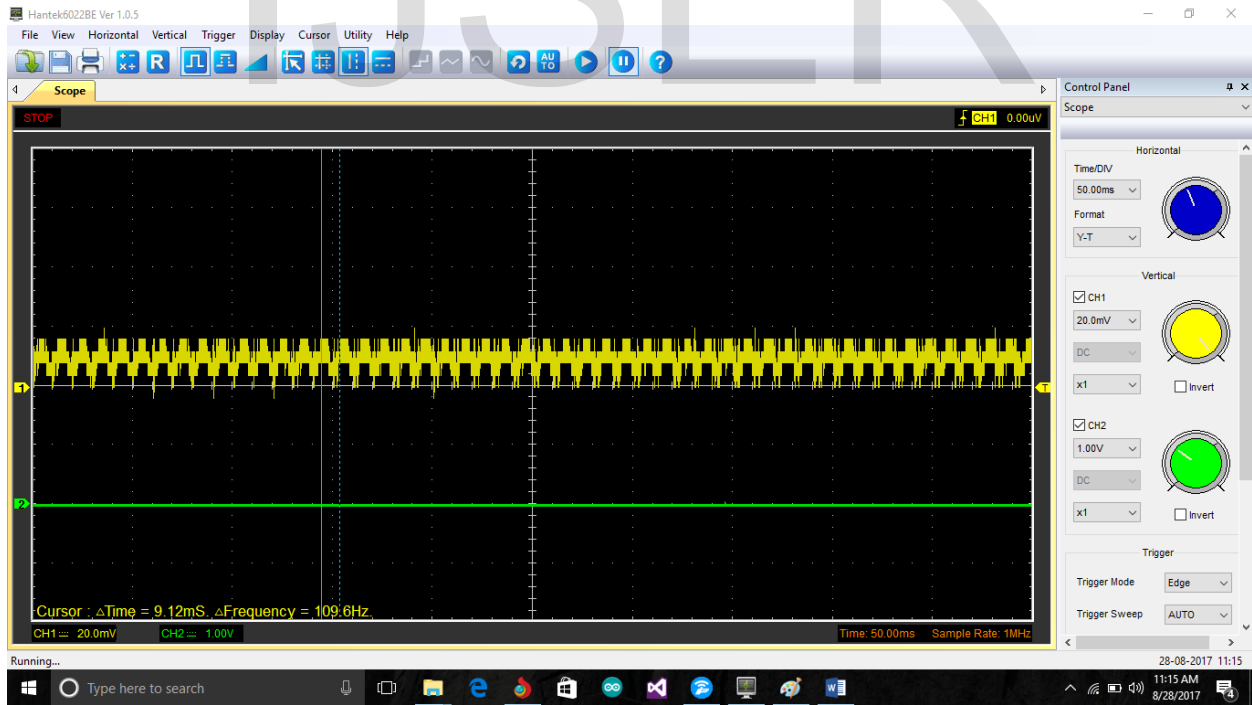
10 KHz 0 Cm 20 turns



1 KHz 0 Cm 20 turns



109 Hz 0 Cm 20 turns



Next we will change number of turns of the secondary coil. Number of turn will be 20, 15, 10, and 5. Frequency and distance will be kept constant where frequency will be 10KHz and distance will be 0 and 1 cm.

Constants for table 3:

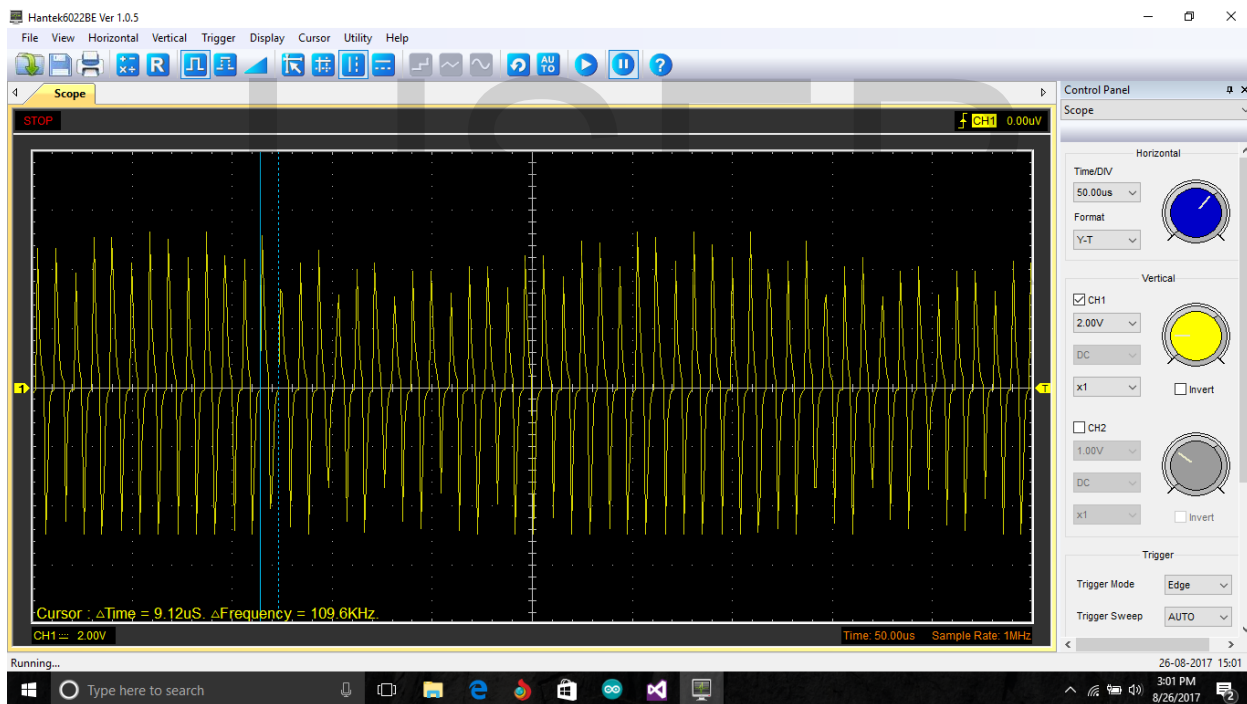
Input voltage	Number of turns in Primary coil	Frequency	Distance
6.5 v	20	110.9 KHz	0 cm

Output voltage for Sine wave (V)	Output voltage for Square wave (V)	Number of turns in secondary coil	Resistance of the coil (Ohms)
1.49	2.59	20	1.4
1.25	2.21	15	1.3
0.796	1.38	10	1.3
0.455	0.798	5	1.2

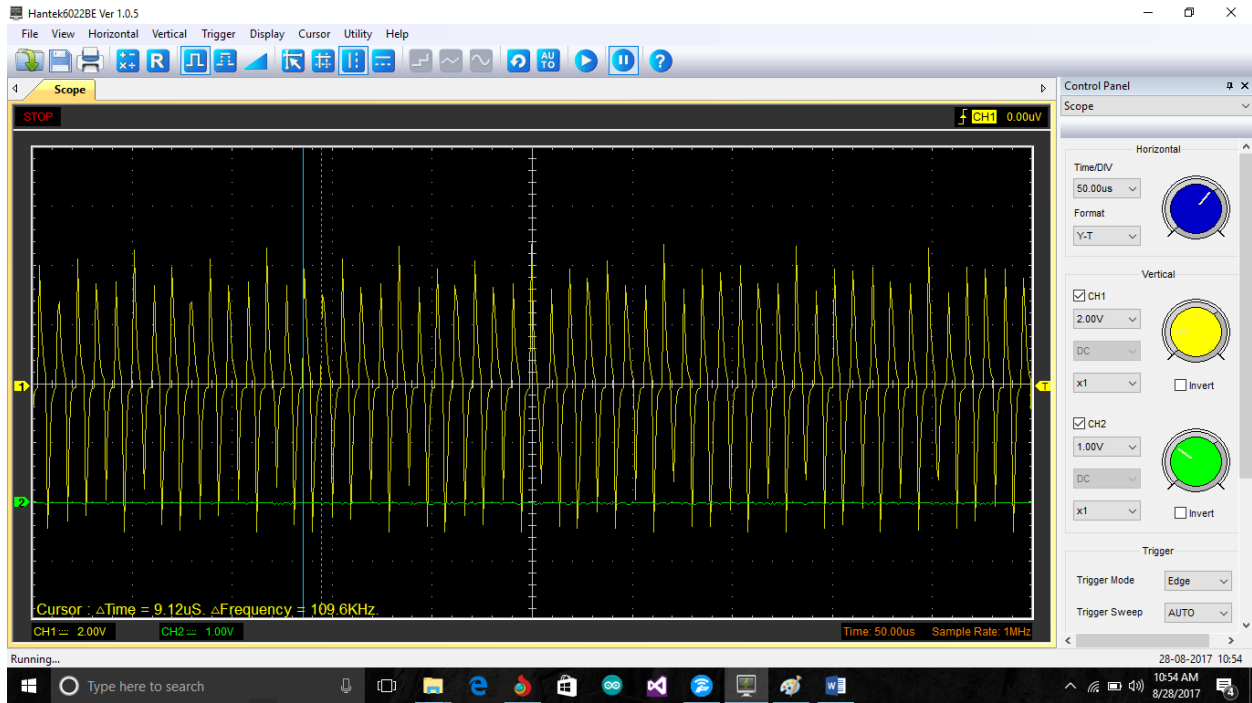
Data Table 4: Relation between Number of turns and Output voltage at 0 cm.

Square wave

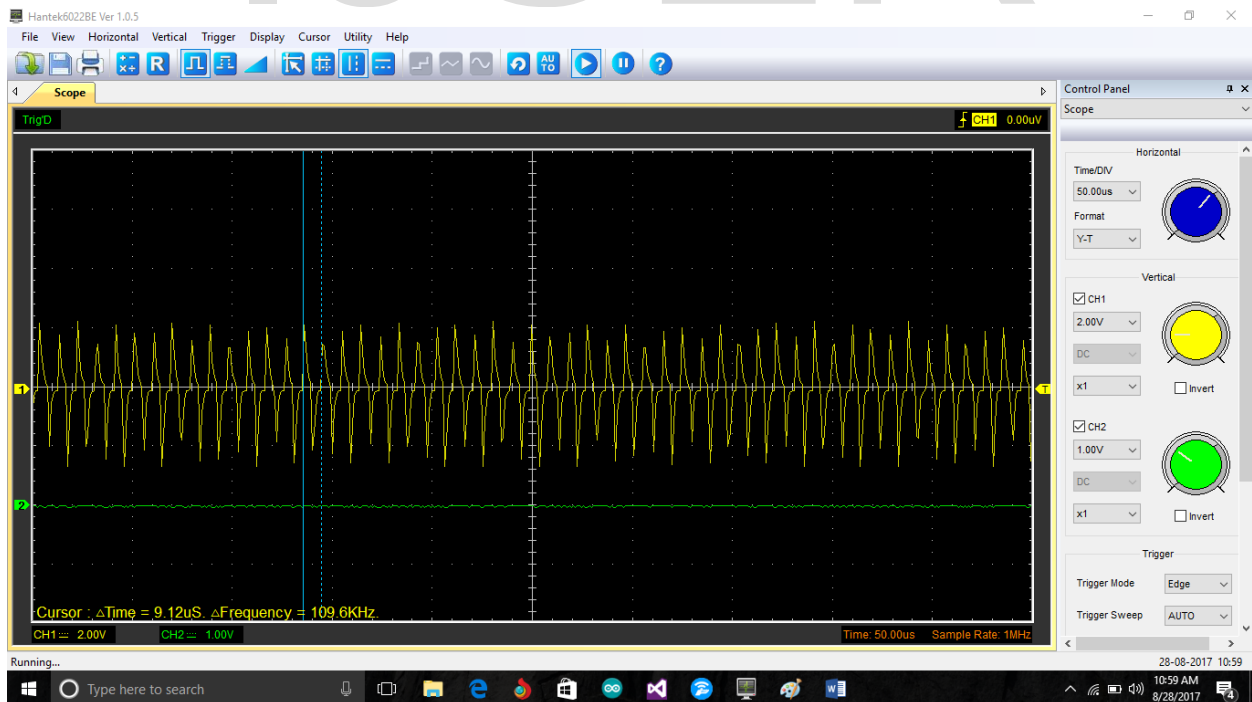
20 turns 109 KHz 0 Cm



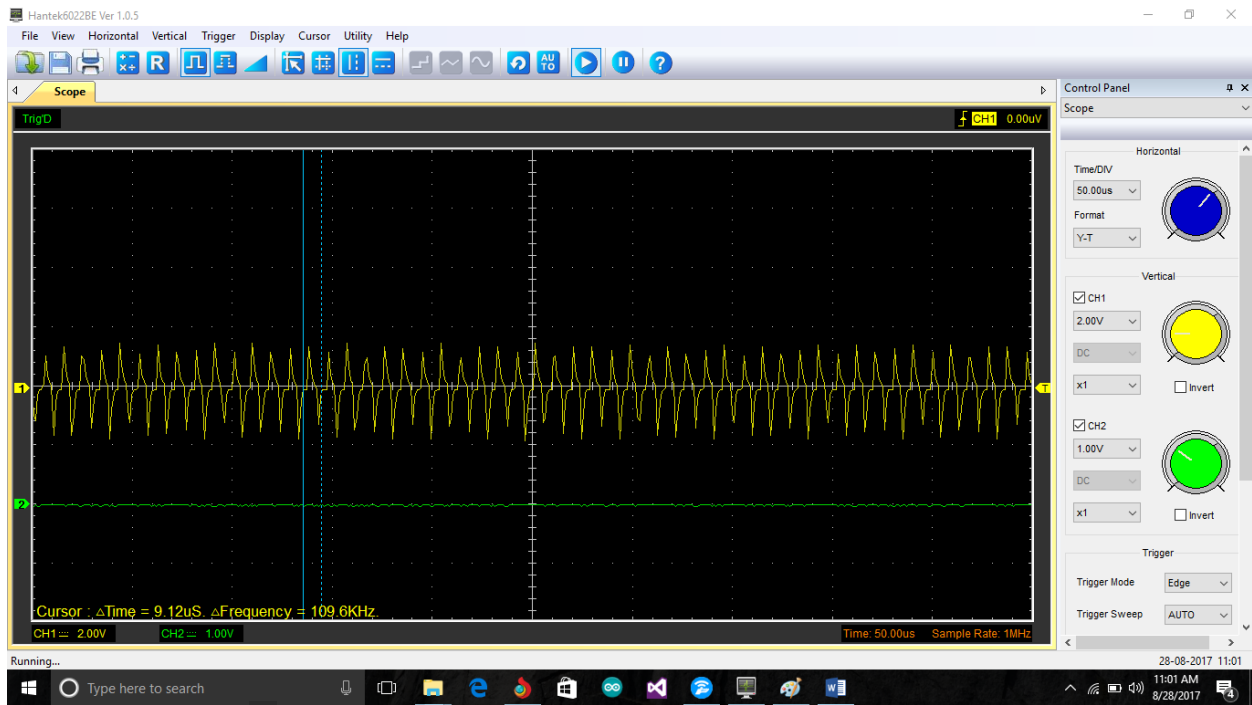
15 turns 109 KHz 0 Cm



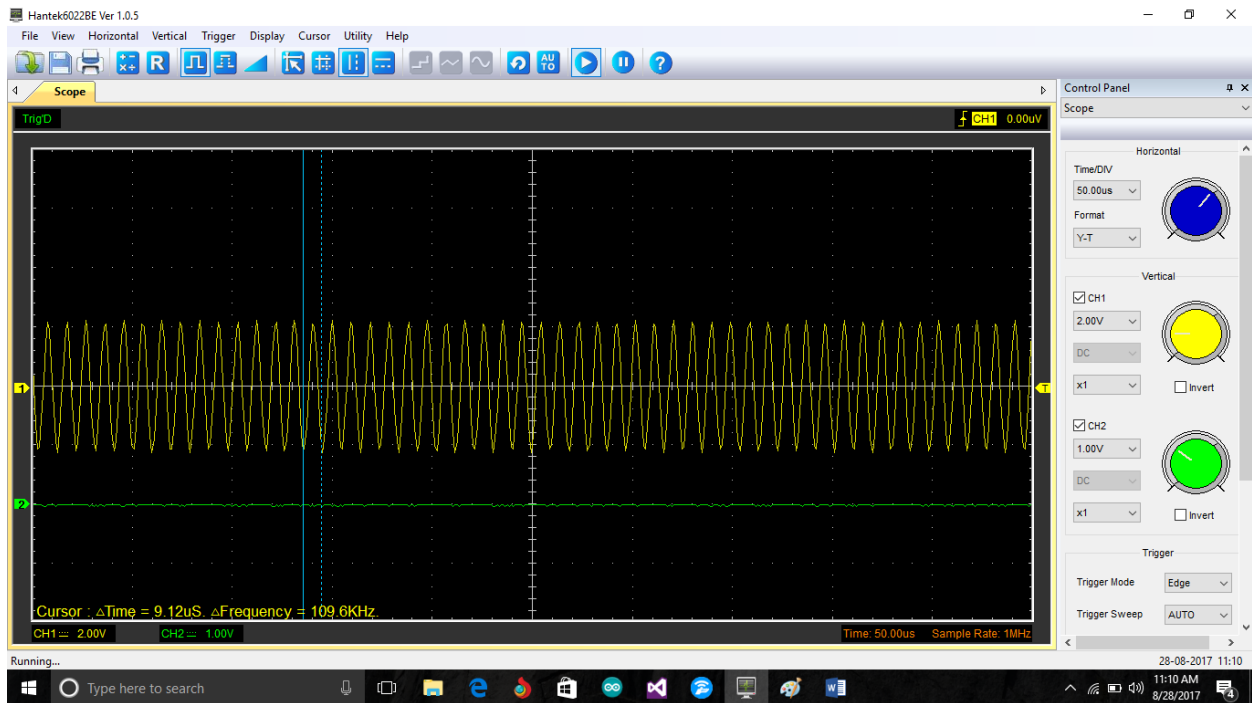
10 turns 109 KHz 0 Cm



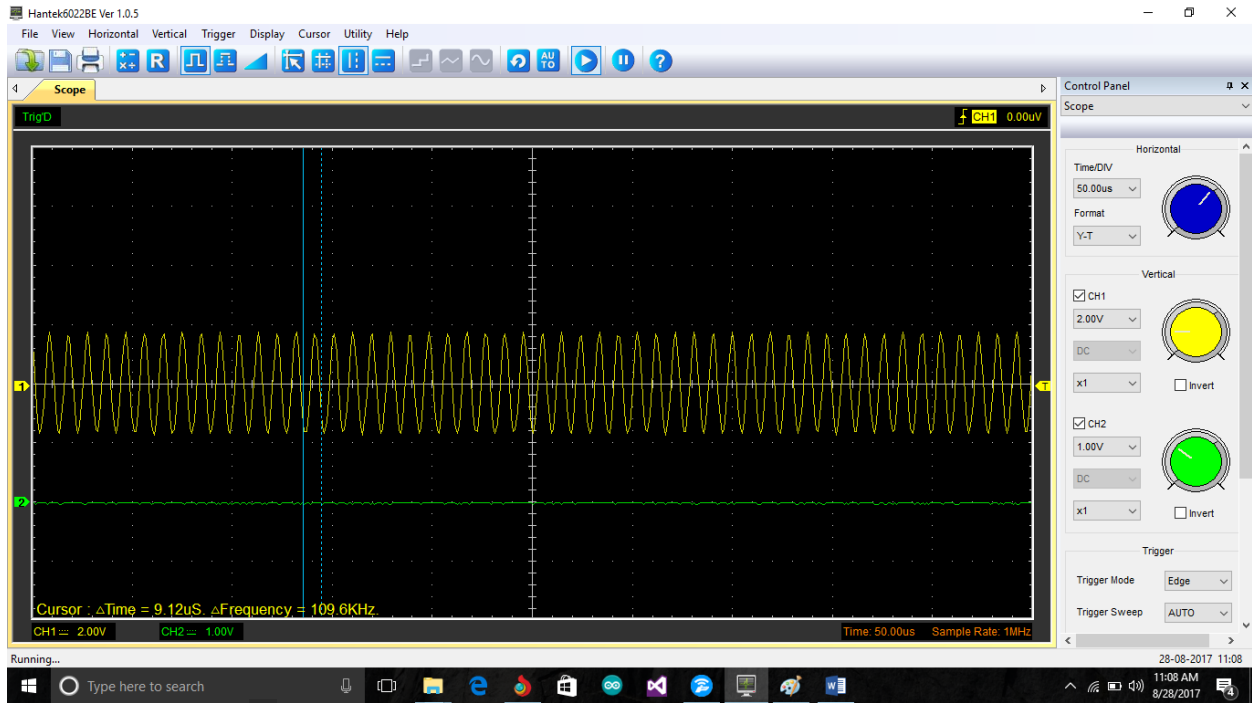
5 turns 109 KHz 0 Cm



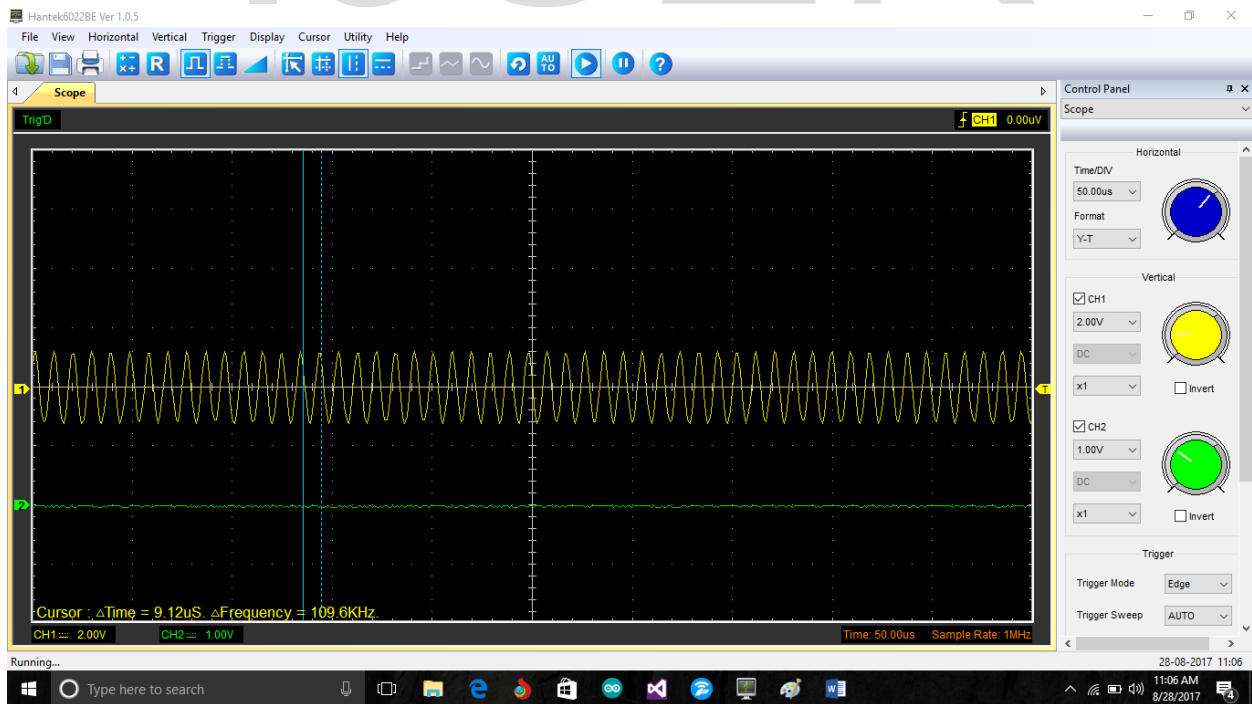
Sine wave 20 turns 109 KHz 0 Cm



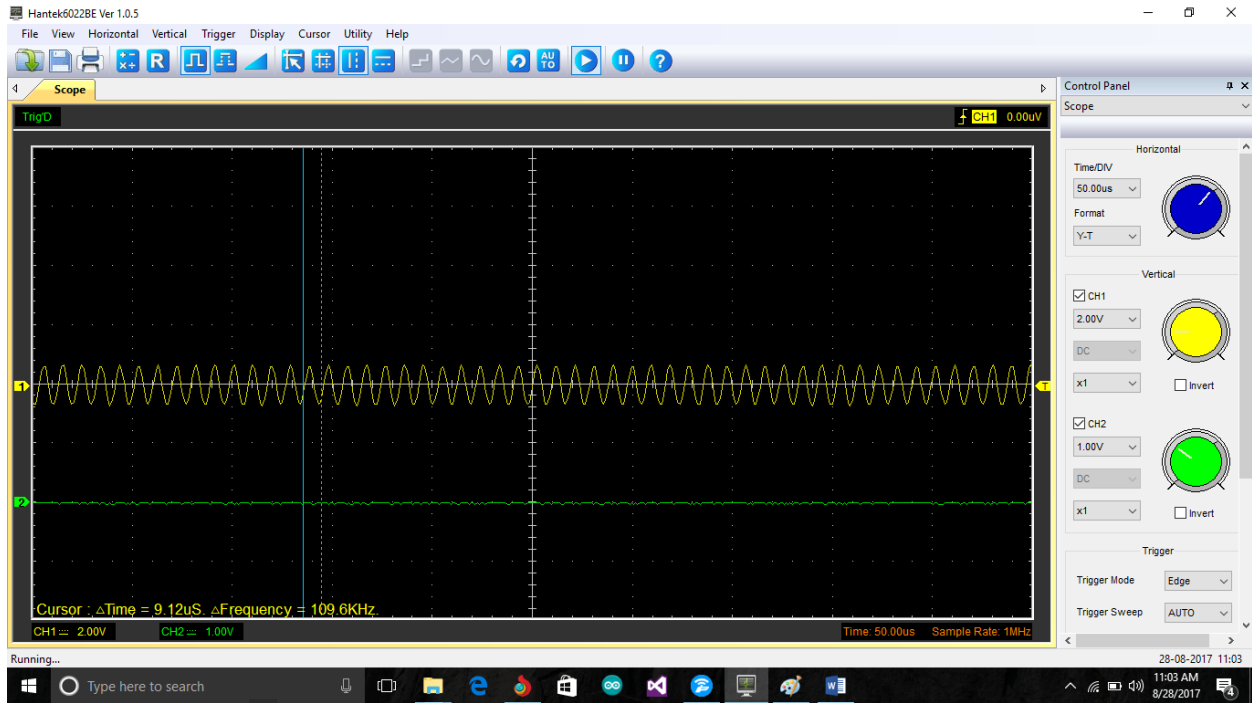
15 turns 109 KHz 0 Cm



10 turns 109 KHz 0 Cm



5 turns 109 KHz 0 Cm



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