Variable HVDC Supply using Integrated High Voltage Transformer with Several Protective Features to the Output Power BJT/ MOSFET

Rahman, Muhammad Muktadir

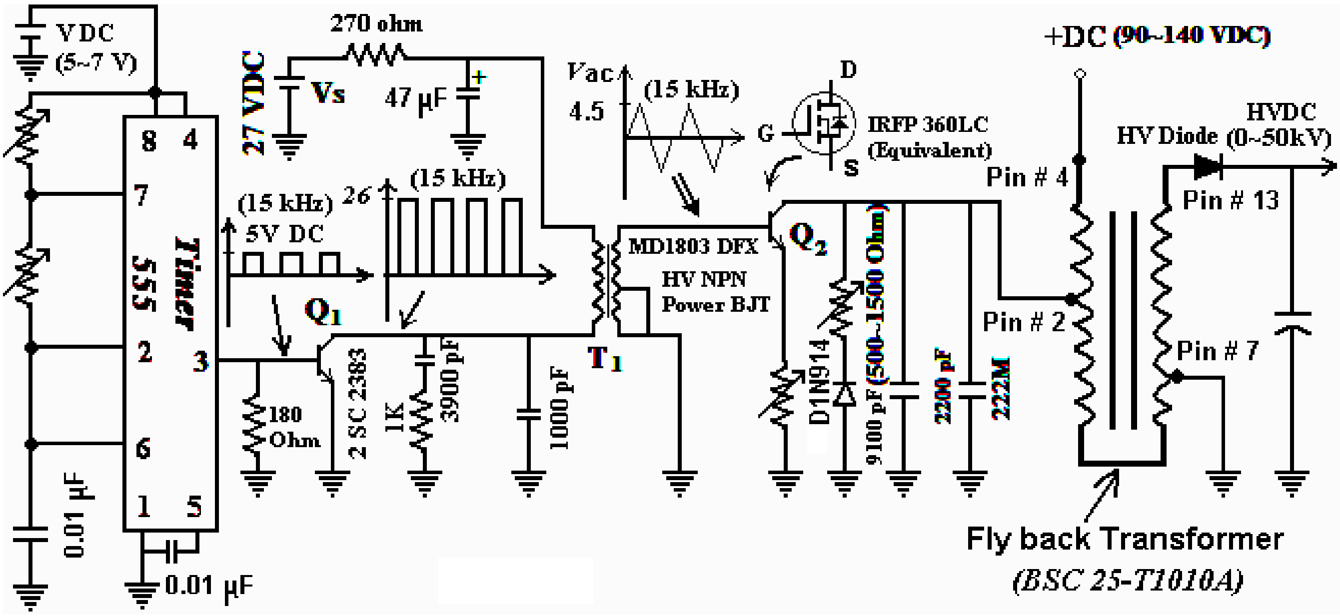

Figure: 1 Driver Circuit

***Abstract*—We can produce Variable HVDC with a little arrangement using Fly back Transformer (IHVT), Tesla coil, car ignition coil & other type of auto transformer found in microwave oven, X-ray units & in similar devices which is very reliable & light weight. In our experiment we made such a power supply & try to give it several protective features to its output power BJT/ MOSFET to increase the longevity of the power supply. As far as the general run of small-scale electronics is concerned, EHT supplies are used mainly for cathode ray tube (CRT) anodes and for some specialized purposes such as Geiger-Muller counters and photomultipliers. None of these applications calls for a large current drain. As an example, X-ray equipment may require 100 kVDC at a current of less than 1 A.**

***Index Terms* — Variable, HVDC, Spark gap**

Manuscript received April 18, 2011; revised July 25, 2011. This work was supported by the department of Electrical and Electronic Engineering, American Intl. University- Bangladesh (AIUB). The material of this paper was presented in part at the 3rd International Conference on Electrical Engineering and Informatics (ICEEI 2011) at the Institut Teknologi Bandung, Bandung, Indonesia on July 17-19, 2011.

Rahman, Muhammad Muktadir has graduated (Bachelor of Science in Electrical and Electronic Engineering) from American Intl. University-Bangladesh (House 83/B, Road 4, Kemal Ataturk Avenue, Banani, Dhaka - 1213, Bangladesh) in 2011 (Corresponding author. Tel. +8801711187792; e-mail: rumirahman1988@yahoo.com).

I. INTRODUCTION

There is no precise definition of what is now meant by EHT (extra high tension)/HVDC, but the original idea was that valve operated equipment could normally be expected to use voltage levels up to 500 VDC and anything higher than this was EHT, whether for a valve transmitter circuit, a TV cathode ray tube, X-ray tube or high voltage test equipments. Some of these EHT supplies such as those used for radio transmitters or particle accelerators demand very substantial currents, others use less than 1 mA. As an example, large radio transmitters may call for a 20 kVDC supply at several amperes of current. The typical Fly back Transformers (IHVT) used in TV sets are similar to those high frequency transformers which are used in SMPS supplies. Using these Fly back Transformers, one can build a HVDC supply. The circuit is known as *flyback power supply* (see Fig. 1) which is similar to SMPS supplies. EHT supplies for laboratory use require considerably better stabilization than those used for TV sets, but the general principles follow much the same lines as are used in SMPS supplies.

II. Experiments

We have implemented the circuit (Figure: 1) on bread board & PCB with necessary power supplies. Where Q_1 and Q_2 are driver and output transistors respectively. The output transistor is operated as an electronic switch, which when forward biased, saturates to close and on reverse biasing cuts-off to cause an open circuit. When in saturated mode, it has to deliver large bursts of power to the secondary coil of FBT. Therefore, it is of great importance that the controlling voltage waveform fed to the base of Q_2 shall always be large enough to firmly turn it 'on' yet also sufficiently negative to reverse bias it when required to be cut-off. The transistor Q_1 is also operated as an electronic switch and triggered into conduction by positive pulses applied at its base. These pulses are received from the oscillator which is formed by 555 timer IC. When Q_1 is saturated its collector is nearly earthed and when turned-off, the collector voltage rises to about the same value as the supply voltage (Vs). Thus the waveform appearing at the collector of Q_1 takes the form of a series of square wave or rectangular pulses of amplitude nearly equal to Vs. These are fed at the base of Q_2 through coupling (step-down) transformer T_1.The coupling transformer has a primary-to-secondary turns ratio of about 6:1 designed to match the high output impedance of Q_1 into the low impedance base circuit of Q_2. The high step-down turns ratio also ensures that a negative pulse of about 5V can be applied to the base of Q_2 when it is desired to turn it off. The connections of T_1 are so arranged that the 'turning-on' of Q_1 causes Q_2 to 'turn-off' and conversely. Output transistor, Q_2 is a class "C" amplifier. Basically the amplifier operates like a switch, operating at a frequency from 1kHz to several kHz. It operates at either saturation or cutoff. Some of these supplies use a bipolar transistor, while others use a MOSFET power transistor to pulse dc current through the primary of the IHVT [1],[6].

III. Results and Discussion

Flyback transformers cannot be connected to the mains directly. They start working at a frequency of about 1 kHz, whereas the mains have only 50Hz. The higher frequency has many advantages, such as smaller and lighter cores, smaller caps for rectifiers etc. We vary frequency of the square wave (received from the oscillator) from 1.5 kHz to 82.5 kHz (with a variable duty cycle from 48%-90%). If we increase frequency of the Oscillator then the diameter of the arc (at the secondary side of Fly back transformer and the spark gap between EHT cord and ground lead is approximately 1cm which indicates a spark-over voltage with a peak of 30 kV in air at 20^0C and 760 torr pressure) [2], will become more thick with less whining which indicates an increase in EHT/HVDC. If we decrease frequency of the Oscillator then the diameter of the arc will become thinner with a hissing sound which indicates a decrease in EHT/HVDC. Arc will not sustain if the frequency of the Oscillator is less than 1.5 kHz. If we increase duty cycle (%) of the square wave (received from the oscillator) then the arc at the secondary side of FBT becomes thinner. If we decrease duty cycle (%) of the square wave of the oscillator then the arc at the secondary side of FBT becomes very thick [9]. In our experiment when the duty cycle of the square wave of the oscillator is ≥ 98%, thin arc vanished suddenly. In addition to higher voltage requirements, some applications need more current and also some degree of stabilization. The current requirement is met by using larger currents in the primary of the coupling transformer (T_1) so that the amount of power that is switched through Q_2 is substantially higher. Output or driver transistors may have collector voltages as low as 26 volts, but they will draw up to 1.0 ampere or more of current. Therefore, transformer windings, rectifiers, and filter chokes of necessary power supplies need to have higher current ratings [5]. If we increase frequency of the Oscillator, current at the output of the Oscillator will increase approximately from 6.5 mA to 12.5 mA during operation. If alternating sine wave has applied at the base of Q_1 then it will damage the power BJT (Q_2) as well as the Oscillator but before that it worked for a while (like few seconds). If E_S (secondary voltage) of FBT is reduced, it impacts an increase in I_P (primary current) and thus damages Q_2 . Adding capacitors (912 H, 222M) in parallel (Figure: 2) between collector & emitter/Drain & source of HV power BJT/ nMOS (Q_2) will increase the voltage (EHT).

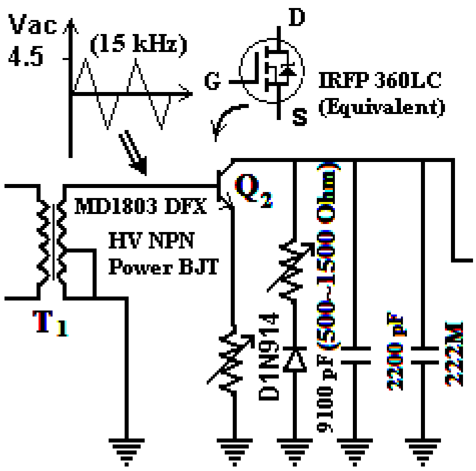

Figure: 2 Output Stage

If we increase the B+ Voltage at pin # 4 of FBT then HVDC will also increase [4]. We can increase HVDC by modifying the Fly back transformer primary winding by adding turns and extending the winding on the same core in this fashion (Fig.3).

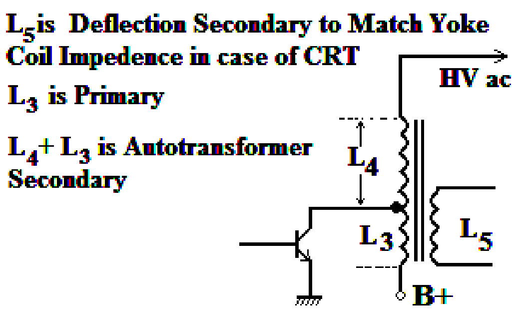

Figure: 3 Flyback Transformer

Using voltage multipliers (triplers, generally), we can reduce the high-voltage requirements of the FBT by a large factor. Voltage tripler modules are used to obtain this additional high voltage. This arrangement also minimizes the insulation requirements of the FBT. Figure: 4 shows a

ISBN: 978-988-18210-9-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

schematic of a tripler circuit. Though there are five rectifiers in the module, two are used to couple the rectified dc from one rectifier to the other. The other three rectifiers and associated capacitors make up the voltage tripler. Rectifiers rather than resistors are used to couple the dc voltage because there would be a loss of both voltage and power if resistors were used.

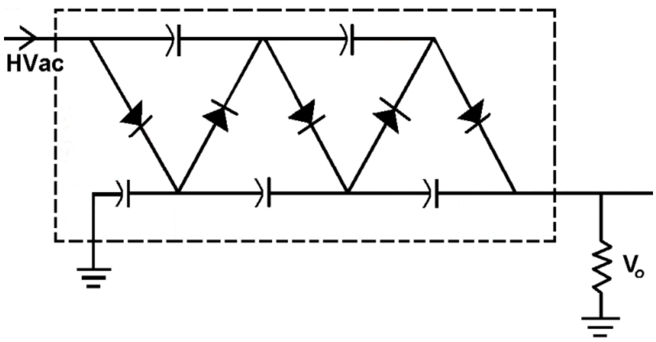

Figure: 4 Typical voltage tripler circuit used as a high voltage rectifier.

IRFP360LC is better than MD1803DFX because I_{DM} (92A) of that nMOS (IRFP360LC) is much greater than I_{CM} (15A) of the BJT (MD1803DFX) which keeps the nMOS cooler than the BJT during operation. Finally the overall results will be optimum if we use such an oscillator which produces less noisy pulse (here square wave).

IV. Protective Features

Although there is an inbuilt damper diode in the power BJT/nMOS (Q_2), we have used an extra 2W diode (polarity inconsequential). The resistor in series with this diode can not have a value less than 500 Ω to avoid damage to the resistor. This is critical in limiting the magnitude of the peak value of the collector emitter voltage during excessive arcing. Thus protective features of the entire schematic shown in figure: 5 ultimately comes down to the D1N914 and its series resistance which clearly brings significant changes in EHT [6]. Increasing the value of R_e,we can make the Q_2 more sustainable.

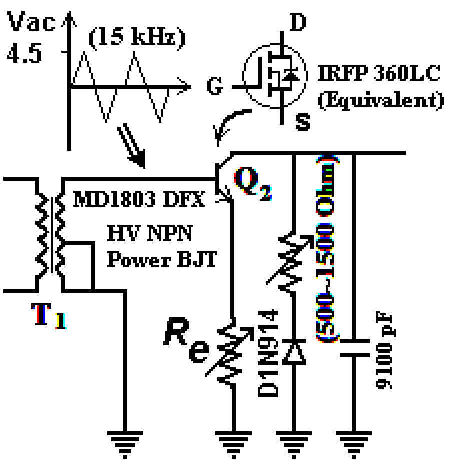

Figure: 5 Output Stage

We have tried to show a design approach using Microwind 3.1 (Figure: 6) of the concept of adding extra diode with power BJT/nMOS (Q_2), discussed above [8].

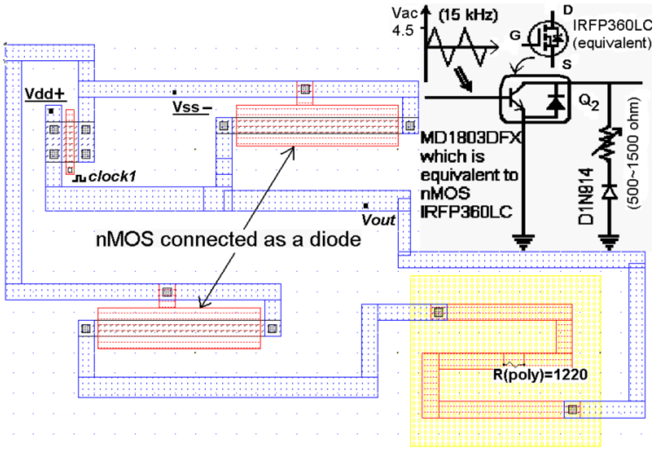

Figure: 6 Design Approach with Corresponding Circuit Diagram as Insets.

V. Measurement & Instrumentation

It is not possible to check directly the voltage pulse waveform at the anode of the high voltage rectifier, because the peak-to-peak amplitude of the pulse may be as high as 50KV. It is possible, however to see the pulse on a scope by bringing the scope probe near the anode lead of the rectifier. There is enough capacitive coupling to give an indication. We have also used a HV probe (Fig.7), connected with a DMM to measure HVDC. A spark gap (Fig.8) can be used for measurement of the peak value of the HVDC [7]. Air is a poor conductor of electricity. However if two conductors are separated by a small gap of air /gas, it is possible to make the electric current jump across the gap. 1 cm spark gap in air between EHT cord (pin # 13) & ground lead (pin #7) indicates a spark over voltage of 30 KV (peak) approximately. If the arc gap becomes too long, the applied voltage could be insufficient to maintain the arc and it breaks off .

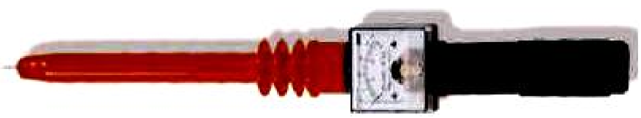

Figure: 7 HV Probe

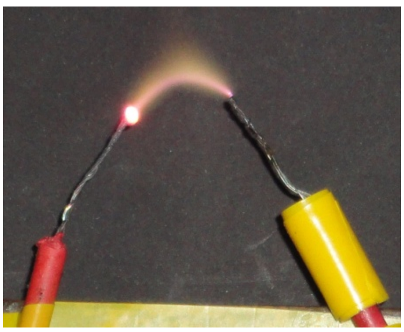

Figure: 8 Spark Gap

VI. Conclusion

The circuit works and is great for many things, such as drawings arcs, Jacob's ladders, charging capacitors, running a HV cascade (not recommended for beginners!), powering plasma globes & lifter, and even powering a small Tesla Coil. Any work on EHT supplies should be carried out with great cautions, because capacitors in the circuit may have been charged to several kilovolts [3]. Even though EHT supplies may be current limited and capacitors values are small compared to the electrolytic capacitors that are used in low voltage supplies, the discharge of a capacitor can represent a large amount of energy which can prove fatal. Switching off and discharging capacitors may not be safe either, because some types of capacitors exhibit a form of voltage hysteresis, so that after being discharged they can build up voltage again and when work is to be carried out on an EHT supply, all capacitors should be discharged completely.

Appendix

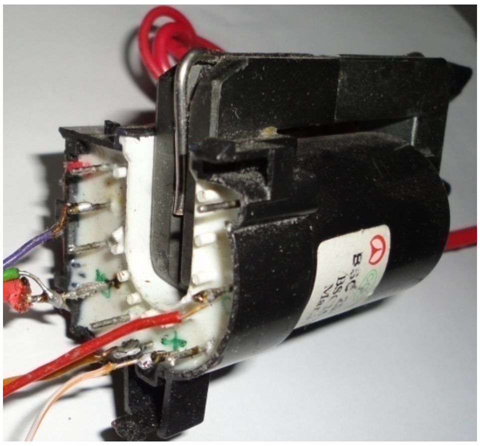

Figure: 9 Diode split Flyback transformer.

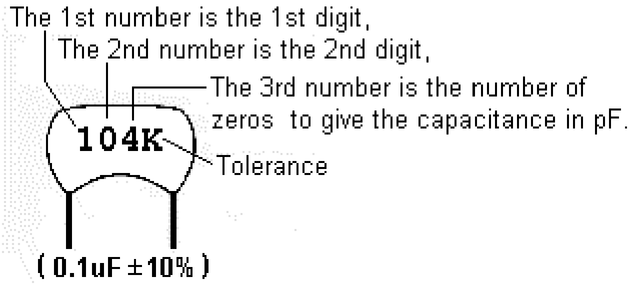

Figure: 10 General Capacitance Code breaking method

References

[1] Robert E. Iannini, *Build your own working Fiber optic, Infrared, and Laser Space-Age Projects*, TAB books, 1987, ISBN: 0-8306-2724-3.

[2] M Naidu, V. Kamaraju, *High Voltage Engineering,* ISBN: 9780070669284 , Nov. 2008.

[3] R.A.Penfold, *Electronics Build & Leran,* First Indian Edition, 1990.

[4] Alexander Schure, *Basic Television*, Vol. 4, Reprint- 1989.

[5] Jack Darr, *Transistor TV Servicing Made Easy,* 3rd INDIAN Reprint-1983.

[6] Arvind M. Dhake, *Television & Video Engineering,* McGraw Hill, 2006.

[7] Bernard Grob, Charles Herndon, *Basic Television and Video Systems,* March 1998.

[8] Etienne Sicard,Sonia Delmas Bendhia, *Basics of CMOS Cell Design,* McGraw Hill, 2007.

[9] *Flyback Transformer Design for the IR40xx Series- International Rectifier Application,* Unitrode Magnetics Design Handbook (SLUP003), Note (AN1024), 2001.

ISBN: 978-988-18210-9-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)