DESIGN, SIMULATE AND CONSTRUCT 15kV COCKCROFT-WALTON VOLTAGE MULTIPLIER

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This report is submitted in partial fulfillment of the requirement for the award of Bachelor of Electronic Engineering (Industrial Electronics) With Honours

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Sesi Pengajian : 2007/2008

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ABSTRACT

In this Cockcroft-Walton project, the theory of this method is to build power supply that can generate voltage with low current. Designing the circuit based on the basic of Cockcroft-Walton circuit that consist of capacitor and diodes. The high voltage equipment is required to study the insulation behavior under all conditions, which the apparatus is likely to encounter. Some objectives are to study the fundamental of voltage multiplier such as type, characteristics, advantage and disadvantages before designed a Cockcroft-Walton's voltage multiplier with 15kV output. The methodology is to study the characteristics of voltage doubler and tripler circuit compared with Cockcroft-Walton's voltage multiplier before designing, simulate the designed circuit with simulation program such as MULTISM, PSpice and other simulation program and construct the designing circuit to prove the theoretical. The result hopefully can fulfill the theory of the Cockcroft-Walton which generates high voltage with low current.

ABSTRACT

Projek pengandaan voltan berteraskan konsep yang diperkenalkan oleh Cockcroft-Walton menggunakan prinsip menggadakan voltan dengan mengurangkan nilai arus yang mengalir di dalam litar penggandaan voltan. Litar yang menggunakan konsep Cockcroft-Walton ini dibina mengunakan gabungan diod dan capcitor untuk menghasilkan voltan arus terus daripada sumber voltan arus ulang alik. Kelemahan yang dimiliki oleh litar ini merupakan sifat voltan arus terus yang dihasilkan masih mempunyai denyutan kecil dan pengurangan voltan dibawah pengaruh beban sukar untuk dikawal disambing kelebihan sebagai litar yang menghasilkan voltan arus terus yang tinggi dengan kos yang rendah. Objektif yang ingin dicapai adalah untuk mempelajari dengan lebih mendalam tentang litar penggandaan voltan berteraskan konsep Cockcroft-Walton dan perisian simulasi serta membina model litar penggandaan untuk membuktikan kebenaran serta mengkaji sifat-sifat litar berteraskan konsep yang telah diperkenalkan oleh Cockcroft-Walton. Langkah-langkah yang diambil untuk mencapai objektif ini adalah dengan membuat jadual aliran, kajian dan pembuktian secara teori dan pengiraan, membuat silmulasi dan menghasilkan model berdasarkan daripada keputusan simulasi.

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CW - Cockcroft-Walton

AC - Alternating Current

DC - Direct Current

CHAPTER I

INTRODUCTION

The main emphasis has been given up at first stage on the simulation, design and development of the high voltage DC power supply. At the second stage, the DC power supply is constructed based on hardware implementation and it can be used for multiple purposes. At the first stage of this work is to study the voltage multiplier circuits such as; voltage doubler circuits and voltage tripler circuits and simulate all the circuits.Finally, based on Cockcroft-Walton (C-W) voltage multiplier circuits to construct a prototype DC power supply in the laboratory at the output range of 15 kV. The conventional technique is used because the designed multiplier circuit is intended to be applied either for impulse generator charging units or for laser excitation. The main components of the DC power supply are rectifier diodes and capacitors. The simplest unregulated power supply consists of three parts namely, the transformer unit, the rectifiers unit and the capacitors unit. Joseph M. Beck has presented his paper the basic operation of voltage multiplier circuits such as half wave voltage doubler and tripler circuits and discussed guidelines for electronic component selection for diode and capacitor. Spencer and his group [6], have designed the prototype surface mounted Cockcroft- Walton (C-W) board and tested for use in a battery operated, palm-sized radiation detection device and it took around 1 kV output voltage and current less than 15 mA. In addition to circuit components, this board contains sockets contains which hold two Hamamatsu R7400P PMTs. Juichi Tanaka, has explained the new idea to develop the high voltage DC power supply. They introduced a high frequency switching converter; as a result its shape becomes smaller. The conventional Cockcroft-Walton multiplier circuit ignores the inductance but they have used the inductance as well. The advantage of this circuit is that low cost, high reliability and simplicity of control. The disadvantage of this circuit is that it cannot completely control the harmonic current. John C, Salmon [9], has explained single phase voltage doubler PWM boost rectifiers and obtain three types of PWM voltage switching patterns namely, unipolar PWM, Bipolar PWM, and phase adjusted unipolar PWM. When high output voltage is required, the voltage doubler rectifier is able to generate AC line currents with the lowest current distortion. Yamamoto and his group, [10], have proposed a power factor correction scheme using a voltage doubler rectifier circuit without switching devices. In this method using a voltage doubler rectifier, the input current is divided into two periods, where one period charges the small input capacitor and the other charges the large output capacitor through a filter capacitor. Zhang, et al [11], in their paper have discussed about the experimental results of the voltage tripler circuit. They proposed improved voltage tripler with a symmetrical stacking charge pump. The main advantage of using this symmetrical staking charge pump is to have a rapid rise time for the output voltage. Zhang, et al [12], in their paper have discussed about the experimental results of the voltage tripler circuit. They proposed improved voltage tripler with a symmetrical stacking charge pump. The main advantage of using this symmetrical staking charge pump is to have a rapid rise time for the output voltage.

Objectives and problem statement

The high voltage equipment is required to study the insulation behavior under all conditions, which the apparatus is likely to encounter. Tests are also made with voltages higher than the normal working voltage to determine the factor of the safety over the working conditions and to ensure that the working margin is neither too high nor too low. The conventional forms of high voltage in use can be divided into the following classes:

i. Alternating current voltages
ii. Direct current voltages
iii. Transient voltages.

The objectives of this project are:

i. To learn about the basic things that transform a voltage multiplier, the concept, circuit, characteristic of the output and the type of the multiplier.
ii. To learn and construct the Cockcroft Walton voltage multiplier.
iii. To create a prototype of 15kV Cockcroft Walton voltage multiplier

The first objective is to learn about the fundamental of voltage multiplier such as the principal, concept, types, and characteristics of each type and the output waveform of each circuit. This is the first stage is the introduction to the voltage multiplier that will give the idea and first view of the project. The second stage is to learn about the Cockcroft-Walton voltage multiplier. The scope of this stage is comparison of the voltage multiplier that has been covered with the Cockcroft-Walton voltage multiplier.

After the comparison has been completed, the final stage is to design, simulate and construct the multiplier circuit to prove the theoretical that has been covered. The consideration of the designed circuit is to get the amplified voltage to 15kV from the actual supply voltage. At the end of this project, a prototype of a Cockcroft-Walton voltage multiplier will be construct, the output of the circuit will be compared with the simulation result and the percentage different between the result will be calculated to prove the theoretical that has been learned about the characteristics of Cockcroft-Walton voltage multiplier.

Scope

1. To analyzed the fundamental of multiplier:
   i. Give the different of each multiplier.
   ii. Advantages and disadvantages.
   iii. The output waveform.

2. Redesign the circuit.
   i. Change the value of component used.
   ii. Calculate the expected output.

3. Simulate the redesign circuit.
   i. Using PSPICE, MATLAB or other simulation programming.
   ii. Get the output waveform.
   iii. Determine the advantage and disadvantage of the circuit.

4. Construct the circuit.
   i. Construct the prototype of the circuit.
   ii. Compared the output with the simulation result.
   iii. Calculate the percentage different.

To achieve the objective of this project, the work scope that has been stated above has been considered. The simulation program and the source are use to limited the current research is based on voltage multiplier and Cockcroft-Walton voltage multiplier. This scope also will give the advantages and disadvantages of each type of voltage multiplier and will be proven with simulation and hardware experimental. This research is about using high voltage in electronic circuit and equipment such as oscilloscope, television and many more electronic devices that needs high voltage to operate.

Methodology

Analyzed the fundamental of multiplier:

Both full wave and half wave rectifier circuits produce a d.c. voltage less than the a.c. maximum voltage. When higher d.c. voltages are needed, a voltage doubler or cascaded rectifier doublers circuits are used. Cascaded voltage doublers are used when larger output voltages are needed without changing the input transformer voltage level. Cascaded voltage multiplier circuits for higher voltages are cumbersome and require too many supply and isolating transformers. It is possible to generate very high d.c. voltages from single supply transformers by extending the simple voltage doubler circuits. This is simple and compact when the load current requirement is less than one milliampere, such as for cathode ray tubes. Valve type pulse generators may be used instead of conventional a.c. supply and the circuit becomes compact.

Redesign a Cockcroft Walton multiplier:

The use of several stages arranged in this manner enables very high voltages to be obtained. The equal stress of the elements used is very convenient and promotes a modular design of such generators. The number of stages, however, is strongly limited by the current due to any load. This can only be demonstrated by calculations, even if ideal rectifiers, capacitors and an ideal a.c. voltage source are assumed. The lowest stage of the cascade circuit is the Cockcroft–Walton voltage doubler. The a.c. voltage source V(t) is usually provided by a transformer, if every stage is built for high voltages, typically up to about 300 kV. This source is always symmetrically loaded, as current is withdrawn during each half-cycle. The voltage waveform does not have to be sinusoidal: every symmetrical waveform with equal positive and negative peak values will give good performance. As often high-frequency input voltages are used. The peak value of Vo is reached at t where the value of input voltage is maximum, the rectifiers, diode; D just stopped to transfer charge to the capacitor; C that are use to smoothed output voltage.

CHAPTER II

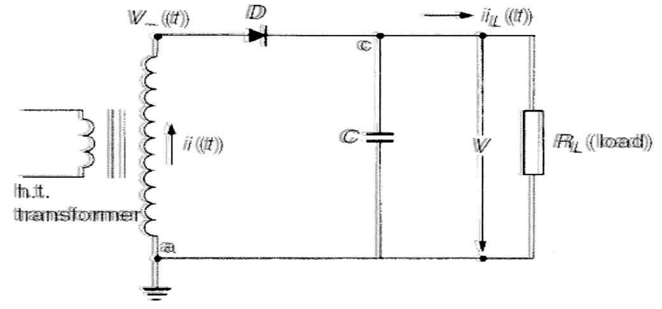
BACKGROUND OF STUDIES

2.1 A.C. to D.C. conversion

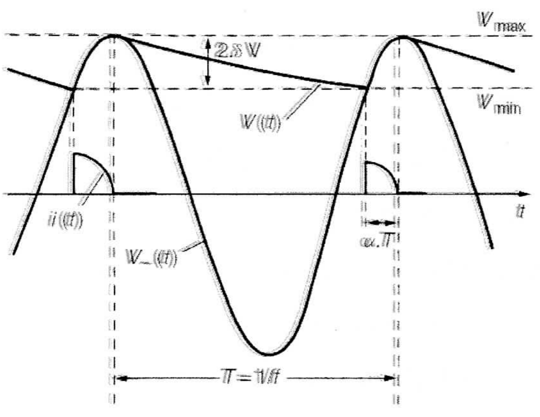
The rectification of alternating currents is the most efficient means of obtaining HVDC supplies. Although all circuits in use have been known for a long time, the cheap production and availability of manifold solid state rectifiers has facilitated the production and application of these circuits fundamentally. Since some decades, there is no longer a need to employ valves, hot cathode gas- filled valves, mercury pool or corona rectifiers, or even mechanical rectifiers within the circuits, for which the auxiliary systems for cathode heating, etc., have always aggravated their application. The state of the art of such earlier circuits may be found in the work of Craggs and Meekwhich was written in 1954. All rectifier diodes used now adopt the silicon type, and although the peak reverse voltage is limited to less than about 2500 V, rectifying diode units up to tens and hundreds of kilovolts can be made by series connections if appropriate means are applied to provide equal voltage distribution during the non-conducting period. One may treat and simulate, therefore, a rectifier within the circuits.

2.2 Voltage multiplier

For a clear understanding of all a.c. to d.c. conversion circuits the single-phase half-wave rectifier with voltage smoothing is of basic interest (Fig. 2.1(a)). If we neglect the leakage reactance of the transformer and the small internal



(a)



(b)

Figure 2.1: Single-phase half-wave rectifier with reservoir capacitance.

(a) Circuit. (b) Voltages and currents with load R_L

A nonlinear circuit component that allows more current to flow in one direction than in the other. An ideal rectifier is one that allows current to flow in one (forward) direction unimpeded but allows no current to flow in the other (reverse) direction. Thus, ideal rectification might be thought of as a switching action, with the switch closed for current in one direction and open for current in the other direction. Rectifiers are used primarily for the conversion of alternating current (ac) to direct current (dc). If the average current is subtracted from the current flowing in the rectifier, the result is an alternating. This ripple current flowing through a load produces a ripple voltage which is often undesirable. Filter and regulator circuits are used to reduce it to as low a value as is required.

2.3 Cockcroft-Walton's multiplier

The Cockcroft-Walton (CW) generator, or multiplier, was named after the two men who in 1932 used this circuit design to power their particle accelerator, performing the first artificial nuclear disintegration in history. John Douglas Cockcroft and Ernest Thomas Sinton Walton used this voltage multiplier cascade for most of their research, which in 1951 won them the Nobel Prize in Physics for "Transmutation of atomic nuclei by artificially accelerated atomic particles". Less known is the fact that the circuit was first discovered much earlier, in 1919, by Heinrich Greinacher, a Swiss physicist. For this reason, this doubler cascade is sometimes also referred to as the Greinacher multiplier. The CW is basically a voltage multiplier that converts AC or pulsing DC electrical power from a low voltage level to a higher DC voltage level. It is made up of a voltage multiplier ladder network of capacitors and diodes to generate high voltages. Unlike transformers, this method eliminates the requirement for the heavy core and the bulk of insulation/potting required. Using only capacitors and diodes, these voltage multipliers can step up relatively low voltages to extremely high values, while at the same time being far lighter and cheaper than transformers. The biggest advantage of such circuits is that the voltage across each stage of the cascade is equal to only twice the peak input voltage, so it has the advantage of requiring relatively low cost components and being easy to insulate. One can also tap the output from any stage, like a multi-tapped transformer. In practice, the CW has some drawbacks. As more and more stages are added, the voltages of the higher stages will 'sag', primarily due to the AC impedance of the capacitors. The ripple also increases, which may or may not be important to the application at hand. A transformer needs the diodes anyway in the rectifier. The choice between a transformer and a capacitor depends on the voltage to current ratio (the resistance) of the power supply one is to build. The border lies at about

1 kΩ. A common configuration uses a transformer for the low voltage stages and a CW for the higher voltage stages.CW multipliers can be used to generate bias voltages of a few volts or tens of volts or millions of volts for purposes such as high-energy physics experiments and lightning safety testing. CW multipliers are also found, with a higher number of stages, in laser systems, high voltage power supplies, X-ray systems, LCD backlighting, traveling wave tube amplifiers, ion pumps, electrostatic systems, air ionizers, particle accelerators, copy machines, scientific instrumentation, oscilloscopes, and many other applications that use high voltage DC.

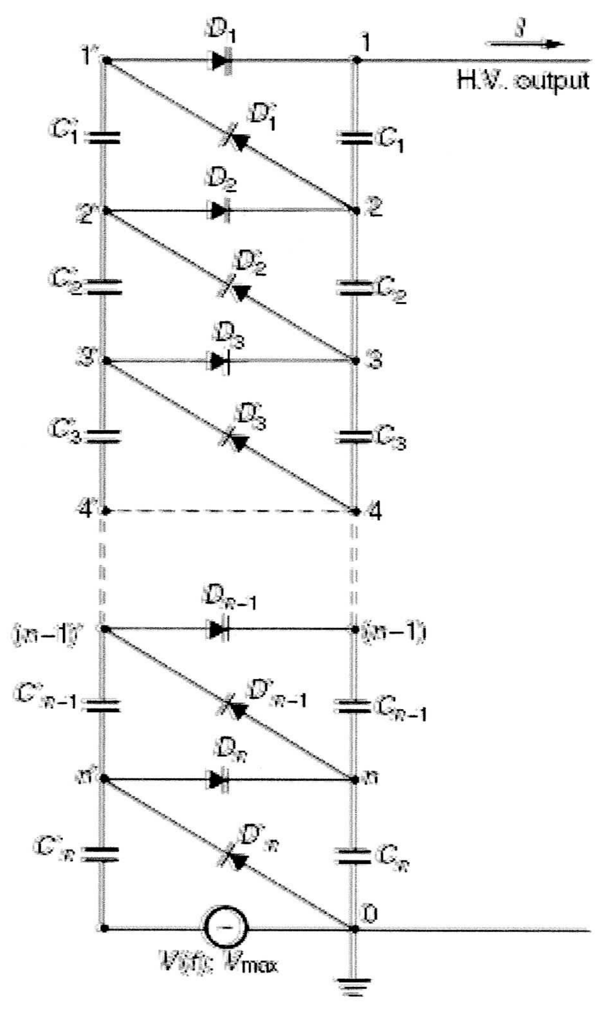


Figure 2.2: Cascade circuit according to Cockroft–Walton

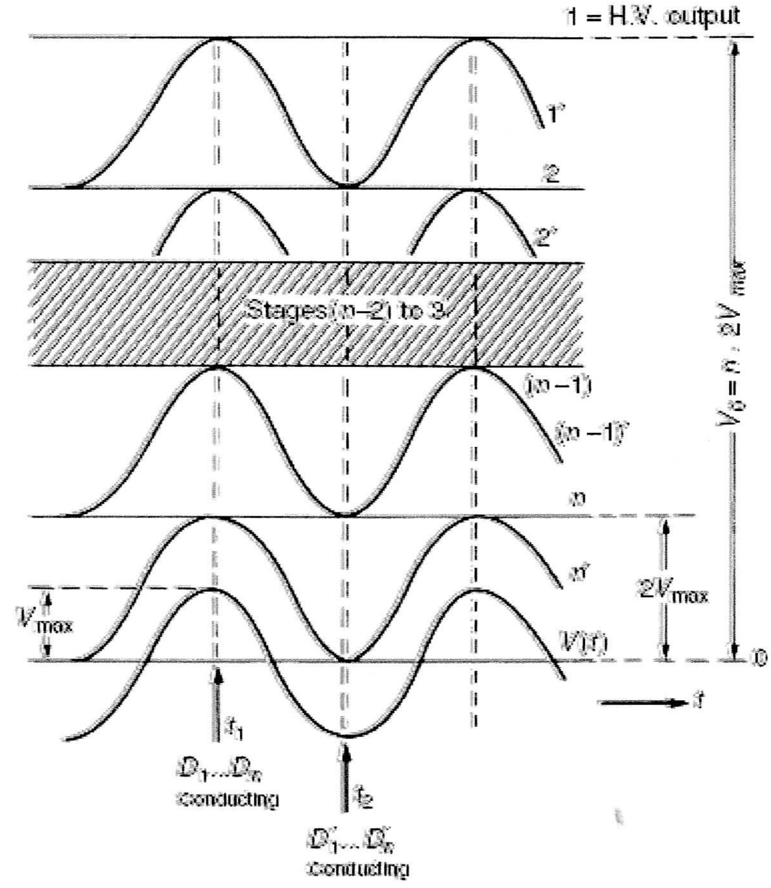


Figure 2.3: Waveform of potentials at the nodes, no load