Design of High-Side MOSFET Driver Using Discrete Components for 24V Operation

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***Abstract*--This paper presents the design of a high-side N-channel MOSFET driver using discrete components for 24Vdc operation. Special level shifting technique is used to increase the gate voltage higher than the supply voltage. Voltage readings at various points of the driver were also taken for reference. The designed high-side driver was tested to observe its performance with respect to different gate input frequencies, from 50Hz up to 150kHz using the MOSFET IRF730 as the switching device. The results obtained indicate that the driver circuit works well up to frequency of 150kHz where the width ratio found to be more than 72%.**

***Index Terms*-- Bootstrap circuit; Floating MOSFET driver; H-bridge inverter design; High-side MOSFET driver; level shifter.**

I. Introduction

It is a common problem in inverter design when a MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) is connected between the load and $+V_{CC}$ of the supply, especially in H-bridge inverter. The high-side MOSFET will not simply operated just by applying the gate voltage (V_{GS}) between 10V to 20V as recommended but a suitable approach must be assigned in order to put the MOSFET into its operating mode.

Custom made ICs are also available such as AN-6076, AN-978 and LM5100A that can be used to drive the high-side MOSFET[1][2][3]. Some designers experienced difficulties in getting the ICs due to certain constrains such as no stock available, long lead time and certainly this is unacceptable to urgent tasks. There are many kinds of circuits that were designed to suit with the requirements. But most of the designs need to connect the driver to the load's terminal where this arrangement will introduces undesirable negative voltage transients into the load voltage[2]. Selection of the bootstrap capacitor for the circuit is quite critical which highly depending on the frequency of operation.

For a typical bridge inverter, it is common to choose either MOSFET or IGBT (Insulated-Gate Bipolar Transistor) as a switching device. They offer several advantages over the BJTs (Bipolar Junction Transistors), ie. very high input impedance, very high switching frequency and low switching loss. The present technology in power electronics circuit, with MOSFETs and IGBTs are preferable due to variety of voltages and currents and also easily available in the market[4].

A MOSFET is a voltage driven device with typical threshold voltage between 3V to 7V. Therefore, it is very important to ensure that the V_{GS} (gate to source voltage) of the MOSFET exceeds the minimum threshold voltage in order to turn it on. In this design, MOSFET IRF730 was used for the inverter circuit as shown in Fig. 1. For optimal operation, the range of V_{GS} is in between 10V to 20V for complete turn-on of the device. Partial turn-on of the MOSFET due to lower V_{GS} may introduce higher R_{DS} (drain to source resistance) and dissipating excessive heat when current flows through it. Thus, an appropriate gate voltage must be applied to drive the MOSFET into its saturation mode during turn-on state.

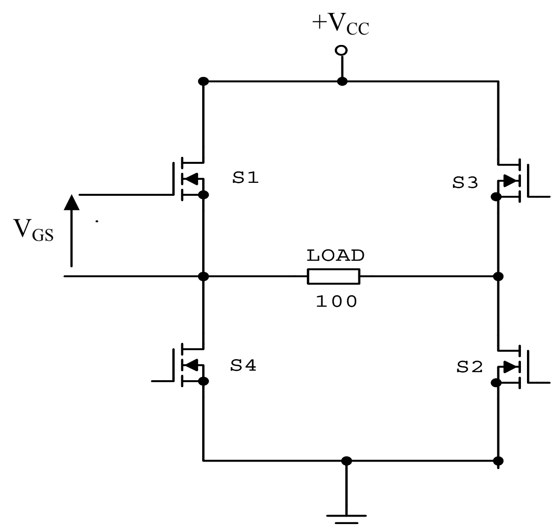

Fig. 1. An H-Bridge inverter circuit.

Turning on the MOSFETs S1 and S3 of the inverter can be quite tricky. At one instance, S1 needs to turn-on so that the top load is at the supply voltage ($+V_{CC}$). But the gate voltage V_{GS} has to exceed the threshold voltage, at least 7V in order to turn S1 on. Therefore by the arrangement, V_{GS} has to be at least 7V higher than the $+V_{CC}$ where this imposed to the complication due to $+V_{CC}$ is the highest available voltage we have to work with[5]. It would not be reasonable to have special higher voltage supply than +Vcc just to turn on the MOSFET. Being a high-side switch, the gate voltage is supposed to be level-shifted higher than the supply voltage when referring to the common ground. The gate must be controlled from certain logic signal which sharing the same ground[6][7][8][9].

II. METHODOLOGY

A high-side MOSFET driver circuit to drive S1 was designed and assembled as shown in Fig. 2. Similarly, the same circuit can be duplicated to drive S3 for bipolar operation.

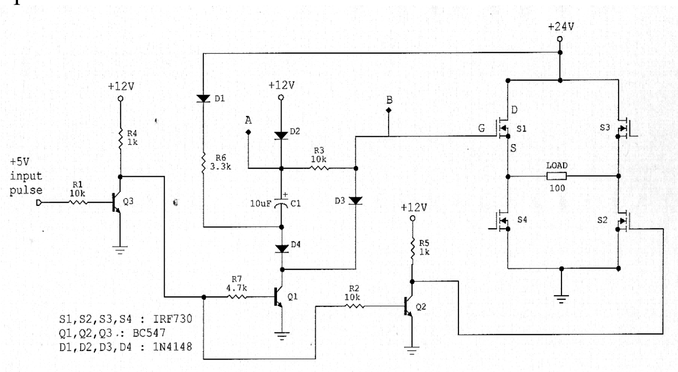

Fig. 2. High-side MOSFET driver circuit.

The significance of the designed driver is the level shifter components that mainly consist of C1, D1, D3 and D4. The function of the level shifter is to add-up the previously stored voltage across C1 with the +Vcc or supply voltage, as described below. This has to be achieved in order to successfully turn-on the MOSFET.

When the +5V input pulse is at low or zero volt, the transistor Q3 is turn-off, consequently turning on the transistors Q1 and Q2, resulting the MOSFET S2 to turn-off . As Q1 is on, the +12V voltage will charge-up across the capacitor C1. On the other hand, the gate terminal of S1 also connected directly to ground through Q1 and turning off S1.

Alternatively, as the input +5V input pulse is at high state, Q3 will turn-on, hence turning off Q1, Q2 and turning on MOSFET S2. As Q1 is in off state, the voltage supply of +24V appears at the collector of Q1 through the diode D1 and add-up to the voltage +12V previously stored across the capacitor C1. Therefore, the voltages at point A and B (as in Fig.2 diagram) with respect to ground would be 36V, thus triggers S1. From the data sheet of IRF730, it is specified that the typical gate threshold voltage (V_{GS}) is 3V, hence any voltage applied across that exceeding 3V will certainly turn it on.

III. RESULTS

A constant +5V dc trigger voltage was applied to the input of the driver, with the transistors (Q1, Q2 &Q3) collector voltage of 12.17V and V_{CC} of 24.39V. Voltage measurements were taken at the specified points referring to Fig. 2 circuit.

The voltage at point A = 36.56V and
the voltage at point B = 36.56V and
the threshold voltage (V_{GS}) = 3.60V

When there was no +5V dc trigger voltage to the input,

The voltage at point A = 11.58V and
the voltage at point B =0.625V
the threshold voltage (V_{GS}) = 0.0V

The frequency response of the driver was tested as shown in Fig. 3 until Fig. 11. CH1 represents switching signal voltage at input side of the driver circuit and CH2 indicates the voltage across the 100 Ohm load resistor.

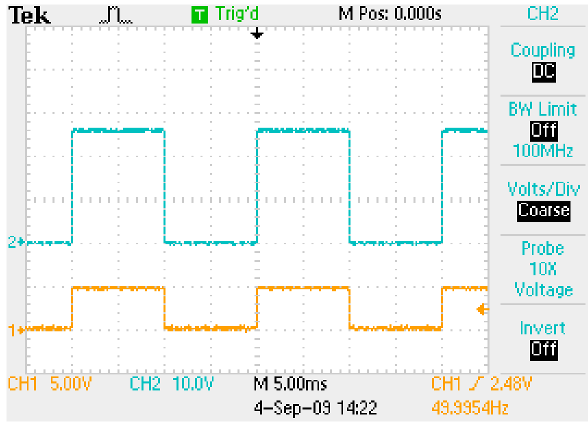

Fig. 3. 50Hz input switching signal.

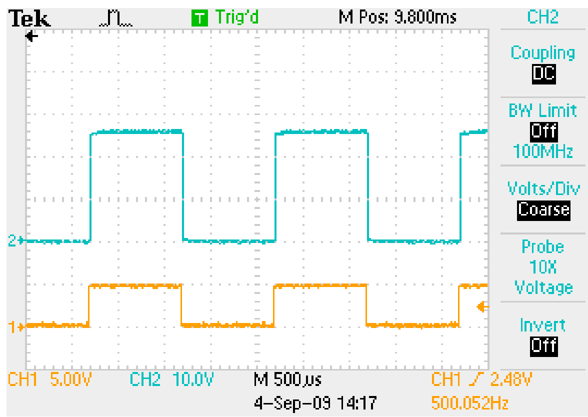

Fig. 4. 500Hz input switching signal.

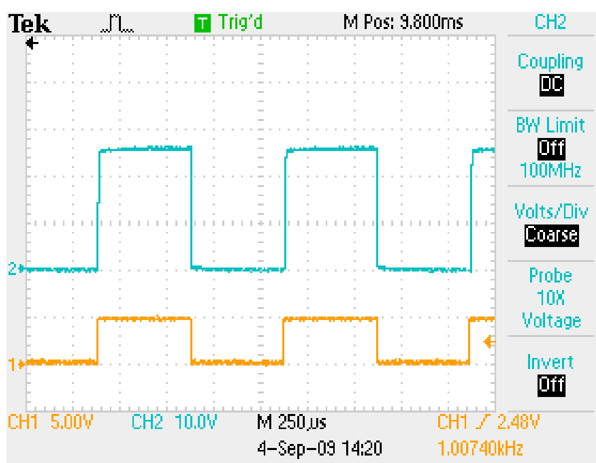

Fig. 5. 1kHz input switching signal.

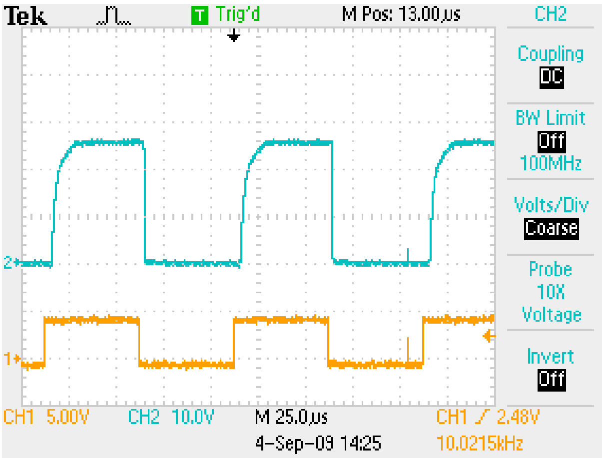

Fig. 6. 10kHz input switching signal.

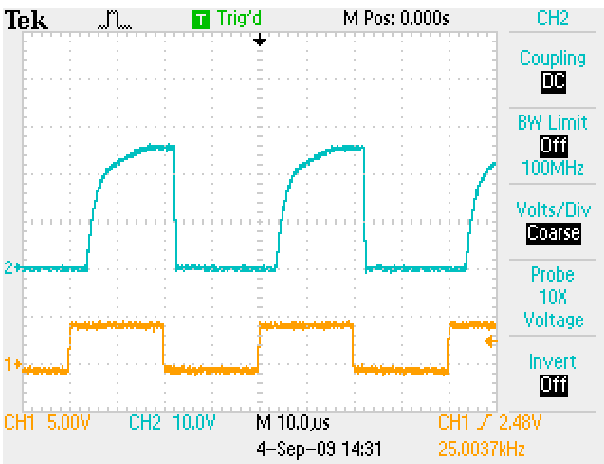

Fig. 7. 25kHz input switching signal.

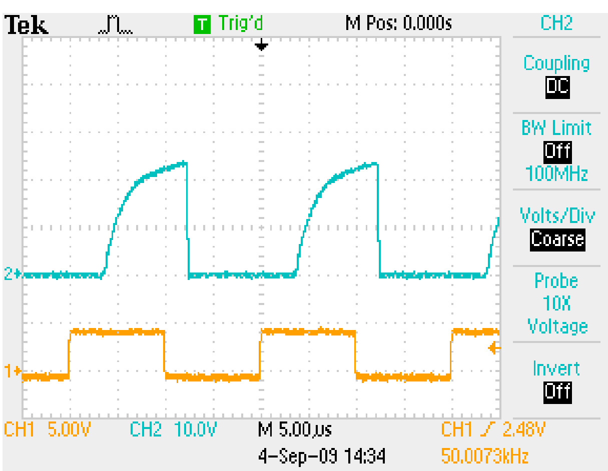

Fig. 8. 50kHz input switching signal.

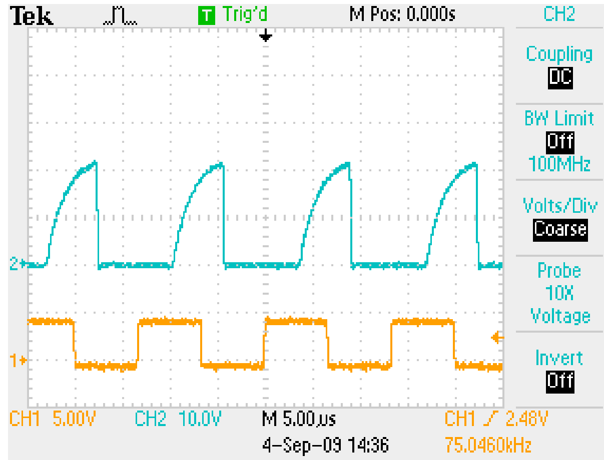

Fig. 9. 75kHz input switching signal.

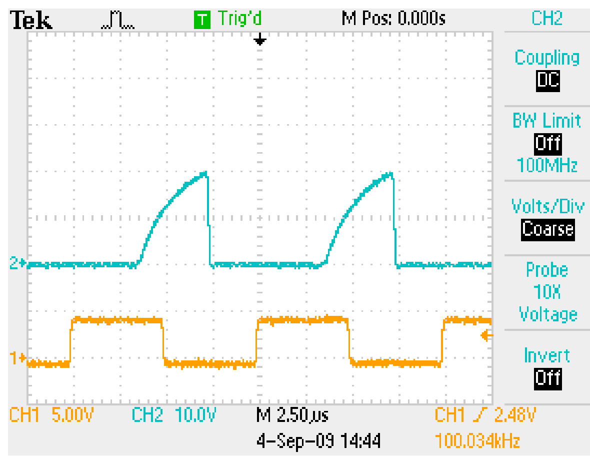

Fig. 10. 100kHz input switching signal.

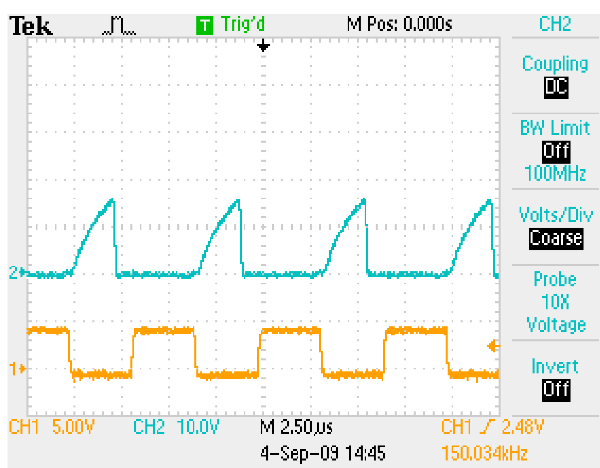

Fig. 11. 150kHz input switching signal.

Table I shows the summary of the results obtained for the input and output widths and the peak voltage output with respect to different input frequencies. The percentage width ratio is calculated from the output width divided by input width.

TABLE I
SUMMARY OF THE RESULTS

Freq. (kHz)	Input Width (μs)	Output Width (μs)	% Width Ratio	Peak Voltage Output (V)
0.05	10000.00	10000.00	100.0	26.4
0.5	1000.00	1000.00	100.0	26.4
1	500.00	500.00	100.0	26.4
10	50.00	50.00	100.0	26.4
25	20.00	18.80	94.0	26.0
50	10.00	8.60	86.0	23.6
75	6.60	5.20	78.8	21.6
100	5.00	3.90	78.0	20.0
150	3.30	2.40	72.7	16.0

The performances of the designed MOSFET driver can be observed from the trends that are shown in Fig. 12 and 13.

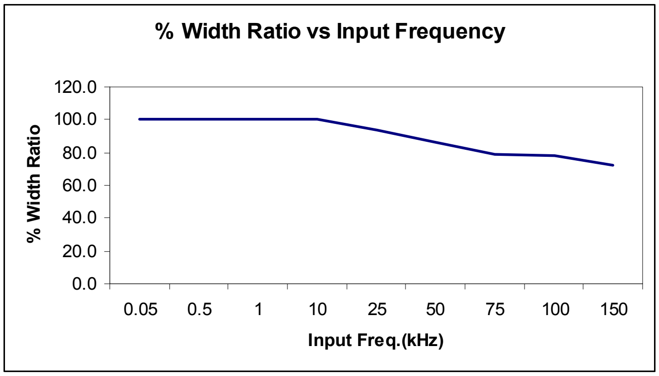

Fig. 12. % Width Ratio vs Input Frequency.

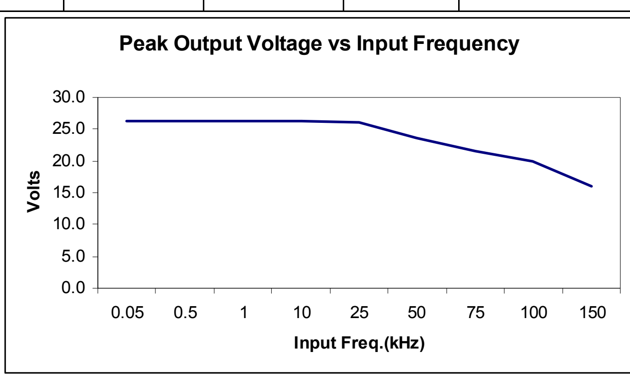

Fig. 13. Peak Output Voltage vs Input Frequency.

IV. DISCUSSION

The results determined the driver circuit performance in response to several input driving frequencies. At lower frequencies from 50Hz to 1kHz, the voltages at point A (as in Fig.2 diagram) and across the load resistor were observed that the original square-wave had the shape as the input. As the frequencies increased from 10kHz to 50kHz, the waveform of the voltages began to change in shape due to the effect of capacitor C1. Referring at 50kHz waveforms, the output voltage across the load resistor shows a slow rise of the peak amplitude, with the capacitor's voltage (at point A) encounters slight distortion.

The frequency response of the output voltage could be improved by changing the capacitance C1 to a lower value when dealing with higher frequencies input. At point A (CH2), it is noted that the voltage level is shifted from 12V to 32.4V. This happen when capacitor C1 storing the 12V and add-up with the 24V (supply) into the next pulse, which is enough to turn-on the MOSFET S1.

As indicated in Fig. 12, the percentage width ratio trend between output and input waveforms starts to slope-down below 90% as the input frequencies exceeding 25kHz and at 150kHz the width ratio falls to 72.7%. Similarly, for the peak output voltage shown in Fig. 13, the voltage starts to drop below than 26V as the input frequencies increased beyond 25kHz.

For H-bridge inverter the MOSFETs or IGBTs will operate satisfactorily for operating frequency, below than 25kHz. This could be suitable for critical and sensitive loads. For non-critical loads, the frequency operation could be different.

V. CONCLUSION

The objective of designing high-side MOSFET driver is achieved using commonly available discrete components. The driver circuit generally can be used to drive the high-side MOSFETs of a bridge inverter to frequencies beyond 25kHz and is concluded the best recommended operational amplitude for the system is up to 100kHz for width ratio to be under 20% of discrepancy.

VI. REFERENCES

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VII. Biographies

Rosnazri Ali received his B.Eng.(Electrical) from Royal Melbourne Institute of Technology in 1988 and M.Sc.(Electrical) from Universiti Sains Malaysia in 2008. His major interest of researches includes renewable energy, energy efficient systems and power electronics.

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