IMPLEMENTING AN ELECTRICALLY ISOLATED POWER SUPPLY FOR IGBT GATE DRIVERS USING ULTRASONIC AIR TRANSDUCERS

Alam Ali[1], Tahir Izhar[2]

[1,2]Department of Electrical Engineering, University of Engineering and Technology, Main GT Road, Lahore

[1]Abdulalamali@gmail.com, [2]Tizhar@gmail.com

ABSTRACT— *This paper primarily investigates the method to build a regulated and electrically isolated power supply which can deliver a constant voltage and power of $15V - 50mW$ with at least $30cm$ of isolation distance between both circuits. This paper proposes an innovative and a completely new method to build an isolated power supply through acoustic energy transfer mechanism where piezoelectric transducers produce and absorb ultrasound waves. This energy transfer through ultrasound waves drive the gate of an IGBT for usage in applications of voltage source converters. Ultrasound transmission system is adopted due to its low cost, complete immunity from electrical and magnetic fields, ruggedness in construction and less complexity in building it.*

Keywords—piezoelectric transducers, IGBTs, gate drivers, acoustic energy transfer, flyback converter

INTRODUCTION

A. Outline of research

This research paper proposes to build a regulated and stable isolated power supply which can deliver $50mW/15V$ of power at an isolation distance of at least $30cm$. Knowledge about series and parallel resonance, impedance matching, standing waves and acoustic characteristics of isolation medium were employed in getting the maximum power output.

Fluctuations in output voltage from the power supply can be stabilized by a controlled DC-DC flyback converter. In conclusion, we successfully constructed a model for transferring $50mW/15V$ at an isolation distance of about $40cm$ using air transducers, but the efficiency achieved was only 8% due to huge power losses in the isolation medium due to reflection and attenuation of sound waves.

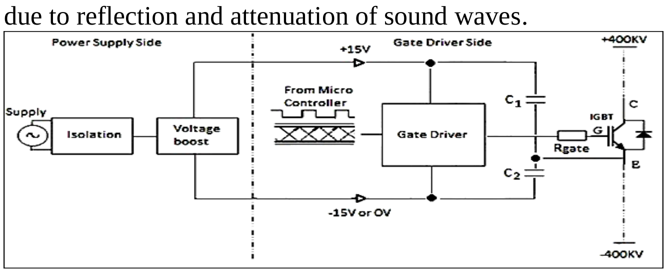

Fig 1: Circuit layout of IGBT gate driver.

B. Need for building an isolation medium for energy transfer

Direct connection of a low voltage gate driving circuit ($\pm 15V$) with the high voltage switching circuit ($\pm 450KV$) can produce many problems and can negatively affect the operation of IGBT gate driving. This can result in large power failures and blackouts and swift replacement of converters can be very costly [1].

Switching IGBTs at high voltage generates a rapidly changing electric field. This dE/dt effect generates huge electromagnetic interference (EMI), high temperature discharges of corona and high electric field at the converter leg causes ionization of air in the conducting medium which causes flashovers and degrades the performance of converters [1, 2]. If the power supply of gate driver circuit is not electrically isolated, the IGBT gate circuit can get damaged due to huge electromagnetic fluctuations leading to complete system failures.

C. Experimental assembly

Experimental assembly of this system is shown in figure 2 below. A sine wave is generated by the waveform generator and is then amplified to $20Vrms$ using an audio amplifier. This sinusoidal signal is then applied to the transmitter transducer which produces sound waves. These sound waves travel through the isolated medium to the receiver transducer which converts these sound waves back into electrical energy. Air enclosed in a tube was tested for proving this idea of building an isolated power supply through acoustics.

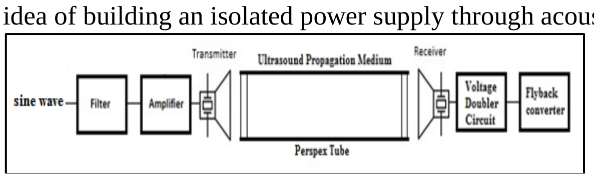

Fig 2: Experimental setup of our proposed system through acoustic energy transfer [3].

I. LITERATURE REVIEW

A. Background study

As the demand for high voltage switching is increasing, especially for HVDC systems, the search for better performance devices has increased as well. In this paper, IGBTs are proposed as they offer much better performance and advantages such as lower conduction losses, high voltage/current rating, fast switching, and easy gate driving capabilities [1].

Nowadays, applications like HVDC require hundreds of kWs of voltage on their converter legs, which cannot be accomplished by a single device, so hundreds of IGBT's are required in series to operate at the same time. Each IGBT requires a gate driver which is needed to be well isolated from its control circuit electronics and its power supply that is driving it [2]. Power supplies are needed for the gate drivers to amplify low power control signals received by the gate driver circuit to provide high output current for large IGBT modules.

The main focus of this research paper is on the isolation requirement for power supply of gate drive circuit of an IGBT. The power supply must be completely isolated to ensure safety of low voltage power supply circuit from high voltage IGBT converter circuit. Isolation is necessary to avoid high speed switching noises and voltages of power devices from interfering the control circuits. As a huge number of IGBT's are to be driven simultaneously, there is a need for developing a better, cheaper and robust isolated power supply for them.

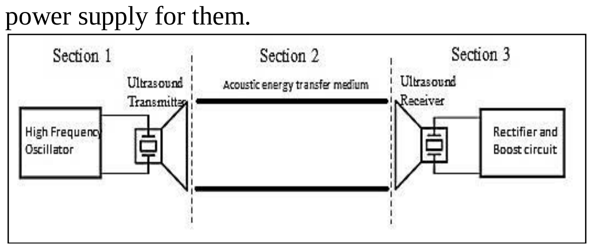

Fig 3: Three sections of acoustic energy transfer system [4].

B. Motivation for this study

We propose an alternative method of providing isolation by introducing an acoustic energy transfer medium between the gate driver circuit of switching device and its power supply circuit and investigating this experimental assembly.

The experimental tests will require materials that are inexpensive, and robust and rugged in construction such as solid tubes, piezoelectric transducers and all the electronics involved in building this system is cheap and easily and readily available from the market. Moreover, the size of transduces to be used in this research are relatively smaller, which gives us flexibility to experiment with more number of transducers such as series connection to get the required power output [5]. Using this method of isolation avoids voltage grading effects of transformer, electromagnetic interference problems and requirement for electric shielding and complexity and sensitivity that other methods possess [6].

The main motivation is that if this project achieves its main objective of delivering 15v-50mW, it would greatly reduce the cost, complexity, size and reliability of IGBT gate driving electronics. The conclusion from these experiments can help us determine the feasibility of creating an isolation medium through acoustics.

C. Overview of existing methods of building an isolated power supply

The current methods of energy transfer which include IPT (Inductive power transfer) and CPT (Capacitive power transfer) have limitations of rapid decrease in efficiency with distance, electromagnetic coupling, capacitive coupling [7], so they are not suitable for building an electrically isolated supply for gate drivers. Photo-couplers cannot operate at high temperatures as it reduces their working life so they are not suitable as well [8]. Acoustic energy transfer offers total immunity from electrical noise and interference and complete isolation of the power source which makes acoustic energy transfer a much better alternative [9].

If a power supply is designed with a transformer, structure of transformer becomes too bulky and complex due to very high insulation requirements, even if we have more isolated outputs from multi-winding transformer, the complexity and bulkiness of the system remains [10]. Wireless power transfer by optical beam is known to be best for transmission over longer distances [8] as many current power electronic companies are using it in their products. Using high powered laser diode and photovoltaic (PV) system with fiber optics has limitations as well. While transmitting power through fiber optics, effects like fiber fusing, end point damage, bending failures and losses due to laser coupling have to be accounted for [9]. The benefits of acoustic energy transfer are insensitivity to voltage fluctuations and electromagnetic disturbances in the area of high voltage operation and cheap and smaller sized transducers deluge other technologies [11, 12].

II. METHODOLOGY OF RESEARCH

A. Voltage and power calculation for transmitter-receiver transducer pair

The methodology of research is getting the required voltage and power for amplification of low power control signal for driving the gate of an IGBT. After getting the required air transducer and acoustic material for medium, practical building of equipment is carried out to get the maximum possible power output.

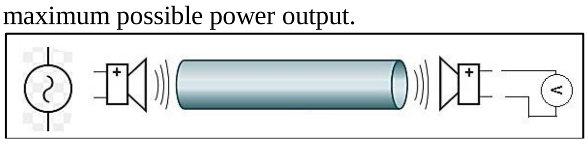

Fig 4: Diagram for acoustic energy transfer [13].

B. Design of an audio amplifier circuit

The signal generator present in the Lab is capable of giving $6Vrms$ sinusoidal signal which is further amplified using an audio amplifier to get the required output voltage of $20Vrms$ for driving the transmitter transducer. The resistors needed for getting the required gain are calculated:

$$A_v(gain) = 1 + \frac{R_1}{R_2} 1 + \frac{12k\Omega}{5k\Omega} = 3.42$$

$$R_1 = 12k\Omega \; and \; R_2 = 5k\Omega \; selected$$

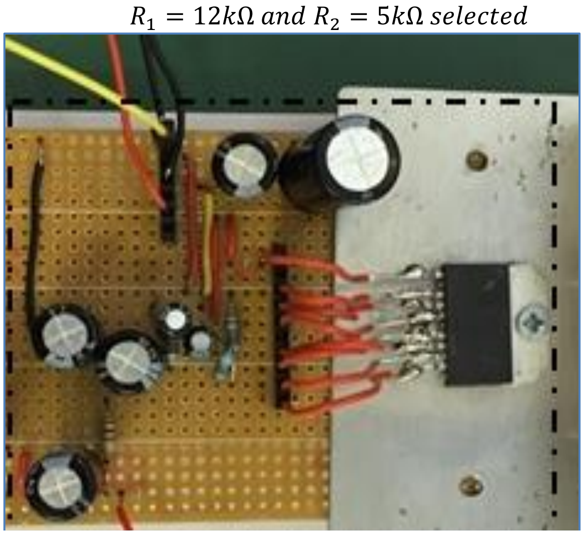

Fig 5: Audio amplifier circuit.

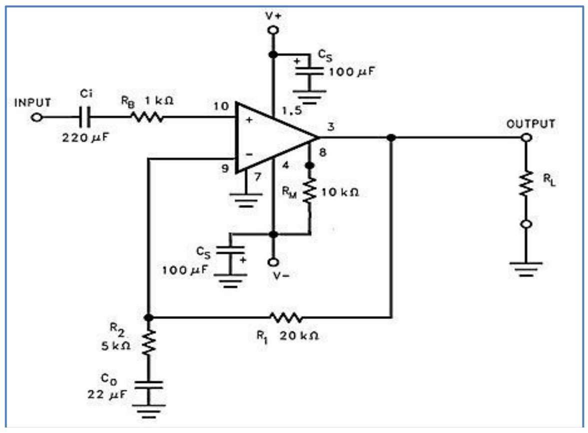

Fig 6: Circuit diagram of a non-inverting audio amplifier.

C. Specifications of air transducers used

TCT40-16R/T were selected as the piezoelectric air transducers as they were easily available in the market and low cost. They had an external diameter of 16mm and the maximum input driving voltage required for them was $20Vrms$. The sound pressure level created is $120dB$ and attenuation of sound pressure level is $-10dB$ and they work in a bandwidth of $5kHz$. The capacitance of these transducers is around $2{,}500pF$ and the frequency required for generating ultrasounds is 40 ± 2 kHz. The weigh $5g$ and their minimum sensitivity is $-60dB/V/\mu bar$.

D. Conditions of all experiments performed

The isolation medium used was Perspex tube having a diameter of $16mm$ and air was used as a material inside this medium. The voltage at transmitter transducer was set as $20Vrms$ and the frequency of excitation used was $40kHz$. The distance between transducers was kept at $37.2cm$ for experiment 1 and was varied in the range of $0cm < distance < 42.2cm$ for experiment 2. For experiment 3, the frequency of transmitter transducer was changed in the range between $36kHz < f < 44kHz$ and was fixed at $40kHz$ for experiment 4 and 5.

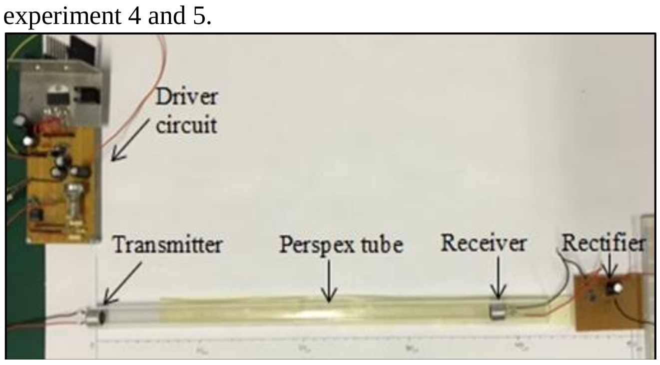

Fig 7: Testing setup for measuring the output voltage at receiver transducer.

III. RESULTS WITH AIR TRANSDUCERS

A. Flow chart of experiments

The figure below shows the flowchart of experiments conducted on these air transducers.

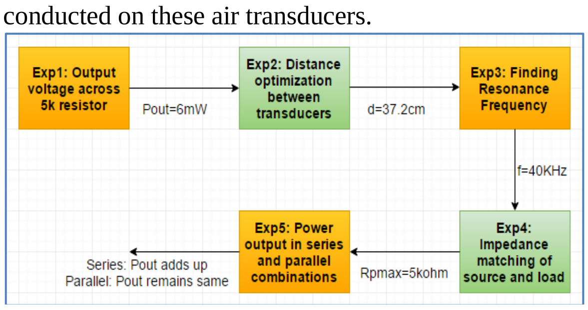

Fig 8: Flowchart of experiments performed on air transducers.

B. Sequence of experiments performed on ultrasonic air transducers

In experiment 1, we got an output voltage of $6mW$ across a $5k\Omega$ resistor which was well below the required output voltage of at least $50mW$. So, we performed experiment 2 where distance optimization was done by finding the resonance point between both the transducers and the optimal resonance distance achieved was $d = 37.2cm$.

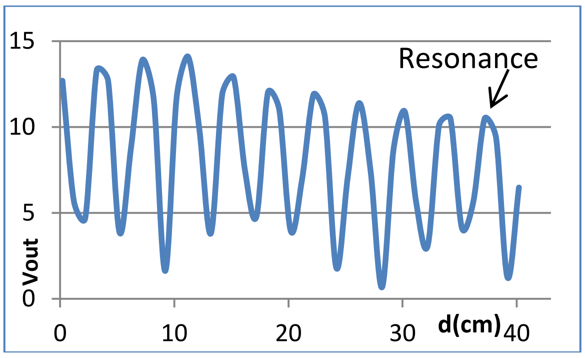

Fig 9: Output voltage plotted versus distance.

Next, experiment 3 was performed where the exact resonance frequency of transmitting transducer was found by conducting a frequency scan in the range of $36kHz < f < 44kHz$.

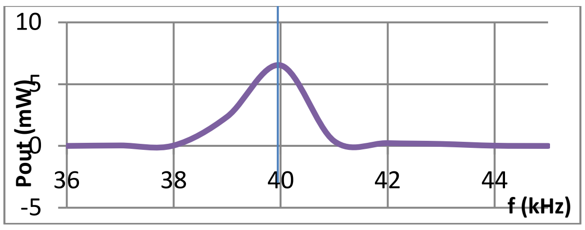

Fig 10: Plot of power output versus frequency.

An experiment 4 was conducted for finding the value of load resistance which is required to match with the source impedance for maximum power transfer. It was conducted in the range of $50\Omega - 500k\Omega$ and the power output at each resistance value was calculated.

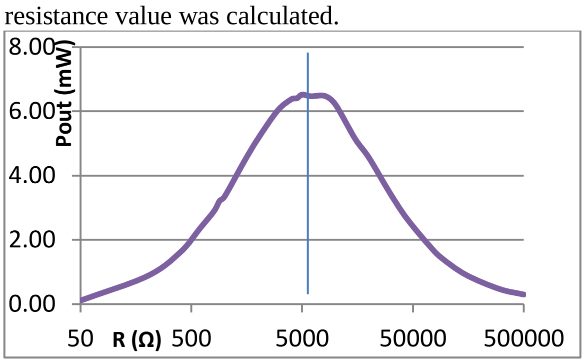

Fig 11: Plot of power output versus load resistance for impedance matching.

The required power output of $50mW$ was still not achieved as there are power losses in acoustic medium to reflections and attenuations of sound waves [13]. In experiment 5, two pairs of transducers were connected in series combination to get an addition of power output from each receiver transducer to get the required power of $50mW$ for building an isolated supply.

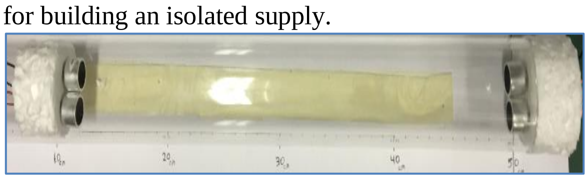

Fig 11: Experimental setup for testing two pairs of transducers which are connected in series.

Theoretical background tells that the impedance of source to be matched adds up in series for receiver transducers connected in series. This is proved using the figure below such that the load resistance value in series connected receivers should be $R_{p,max} = 2 \times 5k\Omega = 10k\Omega$.

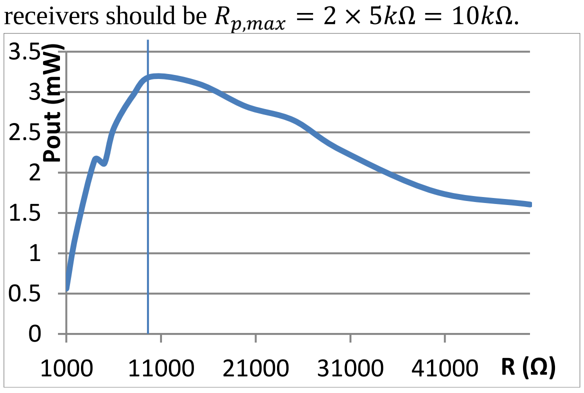

Fig 12: Power output for series connected receivers with different load resistances.

The power output of receiver transducers connected in series combination adds up as shown in below equation:

$$P_{total,series} = P_{out,1} + P_{out,2}$$

$$= 3.52 + 3.08 = 6.60mW \approx 6.23mW$$

Table 1: Addition of power output of receiver transducer 1 and 2 connected in series.

Test No.	P_{out}(mW)
$Rec_{trans,1}$ only	3.52
$Rec_{trans,2}$ only	3.08
$Rec_{trans,1}$ and $Rec_{trans,2}$ in series	6.23

IV. CONCLUSIONS

The results of this experiment show that there is an addition of power output from receiver transducers connected in series. Using the best possible power output of transducers P_{best} from experiment 4 which is $6.54mW$, the total power of the system is the multiplication of this best power P_{best} with the number of series connected receiver transducers N.

$$N = \frac{50mW}{6.54mW} = 7.64 \approx 8$$

This new technique of acoustic isolation can be a game changer in the industry of voltage source converters due to its superior quality, simple working mechanism, cost effectiveness and immunity from electromagnetic effects and easily available components.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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