DESIGN NOTES

Robust High Voltage Over-The-Top Op Amps Maintain High Input Impedance with Inputs Driven Apart or When Powered Down

Design Note 533

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Introduction

Linear Technology's Over-The-Top® op amps have an input stage topology that allows them to operate closed loop well above the positive supply rail. The inputs remain high impedance when split apart in voltage and also when shut down or with complete loss of power supply. They are indispensable in robust systems, where reliability is required in the face of uncertain power sequencing. The LT6015, LT6016 and LT6017 extend the op amp operational input voltage capability to 76V, and improve precision with trimmed offset voltage of 350µV (max) over all common mode input voltages and over temperature.

Input Topology—Theory of Operation

An Over-The-Top input stage is shown in Figure 1. At low common modes, the PNPs Q1 and Q2 form a conventional precision differential pair with tail current provided by I1. The diff pair forwards its collector currents into the folded cascode pair Q7, Q8, which then drive the output stage. As the common mode rises to within 1V of the upper supply rail, Q9 begins to steal the tail current away from the diff pair and passes it through the Widlar of Q11, Q12 which then biases up the diode connected pair Q3, Q4 which in turn bias up the precision common base pair Q5, Q6. The collectors of Q5 and Q6 are paralleled into the same folded cascode as before. So the Q1, Q2 diff pair and the Q5, Q6 common base pair are essentially in parallel, with each pair handling a specific input common mode range. The true power of this approach is that Q12 (as well as all the other junctions involved) can handle a whopping 76V. That means that the Q5, Q6 input stage is active and precise even when taken far above V^+, and the op amp remains closed loop as long as the feedback can get up there too. Be aware that Q5 and Q6 do not provide current gain, so the LT6015 worst case offset current of 15nA rises to 500nA in Over-The-Top mode.

One Useful Circuit that Gets the Feedback "Up There"

The circuit of Figure 2 is a simple 4-resistor difference amplifier. Differential input voltages applied at V_{IN} appear at the output, gained up a factor of 100 with relatively little effect from V_{CM}, especially when the CMRR adjust is dialed in. The op amp inputs can ride on a common mode up to 76V above the –5V supply.

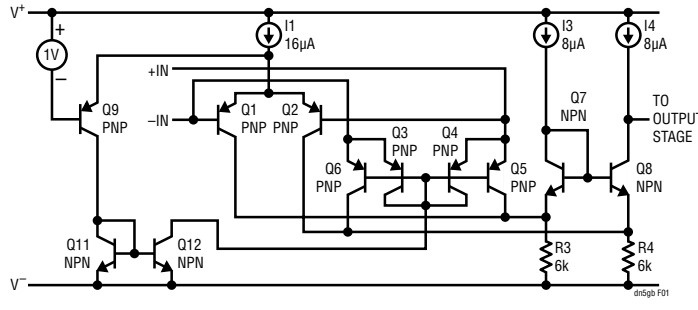

Figure 1. Over-The-Top Input Stage on LT6015 Can Common Mode to 76V, Independent of Positive Supply Voltage

The $V_{CM} + V_{IN}$ voltages applied to the input resistors can be slightly higher due to the attenuation of the resistor divider at the + input. Worst-case input error at high input voltage extremes due to offset current is 500µV, with better accuracy typical between –5V and +5V.

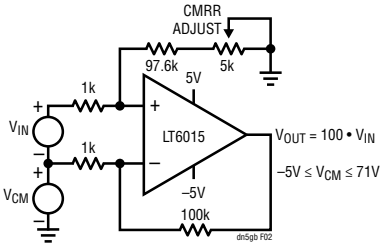

Figure 2. Gain of 100 Differential Amplifier. The Over-The-Top Input Stage of the LT6015 Can Handle Common Mode Input Voltages 76V Above V⁻, Independent of the Positive Supply Voltage

High Side Current Sense

The circuit of Figure 3 is a precision high side current sense amplifier that functions over a wide input common mode range and goes high impedance when its supply vanishes. The inputs of the op amp are held high, and feedback is level shifted "up there" through the FET. Because the FET operates from V_{BAT}, the output clips as it approaches $V_{BAT} – V_{R1} – V_{DS}$. R1 and R3 set the gain accuracy. One might think R2 can be a 5% tolerance resistor, but it is added to accurately reject DC errors created by the input bias current, which is quite high in Over-The-Top mode, so 1% is not a waste. R4 is there for Jim Williams, who never wanted to see a MOSFET gate without a resistor on it. R5 is a current limiting resistor with a cautionary tale. If this circuit is operated at higher V_{BAT} and V_{SUPPLY}, and is driving downstream circuitry which is on lower supply, or is off, and the downstream circuitry has protection diodes to its rails, then unpredictable system glitches may drive the FET gate high, putting the full V_{BAT} voltage across R3. R5 keeps any downstream protection diodes or short-circuits at some distance, and should be sized for value and power, assuming the FET can turn hard on. This is an example of circuit considerations necessary when designing robustness into high voltage systems.

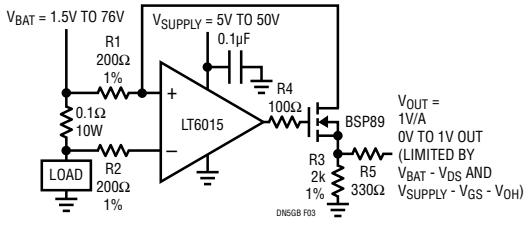

Figure 3. High Side Current Sense Amp Operates Up to 76V Even on a Single 5V Supply. FET Provides Feedback. Full Scale Output Is Limited by V_{BAT} And V_{SUPPLY}. The 330Ω Output Resistor Is Precautionary—See Text. For Robust Operation if V_{SUPPLY} Goes Low or Is Removed Completely, All Inputs Go High Impedance So V_{BAT} Is Not Loaded

To extend the serviceability of the high side current sense amplifier to lower input voltages, the dual LT6016 can be used, as shown in Figure 4. Taking less gain in the first stage keeps the MOSFET source voltage low, allowing for a lower input common mode voltage limit down to 0.2V. Circuit gain is recovered in the second amplifier stage.

Conclusion

The Over-the-Top LT6015 family of amplifiers provides the industrial system designer a precision solution for high voltage monitoring using conventional low voltage regulated power supply rails. These amplifiers have built in protection mechanisms for many extreme operating conditions to ensure robust designs.

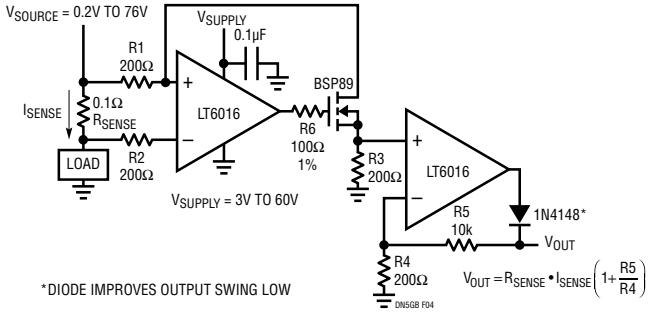

Figure 4. Extended Range High Side Current Sense Amplifier with V_{SOURCE} Down to 0.2V

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