SEMICONDUCTOR DEVICE OPERATION AND CONTROL

Power Electronics Assignment 1 - DT021A/3

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Lab 1: Transistor Switching

1.1. Bipolar Junction Transistors

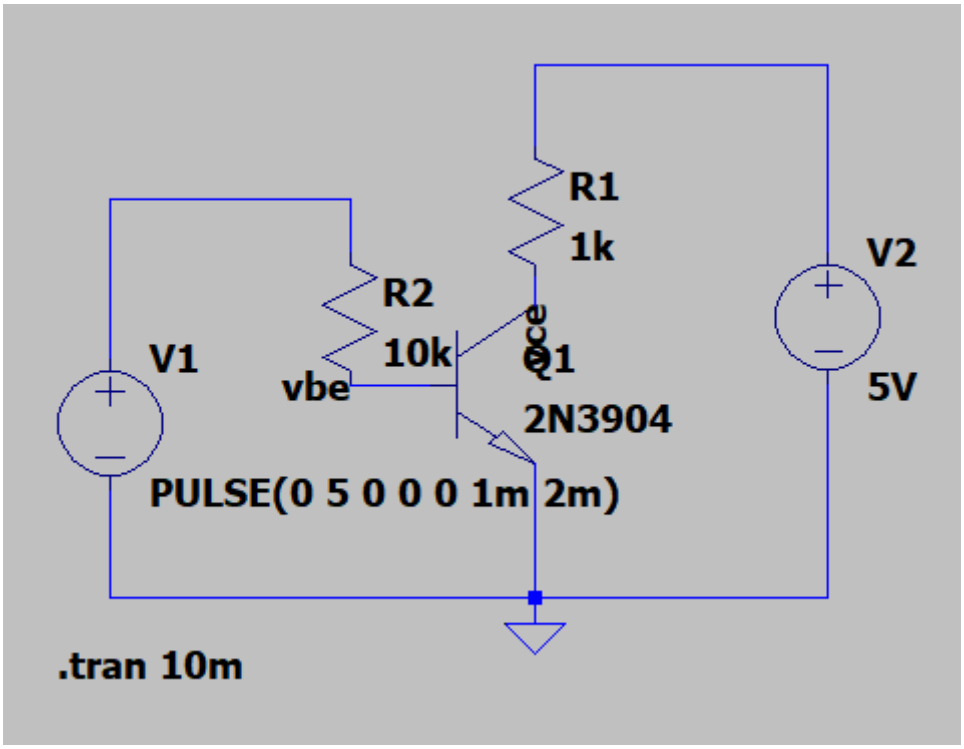


Figure 1 - Schematic diagram of BJT

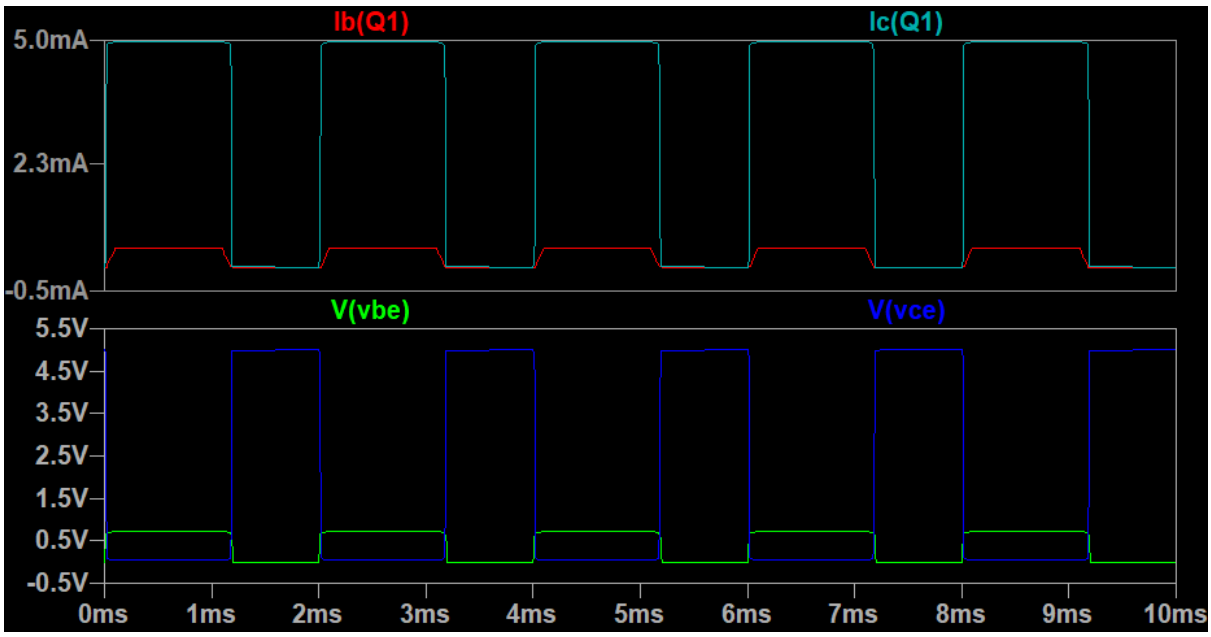


Figure 2 - Simulation of the BJT circuit

The maximum voltage between base and emitter is 0.71v as the diode in the BJT requires 0.7v to turn on the forward bios by $Vbe = Vb - Ve$

$$Current\ Gain\ = \frac{Ic}{Ib}$$

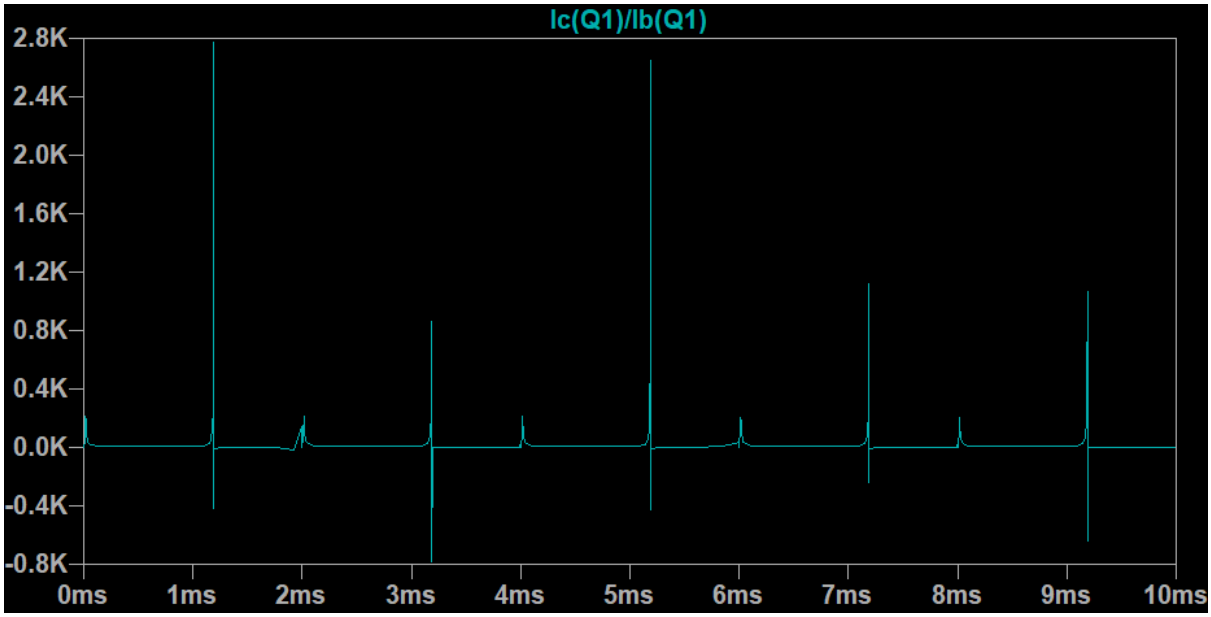


Figure 3 - Simulation of circuit 1 shows the current in the collector

The current gain shows noise along with the current gain of around 220.

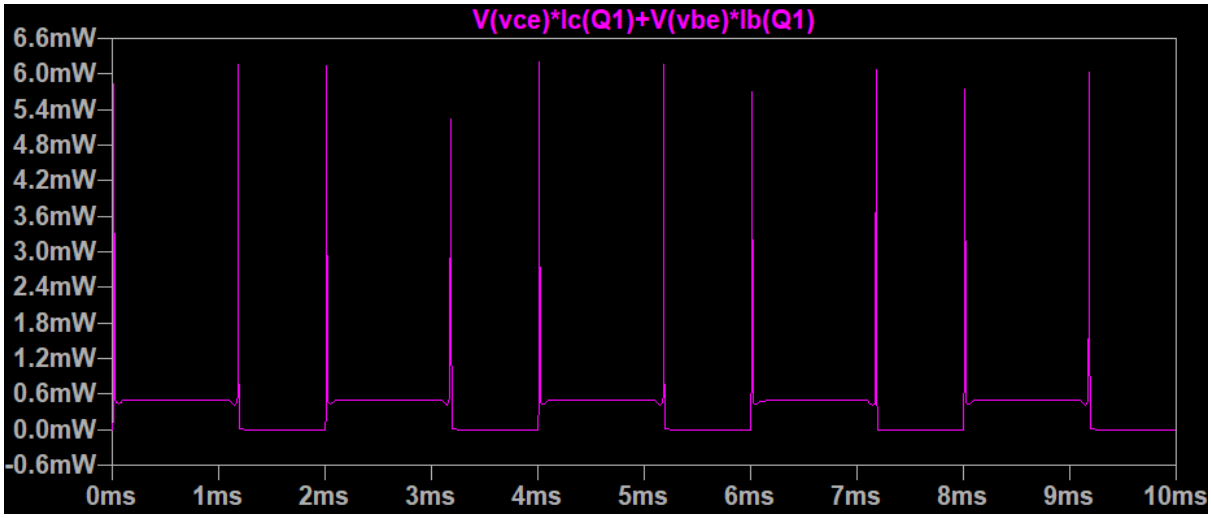


Figure 4 - Power dissipation in BJT

Power dissipation in the BJT is shown in figure 4. It shows that the BJT produces 0W power dissipation when the device is off, however, when the device is on then it produces steady 0.5mW power dissipation. When the device is transitioning between on and off the power boost around up to 6.16mW which is known as switching power loss.

1.2. BJT Push-Pull pairs

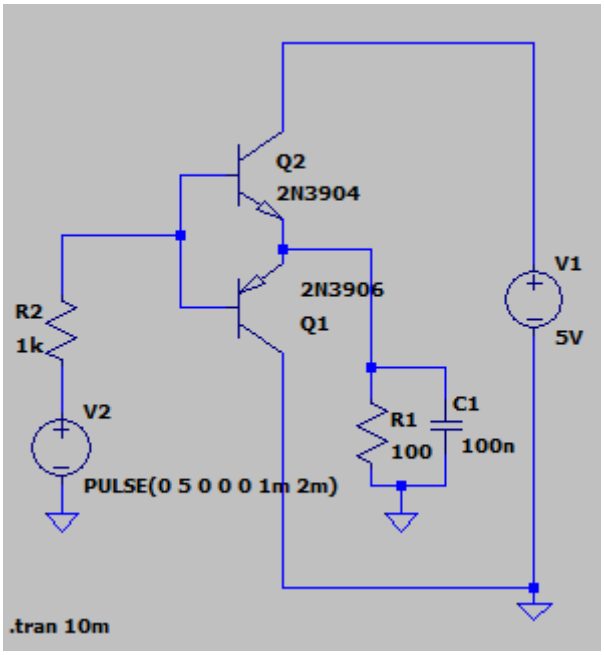


Figure 5 – Schematic diagram of BJT Push-Pull pairs

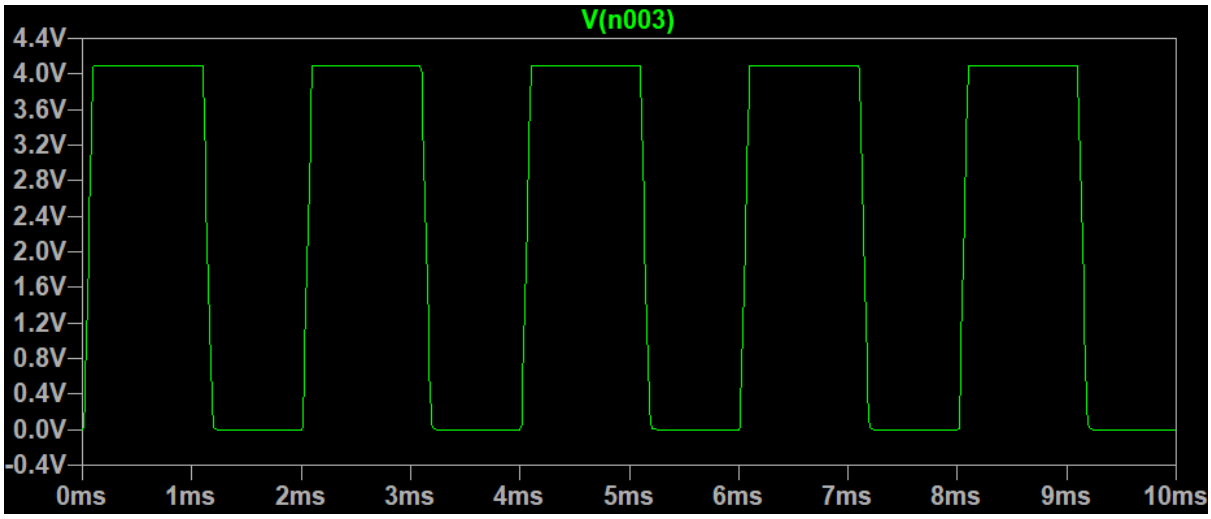


Figure 6 – Simulation of the Voltage across load R1

The peek voltage amplitude of the across R1 is at 4.01v where the 0.7v is the drop across the diode and the rest of the voltages are dropped in collector and emitter.

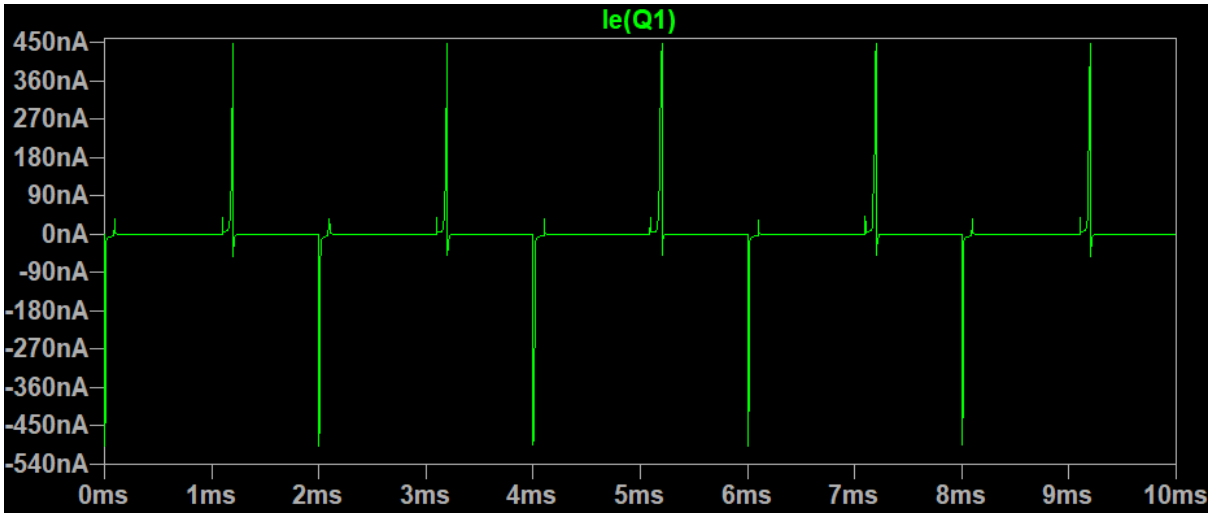


Figure 7 - Simulation of the emitter current in BJT (Q1)

The emitter current is made up of, current that is coming in from capacitor which discharges very quickly and the waveform is oscillating from +447nA to -497nA as it is really small due to the short discharge period.

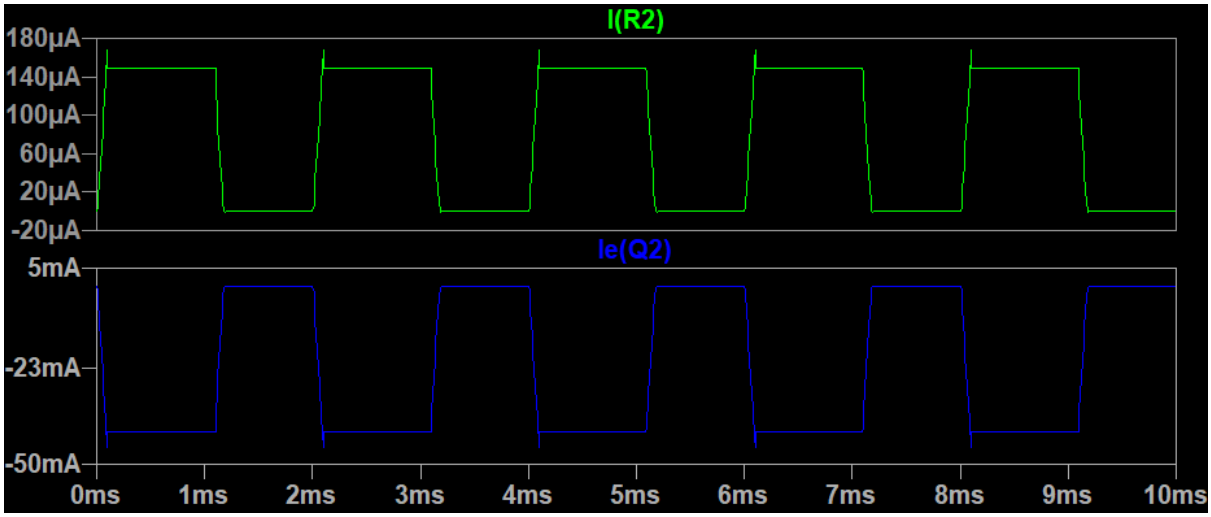


Figure 8 - Current that is going to BJT in over going out

This device might not be the best when it comes to the voltage gain, However, this circuit produces a lot more current out than you put in. The input current across the resistor steadies at 149uA & the output current peak amplitude steadies at 42mA, which is quite high when comparing with the input current.

$$Current\ Gain = \frac{output\ current}{Input\ current}$$

$$Current\ Gain = \frac{42 * 10^{-3}}{149 * 10^{-6}}$$

$$Current\ Gain = 281.8$$

Lab 2: MOSFET Switching and gate drivers

2.1. Circuit 1

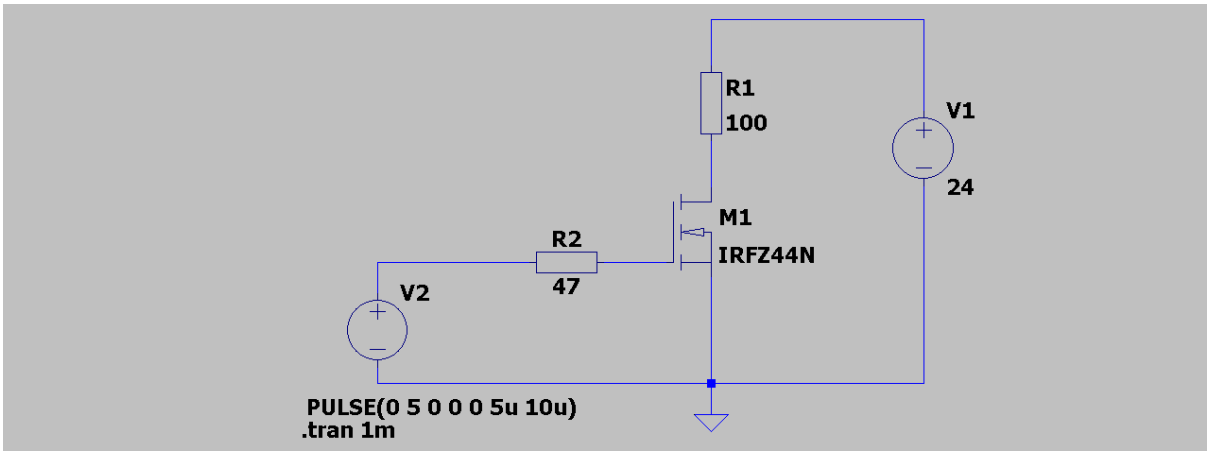


Figure 9 - Schematic diagram of MOSFET in circuit 1

The voltage across the R2 is still 5v as the resistance is too small.

2.1.1. Resultant output when R2 is 47Ω

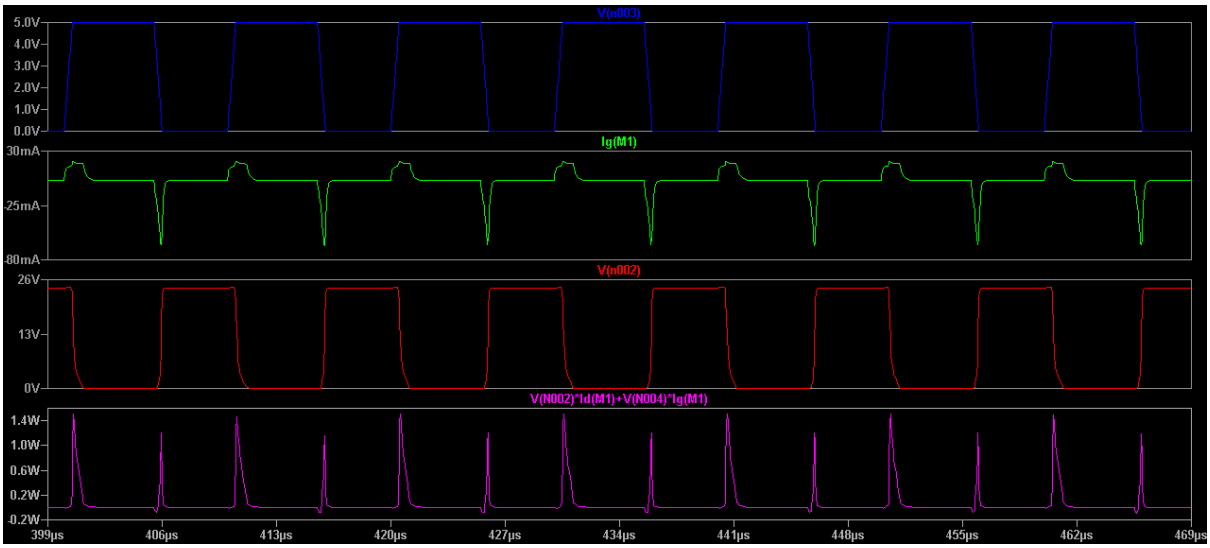


Figure 10 - Captured screenshot of the multiple graphs, V2, Ig, Vds, Power loss in M1

The blue waveform is the controlling voltage coming from the Square voltage supply. When the V2 goes high the MOSFET turns on causes the voltage across the source and drain to be at 0 volts as the drain terminal is connected to the ground. When the V2 goes low the MOSFET voltage is high (24v) as behaves like an open circuit, and this can be observed in the red waveform figure 9.

The gate current in the green waveform is approximately zero except its switching edges. Switching edges are formed when the current enters and leaves the gate and it behaves like a charging & discharging a capacitor.

Power loss in MOSFET is peeking around 1.6W as power is loss is given by $(V_d * I_d) + (V_g * I_g)$. The power loss only occurs when the MOSFET transitions from on to off or off to on as it consumes

most of the energy between those transitions. If MOSFET switches faster the average power loss will be much higher as it increases the unwanted propagation delay.

2.1.2. Resultant output when R2 is 470Ω

The voltage across the R2 is 4.1v as the resistance has increased.

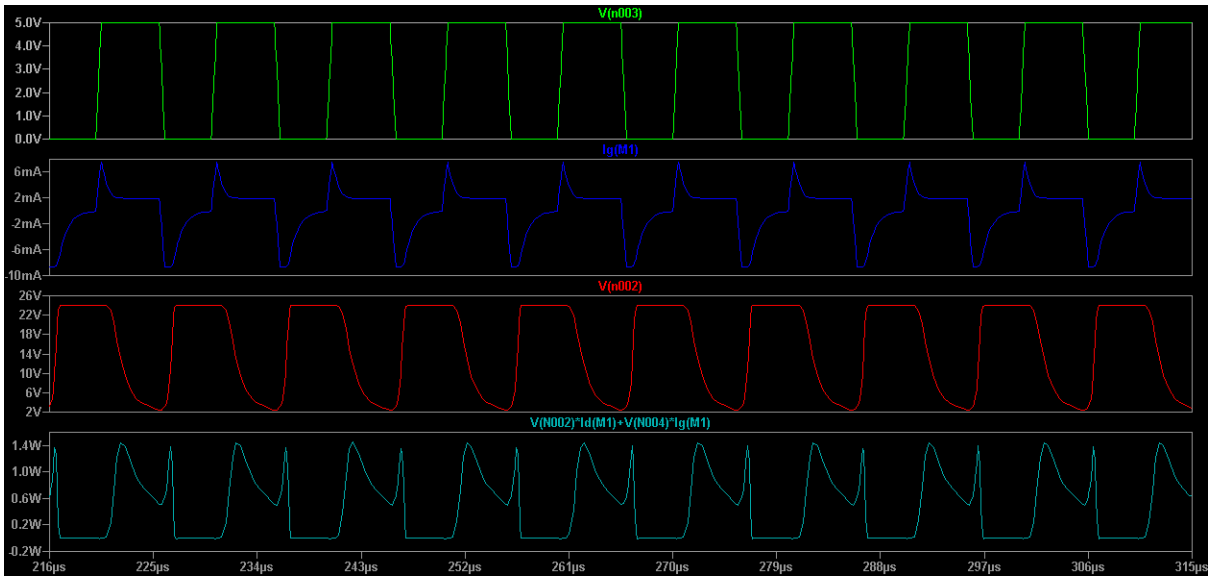


Figure 11 - Simulation of the circuit when R2 is 470 Ω

As the R2 Resistance increases the gate current reduces to 7mA. The Power loss is averaging around 1.5W and most of the time the power loss is high as it takes longer for the voltage to discharge in M1 when V2 is high.

2.1.3. Resultant output when R2 is 4700Ω

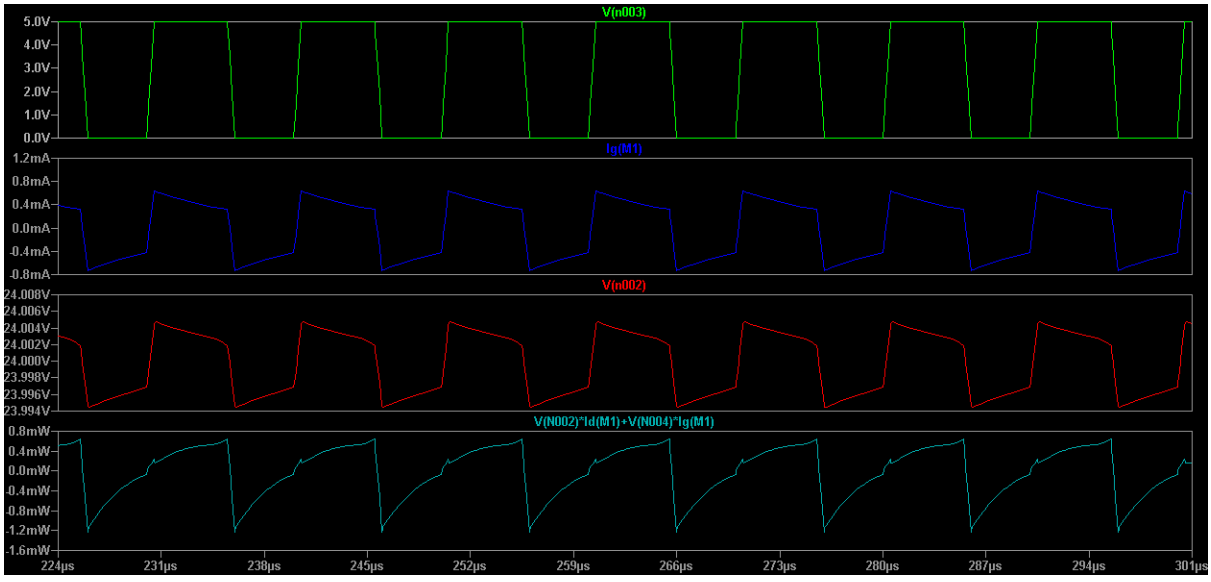


Figure 12 - Simulation of the circuit when R2 is 4.7k Ω

The R2 Resistance has increased by 4.7k ohms and the gate current has reduced and peeking around 0.7mA.

The Power loss is averaging around 0.7mW and most of the time the power loss is high as it takes longer for the voltage to discharge in M1 when V2 is high. Meaning that if the resistance is high than power loss reduces magnificently in the MOSFET as the MOSFET can be operated with small currents.

2.1.4. Resultant output when R2 is 47k Ω

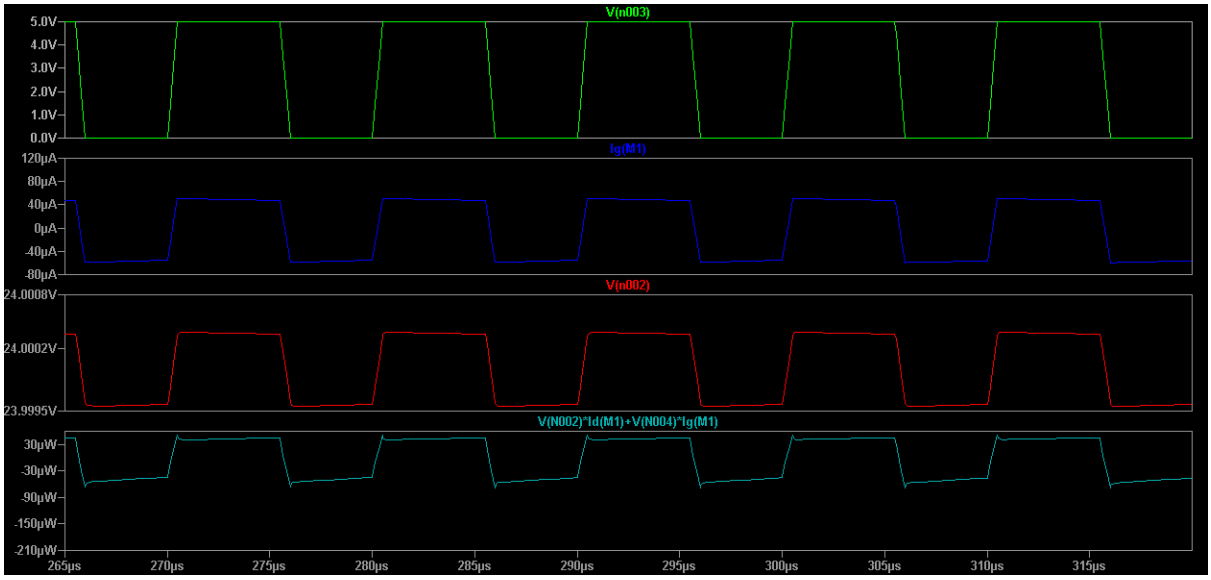


Figure 13 - Simulation of the circuit when R2 is 46k Ω

The R2 Resistance has increased by 47k ohms and the gate current has reduced significantly, peeking around 50uA. The Power loss is averaging around 45uW and most of the time the power loss is quite low. Power loss reduces in the MOSFET when the resistance is high.

2.1.5. Circuit diagram 1 when Vin -12v to +12v & R2 is 47Ω

When changing the Vs pulse amplitudes from +12v to -12v the Gate Current in MOSFET increases along with power dissipated in MOSFET.

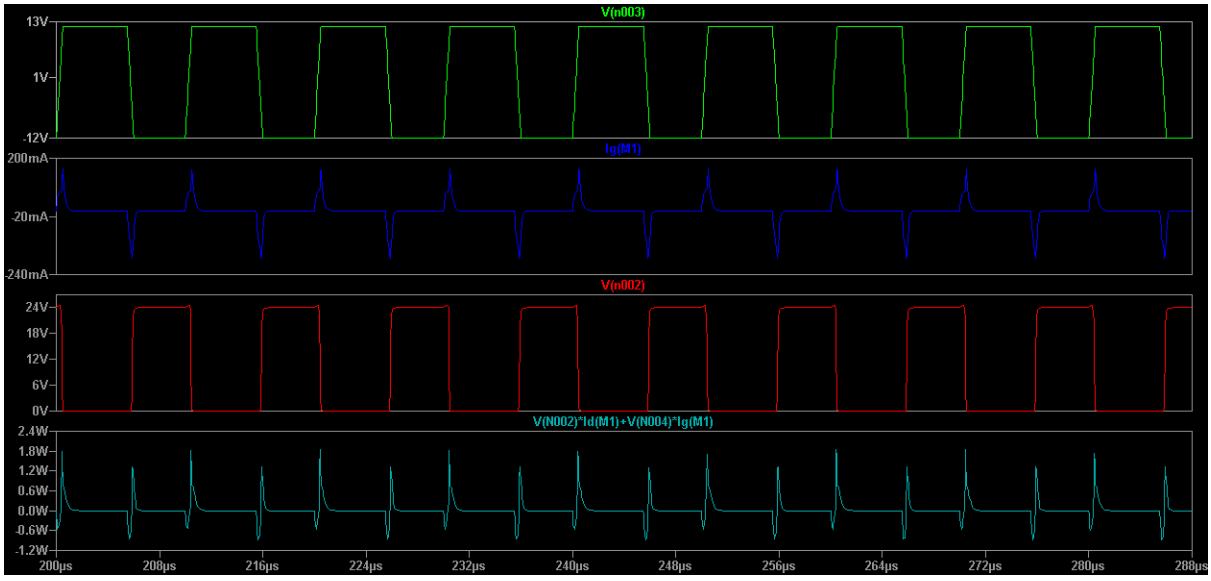


Figure 14 - Simulation of the MOSFET circuit when 12vpp is applied

The R2 resistance is 47 ohms which increase gate current significantly, peeking around 159mA. The Power loss is averaging around 1.8W. Power loss is much greater in the MOSFET during the time of switching edges when the voltage source is 12v is applied to the gate. All that energy is been lost in the MOSFET, which can be avoided with the following circuits.

2.2. Circuit 2

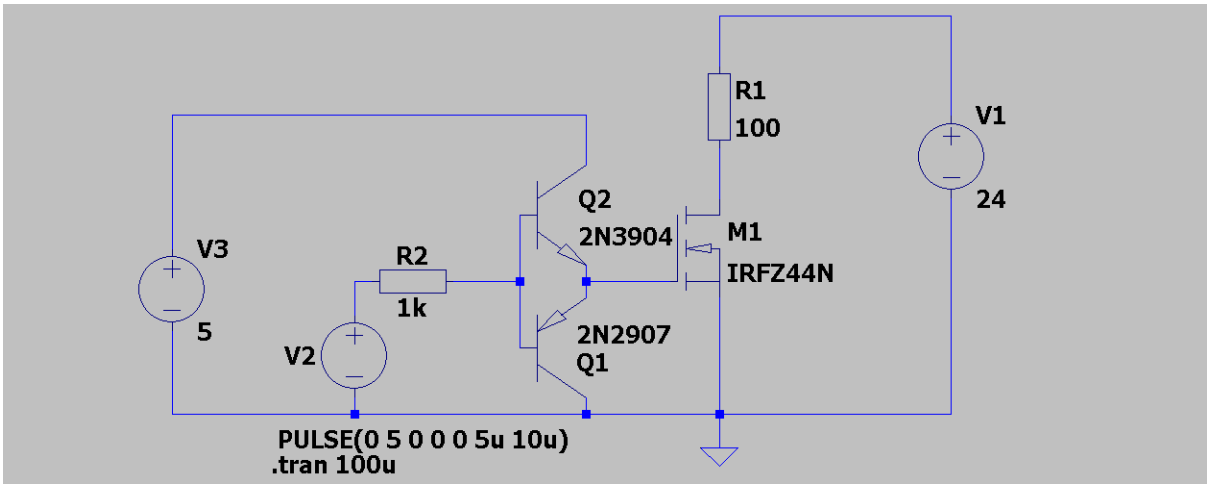


Figure 15 - Circuit Diagram of the MOSFET along with BJT

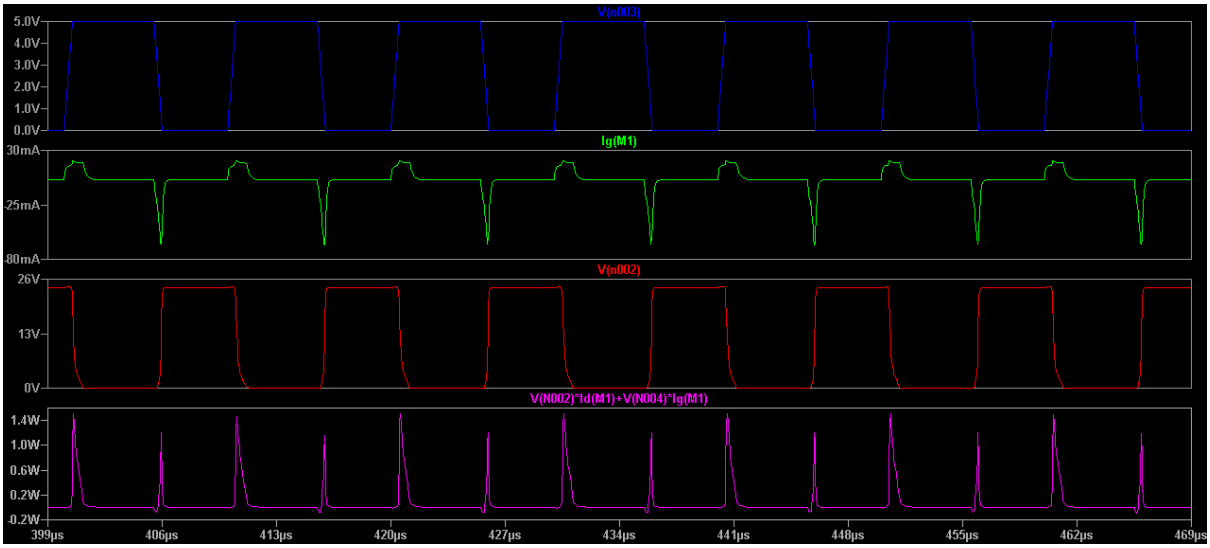


Figure 16 - Simulation of circuit 2 shows the various plots

The switching speed has increased over the circuit 2 due to the PNP BJT transistor which helps MOSFET to charge and discharge quicker as the MOSFET has its capacitance. But the current is peeking quite high (+26mA to -132mA) at the gate of M1 switching transitions, compared to the previous circuit (+19.6mA to -65.4mA). Which means the power should do the same as shown in figure 15.

2.3. Circuit 3

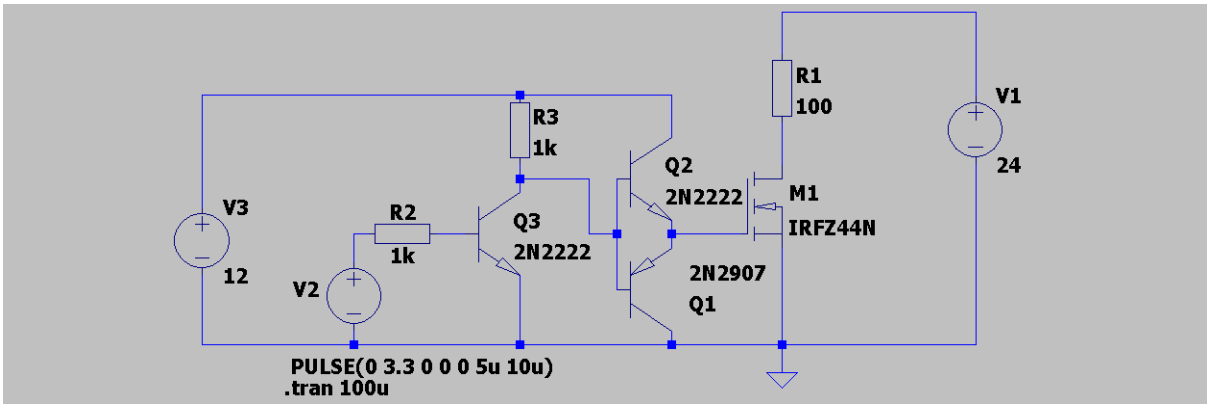


Figure 17 - Circuit 3 shows the Push & Pull configuration in MOSFET

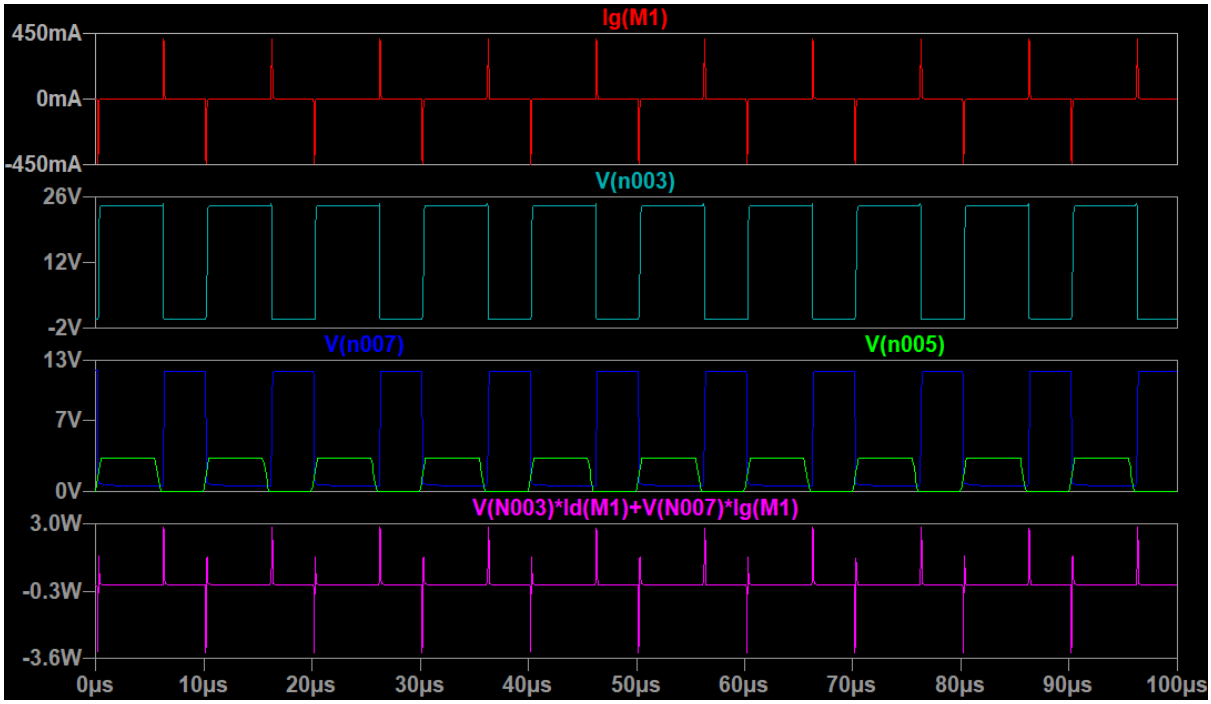


Figure 18 - Circuit 3 simulation shows the signal source voltage to be different from the gate drive voltage

The signal source voltage is at 3.3v whereas the gate drive voltage is much greater due the NPN BJT transistor, which turns on and supplies 12v coming from external dc voltage supply coming through the collector to emitter of Q2.

The MOSFET has a power loss of a 3.3W and the switching time is much greater than previous circuits due to the PNP transistor which allows to turn the MOSFET off quicker but the current peek spikes are a lot higher than previous circuits.

2.4. Circuit 4

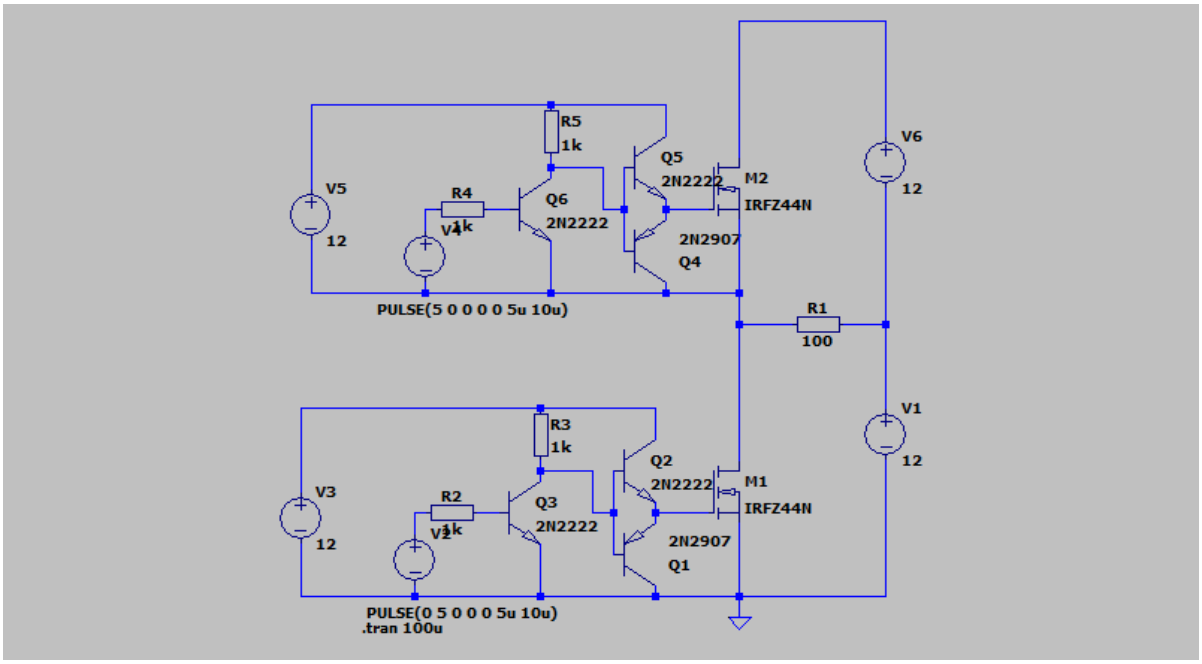


Figure 19 - Schematic diagram of the upper and lower MOSFETs in a half-bridge

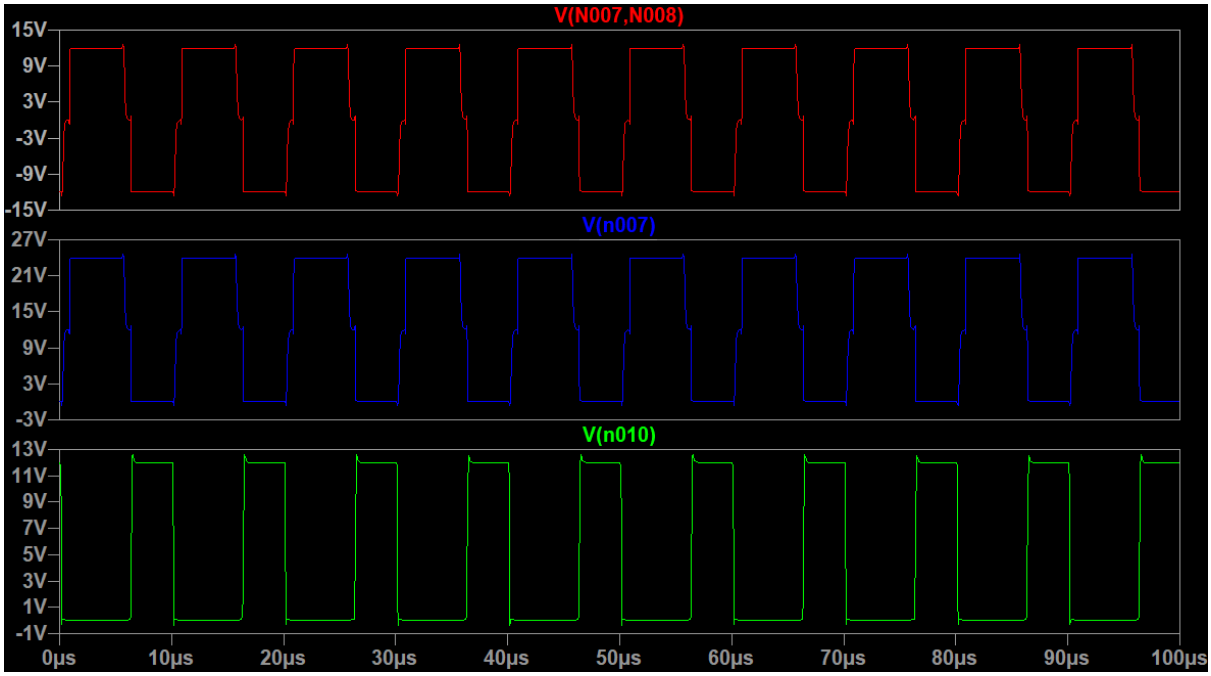


Figure 20 - Simulation of the circuit 4 shows the voltage across the resistor & voltage at Q3 & Q6 emitter terminal

The voltage across R1 is 12vpp & the emitter voltage in Q6 is 24v whereas, the voltage at the emitter terminal of the Q3 at 0 volts, However, the green waveform is voltage respect to ground in Q3 which has a peak amplitude of 12v. The emitter current in Q6 flows to the collector terminal of M1 and when M1 turn on, the current goes to the ground. The gate driver common ground rules out as they do not share the same ground because of the BJT configuration.

2.5. Circuit 5

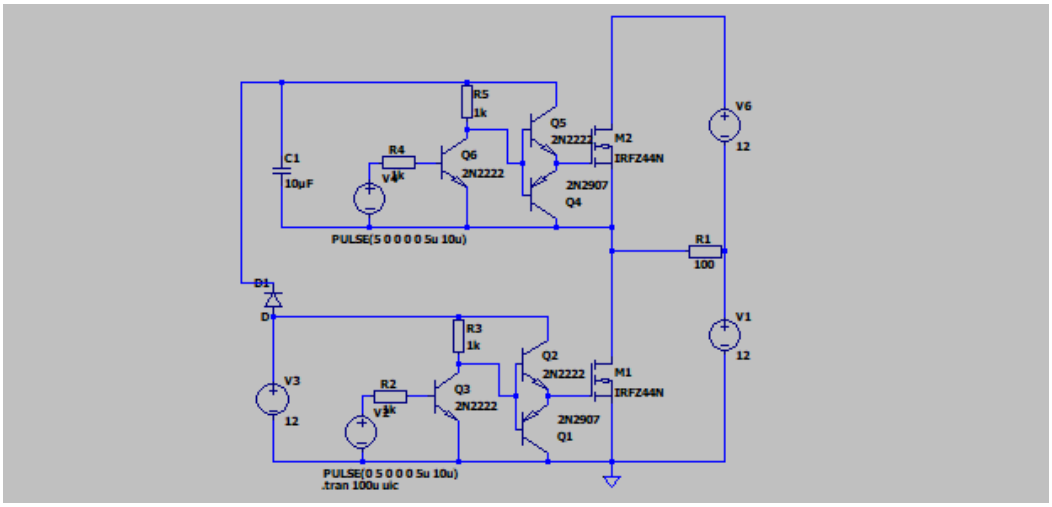


Figure 21 - Circuit diagram of the 2 MOSFET to eliminate the power source for the upper gate

This configuration of the diode and Capacitor eliminates the power source for the upper gate driver.

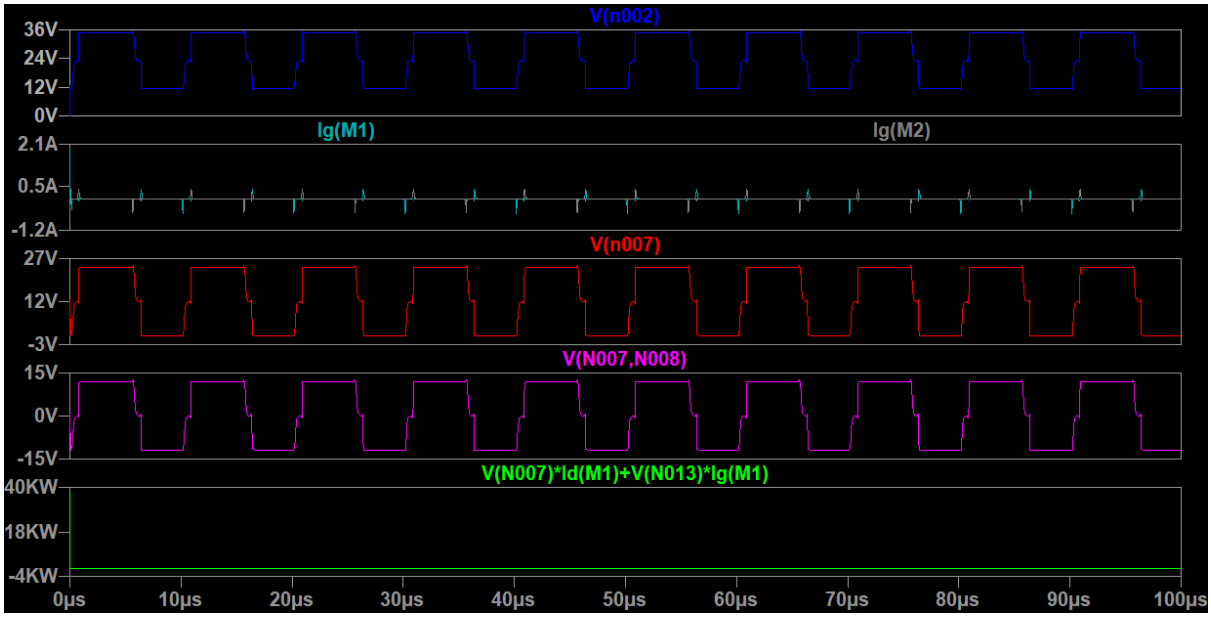


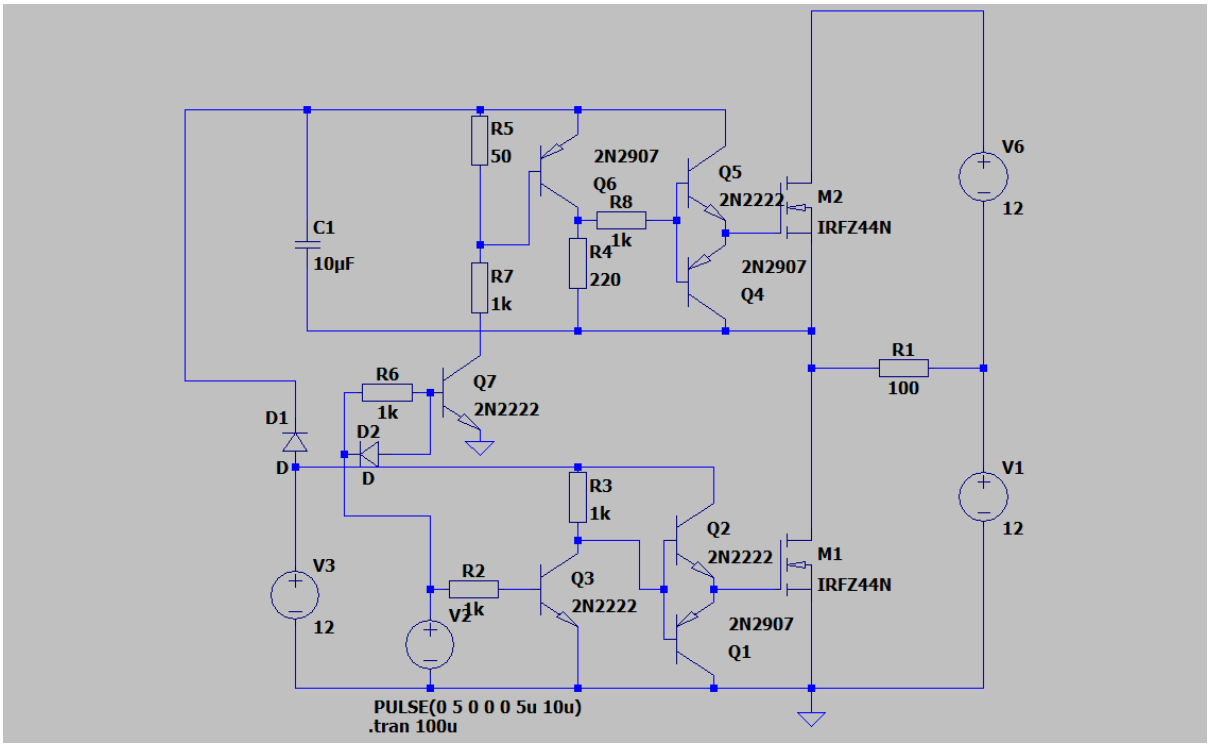
Figure 22 - Simulation of circuit 5 shows the voltage and power loss in M1

Table 1 - Varying capacitor values to see the difference

Capacitor	M1 Power loss	Voltage capacitor and diode node	Gate Current in M1	Voltage across R1	Q6 Emitter Voltage
100mF	1.65kW	11Vp to 12Vp	253mA peak	-1Vp to -187.4uVp	10.95 Vp to 12Vp
100uF	86.6uW	11.2 Vp to 35.17 Vp	405mA peak	12Vpp	9Vp to 24Vp
100nF	25uW	11.3Vp to 34.8Vp	395mA peek	12Vpp	1.5mVp to 24Vp

If the capacitor is small in 100nF range then MOSFET has extremely small power loss, whereas If the capacitor is big in a range around 100mF, the M1 has an extremely high-power loss, therefore not so efficient.

2.6. Circuit 6



The circuit 6 derives the signal for the upper transistor from the lower signal.

Table 2 - ON / OFF state for all transistor when input is high and low

Transistors	When V2 High	When V2 Low
Q3	ON	OFF
Q2	OFF	ON
Q1	ON	OFF
M1	OFF	ON
Q7	ON	OFF
Q6	ON	ON
Q5	ON	ON
M2	ON	ON
Q4	ON	ON

The drain current of M2 is showing huge current peaks as the current that is coming out of the power supply V6 is producing a huge current of -95A known as shoot-through which is caused by the 2 MOSFET switching on and off at same time causing a short circuit, it is a switching period between M2 turns off and M1 turns on. One of the ways to prevent this is to implement dead time.

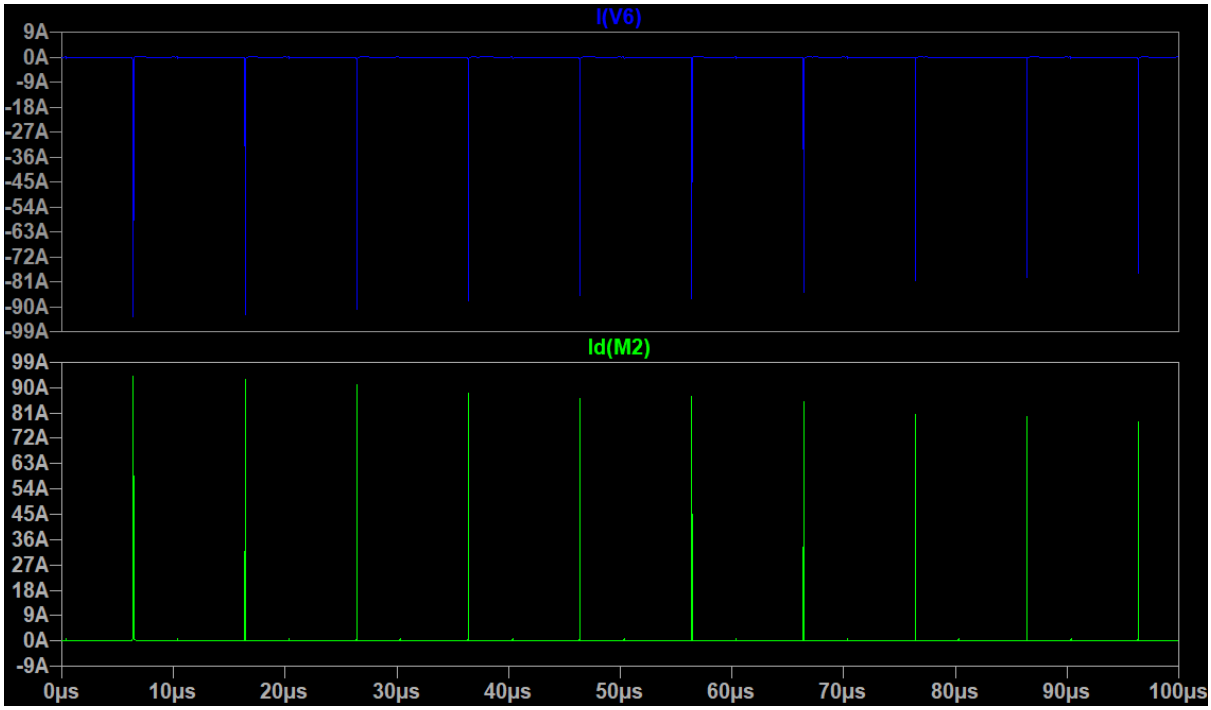


Figure 23 - Simulation of the circuit 6 shows the current in M2 & Current leaving the power supply

2.7. Circuit 7

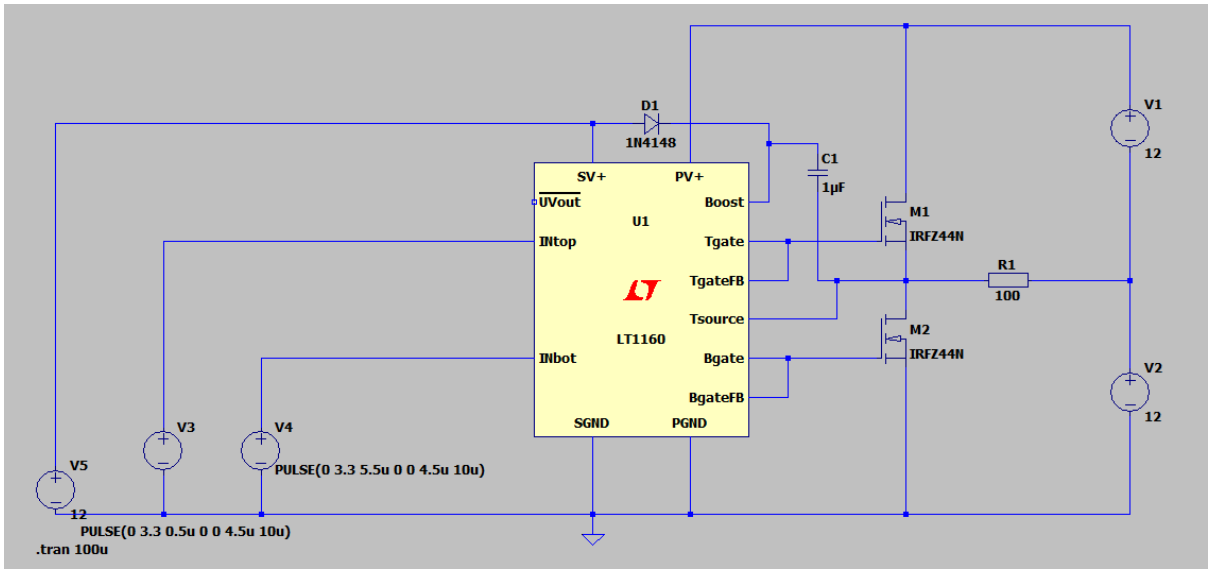


Figure 24 – Circuit 7 shows a commercial high/low side gate driver LT1160 IC along with MOSFETS

When comparing the performance with circuit 6 in the shoot-through the performance of circuit 7 is mush better comparing with circuit 6. The circuit 7 only produces around 3A whereas in circuit 6 the power supply was producing -95A shoot-through. This shoot-through is avoided by the dead time. The internal logic in LT1160 internal logic prevents the inputs from turning on the power of MOSFET's in a half-bridge at the same time. It is unique adaptive protects against shoot-through currents eliminates all matching requirements for the two MOSFET. This greatly eases the design of the high-efficiency motor control and switching regulator systems.

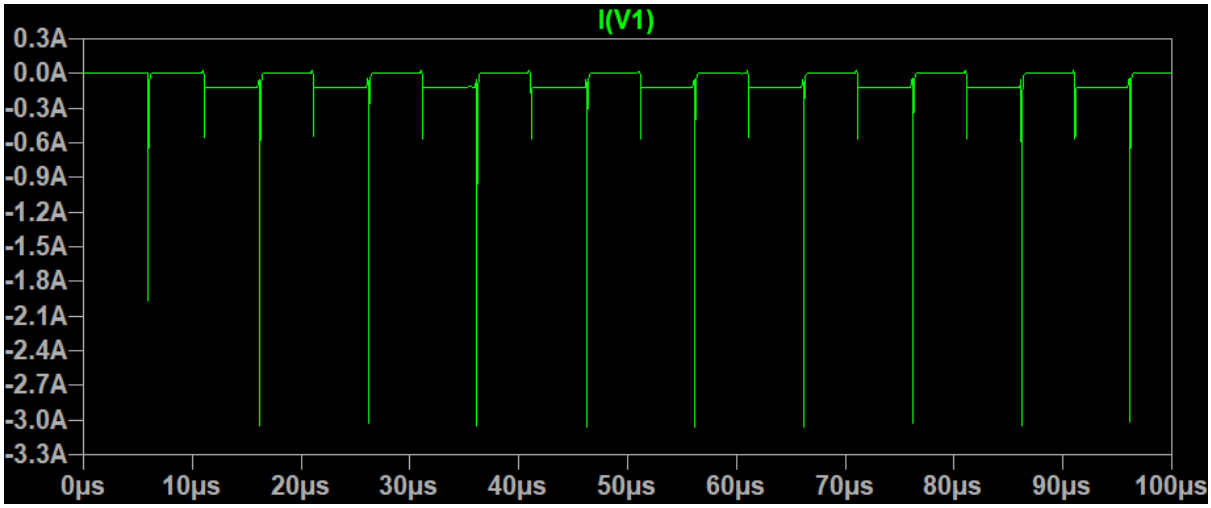


Figure 25 - Simulation of circuit 7 shows the Shoot-through of the LT1160

High/low gate driver IC such as LT1162 also helps to avoid overshoot-thorough