Appendix

Design Review

Content Page

VII. Appendix

Solar Panel Research and Comparisons

Ebay

http://www.ebay.com/itm/40w-New-40-watt-Module-Sun-Solar-Panel-PV-Monocrystalline-25-year-warranty-/320991420226?pt=LH_DefaultDomain_0&hash=item4abc945f42

Cost per watt = $72/40 Watt = $1.8/Watt

Model	SR-40
Open-Circuit Voltage (Voc)	21.8V
Optimum Operating Voltage (Vmp)	17.6V
Short-Circuit Current (Isc)	2.56A
Optimum Operating Current (Imp)	2.27A
Maximum power at STC (Pmax)	40Wp
Maximum System Voltage	600V
Series Fuse Rating	15A
Power Tolerance	+/-3%

http://www.ebay.com/itm/New-40-watt-Sun-Solar-Panel-PV-Mono-crystalline-25-Years-Warranty-/160883141271?pt=LH_DefaultDomain_0&hash=item257561

Cost per watt = $76/40 Watt = $1.9/Watt

Model	SR-40
Open-Circuit Voltage (Voc)	21.8V
Optimum Operating Voltage (Vmp)	17.6V
Short-Circuit Current (Isc)	2.56A
Optimum Operating Current (Imp)	2.27A
Maximum power at STC (Pmax)	40Wp
Maximum System Voltage	600V
Series Fuse Rating	15A
Power Tolerance	+/-3%

http://www.ebay.com/itm/1x30-W-Solar-Panels-Monocrystalline-Anodised-Alum-Frame-With-Mc4-connectors-/251081818786?pt=LH_DefaultDomain_0&hash=item3a75a482a2

Cost per watt = $80/30 Watt = $2.67/Watt

http://www.ebay.com/itm/30W-SOLAR-PANEL-MODULE12V-Watt-Mono-Crystalline-Free-Shipping-New-PV-no-MC4-/261090826576?pt=LH_DefaultDomain_0&hash=item3cca39d950

Cost per watt = $79/30 Watt = $2.63/Watt

Maximum Power(Pmax):	30Watt	**Max Series Fuse:**	12A
Maximum power Voltage (Vmp):	17.2 v		
Maximum Power Current (Imp):	1.74A	**Operating temperature:**	-40C to +85C
Open Circuit Voltage (Voc):	21.6 V	**Tolerance:**	+/- 5%
Short Circuit Current (Isc):	1.92 A	**Cell:**	9, 5" x5"
Maximum System Voltage:	600 V	**Front Glass:**	3.2 mm tempered
Dimension:	22.4” x 16.3” x 1”	**Junction Box:**	IP-65 Rated
Outside Box:	24” x 18” x 2”		
Weight:	6 lb (2.5 Kg)	**Cable Length:**	2 FT (No MC4 Connectors)
Frame:	High quality Anodized aluminum alloy type 6063-T5	**Encapsulation Material:**	EVA (0.5 + 0.05 mm thickness)
Back Foil:	White PET (0.2 + 0.03 mm thickness)	**Max Load:**	5400 Pa

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Open circuit voltage	State-of-Charge in %
12.65V	100%
12.45V	75%
12.24V	50%
12.06V	25%
11.89V or less	Discharged

Figure 3: BCI standard for SoC estimation of a 12V flooded lead acid car battery.

Test the battery at room temperature. Allow 4-8 hour of rest after charge or discharge.
Courtesy of BCI

Hydrostatic Pressure Concerns:

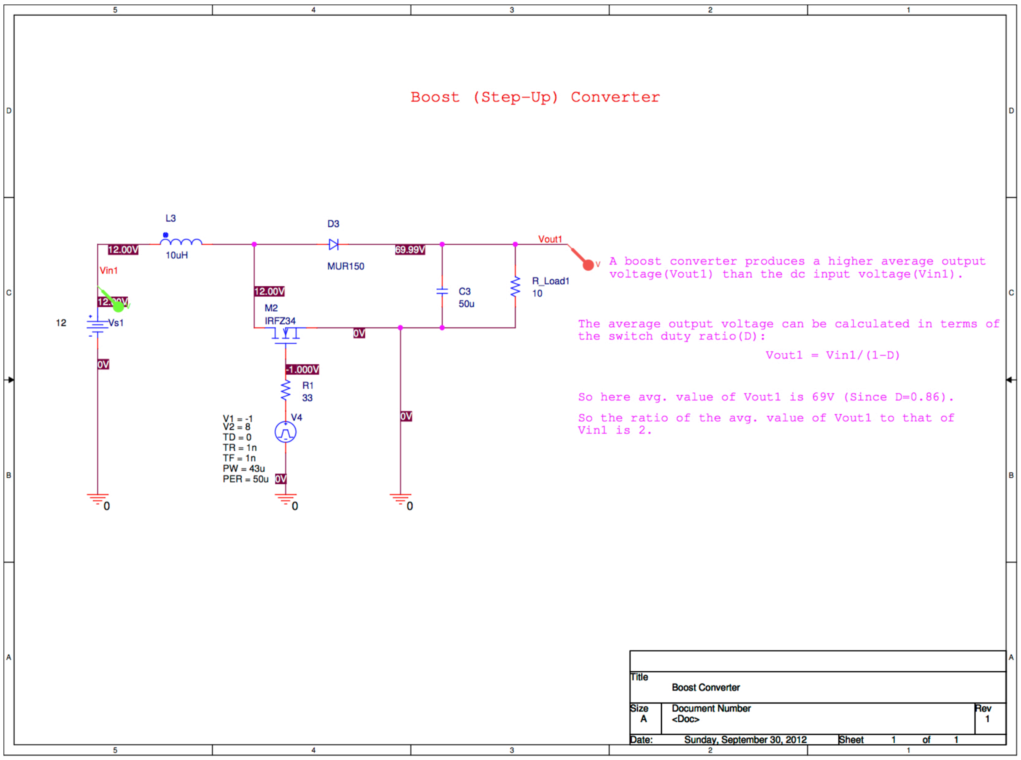
p = hpg
p = pressure (N/m^2, Pa)
h = depth at which the pressure is measured (m)
p = density of liquid (kg/m^3)
g = gravitational constant (9.81 m/s^2)

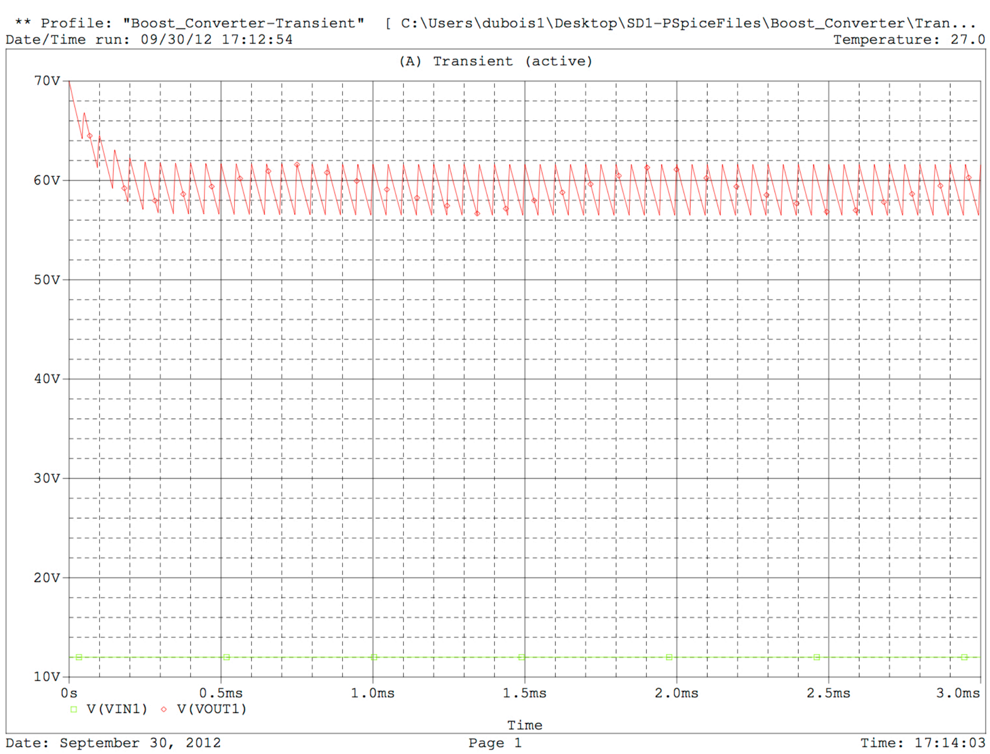
Height of Water Column		Pressure		
(m)	*(ft)*	*(kPa)*	*(bar)*	*(psi)*
1	3.3	9.8	0.1	1.4
2	6.6	19.6	0.2	2.8
3	9.8	29	0.3	4.3
4	13.1	39	0.4	5.7
5	16.4	49	0.5	7.1
6	19.7	59	0.6	8.5
7	23	69	0.7	10.0
8	26	78	0.8	11.4
9	30	88	0.9	12.8
10	33	98	1.0	14.2
12	39	118	1.2	17.1
14	46	137	1.4	19.9
16	52	157	1.6	23
18	59	177	1.8	26
20	66	196	2.0	28
25	82	245	2.5	36
30	98	294	2.9	43
35	115	343	3.4	50
40	131	392	3.9	57
50	164	491	4.9	71
60	197	589	5.9	85
70	230	687	6.9	100
80	262	785	7.8	114
90	295	883	8.8	128
100	328	981	9.8	142

Retrieved From http://www.engineeringtoolbox.com/hydrostatic-pressure-water-d_1632.html

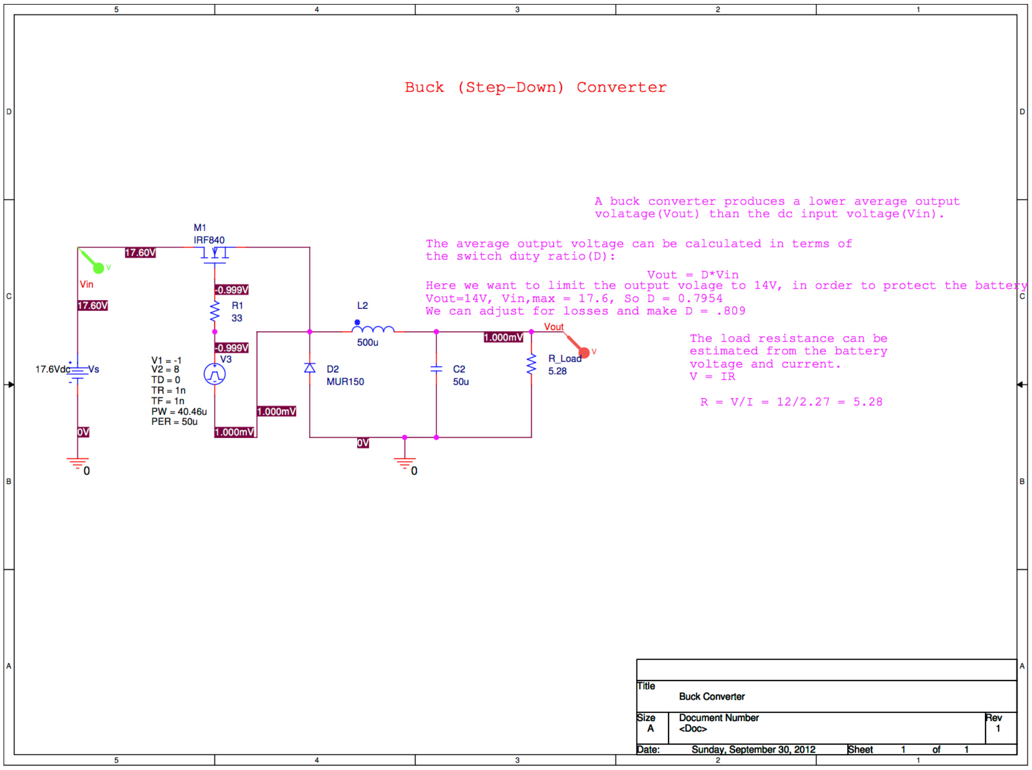
Schmatics, Circuits, and Simulations:

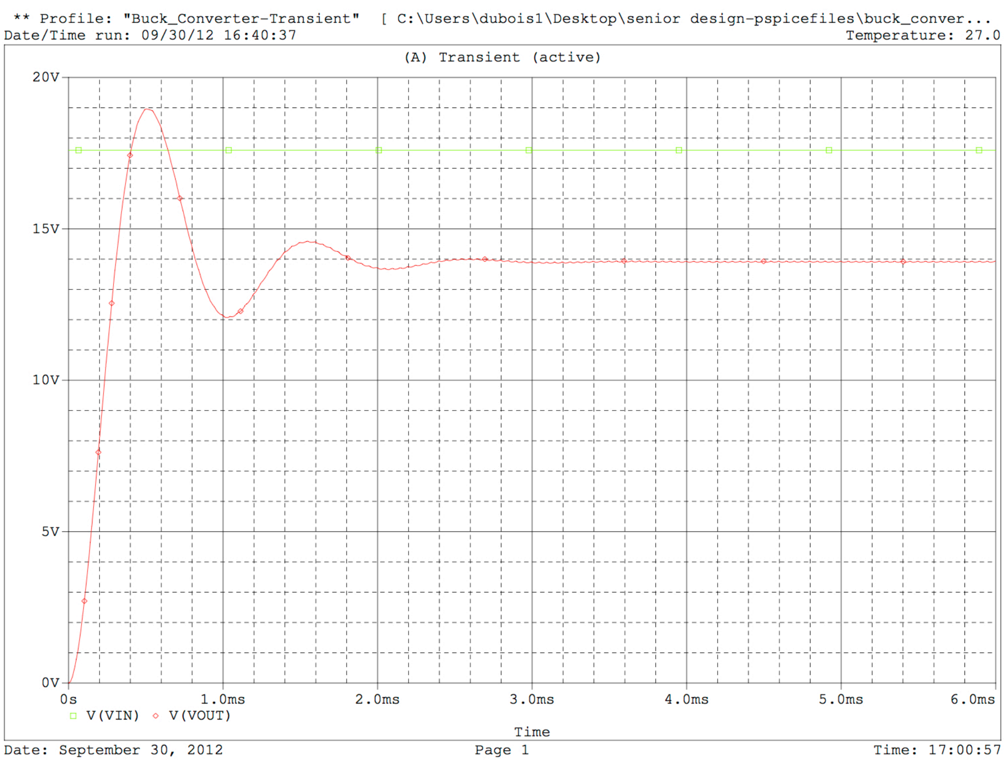
Transient Boost Converter:





Transient Buck Converter:





A DC-Pulse Power Supply Designed for Plasma Applications

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***Abstract* -- A DC-pulse power supply designed for reactive sputtering plasma applications is presented in this paper. It consists of an H-bridge switching circuits and two DC sources. All pulse parameter values are set in a control panel developed with LabVIEW software. The designed panel adopts RS232 protocol to sequentially transmit the set parameter values to a low-cost 8-bit microcontroller. The microcontroller controls the switching sequences of the H-bridge circuit and the voltage of DC sources. Depending on the user's requirements, the designed power supply can offer positive and negative pulse trains, unipolar and bipolar pulse trains, symmetric and asymmetric pulse trains and other asymmetric pulse trains. The adjustable pulse parameters include pulse dominant time, recessive time, pulse levels and pulse numbers. Experimental results demonstrate that the desired pulsing functions of DC-pulse power supply are all achieved.**

***Index Terms*— Plasma applications, Pulse power.**

I. NOMENCLATURE

In this article, the required pulse power supply may output positive and negative, unipolar and bipolar, symmetric and asymmetric pulse trains. Fig. 1 shows a typical bipolar pulse train with six variable pulse parameters. Linguistic explanation of those parameter meanings are as follows:

V_{dc1} : Voltage level of positive DC pulses.

V_{dc2} : Voltage level of negative DC pulses.

T_1 : Dominant time or ON time of a positive pulse

T_2 : Recessive time or OFF time of a positive pulse.

T_3 : Dominant time or ON time of a negative pulse.

T_4 : Recessive time or OFF time of a negative pulse.

In order to present asymmetric pulse trains, capital letter "P" and "N" are used in the following paragraphs to represent the quantities of pulses in a positive-half cycle and a negative-half cycle, respectively.

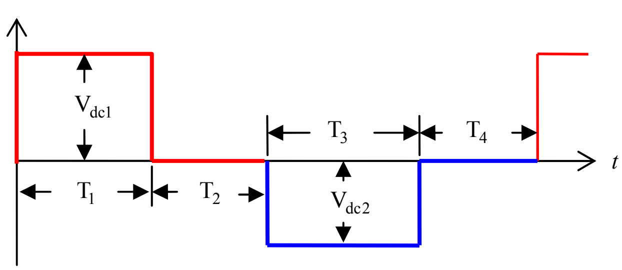


Fig. 1. A typical bipolar pulse train with six variable parameters.

II. INTRODUCTION

For a long time, the widely utilization of pulsed powers has been promoted the development of pulsed power generators in the area of food processing, medical treatment, ion implantation, ozone generation and other applications. And, many kinds of pulsed power generators had been designed and implemented for specific applications [1-4]. Especially, the development of semiconductor switches increasingly makes progress the performance of pulse power supplies in the field of pulse shape, pulse repetition rate, lifetime and stability. Most plasma processes, such as cleaning, activation, etching, diffusion, and sputtering all require an adequate DC-pulse power supply to generate specific and necessary pulse trains. In this article, a DC pulse power supply specially designed for reactive magnetron sputtering system is introduced.

As shown in Fig. 2, the system is a plasma process control system and, indeed, is just an experimental system for reactive magnetron sputtering. In the vacuum chamber, there are two electrodes E1 and E2 and one of the electrodes is chosen as substrate holder. Because the electrode surfaces form two conductive boundaries, while the two electrodes are fed with specific voltage pulse trains, plasma will present in the space between the boundaries. The spectrum of plasma reaction inside the chamber is observed by an optical spectrometer through a glass window embedded in the wall of chamber. During the sputtering process, several kinds of specific gas can be chosen to inject into the chamber for improving the reaction in the electrodes. The spectrometer feedbacks immediate spectrum data to a computer and the computer immediately and consecutively regulates the flow rates of the reaction gas that injected into the chamber. For cost consideration, a miniature fiber optic spectrometer, USB4000, is adopted in this experimental system.

As mentioned above, a well designed DC-pulse power supply should be able to generate different kinds of pulse trains to satisfy specific requirements in plasma processes. Fig. 3 illustrates some typical pulse trains that a DC-pulse power supply could be possibly requested to output. From top to bottom, the displayed pulse trains are positive and negative DC levels, positive and negative uni-polar pulse trains, symmetric and asymmetric bipolar pulse trains and asymmetric pulse trains with specified pulse numbers and pulse levels. All pulse parameters, as explained in section I, should be able to be freely set by the user.

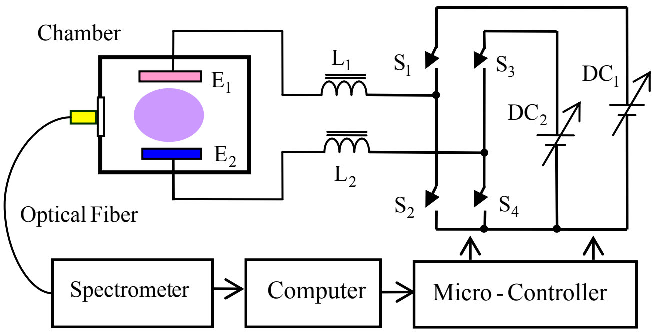


Fig. 2. A simplified plasma process control system.

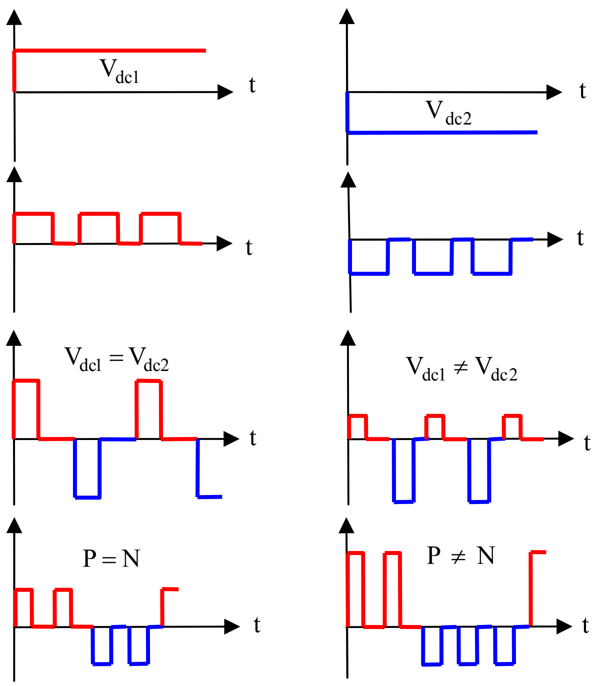


Fig. 3. Typical pulse trains of a DC-pulse power supply.

III. Design And Implementation

In order to design a DC-pulse power supply adequate for the system shown in Fig. 2, some circuit and control requirements must be taken into considerations. In respect to circuitry, at first, based on the requirement of capable outputting asymmetric pulse trains, two independent DC voltage sources are needed. Next, in view of the requirement of capable generating pulse trains with arbitrary pulse-time parameters, two independently controlled switch legs, S1&S2 and S3&S4, are used. Moreover, since the pulse-train requirements are diverse, a microcontroller with EEPROM is adopted for providing the required four switching signals and two voltage control signals.

In respect to control, because parameter values are recommended to be set and displayed on a computer control panel, therefore, a desktop computer and a properly designed man-machine interfacing program are both required. The computer informs the used microcontroller of new parameter values with a serial port and RS232 protocol. In this paper, the specification of pulse-train frequency is set about 0~50 kHz, and pulse voltage level is under 500 volts. A common microcontroller is enough to control the pulse time in the range of several tens of micro-seconds and a general power MOSFET easily meet the voltage requirements. Finally, it should be noted that the surface of the substrate holder is normally smaller than the surface of the chamber wall and hence positive pulse current is usually higher than negative pulse current, in DC-pulse sputtering applications. In the following paragraph, the implementation of the designed DC-pulse power supply is divided into two parts. One is the switching circuit and the other is the control program. Two parts are respectively depicted as follows.

A. Switching Circuit

As shown in the diagram of Fig. 4, two switch legs and two accompanied DC sources are employed to generate symmetric and asymmetric voltage pulse trains. Each switch leg of the H-bridge circuit consists of two switching devices and each switching device has its own driving signals. For the switching circuit designed in this work, each switching device only includes one MOSFET and required driver. Higher voltage usually needs more MOSFETs connected in series. In other respect, since the potential of the middle point of switch legs is floating, the two driving signals of upper switch S1 and S3 should be electrically isolated from ground. In the light of driving signals are asymmetric waveforms, isolation with transformers is hence inadequate and the widely used photo-coupler TLP250 is adopted here for isolation. However, for simplification, detailed circuits are not completely displayed in the circuit diagram.

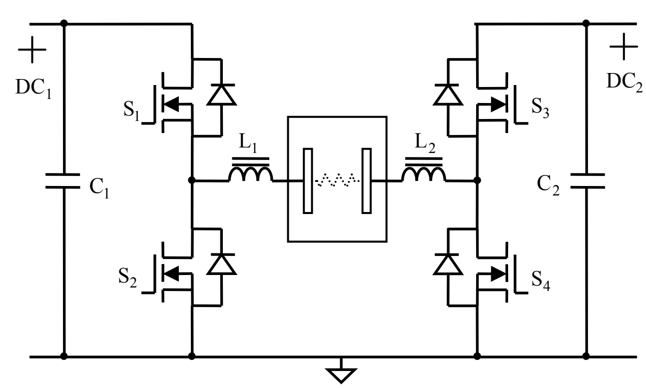


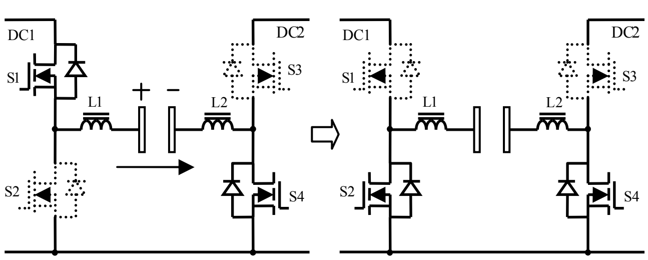
Fig. 4. Schematic diagram of an H-bridge switching circuit.

The glow discharge inside the vacuum chamber behaves as a resistive load and the shape of current is pulse like. Therefore, accessory high frequency capacitors, C1 and C2, and inductors, L1 and L2, are installed. In general, ceramic capacitors are in parallel for supplying high frequency currents and ferrite-core inductors are in series to suppress sharp current spikes. Basically, while a capacitor is charged by an ideal voltage source through a resistor, the resistor may dissipate a half of the total energy provided by the ideal voltage source. And, the resistive component existed in the switching circuit dissipates a lot of energy and hence deteriorates the overall power conversion efficiency.

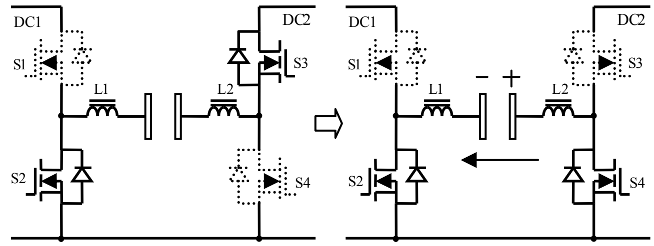
The switching circuit can output positive and negative DC, positive and negative unipolar pulse trains and symmetric and asymmetric bipolar pulse trains. Table I lists the six output modes in the first column, and the second and third columns respectively list the corresponding switching sequences and the used DC sources. In the first row, while a positive DC level is required, the conducted switches are S1 and S4, and the used DC source is DC1. Similarly, as shown in the fifth row, while symmetric bipolar pulses are needed, the switch pairs S1&S4, S2&S4, S2&S3 and S2&S4 are switched on and off in sequence, DC1 and DC2 are used. Fig. 5 graphically depicts the four switching sequences required for generating bipolar pulses. In practice, many kinds of asymmetric bipolar pulse trains can be generated. The pulse parameters, such as pulse level, pulse ON time, OFF time, or pulse quantity in a positive or negative half cycle, as shown in Fig. 3, can be set to form the desired asymmetric bipolar pulse trains.

TABLE I
OUTPUT MODES OF THE DESIGNED DC-PULSE POWER SUPPLY

Mode	Switching sequence	Source
Positive DC	S1&S4	DC1>0, DC2=0
Negative DC	S2&S3	DC1=0, DC2>0
Positive Unipolar	S1&S4, S2&S4	DC1
Negative Unipolar	S2 &S3, S2&S4,	DC2
Symmetric Bipolar	S1&S4, S2&S4, S2 &S3,S2&S4,	DC1=DC2, P=N
Asymmetric Bipolar	S1&S4, S2&S4, S2 &S3,S2&S4,	DC1≠DC2, P≠N



(a) S1&S4 (b) S2&S4



(c) S2&S3 (d) S2&S4

Fig. 5. Four switching operations for generating a bipolar pulse.

B. *Control Panel*

Although the control system shown in Fig. 3 is an automatic closed-loop control system, however, the manual control is still preserved. Users can manually set pulse parameters to control the plasma reaction as the user's requirements. For ease of operation, a graphical user interface named as "control panel" in this article is developed with LabVIEW software. Fig. 6 illustrates the developed computer control panel for setting pulse-train parameters. Respective parameter meanings are graphically displayed on the panel to remind the user. The following subfigure is the corresponding block diagram. It states that the control panel adopts commonly used RS232 serial protocol and the parameter values, T1~T4, P, N, Vdc1, Idc1, Vdc2, and Idc2 are sent sequentially.

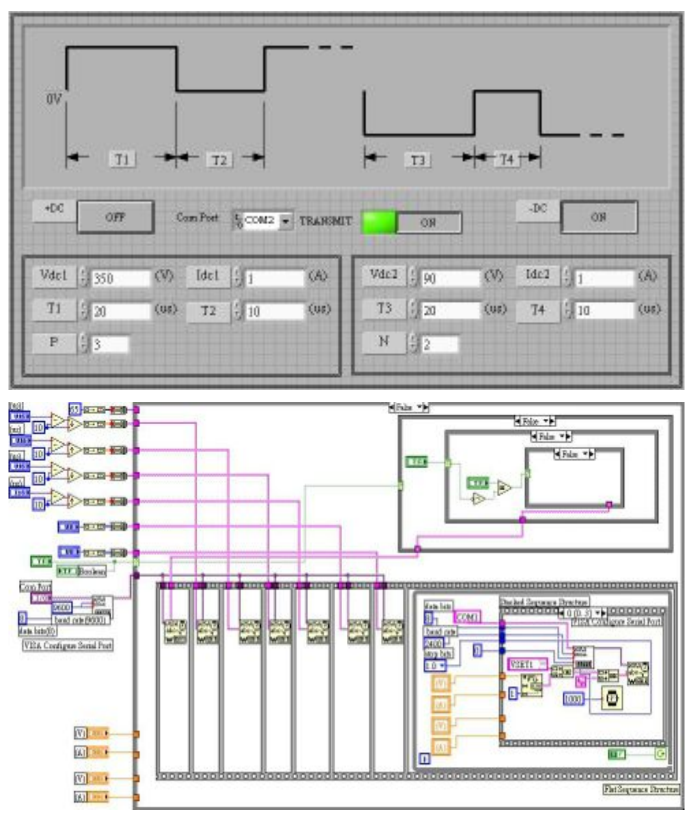


Fig. 6. Designed parameter control panel and block diagram.

Basically, the control panel sequentially transmits parameter values and the microcontroller cooperatively receives the parameter values. After a transmission, the control loop keeps running at DC sources to regulate pulse voltage and current. And, at the same time, the microcontroller runs with new parameter values to control the H-bridge circuit and generate pulse trains, as mentioned before. The control program of the microcontroller 89C51 can be graphically illustrated with a simplified flowchart, as shown in Fig. 7. Normally, the main program runs a sequence of switching operations and checks the reception interruption flag "RI" one time while a positive or a negative pulse ON time is over. While the flag RI is logic high, the main program will be interrupted and a subroutine named as "receive parameters" is run. Similar to main program, the reception subroutine checks the interruption flag RI. While flag RI is from logic low to high, the subroutine starts to receive next parameter.

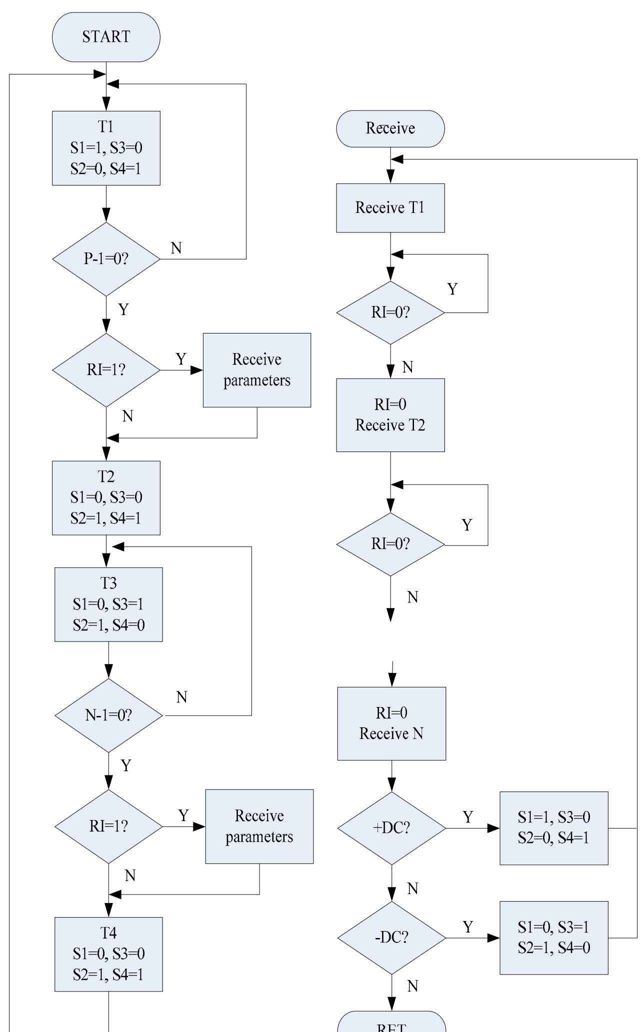


Fig. 7. Simplified flow charts of the designed microcontroller program.

IV. Experimental Results

In this work, a prototype circuit of the designed DC-pulse power supply is built for the reactive sputtering system shown in Fig. 2. A load composed of a 20-watt fluorescent lamp and a 100-ohm winding resistor is used to simulate the plasma load. In order to verify the pulsing functions of the designed switching circuit and control panel program, some kinds of pulse trains are generated, and are measured with digital oscilloscopes and differential probes.

Fig. 8 records two kinds of unipolar pulse-train waveforms. The top subfigure shows a positive pulse train and the bottom subfigure displays a negative one. Two waveforms have different pulse ON time but same pulse OFF time. Fig. 9 shows three bipolar pulse trains, including a symmetric and two asymmetric pulse trains. Comparing with the symmetric pulse train shown in the top subfigure, the asymmetric one shown in the middle subfigure has the same positive pulse but different negative pulse. The bottom subfigure is an asymmetric pulse train that positive and negative pulses are both different. Fig. 10 illustrates other kinds of asymmetric bipolar pulse trains, where pulse level and numbers of pulses are both different.

In each figure, the shape of the DC pulses is not an ideal rectangular. At each falling edge of pulse, there is a smooth decay. The smooth decay of waveforms is arisen from the stray capacitance of switching devices. It is seen that the driving of the upper and lower switches of a leg needs dead time. While the upper switch is turned off, the charges stored in the drain-source capacitance of the lower switch starts to discharge. The discharging results in a smooth-edge pulse waveform. Similar phenomenon also exists in negative pulses. Fig. 11 displays the simulation results of using switching pair S1&S4 and S2&S3 to generate bipolar pulse trains. From top to bottom, the loaded resistance is decreased and the resulted bipolar pulse trains are not rectangular. The effects of switch capacitance on pulse waveforms are more obvious than using S1&S4, S2&S4, S2&S3, and S2&S4.

Fig. 8. Positive and negative unipolar pulse trains, voltage scale: 100V/div, time scale: 40us/div.

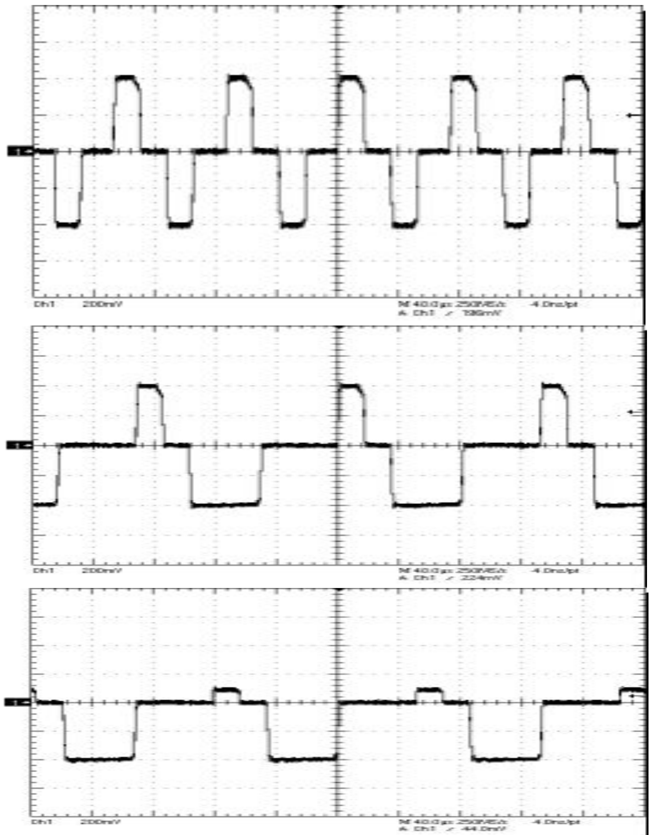


Fig. 9. Bipolar symmetric and asymmetric pulse trains, P=N=1, voltage scale: 200V/div, time scale: 40us/div.

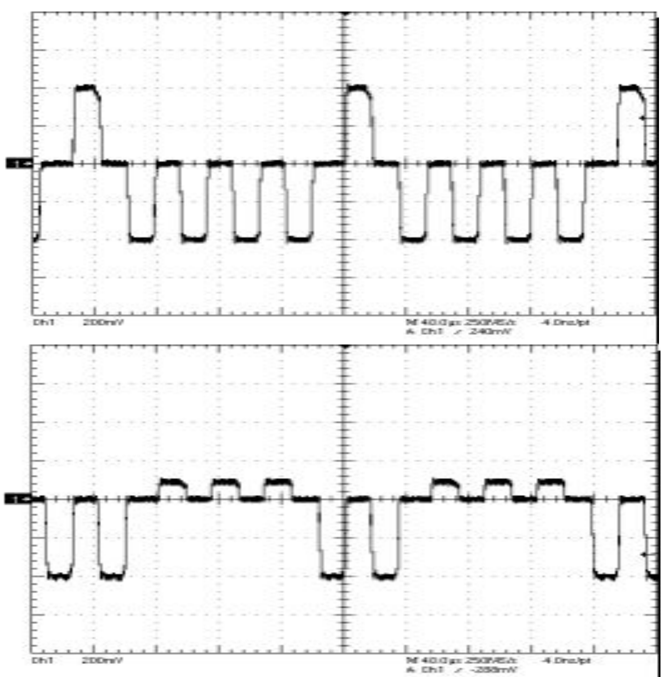


Fig. 10. Bipolar asymmetric pulse trains, P≠N, voltage scale:200V/div, time scale: 40us/div.

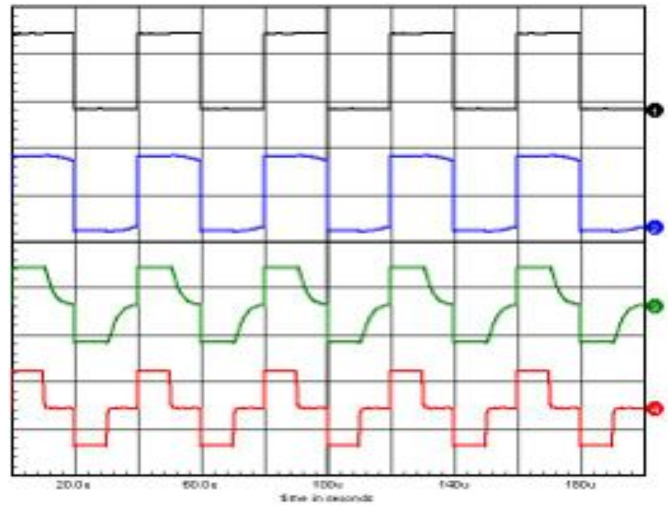


Fig. 11. Simulation of switch capacitance effect.

V. CONCLUSIONS

A prototype circuit of a DC-pulse power supply designed for reactive plasma sputtering control system has been built and tested in laboratory. According to specific requirements for processes, specific pulse trains are generated. Pulse trains are adjusted to regulate the reaction inside the chamber. The required output pulse shapes, such as positive DC level, negative DC level, positive unipolar pulse train, negative unipolar pulse train, symmetric bipolar pulse train, and asymmetric bipolar pulse train, are all acquired. Moreover, the designed man-machine interfacing control panel based on LabVIEW is friendly and can meet the user's requirements in this work. In the future, the work is to improve the circuit efficiency and enlarge the parameter ranges.

ACKNOWLEDGMENT

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REFERENCES

[1] H. Akiyama, T. Sakugawa, T. Namihira, K. Takaki, Y. Minamitani, and N. Shimomura, "Industrial applications of pulsed power technology," *IEEE Trans. Dielectrics and Electrical Insulation*, vol.14, No. 5, pp.1051-1064, Oct 2007.

[2] W. Jiang, K. Yatsui, K. Takayama, M. Akemoto, E. Nakamura, N. Shimizu, A. Tokuchi, S. Rukin, V. Tarasenko, and A. Panchenko, "Compact solid-State switched pulsed power and its applications," *Proceedings of the IEEE*, vol. 92, no. 7, pp.1180-1196, July 2004.

[3] J. H. Kim, M. H. Ryu, S. Shenderey, J. S. Kim, G.H. Rim, and G.Y. Jeong, "Pulse power supply using an IGBT switch stack for plasma source ion implantation." *35th Annual IEEE Power Electronics Specialists Conference, PESC 04,* vol. 1, 20-25, June 2004, pp.806-809.

[4] J. H. Kim, B. D. Min, S. V. Shenderey and G. H. Rim, "High voltage pulsed power supply using IGBT stacks," *IEEE Trans. Dielectrics and Electrical Insulation*, vol.14, no.4, pp.921-926, Aug. 2007.