

Reference Design RD-344

Fairchild Motion-SPM® FNA41560 – Three-Shunt Design

The following reference design supports a design of **FNA41560**. It should be used in conjunction with the FNA41560 datasheet as well as Fairchild’s application notes (AN-9070, AN-9071, AN-9072) and technical support team. Please visit Fairchild’s website at <http://www.fairchildsemi.com>.

| Application | Fairchild Device | Input Voltage Range | Typical Power Rating | Topology |
|-------------------------------------|---------------------------------|------------------------|----------------------|---|
| Home Appliance (Air-Conditioner) | FNA41560 MMSZ5252B LMV324 | 300~400V _{DC} | 1500W | Three Shunt Solution (Single Ground) |

Key Features

FNA41560

- 600V-15A 3-phase IGBT inverter bridge including control ICs for gate driving and protection
- Easy PCB layout due to built-in bootstrap diode and independent VS pin
- Divided negative DC-link terminals for inverter current-sensing applications
- Single-grounded power supply due to built-in HVIC
- Built-in NTC thermistor for over-temperature monitoring
- Isolation rating of 2000V_{rms}/min.

MMSZ5252B

- Silicon planar power Zener diodes, DO-41 glass case
- 24V/1.0W rating Zener diode
- For use in stabilizing and clipping circuits with high power rating
- Standard Zener voltage tolerance: ±5%

LMV324

- General-purpose, low-voltage, rail-to-rail output amplifier
- 80µA supply current per channel
- 1.2MHz GBP(Gain Bandwidth Product)
- 1.5V/µs slew rate
- Low offset voltage

2. Key Parameter Design

2.1. Selection of Bootstrap Capacitance (C_{BS})

The bootstrap capacitor can be calculated by:

$$C_{BS} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}} \quad (1)$$

where:

Δt = maximum on pulse width of high-side IGBT;

ΔV_{BS} = the allowable discharge voltage of the C_{BS} (voltage ripple); and

I_{Leak} = maximum discharge current of the C_{BS} .

Normally, I_{Leak} consist of the following items:

- Gate charge for turning the high-side IGBT on
- Quiescent current to the high-side circuit in the HVIC
- Level-shift charge required by level-shifters in HVIC
- Leakage current in the bootstrap diode
- C_{BS} capacitor leakage current (ignored for non-electrolytic capacitors)
- Bootstrap diode reverse recovery charge.

Practically, 2mA of I_{Leak} is recommended for μ Mini DIP SPM family in Motion-SPM® products (I_{PBS} (operating V_{BS} supply current) value in datasheet) .

Calculation Examples of C_{BS}

I_{Leak} = circuit current (I_{PBS}) = 2mA (recommended value)

ΔV_{BS} = discharged voltage = 0.1V (recommended value)

Δt = maximum on pulsewidth of high-side IGBT = 2ms (depends on system)

$$C_{BS_min} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}} = \frac{2mA \times 0.2ms}{0.1V} = 4.0 \times 10^{-6} \quad (2)$$

→ More than 2~3times → 8 μ F → Standard nominal capacitance 10 μ F.

2.2. Design of Current-Sensing Circuit

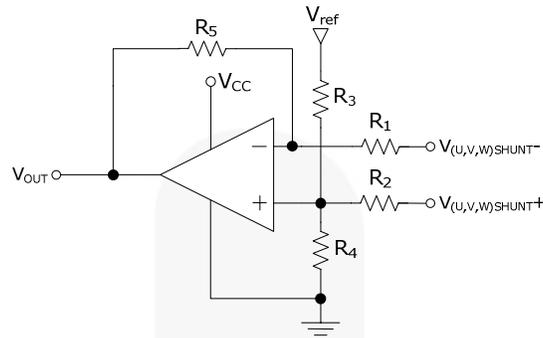


Figure 3. General Circuit for Current Sensing

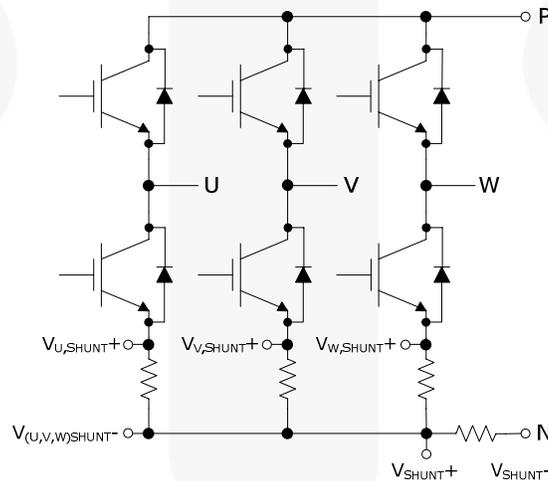


Figure 4. Typical Low-Side Current-Sensing Circuit

FNA41560 has a divided negative DC-link terminal (N_U , N_V , N_W) for current sensing to simplify current-sensing circuit design. Figure 3 and Figure 4 show the typical three-shunt current-sense circuit using the FNA41560 in Motion-SPM®.

The value of application circuit is calculated by the following equations. In Figure 5, the output voltage of op-amp (V_{OUT}) can be calculated by:

$$V_{out,min} = (V_{Shunt,min} \times \frac{R_7}{R_2 + R_4}) + (V_{ref} \times \frac{R_5}{R_5 + R_6}) \quad (3)$$

$$V_{out,max} = (V_{Shunt,max} \times \frac{R_7}{R_2 + R_4}) + (V_{ref} \times \frac{R_5}{R_5 + R_6}) \quad (4)$$

According to Equation 3, the voltage between shunt resistor (V_{Shunt}) can be calculated by:

$$V_{Shunt,max} = [V_{out,max} - V_{ref} \times \frac{R_5}{(R_5 + R_6)}] \times \frac{R_2 + R_4}{R_7} \quad (5)$$

$$V_{Shunt,min} = [V_{out,min} - V_{ref} \times \frac{R_5}{(R_5 + R_6)}] \times \frac{R_2 + R_4}{R_7} \quad (6)$$

2.3. Calculation Examples for Current-Sensing Circuitry

Calculation Conditions

- DUT: FNA41560
- Op-Amp: LMV324
- Resistance of shunt resistor: $8\text{m}\Omega$, $\pm 1\%$ tolerance, KOA
- SC trip current: 22.5A ($1.5 \times I_C$ (rated current))
- Input voltage range of ADC of MCU: $0\sim+5\text{V}$
- Components value: refer to Figure 5 and Figure 6

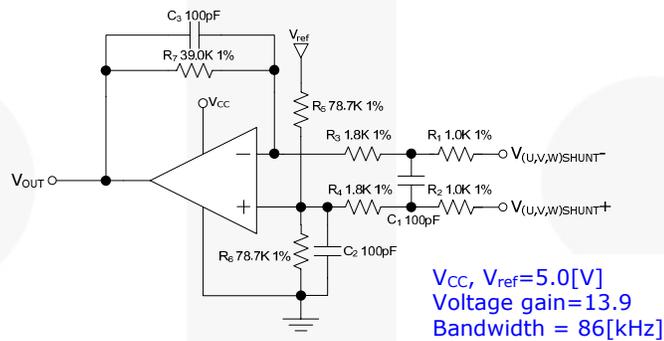


Figure 5. Application Circuit of Current Sensing ($V_{CC}=5.0\text{V}$, Voltage Gain=13.9)

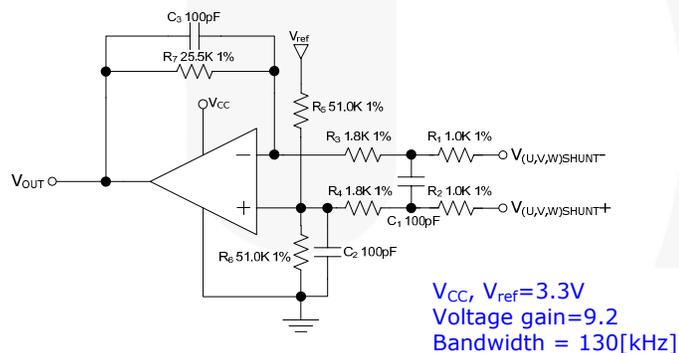


Figure 6. Application Circuit of Current Sensing ($V_{CC}=3.3\text{V}$, Voltage Gain=9.1)

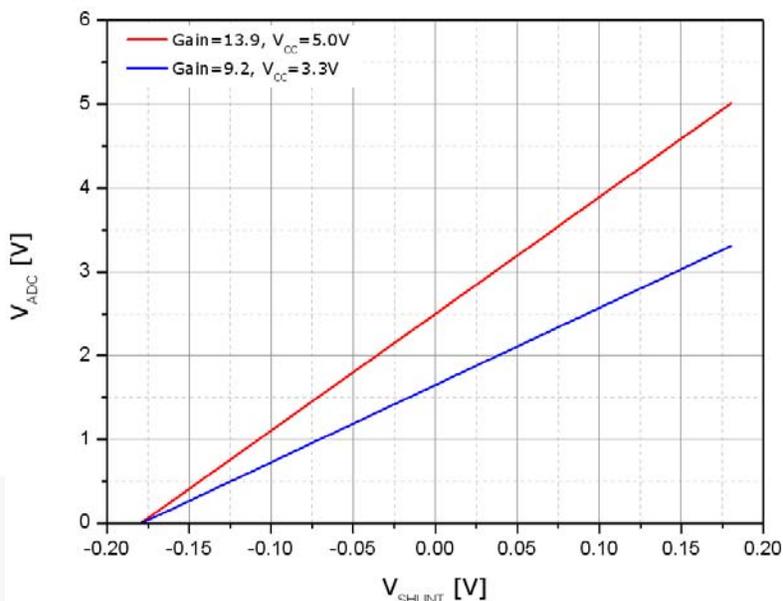


Figure 7. V_{ADC} (Input Voltage of AD Converter of MCU) vs. V_{Shunt} (Voltage of Shunt Resistor) in Current Feedback Circuitry (Figure 5, Figure 6)

According to calculation conditions, Figure 5, and Equations 5 and 6, the voltage between shunt resistor ($V_{Shunt,min}$, $V_{Shunt,max}$) can be calculated by:

$$V_{Shunt,min} = [V_{out,min} - V_{ref} \times \frac{R_5}{(R_5 + R_6)}] \times \frac{R_2 + R_4}{R_7} = [0V - 5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega}] \times \frac{2.8k\Omega}{39k\Omega} = -0.179V$$

$$V_{Shunt,max} = [V_{out,max} - V_{ref} \times \frac{R_5}{(R_5 + R_6)}] \times \frac{R_2 + R_4}{R_7} = [5V - 5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega}] \times \frac{2.8k\Omega}{39k\Omega} = 0.179V$$

According to Equation 3 and 4, the voltage of op-amp output can be calculated by:

$$V_{out,min} = (V_{Shunt,min} \times \frac{R_7}{R_2 + R_4}) + (V_{ref} \times \frac{R_5}{R_5 + R_6}) = (-0.179V \times \frac{39k\Omega}{2.8k\Omega}) + (5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega}) = 0V$$

$$V_{out,max} = (V_{Shunt,max} \times \frac{R_7}{R_2 + R_4}) + (V_{ref} \times \frac{R_5}{R_5 + R_6}) = (0.179V \times \frac{39k\Omega}{2.8k\Omega}) + (5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega}) = 5.0V$$

For low control voltage systems, such as $V_{CC}=3.3V$, the same consideration can be performed on the circuit shown in Figure 6. The circuit in Figure 6 has a same performance as the circuit in Figure 5. Figure 7 shows V_{Shunt} vs. V_{ADC} according to V_{CC} variation (3.3V, 5.0V) and gain of op-amp.

2.4. Components Calculation Examples for SCP

Calculation Conditions

- DUT: FNA41560
- Op-Amp: LMV324
- Resistance of shunt resistor: $8m\Omega$, $\pm 1\%$ tolerance, KOA
- SC trip current: 22.5A ($1.5 \times I_C$ (rated current), can be changed by designer)
- SC trip reference voltage: $V_{SC(min)}=0.45V$, $V_{SC(typ)}=0.50V$, $V_{SC(max)}=0.55V$
- Components value: refer to Figure 8

$$V_{out} = \left(\frac{R_{13}}{R_8 + R_9} \right) \times (V_{shunt+} - V_{shunt-}) = \left(\frac{7.87k\Omega}{1.0k\Omega + 1.8k\Omega} \right) \times 0.179 = 0.505V$$

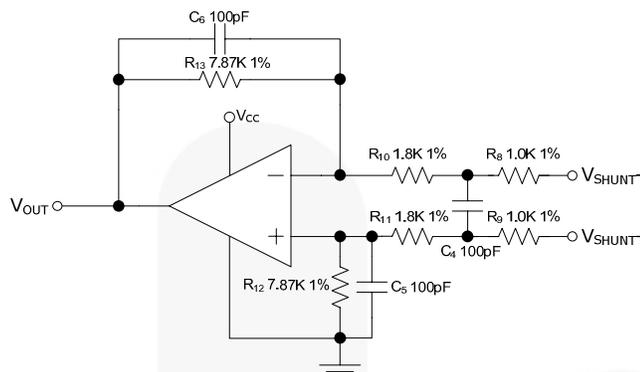


Figure 8. Application Circuit of SCP(Short-Circuit Current Protection)

2.5. Power Rating of Shunt Resistor Calculation Example

Calculation Conditions

- Vendor of shunt resistor: KOA (TLR3AW 8mΩ)
- Maximum load current of inverter (I_{rms}): 10A_{rms}
- Shunt resistor value at $T_C=25^\circ C$ (R_{SHUNT}): 8.0mΩ
- Derating ratio of shunt resistor at $T_{SHUNT}=100^\circ C$: 65%
- Safety margin: 20%

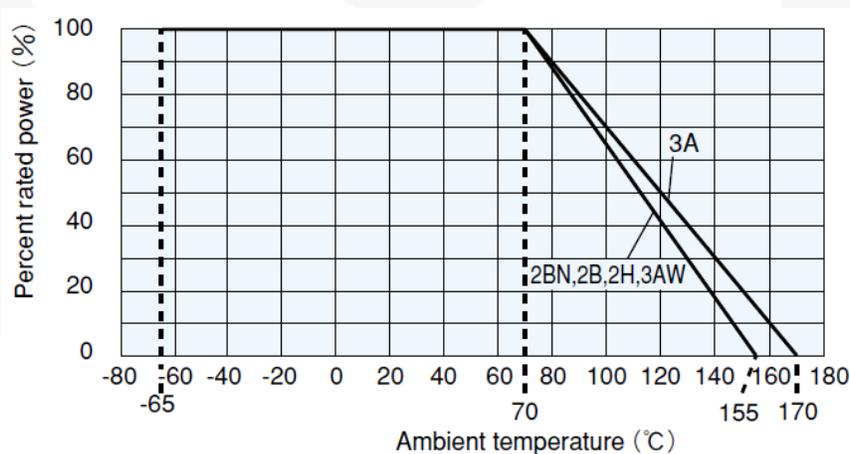


Figure 9. Derating Curve of Shunt Resistor (KOA, TLA Series)

- $P_{SHUNT} = (I_{rms}^2 \times R_{SHUNT} \times \text{Margin}) / \text{Derating ratio} = (10^2 \times 0.008 \times 1.2) / 0.65 = 1.48W$
(Therefore, the proper power rating of shunt resistor is over 2.0W)

2.6. Temperature-Monitoring Circuit

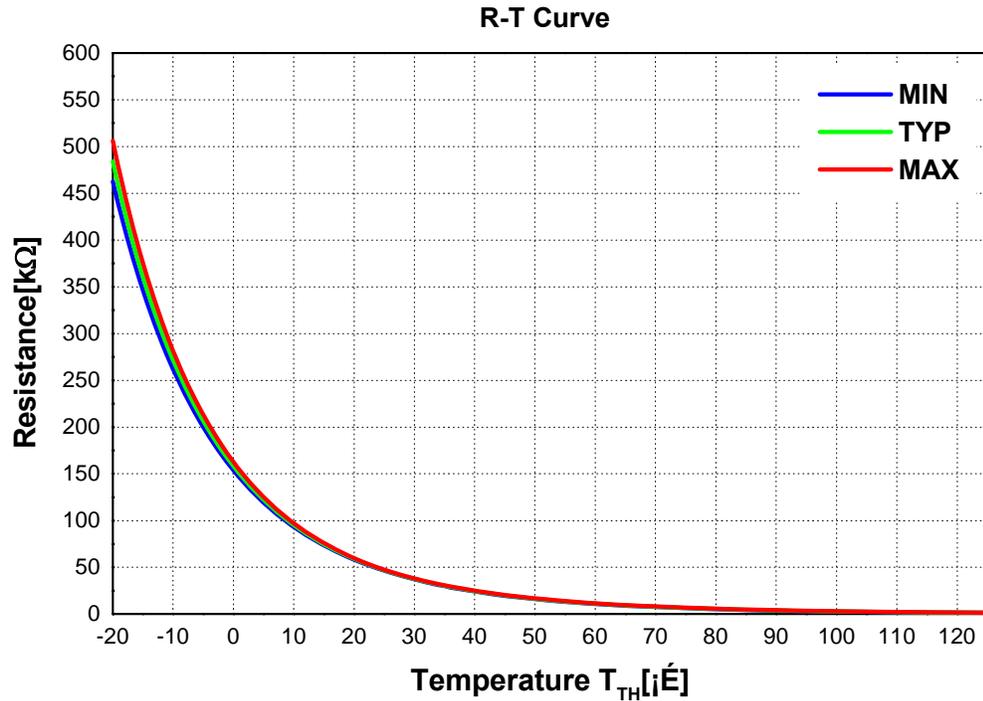


Figure 10. R-T Curve of NTC thermistor in μ Mini DIP SPM® Package

Figure 10 is R-T curve of the integrated NTC thermistor in μ Mini DIP SPM® package. For R-T table of NTC thermistor, refer to application note μ Mini DIP SPM® (AN-9070).

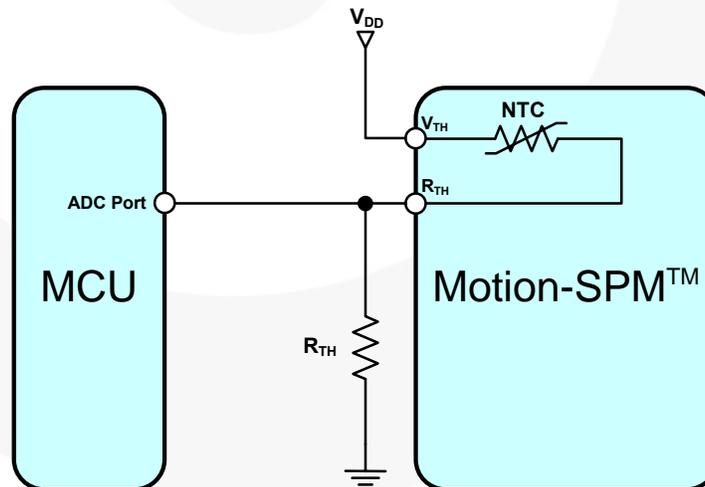


Figure 11. Temperature-Sensing Circuit by NTC Thermistor

Figure 11 is example of a temperature-sensing circuit by NTC thermistor. In this reference design, R_{TH} is 6.8kΩ and Figure 12 is the V-T curve at $R_{TH}=6.8k\Omega$, $V_{CC}=3.3V$, and $V_{CC}=5.0V$.

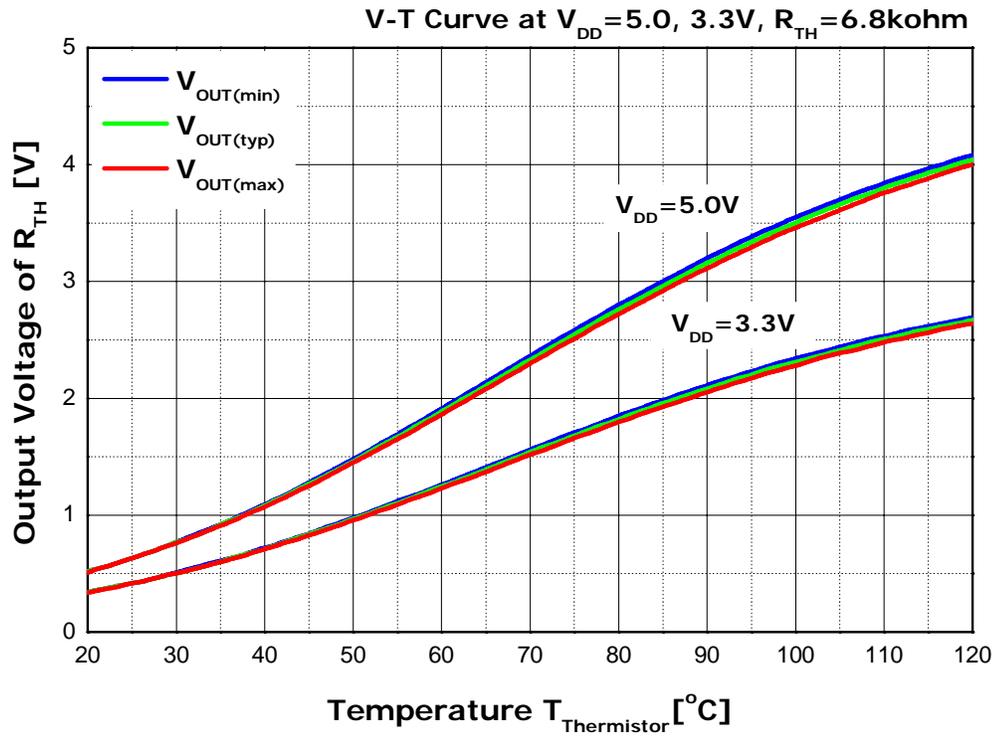


Figure 12. V-T Curve of Temperature-Sensing Circuit in Reference Design

2.7. Print Circuit Board(PCB) Layout Guidance

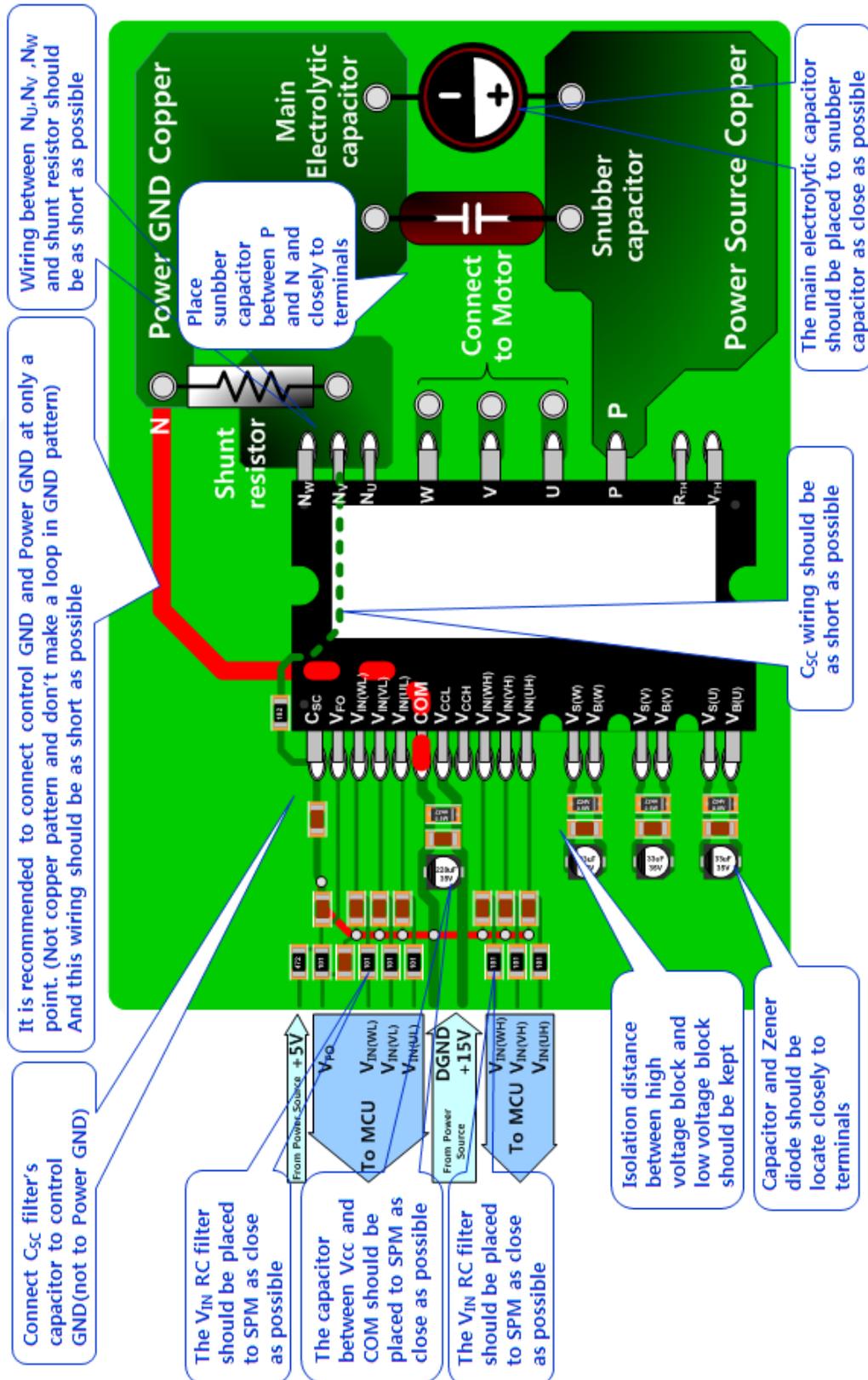


Figure 13. PCB Layout Guidance

3. Related Resources

[FNA41560 – Smart Power Module Motion-SPM®](#)

[AN-9070 – Smart Power Module Motion-SPM® in \$\mu\$ Mini DIP SPM® User Guide](#)

[AN-9071 – Smart Power Module Motion-SPM® in \$\mu\$ Mini DIP SPM® Thermal Performance Information](#)

[AN-9072-Smart Power Module Motion-SPM® in Mini DIP SPM® Mounting Guidance](#)

<http://www.fairchildsemi.com/referencedesign/>

Reference Design Disclaimer

Fairchild Semiconductor Corporation ("Fairchild") provides these reference design services as a benefit to our customers. Fairchild has made a good faith attempt to build for the specifications provided or needed by the customer. Fairchild provides this product "as is" and without "recourse" and MAKES NO WARRANTY, EXPRESSED, IMPLIED OR OTHERWISE, INCLUDING ANY WARRANTY OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

Customer agrees to do its own testing of any Fairchild reference designs in order to ensure design meets the customer needs. Neither Fairchild nor Customer shall be liable for incidental or consequential damages, including but not limited to, the cost of labor, requalifications, rework charges, delay, lost profits, or loss of goodwill arising out of the sale, installation or use of any Fairchild product.

Subject to the limitations herein, Fairchild will defend any suit or proceeding brought against Customer if it is based on a claim that any product furnished hereunder constitutes an infringement of any intellectual property rights. Fairchild must be notified promptly in writing and given full and complete authority, information and assistance (at Fairchild's expense) for defense of the suit. Fairchild will pay damages and costs therein awarded against Customer but shall not be responsible for any compromise made without its consent. In no event shall Fairchild's liability for all damages and costs (including the costs of the defense by Fairchild) exceed the contractual value of the products or services that are the subject of the lawsuit. In providing such defense, or in the event that such product is held to constitute infringement and the use of the product is enjoined, Fairchild, in its discretion, shall procure the right to continue using such product, or modify it so that it becomes noninfringing, or remove it and grant Customer a credit for the depreciated value thereof. Fairchild's indemnity does not extend to claims of infringement arising from Fairchild's compliance with Customer's design, specifications and/or instructions, or the use of any product in combination with other products or in connection with a manufacturing or other process. The foregoing remedy is exclusive and constitutes Fairchild's sole obligation for any claim of intellectual property infringement and Fairchild makes no warranty that products sold hereunder will not infringe any intellectual property rights.

All solutions, designs, schematics, drawings, boards or other information provided by Fairchild to Customer are confidential and provided for Customer's own use. Customer may not share any Fairchild materials with other semiconductor suppliers.