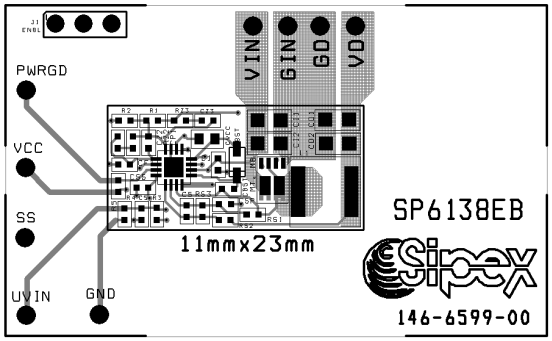
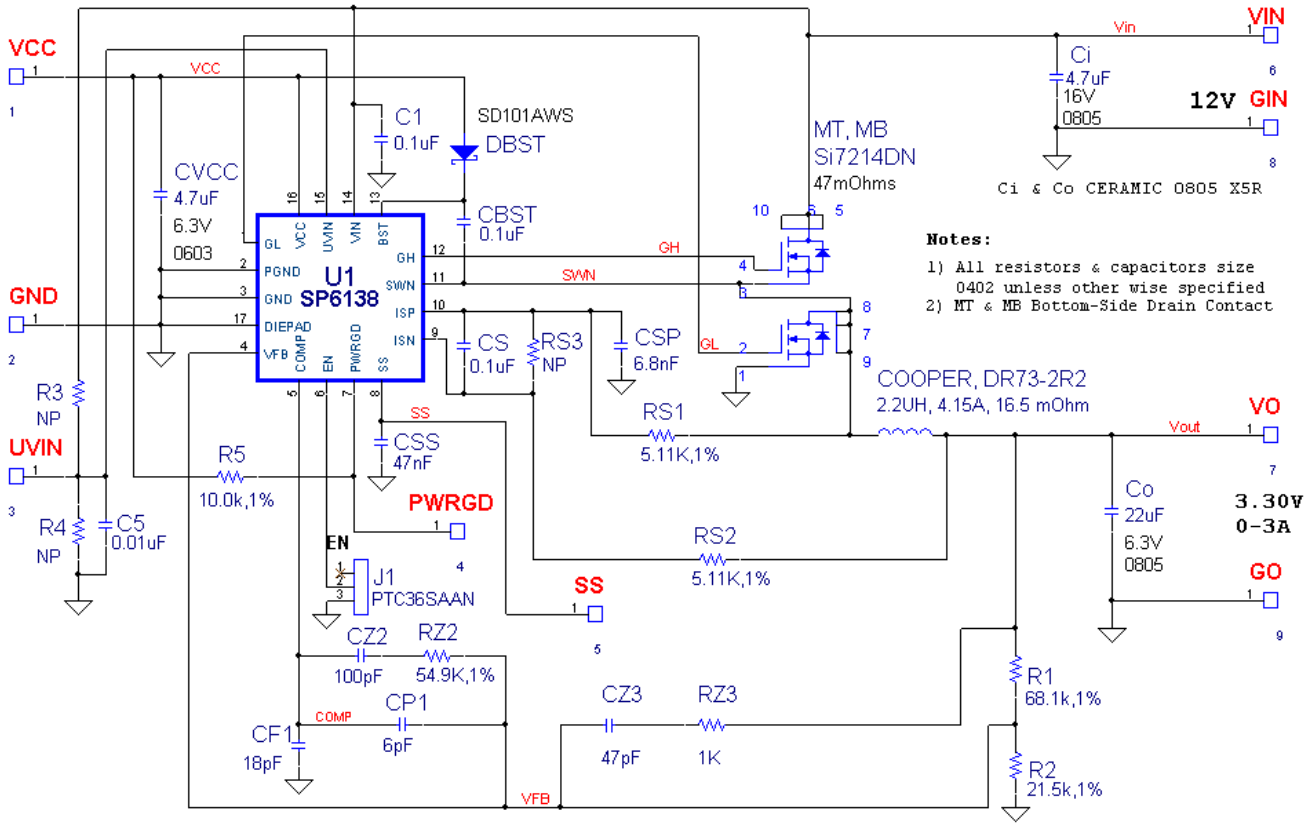
# SP6138 (3A MAX.)

# Evaluation Board Manual

- Easy Evaluation for the SP6138ER1 12V Input, 0 to 3A Output Synchronous Buck Converter
- Precision 0.80V with ±1% High Accuracy Reference
- Small form factor
- Feature Rich: Single supply operation, Over-current protection with auto-restart, Power Good Output, Enable input, Fast transient response, Supply and Output Dead Short Circuit Shutdown Protection, Programmable soft start.




## SP6138EB SCHEMATIC



## USING THE EVALUATION BOARD

### 1) Powering Up the SP6138EB Circuit

Connect the SP6138 Evaluation Board with an external +12V power supply. Connect with short leads and large diameter wire directly to the "$V_{IN}$" and "$G_{IN}$" posts. Connect a Load between the "$V_O$" and "$G_O$" posts, again using short leads with large diameter wire to minimize inductance and voltage drops.

### 2) Measuring Output Load Characteristics

It's best to ground any reference scope and digital meters using the Star GND post in the center of the board. $V_{OUT}$ ripple can best be seen by touching the probe tip to the pad for $C_{OUT}$ and the scope GND collar touching the Star GND post – avoid a GND lead on the scope which will increase noise pickup.

### 3) Using the Evaluation Board with Different Output Voltages

The SP6138 Evaluation Board has been tested and delivered with the output set to 3.30V. By simply changing one resistor, R2, the SP6138 can be set to other output voltages. The relationship in the following formula is based on a voltage divider from the output to the feedback pin $V_{FB}$, which is set to an internal reference voltage of 0.80V. Standard 1% metal film resistors of surface mount size 0603 are recommended.

$V_{OUT} = 0.80V ( R1 / R2 + 1 ) \Rightarrow R2 = R1 / [ (V_{OUT} / 0.80V ) – 1 ]$

Where R1 = 68.1KΩ and for the $V_{OUT}$ = 0.80V setting, simply remove R2 from the board. Furthermore, one could select the value of R1 & R2 combination to meet the exact output voltage setting by restricting R1 resistance range such that $50K\Omega \leq R1 \leq 100K\Omega$ for overall system loop stability.

Note that since the SP6138 Evaluation Board design was optimized for 12V down conversion to 3.30V, changes of output voltage and/or input voltage will alter performance from the data given in the Power Supply Data section.

## POWER SUPPLY DATA

The SP6138EB is designed with an accurate 1.5% reference over line, load and temperature. Figure 1 data shows a typical SP6138ER Evaluation Board efficiency plot, with efficiencies to 86% and output currents to 3A. SP6138ER Load Regulation in Figure 2 shows only 0.09% change in output voltage step response from no load to 3A load. Figures 3 and 4 show the fast transient response of the SP6138. Start-up response in Figures 5, 6 and 7 show a controlled start-up with different output load behavior when power is applied where the input current rises smoothly as the soft-start ramp increases. In Figure 8 the hiccup mode gets activated in response to an output dead short circuit condition and will soft-start until the over-load is removed. Figures 9 and 10 show output voltage ripple less than 10mV over the complete load range.

While data on individual power supply boards may vary, the capability of the SP6138ER of achieving high accuracy over a range of load conditions shown here is quite impressive and desirable for accurate power supply design.

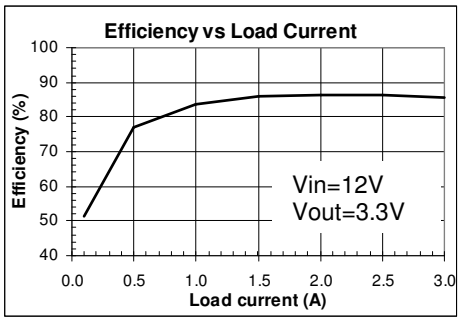



**Figure 1. Efficiency vs Load**

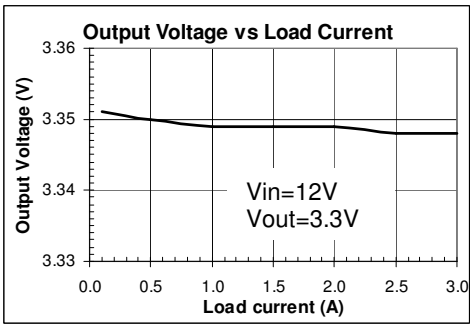



**Figure 2. Load Regulation**

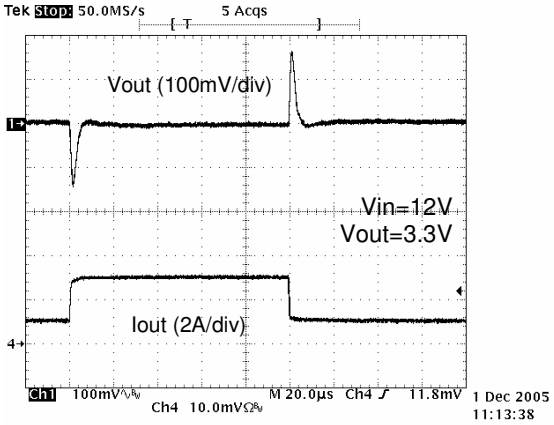



**Figure 3. Load Step Response: 1->3A**

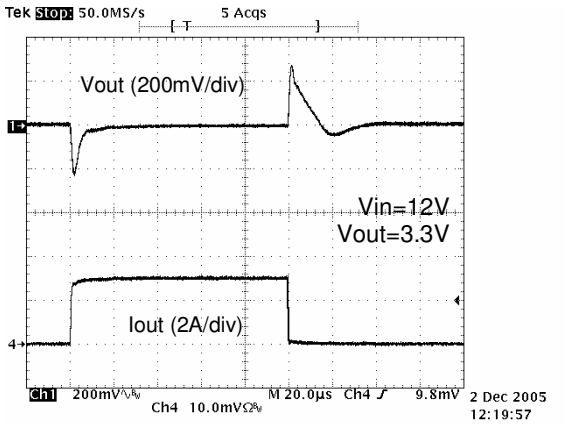



**Figure 4. Load Step Response: 0->3A**

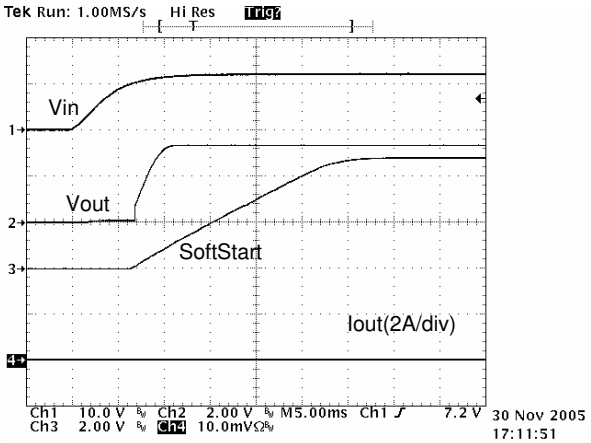



**Figure 5. Start-Up Response: No Load Load**

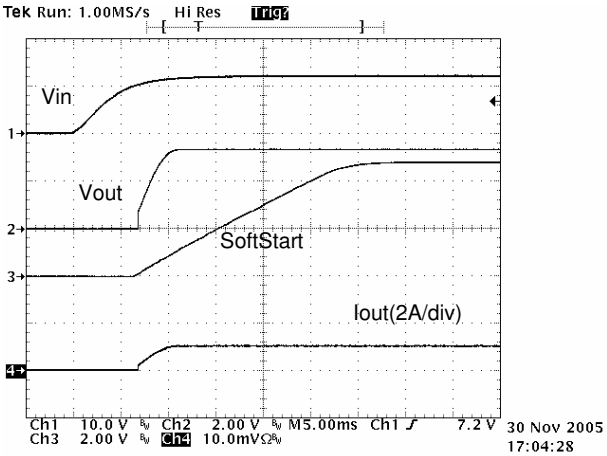



**Figure 6. Start-Up Response: 1A**

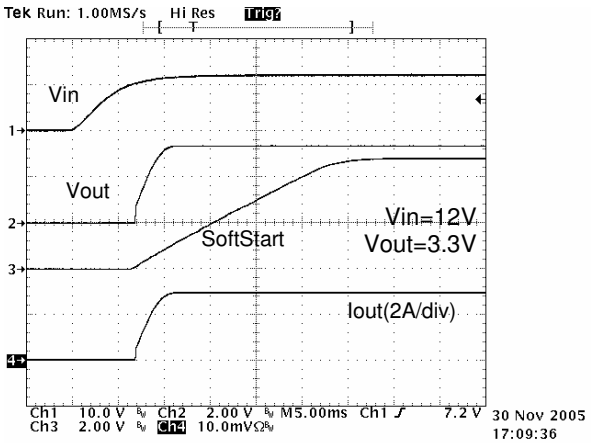



**Figure 7. Start-Up Response: 3A Load**

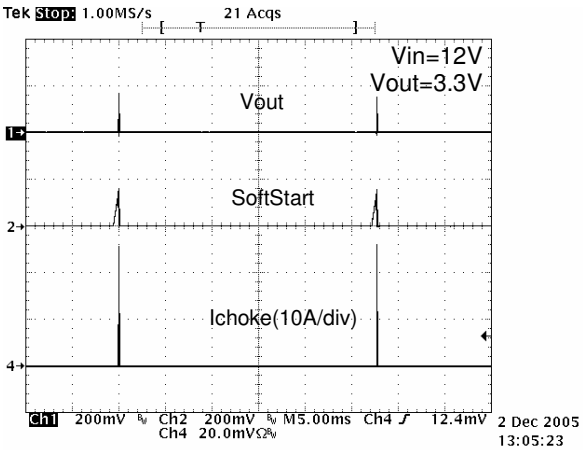



**Figure 8. Output Load Short Circuit**

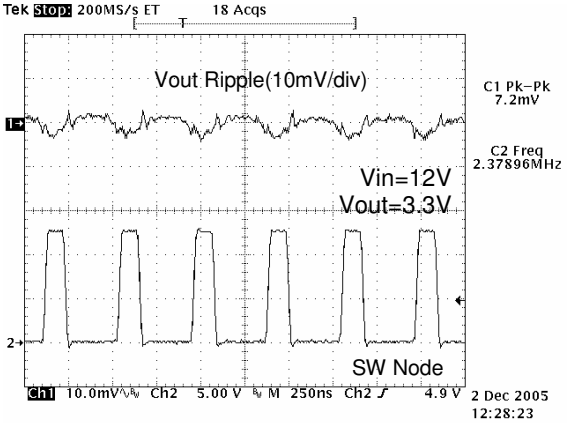



**Figure 9. Output Noise at No Load**

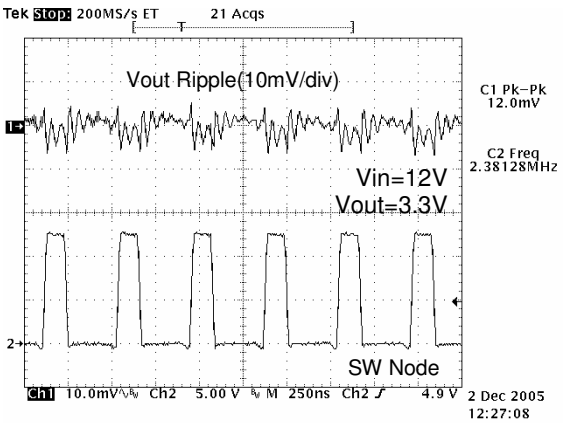



**Figure 10. Output Noise at 3A Load**

| INDUCTORS - SURFACE MOUNT | | | | | | | |
|---|---|---|---|---|---|---|---|
| Inductance (uH) | Manufacturer/Part No. | Inductor Specification | | | | | Manufacturer Website |
| | | Series R mOhms | Isat (A) | Size LxW(mm) | Size Ht.(mm) | Inductor Type | |
| 2.2 | COOPER DR73-2R2 | 16.5 | 5.52 | 7.6X6.0 | 3.55 | Shielded Ferrite Core | www.cooperet.com |

| CAPACITORS - SURFACE MOUNT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Capacitance( uF) | Manufacturer/Part No. | Capacitor Specification | | | | | | Manufacturer Website |
| | | ESR ohms (max) | Ripple Current (A) @45C | Size LxW(mm) | Size Ht.(mm) | Voltage (V) | Capacitor Type | |
| 4.7 | AVX 08053D475MAT | 0.005 | 4.00 | 2.0x1.25 | 1.25 | 16.0 | X5R Ceramic | www.avx.com |
| 22 | AVX 08056D226MAT | 0.005 | 4.00 | 2.0x1.25 | 1.25 | 6.3 | X5R Ceramic | www.avx.com |

| MOSFETS - SURFACE MOUNT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MOSFET | Manufacturer/Part No. | MOSFET Specification | | | | | | Manufacturer Website |
| | | RDS(on) ohms (max) | ID Current (A) | Qg nC (Typ) | Qg nC (Max) | Voltage (V) | Foot Print | |
| Dual N-Ch | VISHAY Si7214DN | 0.047 | 5.9 | 4.2 | 6.5 | 30.0 | Power-PAK 1212-8 | www.vishay.com |

**Table 1: SP6138EB Suggested Components and Vendor Lists**

## LOOP COMPENSATION DESIGN

The open loop gain of the SP6138 Evaluation Board can be divided into the gain of the error amplifier **GAMP(s)**, PWM modulator **GPWM**, buck converter output stage **GOUT(s)**, and feedback resistor divider **GFBK**. In order to crossover at the selected frequency **fco**, the gain of the error amplifier must compensate for the attenuation caused by the rest of the loop at this frequency. The goal of loop compensation is to manipulate the open loop frequency response such that its gain crosses over 0dB at a slope of –20dB/dec. The open loop crossover frequency should be higher than the ESR zero of the output capacitors but less than 1/5 of the switching frequency **fs** to insure proper operation. Since the SP6138EB is designed with ceramic type output capacitors, a Type III compensation circuit is required to give a phase boost of 180° in order to counteract the effects of the output **LC** underdamped resonance double pole frequency.

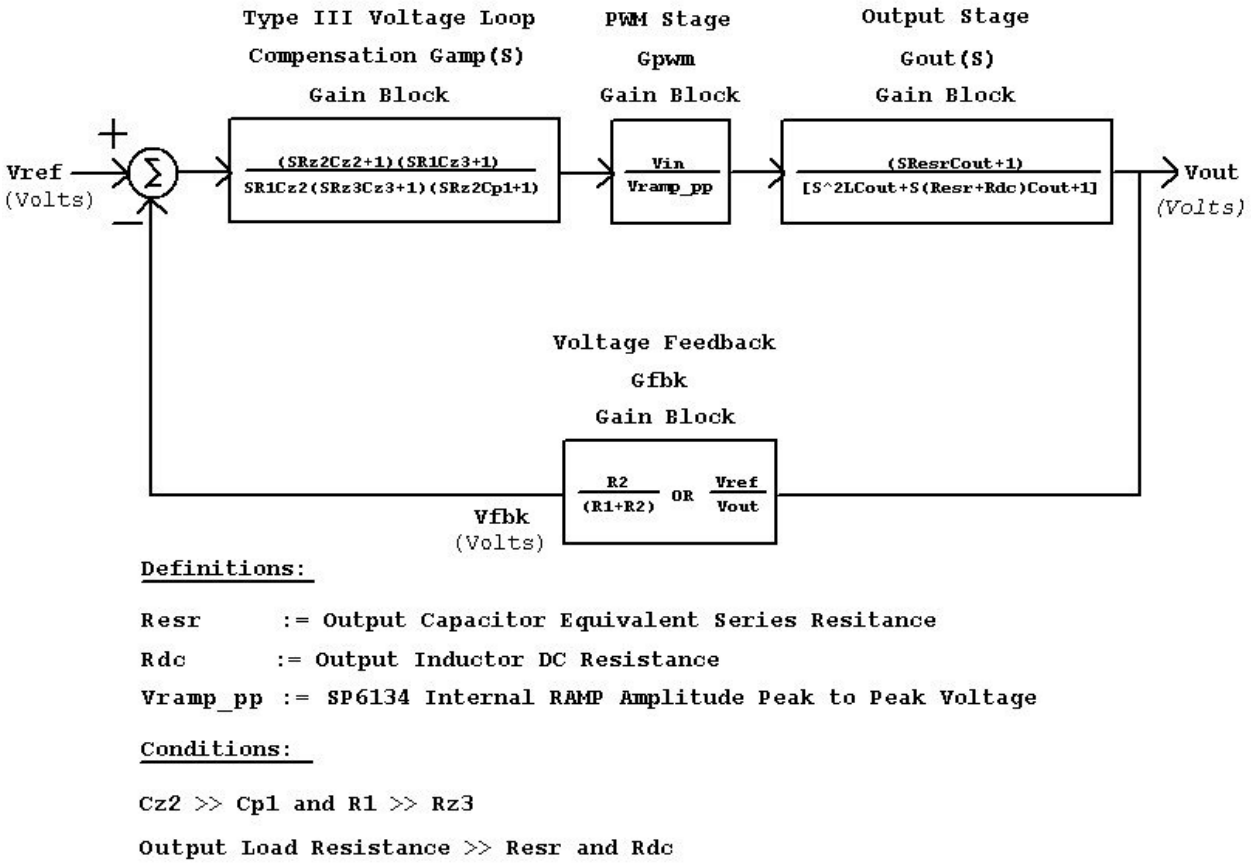



**Figure 11. SP6138EB Voltage Mode Control Loop with Loop Dynamic**

The simple guidelines for positioning the poles and zeros and for calculating the component values for a Type III compensation scheme are as follows:

$$R1 = 68.1K$$

$$R2 = \frac{0.8 \bullet R1}{Vout - 0.8} \quad \text{(sets output voltage)}$$

$$C_{Z3} = \frac{1}{ZSF \bullet \frac{1}{\sqrt{LC}} \bullet R1} \quad \text{(sets first zero)}$$

$$R_{Z2} = \frac{(6.28 \bullet f_{crsover})^2 \bullet L \bullet C_{out} + 1}{6.28 \bullet f_{crsover} \bullet C_{Z3}} \bullet \frac{V_{ramp}}{V_{in}} \quad \text{(sets bandwidth)}$$

$$C_{Z2} = \frac{1}{ZSF \bullet \frac{1}{\sqrt{LC}} \bullet R_{Z2}} \quad \text{(sets second zero)}$$

$$C_{P1} = \frac{1}{6.28 \bullet f_{sw} \bullet R_{Z2}} \quad \text{(sets first high frequency pole)}$$

$$R_{Z3} = \frac{1}{6.28 \bullet f_{sw} \bullet C_{Z3}} \quad \text{(sets second high frequency pole)}$$

Where ZSF=(f compensation double zero)/(f circuit double pole)
Here ZSF is set at 1.2.

As a particular example, consider for the following SP6138EB, 3A$_{MAX}$ with a type III Voltage Loop Compensation component selections:

Vin_max = 15V
Vout = 3.30V @ 0 to 3A load
Select L = 2.2 uH => 15% current ripple.
Select Cout = 22uF Ceramic capacitors (Resr ≈ 5mΩ)
fs = 2500KHz SP6138ER1 internal Oscillator Frequency
Vramp_pp = 1.0V SP6138ER1 internal Ramp Peak-to-Peak Amplitude

**Step by step design procedures:**

a. **R2** = 21.8Ω

b. **CZ3** = 85pF

c. **Let fcrsover=200KHz then:**

d. **RZ2** = 60.3kΩ

e. **CZ2** = 96pF

f. **CP1** = 1.1pF

g. **RZ3** = 0.75KΩ

h. **CF1** = 18pF to stabilize SP6138ER1 internal Error Amplify

The above component values were used as a starting point for compensating the converter and after laboratory testing the values shown in the circuit schematic of page 1 were used for optimum operation.

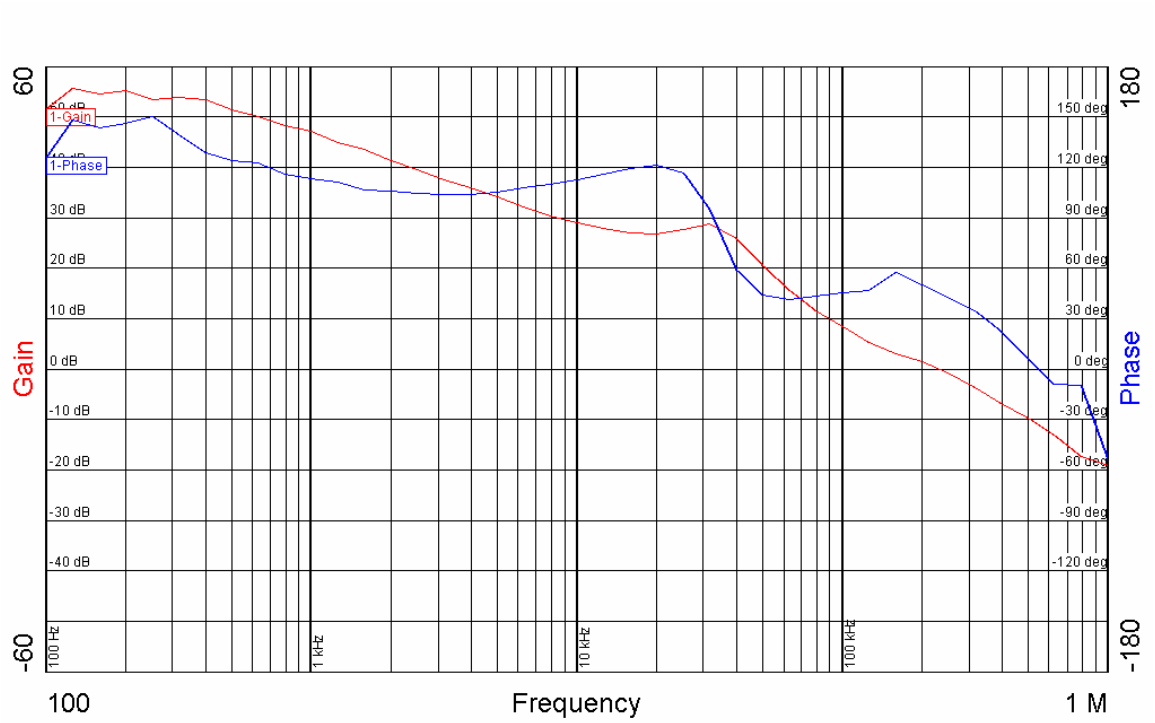



**Figure 12- Gain/Phase measurement of SP6138EB shown on page 1, cross-over frequency (fc) is just above 200KHz with a corresponding phase of 45 degrees**

## PCB LAYOUT DRAWINGS

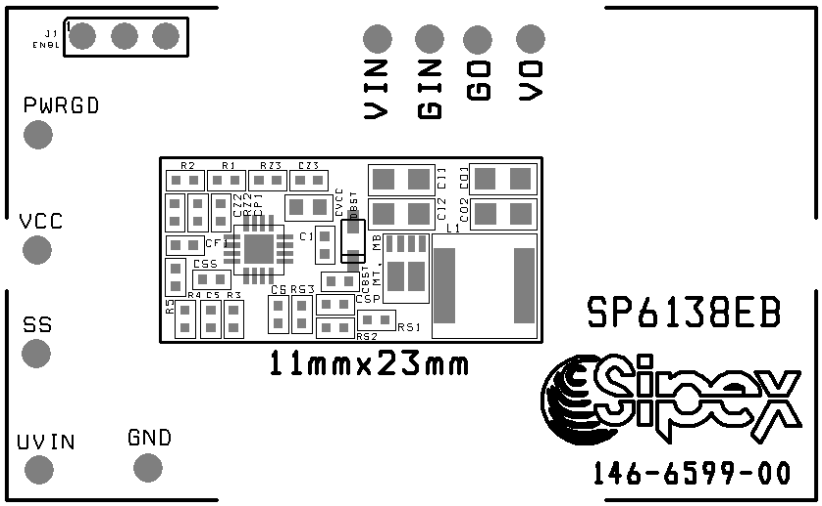



**Figure 13. SP6138EB Component Placement**

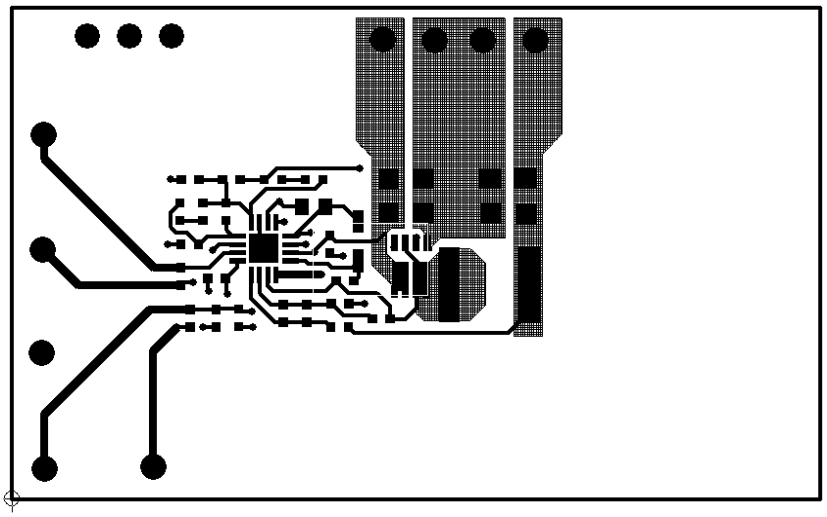


**Figure 14. SP6138EB PCB Layout Top Side**

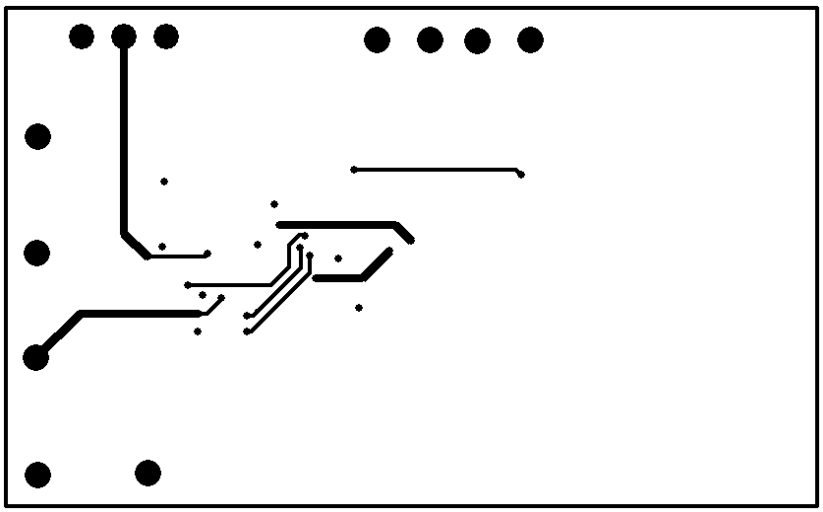


**Figure 15. SP6138EB PCB Layout Bottom Side**

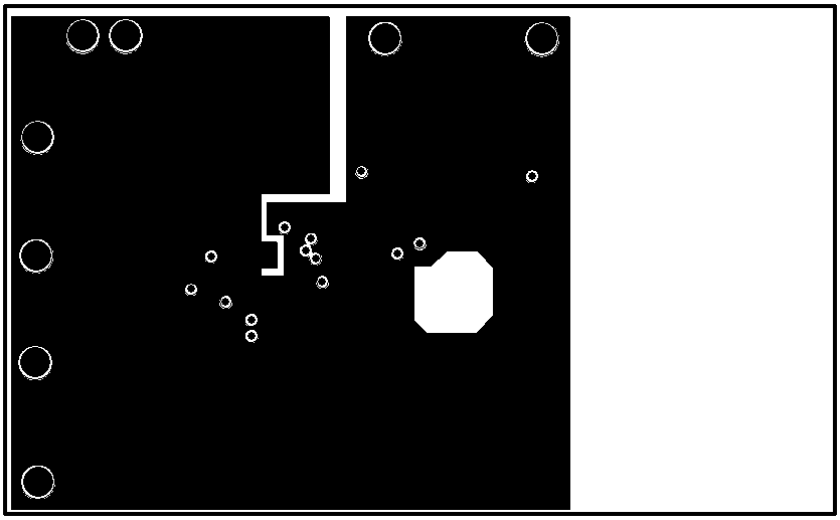


**Figure 16. SP6138EB PCB Layout Inner Layer 1 & Inner Layer 2**

| Line No. | Ref. Des. | Qty. | Manuf. | Manuf. Part Number | Layout Size | Component | Vendor Phone Number |
|---|---|---|---|---|---|---|---|
| 1 | PCB | 1 | Sipex | 146-6599-00 | 1.175"x1.934" | SP6138EB | 978-667-7800 |
| 2 | U1 | 1 | Sipex | SP6138ER1 | QFN-16 | 2.5MHz Synchronous Buck Controller | 978-667-7800 |
| 3 | MT,MB | 1 | Vishay Semi | Si7214DN | PowerPAK 1212-8 Dual | Dual NFET 30V, 47mOhm | 402-563-6866 |
| 4 | DBST | 1 | Vishay Semi | SD101AWS | SOD-323 | 15mA-30V Schottky Diode | 800-344-4539 |
| 5 | L1 | 1 | COOPER Bussmann | DR73-2R2 | 7.6x6mm | 2.20uH Coil 4.15A 16.5mOhm | 561-752-5000 |
| 6 | C1, CBST, CS | 3 | TDK | C1005JB1C104K | 0402 | 0.1 uF Ceramic X5R 16V | 978-779-3111 |
| 7 | CSP | 1 | TDK | C1005JB1H682K | 0402 | 6.8nF Ceramic X5R 50V | 978-779-3111 |
| 8 | CI | 1 | AVX | 08053D475MAT | 0805 | 4.7uF Ceramic X5R 25V 20% | 843-448-9411 |
| 9 | CO | 1 | AVX | 08056D226MAT | 0805 | 22uF Ceramic X5R 6.3V 20% | 843-448-9411 |
| 10 | CVCC | 1 | TDK | C1608JF0J475Z | 0603 | 4.7uF Ceramic X5R 6.3V | 978-779-3111 |
| 11 | C5 | 1 | TDK | C1005JB1E103K | 0402 | 0.01uF Ceramic X7R 25V | 978-779-3111 |
| 12 | CSS | 1 | TDK | C1005JB1E473K | 0402 | 47nF Ceramic X7R 25V | 978-779-3111 |
| 13 | CP1 | 1 | TDK | C1005CH1H060D | 0402 | 6pF Ceramic COG 50V 5% | 978-779-3111 |
| 14 | CF1 | 1 | TDK | C1005CH1H180J | 0402 | 18pF Ceramic COG 50V 5% | 978-779-3111 |
| 15 | CZ2 | 1 | TDK | C1005CH1H101J | 0402 | 100pF Ceramic COG 25V 5% | 978-779-3111 |
| 16 | CZ3 | 1 | TDK | C1005CH1H470J | 0402 | 47pF Ceramic COG 50V 5% | 978-779-3111 |
| 17 | R1 | 1 | Panasonic | ERJ-2RKF6812X | 0402 | 68.1K Ohm Thick Film Res 1% | 800-344-4539 |
| 18 | R2 | 1 | Panasonic | ERJ-2RKF2152X | 0402 | 21.5K Ohm Thick Film Res 1% | 800-344-4539 |
| 19 | R3, R4, RS3 | | Not populated | | | | |
| 20 | R5 | 1 | Panasonic | ERJ-2RKF1002X | 0402 | 10.0K Ohm Thick Film Res 1% | 800-344-4539 |
| 21 | RZ2 | 1 | Panasonic | ERJ-2RKF5492X | 0402 | 54.9K Ohm Thick Film Res 1% | 800-344-4540 |
| 22 | RZ3 | 3 | Panasonic | ERJ-2RKF1001X | 0402 | 1.0K Ohm Thick Film Res 1% | 800-344-4540 |
| 23 | RS1, RS2 | 1 | Panasonic | ERJ-2RKF4991X | 0402 | 5.11K Ohm Thick Film Res 1% | 800-344-4541 |
| 24 | J1 | 1 | Sullins | PTC36SAAN | .32x.12 | 36-Pin (3x12) Header | 800-344-4539 |
| 25 | (J1) | 1 | Sullins | STC02SYAN | .2x.1 | Shunt | 800-344-4539 |
| 26 | VIN, VOUT, VCC, GIN, GO, GND, SS, PWRGD, UVIN | 9 | Vector Electronic | K24C/M | .042 Dia | Test Point Post | 800-344-4539 |

**Table 2: SP6138EB List of Materials**

## ORDERING INFORMATION

| Model | Temperature Range | Package Type |
|---|---|---|
| SP6138EB | – 40°C to +85°C | SP6138 Evaluation Board |
| SP6138ER1 | – 40°C to +85°C | 16-pin QFN |