

## **Detection Amplifier Simplifies Monitoring Of High-Voltage Buses And Batteries**

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Many high-power electronics designs require continuous monitoring of either batteries or a high-voltage bus. Monitoring is common not only in automotive electronics, especially in electric vehicles, but also in industrial equipment such as spot welders, induction heaters, and power supplies. Traditionally this has been done by using a divider consisting of a series string of resistors (either through-hole or surface-mount) along with a differential amplifier.

When using discrete resistors long-term accuracy is dependent on several things. Initial resistor tolerance, voltage coefficient of resistance, change of resistance with humidity and long-term aging need to be considered. Breakdown voltage rating for the resistors often leads to a higher wattage rating than otherwise required. PCB creepage and clearance must be appropriate for the voltage involved and in consideration of condensation and humidity.

A new IC from Rohm Semiconductor, the BM67301FV-C, simplifies these requirements by integrating a high-voltage resistor divider string along with a differential amplifier and other features useful in monitoring a high voltage bus. These include a user-selectable optimized setting for 0 to 600 V or 0 to 1200 V and a precision offset generator. In addition to EV battery monitoring during vehicle operation, other applications for this IC include EV and HEV charging where it can be used to detect when precharging is completed.

In this article, we'll discuss how the resistor string is designed in the conventional case when discrete components are used. Then we'll explain how ROHM Semiconductor's BM67301FV-C addresses these requirements and provide some guidelines for designing voltage monitoring circuits with this IC.

### **Designing A High-Voltage Divider**

Shown here in Fig. 1 is an example of a typical high-voltage divider resistance string built with discrete resistors.



*Fig. 1. In addition to selecting high-voltage-rated resistors, design of a high-voltage resistive voltage divider must account for the required creepage and clearance spacings, which in turn are influenced by the insulation resistance of the PCB substrate.*

The PCB used for construction of the high-voltage divider resistance string should be appropriate for the voltage involved. A test called "Comparative Tracking Index" (CTI) is used to determine the insulation resistance of the PCB substrate. The procedure is defined in IEC 60112. Based on testing results the material is classified into Groups I, II, IIIa, or IIIb, with Group I being the best.

For the PCB used in the high-voltage divider application, the CTI level needs to be suitable with ratings from 0 (Material Group I) to 4 (Material Group IIIb) and 5 (worst). Required creepage and clearance distances are

affected by the CTI level and the Material group classification. Conformal coating may be needed if condensation is expected. Altitudes above 2000 meters require increased distances.

The allowable maximum operating voltage across a surface-mount resistor is based on the resistor size. From IEC Publication 60115-8 we have the following guidelines in Table 1.

Table 1. Max operating voltage for chip resistors. (Data courtesy of Walsin Technology, 2014 chip resistor product catalog.)

Series No.	WR25X	WR20X	WR18X	WR10X	WR12X	WR08X	WR06X	WR04X	WR02X	WR01X
Size code	2512 (6432)	2010 (5025)	1218 (3248)	1210 (3225)	1206 (3216)	0805 (2012)	0603 (1608)	0402 (1005)	0201 (0603)	01005 (0402)
Resistance Range ±5% Tolerance (E24) ±1% Tolerance (E24+E96)	±5% (E24): 1Ω~10MΩ; Jumper ±1% (E2+E964): 1Ω~10MΩ									
TCR (ppm/°C) R>1MΩ 1MΩ≥R>10Ω R≤10Ω	≤±200 ≤±100 ≤±200		≤±200 ≤±100 ≤±200		≤±100 ≤±100 ≤±200			≤±200 ≤±300		≤±200 ≤±300
Max. dissipation @ Tamb=70°C	1.0 W	1/2 W	1.0 W	1/3 W	1/4 W	1/8 W	1/10 W	1/16 W	1/20 W	1/32 W
Max. Operation Voltage (DC or RMS)	250V	200V	200V	200V	200V	150V	50V	50V	25V	20V
Operation Temperature	-55 ~ +155°C								-55 ~ +125°C	
Basic Specification	JIS C 5201-1 / IEC 60115-1									

- Note:
1. This is the maximum voltage that may be continuously supplied to the resistor element, see "IEC publication 60115-8".
  2. Max. Operation Voltage: So called RCWW (Rated Continuous Working Voltage) is determined by  $RCWW = \sqrt{\text{Rated Power} \times \text{Resistance Value}}$  or Max. RCWW listed above, whichever is lower.
  3. Detailed TCR please refer to specific specification.

Fig. 2 is a schematic of the typical resistor divider string used to reduce 1200 V down to 5 V.

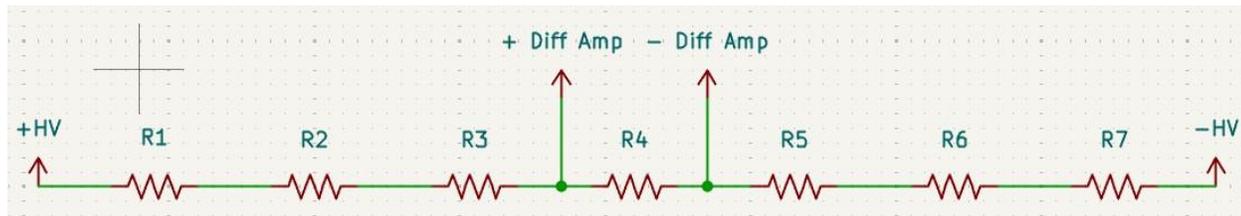


Fig. 2. Resistive divider.

The middle resistor (R4) typically drops just a few volts. Therefore, the other six resistors (R1, R2, R3, R5, R6, R7) must drop almost all the voltage. The drop across each resistor will be approximately  $1200 \text{ V} / 6 = 200 \text{ V}$ . Allowing for some margin, that would suggest that size 2512 resistors with a 250-V rating would be in order. Or you could add more resistors to the divider string for more margin.

However, the same capability can be achieved with the BM67301FV-C. This is an AEC-Q-qualified IC which contains not only the high-voltage resistor divider chain but also a differential amplifier with pin-selectable gain and offset.

The integration of the resistor string with the BM67301FV-C is achieved through selection of isolating materials: The resistors within the IC are fully surrounded by Material Group I epoxy, and fully shielded from dust and condensation. The dielectric strength of the epoxy is approximately 500 V per mil.

Because battery electric vehicles (BEVs) typically run from either 400 V, 800 V, or 1 kV, the IC has two full-scale selectable ranges. The 0- to 600-V range is suitable for a 400-V battery, whilst the 1200-V range is suitable for either 800-V or 1-kV battery systems. Absolute maximum input is 1400 Vdc.

In many cases it is desirable to include a small amount of offset when the input is at zero (to ensure the system A/D converter is not against the rail) so we provide a selectable 0.1-V or 0.5-V ( $\pm 10$  mV) offset adjustment. Fig. 3 is a block diagram.

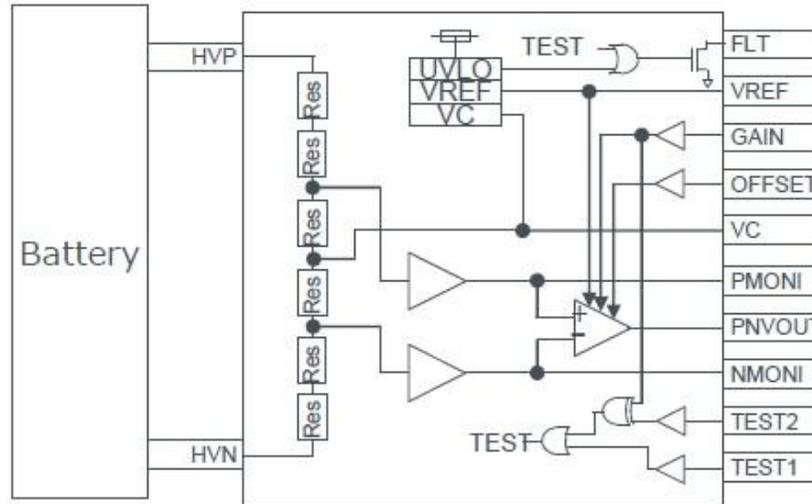


Fig. 3. Block diagram illustrating the BM67301FV-C's integration of the HV resistive divider with a differential amplifier.

Resistance between the HVP and HVN terminals is a minimum of 60 M $\Omega$ . The recommended supply voltage is 4.7 to 5.5 Vdc. Operating temperature range is  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

Although the part is not galvanically isolated, it is rated to withstand 3850 Vdc (3000 Vrms) from the HVP/HVN pins to GND for 1 minute. Output error is typically less than  $\pm 1.5\%$ .

### Input Voltage Range And Accuracy Calculation

Along with PNVOUT, two additional outputs (PMONI and NMONI) are provided which can be monitored for increased confidence in the PNVOUT measurement, which is important for FuSa/ASIL-B requirements.

By understanding the relationships between input voltages, gain, and offset parameters, designers can optimize sensing accuracy and ensure reliable system performance.

The formula for calculating expected values of PNVOUT, PMONI, and NMONI changes with

- input voltage ( $V_{in}$  for PNVOUT, HVP for PMONI, and HVN for NMONI) and
- pin-selectable GAIN and OFFSET settings

Regardless of sensed voltage and settings, all outputs saturate at 5 V. Note that we define the sensed input voltage as  $V_{in} = \text{HVP} - \text{HVN}$  and will refer to either " $V_{in}$ " or " $(\text{HVP} - \text{HVN})$ " interchangeably.

### PNVOUT Calculation—Case 1

Sensing accuracy is optimized for the following input ranges and settings.

- $V_{in} = 300 \text{ V} - 600 \text{ V}$ ; GAIN = L, OFFSET = L
- $V_{in} = 600 \text{ V} - 1200 \text{ V}$ ; GAIN = L, OFFSET = L
- $V_{in} = 300 \text{ V} - 623 \text{ V}$ ; GAIN = L, OFFSET = H

The typical value of PNVOUT in the above cases is

$$PNVOUT\_typ = GA1 \times (HVP - HVN) + VREF \quad (1)$$

where GA1 is the gain from internally sensed high-voltage input to PNVOUT: 3.85/600 when GAIN = Low (0 to 600-V range), 4.5/1200 when GAIN = High (600 to 1200 V range), GA1 has ( $\pm 1.2\%$ ) tolerances; and VREF is the offset voltage: 0.1 V when OFFSET = Low, minimum = 0.09 V, maximum = 0.11 V; and 0.5 V when OFFSET = High, minimum = 0.49 V, maximum = 0.51 V.

The minimum and maximum values of PNVOUT are calculated by accounting for the tolerances of GA1 and VREF:

$$PNVOUT\_min = GA1 \times (HVP - HVN) \times 0.988 + VREF\_min \quad (2)$$

$$PNVOUT\_max = GA1 \times (HVP - HVN) \times 1.012 + VREF\_max \quad (3)$$

Accuracy is the larger of the two values:

$$\frac{PNVOUT\_max - PNVOUT\_typ}{PNVOUT\_typ} \quad \text{or} \quad \frac{PNVOUT\_typ - PNVOUT\_min}{PNVOUT\_typ}$$

### PNVOUT Calculation—Case 2

This applies when Vin is outside the ranges specified in case 1 or the GAIN and OFFSET settings are different from those specified for best accuracy for those ranges, and an additional offset error term named Vospx must be added to the formulas for PNVOUT. Similarly to GA1, Vospx depends on the input voltage range and GAIN and OFFSET settings as defined in Table 2.

$$PNVOUT\_typ = GA1 \times (HVP - HVN) + VREF + Vospx\_typ \quad (4)$$

$$PNVOUT\_min = GA1 \times (HVP - HVN) \times 0.988 + VREF\_min - Vospx \quad (5)$$

$$PNVOUT\_max = GA1 \times (HVP - HVN) \times 1.012 + VREF\_max + Vospx \quad (6)$$

Table 2. Vospx definition.

	MIN (mV)	TYP (mV)	MAX (mV)	Condition
<b>Vospn1</b>	-23.1	0	+23.1	Vin = 0 V to 300 V. GAIN = L, OFFSET = L
<b>Vospn2</b>	-27	0	+27	Vin = 0 V to 600 V. GAIN = H, OFFSET = L
<b>Vospn3</b>	-23.1	0	+23.1	Vin = -23 V to < 300 V. GAIN = L, OFFSET = H

### PMONI And NMONI Calculations

The differential outputs PMONI and NMONI provide independent measurements of HVP and HVN, respectively, relative to the internal 2.5-V reference (VC):

$$PMONI = VC + GA2 \times (HVP - VC)$$

$$NMONI = VC + GA2 \times (HVN - VC)$$

where GA2 is the gain from high voltage to PMONI/NMONI: 2/720  $\approx$  0.00278 when GAIN = Low and 2/1232  $\approx$  0.00162 when GAIN = High; and VC is the internal 2.5-V reference output.

These outputs allow for cross-verification of the PNVOUT signal and can be used in redundant safety architectures.

### Support For Functional Safety

The BM67301FV-C includes several features that support functional safety, making it suitable for automotive applications requiring compliance with standards ISO such as ISO 26262. Safety mechanisms include undervoltage lockout (UVLO) and test pins (TEST1/TEST2) for gain configuration verification.

- UVLO ensures that the IC disables its outputs (PNVOUT, PMONI, NMONI) when the supply voltage drops below a safe threshold (typically 4.15 V), preventing erroneous readings during brownout conditions. The open-drain fault output FLT is driven low whenever the power supply voltage is below the UVLO threshold.
- The on-chip memory which stores IC trimmings is protected with ECC (error correction code) which can correct single-bit errors and detect multi-bit errors. When it detects data are corrupted, the ECC logic asserts fault signal FLT to MCU to indicate PNVOUT, PMONI, and NMONI outputs may not be correct.
- TEST1 and TEST2 pins allow verification of gain settings during startup or diagnostics.

In normal operation, TEST1 must be grounded and TEST2 must have the same logic level as GAIN. Otherwise, FLT would be asserted. This ensures the GAIN setting is intentional and correct, preventing inadvertent software error, pin/wiring connectivity error due to incorrect PCB layout, dynamic short or open during operation, etc.

The system designer can implement a form of A/B tests to verify correct settings. For example, TEST1 can be connected to a microcontroller's GPIO. The MCU can drive TEST1 to logic "1" and verify that FLT is asserted low. Similarly, it can toggle TEST2 and verify FLT assertion when TEST2 doesn't match GAIN.

### Conclusion

The BM67301FV-C can benefit designers of both automotive and industrial systems which require monitoring of high voltage. By incorporating internal high-voltage resistors, substantial PCB space can be saved. Moreover, its functional safety features, combined with the IC's high accuracy and fast response time, enable robust fault detection and system-level diagnostics, contributing to a safer and more reliable high-voltage monitoring solution.

### About The Authors



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For more on voltage monitoring in power supply design, see How2Power's [Design Guide](#), locate the "Design area" category and select "[Board-level Power Protection](#)".