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Spec No: 001-34581

Spec Title: PSOC(R) 1 DIGITAL BIPOLAR POWER CHOPPER
(INVERTER) - AN2192

Sunset Owner: SRINIVAS NVNS (SNVN)

Replaced by: NONE

PSoC® 1 Digital Bipolar Power Chopper (Inverter)

AN2192

Authors: Chris and Vincent Paiano
Associated Project: Yes
Associated Part Family: CY8C26xxx
Software Version: PSoC Designer™ 4.2
Associated Application Notes: None

Application Note Abstract

This application note describes a way to directly produce power for a residence using a stored sine table–driven open-loop algorithm. Using this information, you can design a low-power open-loop inverter without the need for a heavy, expensive, inefficient transformer. For simplification, the closed-loop algorithms such as PI, PID, and others are not discussed in this application note.

Introduction

This application uses a large solar panel array and the PSoC 8-bit PWM with Dead Band (PWMDB8) User Module to generate AC waveforms. Standard house 110 V/60 Hz AC has been selected as the target output. This is accomplished by using two DC power supplies (such as batteries, bench supplies, or solar cells), a MOSFET half-bridge power section, and a PSoC. The signal is generated through a "breathing" pulse width output based on a hardcoded sine wave lookup table.

To directly produce house power, a large solar panel array can be configured to supply the +/-160 V needed without a heavy, expensive, inefficient transformer. For the testing and development of this project, floating boost regulators were configured to achieve the proper EMF, as shown in the block diagram in Figure 1. Although the bipolar configuration requires two supplies, it results in fewer components per channel and—more importantly—a common ground. Note in Figure 7 and Figure 8 that the logic ground is the most negative supply. Care (optical isolation) must be used if any additional I/O involving the PSoC is required.

Software/PSoC Implementation

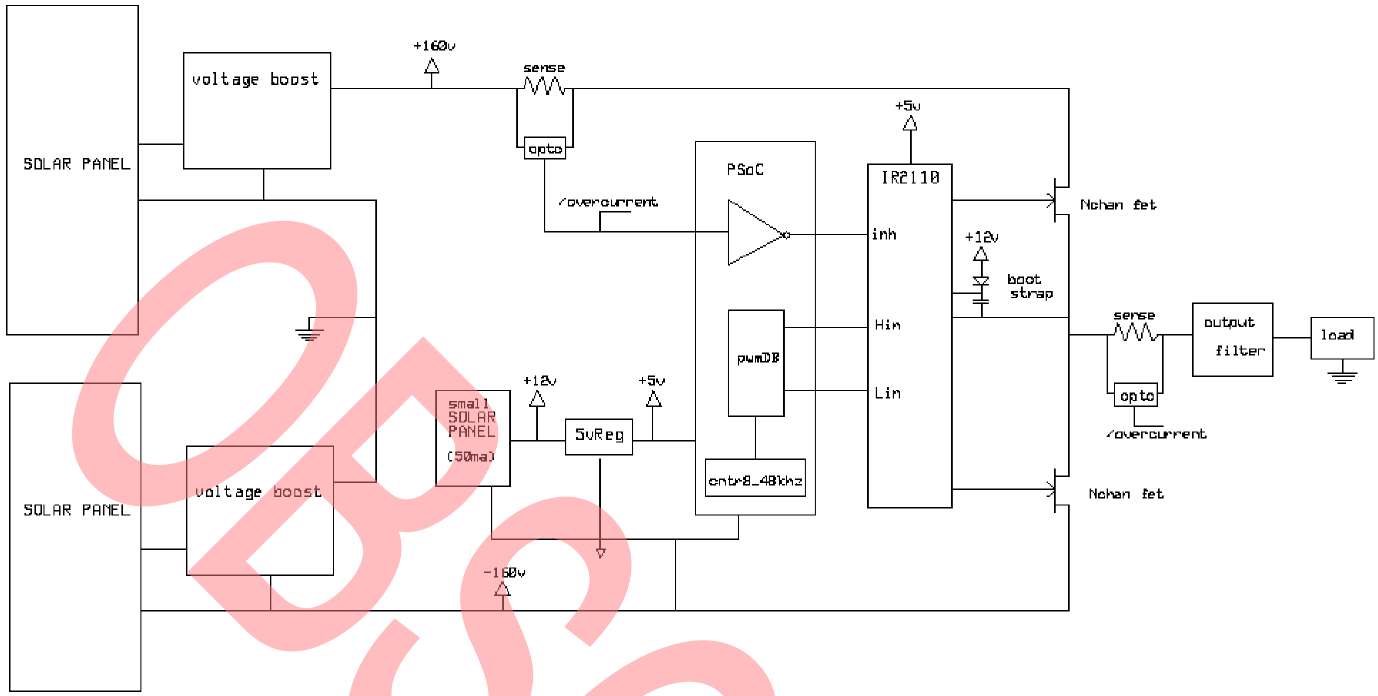
The implementation of the PSoC in this digital bipolar power chopper consists of an 8-bit PWMDB User Module and an 8-bit Counter User Module to generate the 38 kHz clock (to drive). First, a 64-step lookup table, shown in Table 1 on page 3 was generated using Microsoft Excel. The sine is calculated for selected values, each a step size apart. The result is scaled to an 8-bit unsigned integer value for assigning proper approximations to the pulse width register.

The effective formula in use is:

$$PW(x) = (\text{int})\left(\frac{\sin(x) * 255}{2} + 128\right) \qquad \text{Equation 1}$$

The resulting 8-bit integers are laid out as a lookup table array in the PSoC, and called upon in order to be written to the pulse width register of the PWMDB8 to achieve the "breathing" effect. The two out-of-phase PWM signals generated, in other words, will change sinusoidally between their minimum and maximum values (full off to full on) to generate an output that can be used to fabricate a sine wave. In the actual implementation, however, you must take care to avoid 0% and 100% duty cycles, so any 0 or 255 values are clipped to a 1 or 254, respectively. This ensures that there is always a small pulse for the bootstrap circuitry to charge itself. The code necessary to achieve this functionality is shown in Code 1; a flowchart of the code in Figure 2; and the configuration of the PSoC resources appear in Figure 3, Figure 4, Figure 5, and Figure 6.

Figure 1. Block Diagram



Hardware Implementation

The main advantages of using two DC power supplies (one for each side—above and below earth ground) in a bipolar chopper configuration to generate AC sine waves lie in the scalability and the safety. Standard inverters turn a single DC power supply into AC by switching the two sides (+ and –) through a full bridge (or an H-bridge) to generate the two sides of the sine wave. This is twice as many components per channel and requires both outputs to float. The half bridge has one +/– output, referenced to earth ground, very much like the mechanically generated house current we want to synthesize and synchronize for sale back to the power grid.

To simulate the large bipolar EMF that will be supplied by the solar array, two TL3843 PWM Controllers, configured as boost converters, are used. R_t and C_t form the timing ramp for the fixed frequency PWM. The voltage boost comes from charging the toroid inductor L_1, thru Q_1 and R_{sen1}. When the current limit I_{sen} (1 volt) is reached, Q_1 is turned off, and L_1 discharges through D_1 into C_1. This repeats until the voltage divider R_{reg} outputs V_{fb} (2.5 V). The values selected max out at a 2-amp input charge rate and 190 V output under no load.

The FET driver is used with an IR2110, a dual-out, floating high-side driver. This chip bootstraps its own high-side gate charge through D_{boot} into C_{boot} on each negative cycle. The high-side driver can then float up to 500 V above the rest of the chip!

To minimize shoot-through currents, D_g/R_g ensure turn off before turn on of the power FETs. L_f/C_f filters out the 30 kHz PWM component, leaving a relatively clean sine wave. Complex repetitive waveforms in multiple channels can be implemented with this scheme.

Current limit resistors R_{senH} and R_{senL} trigger U_5, the TLP2530 Dual Hi-Speed Opto-coupler, which reacts in less than .3 us when its forward voltage is above 1.7 V. The active low over current signal is inverted in the PSoC and inserted into the shutdown input of the FET driver, giving fast cycle-by-cycle protection of the output FETs. The high leg sense resistor also protects against shoot-through currents. The plan for the larger unit is to incorporate Hall effect current sensors.

The IR2110 is capable of 2A of gate drive current per channel and can switch an array of FETs or IGBTs. The required gate charge, the on-resistance, the power handling capacity, and the price of the devices are continually falling. With the FETs used in this model, a dozen could easily be driven with one chip. One could imagine a hot-swappable kilowatt module, with diagnostics, in a 1-x-19-inch rack space with less than 50 components.

A basic circuit board has been laid out with the free software package ExpressPCB (www.expresspcb.com) and is freely available upon request.

Table 1. Sine Wave Lookup Table

Radians	Sine Sin(Rads)	Scaled (0-255) Sin*255	Pulse Width (int)(Scaled/2)+128	Quadrant of Sine Function
0	0	0	128	1
0.09813	0.09797	24.9817404	140	1
0.19625	0.19499	49.7231367	153	1
0.29438	0.29014	73.986157	165	1
0.3925	0.3825	97.5373718	177	1
0.49063	0.47118	120.1502	188	1
0.58875	0.55532	141.607088	199	1
0.785	0.70683	180.240421	218	1
0.88313	0.77273	197.045183	227	1
0.98125	0.83119	211.954215	234	1
1.07938	0.88166	224.824079	240	1
1.1775	0.92365	235.530957	246	1
1.27563	0.95675	243.971841	250	1
1.37375	0.98065	250.065522	253	1
1.47188	0.99511	253.753375	255	1
1.57	1	254.999919	255	2
1.66813	0.99527	253.793162	255	2
1.76625	0.98096	250.144714	253	2
1.86438	0.95721	244.089675	250	2
1.9625	0.92426	235.6863	246	2
2.06063	0.88241	225.015437	241	2
2.15875	0.83208	212.179746	234	2
2.25688	0.77374	197.302718	227	2
2.355	0.70795	180.527482	218	2
2.45313	0.63535	162.015428	209	2
2.55125	0.55665	141.944657	199	2
2.64938	0.47258	120.508267	188	2
2.7475	0.38397	97.912491	177	2
2.84563	0.29167	74.3747196	165	2
2.94375	0.19655	50.1214044	153	2
3.04188	0.09955	25.3858816	141	2
3.14	0.00159	0.40612649	128	3
3.23813	-0.0964	-24.577536	116	3
3.33625	-0.1934	-49.324743	103	3
3.43438	-0.2886	-73.597407	91	3
3.5325	-0.381	-97.162005	79	3
3.63063	-0.4698	-119.79183	68	3
3.72875	-0.554	-141.26916	57	3

Radians	Sine Sin(Rads)	Scaled (0-255) Sin*255	Pulse Width (int)(Scaled/2)+128	Quadrant of Sine Function
3.82688	-0.6329	-161.38737	47	3
3.925	-0.7057	-179.9529	38	3
4.02313	-0.7717	-196.78715	30	3
4.12125	-0.8303	-211.72815	22	3
4.21938	-0.8809	-224.63215	16	3
4.3175	-0.923	-235.37502	10	3
4.41563	-0.9563	-243.85339	6	3
4.51375	-0.9803	-249.9857	3	3
4.61188	-0.995	-253.71294	1	3
4.71	-1	-254.99927	1	4
4.80813	-0.9954	-253.83231	1	4
4.90625	-0.9813	-250.22327	3	4
5.00438	-0.9577	-244.20689	6	4
5.1025	-0.9249	-235.84105	10	4
5.20063	-0.8832	-225.20622	15	4
5.29875	-0.833	-212.40474	22	4
5.39687	-0.7747	-197.55975	29	4
5.495	-0.7091	-180.81408	38	4
5.59312	-0.6366	-162.32884	47	4
5.69125	-0.558	-142.28187	57	4
5.78937	-0.474	-120.86603	68	4
5.8875	-0.3854	-98.287362	79	4
5.98562	-0.2932	-74.763093	91	4
6.08375	-0.1981	-50.519545	103	4
6.18187	-0.1011	-25.789958	115	4
6.28	-0.0032	-0.812252	128	4

Code 1. PSoC C Code

```
#include <m8c.h> // part-specific constants and macros
#include "PSoCAPI.h" // PSoC API definitions for all User Modules
#include "ports.h"
#define Trigger60(b) (PRT2DR = (b==0) ? (PRT2DR&0x7F) : (PRT2DR|0x80))
#define MinPWM 1 //how far from edge PWM is clipped - top and bottom
#define PwmChangeDelay 50 //sine wave frequency
#define STEPS 63
char Sine[STEPS]={128,140,153,165,177,188,199,218,227,234,240,246,250,253,\
254,255,254,253,250,246,241,234,227,218,209,199,188,177,165,153,141,\
128,116,103,91,79,68,57,47,38,30,22,16,10,6,3,1,0,1,3,6,10,15,22,29,\
38,47,57,68,79,91,103,115};
char SineStep=0;
char PwmValue = 128;
int PwmChangeDelayCounter = 0;
void main()
{
Trigger60(0);
Clk_PWM_DisableInt();
Clk_PWM_Start();
PWMDB_DisableInt();
PWMDB_WritePulseWidth(PwmValue);
PWMDB_Start();
M8C_EnableGInt;
while(1)
{
if (++PwmChangeDelayCounter > PwmChangeDelay)
{
PwmChangeDelayCounter = 0;
PwmValue=Sine[SineStep];
if (PwmValue > (255-MinPWM)) PwmValue = 255-MinPWM; //top clipping
else if (PwmValue < MinPWM) PwmValue = MinPWM; //bottom clipping
PWMDB_WritePulseWidth(PwmValue);
if (++SineStep==STEPS)
{
SineStep=0;
Trigger60(1);
Trigger60(0);
}
}
}
}
```

Figure 2. Program Flowchart

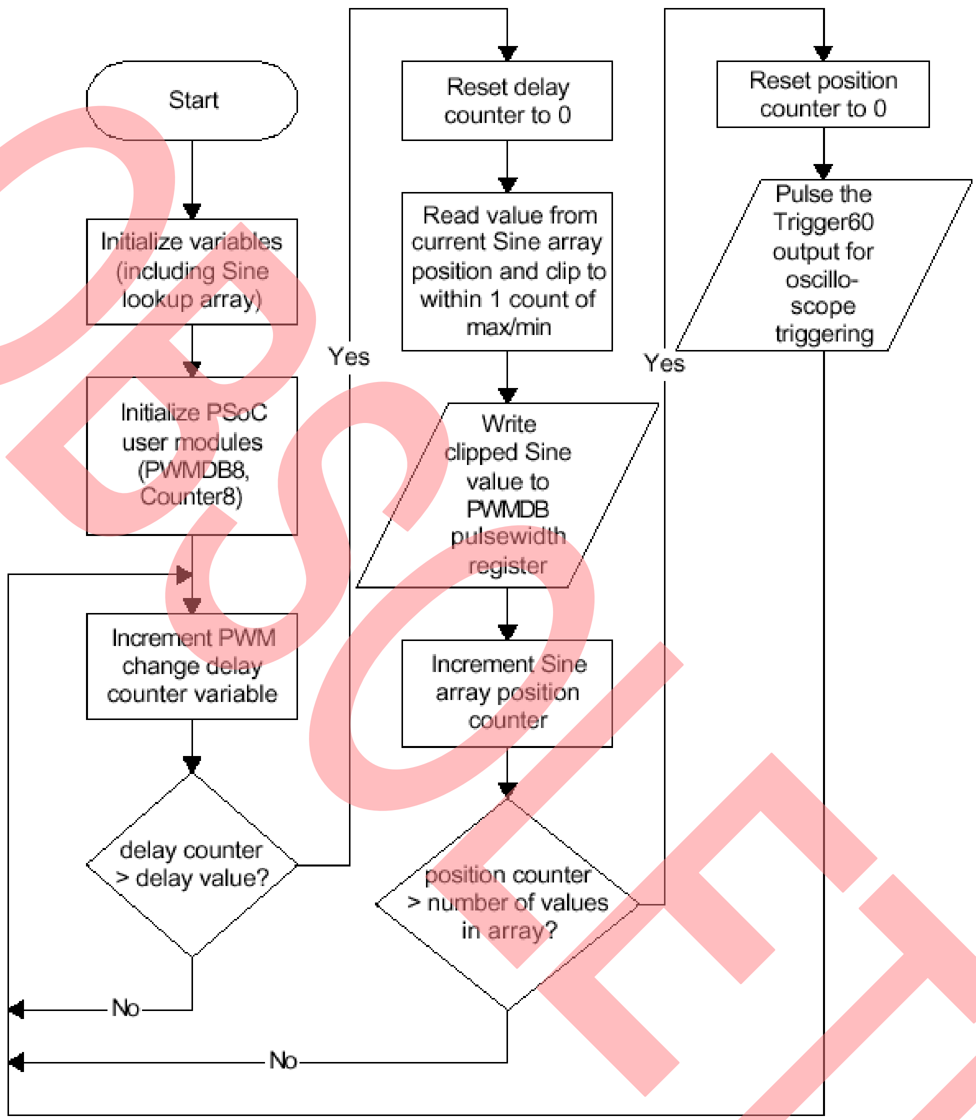


Figure 3. PSoC Pin Configuration

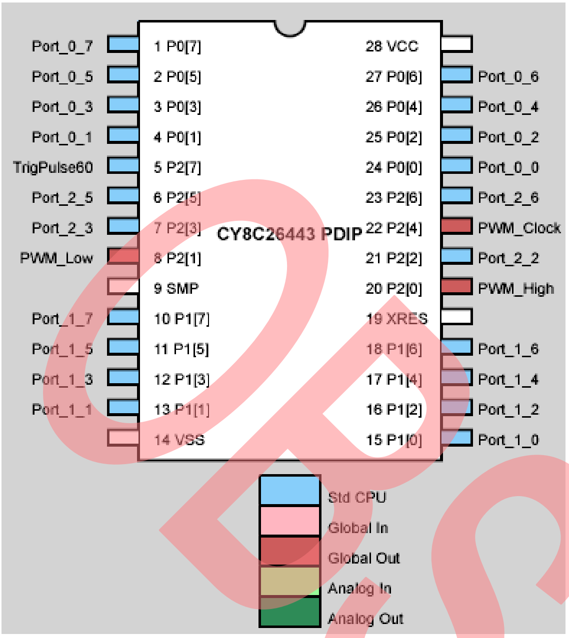


Figure 4. PSoC Configuration GUI

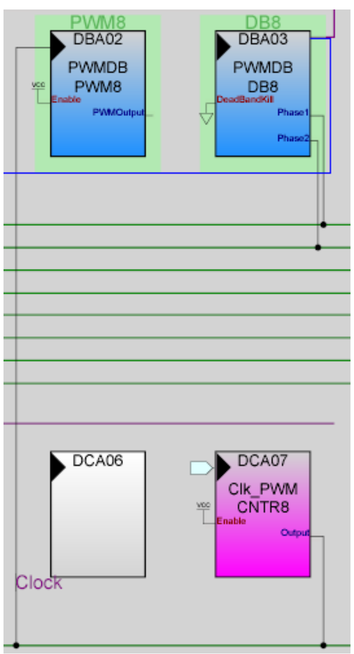


Figure 5. PSoC Configuration Settings

Clk_PWM

User Module Parameters	
Clock	48M
Enable	High
Output	Global_OUT_4
Period	3
CompareValue	2
CompareType	Less Than Or Equal
InterruptType	Terminal Count

PWMDB

User Module Parameters	
Clock	Global_OUT_4
Enable	High
Period	255
PulseWidth	0
InterruptType	Terminal Count
PWMOutput	None
DeadTime	3
Phase1	Global_OUT_0
Phase2	Global_OUT_1
DeadBandKill	Low

Figure 6. PSoC Global Resource Settings

Global Resources	
CPU_Clock	24_MHz
32K_Select	Internal
PLL_Mode	Disable
Sleep_Timer	512_Hz
24V1= 24MHz/N	16
24V2= 24V1/N	11
Analog Power	SC On/Ref Low
Ref Mux	(Vcc/2)+/-BandGap
Op-Amp Bias	Low
A_Buff_Power	Low
SwitchModePump	OFF
Trip Voltage [LVD (SMP)]	4.64V (5.00V)
Supply Voltage	5.0V
Watchdog Enable	Disable

Figure 7. Bipolar Chopper Schematic

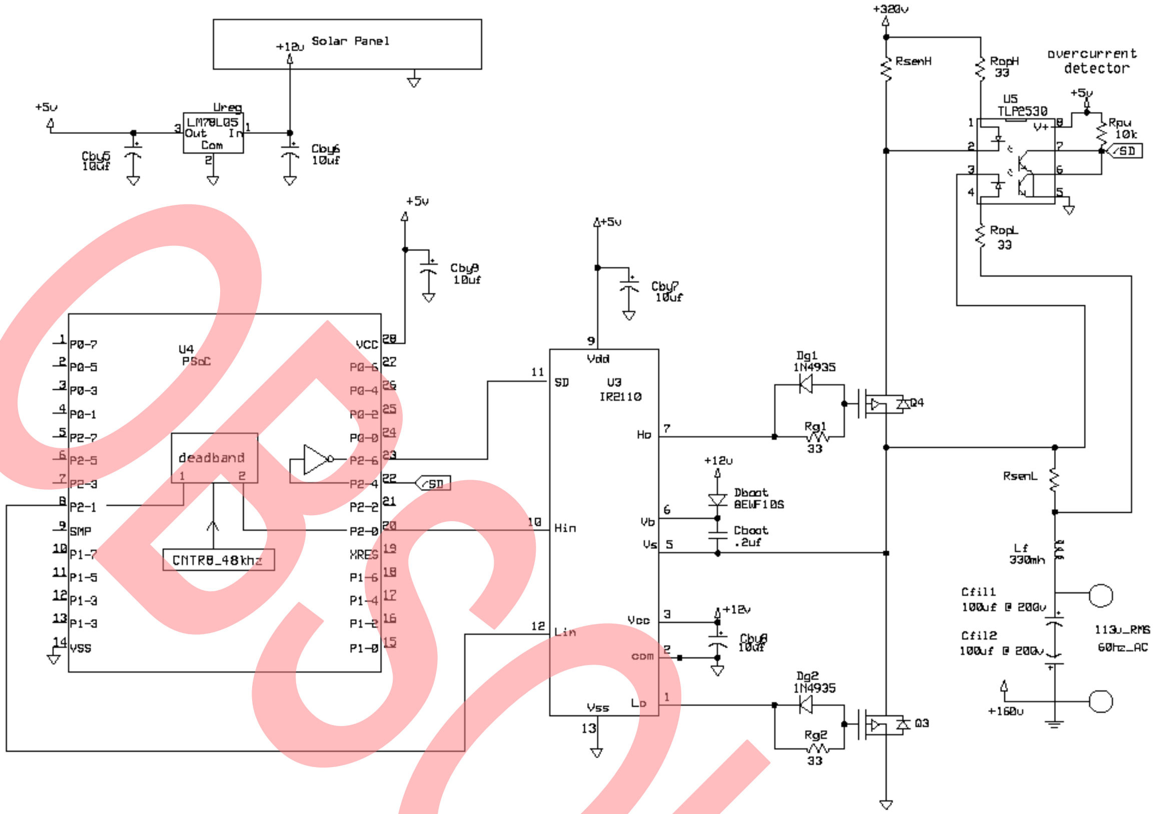
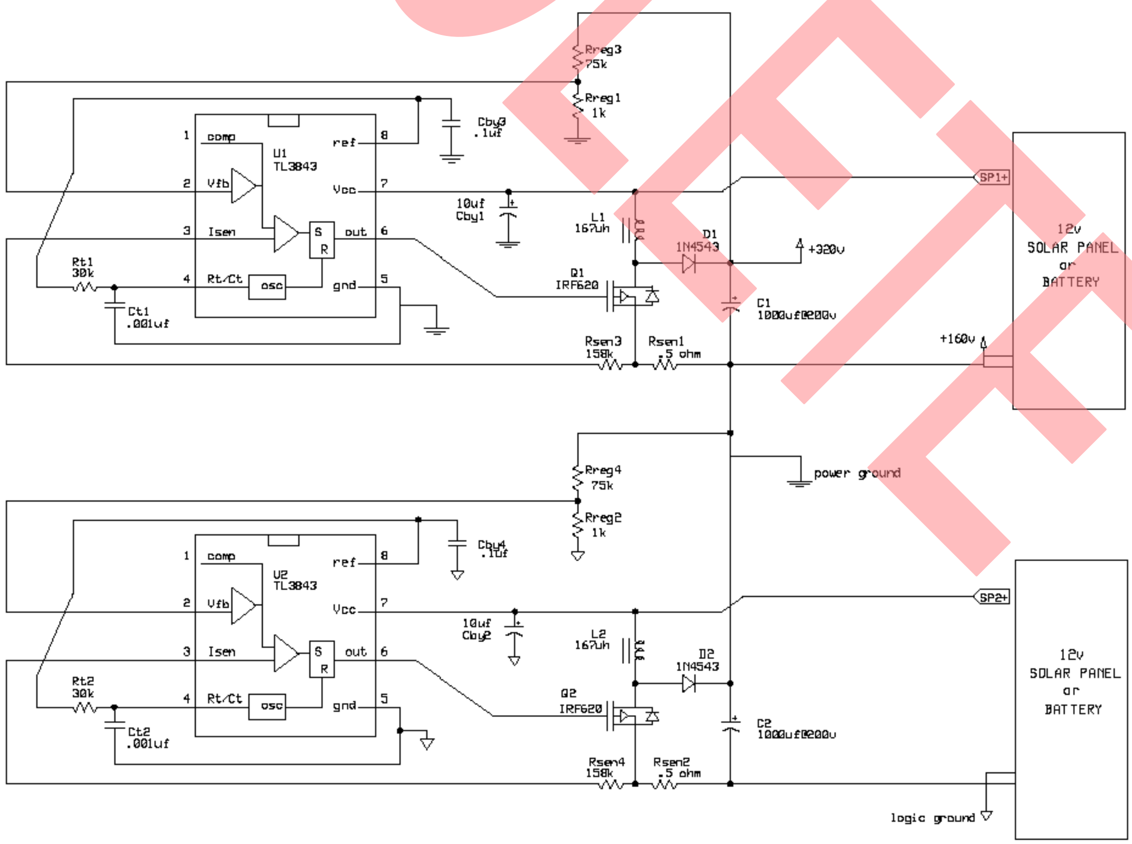


Figure 8. Dual High-Voltage Power Supply Schematic



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Document History

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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	1505943	KANT	10/08/2007	New application note.
*A	3197495	KANT	03/16/2011	Updated title, abstract, and introduction. Updated the associated project and compiled with latest PSoC Designer software.
*B	4324565	KANT	3/28/2014	Obsolete document.

In March of 2007, Cypress recataloged all of its Application Notes using a new documentation number and revision code. This new documentation number and revision code (001-xxxxx, beginning with rev. **), located in the footer of the document, will be used in all subsequent revisions.

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