Taser V2

# Considerations:

1. ~~MOSFETs blow up when Vin > 10V~~
2. ~~Require tuneable SMPS for input voltage~~
3. Require tuneable frequency
4. Require lithium ion batt
5. [Transformer](https://www.coilcraft.com/en-us/products/transformers/power-transformers/power-converter-transformers/#/)? ([more transformers](https://www.ti.com/lit/ds/symlink/lm2587.pdf?ts=1633753282124&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM2587))
6. ~~Cockroft Walton~~
7. Inrush current limit
8. Fuse
9. Require pcb
10. Digital voltmeter

Contents

[Considerations: 1](#_Toc87478526)

[Exploding MOSFETs 3](#_Toc87478527)

[Tunable frequency 5](#_Toc87478528)

[Power supply 6](#_Toc87478529)

[Determining output voltage 6](#_Toc87478530)

[Choosing a suitable boost controller 6](#_Toc87478531)

[Cockroft Walton generator 8](#_Toc87478532)

[Theory 8](#_Toc87478533)

[Simulations 9](#_Toc87478534)

[Components 9](#_Toc87478535)

[PCB 11](#_Toc87478536)

[Libraries 11](#_Toc87478537)

# Exploding MOSFETs

According to the LTSpice simulation, at 10V, gate voltage of the MOSFET (Vg) stabilises at while the Vmin of the LC circuit stabilises at

Hence,

Forward voltage of the diode (Vf) is found by

From the datasheet of the 1N4148, the maximum power dissipation is given by at . Beyond that temperature, power dissipation is even lower. Hence, the maximum forward current is given by

And if the input voltage is 7V,

And if the input voltage is 5V,

All of this data can be rearranged into the table as shown below.

|  |  |
| --- | --- |
| Voltage level () | Forward current (mA) |
|  | 44.1 |
|  | 630 |
|  | 883 |

This is then plotted onto a graph

As such, with an increasing input voltage, the forward current of the diodes only decrease.

Additionally, since the temperature of the diode is likely to be higher than after extended use, the actual forward current might be far lower.

With a much lower forward current, it makes it harder for the diode to completely turn the MOSFETs off, hence resulting in the MOSFET being on for an extended period of time, which could have caused it to either overheat or short.

Going forward, it will be necessary to use MOSFETs and Schottky diodes with a higher power dissipation.

Current choices:

MOSFET: IRFP260N

Schottky diode: UF4007

**Remember to use heatsinks**

**Should this choice of parts fail, simply refer to** [**electrobooms vid**](https://www.youtube.com/watch?v=jW3_txSfIAQ&t=307s)

# Tunable frequency

Initially, having a tunable frequency seemed to be a good idea, what with certain frequencies being able to cause an obnoxious amount of pain and what not. However, through further calculation and analysis, this seemed to be more and more of an unfeasible and undesirable outcome.

Firstly, in order to have a tunable frequency affect the output, the taser must output an AC spark. This limits our choice of voltage multipliers since the Cockroft Walton generator creates a DC output.

Secondly, through calculations, a frequency that would cause a significant amount of pain (2kHz according to Electroboom) would require capacitor values that was simply not feasible.

The formula for the resonant frequency within a ZVS driver is given as

Where

is the inductance of the primary coil of the transformer

is the capacitance of the capacitor in parallel with the primary coil

From previous experimentations, was found to be . Hence with a frequency of 2kHz,

We then take the maximum voltage across the capacitor (when the input voltage is ) to be around according to the scope readings. This implies that the current through the capacitor would be

Even if we increase the frequency to , which means the implies capacitance is now , the current through the capacitors would still be around . Simply put, that amount of current is not something I would like to have to deal with.

Hence, the idea for having a tunable frequency is scrapped.

# Power supply

## Determining output voltage

Using a ballpark figure of , used for DC spark gaps over needle points, in order to create a spark gap over 1cm of dry air, we would need a 10kV output.

**Note: it should be recalled that the output voltage over the spark gap is in fact limited by the spark gap distance itself, even if the output voltage can go up to 100kV, if the gap is still 1cm, the spark will still only discharge 10kV. Hence, we might also need a way to vary the gap distance.**

According to the LTSpice simulation, for an output of 10kV, we would require an input of 27V. As it is impossible to get a 27V battery and still hope for this device to be portable, we require some DC-DC converting.

However, after further investigation, it was realized via the LTSpice simulation that with an input of 27V the voltage across the primary coil and hence the drain-source voltage of the MOSFETs can go up to 160V. Hence, in order to protect the MOSFETs while still being able to create a spark gap that greater than 1cm, voltage multipliers such as the Cockroft Walton generator will need to be used.

From previous experiments, input voltage and spark gap distance varies as such:



As it is unlikely we will ever go below as the input, we shall use a boost converter to step up the voltage.

According to the LTSpice simulation, current draw could rise to 3.14A, hence the boost converter needs to have the following capabilities

1. Input: 5V
2. Output: Ranges from 5V to 30V
3. Output current: > 4A

However, after some research, such a boost converter does not exist. Hence, the requirements are changed yet again to

1. Input: 5V
2. Output: 5V-20V
3. Output current: >2.3A

## Choosing a suitable boost controller

Eventually, the [LM3478](https://www.ti.com/lit/ds/symlink/lm3478.pdf?ts=1634484082879&ref_url=https%253A%252F%252Fwww.google.com%252F) is found to be a suitable controller that meets these requirements. This controller was picked due to the available tools to simulate it. For example:

By utilizing the [WEBENCH power designer](https://webench.ti.com/power-designer/switching-regulator) by Texas Instruments, we can even simulate our design before ever needing to physically test it. The following schematic is designed and tested according to the [LM3478’s datasheet](https://www.ti.com/lit/ds/symlink/lm3478.pdf?ts=1634484082879&ref_url=https%253A%252F%252Fwww.google.com%252F).

Diagram, schematic

Description automatically generated

Hence, we will also be using the parts suggested by the simulation.

A full components list is available in the appendix

As this power supply will be a variable one, the second feedback resistor will be replaced with that of a potentiometer. The input voltage for the ZVS driver will range from , hence, following the equation for the output voltage of the LM3478,

The variable resistor should thus have a range of .

However, according to the LTspice simulation, the startup current for the ZVS driver can go up to 4A while the current limit is set to 3.6A. This is only exacerbated by the high inrush current from the addition of the Cockroft Walton generator.

# Cockroft Walton generator

## Theory

The goal of the Cockroft Walton generator is to increase the voltage with every cascading stage added.

Below shows a 2-stage Cockroft Walton generator.

A picture containing text, clock

Description automatically generated

By adding this circuit to the output of the secondary coil of the transformer in the ZVS driver, we can double the peak-to-peak output voltage even further.

Simply put,

1. When the AC input gets to its negative half, D1 is forward biased and current flows through C1, charging it up to the peak voltage.
2. When the AC input gets to its positive half, D1 is reverse biased and no current through flows through C1, however it adds to the voltage across the capacitor such that the voltage on C1's righthand plate is twice the peak voltage (relative to ground). D2 is forward biased, thus current flows from C1, through D2, and charging C2 to 2 times the peak voltage.
3. Additionally, D2 acts as a rectifier and rectifies the output voltage to DC.

Hence, with every cascading stage, the peak-to-peak output voltage is multiplied[[1]](#footnote-1), and rectified.

## Simulations

This is only further confirmed with the use of SPICE simulation software.

With a 3 stage Cockroft Walton generator attacked to the output of the ZVS driver, the output waveforms are as follows.

A picture containing background pattern

Description automatically generated

Green represents the output voltage after just 1 stage, with a peak voltage of around

Red represents the output voltage after 2 stages, with a peak voltage of around

Red represents the output voltage after the full 3 stages, with a peak voltage of around

Hence, each stage increases the output voltage by around .

## Components

While the circuit is simple (needing only diodes and capacitors), the parts must be chosen carefully. By measuring the voltage across the capacitors and diodes with the help of the SPICE simulation, it can be determined that the maximum voltage across these parts is around . Hence, we choose diodes and capacitors with a voltage rating of for some leeway.

The maximum diode forward current it will have to sustain is around , however, any value lower than that might also work **(must test out)**

As for the capacitance values, a larger capacitance will lead to a much higher inrush current. However it seems that past a certain point, lower capacitance values will lead to higher inrush currents again. For example, the following values for inrush current and capacitance values used are obtained from the SPICE simulation software:

|  |  |
| --- | --- |
| Inrush current (A) | Capacitance values (pF) |
| 5.4 | 1 |
| 4.9 | 10 |
| 10.5 | 100 |

Hence, for this project, it seems that 10pF is a good value to go with. However, this means that the inrush current is still 4.9A, whereas the output current for the boost converter has been limited to around 3.6A.

One should consider the addition of an inrush current limiter, as well as a fuse.

# PCB

## Libraries

After everything, we must incorporate it all into a PCB. Autodesk EAGLE is utilized for this. However, before we jump into this, we need to acquire a few EAGLE libraries.

CSD16327Q3: <https://www.snapeda.com/parts/CSD16327Q3/Texas%20Instruments/view-part/>

UF4007: <https://www.snapeda.com/parts/UF4007/Onsemi/view-part/>

IRFP260N: <https://www.snapeda.com/parts/IRFP260N/Infineon%20Technologies/view-part/>

LM3478: The eagle library is custom made since its footprint is a rather common one (the SOIC8).

0.1uF MKP capacitor: part of the MKP4 series and can fit into a regular 5-hole connector.

100uH inductor: a standard inductor that can fit into a regular 4-hole connector.

## Board arrangement

## Trace width

In the creation of this board, one of the most important considerations would be the current carrying capacity of the traces. Since such a high-power device would be carrying high currents, the width of the traces are such that it will be able to handle these current levels.

A [trace width calculator](https://www.4pcb.com/trace-width-calculator.html) is used to calculate the minimum trace width required for a given amount of current passing through it. The default thickness of the copper in PCBs from JLCPCB would be 1oz/ft^2. We leave the other settings as their default variations. We will be reading the results for external layers in air since this is a 2-layered board.

### ZVS driver

Firstly, we start with the ZVS driver.

|  |  |  |  |
| --- | --- | --- | --- |
| Component | Quantity | Max max current (A) | Calculated min. trace width (mm) |
| resistors | I(R4)/I(R3) | 1.18 | 0.377 |
| resistors | I(R1)/I(R2) | 2.0e-3 | 2.37e-6 |
| Shottky diodes | I(D3)/I(D4) | 2.01 | 0.787 |
| MOSFET | Ig(M1)/Ig(M2) | 0.75 | 0.202 |
| MOSFET | Id(M1)/Id(M2) | 12.94 | 10.3 |
| MOSFET | Is(M1)/Is(M2) | 12.3 | 9.57 |
| Inductor | I(L3) | 2.67 | 1.16 |
| Capacitor | I(C1) | 9.60 | 6.80 |
| Transformer (primary) | I(L1) | 12.2 | 9.46 |

## Boost converter

Another part of the board dealing with potentially high currents would be the boost converter

The simulation report gives the RMS currents, we must convert them back to current by dividing by 0.707

|  |  |  |  |
| --- | --- | --- | --- |
| Component | Quantity | Max max current (A) | Calculated min. trace width (mm) |
| Input capacitor | I(Cin) | 0.875 | 0.25 |
| Output capacitor | I(Cout) | 6.07 | 3.61 |
| Inductor | I(L1) | 14.5 | 12 |
| MOSFET | Ig(M1) | 1 (determined from max driver output current of LM3478) | 0.3 |
| MOSFET | Id(M1) | 13.6 | 11 |

# Battery

[5V 3A](https://item.taobao.com/item.htm?id=574912199865&ali_refid=a3_430008_1006:1103985817:N:T%2B2rVLs26dDI%2BXhgd%2BAzYQ%3D%3D:fcca357ed24d530b64ad4fc58f6cc99c&ali_trackid=1_fcca357ed24d530b64ad4fc58f6cc99c&spm=a230r.1.0.0)

1. While the term “multiplied” is used, the output voltage is not actually being multiplied by a factor. As will be shown later on, the output voltage is simply increased by a fixed amount with each cascading stage [↑](#footnote-ref-1)