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A Cost-Effective System for Wireless Power Transmission

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Abstract— **In recent years, the notion of transfer of power using wireless techniques has attracted many researchers. Transfer of power by wireless means has been recently demonstrated in the Massachusetts Institute of Technology (MIT). This system operates at 9.9 MHz. In this paper, we have discussed the design of a simple and cost-effective system which can enable transmission of power over short distances. We have employed the H – Bridge Inverter configuration to convert DC power to high frequency (100 kHz) which is then radiated with the help of a suitable loop antenna. It is observed that this system can also be used as a induction heating unit. In this form it can be used to replace conventional convection heating based electric stoves.**

Keywords-Induction heating; H-Bridge inverter; wirelesspower transmission

I. INTRODUCTION

Wireless power transmission is still in its infancy as a topic. Although devices and applications have been designed that transmit power over short distances, their price and design complexity keep them out of the reach of ordinary users. There is a need for a simple, efficient and cost-effective system which can create the changing electromagnetic field required to initiate wireless power transfer. In addition, this can be used to heat vessels as an induction coil based stove. By suitably replacing the induction coil element with an efficient antenna, the system can be applied to deliver limited amounts of power wirelessly, for small applications like the charging of mobile handsets, or laptops. The aim is to design a system that can be constructed from easily available and low cost electronic components, thus facilitating the transfer of this technology for the benefit of humanity.

The fundamental principle guiding this system is the use of a suitable inverter circuit to convert D.C voltage into an alternating supply. Such an alternating voltage would create a rapidly changing magnetic flux, as per the equation:

$$\phi = B * A * \cos\theta \qquad (1)$$

where ‘ϕ’ is the magnetic flux, ‘B’ is the magnetic field density, ‘A’ is the cross sectional area of the loop and ‘θ’ is the angle between the magnetic field density and the surface of the loop.

This flux change induces an e.m.f (electromotive force) in any wire loop or metal surface that cuts the magnetic flux lines. Such an e.m.f, if suitably tapped, can be used either for heating (where it manifests itself in the form of eddy currents in the vessel to be heated) or for wireless power transfer.

II. SYSTEM DESIGN

The goal is to develop a system capable of operating at a frequency of 100 KHz, with an inverter supply voltage of 300V DC. This frequency is chosen because efficient low cost power MOSFET switches can be operated efficiently at these frequencies. If the frequency of operation is further increased, we will have to use expensive power devices which would not be readily available and would increase the cost of the system.

The system as designed by us can be partitioned into 4 functional blocks, as described in Figure 1.

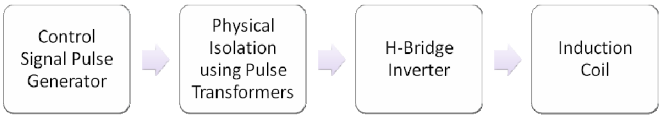

Figure 1. Functional Diagram

A. Design of Control Signal Waveforms

It is required to produce two sets of non-overlapping pulses to drive the inverter circuit. The SG3524 circuit manufactured by Philips semiconductor is ideal for this purpose. As detailed in [5], it allows for duty ratio variation up to a maximum of 40%. In addition, a blanking pulse to both outputs rules out the possibility of pulse overlap. The SG3524 is connected as shown in figure 2 with the output pulses seen at pins 11 and 14.

B. Physical Isolation

The H-bridge inverter employs high side and low side switches (four switches in all). The pulses used to drive the high side switches are derived from the pulses used to drive the low side switches. However, physical isolation using a suitable isolating technique needs to be implemented before these pulses are used to drive the high side MOSFETs. This precaution is essential, for if the same signal is used to drive both the high side and low side MOSFETs in the circuit without physical isolation, a short circuit will result due to creation of a parasitic path between the ground and the source of the high side MOSFET. This can result in serious damage to the MOSFET switches.

Physical isolation of the high side drive waveforms can be implemented using several methods. One such method is to use a high side driver which is available from several manufacturers. However, we have used pulse transformers to realize this function in the interests of simplicity, ease of availability and low cost.

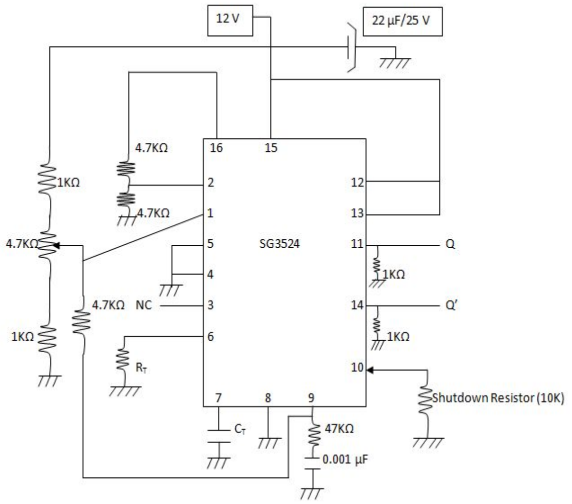

Figure 2. Control Signal Pulse Generator

A 1:1:1 pulse transformer is used. The output of the SG3524 is used to drive the primary winding of the transformer after suitable current amplification. Current amplification becomes necessary because the outputs of the SG3524 are not designed to drive inductive loads directly. The drive waveform is replicated at the two secondary windings which are physically isolated from the primary windings. A free wheeling diode (BA 159) is connected across the primary winding of the transformer. A combination of a resistor and a zener diode is used across the secondary windings of the transformer to obtain pulses suitable for driving the MOSFET switches. These details are described in Figure 3. A discussion of driver circuits suitable for use in various inverter configurations can be found in [1].

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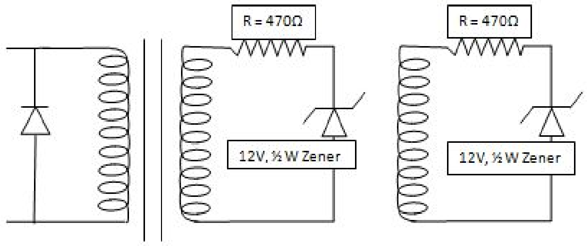

Figure 3. Pulse Transformer Arrangement

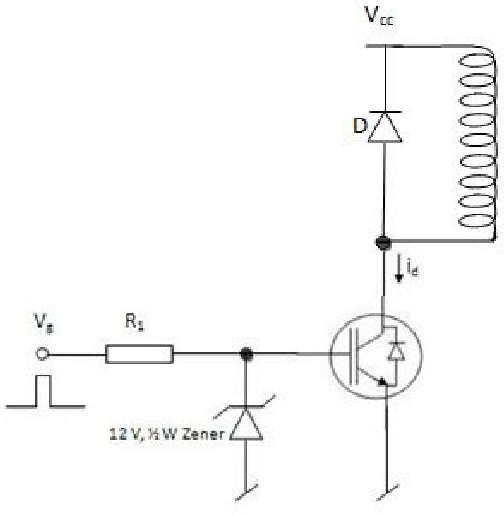

Figure 4. Driver Circuit

C. Inverter Circuit

The outputs from the secondary windings of the pulse transformers are sent to the H-bridge inverter circuit detailed in Figure 5.

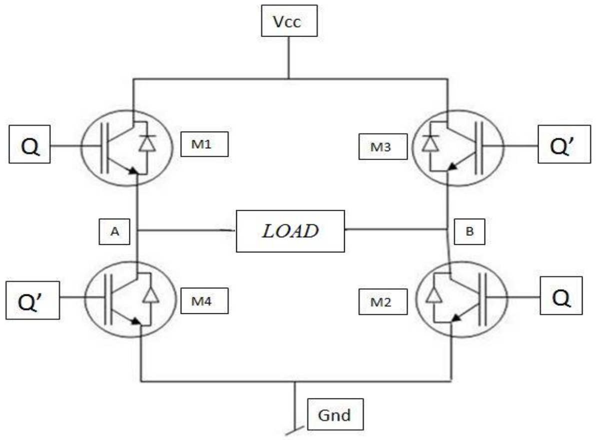

Figure 5. H-Bridge Inverter

One of the advantages of using an H-bridge inverter is that the load experiences a peak-to-peak voltage of 2Vcc. The inverter works in the required manner i.e. when Q is high, M1 and M2 are turned ON and current flows from Vcc to Gnd via the path M1- - A -- Load -- B -- M2. At this stage, the other two MOSFETs will not be conducting because their input Q' will be low. When Q becomes low turning Off M1 and M2, Q' becomes high after sometime, which turns on M3 and M4. Now, the current flows from Vcc to Gnd via the path M3 -- B -- Load -- A -- M4.

The power MOSFETs used to build the inverter are of type IRFPG50. As per [4], the V_{DS}=1000 V, $I_{D\,(max)}$ = 6.1 Amp and on resistance R_{on} =2 ohms.

D. Load

1) Induction Coil Design

A wide variety of coil designs are described in literature [2]. The choice of shape depends on the nature of radiation pattern to be established (if the application is wireless power transfer) and the shape of the vessel to be heated (if the system is also to be employed as an induction cooking unit). We have found the pancake design to be most suitable for a wide range of applications. Hence, we have designed and fabricated a pancake coil shown in Figure 6 for use in this system. As a result of the pancake coil design, the energy is focused in the region of space immediately above the surface of the coil. It is mentioned in literature [2], that the coupling efficiency increases with frequency. It has been documented [2] that the coupling efficiency of pancake coil with magnetic steel is 0.35 at a frequency of 10 Hz and this figure increases to 0.5 at a frequency of 450 kHz. It is for this reason that we have chosen an operating frequency of 100 kHz.

The pancake coil is constructed out of enamel-coated copper of size SWG 22. Giving a clearance of approx. 1.5 cm on each side, and the gap between subsequent turns at 3mm, the length of wire required is estimated to be 20m before braiding. Nails are placed on the board in perpendicular directions at the specified interval to keep the coil in place while winding. After winding is completed, further nails are driven in to ensure no two consecutive turns are touching each other. In order to make the coil permanent, the gaps are filled with Araldite adhesive and allowed to set overnight, after which the nails are removed. On analyzing the coil characteristics, its parameters were found to be:

$L = 60.2\ \mu H$.

$R = 0.790\ \Omega$.

Figure 6. Induction coil

2) Snubber circuit

Due to the high speed switching coupled with the presence of an inductive load, the switch experiences a huge amount of back e.m.f during the turn off stage described by the equation:

$$E = -L*(di/dt) \quad (2)$$

where 'E' is the induced e.m.f, 'L' is the inductance of the coil, and 'di/dt' is the change in current with respect to time.

This leads to the spikes in voltage across the switches, which can damage the device in the long term. In order to combat these spikes, turn-off snubber circuits described in [1] have been designed and put in place across every switch to absorb the back e.m.f and protect the device.

The value of Capacitance and Resistance are given by the following equations:

$$C = i_L * t_f / (2V_{cc}) \quad (3)$$

$$V_{cc}/ (I_{cm}-i_L) < R < T_{on\text{-}min}/5C \quad (4)$$

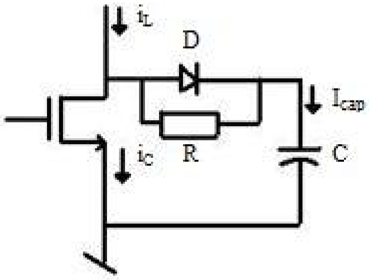

Figure 7. Turn- OFF Snubber Circuit

where i_L is the load current at the collector, t_f is the fall time of the signal, I_{cm} is the maximum collector current rating of the MOSFET, and $T_{on\text{-}min}$ is the minimum time during which the MOSFET should remain ON so that the capacitor can fully discharge.

Assuming i_L to be 3A and t_f to be 0.12 µSec and since we are operating at a V_{cc} of 200V, C is found to be 1nF with 1 kV rating. As per device characteristics, I_{cm} and $T_{on\text{-}min}$ were found to be 8A and 4 µSec respectively since the duty ratio is 40%. From these, we choose the resistance value to be 470Ω.

Figure 8. Waveform across the load without snubber circuits

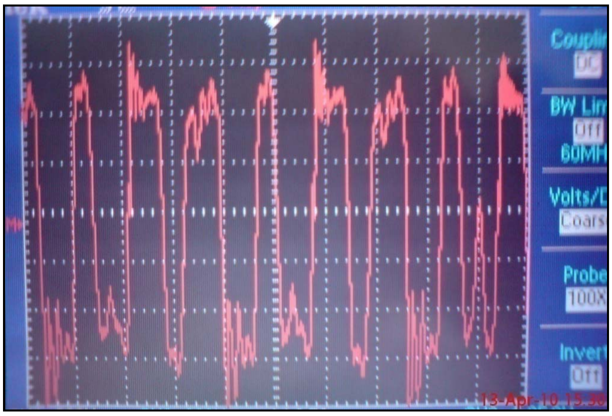

Figure 9. Waveform across the load with the snubber circuits

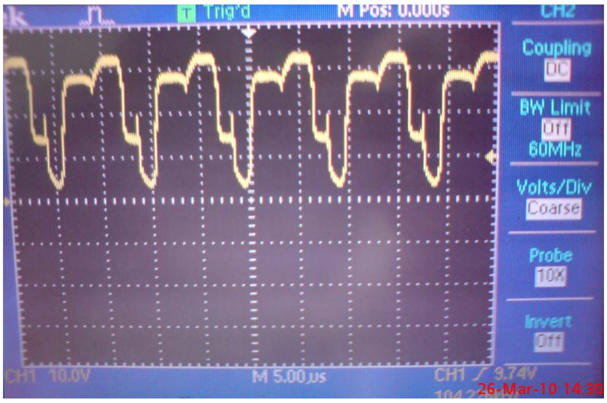

Figure 10. Waveform at A in Figure 5

III. RESULTS

The addition of snubber circuits lead to signification suppression of spikes across the switching devices as shown in figures 8 and 9. On connecting the circuit to the Induction Coil in series with a 60W bulb at an operating voltage of 60V, the waveforms listed in Figures 10, 11 and 12 were observed. We increased the operating voltage to 120 V. When a coil of wire (closed wire loop) connected to a 6V bulb was brought close to the Induction coil, it was observed to light up. This is shown in Figure 11. A few observations were noted:

- On increasing the distance between the loop and the coil, the glow of the bulb gradually diminishes.
- For a given distance, the intensity of the bulb's glow is maximum when the surface of the wire loop is parallel to the surface of the coil. The intensity reduces when the loop is placed at an angle to the coil.
- For a given distance, the intensity of the bulb's glow is maximum when the loop is placed near the centre of the coil, and reduces as the loop is moved away from the coil.

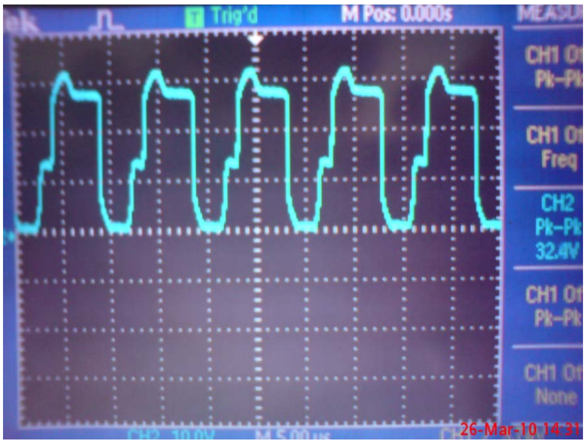

Figure 11. Waveform at B in Figure 5

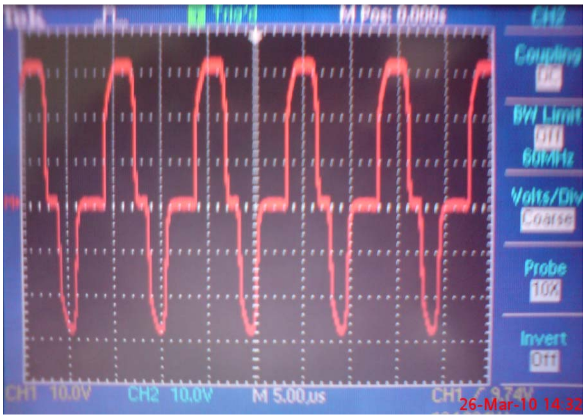

Figure 12. Waveform across the LOAD in Figure 5.

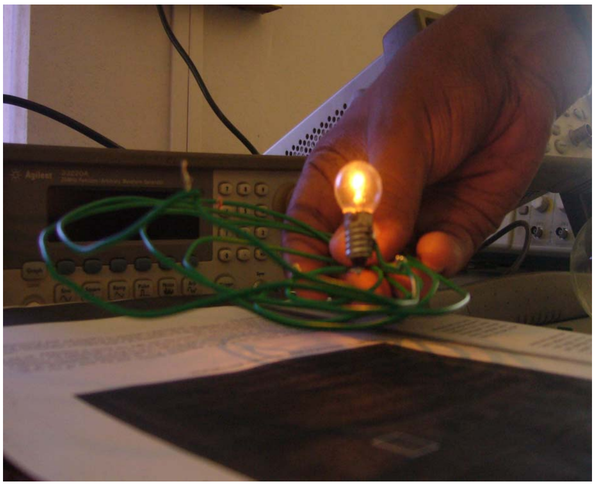

Figure 13. 6V bulb lighting up when placed next to the coil.

Thus, it is demonstrated that wireless power transmission is practically possible on such a system.

IV. CONCLUSIONS

The system provides conclusive evidence that despite the absence of an antenna of suitable directivity, a sizeable amount of power can be wirelessly transmitted over short distances. The next step in the development of this system is to design and build a helical transmitter and receiver antenna system of suitable dimensions, which can increase the distance of transmission by improving directivity and gain. By increasing the operating voltage through repeated testing, the Coil can be applied for use as a heating stove.

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