# Effect of DC voltage source on the voltage and current of transmitter and receiver coil of 2.5 kHz wireless power transfer

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**ABSTRACT**

A solenoid supplied by alternating current (AC) voltage generates electromagnetic which has a field area depends on the level of supplied voltage and current flows through the solenoid. The electromagnetic filed can be captured by the other solenoid in the field area. This concept can be applied in a wireless power transfer (WPT) as presented in this paper. The WPT has transmitter coil and receiver coil which each has form of solenoid. The transmitter coil is connected a half bridge circuit to generate AC voltage on the transmitter coil which transferred to the receiver coil. In the experimental set up, the receiver coil is supplied by DC voltage source and it is changed to observe its effect on the voltage and current on the transmitter and receiver coil of the WPT system.



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## 1. INTRODUCTION

The function of cable as a transmission medium already can be seen in the use of telegrams as a telecommunications medium. In the telegram, the message was encoded into the password morse and then translated into electrical signals that are then sent through a piece of wire by Morse in the year of 1844 [1, 2]. The working principle of telegram later became the basis of the development of shipping technology information using media cable. Along with the development of technology, the transmission of information in the end can also be conducted through the medium of non-cable, called wireless. Wireless communication is done with how to utilize electromagnetic waves as a media delivery information. Through an antenna, the electromagnetic waves emitted and captured to processed into useful information.

Recent developments in electronic devices have seen increasing demand for embedding electronics into fabrics for wearable applications. One of the difficulties with such applications is how to provide a sufficient and reliable power source. Traditional batteries are not an ideal solution for this application because its bulky size makes it difficult to be integrated into fabrics. Furthermore, they have limited capacity and, therefore, require constant maintenance such as replacement or recharging [3, 4]. Research on flexible energy storage devices, such as batteries and supercapacitors, has been reported by [5, 6], but their capacity and performance to date are relatively poor. Thus, an alternative power source is important to be looked for as DC voltage source in the electronic device, especially in the wireless power transfer (WPT) system.

A solenoid is coil wound into tightly packed helix. A long straight coil of wire can be used to generate a nearly uniform magnetic field. The magnetic field is concentrated into nearly uniform field in the centre of a long solenoid. The field of side is week and divergent. The magnetic field density in a solenoid can be generated if there are current flows through it. The mechanical connection between the current and magnetic field is explained by [7]. It is considered that the current was somehow gripping the molecular vortices of the magnetic fields and causing them rotate. The magnetic field in solenoid has been applied in some areas. The energy of magnetic field generated in the solenoid is transferred using a concept of magnetic resonant and it is called a WPT [8, 9].

There are some concpets of transmitter and receiver coil applied in WPT system. A circular spiral coil is designed by [10] for transmitter and receiver coil. It studied the effect of distance between transmitter and receiver coil on the performance of the WPT system. A single squarel plane inductor is designed by [11] for the transmitter and receiver coil of WPT system using Matlab software. A single layer dual band printed spiral inductor is designed by [12]. It studied the effect of frequency given on the peak transfer efficiency (PTE). A metal wall power transfer is applied by [13] trough 3.1 mm aluminium barrier. The design is based on Class E amplifier and the result shows that it can achieve a power gain of 25.2 dB and efficiency of 57.3% at the frequency of 200 Hz. Generally, the electrical power transferred from transmitter to receiver coil is AC that has a frequency. The required frequency is very important in the design of WPT as has been explained by some reserchers. The study of WPT system by [14] that apply the frequnacy of 2 GHz and the frequency of 2.45 GHz is studied by [15-18]. The WPT system can be applied in the electrical area, especially in the biomedical device as explained by [19-24]. It can also be applied as battery charging [25] for DC source of electrical vehicle [26].This paper present the effect of DC voltage source on the voltage and current of 2.5 kHz WPT system. A propose 2.5 kHz WPT system is explained in a block diagram and implemented in hardware. An experimental setup is conducted to observe the effect of DC voltage change on the voltage and current of the 2.5 kHz WPT system.

## 2. RESEARCH METHOD

A research method that consists of a block diagram and experimental setup of effect of DC voltage change on the WPT system are presented in this section. The block diagram contains the DC voltage source, driver circuit which drive the circuit of transmitter, receiver circuit and rectifier circuit. The experimental setup conducts the WPT system implemented in a hardware and it is tested for the condition of differenct and same turn number of transmitter and receiver coil. The DC vottage source is changed for the constant distance between the transmitter and receiver coil.

### 2.1. Block diagram of 2.5 kHz wireless power transfer

The first concept of 2.5 kHz WPT is an induction process of AC voltage waveform on the side of transmitter coil that produces an electromagnetic field as function of time and induces AC voltage waveform on the side of the receiver coil. The second concept is following electromagnetic resonance, whereas if the transmitter and receiver coil are in the same frequency, thus the received power by the receiver coil to be effective.

The transmitter and receiver coil transmits and receives the 2.5 kHz AC voltage waveform. The AC voltage is a conversion result from DC voltage to be AC voltage that it is converted by half bridge circuit that connected to the negative terminal of photovoltaic module as shown by block diagram of proposed 2.5 kHz WPT in Figure 1. The positive terminal of photovoltaic module is connected to the centre tap of transmitter coil. The half bridge circuit is constructed by MOSFET with its gate terminal is driven by the pre amplifier circuit. It is constructed by transistor that its base terminal is driven by the pulse driver circuit which is microcontroller PIC16F628A as a main component.

The 2.5 kHz AC voltage waveform induced by the transmitter coil is received by the receiver coil. The type of AC voltage waveform is not suitable for the normal AC loads. It is due its frequency is categorized as high frequency voltage level. The normal frequency AC loads are always 50 Hz or 60 Hz. Therefore, the AC voltage waveform on the side of receiver coil should be rectified by the rectifier circuit to be applied into the DC loads. The detail explanation of each part of transmitter and receiver side of 2.5 kHz WPT are explained in sub chapter below.

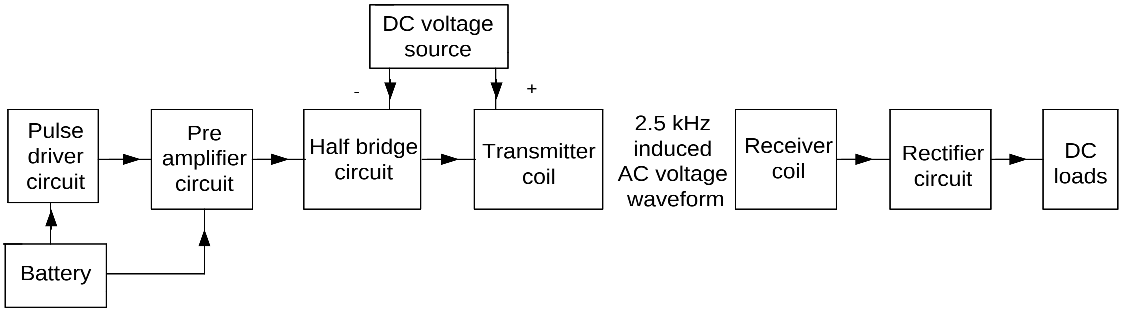



Figure 1. Block diagram of proposed 2.5 kHz wireless photovoltaic power transfer

## 2.2. Experimental setup of 2.5 kHz wireless power transfer

The experimental setup of 2.5 kHz WPT for the number of turn of receiver coil is lower than and equals the number of turn of transmitter coil is conducted into four circuit conditions. The first condition is for the pulse driver circuit. The second condition is for the transmitter and receiver circuit without the connection of rectifier circuit. The third condition is for the transmitter and receiver circuit with the connection of rectifier circuit but no connecting the DC loads. The fourth condition is for the transmitter and receiver circuit with the connection of rectifier circuit and the DC loads.

The first objective of experimental setup for the condition observation of pulse driver circuit is to make sure that the pulse wave generated by the microcontroller PIC16F628A has the frequency of 2.5 kHz or period of 400 µs. It is due that the pulse waves are a main driver to drive the transistors MJE13001 and MOSFETS IRFP 460 to generate a 2.5 kHz sinusoidal waveform at transmitter coil. The pulse wave outputs at pin 11 and pin 12 of the microcontroller PIC16F628A are measured using textronix oscilloscope as shown in Figure 2. The second objective of experimental set up for the transmitter and receiver circuit without the connection of rectifier circuit is to observe the 2.5 kHz AC voltage waveform on the transmitter and receiver side. The magnitude AC voltage, current and power on the both side are also observed and analysed, especially for the efficiency of the WPT.

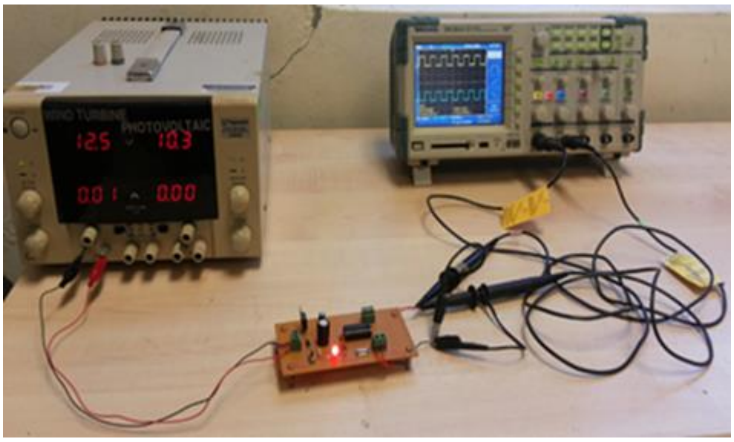


Figure 2. Experimental setup of pulse waves generated by the microcontroller PIC16F628A

The third objective of experimental set up for the transmitter and receiver circuit with the connection of rectifier circuit but no connecting the DC loads is to observe the DC voltage on the output of the rectifier circuit which is as the DC voltage source of DC loads. The DC voltage is a result of rectified voltage of the AC voltage waveform on the terminal of capacitor on the receiver coil. The DC voltage is compared to the input DC voltage of the transmitter side and analysed in term of the losses on the transmitter side and the receiver side. Figure 3 shows the experimental set up for the transmitter and receiver circuit with and without the connection of rectifier circuit.The input of transmitter coil of 2.5 kHz WPT is connected to the DC power supply and the receiver coil is connected to the LED lamp. Figure 4 shows the experimental set up for 2.5 kHz WPT connected to DC loads.

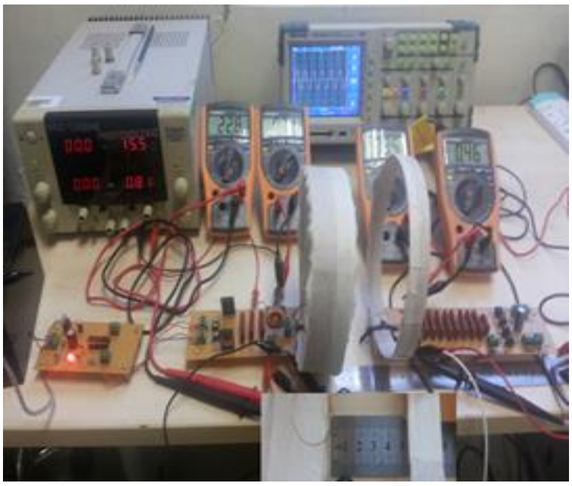


Figure 3. Experimental set up on the constant distance

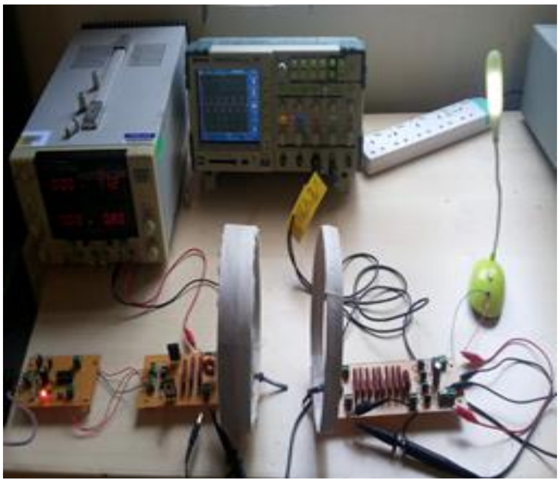


Figure 4. Experimental setup for the 2.5 kHz WPT connected to DC loads

## 3. RESULTS AND DISCUSSION

2.5 kHz WPT system is designed to have a capability to transfer DC voltage source using the concept of electromagnetic principle generated by transmitter coil which it is solenoid concept. 2.5 kHz WPT system has a good performance and stable in the process of transferring power. It means that the 2.5 kHz WPT system can respond well the change of DC voltage source on the input terminal of transmitter side. The pulse wave driver circuit can generate well 2.5 kHz pulse wave by pin 11 and 12 of microcontroller PIC16F628A. These two pulse waves drive the two MOSFET IRFP 460 to generate the 2.5 kHz sinusoidal voltage waveform on the transmitter coil and transmits to the receiver coil based on the concept of electromagnetic principle. An experimental setup has been conducted to prove this concept and their results as stated and explained in this sub section.

### 3.1. 1 pulse and sinusoidal voltage waveform on transmitter and receiver side

A measurement of pulse wave on the pin 11 and 12 of microcontroller PIC16F628A has been conducted following Figure 2. The measurement use tektronik oscilloscope. Its objective is to prove that the pulse wave generated by microcontroller PIC16F628A has frequency of 2.5 kHz as shown in Figure 5. The sinusoidal AC voltage waveform of transmitter and receiver coil for the receiver solenoid diameter of 16.6 cm is shown in Figure 6.

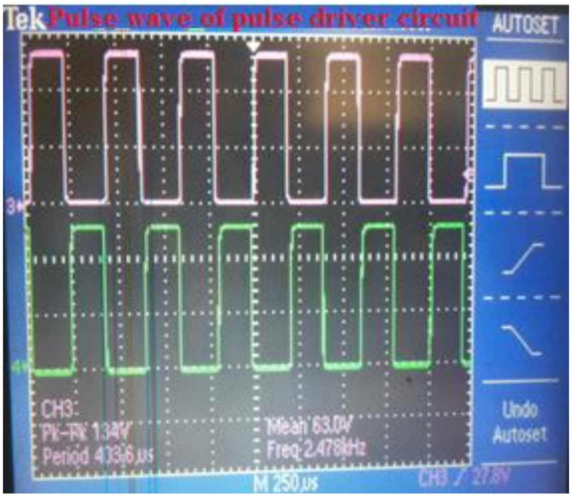



Figure 5. Pulse wave of pulse driver circuit on the pin pin 11 and 12 of microcontroller PIC16F628A

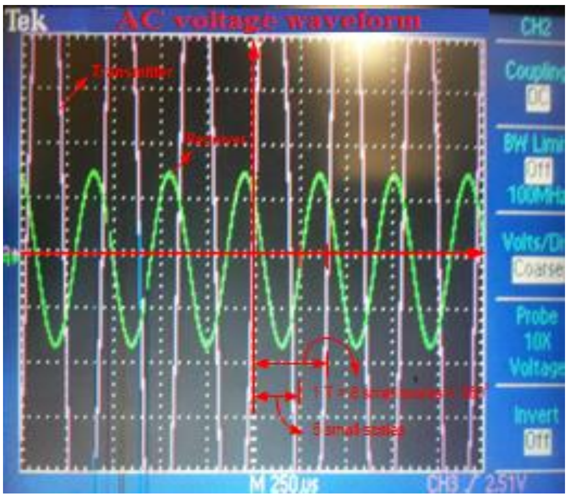



Figure 6. AC voltage waveform on transmitter and receiver coil for receiver solenoid diameter of 16.6 cm

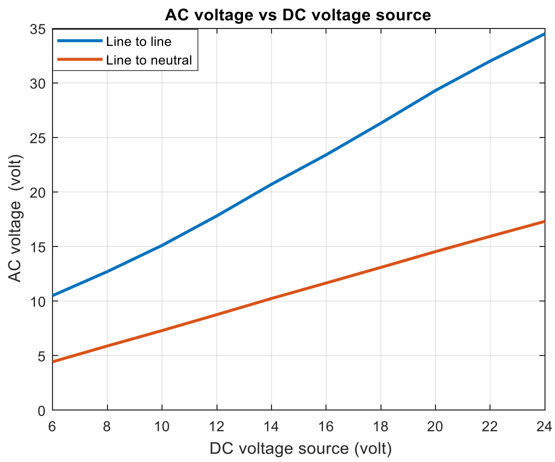
The transmitter coil of WPT system has a centre tap because the type of bridge circuit is half bridge circuit and measurement of AC voltage on the transmitter coil is on the position of line to line. Normally, the line to line voltage of transmitter coil is equal to twice of the line to neutral voltage. The measurement is done on the distance of 5 cm between transmitter and receiver coil for DC voltage source of 18 V at the input terminal of transmitter side and the receiver coil is not connected to the rectifier circuit.

The line to line AC voltage and line to neutral AC voltage of transmitter coil are 26.30 V and 13.06 V, respectively. The AC voltage of receiver coil is 4.2 V. By observing the AC voltage waveform of transmitter coil that it has period, T=8 small scales=360$^0$, thus 1 small scale is 45$^0$. The AC voltage waveform of receiver coil appears 5 small scales=225$^0$ after appearing the AC voltage waveform of transmitter coil. It indicates that the AC voltage waveform of receiver coil leads the AC voltage wave form of the receiver coil by 225$^0$ and it means that the transmitter side is more inductive compared to the receiver side of WPT system

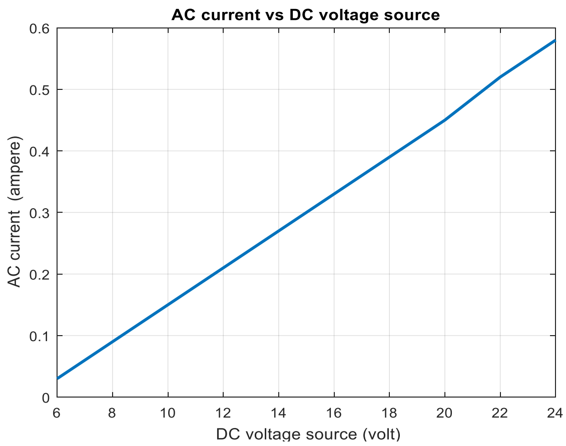
### 3.2. Effect of DC voltage change on the WPT system

The effect of DC voltage source change on the AC voltage and current of transmitter coil and also on the AC voltage and current of receiver coil for the constant distance of transmitter and receiver coil of 5 cm as shown in Figure 7 and Figure 8. It is applied on the condition that the rectifier circuit is not connected to the receiver coil.

Figure 7 and Figure 8 show that for the constant distance between the transmitter and receiver coil, if the DC voltage source on the input terminal of transmitter side is increased, thus the AC voltage and current of transmitter and receiver coil will increase also. It is due to the DC voltage source is main DC voltage source and its positive polarity is directly fed to the centre tap of transmitter coil and its negative polarity is connected to the negative of transmitter circuit. The magnitude of DC voltage source is directly converted to be AC voltage by switching the MOSFETs in the half bridge circuit. When the magnitude of AC voltage generated by transmitter coil is increased, thus the magnitude of AC voltage of receiver coil will increase also. It is due to the magnetic field generated and arrive the receiver coil is proportional to the AC voltage.




(a)




(b)

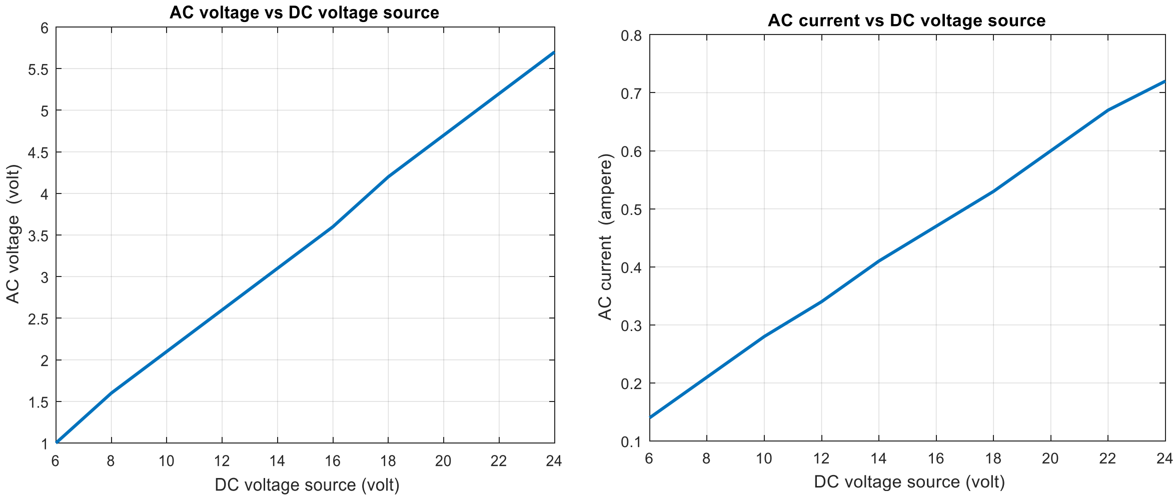
Figure 7. Effect of DC voltage source change on the AC voltage and current of transmitter coil (a) AC voltage, (b) AC current

Based on the Figure 7 and Figure 8, it can be seen that the AC voltage of transmitter, $V_t$ is higher than the AC voltage of receiver coil, $V_r$, but the AC current of receiver coil, $I_r$is higher than the AC current of transmitter coil, $I_t$. It is due to the turn number of transmitter coil, $N_t$=78 turns is higher than the turn number of receiver coil, $N_r$=42 turns. It is following a characteristic of magnetic circuit with a transmitter material media. In this case, air is as transmitter material media and the comparison of the AC current of transmitter coil, $I_t$ and the AC current of receiver coil, $I_r$ is explained below.

$$\frac{I_t}{I_r} = \frac{N_r}{N_t}$$

$$I_r = \frac{N_t}{N_r} x I_t$$

When the turn number of transmitter coil, $N_t$is higher than the turn number of receiver coil, $N_r$.It means that the comparison of $N_t$: $N_r$> 1, thus the AC current of receiver coil, $I_r$ is higher than the AC current of transmitter coil, $I_t$.




(a) (b)

Figure 8. Effect of DC voltage source change on the AC voltage and current of receiver coil (a) AC voltage, (b) AC current

The function of rectifier circuit on the receiver side of WPT system is to rectify the AC voltage of receiver coil. Figure 9shows the AC voltage waveform of receiver coil that it is rectified by rectifier circuit. It is tested on the DC voltage source of 18 V that produce the rms AC voltage of receiver coil of 4.2 V and the DC voltage output of rectifier of 6.18 V for the distance between transmitter and receiver coil is 5 cm. The DC voltage source changes the open circuit voltage of rectifier circuit. The increasing DC voltage source causes the increasing of rms AC voltage of receiver and the open circuit voltage of rectifier circuit as shown in Figure 10.

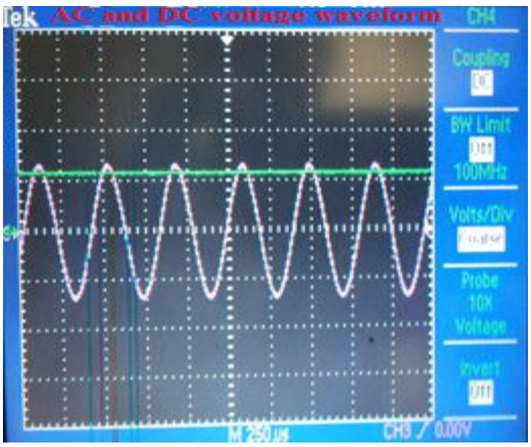



Figure 9. AC voltage waveform of receiver coil and DC voltage output of rectifier circuit

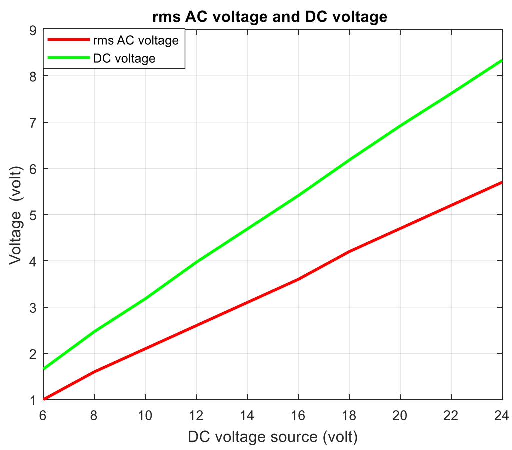



Figure 10. rms AC voltage of receiver coil and open circuit voltage of rectifier circuit

## 4. CONCLUSION

The magnetic field density and power on the receiver side of WPT system are affected by the magnitude of DC voltage source converted to be AC voltage and AC current that flows through the transmitter coil for the turn number of transmitter coil. The magnitude of AC current that flows through the transmitter coil depends on the level of DC voltage source. The increasing of DC voltage source causes the increasing of AC current and magnetic field density on the transmitter coil and increasing the capability of arriving magnetic field on the receiver coil, lastly the DC power rectified by the rectifier circuit will also increase.

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