Design And Construction Of Wireless Charging System Using Inductive Coupling

Do Lam Mung, Kyaw Soe Lwin, Hla Myo Tun

Abstract: Wireless charging system described by using the method of inductive coupling. In this project, oscillation circuit converts DC energy to AC energy(transmitter coil) to transmit magnetic field by passing frequency and then induce the receiver coil. The properties of Induction coupling are wave(magnetic field-wideband), range(very short~cm), efficiency(hight) and operation frequency(LF-band~several handred kHz).The project shows as a small charging for 5V battery of phone in this method. The system bases on coupling magnetic field, then designed and constructed as two parts. There are transmitter part and receiver part. The transmitter coil (transmitter part) transmits coupling magnetic field to receiver coil (receiver part) by passing frequency at about 1.67MHz. The Ampere's law, Biot-Savart law and Faraday law are used to calculate the inductive coupling between the transmitter coil and the receiver coil. The calculation of this law shows how many power transfer in receiver part when how many distance between the transmitter coil and the receiver coil. The system is safe for users and neighbouring electronic devices. To get more accurate wireless charging system, it needs to change the design of the following keywords.

Keywords: Wireless, power, transfer, inductive

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1 INTRODUCTION

WIRELESSpower transfer transfer (WPT) refers to a family of techniques for delivering power without wires or contacts.[1] It was demonstrated firstly by MIT using inductive coupling the summer 2007.[2] In 2008, Intel also achieved wireless power though inductive coupling.[3]Wireless power transfer technology has existed for a long time: however, recent advances have allowed it to become more practical, and recent interest in the consumer market has bought it to the center of attention.[4] This project can be charged several different handheld devices, such as cellular phones and MP3 player (like 5V charging adapter). It can be charged on the surface of the transmitter coil by putting receiving coil at the device. Wireless power transfer means the power supply is not plugged into the device being charged (close proximity or physical contact)[5].

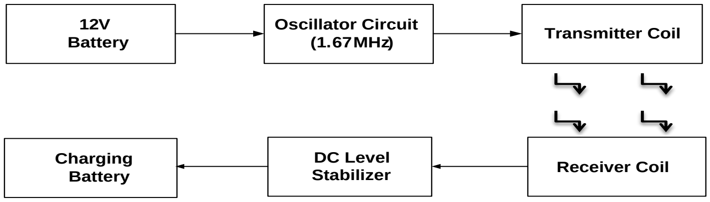


Fig. 1._Block diagram of wireless power transfer system_

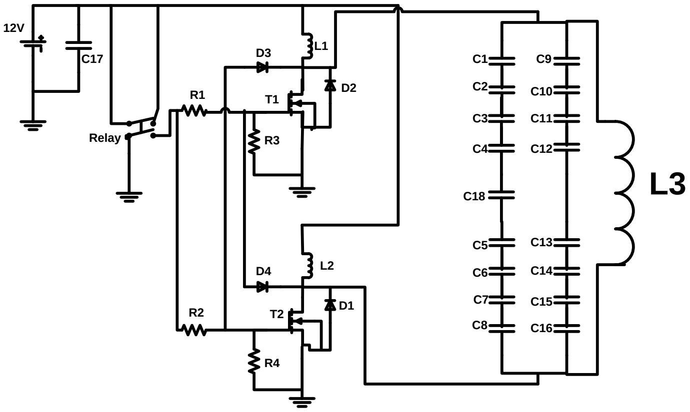
In this project, supply voltage 12 DC drives oscillator circuit as push-pull driver to operate transmitter coil. Then, the transmitter coil transmits coupling magnetic field by passing frequency at about 1.67MHz. In this state, there are AC voltage and the receiver coil receiver coupling magnetic field as ACvoltage. DC level stabilizer converts AC to DC voltage again to charge the battery of device.

2 PROPOSED SYSTEM DESIGNA

The hardware configuration of wireless power transfer system is basically on inductive coupling method. The complete circuit diagram of project can be divided in two different sections:

- Transmission section and
- Receiving section

In transmission section, oscillation circuit operates as push-pull devices to transmit magnetic field to the receiving coil. The system uses coupled magnetic fields as a frequency to transfer electromagnetic energy from the transmitter to receiver.[6] Fig2 show the circuit diagram of transmission section.



C_{17}=220nF, C_{18}=0.22uF, $C_1=C_2=C_3=C_4=C_5=C_6=C_7=C_8=C_9=C_{10}=C_{11}=C_{12}=C_{13}=C_{14}=C_{15}=C_{16}$=0.1uF, Relay=12V $R_1=R_2$=100Ω(2W), $R_3=R_4$=5.6kΩ, $D_1=D_2=D_3=D_4$=6A10MICdiode L1=L2=28.18uH(8-turns, FT-50-43,ferrite core) L_3=1 turn(220mm diameter,13mm copper tube) $T_1=T_2$=IRF 2807 (n-channel)

Fig. 2. *Circuit diagram of Transmission section*

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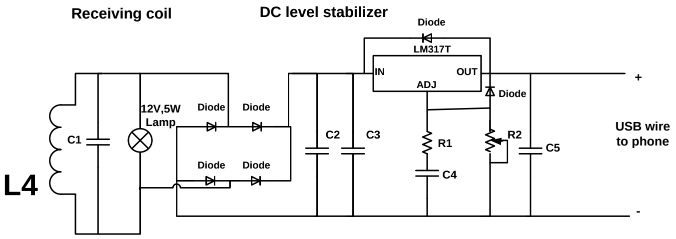


L_4=1turn (220mm diameter, 13mm copper tube),
C_1=0.02uF, Diode=1N4007, C_2=470uF, C_3=1uF, R_1=47Ω,
C_4=10uF, VR=5kΩ, C_5=1uF, R_3=100kΩ, R_4=11.11kΩ

Fig. 3. *Circuit diagram of Receiving section*

2.1 Opetation Of Power MosfetT1 And T2

When T_1 is LOW (off) and the pass transistor gate is pulled up to T_2 to keep it turned on. When T_1 is HIGH(on), the pass transistor gate is pulled to ground, and the transistor T_2 turns off.

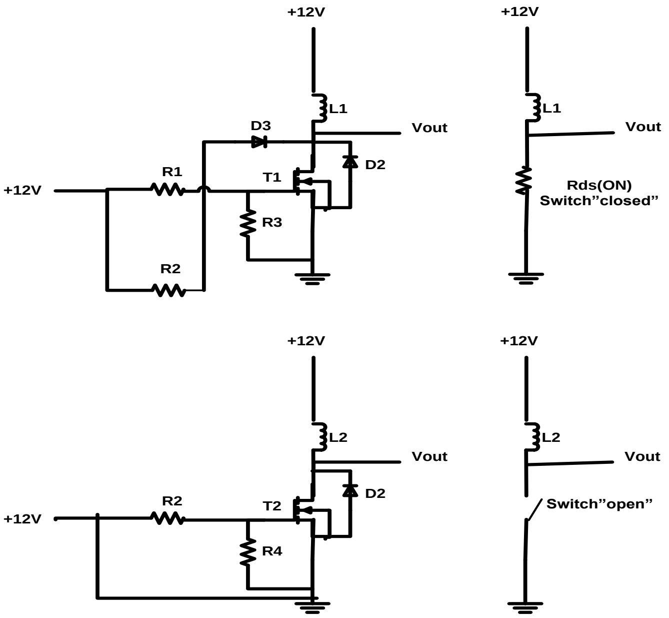


Fig. 4. *Power mosfet T1 HIGH(on) and T2 LOW(off)*

2.2 Calculation of frequency(C and L) and Coil Design

The frequency oscillation is calculated as the following:

$1/C_a=1/C_1+1/C_2+1/C_3+1/C_4$, C_a=25nF
$1/C_b=1/C_5+1/C_6+1/C_7+1/C_8$, C_b=25nF
$1/C_c=1/C_9+1/C_{10}+1/C_{11}+1/C_{12}$, C_c=25nF
$1/C_d=1/C_{13}+1/C_{14}+1/C_{15}+1/C_{16}$, C_d=25nF
C_a,C_{18} and C_b are series, C_x=11.83nF
C_c and C_d are series, C_y=12.5nF
C_x and C_y are parallel, C=24.5nF

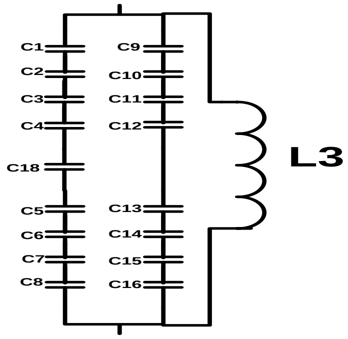


Fig. 5. *Frequency oscillation by Inductor coil and Capacitors*

$f=1/2\pi\sqrt{LC}=1.57MHz$

Fig. 6.*Copper tube(13mm diameter) and Diameter of coil*

3 Hardware Implementation

The hardware design of wireless charging system describes as two sections.

(1). Transmitter section and
(2). Receiver section

Transmitter section consists of electronic parts shown as the circuit diagram fig 2. It drives as push-pull deriver (alternate power mosfet transistors T1 and T2) to transfer magnetic field (inductive coupling) by passing the frequency oscillation about 1.67MHz.

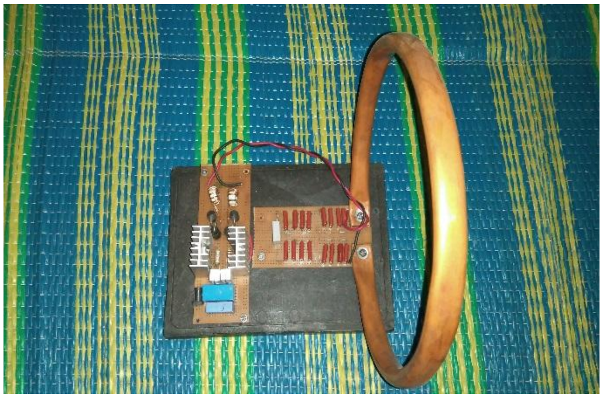


Fig. 7.*The project of transmitter section*

Receiver section is used for to receive power by magnetic field and passing the frequency oscillation. In this state is AC voltage and then it needs to convert DC voltage for charging the battery of phone.

Fig. 8.*The project of receiver section*

Fig. 9.*The wireless charging system of mobile phone*

3.1 CALCULATION OF MAGNETIC FIELD(B) AND DISTANCE(X)

(A) PRIMARY COIL

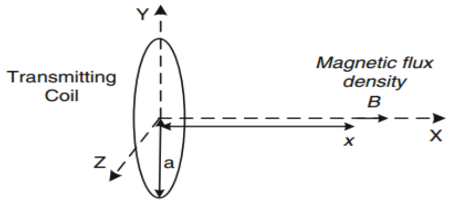
Biot-Savart law gives out the magnetic flux density generated by the flow of charges:

$$B = -\frac{\mu_0}{4\pi}\oint_l \frac{Idl \times e_r}{r^2}$$

Where;
r=the full displacement vector from wire element to the point
e_r=the unit vector of r
Idl=linear-current-element in the wire
μ_0=the magnetic constant

For the circular coil, the generated magnetic flux density B at the point x;

$$B_x = \frac{\mu_0 N I a^2}{2(a^2+x^2)^{3/2}} e_x$$



a=110mm=$11*10^{-2}$m, let x=5cm=$5*10^{-2}$m, I_p=I=11.6A
$B_x=5*10^{-5}e_x$T
$V_0(t)=2V_m\sin\theta$ (V_m=12V,$V_p=2V_m$)
θ=0, 90, 180, 270, 360,…
$V_p=V_0$=0V, 24V, 0V, -24V, 0V, …

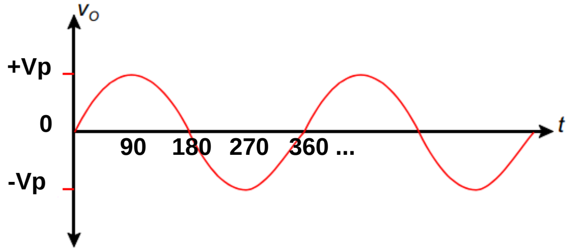
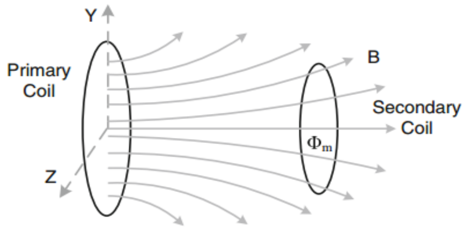


Fig.10. *Calculation by Power Mosfet T1 and T2 passing L and C*

(B) SECONDARY COIL



The total time-varying magnetic flux φ_m crossing the secondary coil can be expressed by:

$$\Phi_m = \int_s B \cdot dS$$

According to the Faraday's law of induction, the induced voltage in the secondary coil is:

$$V(t) = -\frac{d\Phi_m(t)}{dt}$$

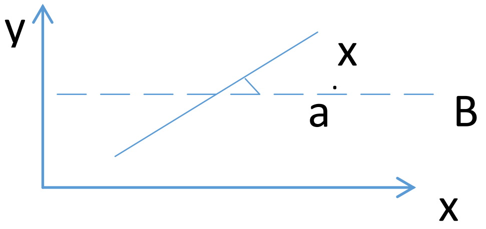


Fig. 11. *Angle between the magnetic field and receiving coil*

$\varphi_m(t)=\int_s B.dS$=NBA cosa coswt=NBAcoswt (a=0) V(t)=-d $\varphi_m(t)/dt$=-NBA d/dt coswt=NBAwsinwt=NBAwsinθ θ=0, 90, 180, 270, 360 N=1, $B_x=0.5\mu e_x T$, $A=\pi r^2$ ($r=11*10^{-2}$m), w=2πf (f=1.25MHz) Vp=0V, 15V, 0V, -15V, 0V (distance between 5cm transmitter and receiver)

3.1 CALCULATION BY DIGITAL OSCILLOSCOPE

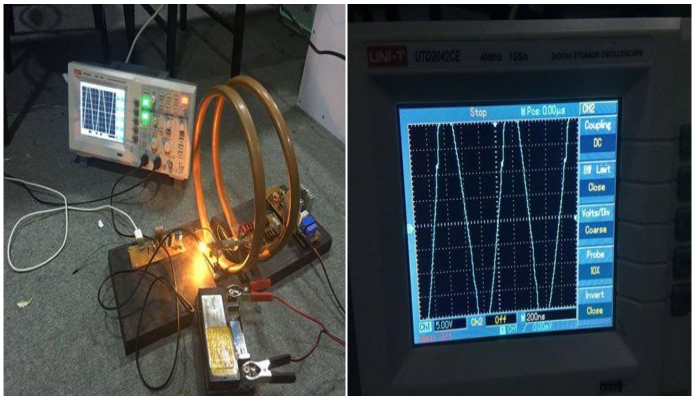


Fig. 12. *Waveform of Vp(Primary coil) In the transmitter coil; Vp=24V, f=1/T=1/800ns=1.25 MHz (T=800ns)*

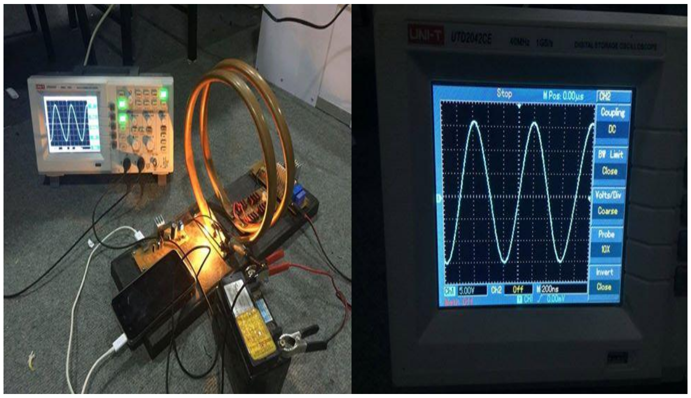


Fig. 13. *Waveform of Vp(Secondary coil) In the receiver coil; Vp=15V, f=1/T=1/800ns=1.25 MHz (T=800ns)*

3.2 CALCULATION OF TRANSMITTER AND RECIVER COILS (L3=L4=1TURN=420NH)

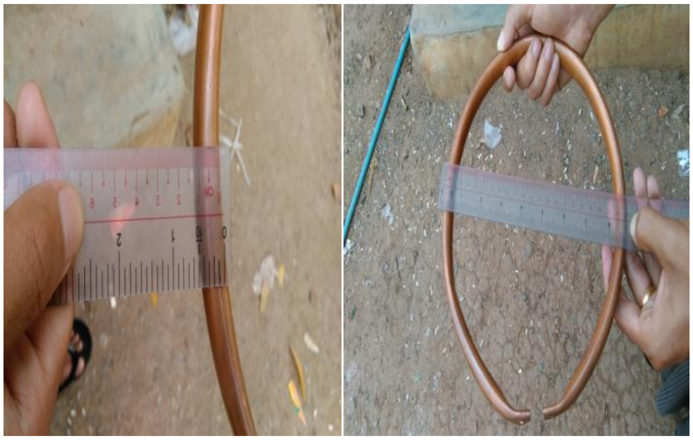


Fig. 14. *Transmitter coil and receiver coil (13mm copper tube and 22omm diameter)*

The number of turn to get L3=L4=1turn=420nH calculates as the following:

$L= \mu_0 N^2 A/\ell$

From **emf=$\int_C E d\ell = -d/dt \int_A B dA$**

[the induction theorem (in general form)] and

e.m.f=d/dtφ(Faraday's law)

Air core coil (L3=L4=420nH transmitting and receiving coils) ℓ=the length of the gap=diameter of the coil ℓ =220mm=22cm=$22*10^{-2}$m r=11cm=$11*10^{-2}$m, L=420nH, A= π r^2,$\mu_0=4\pi*10^{-7}$H/m Get :N=1.3≈1 turn

3.3 CALCULATION THE NUMBER OF TURNS IN CHOKE

The inductance of inductor with toroidal core calculates in the following:

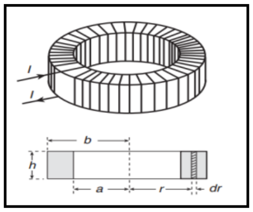


Fig. 15. *The inductance of inductor with toroidal core*

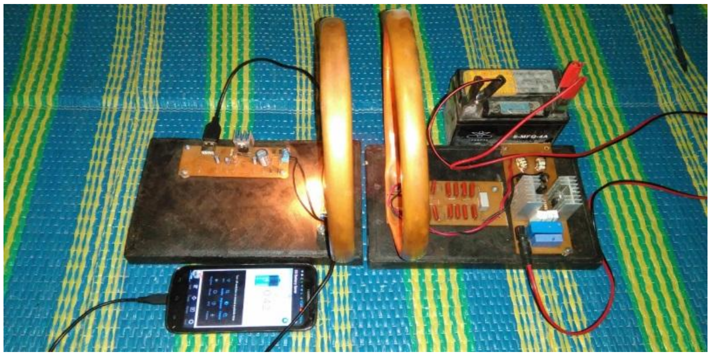
$L=\lambda/I=\mu_{rc}\mu_0 h N^2/2\pi$ Ln(b/a) From **$\int_c H.dl = NI$ (dl=rdφ)** **(** Applying Ampere's law) L=28.18uH,$\mu_{rc}=800$,$\mu_0=4\pi*10^{-7}$H/m, $h=0.47752*10^{-2}$m, $a=0.35687*10^{-2}$m,$b=0.635*10^{-2}$m, Get: N=8 turns

3.4 Calculation By Digital Voltmeter (DC Voltage)

Fig. 16. *DC Voltage and Ampere(between transmitter and receiver=1.3inches)*
*P=VI=1.005*7.63=7.4W (Loading 10Ω,5W)*

Fig. 17. *DC Voltage and Ampere*
(between transmitter and receiver=4inches)
*P=VI=145.1m*1.22=0.18W (Loading 10Ω,5W)*

3.5Efficiency, ɳ Efficiency,ɳ={P(receiving coil) / P (transmitting coil)}



Calculation of 1.3inches=transmitting coil and receiving coil;
P(receiving coil)=7.4W
*P(transmitting coil)=12*1.3=15.6W*
Get; Efficiency,ɳ=0.47=47%

4 Simulation Result

In simulation, it shows the calculation of the waveform, DC voltage waveform by each power mosfet transistor, AC voltage by both power mosfet transistors.

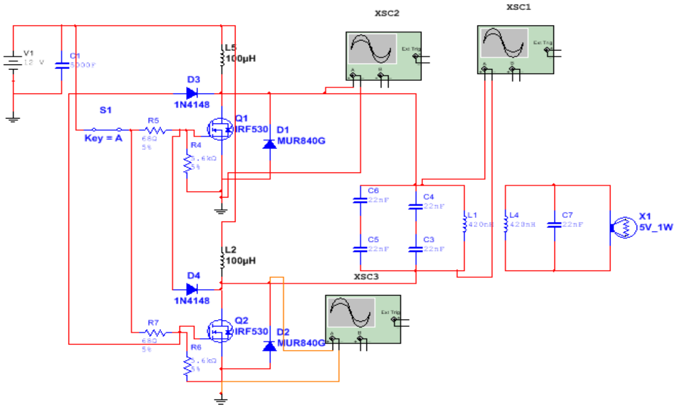
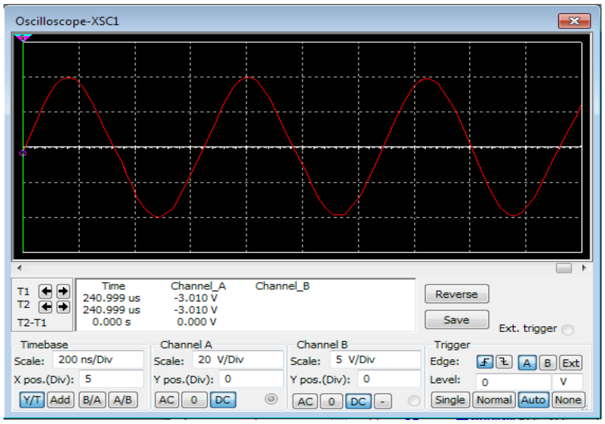


Fig. 18. *Multisim Test for Wireless Power Transfer Circuit*



	Time	Channel_A	Channel_B
T1	240.999 us	-3.010 V	
T2	240.999 us	-3.010 V	
T2-T1	0.000 s	0.000 V	

Ext. trigger

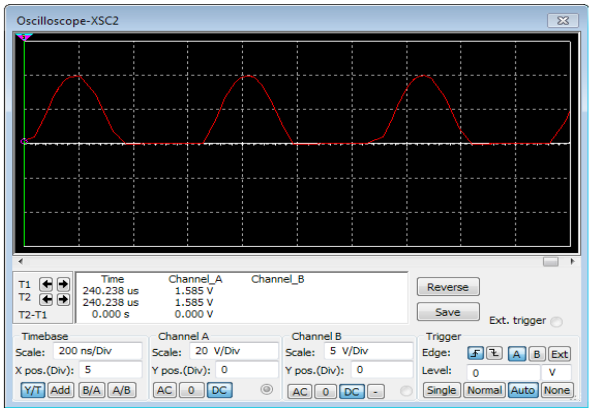
Timebase
Scale: 200 ns/Div
X pos.(Div): 5

Channel A
Scale: 20 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Fig. 19. *Frequency oscillation by simulation, XSC1 (both of power mosfet transistor T1 and T2)*



	Time	Channel_A	Channel_B
T1	240.238 us	1.585 V	
T2	240.238 us	1.585 V	
T2-T1	0.000 s	0.000 V	

Ext. trigger

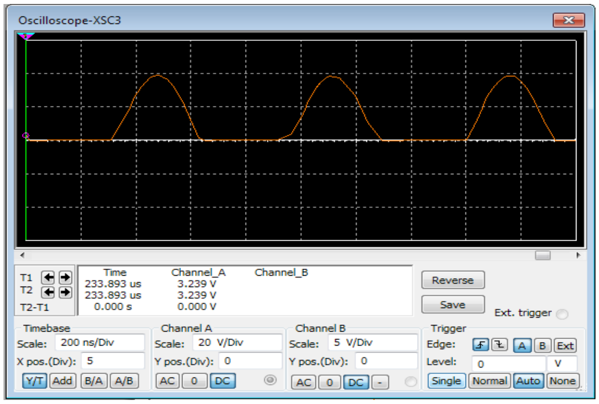
Timebase
Scale: 200 ns/Div
X pos.(Div): 5

Channel A
Scale: 20 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Fig. 20. *Frequency oscillation XSC2 by power mosfer transistor T1*



	Time	Channel_A	Channel_B
T1	233.893 us	3.239 V	
T2	233.893 us	3.239 V	
T2-T1	0.000 s	0.000 V	

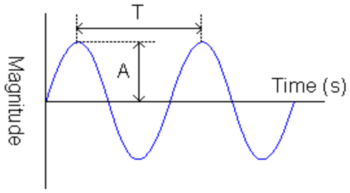
Timebase
Scale: 200 ns/Div
X pos.(Div): 5

Channel A
Scale: 20 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

Trigger
Edge:
Level: 0 V

Fig. 21.*Frequency oscillation XSC3 by power mosfer transistor T2*



f = 1/T = 1/617.424n
= 1.65MHz

Fig. 22. *Calculation of frequency oscillation by simulation*

5 CONCLUSION

Wireless power transfer by inductive coupling is described in this paper. In this circuit project, power transfer about 7.4watt when the transmitter and receiver are between 1.3inches. It needs to redesign and reconstruct by changing power mosfet transistor. In the paper, the design is not perfect and redesign in this jounal. The components need to change. Wireless power transfer system can be realized to perform to high standards followed more distance between transmitter and receiver by changing the size of copper wire guage or copper tube and design of inductance in toroidal core.

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