## Supertex inc.

## HV9112DB3

## HV9112DB3 Demo Board

by Derek Koonce, Senior Applications Engineer

## **Performance Summary**

Input voltage 20REN max	+42.5V to +70VDC		
Output voltages	+55V, +12V, +5V, -155V		
Differential output voltage	210V		
Output power	15W		
Efficiency	>70%		
Output Load regulation	10% to 100% 10%		
Differential Line regulation	40V to 70V 1.3%		
Operating frequency	72kHz		

## **General Description**

The Supertex demonstration board HV9112DB3 is a DC to DC discontinuous flyback converter designed for exhibiting the functionality of the Supertex HV9112 integrated circuit. The HV9112DB3 is also used to provide the required DC voltages for the Supertex HV441DB1, HV441DB2, HV440DB1, and HV440DB2 ring generator boards. This converter is designed to accept a nominal input voltage of 48V and produce a set of output voltages: +55V, +12V, +5V, and -155V. The converter can be turned off by connecting the Shutdown pin to GND, and turned on by leaving it floating or connected to  $V_{DD}$ . The +55V and -155V regulation is accomplished by regulating the difference at 210V, while the +12V and +5V are linear regulated from a +20V winding. The demo unit can drive loads up to 15W, which is equivalent to a 20-REN load when used with the HV441DB2 or HV440DB2 demo boards. The circuit shown in Figure 1 is designed to meet safety agency requirements by providing an active discharge of the high voltage capacitors when power is removed. The bill of materials is shown in Table I. The PC board layout showing the silkscreen, bottom layer copper, and top layer copper are in Figures 2, 3, and 4 respectively. The board dimensions are 2.15 inches by 3 inches.

## Theory of Operation

The circuit uses a discontinuous flyback architecture and can be broken into the five basic functional blocks as follows:

- 1. PWM control circuitry
  - a. Start-up
  - b. A power switch
  - c. Current loop/current limit
- 2. Transformer

- 3. Output rectifier and filter
- 4. Feedback circuitry
- 5. Active discharge circuitry

#### **PWM Control Circuitry**

The main control of the power converter is the Supertex HV9112NG PWM IC, U<sub>1</sub>. This device can be powered from a voltage source of up to 80 volts. This ability comes from a state of the art High Voltage BiCMOS process developed by Supertex. The capability to stand-off high voltage simplifies the start-up circuitry required for the converter. Please refer to the Supertex HV9112NG data sheet for details.

A spread sheet was developed for ease of calculating all initial component values for the HV9112 PWM controller. The equations are based on the application note AN-H13, *Designing High-Performance Flyback Converters with the HV9110 and HV9120*. From these initial values, additional circuitry was added to maximize performance when used with the ring generator demo boards.

#### Start-up

When power is applied to the unit, the start-up circuit, consisting of a high voltage depletion-mode MOSFET, an operational amplifier, and a voltage reference inside U<sub>1</sub> generates the V<sub>DD</sub> supply to power U<sub>1</sub>'s internal circuitry. When V<sub>DD</sub> increases above the under-voltage lockout of typically 8.1V, U<sub>1</sub> will begin to pulse the gate of power switch Q<sub>1</sub> turning it on and off. The primary winding of T<sub>1</sub> is charged when Q<sub>1</sub> is turned on. The energy stored in the primary is transferred to the secondary windings during the off state of Q<sub>1</sub>. This charges capacitors C<sub>1</sub>, C<sub>8</sub>, and C<sub>9</sub>. The V<sub>DD</sub> supply for U<sub>1</sub> is generated by a linear regulator, U<sub>2</sub>, storing energy to C<sub>2</sub>. As the voltage across C<sub>2</sub> increases above 8.6V, the start-up circuit will automatically turn off. The V<sub>DD</sub> supply is now generated by an auxiliary winding, providing the supply voltage for the IC.

#### **Power Switch**

The flyback cycle starts when the HV9112NG MOSFET drive stage turns  $Q_1$  on. This output drive stage has rail-to-rail swing for optimal drive of  $Q_1$ , the VN2224N3. This Supertex MOSFET is a 240 volt, 1.25 ohm device designed to work in DC-DC converter applications like the HV9112DB3. The VN2224N3 is available in the cost-effective TO-92 package, which occupies a small area on the board. Its low input capacitance reduces

Supertex Inc. does not recommend the use of its products in life support applications and will not knowingly sell its products for use in such applications unless it receives an adequate "products liability indemnification insurance agreement." Supertex does not assume responsibility for use of device described and limits its liability to the replacement of devices determined to be defective due to workmanship. No responsibility is assumed for possible omissions or inaccuracies. Circuitry and specifications are subject to change without notice. For complete liability information covering this and other Supertex products, refer to the Supertex 1998 Databook.

<sup>9/7/98</sup> 

the drive current required thereby improving power converter efficiency. Another feature of the power switch is that the design engineer's task is eased by these lower currents because the parasitic elements in the gate path on the PC board become less critical, simplifying the layout task.

In this application, the MOSFET is a switch; it either conducts current (on), or does not conduct current (off). The time it takes for the MOSFET switch to transition between the on and off state must be reduced to keep the power dissipation in the VN2224N3 low. The power dissipated in the switch comes from two primary sources:

1. Voltage and current across the device during the transition time between on and off states. In the discontinuous flyback design, there is little current in the off-to-on transition. Most of the losses occur during the on-to-off interval. We call these transition or switching losses.

2. When the switch is on, the current is building linearly in the transformer primary winding. As this current increases, the dissipation in the switch also increases by the resistive loss:  $I^2 R_{DS(ON)}$  which is called the conduction loss.

#### **Current Loop / Current Limit**

Resistor  $R_4$  converts the linearly increasing current ramp in the primary to a voltage ramp. The low pass filter formed by  $R_1$  and  $C_5$  filters out the high frequency spikes generated by the switching action of  $Q_1$ . A high speed comparator in the HV9112 compares the current ramp with an error voltage (the feedback signal) and shuts off  $Q_1$  when the current equals the error voltage. This is the "inner" control loop.

A second comparator in the HV9112 limits the peak current to a fixed maximum value in case of a short on the output (a very large feedback signal). When the voltage across the current sense resistor  $R_4$  reaches a nominal peak value of 1.2V, the current limit comparator will turn  $Q_1$  off.

#### Transformer

When  $Q_1$  impresses the input voltage across T1's primary, it causes the primary current to increase linearly with time. The primary winding uses 19 turns of 24 AWG magnet wire. The core is pre-gapped for a primary inductance of 217µH.

Three secondary windings are used to generate the necessary voltages to operate the ring generator demo boards. Since all three windings are referenced to the same ground, these windings are combined as one with multiple taps. Leakage inductance, which can cause ringing, is not a primary concern because there is a feedback loop and linear regulators to control all output voltages. Starting from the -155V output, 90 turns of 30AWG are used to reach ground. Another 12 turns are used to develop the +20V tap, and a final 22 turns are used to generate the +55V output.

#### **Output Rectifier and Filter**

When  $Q_1$  turns off, the energy stored in  $T_1$  causes current to flow in the secondary windings. Diodes  $D_2$ ,  $D_3$  and  $D_4$  turn on and  $C_1$ ,  $C_8$  and  $C_9$  store the energy from the transformer to provide output filtering.

The +55V and -155V outputs are controlled by the feedback control loop. However,  $V_{DD}$ , the HV9112 supply voltage, is regulated by the linear regulator U<sub>2</sub>. When using the ring generator demo boards, the ring generator IC is typically in a standby mode and draws very little power from the power supply.

The HV9112 operates in a burst mode in this "no-load" type operation. When the HV9112 is generating pulses to the gate of  $Q_1$ , all three output capacitors are charging during the flyback period. When the feedback loop tells the HV9112 to narrow the  $Q_1$  pulse width to less than its minimum pulse width rating, the three capacitors stop charging from T<sub>1</sub>. Energy is withdrawn from the +55V and -155V outputs at a very slow rate, and there is a larger power requirement from the +20V output due to the 12V and 5V supply usage. Regulation is based on the +55V and -155V outputs which will discharge very slowly. Thus voltage on the +20V capacitor, C<sub>1</sub> will droop. C<sub>1</sub> is sized to handle the voltage droop during this narrow pulse width time frame.

To calculate C<sub>1</sub>, the following assumptions are made:

- 1. Voltage allowed to droop from +20V to +16V on  $C_1$ .
- 2. +55V dummy load is  $6.8k\Omega$ , a constant 0.44W.
- 3. +55V output is allowed to droop 5%, +55V to +52V, before next burst mode to account for a resistive dummy load on the -155V output.
- 4. +55V capacitance must be 220 $\mu$ F.
- 5. 14mA is drawn from C<sub>1</sub>; 1mA for HV9112NG; 0.5mA for LM2904; 5mA for each linear regulator; 1.5mA for VN2224, and 1mA overhead.

Energy (1/2CV<sup>2</sup>) in the +55V output capacitor will drop from 0.333J to 0.297J, or 35mJ. The time required to drop this amount of energy is  $\Delta J/W = 36mJ/0.44W = 82ms$ . Therefore, the minimum capacitor value for C<sub>1</sub> is

I \* dt / dV = 14mA \* 82ms / 4V = 287µF

Select the next size capacitor of 330µF.

#### Feedback Control Loop

Since both the +55V and -155V outputs need to be regulated, a resistor divider network is used with differential amplifier U4 to generate a 4V feedback voltage to the HV9112 PWM controller feedback. The +55V output is divided down to a positive DC voltage signal and fed into the amplifier's non-inverting input. The -155V signal is divided down to a negative DC voltage signal and fed into the amplifier's inverting input. With the difference between the input and an amplifier gain of one, the resulting output is 4V. Resistors R<sub>7</sub> through R<sub>14</sub> provide both division and gain for this circuit. Extensive analysis was performed to keep the power dissipation low and maximum differential voltage to 220V including component tolerances. Component tolerance accounts for 6% variation, using 1% resistor tolerances and 2% reference voltage tolerance. Therefore the resistor selection is such that for a 220V \* 0.94 = 206.8V output differential voltage produces a 4.00V op amp output voltage. From the multiple combinations of 1% resistors that satisfy this condition, all combinations that yielded more than 8mW of power dissipation were eliminated due to high power dissipation for the 1206 resistor package size.

The output of  $U_{4A}$ , typically 4V, is fed into the error amplifier of the PWM controller. This is compared with an accurate 4.0V reference. The voltage difference between  $U_4$ 's output and the reference voltage is multiplied by a high gain error amplifier. The output of the error amplifier combined with the current sense comparator will adjust the duty cycle of  $Q_1$  to reduce the difference detected by the error amplifier. These functions are all done inside the HV9112.

Components  $R_5$ ,  $C_{10}$ , and  $C_{11}$  provide compensation for the internal error amplifier. Components  $R_6$ ,  $R_{23}$ , and  $C_{13}$  provide loop compensation for best performance. If either the +55V output or -155V outputs vary, the feedback loop will control the pulse width of Q1 by providing an appropriate amount of energy to transfer to the output capacitors, in order to keep the difference between the two voltage rails at 210V.

#### **Active Discharge Circuitry**

Active discharge circuits are included to quickly (less than one second) reduce output voltage to an acceptable level when the supply voltage is removed. Discharge circuits are added to both the +55V and -155V capacitors due to their high voltages.

When a voltage is applied to the HV9112DB3 board,  $Q_3$  is turned on through  $R_{17}.$  This keeps the base of  $Q_2$  low and off. When the input voltage is removed,  $Q_3$  is turned off and allows  $Q_2$  to be turned on through  $R_{18}.$  This allows the 60V 220 $\mu F$  capacitor to discharge to less than 40V through  $R_{19}$  in less than one second.

The active discharge circuitry for the -155V capacitor, C<sub>8</sub>, is turned off by applying an input voltage to the HV9112DB3. This turns off Q<sub>4</sub> through a resistor divider R<sub>21</sub> and R<sub>20</sub> – assuming the -155V output starts at zero volts. When the -155V output is on, a minimum input voltage of 10V is required to keep Q<sub>4</sub> off through the resistor divider of R<sub>21</sub> and R<sub>20</sub> (D<sub>6</sub> is present to protect the base to emitter junction of Q<sub>4</sub>). When the input voltage is removed, Q<sub>4</sub> will be turned on by the -155V and the component network of R<sub>20</sub>, R<sub>21</sub>, R<sub>17</sub>, and V<sub>BE</sub> drop of Q<sub>3</sub>. Once Q<sub>4</sub> is turned on, C<sub>8</sub> will be discharged through R<sub>22</sub>. The discharge current will eventually decrease due to both the voltage reduction on C<sub>8</sub> and the base of Q<sub>4</sub>.

Since the active discharge circuitry is not used frequently and board space is to be kept to a minimum, 1W surface mount resistors were used. Peak power dissipations in both  $R_{19}$  and  $R_{22}$  are 1.8W and 12.8W, respectively. Chip resistors can handle peak power dissipations above the DC rating. Based on test results, a one watt chip resistor for both instances can sustain the peak power dissipation. For example, a 1W chip resistor can sustain power dissipation of 32 watts for 0.1 seconds and can sustain a power dissipation of 6.3W for one second<sup>1</sup>.

### **Initial Testing**

The initial design used a 50kHz PWM frequency, which used a primary inductance of 239mH (20 turns on the primary with the other windings kept at the same turn ratio). This initial design showed signs of core saturation when a 16W load was applied. It was therefore decided to reduce the number of primary turns and increase the operating frequency to provide some margin from core saturation. Reducing the number of primary turns to 19 yielded a primary inductance of 217 $\mu$ H. The power supply PWM frequency was increase to 72kHz to accommodate this new inductance value. The change in frequency did not affect any other component values.

#### HV9112DB3 Usage with HV441DBx

The HV9112DB3 can be used with the HV441DB1, HV441DB2, HV440DB1 and HV440DB2 ring generator demo boards. Interconnection between the HV9112DB3 and HV441DB2 is shown in Figure 5.

Testing with a 20 REN load and the HV441DB2 at +48V input resulted in the following output ripple voltages at 20Hz:

V <sub>OUT</sub>	V <sub>RIPPLE</sub>	
V <sub>PP</sub>	3.6V	
V <sub>NN</sub>	6.0V	
$V_{PP}$ - $V_{NN}$	2.6V	

#### **Component Suppliers**

Most components can be obtained through an electronic parts distributor such as DigiKey.

Transformers can be obtained through:

TNI Inc. 1001 Steeple Square Ct. Knightdale, North Carolina 27545-9604 USA (919) 266-4411 (919) 266-6008 FAX

<sup>&</sup>lt;sup>1</sup> Further information on pulse power handling capability for chip resistors can be obtained from Dale Electronics technical support, (402) 371-0080.

## Table I: Bill of Materials for HV9112DB3

ITEM	QTY	SYMBOL	DESCRIPTION	PART NO.	MANUFACTURER
1	1	C1	330µF, 35V electrolytic capacitor	-	any
2	5	C2, C3, C6, C7, C12	0.1µF, 50V ceramic capacitor	-	any
3	1	C4	47µF, 100V electrolytic capacitor	-	any
4	1	C5	150pF, 50V ceramic capacitor	-	any
5	1	C8	220µF, 200V electrolytic capacitor	-	any
6	1	C9	220µF, 100V electrolytic capacitor	-	any
7	1	C10	390pF, 50V ceramic capacitor	-	any
8	1	C11	short	-	any
9	1	D1, D6	70V, 350mW high speed switching diode	BAV70	Diodes Inc.
10	2	D2, D4	1.0A, 200V fast recovery diode	DL4935	Diodes Inc.
11	1	D3	1.0A, 400V fast recovery diode	FR1G	Diodes Inc.
12	1	D5	1.A, 200V silicon & glass passivated diode	S2D	Diodes Inc.
13	1	JP1	5 pin, male, right angle connector	22-05-3051	Molex
14	1	JP2	5 pin, female, right angle connector	22-15-2056	Molex
15	1	Q1	240V, 1.25Ω, N-channel MOSFET	VN2224N3	Supertex
16	2	Q2, Q3	500mW, 140V, NPN bi-polar transistor	FMMT494	Zetex
17	1	Q4	200V, PNP transistor	FMMT597	Zetex
18	1	R1	1.0KΩ, 1/8W, 5% chip resistor	-	any
19	1	R2	390KΩ, 1/8W, 5% chip resistor	-	any
20	1	R3, R16	220KΩ, 1/8W, 5% chip resistor	-	any
21	1	R4	0.68Ω, 1/4W, 5% chip resistor	-	any
22	1	R5	330KΩ, 1/8W, 5% chip resistor	-	any
23	1	R6	10K $\Omega$ , 1/8W, 5% chip resistor	-	any
24	4	R7, R8, R9, R10	102K $\Omega$ , 1/8W, 1% chip resistor	-	any
25	1	R17	100K $\Omega$ , 1/8W, 5% chip resistor	-	any
26	1	R11	2.61KΩ, 1/8W, 1% chip resistor	-	any
27	1	R12	9.31KΩ, 1/8W, 1% chip resistor	-	any
28	1	R13	432KΩ, 1/8W 1% chip resistor	-	any
29	1	R14	137K $\Omega$ , 1/8W, 1% chip resistor	-	any
30	1	R15	6.8KΩ, 1W, 5% chip resistor	-	any
31	1	R18	36K $\Omega$ , 1/8W, 5% chip resistor	-	any
32	1	R19, R22	2.0KΩ, 1W, 5% chip resistor	-	any
33	1	R20	620KΩ, 1/8W, 5% chip resistor	-	any
34	1	R21	75KΩ, 1/8W, 5% chip resistor	-	any
35	1	T1	Power transformer	T8434	TNI Transformers
36	1	U1	IC, PWM controller	HV9112NG	Supertex
37	1	U2	Linear regulator, 12V	LM7812	any
38	1	U3	Linear regulator, 5V	LM7805	any
39	1	U4	Amplifier	LM2904M	National Semiconductor

## Figure 1: HV9112DB3 Schematic Diagram



### Figure 2: Silk Screen

#### ASSY: HV9112DB3 REV. D4 D3 R4 JP1 ിജ' ജ QI R15 ш₽ Ċ R6 Ξ C2 Ξ UΙ R.3 ) Ca Г 1<sub>01 R7</sub>= 2.15 in. C7 R23 68 U4r ]U2 C12 C13 шĘ R14 R11 R10 R13 R16 \_\_\_\_\_\_ C3\_\_\_\_ C10 R20R8R9 С11 D6 R5 Г Т <u>\_</u>02 R19 R21 U3 RT2 L ] Q4 1 R22 3.00 in.

# Figure 3: Bottom Layer Copper



## Figure 4: Top Layer Copper









1235 Bordeaux Drive, Sunnyvale, CA 94089 TEL: (408) 744-0100 • FAX: (408) 222-4800 www.supertex.com