Sparky-1 Circuit Description

Intro & Components:

Sparky-1 is basically a SMPS or a switch mode power supply, similar to the switching power supply in your computer. I designed and built it this way so one could see how everything effects the other, also one can see what is needed and what is not. It is capable of producing 20 watts of total power with 5 volts in. This circuit was designed to work at 5 volts but it can run at 11.8 volts with no changes. The nice thing about this circuit is that you don't have to use a CCFL inverter transformer, you can use almost any transformer you wish. You also can use transistors (BT & BJT) or IGBT's instead of MOSFET's. For a more in depth circuit explanation on SMPS go to http://en.wikipedia.org/wiki/Switched-mode_power_supply.

The circuitry consists of 4 IC's, 2 MOSFET's, a CCFL inverter, an SCR, an Opto-Coupler, a 0.47uf 800 volt capacitor, and the necessary diodes, resistors, and small capacitors to complete the circuitry. The 4 IC's consist of a NE555P Timer, IR2302 Half-Bridge Controller, DF08MA-E3/45 Bridge Rectifier, and a 4N36 Opto-Coupler.

The CCFL inverter has a recommended operating frequency of between 40 kHz and 80 kHz, I use the mid-point of 60 kHz. The 60 kHz is supplied by the NE555P timer, the timer is set for a square-wave of 50% duty cycle. The DF08MA-E3/45 is a bridge rectifier rated at 1 amp and 800 volts, it comes in a 4 pin DIP. The 4N36 Opto-Coupler (Transistor with Base) is a bulk 30 volt type. The main IC is an IR2302 Half-Bridge controller capable of driving transistors, MOSFETs, or MOSFET's. It has a under volt shut off of 4.1 volts, this only comes into play if you use 4.8 battery with no 5 volt regulator.

The NE555P Timer can operate from 4.5 to 16 volts but I have seen them go to 18 volts. The timer or oscillator runs in astable mode at 68 kHz and 52% duty cycle. You use the timer to match the frequency to the IR2302 to the primary inductance of step-up transformer. What your going for, is the highest frequency that the coil is rated for or the highest frequency with an X_L (inductive reactance/impedance) that allows the maximum current flow you want. If the X_L is too high then current flow, voltage, and cap charging will be restricted. Too low of frequency you'll once again restrict the current transfer and you'll increase the ripple voltage on the step-up transformer output. One of the big things about SMPS is the frequency they use to transfer current, some are using frequencies as high as 5 MHz.

The IR2302 Half-Bridge Controller http://www.irf.com/product-info/datasheets/data/ir2302.pdf, is typical of most half-bridge controllers. It's main features are that it has a supply positive going threshold of 4.1(typ.) and a supply negative going threshold of 3.8 (typ.). This means that it needs at least 4.1 volts to turn on and at 3.8 volts it turns off. The output H_O is synched with the input (IN) and matches it's frequency, so long as the IN signal is close to 50% duty cycle. The voltage feedback, if needed, can be coupled back to the $\overline{SD}$ pin, a low here will turn off the output. This is good for turning the MOSFET's off saving power and reducing heat. With voltage feedback the controller can go into hic-up mode keeping the cap charged up to the level you set. This is a lot better than using an oscillator that is always on and wasting power. The ($V_{SD,TH+}$) is the SD input positive going threshold and is 2.9 volts, the ($V_{SD,TH-}$) is the SD input negative going threshold and is 0.8 volts. Which means, if the IR2302 is on the low turn off voltage as to go down to 0.8 volts to turn off and the IC will not turn on again until the voltage reaches 2.9 volts, so there is some hysteresis and it can be seen on the scope. The IR2302 has a fixed dead-time of 540 nsec. which is the time between switching of the MOSFET's. This is the time allowed for the magnetic field built up in the coil to collapse before the other side of the primary is turned on and allowed to charge.

I use a DF08MA-E3/45 Bridge Rectifier instead of individual rectifier diodes because it is more convenient. You could use 4 high voltage diodes instead of the DF08MA. The DF08MA-E3/45 bridge rectifier is rated for 800 volts AC and 1 amp of current, as we have seen it can take more than 800 volts.

The 4N36 Opto-Coupler is used for voltage feed back and allows for adjustable voltage limit. The version I use has a collector-emitter voltage of 30 volts and a LED current of 30ma max. The 4N36 is a general purpose opto-isolator, if you use a different version then you will have to adjust the resistance as needed to get the voltage output you want. I am getting a current drain of 29ma with no trigger input, so the cap voltage was at 620 volts and holding, so the LED was turned full on. At 2,800 rpm the current draw is down to 9ma DC and at 6,000 rpm it is down to 2ma DC, so there is not too much power being wasted and with the cap fully charged starting gets full power.

What the Circuitry Components Do:

C1 is a 4700uf capacitor I would like to use a bigger one but I'm limited by physical size. C1 provides most of noise filtering and short term power boosting after ignition pulses, so use as BIG as you can fit.

D1 & D2 provide a voltage drop of about 1.5 volts and they isolate the opto-isolator and the MCU from interfering with each other.

R1, R2, and C2 provide the timing pulse rate and duty cycle output of the astable timer IC1.

C3 is a decoupling cap and sets the control voltage it can be omitted but, from the datasheet "with the decoupling CONTrol voltage to ground with a capacitor can improve operation. This should be evaluated for individual applications" it is best to use it.

C4 is between the Vcc and COM and helps to balance the internal positive line and improve spark output.

R4 & R5 have 2 functions and are known as gate resistors (Rg) and with the MOSFET's I'm using, I find 33 ohm for MOSFET's and 220 ohm for IGBT's to be close to ideal. The values for these are not readily easy to calculate but, there are formulas for getting their values. The gate resistors have to be matched to the MOSFET'S/IGBT's and the voltage you are using. The Rg resistor controls how fast the MOSFET/IGBT turns on and gate voltage. To turn on the

MOSFET's that I'm currently using require from the datasheet "Gate threshold voltage = (VCE= VGE, IC= 250µA) min. 2, max. 5 V" so to turn on this MOSFET, I need a minimum of 2 volts. Another thing that Rg does is control the amount that the MOSFET is turned on, to a point. The VCE (sat) Collector-emitter saturation voltage is:

VGE= 15 V, IC= 3 A, Typical is 2.3 and Max is 2.8 V
VGE= 15 V, IC= 3 A, TJ=125 °C, Typical is 2.2 V and Max is 2.8 V

So once you hit the above values the MOSFET is fully turned on, it can be touchy to get the current flow you want. But it is better than over saturating your primary coil.

R3 is used whenever you want to limit the current flow/transfer through the MOSFET'S/IGBT's. How I do this is by using a 100 ohm trimmer pot and adjust it until I get the current flow through the MOSFET's/IGBT's that I want. I then replace the trimmer with a fixed resistor of the trimmer value. There is no reason to use more power than you need, cause you'll just make more heat. If the spark is strong enough so that you get your max rpm under full load without miss-firing and you fix the power at that level your battery and sparkplug will last that much longer.

L1 is more for noise reduction than anything else and cuts the inductive noise from 1 volt to 300 milli-volts, any reduction in noise is good. It does help to boost the efficiency of the step-up transformer and cool the MOSFET's by 10°C.

MOSFET1 & MOSFET2 are the drivers for the primary coil and are hooked up in a push-pull configuration. MOSFET1 handles P1 and MOSFET2 handles P2, both supply a negative side to P1 & P2. The centre tap of the primary is hooked up to the 5 volt positive and the SOURCES of both MOSFET's are connected to negative/ground. Here is some neat info, for a time everyone started using MOSFET's but, when IGBT's were introduced and as they improved everyone started using IGBT's because of their low turn on resistance. But then they started making MOSFET's better and now they almost work the same and have similar on resistance. The only real difference I see between them is that IGBT's have a high voltage advantage.

Inverter T1 is a CCFL inverter and its maximum voltage is 1300 volts, I limit mine to 620 volts. Why do I use so much voltage, well when you discharge the HV-cap through the ignition coli you are trying to get as much current as you can through the primary coil without shorting it out. Voltage is pressure and current is the amount of flow, so you can have voltage without current but, you can't have current without voltage, so the more voltage the more current flow. There is another thing P = V x I and because I use a smaller cap it charges up faster but, the power out is the same as if I were to use a larger cap at 200v. For comparison, the MSD 6AL uses about 547 volts and the popular drag racing 7AL uses about 650 volts, so I'm right in the ballpark with the performance stuff.

C5 is the resonance capacitor and is matched to the frequency that the circuit uses, it forms a parallel LC tank circuit with the primary coil. You use the parallel LC resonate formula to calculate it's size. Without C5 the primary wave forms are quite distorted. To calculate for C: we know that $X_L = X_C$ in a resonate tank circuit, we know that with the coil I use that it has 20 uH per primary (40uh total primary), so $X_L = 2\pi f L$ which gives us 2 x 3.14 x 68000 x .000040 = 17.08Ω. We can now solve for C, using $C = \frac{1}{2\pi X_c f}$ or $C = \frac{1}{6.28*17.08*68000}$ = 137nf. Use this formula for the transformer you are using. So set IC1 for the frequency recommended for the inverter and size C5 for the same frequency, also use a low ESR ceramic for the cap.

BR1 the DF08MA-E3/45 bridge rectifier is a full wave bridge rectifier and is straight forward AC to DC.

D3 is a RGP02-12E high voltage diode rated at 1200 volts and 500ma. I use it as a simple snubber to prevent feedback into the bridge, I'm not sure why but without it there is a lot of ripple, 50 volts without and 15 volts with it.

The 4N36 is a general purpose opto-isolator that has been around for a long time and is very rugged. I've used the 4N36 and others in it's family for all types of circuits, a very good opto-isolator. In this circuit the feedback that it supplies varies from 29ma to 2ma as the rpm goes up. It is not a digital device so the feedback is gradual and provides very smooth voltage regulation. R6 provides an adjustable voltage limit and I have found when paired with the 4N36 that voltage output from the IR2302 and related circuitry is about 32k ohms per volt output of the inverter. For 620 volts out this means R6 is 20.7 Meg ohms. Because we are dealing with a purely analog circuit I can't say for sure what the value should be, it changes with each opto-isolator but, the variance is small. So 20.7 x 32 = 662.4 volts, if you want 400 volts then 400 ÷ 32 = 12.5 (Megs). The voltage limit goes up when the resistance goes up.

LED1(15ma-20ma) & R7 (R_S) provide the biasing for the SCR gate. LED1 limits the gate current and sets the voltage along with R7. Usually you want as much gate current as possible but, you also want to limit noise. R7 is the R_S resistor that reduces the sensitivity of the gate which helps to reduce false triggering. For further information read "Thyristor Theory and Design Considerations ON Semi.pdf" http://www.onsemi.com/pub_link/Collateral/HBD855-D.PDFand follow this rule from the application notes "Use a thyristor with a less sensitive gate such as the BT151, or reduce the existing thyristor's sensitivity by including a gate-to-cathode resistor of 1k Ω or less."

For the SCR (SCR1) I use the BT151. The BT151 is almost like a universal CDI SCR because so many CDI's use it. The model I use, the BT151-1000RT,127 has a Voltage - Off State of 1000V and sells for $1.10 CAD. It is over-kill but it has everything that is needed and is cheap. I tried using IGBT's like I do with MegaSquirt but with only 5 volts to work with and 600+ volts, I would need to use a gate driver and I don't want to complicate the circuit anymore than I have to, so an SCR it is.

C6 is the discharge capacitor. It is a metalized polypropylene cap rated at 875 volts and of either a 0.47uf, 1uf, or 2uf, it all depends on the voltage, the ignition coil, and rpm you want to use. The higher the rpm the smaller the cap and so the higher the voltage used, same goes for the ignition coil, the bigger the coil the more uF's needed. One thing I want to point out here is that you do not need to charge a capacitor up all the way to get sufficient energy to fire the sparkplug with more than enough energy to ignite a fuel/air mixture. Almost all CDI ignition voltage output to the ignition coil drops as rpm increases. The same thing happens with this ignition design. The only way to overcome this is to output more power with a larger inverter and less resistance but, then the battery or batteries won't last very long. It would work great with an alternator on a vehicle like a motorcycle or car but, not an RC airplane.

T2 or the ignition coil is a RT-442 coil from KINGDATRON ELECTRONIC INDUSTRIAL CO., LTD. I plan on supplying them but, for now I only have about 5 that I can sell. You do not need to use the RT-442, you can use a Zenoah coil like this one on EBay http://www.ebay.com/itm/New-Ignition-Coil-fit-ZENOAH-G260PUM-Gas-Marine-Engine-for-RC-Boat-/141028099146?pt=Radio_Control_Parts_Accessories&hash=item20d5ee044a

I've tried it and it works well, I've also tried the GY6 scooter ignition coil but you have to use the Cooper Bussmann CTX210611-R inverter and 1 or 2 uf cap or use 12 volts because the GY6 requires more power.

NOTES:

1. Use a bread-board to work out your circuit, you'll be thankful you did.
2. You do not need to put a free-wheeling diode between ground and the line between C6 and T1, in fact when I tried it things were made worse, so it is gone.
3. Do not put a diode across the Rg resistor, the diode is there to speed up the turn-off of the MOSFET/IGBT but, the IR2302 has only 540 nsec. of dead-time which is not enough. This little trick will force switching to slow down just slightly giving the magnetic field in the primaries a little more time to decay.
4. I tried capacitance triggering with the SCR but, that didn't work to well so the cap is gone.
5. Everything in this circuit starts with 2 things, 1. The ignition coil used and 2. The inverter coil/transformer used and its primary coil size. You have to pick a frequency and inductive reactance that is satisfactory to the power you want to use. In the case of the CTX210611-R the manufacturer recommends a frequency of between 40 kHz – 80 kHz so I went with 68 kHz. I kept the frequency for the Bourns inverters, they seem to like it. The higher the frequency the more efficient the energy transfer but, the higher the X_L impedance. For more power use an inverter/transformer with lower DCR on the primary.
6. Use a charging voltage of at least 300v or a 1:30 ratio transformer.
7. A discharge cap voltage of 600v provides for much better spark energy out. Once an arc has been created the remaining voltage gets converted to current.
8. LED1 works great; it shows the pulses and limits the current from the MCU going to the SCR perfectly.

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