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

1. Schematics

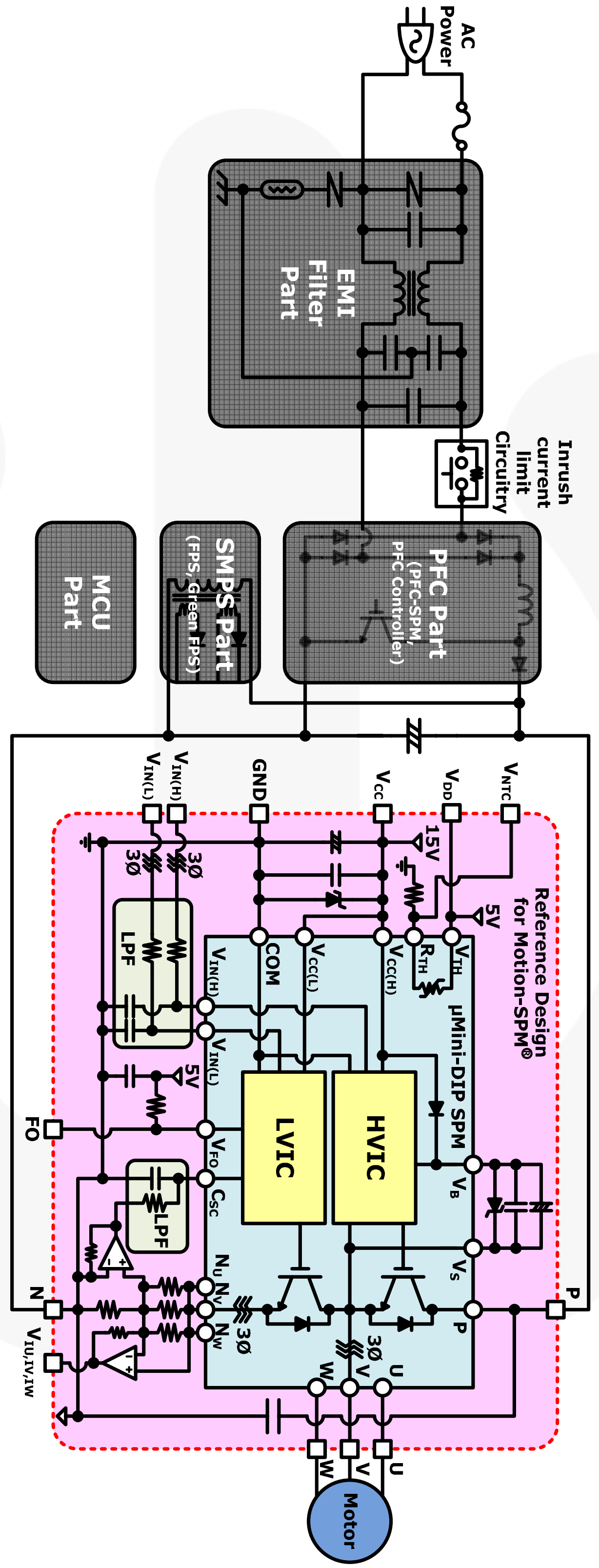

Figure 1. Block Diagram of Air Conditioner

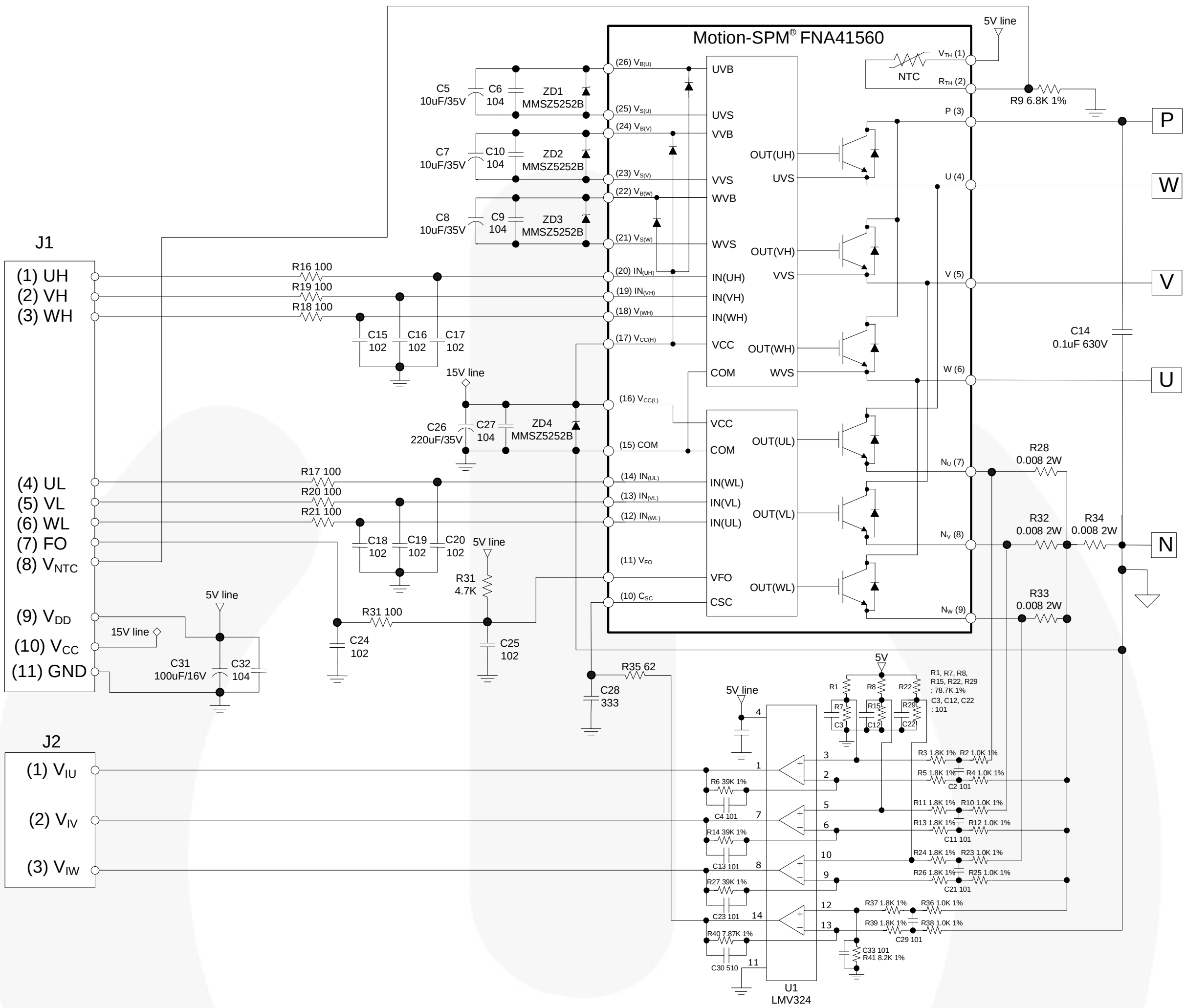

Figure 2. Reference Design for 3-Phase Inverter

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 µMini 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 → 8µF → Standard nominal capacitance 10µF.

2.2. Design of Current-Sensing Circuit

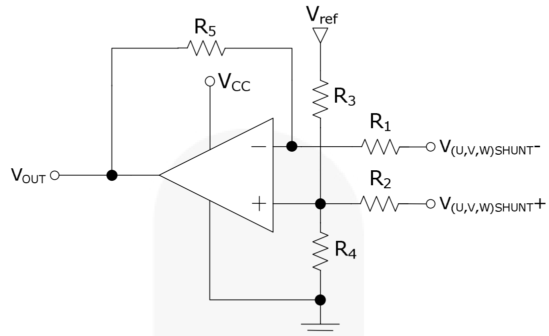

Figure 3. General Circuit for Current Sensing

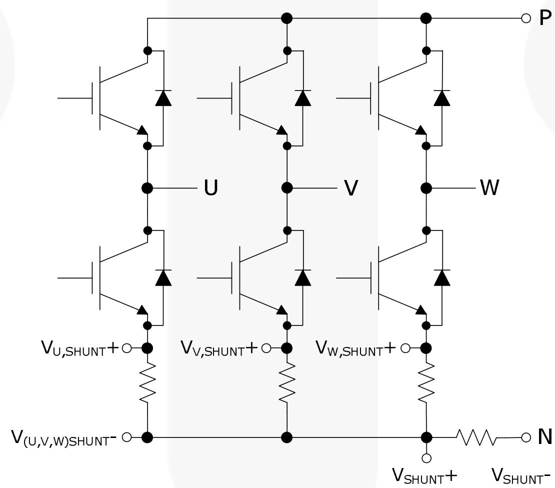

Figure 4. Typical Low-Side Current-Sensing Circuit

FNA41560 has a divided negative DC-link terminal (N_U, N_V, N_W) for current sensing to simplify current-sensing circuit design. Figure 3and 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: 8mΩ, ±1% tolerance, KOA
- SC trip current: 22.5A (1.5 x I_C (rated current))
- Input voltage range of ADC of MCU: 0~+5V
- Components value: refer to Figure 5 and Figure 6

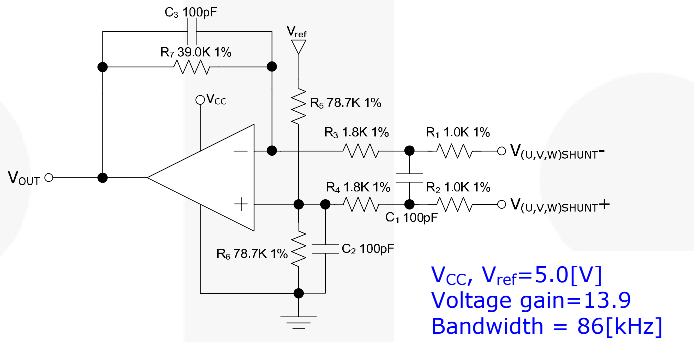

Figure 5. Application Circuit of Current Sensing (V_{CC}=5.0V, Voltage Gain=13.9)

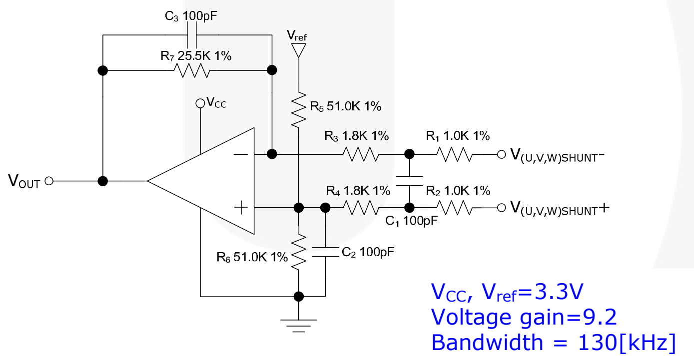

Figure 6. Application Circuit of Current Sensing (V_{CC}=3.3V, Voltage Gain=9.1)

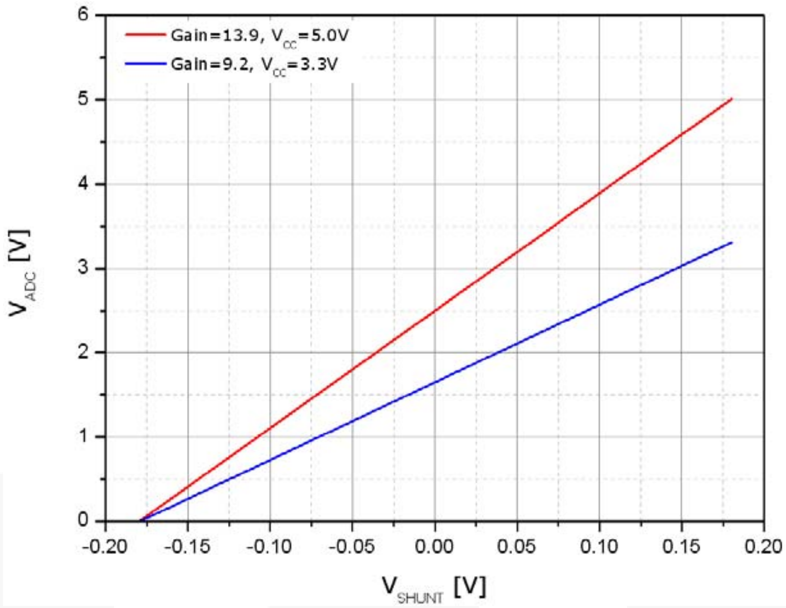

Figure 7. V_{ADC} (Input Voltage of AD Converter of MCU) vs. V_{Shunt} (Voltage of Shunt Resistor) in Current Feedback Circuitry (Figure 5, Figure 6)

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: 8mΩ, ±1% tolerance, KOA
- SC trip current: 22.5A (1.5 x 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

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

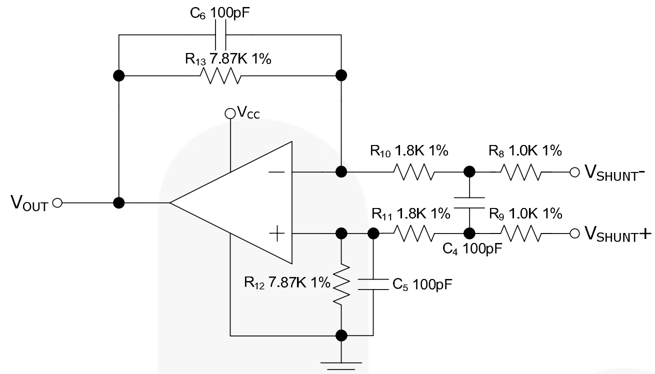

Figure 8. Application Circuit of SCP(Short-Circuit Current Protection)

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°C (R_{SHUNT}): 8.0mΩ
- Derating ratio of shunt resistor at T_{SHUNT}=100°C: 65%
- Safety margin: 20%

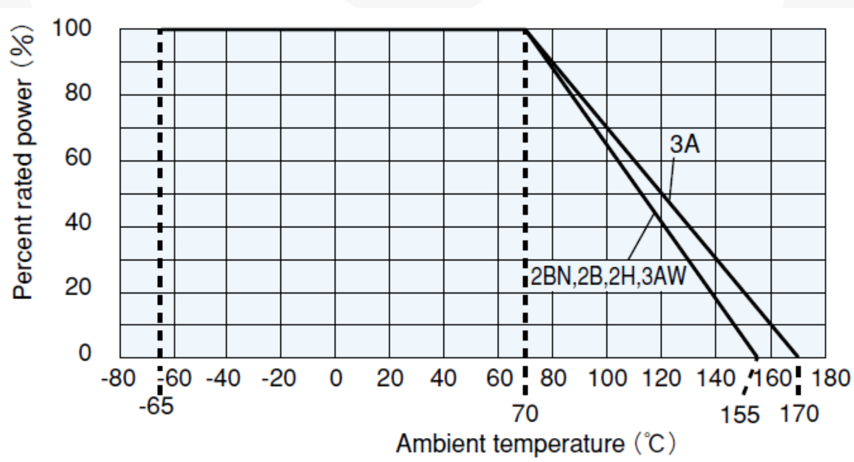

Figure 9. Derating Curve of Shunt Resistor (KOA, TLA Series)

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

2.6. Temperature-Monitoring Circuit

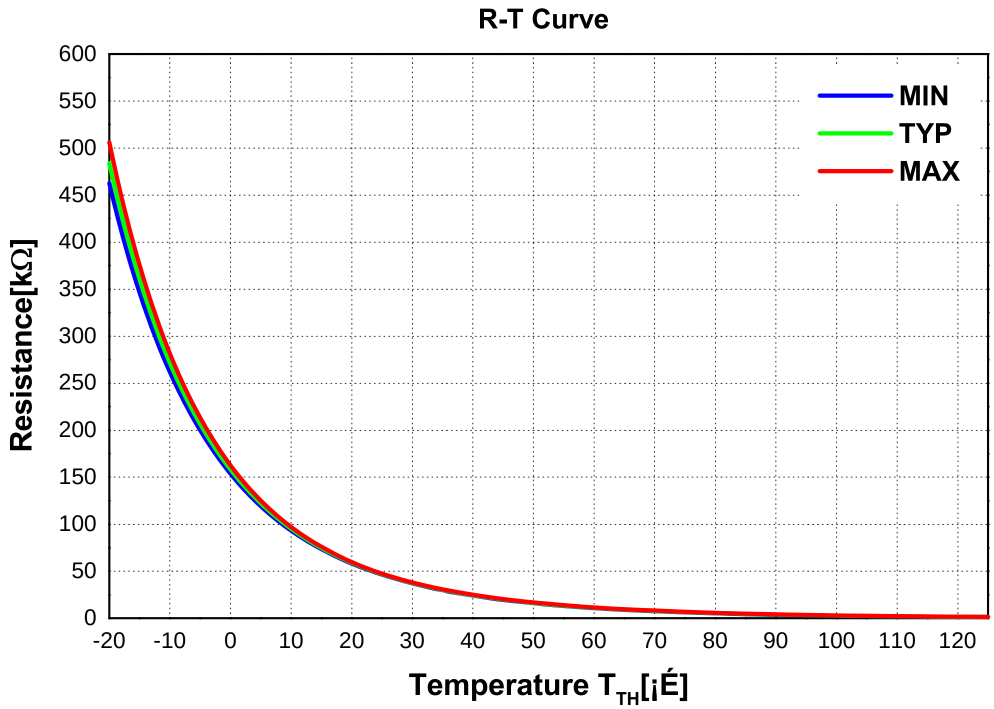

Figure 10. R-T Curve of NTC thermistor in μMini DIP SPM® Package

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

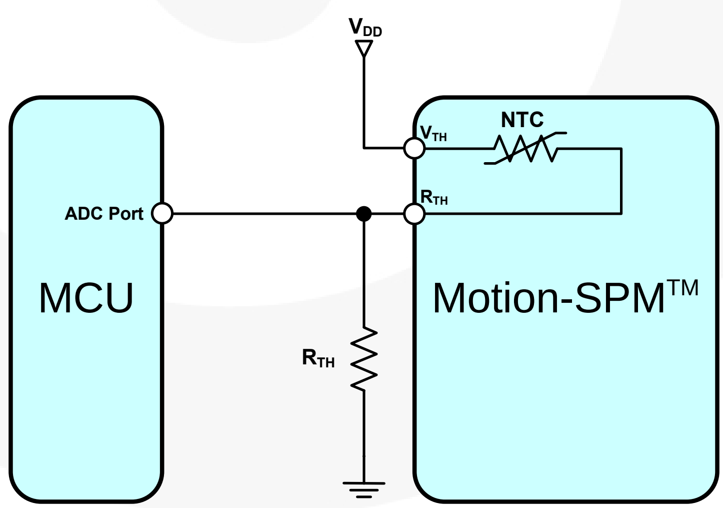

Figure 11. Temperature-Sensing Circuit by NTC Thermistor

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}=6.8kΩ, V_{CC}=3.3V, and V_{CC}= 5.0V.

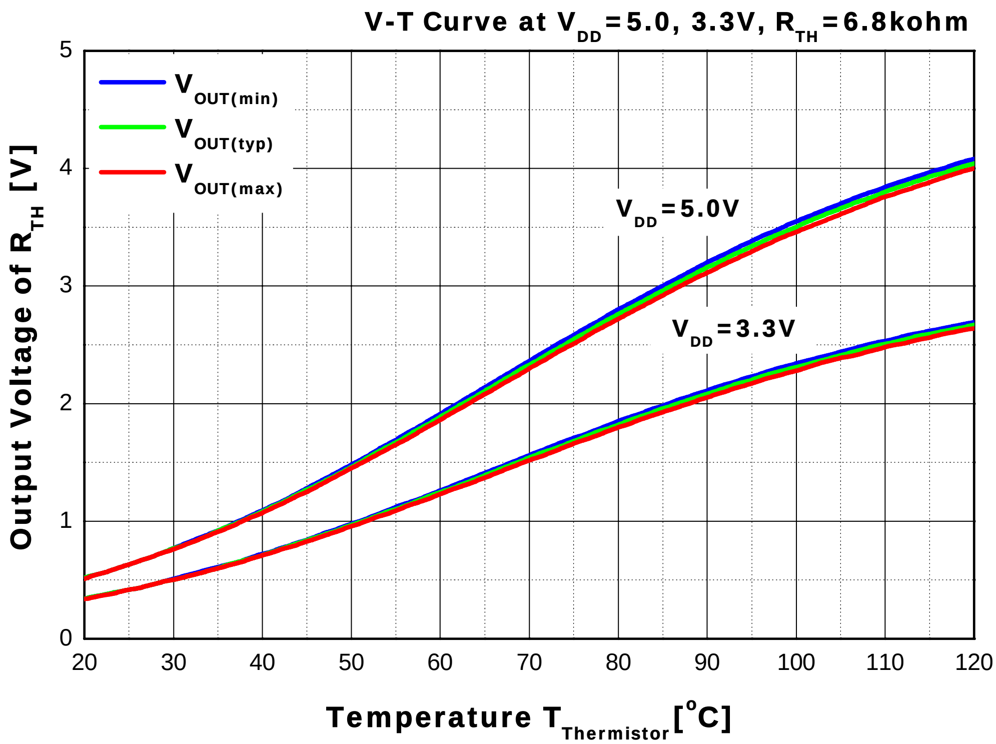

Figure 12. V-T Curve of Temperature-Sensing Circuit in Reference Design

2.7. Print Circuit Board(PCB) Layout Guidance

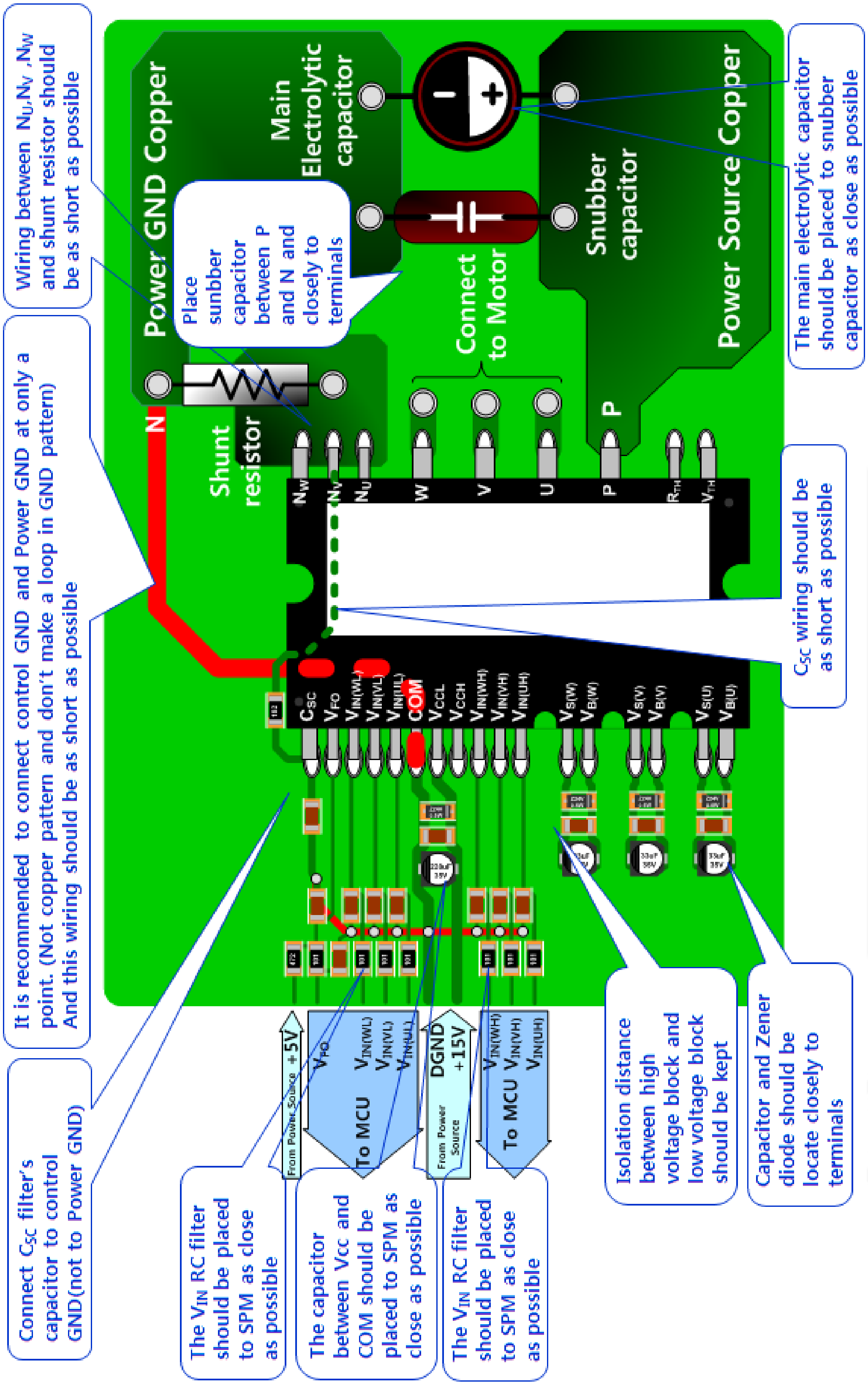

Figure 13. PCB Layout Guidance

3. Related Resources

FNA41560 – Smart Power Module Motion-SPM®

AN-9070 – Smart Power Module Motion-SPM® in µMini DIP SPM® User Guide

AN-9071 – Smart Power Module Motion-SPM® in µMini DIP SPM® Thermal Performance Information

AN-9072-Smart Power Module Motion-SPM® in Mini DIP SPM® Mounting Guidance

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