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A Voltage Multiplier Using Timer Circuit

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Abstract: This study describes a DC to DC voltage multiplier using the 555 Integrated Circuit (IC) timer in an astable state. The major motivation of the design is to be able to produce an inexpensive and light form of generating high DC voltage to power devises that would normal need a really large and heavy battery to be operated. The study also briefly touch on the negative aspects of large DC voltage, heat dissipation and general battery life. With the help of the astable state of the multivibrator, a circuit which uses the same concept found under AC voltage multiplying of using a connection of diode and capacitors to charge the capacitors using the AC nature of rising and lowering voltage levels in a sinusoidal wave, a pulse similar to this will be generated and the same properties and relationship of diodes and capacitors taken advantage of. The study also offers calculations governing the astable 555 timer and practical diagrams on this application. Finally, the study ends with a successful and practical design schematic for a DC to DC voltage multiplier that rises the output DC voltage to about four times the original input.

Key words: Design, voltage multiplier, integrated circuit, 555 timer, simulation, DC to DC, multisim

INTRODUCTION

In the field of electronic there is a requirement to produce voltage higher than that which the power supply can provide for one reason of another (Zungeru *et al*., 2016; Golla and Vespi, 1998). Supported this need taking the field of programmable non-volatile memories such as EEPROM and flash EEPROM types as an example of devices which many need more supply voltage than the source, V_{CC} in this case can master.

However, researchers by Golla and Vespi (1998) try to multiply relatively low voltage from supply of about 3 V to about 5.5 V. In the case of this design, however, the aim is to be able to multiply a minimum of about 6 V to about 24 V and a maximum 14 V to about 56 V. A 40 V battery could be used to power a large outdoor lawnmower. The range is meant to allow for flexibility to meet most for the needs by the user. There for the design has the capability to in essence double then triple and finally quadruple a range of voltages between and including 6 and 14. This range is governed by the activation voltage of the 555 timer which according to Dwivedi and Daigavane (2011), it is between +5 and +15 V, the slight deviation from the true value inwards is to allow for any voltage drops due to other components in the circuit and loss of current and energy to eddy current and heat which is a major problem in high DC voltages (Moss, 1998).

Voltage multipliers are wide defined AC (Alternating Current)-to-DC power conversion devices, comprised of diodes and capacitors that produce a high potential DC voltage from a lower voltage AC source (Anonymous, 2011; John, 2009). This is because of the dangers of DC as observed by Moss (1998), DC can be is difficult to handle in high voltages, it requires very thick and heavy wire, so, they are not burnt right through also at high voltage components cannot usually handle the power dissipated by high DC voltages. This among others is the reason voltage multipliers for DC to DC are not popular, they are seen as too expensive to even bother with as they need far too many thing for them to be safe (Harmon and Atherton, 1982) concurs with this view.

Since, the gaining viability in 1888 thanks to Galileo Ferraris and Nikola Tesla AC systems have been the means and mode of powering the lives of homes and the appliances found there to make the home and easier and lovelier place to be in. Despite the obvious benefit of AC over DC there is one thing DC can do that AC cannot and that is to be stably stored in a casing to be used which our appliances are not connected to a wall, a generator or have on installed in them. Plainly put AC can be used to charge a battery but a buttery does not produce AC once charged.

To store large amounts of voltage in a battery also is not without its challenges if we take an example of a car batter with houses about 12 V, we can start to see the

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scale at which housing close to 40 V can be. Batteries that produce such amounts of power are usually housed in one larger container with smaller sections called cells (Mooney, 2015; Agarwal, 2015). Their size and weight make them practically unusable with many of the devices we wish to have more power but also light enough to carry around and use as we see fit.

MATERIALS AND METHODS

In a representation of a DC and an AC, the DC voltage is at some content value higher and straight line value, while the AC is alternating at some frequency (f_0). AC describes the flow of charge that changes directions periodically (Agarwal, 2015), this results in a voltage level that changes along with the changing current. DC on the other hand describes unidirectional flow of current (Agarwal, 2015) because the current flows in one direction, here the voltage level does not change.

Using the nature of the AC to release voltage levels periodically, voltage multipliers are based on a simple two-section diode-capacitor type of rectifier network that was originally designed way back in the 1930s for use in high-value AC to DC voltage conversion applications (Marston, 2017).

In Fig. 1, the Capacitor (C1) to Diode (D1) network is a simple clam circuit of the diode application (diode clamp) of which when fed with an alternating signal input (AC), alternating between 0 V and Peak Voltage (V_P), it produces an output signal in the form of a waveform which is identical to the input voltage but in this case, the Voltage is Peak-to-Peak (V_{P-P}). This is also equivalent to the D2-C2 network of which the input to the network is the output from the C1-D1 network (Marston, 2017).

This example show the simplest and most affordable way of creating a voltage doubler tried and tested for years, using the same principle the idea is to convert DC into a signal that behaves like the AC voltage, rising up and falling for this we turn to the stable state of the 555 timer. Zungeru *et al.* (2016) describes a timer in this state as one whose 'low' and 'high' states are both unstable, therefore, it toggles between them resulting in a continuously train of pulses. Figure 2 is the general block diagram showing the major parts of the system.

Design requirements: There is a lot, however, that goes into choosing the diode and capacitor, the 1400 N diode is the most common and a general purpose silicon diode with an estimated forward bias voltage drop of 0.7 and a temperate range of 1.4-500 K (Boylestad and Nashelsky, 2002) which should be high enough to deal with the heat factor that DC voltage comes with. The capacitor have to have a voltage rating at least 10 V higher that the maximum voltage the circuit can produce in the case of this study, the design is set to produce a maximum of 56 V which would dictate a capacitor rating of 60 V minimum. The design did not look into the type, thickness the connecting cables have to be to withstand this amount of power.

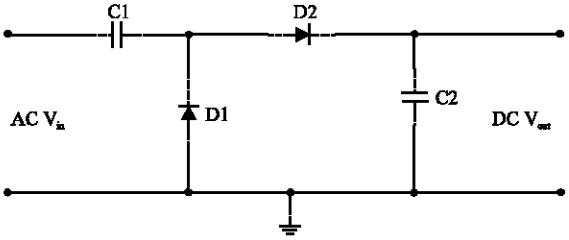

Fig. 1: A voltage multiplier circuit

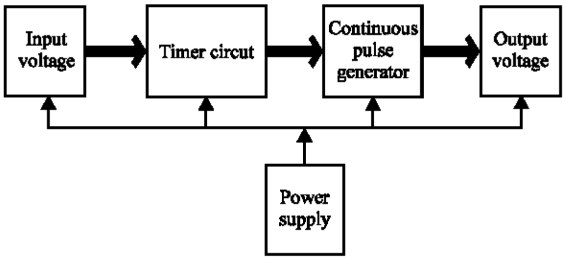

Fig. 2: Block diagram showing the major parts of the system

DC is also polarized that is to say it has a distinct positive and negative, therefore, there is also need to use not just rated capacitors but they must be polarized too. To enable the switching between doubling the output voltage and quadrupling it a series of switches which will move between the cascaded study of the circuit will also be a part of the circuit.

Design description: The circuit uses a pulse generation timer to turn a constant DC voltage into a pulse that move between 0 which is low and high which is the DC input voltage. For a 5 V DC, a straight DC voltage into say '5 V' because of the timer's in an astable state condition is given and the timer will allow the 5 V to pass through it for a time assume for 3 sec, then cut it off completely there by giving no output voltage, here referred to as the low state or 0 for a time a well say 3 sec again. Just as it have cut off the voltage it will after the 3 sec have ended allow the 5 V to pass once again, this cycle will repeat every 3 sec as long as the power supply is connected.

The output of the timer is then fed into a similar circuit as that shown in Fig. 1. Then, during the study when the pulse is high (at 5 V) the Capacitors C1 and C2 are charged to a voltage equal to the 5 V, during the low study the capacitors discharges and produce double the amount of input voltage ((2×5 V) = 10 V) this process is then repeated for the second time and another 5 V essentially tripling the voltage the a third, now to quadruple the output.

Looking at the logical operations. It make sense to conclude that the addition could be infinite, so, as to multiply the output even farther but cushion must be taken because of the danger of DC. Here, calculation will need to be employed to see if the components will be able to handle such high outputs of DC voltage.

The 555 'timer' IC used in this circuit is used as a free-running square wave generator which operates at about 0.3 kHz for which the frequency of operation is determined by the resistors and capacitor connected between the pins 6, 7 and 2 of the 555 timer IC (Fig. 3). Using the equation from (Zungeru *et al*., 2016):

$$T = 0.693\times(R_1+R_2)\times C+0.693\times(R_2)\times C = 0.693\times(R_1+2+R_2)\times C \quad (1)$$

Where:

R_1 = 90 Ω

R_2 = 20 Ω

C = 100 nF

Giving:

$$T = 0.002778237 \text{ sec} \quad (2)$$

And:

$$F(\text{Frequency}) = \frac{1}{T} \quad (3)$$

$$\therefore F = 359.9404946 \text{ Hz} \quad (4)$$

$$F \approx 0.3 \text{ kHz} \quad (5)$$

The system directly drives the resistor-capacitor connection on the right hand side of the timer (Fig. 3) which is the 'multiplier' stage which (ideally) produces a DC output equal to the peak-to-peak output of the square wave which (ideally) equals the V_{cc} value.

In practice, the square wave's peak-to-peak value is slightly less than V_{cc} and the 'multiplier' loses voltage in voltage drops across the diodes at about 0.7 V pair diode, the net result being that the actual output (when very lightly loaded) is about 1.6 V less than V_{cc} for the doubler, 3.2 V for the tippler 4.8 V for the quadrupler and so on, e.g., 8.4 V with a 10 V supply. The circuit can use any supply in the range 5-15 V (Zungeru *et al*., 2016). However, for the purposes of this report the minimum has been set to 6 V and maximum to 14 V to ensure the 555 timer is always fed enough voltage to operate but not too much to overload it. Looking at Fig. 3, the following equation can be derived using Ohm's law:

$$-V_{s\,max}-V_{C1}+V_{C2} = 0 \quad (6)$$

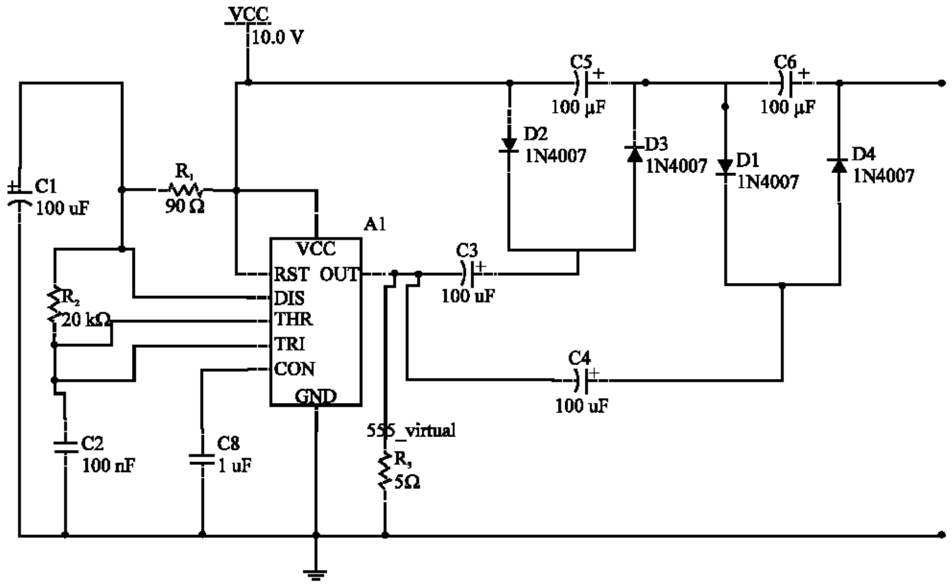

Fig. 3: Circuit schematic of voltage doubler

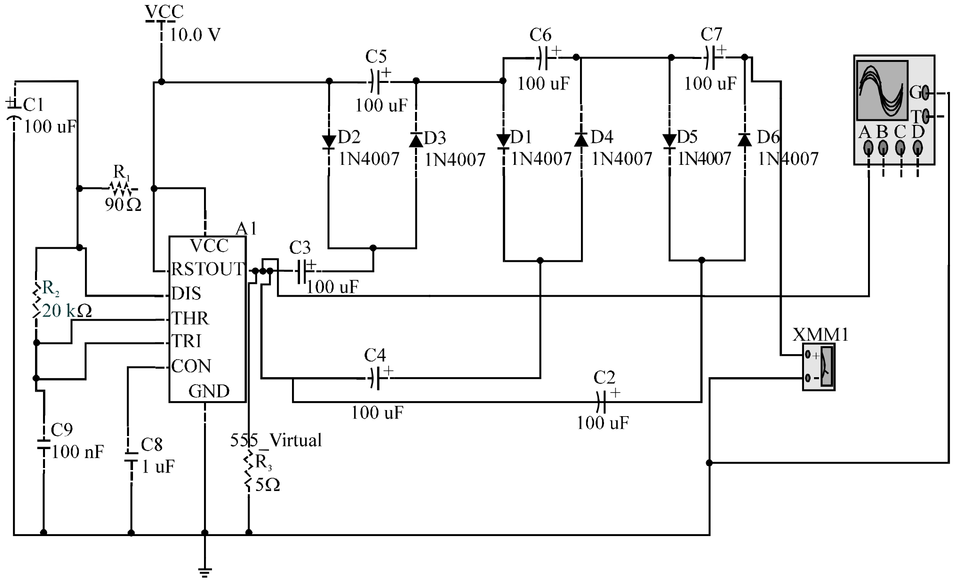

Fig. 4: Complete circuit diagram of a voltage multiplier system using timer circuit

$$V_{C2} = V_{smax}+V_{C1} = V_{smax}+V_{smax} = 2V_{smax} \tag{7}$$

$$V_{C2} = \text{Twice the high value of the timer voltage (since, } V_{C1} = V_{smax}) \tag{8}$$

Type of diodes: Diodes are semiconductor devices with two terminals and usually allow unidirectional flow of current (Boylestad and Nashelsky, 2002), this is referred to as the bias of the diode and practically they are some current that it allows to pass in it reverse bias state, however, the amount is negligible. Diodes are commonly made out of two primary semiconductors Silicon and Germanium, the former taking the name of it primary component (silicon diode) and the later called a zener diode.

The two terminals for which these devices are defined by are the ones that give them their functionality, the forward being from the negative to the positive terminal (anode to cathode).

Selection process: When deciding the best type of diode to use it is impotent to note desired function of the diode, for example the silicon diode has a larger forward bias rating and a lower reverse bias rating as compared to the zener diode for this design reserarch and the desire diode was the one that prevented as much current as possible from flowing back, therefore by the process of elimination the zener diode was removed from being a potential component.

The next criteria was to check the readily availableness amongst the silicon diode, the most logical set was to look for an inventory of all the available silicon diodes in the lab and used each to use if they satisfy the desired output.

Evaluation: Theoretically the design research having proven all that is needed by hand calculations, the design was later built and simulated using the multisim software (Fig. 4), the results agree with does done through hand calculations. Taking into consideration the voltage drops of the diodes and the equations shown above the results have also been compare to other sources which have performed similar experiments using smaller DC voltages. It should be noted that the multisim simulation runs properly for only a length of time and then the program shows some fault. Because of the unpredictability and power associated with high DC voltages, the virtual components which have been configured to simulate ideal conditions may not be able to handle the perfectly high DC voltages, reducing the voltage does allow the simulation to go on for a bit longer but eventually terminates by itself. The software indicates the problem as being a convergence issue which could indicate the use of extremely small resistors or the default conditions of the programme having not working well with the condition required by the circuit.

RESULTS AND DISCUSSION

Figure 5-9 are the results of our simulation using multisim. In Fig. 5, we shows the schematic of the system for different multiplier. It can be seen that at the first multiplier (×2), the output voltage is 19.0 which is

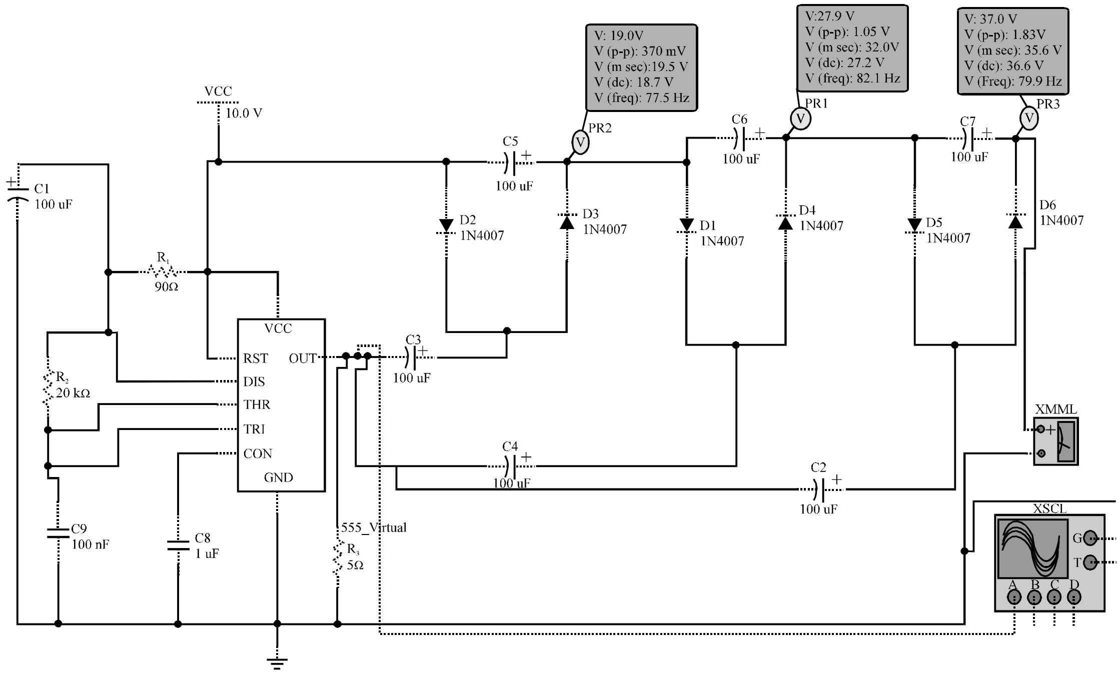

Fig. 5: Circuit schematic from multisim with results

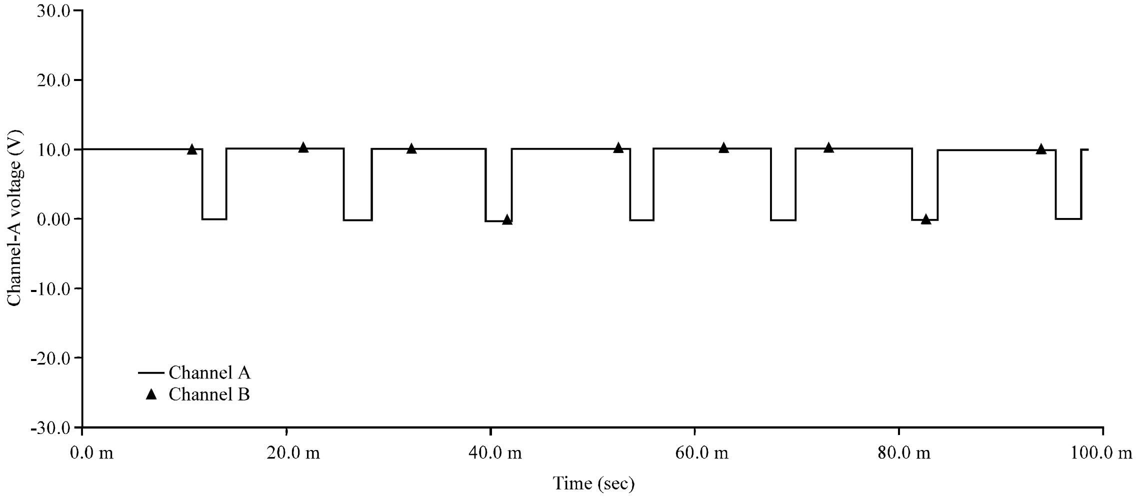

Fig. 6: The pulse generated by the timer from the simulation

approximate to 20 V (2×10 V). Also, at the third multiplier (×3), the output voltage is 27.0 which also corresponds to the 30 V value (3×10 V). Though 27.0 V is <30 V, the difference is due to diode voltage drops and capacitors which takes time to charge up and get discharge to the load. If we consider the fourth multiplier, we also see that the output voltage is 37 V which is approximate to 40 V (4×10 V). Also, the difference is due to drops across the diodes. As such, it should be noted that when a certain voltage is required for as particular application, diodes drops has to be put into consideration during the design stage of the multiplier circuit. Figure 6 shows the waveform of the input signal (10 V) gotten from the multisim grapher. Also, as seen in Fig. 7 is the output results with addition of multimeter showing the final output voltage of the multiplier system of the value 36.959 V. Figure 8 and 9 shows both the input signal (10 V) at the output of the 555 timer IC and the pure (smooth) DC output signal (approximate 40 V) as a multiple of the input signal (4×10 V). The results clearly shows that, the use of 555 timer as voltage multiplier is profitable.

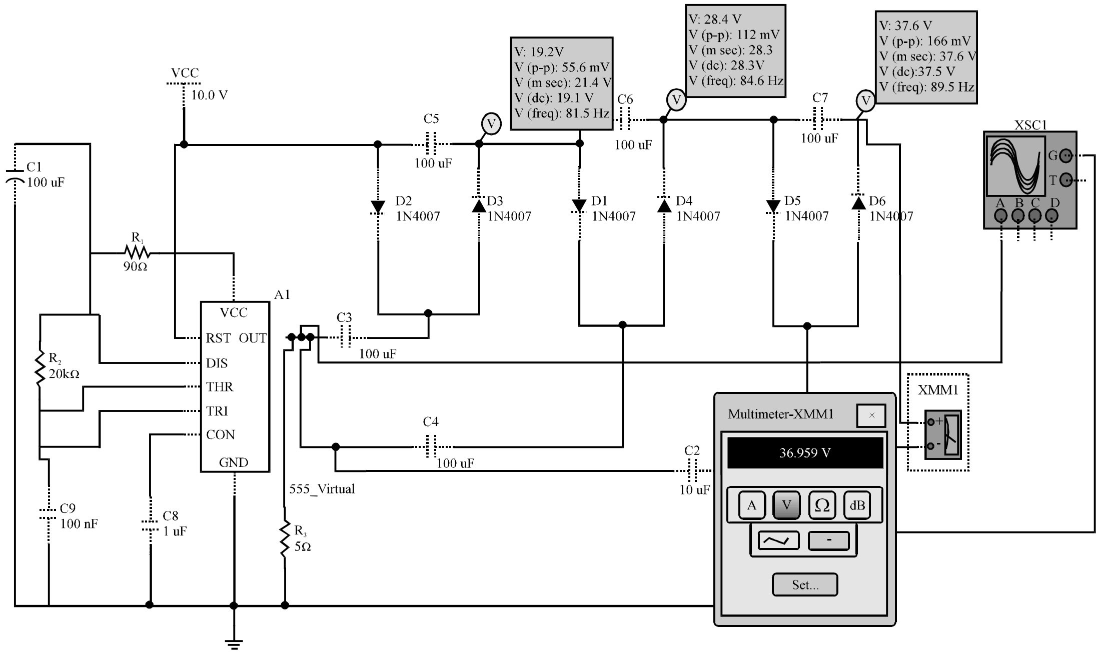

Fig. 7: Simulation output of 10 V input voltage

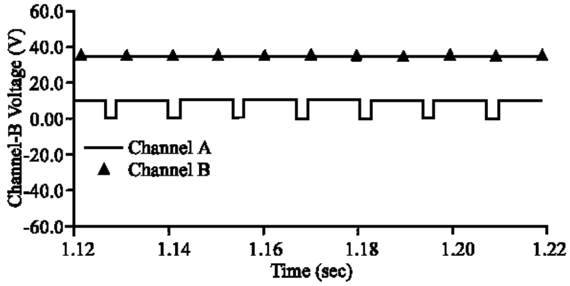

Fig. 8: The 555 timer pulse and the output voltage at 4X the input voltage

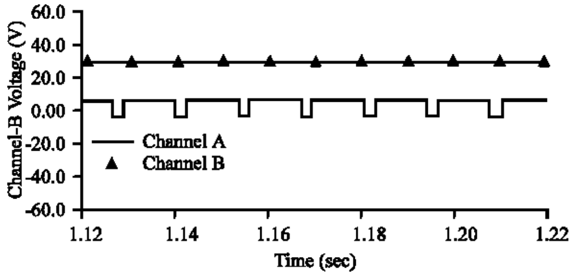

Fig. 9: Graph diagram showing 555 timer pulse and the output voltage at 4X the input voltage

CONCLUSION

There is a great need for a method that enables the use of devices which use up massive amount of DC voltage to operate without having to carry or house large DC batteries to do so. As it stand little has been done on this area because of the physical limitations of the components available at this time. However, with advancement in the science of energy engineering and other related fields hope is not lost yet. In idle condition where the voltage supply does not run out the circuit is a successful model of what it is intended for however when applier to the real world setting of heat and decay the model is shown lacking. As far at this study is concerned, however, a DC to DC circuit multiplier using the IC 555 timer is a success.

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