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.

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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 2000Vrms/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:

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

where:
- $\Delta t =$ maximum on pulse width of high-side IGBT;
- $\Delta V_{BS} =$ the allowable discharge voltage of the $C_{BS}$ (voltage ripple); and
- $I_{\text{Leak}} =$ maximum discharge current of the $C_{BS}$.

Normally, $I_{\text{Leak}}$ 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 $I_{\text{Leak}}$ is recommended for $\mu$Mini DIP SPM family in Motion-SPM® products ($I_{\text{PBS}}$(operating $V_{BS}$ supply current) value in datasheet).

**Calculation Examples of $C_{BS}$**

$$I_{\text{Leak}} = \text{circuit current (I_{PNS})} = 2mA \text{ (recommended value)}$$

$$\Delta V_{BS} = \text{discharged voltage} = 0.1V \text{ (recommended value)}$$

$$\Delta t = \text{maximum on pulsewidth of high-side IGBT} = 2ms \text{ (depends on system)}$$

$$C_{BS, \text{min}} = \frac{I_{\text{Leak}} \times \Delta t}{\Delta V_{BS}} = \frac{2mA \times 0.2ms}{0.1V} = 4.0 \times 10^{-6}$$  \hspace{1cm} (2)

→ More than 2~3times → 8μF → Standard nominal capacitance 10μF.
2.2. Design of 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:

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

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

According to Equation 3, the voltage between shunt resistor (V_Shunt) can be calculated by:

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

\[
V_{\text{Shunt}, \min} = [V_{\text{out}, \min} - V_{\text{ref}} \times \frac{R_5}{(R_5 + R_6)}] \times \frac{R_2 + R_4}{R_7}
\]
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 IC (rated current))
- Input voltage range of ADC of MCU: 0→±5V
- Components value: refer to Figure 5 and Figure 6

![Application Circuit of Current Sensing (V CC=5.0V, Voltage Gain=13.9)](image)

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

![Application Circuit of Current Sensing (V CC=3.3V, Voltage Gain=9.1)](image)

**Figure 6.** Application Circuit of Current Sensing (V CC=3.3V, Voltage Gain=9.1)
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:

\[
V_{Shunt,min} = [V_{out,min} - V_{ref} \times \frac{R_s}{(R_s + R_n)}] \times \frac{R_s + R_n}{R_f} = [0V - 5V \times \frac{78.7k\Omega}{8.2k\Omega + 78.7k\Omega}] \times \frac{2.8k\Omega}{39k\Omega} = -0.179V
\]

\[
V_{Shunt,max} = [V_{out,max} - V_{ref} \times \frac{R_s}{(R_s + R_n)}] \times \frac{R_s + R_n}{R_f} = [5V - 5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega}] \times \frac{2.8k\Omega}{39k\Omega} = 0.179V
\]

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

\[
V_{out,min} = \left( V_{Shunt,min} \times \frac{R_s}{R_s + R_n} \right) + \left( V_{ref} \times \frac{R_s}{R_s + R_n} \right) = \left( -0.179V \times \frac{39k\Omega}{2.8k\Omega} \right) + \left( 5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega} \right) = 0V
\]

\[
V_{out,max} = \left( V_{Shunt,max} \times \frac{R_s}{R_s + R_n} \right) + \left( V_{ref} \times \frac{R_s}{R_s + R_n} \right) = \left( 0.179V \times \frac{39k\Omega}{2.8k\Omega} \right) + \left( 5V \times \frac{78.7k\Omega}{78.7k\Omega + 78.7k\Omega} \right) = 5.0V
\]

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$\Omega$, ±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
2.5. Power Rating of Shunt Resistor Calculation Example

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

\[
V_{\text{out}} = \left( \frac{R_{13}}{R_S + R_0} \right) \times (V_{\text{shunt}^+} - V_{\text{shunt}^-}) = \left( \frac{7.87k\Omega}{1.0k\Omega + 1.8k\Omega} \right) \times 0.179 = 0.505V
\]

\[
\Omega = -\frac{V_{\text{shunt}^+} - V_{\text{shunt}^-}}{V_{\text{out}}} = -\frac{505}{-179} = 2.80\Omega
\]

\[
\Omega = -\frac{V_{\text{shunt}^+} - V_{\text{shunt}^-}}{V_{\text{out}}} = -\frac{505}{-179} = 2.80\Omega
\]

\[
P_{\text{SHUNT}} (I_{\text{rms}}^2 \times R_{\text{SHUNT}} \times \text{Margin}) / \text{Derating ratio} = (10^2 \times 0.008 \times 1.2) / 0.65 = 1.48W
\]

(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 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 $6.8\,k\Omega$ and Figure 12 is the V-T curve at $R_{TH}=6.8\,k\Omega$, $V_{CC}=3.3\,V$, and $V_{CC}=5.0\,V$. 
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**