HIGH EFFICIENCY VOLTAGE DOUBLER FOR UNMANNED MULTI-ROTOR HELICOPTER POWER SUPPLY

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Abstract:

During the last few years unmanned multi-rotor helicopters are getting ubiquitous due to their low cost and efficiency. The power supply of these machines is lacking behind as are doing many other modules in the avionics as well and users are suffering from being unable to utilize fully the capabilities of these modern aircraft.

In order to increase flight times, high efficiency power supplies are needed. Current models of lower class use passive power supplies with efficiencies in the range of 50%. More common among expensive models are inductive power supplies. The latter ones offer efficiencies from 70% to 95%. The upper limit is hardly achievable and also these power supplies suffer from a number of drawbacks such as electromagnetic interference, high frequency operation, weight, form factor, etc.

The present article demonstrates a capacitive voltage doubler especially designed for unmanned multi-rotor helicopters with efficiency of over 98% and very small dimensions and weight. The lack of inductors and low working frequency guarantee almost none electromagnetic interference to other modules of the avionics.

Keywords: Unmanned helicopter power supply, Unmanned multi-rotor helicopter.

Introduction

Onboard unmanned helicopter power supplies are important units of the avionics. If they exhibit high efficiency, the aircraft will be capable of high efficiency of flight, hence longer flying times and increased range. Another aspect of unmanned helicopters power supply is their electromagnetic interference with other more sensitive modules such as the radio transceiver.

In order to increase efficiency and lower the electromagnetic disturbances a capacitive power supply should be addressed for implementation. The inductive power supplies are plagued with electromagnetic interference problems and often have efficiencies in the range of 70-95% but the upper limit is hard to achieve.

Capacitive power supply has no inductors, which radiate magnetic field. The efficiency is greater than 98-99%. Dimensions of these units are more compact and also weight is considerably less in comparison to the inductive modules.

The current article focuses on a capacitive voltage doubler and its most efficient and cost-effective implementation for the onboard power supply of unmanned helicopters.

History of capacitive voltage doublers

One of the oldest voltage doubler circuits is the Greinacher voltage doubler (Fig. 2). It is designed as an improvement of the voltage clamp circuit know as the Villard voltage doubler (Fig. 1).

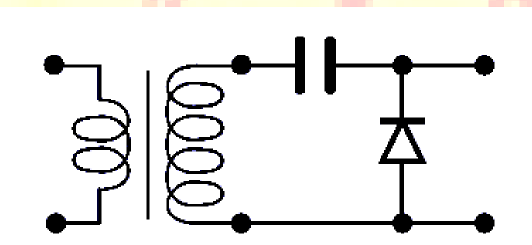

Figure 1. Villard voltage doubler

The Greinacher circuit works by following a Villard stage with a peak detector or an envelope detector stage. The peak detector smoothes the ripple of the Villard stage while assuring a doubled voltage at the output. The circuit was invented in 1913 by Heinrich Greinacher and was used to provide voltage supply for the newly invented ionometer.

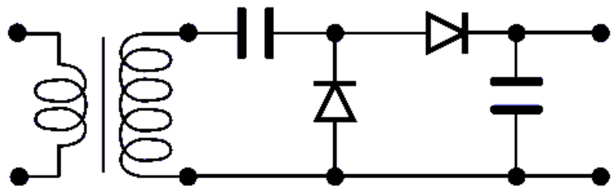

Figure 2. Villard voltage doubler

Later in 1920 this circuit was extended into a cascade of multiplier Greinacher cells known as Cockcroft–Walton multiplier used in the particle accelerator machine invented by John Cockcroft and Ernest Walton.

Why voltage doubler?

Some of the scenarios onboard unmanned helicopters requiring voltage doublers are as follows:

1. Combination of motors working at different voltages. For example 4 motors working at 11.1V and one motor working at 22.2V.
2. Combination of servos with different voltages.
3. Supplying radio transmitters that require high voltage for the final transmitter stage.

The doubler will not present an exact voltage but it will nevertheless offer a close voltage to the nominal for the given module. A voltage regulator after the voltage doubler may be installed. For most units a regulator is either inbuilt or is not needed as is the case with most servos that tolerate certain deviation from the supply voltage.

Voltage doubler to be used onboard of unmanned helicopter series XZ

The Greinacher voltage doubler on Fig. 2 is applicable for AC voltage supply. When used on board of an unmanned helicopter where the voltage source is a battery then a chopper circuit is needed, namely a push-pull transistor generator. Such a solution is shown on Fig. 3.

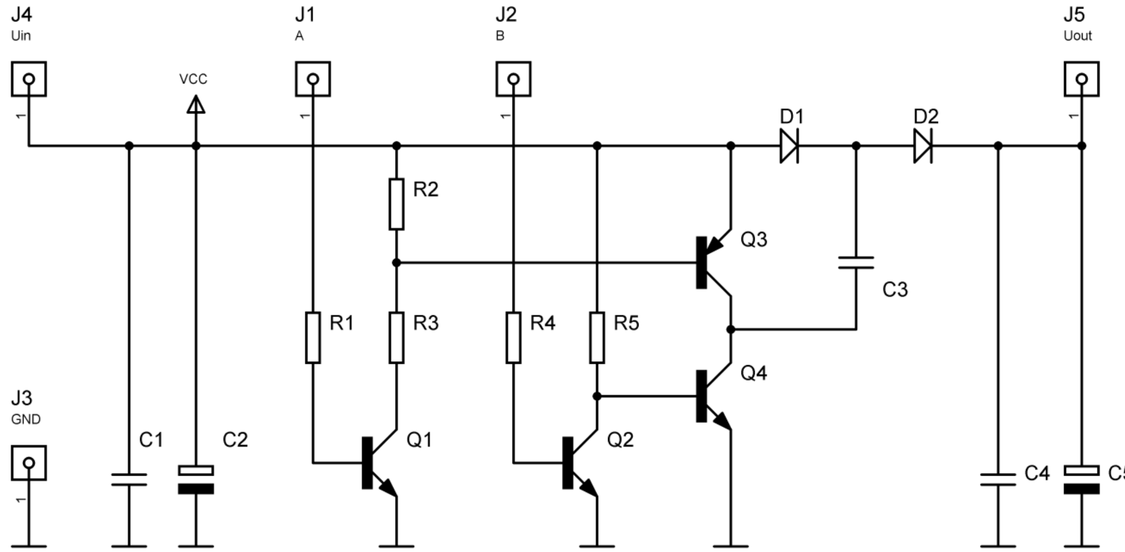

Figure 3. Greinacher voltage doubler with input TTL buffers

The above circuit needs control TTL signals from a microprocessor or another control device. The control signals A and B should have certain timing in order to keep the upper and lower transistors never conducting at the same time (see Fig. 4).

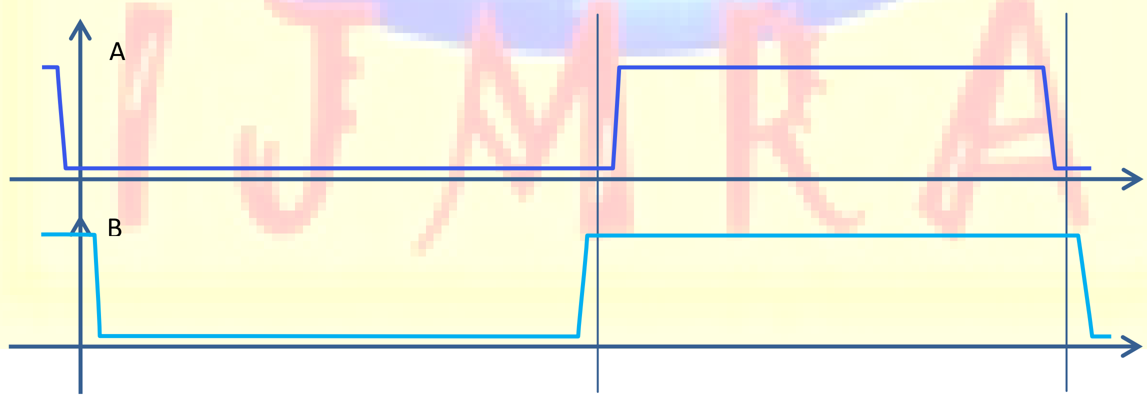

Figure 4. Control TTL signals for the Greinacher voltage doubler with input TTL buffers

Constructed this way the transistor circuit will function properly but at low efficiency especially when drawing current from a low voltage battery of 1 to 6 Li-Poly or Li-Ion cells. The voltage drop across transistors and diodes is in the order of 1.4 V to 3 V making the circuit efficiency low. For example using a battery of three cells at nominal voltage of 11.1 V the voltage drop in the circuit's semiconductors will be 1 V at the diodes (only if Schottky diodes are used) and 0.4 V at the transistors (only if low V_{CEsat} transistors are used). Thus the total voltage drop will be 1.4 V or 12.6%. The solution to this low efficiency problem is to use a charge pump configuration. Bipolar diodes and transistors should be replaced with MOSFET transistors. An improved circuit is shown on Fig. 5.

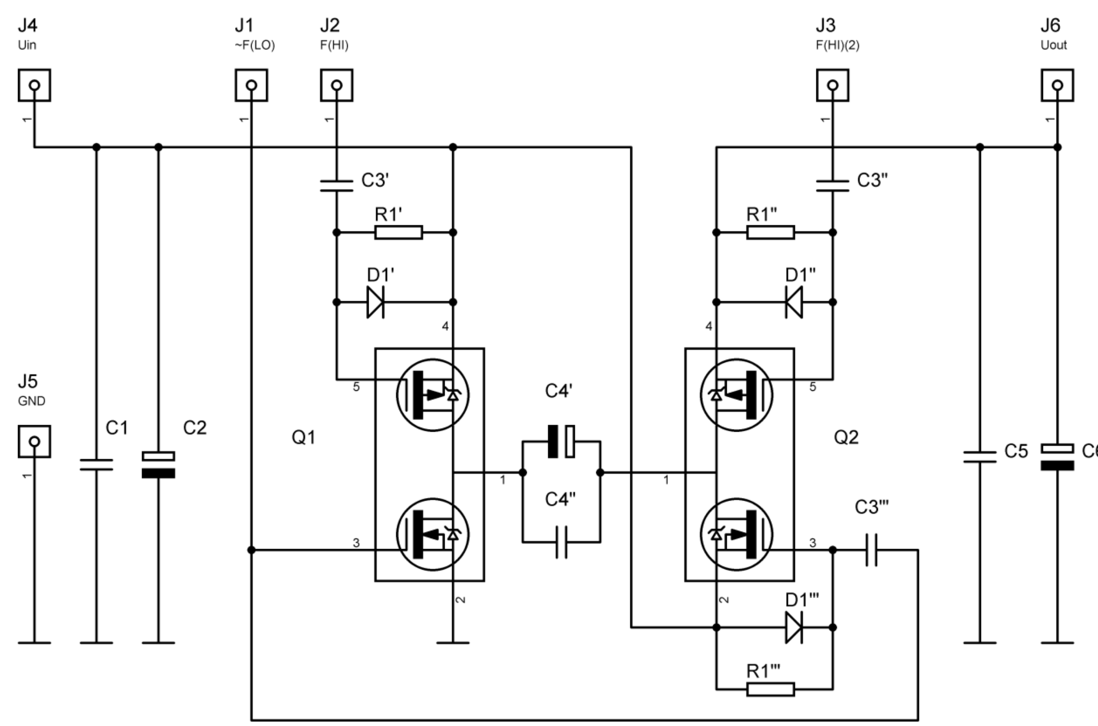

Figure 5. Greinacher voltage doubler in charge pump configuration

The improved circuit from Fig. 5 needs three instead of two control signals, because three of all four MOSFET transistors are controlled using auxiliary charge pumps. Those charge pumps charge at different moments after circuit startup and correct timing could be achieved only using three instead of two control signals. The above circuit delivers power at very high efficiency. For example let us test the circuit again with a three cell battery with nominal voltage of 11.1 V and let us draw 10 A current from it (5 A at the voltage doubler output). Then let us implement transistors with R_{DSon} equal to 1 mOhm each and a capacitor with ESR equal to 2 mOhm. Then there is defined a voltage drop across the transistors and capacitor of 10 A * 0.004 Ohm = 0.04 V. The power loss will be 0.4 W. The gate switching loss is $C_{gate} * f * V^2$ and is around 60 mW, which can be neglected. Thus the total power loss is only 0.36%. This makes the circuit a winner with efficiency of over 99.5%. The major problem with this circuit is that it needs a microprocessor to run. Is there a way of making it work without a microprocessor thus guaranteeing higher reliability? A voltage doubler driving essential parts of the avionics should be extraordinarily reliable, thus a software error should be excluded. The best solution is to use combinatorial-memory logical circuit when generating the control signals. This solution is shown no Fig. 6.

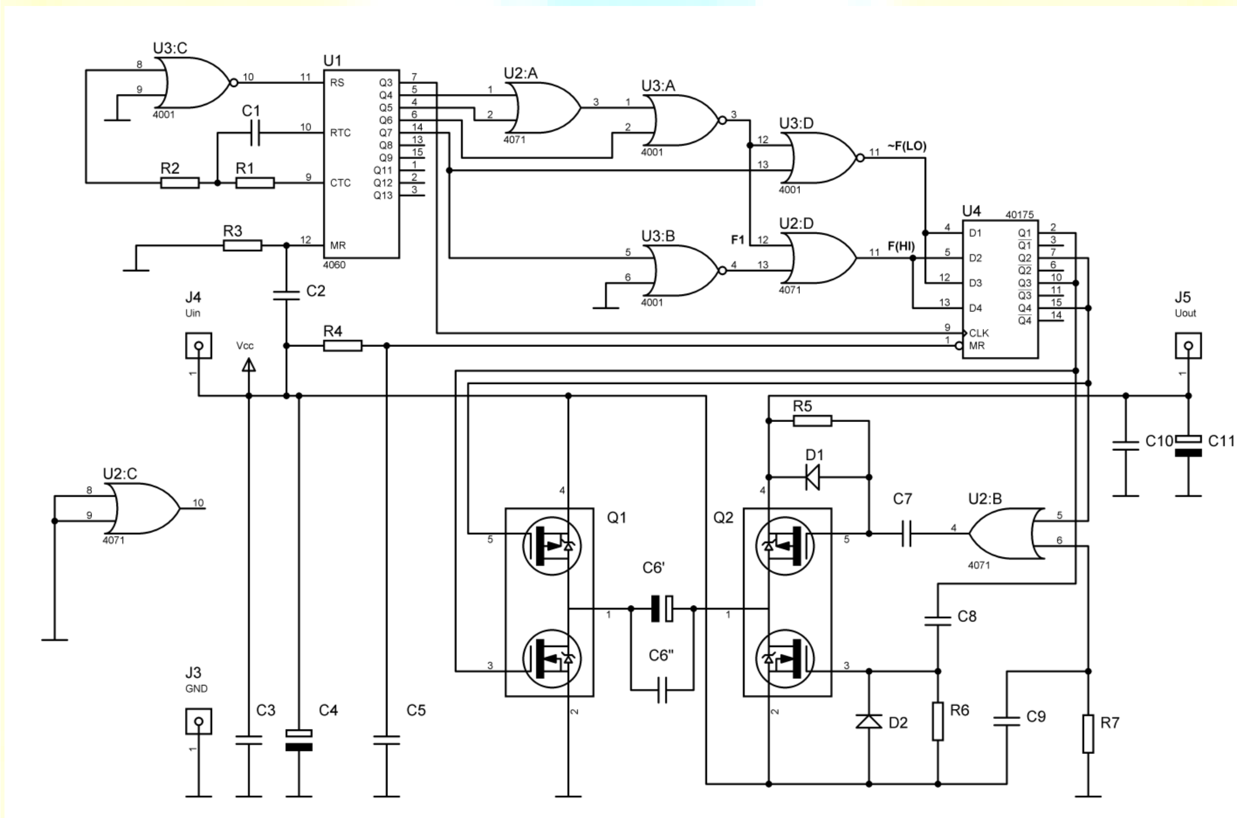

Figure 6. Charge pumped Greinacher voltage doubler with control signals generated without a microprocessor

As already mentioned the control signals should be timed correctly. These signals could be digitized with a granular time step that satisfies the efficiency considerations and timing delays of the used logic gates. A division of the main generator period by 16 is satisfactory. A digital binary counter is used for this purpose driven by an RC generator. The timing diagram of the control signals for driving the circuit from Fig. 6 is shown in Table 1 below.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X_0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
X_1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
X_2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
X_3	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
F_{LO}	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
F_{HI}	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0

Table 1. Control signals in digitized time sub-periods

There are two control functions F_{LO} and F_{HI} (see Fig. 6). One needs to generate those using combinational logic circuits. For the purpose of synthesizing the two control functions the logic series 4000 logic gates are used and Veitch charts are drawn (see Table 2 and Table 3).

F_{LO}:

	X_0	X_0			
X_1	1	1	0	0	
X_1	1	1	0	0	X_3
	1	1	0	0	X_3
	1	1	0	1	
		X_2	X_2		

Table 2. Synthesizing control function F_{LO} *using Veitch diagram*

Canonical disjunctive normal form is used. The minterms of the two given functions are observed and grouped in maximal groups as the rules of the Veitch diagrams denote (see Table 2 and Table 3 blue coloured fields).

F_{HI}:

	X_0	X_0			
X_1	0	0	1	1	
X_1	0	0	1	1	X_3
	0	0	1	1	X_3
	1	0	1	1	
		X_2	X_2		

Table 3. Synthesizing control function F_{HI} *using Veitch diagram*

The result is as follows:

$$\mathbf{F_{LO} = X_0 \mid \sim X_1 \ \& \sim X_2 \ \& \sim X_3 = X_0 \mid \sim(X_1 \mid X_2 \mid X_3)}$$

$$\mathbf{\sim F_{LO} = \sim(X_0 \mid \sim(X_1 \mid X_2 \mid X_3))}$$

$$\mathbf{F_{HI} = \sim X_0 \mid \sim X_1 \ \& \sim X_2 \ \& \sim X_3 = \sim X_0 \mid \sim(X_1 \mid X_2 \mid X_3)}$$

It becomes clear that the most appropriate logic gates for synthesizing these two functions are two input NOR and OR gates. Let us define a sub-function F_1:

$$\mathbf{F_1 = \sim(X_1 \mid X_2 \mid X_3)}$$

Then F_1 is synthesized as follows:

$$\mathbf{F_1 = NOR_2(X_1, OR_2(X_2, X_3))}$$

Further $\sim F_{LO}$ is synthesized:

$$\sim F_{LO} = \sim(X_0 \mid F_1) = NOR_2(X_0, F_1)$$

F_{HI} is obtained in a similar way:

$$F_{HI} = \sim X_0 \mid F_1 = OR_2(NOR_2(X_0, 0), F_1)$$

The correct timing is guaranteed by a four bit D-trigger memory and a few delay networks.

Conclusion

Using high-efficiency capacitive power supplies onboard of unmanned multi-rotor helicopters increases range and flying times. Further this solution lowers electromagnetic interference among modules of the avionics guaranteeing higher reliability of the aircraft. To increase the reliability even further the current material presents a microprocessor free solution of a MOSFET charge pump based voltage doubler.

Authors are continuing their work on improving the flying time, efficiency and reliability of the unmanned helicopters thus offering to users even more risk free and capable flying platforms.

References

1. Edward W. Veitch, 1952, "A Chart Method for Simplifying Truth Functions", Transactions of the 1952 ACM Annual Meeting, ACM Annual Conference/Annual Meeting "Pittsburgh", ACM, NY, pp. 127–133.
2. Maurice Karnaugh, November 1953, The Map Method for Synthesis of Combinational Logic Circuits, AIEE Committee on Technical Operations for presentation at the AIEE summer General Meeting, Atlantic City, N. J., June 15–19, 1953, pp. 593–599.
3. Clive Maxfield. Logic 101 - Part 3 - Reed-Muller Logic. http://www.eetimes.com/document.asp?doc_id=1274545
4. Black, Paul E. Gray code. 25 February 2004. NIST.
5. Ahmed, Syed Imran Pipelined ADC Design and Enhancement Techniques, Springer, 2010 ISBN 90-481-8651-X.

6. Bassett, R.J.; Taylor, P.D., "17. Power Semiconductor Devices", Electrical Engineer's Reference Book, pp. 17/1-17/37, Newnes, 2003 ISBN 0-7506-4637-3.
7. Campardo, Giovanni; Micheloni, Rino; Novosel, David VLSI-design of Non-volatile Memories, Springer, 2005 ISBN 3-540-20198-X.
8. Kind, Dieter; Feser, Kurt High-voltage Test Techniques, translator Y. Narayana Rao, Newnes, 2001 ISBN 0-7506-5183-0
9. Kories, Ralf; Schmidt-Walter, Heinz Taschenbuch der Elektrotechnik: Grundlagen und Elektronik, Deutsch Harri GmbH, 2004 ISBN 3-8171-1734-5.
10. Liou, Juin J.; Ortiz-Conde, Adelmo; García-Sánchez, F. Analysis and Design of MOSFETs, Springer, 1998 ISBN 0-412-14601-0.
11. Liu, Mingliang Demystifying Switched Capacitor Circuits, Newnes, 2006 ISBN 0-7506-7907-7.
12. McComb, Gordon Gordon McComb's gadgeteer's goldmine!, McGraw-Hill Professional, 1990 ISBN 0-8306-3360-X.
13. Mehra, J; Rechenberg, H The Historical Development of Quantum Theory, Springer, 2001 ISBN 0-387-95179-2.
14. Millman, Jacob; Halkias, Christos C. Integrated Electronics, McGraw-Hill Kogakusha, 1972 ISBN 0-07-042315-6.
15. Peluso, Vincenzo; Steyaert, Michiel; Sansen, Willy M. C. Design of Low-voltage Low-power CMOS Delta-Sigma A/D Converters, Springer, 1999 ISBN 0-7923-8417-2.
16. Ryder, J. D. Electronic Fundamentals & Applications, Pitman Publishing, 1970 ISBN 0-273-31491-2.
17. Wharton, W.; Howorth, D. Principles of Television Reception, Pitman Publishing, 1971 ISBN 0-273-36103-1.
18. Yuan, Fei CMOS Circuits for Passive Wireless Microsystems, Springer, 2010 ISBN 1-4419-7679-5.
19. Zumbahlen, Hank Linear Circuit Design Handbook, Newnes, 2008 ISBN 0-7506-8703-7.