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APPLICATION NOTE 5272

Selecting External Components for an Automotive Remote Antenna Regulator and Current-Sense Amplifier

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Abstract: This application note helps system designers choose the correct external components for use with the MAX16946 remote antenna regulator and current-sense amplifier (CSA), ensuring that automobile antenna-detection subsystems meet their performance objectives. An electronic calculator is provided that helps specify the critical external components for the MAX16946. The calculator also determines the device's operational ranges and analog output voltage accuracy.

Introduction

The MAX16946 is a high-voltage regulator with a precision current-sense amplifier (CSA), designed to provide phantom power to remote radio antennas in automotive applications. The device provides short-circuit protection, current-limit protection, and open-load detection. The current levels for current-limit protection and open-load detection are programmable with external resistors. To ensure that antenna detection circuitry meets performance objectives, the design engineer must choose the correct external components for the design.

Figure 1 shows a typical application for the MAX16946. The main external components and their functions are as follows:

- R_{SENSE} is the resistor across which the load current is sensed. The CSA measures and amplifies the voltage across this resistor. For this reason, the value of the sense resistor is important in determining the overall system accuracy.
- R_5 and R_6 set the regulator output voltage.
- The capacitor at COMP ensures the stability of the regulator under all operating conditions.
- R_1 and R_2 set the current limit during a fault condition. If the current remains at current limit for a blanking time of 100ms (min), the output is turned off, the active-low SC output is asserted low, and a retry is attempted after 1100ms.
- R_3 and R_4 set the threshold for the open-load detection. Below this load current, the active-low OL output asserts low.

The Schottky diode D_{OUT} protects the MAX16946 from negative voltage transients on its OUT pin when the output is turned off and L_{OUT} attempts to maintain current flow. Without this diode, OUT might go below its absolute maximum voltage of -0.3V, which should not be allowed.

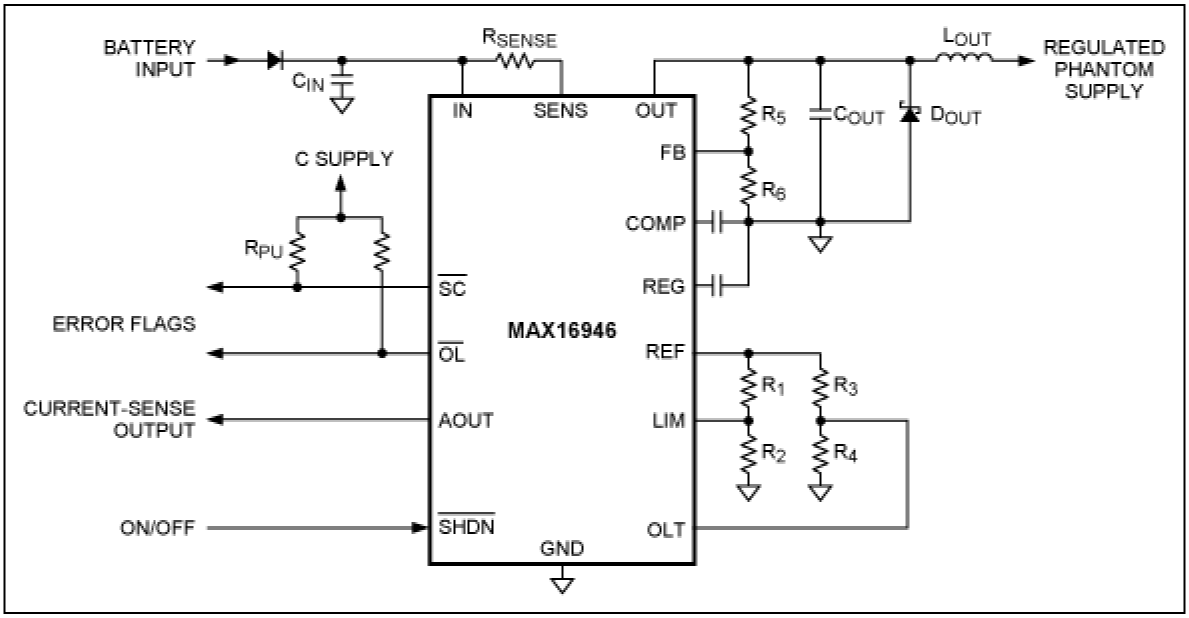

Figure 1. Typical operating circuit of the MAX16946 remote antenna CSA and switch.

When working with CSAs and switches for antenna applications, the designer must often determine the ranges for open load, normal operation, short circuit, and current limiting (**Figure 2**). In addition, the accuracy of the CSA's analog output voltage must be verified.

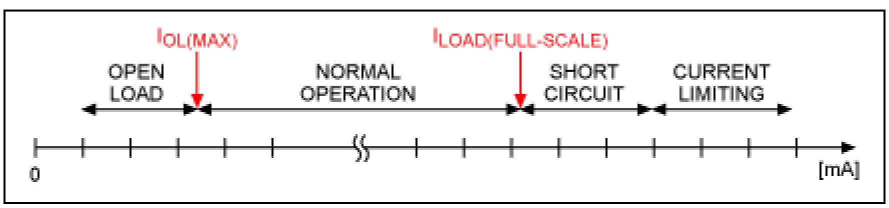

Figure 2. Operation ranges for the current-sense amplifiers.

Use the MAX16946 Calculator to determine the correct values for the sense resistor and the resistive dividers, which set the current-limit and the open-load thresholds. It takes into account the tolerances of both the external components and the MAX16946. By calculating the tolerance ranges for each of the design parameters, the designer ensures that the design parameters are within the limits imposed by the system specification.

Calculating the Sense Resistor Value

Ideally, the maximum load current develops the full-scale sense voltage across the current-sense resistor, R_{SENSE} (Figure 1). The upper limit is represented by the short-circuit current threshold of 1.7V compared to AOUT. The maximum load current in the application should never exceed the short-circuit current threshold, otherwise a short-circuit will be erroneously indicated. Calculate an initial value for

R_{SENSE} using:

$$R_{SENSE}\,(\Omega) = \frac{1.7V - 0.4V}{26V/V \times I_{SC}} \qquad \text{(Eq. 1)}$$

Where 1.7V is the short-circuit current threshold, 0.4V is the zero-current offset of AOUT, 26V/V is the gain of the current-sense amplifier, and I_{SC} is the short-circuit threshold.

Because the sense resistor has some tolerance, the nominal value needed will be lower than the value calculated in Equation 1. To calculate for the tolerance:

$$R_{SENSE(NOM)}\,(\Omega) = \frac{R_{SENSE}\,(\Omega)}{\left(\frac{R_{SENSE-TOLERANCE}\,(\%)}{100} + 1\right)} \qquad \text{(Eq. 2)}$$

Where R_{SENSE} is the value of the sense resistor calculated in Equation 1, and $R_{SENSE\text{-}TOLERANCE}$ is the tolerance of the sense resistor.

Normally one would choose the closest smaller standard value for $R_{SENSE(NOM)}$. Alternatively, serial or parallel combinations of standard resistors can be used to attain the optimal value for the sense resistor.

Calculating the Short-Circuit Current-Detection Range

After choosing the nominal value of the sense resistor, next the typical current through the sense resistor needs to be determined. This current, which allows a short circuit to be detected, can be calculated as follows:

$$I_{SC(TYP)}\,(A) = \frac{1.7V - 0.4V}{26V/V \times R_{SENSE(NOM)}} \qquad \text{(Eq. 3)}$$

Where $R_{SENSE(NOM)}$ is the sense resistor selected above.

However, since the short-circuit current threshold (1.7V), the CSA gain (26V/V), and the AOUT zero-current offset voltage (0.4V) have uncorrelated tolerances (i.e., have minimum and maximum values that vary independently of each other), the value of I_{SC} will vary within a certain range. The limits of this range are:

$$I_{SC(MIN)}\,(A) = \frac{1.65V - 0.432V}{26.65V/V \times R_{SENSE(MAX)}} \qquad \text{(Eq. 4)}$$

And

$$I_{SC(MAX)}\,(A) = \frac{1.75V - 0.368V}{25.35V/V \times R_{SENSE(MIN)}} \qquad \text{(Eq. 5)}$$

Where $R_{SENSE(MAX)}$ is the maximum value of the sense resistor (including its tolerance) and $R_{SENSE(MIN)}$ is its minimum value. The active-low short-circuit flag (SC) will thus assert low when the current falls between $I_{SC(MIN)}$ and $I_{SC(MAX)}$.

Setting the Output Voltage

The resistors R_5 and R_6 in Figure 1 set the output voltage of the MAX16946. The equation governing their values is:

$$R_6 = \frac{R_5}{\left(\frac{V_{OUT}}{V_{FB}} - 1\right)} \qquad \text{(Eq. 6)}$$

Where V_{FB} is the voltage at the feedback pin in regulation (1V nominal). The minimum and maximum values of the output voltage are then:

$$V_{OUT(MIN)} = V_{FB(MIN)} \times \left(\frac{R_{5(MIN)}}{R_{6(MAX)}} + 1\right) \qquad \text{(Eq. 7)}$$

And

$$V_{OUT(MAX)} = V_{FB(MAX)} \times \left(\frac{R_{5(MAX)}}{R_{6(MIN)}} + 1\right) \qquad \text{(Eq. 8)}$$

Where $V_{FB(MIN)}$ is 0.97V and $V_{FB(MAX)}$ is 1.03V (over the current range of 5mA to 150mA). $R_{5(MAX)}$, $R_{5(MIN)}$, $R_{6(MAX)}$, and $R_{6(MIN)}$ are the maximum and minimum values of R_5 and R_6, respectively.

Note that the output voltage can be set to 8.5V by connecting the FB pin to REG. In this mode, higher output voltage accuracy is achieved because the tolerance of external resistors does not need to be taken into account.

Setting the Current-Limit Range

The MAX16946 limits its output current when the AOUT voltage reaches the voltage on the LIM pin, which is set using a resistor-divider between REF, LIM, and GND. The nominal REF voltage is 3V. Thus, the following equation applies:

$$\frac{3V \times R_2}{R_1 + R_2} = I_{LIM} \times 26V/V \times R_{SENSE} + 0.4V \qquad \text{(Eq. 9)}$$

Where I_{LIM} is the desired current-limit threshold. Choose the standard value of 100kΩ for R_1. R_2 can then be calculated:

$$R_2 = \frac{R_1}{\left(\frac{3V}{R_{SENSE} \times I_{LIM} \times 26V/V + 0.4V} - 1\right)} \qquad \text{(Eq. 10)}$$

Considering uncorrelated tolerances, the worst-case current-limit range is:

$$I_{LIM(MIN)}\ (A) = \frac{1}{R_{SENSE(MAX)} \times 26.65V/V} \times \left(\frac{2.94V \times R_{2(MIN)}}{R_{1(MAX)} + R_{2(MIN)}} - 0.368V\right) \quad \text{(Eq. 11)}$$

And

$$I_{LIM(MAX)}\ (A) = \frac{1}{R_{SENSE(MIN)} \times 25.35V/V} \times \left(\frac{3.06V \times R_{2(MAX)}}{R_{1(MIN)} + R_{2(MAX)}} - 0.432V\right) \quad \text{(Eq. 12)}$$

Where $R_{1(MAX)}$, $R_{1(MIN)}$, $R_{2(MAX)}$, and $R_{2(MIN)}$ are the maximum and minimum values of R_1 and R_2, respectively.

Setting the Open-Load Detection Threshold

The open-load threshold for the MAX16946 can be adjusted externally with a resistor-divider placed between REF, OLT, and GND. The following equation applies:

$$\frac{3V \times R_4}{R_3 + R_4} = I_{OL} \times 26V/V \times R_{SENSE} + 0.4V \quad \text{(Eq. 13)}$$

Where I_{OL} is the desired open-load threshold. Choose the standard value of 100kΩ for R_3. R_4 can then be calculated:

$$R_4 = \frac{R_3}{\left(\frac{3V}{R_{SENSE} \times I_{OL} \times 26V/V + 0.4V} - 1\right)} \quad \text{(Eq. 14)}$$

After defining the values of R_3 and R_4, the following equations can calculate the range of the open-load detection threshold:

$$I_{OL(MIN)}\ (A) = \frac{1}{R_{SENSE(MAX)} \times 26.65V/V} \times \left(\frac{2.94V \times R_{4(MIN)}}{R_{3(MAX)} + R_{4(MIN)}} - 0.368V\right) \quad \text{(Eq. 15)}$$

And

$$I_{OL(MAX)}\ (A) = \frac{1}{R_{SENSE(MIN)} \times 25.35V/V} \times \left(\frac{3.06V \times R_{4(MAX)}}{R_{3(MIN)} + R_{4(MAX)}} - 0.432V\right) \quad \text{(Eq. 16)}$$

Where $R_{3(MAX)}$, $R_{3(MIN)}$, $R_{4(MAX)}$, and $R_{4(MIN)}$ are the maximum and minimum values of R_3 and R_4, respectively.

Measuring the Output Current by Means of the AOUT Voltage

With a given sense resistor, R_{SENSE}, and a defined load current, I_{LOAD}, the worst-case range of voltage values measured at the CSA's output, AOUT, can now be calculated. The general expression for the voltage on AOUT is:

$$V_{AOUT} = I_{LOAD} \times R_{SENSE} \times 26V/V + 0.4V \quad \text{(Eq. 17)}$$

If we again take into consideration all uncorrelated tolerances, the AOUT voltage will lie between the following equations:

$$V_{AOUT(MIN)} = I_{LOAD} \times R_{SENSE(MIN)} \times 25.35V/V + 0.368V \quad \text{(Eq. 18)}$$

And

$$V_{AOUT(MAX)} = I_{LOAD} \times R_{SENSE(MAX)} \times 26.65V/V + 0.432V \quad \text{(Eq. 19)}$$

In other words, the sensed current produces a worst-case AOUT voltage variation between $V_{AOUT(MIN)}$ and $V_{AOUT(MAX)}$.

Normally the AOUT voltage is measured using the ADC of a microcontroller and the load current is then calculated based on the nominal values of all parameters. With the above worst-case AOUT voltages, the microcontroller would then conclude that the current is within range of the following two values:

$$I_{EVALUATED(MIN)}\ (A) = \frac{V_{AOUT(MIN)}\ (V) - 0.4V}{26V/V \times R_{SENSE}} \quad \text{(Eq. 20)}$$

And

$$I_{EVALUATED(MAX)}\ (A) = \frac{V_{AOUT(MAX)}\ (V) - 0.4V}{26V/V \times R_{SENSE}} \quad \text{(Eq. 21)}$$

The tolerance of the current measurement made by the ADC, I_{TOL}, is:

$$I_{TOL}\ (\%) = \frac{I_{LOAD} - I_{EVALUATED(MIN)}\ (A)}{I_{LOAD}} \times 100\% \quad \text{(Eq. 22)}$$

A Sample Calculation

For the following example, we assume an antenna phantom supply application where the upper end of the normal operation range is set at 100mA and the antenna requires a regulated voltage of 5V. If we set the short-circuit threshold 10% higher at 110mA, then the initial value of the sense resistor is:

$$R_{SENSE}\ (\Omega) = \frac{1.7V - 0.4V}{26V/V \times 0.11A} = 0.455\Omega \quad \text{(Eq. 23)}$$

When using a resistor with a 1% tolerance, the maximum nominal value of the sense resistor is:

(Eq. 24)

$$R_{SENSE(NOM)}\ (\Omega) = \frac{R_{SENSE}\ (\Omega)}{\left(\frac{R_{SENSE-TOLERANCE}\ (\%)}{100} + 1\right)} = \frac{0.455\Omega}{\left(\frac{1\%}{100} + 1\right)} = 0.45\Omega$$

If the next-lowest E12 series value of 0.39Ω is selected, the typical value for short-circuit detection with this resistor can be calculated:

$$I_{SC(TYP)}\ (A) = \frac{1.7V - 0.4V}{26V/V \times R_{SENSE}} = \frac{1.3V}{26V/V \times 0.39\Omega} = 0.128A \quad \text{(Eq. 25)}$$

Short-Circuit Threshold

The minimum and maximum values of the short-circuit detection threshold can then be determined using the minimum and maximum values of the sense resistor (0.386Ω and 0.394Ω, assuming a 1% type is used):

$$I_{SC(MAX)}\ (A) = \frac{1.75V - 0.368V}{25.35V/V \times R_{SENSE(MIN)}} = \frac{1.75V - 0.368V}{25.35V/V \times 0.386\Omega} = 0.141A \quad \text{(Eq. 26)}$$

And

$$I_{SC(MIN)}\ (A) = \frac{1.65V - 0.432V}{26.65V/V \times R_{SENSE(MAX)}} = \frac{1.65V - 0.432V}{26.65V/V \times 0.394\Omega} = 0.116A \quad \text{(Eq. 27)}$$

Output Voltage

The output voltage of 5V is set by selecting resistor R_6 (after first selecting a value of 22kΩ for R_5) according to the following equation:

$$R_6 = \frac{R_5}{\left(\frac{V_{OUT}}{V_{FB}} - 1\right)} = \frac{22000\Omega}{\left(\frac{5V}{1V} - 1\right)} = 5500\Omega \quad \text{(Eq. 28)}$$

If the nearest E12 series resistor of 5600Ω is selected, the nominal output voltage will be 4.93V and the variation of the output voltage will be between:

$$V_{OUT(MIN)} = 0.97V \times \left(\frac{21780\Omega}{5656\Omega} + 1\right) = 4.705V \quad \text{(Eq. 29)}$$

And

$$V_{OUT(MAX)} = 1.03V \times \left(\frac{22220\Omega}{5544\Omega} + 1\right) = 5.158V \quad \text{(Eq. 30)}$$

Current Limit

Next, the resistors can be selected to set the output current limit. Assuming a current limit of approximately 200mA, use a 100kΩ resistor for R_1:

$$R_2 = \frac{R_1}{\left(\frac{3V}{R_{SENSE} \times I_{LIM} \times 26V/V + 0.4V} - 1\right)} = \frac{100000\Omega}{\left(\frac{3V}{0.39\Omega \times 0.2A \times 26V/V + 0.4V} - 1\right)} \qquad \text{(Eq. 31)}$$

$$= 424476\Omega$$

Choosing the nearest E12 standard value of 390kΩ gives an actual current limit of 0.196A. Considering all tolerances and assuming 1% resistors are used, the minimum and maximum values for the current-limit range are:

$$I_{LIM(MIN)}\ (A) = \frac{1}{0.393\Omega \times 26.65V/V} \times \left(\frac{2.94V \times 386100\Omega}{101000\Omega + 386100\Omega} - 0.368V\right) = 0.187A \qquad \text{(Eq. 32)}$$

And

$$I_{LIM(MAX)}\ (A) = \frac{1}{0.386\Omega \times 25.35V/V} \times \left(\frac{3.06V \times 393900\Omega}{99000\Omega + 393900\Omega} - 0.432V\right) = 0.206A \qquad \text{(Eq. 33)}$$

Open-Load Detection Threshold

To set a nominal open-load detection current of 10mA, select R_4 using the following equation (having first selected a value of 100kΩ for R_3):

$$R_4 = \frac{100000\Omega}{\left(\frac{3V}{0.39\Omega \times 0.01A \times 26V/V + 0.4V} - 1\right)} = 20067\Omega \qquad \text{(Eq. 34)}$$

Using a standard resistor for R_4 of 20kΩ, calculate the minimum and maximum values of the open-load threshold:

$$I_{OL(MIN)}\ (A) = \frac{1}{0.394\Omega \times 26.65V/V} \times \left(\frac{2.94V \times 19800\Omega}{101000\Omega + 19800\Omega} - 0.368V\right) = 0.0108A \qquad \text{(Eq. 35)}$$

And

$$I_{OL(MAX)}\ (A) = \frac{1}{0.386\Omega \times 25.35V/V} \times \left(\frac{3.06V \times 20200\Omega}{99000\Omega + 20200\Omega} - 0.432V\right) = 0.0088A \qquad \text{(Eq. 36)}$$

AOUT Accuracy

To evaluate the analog output (AOUT) accuracy, we assume the same sense resistor selected above (0.39Ω) and evaluate the accuracy at a load current of 100mA. At this current, the minimum and maximum values of the AOUT voltage are:

$$V_{AOUT(MIN)} = 0.1A \times 0.386\Omega \times 25.35V/V + 0.368V = 1.347V \quad \text{(Eq. 37)}$$

And

$$V_{AOUT(MAX)} = 0.1A \times 0.394\Omega \times 26.65V/V + 0.432V = 1.482V \quad \text{(Eq. 38)}$$

Taking these voltages and using the microcontroller's software to calculate these voltages back to current (i.e., using the typical values from the data sheet), a range of an evaluated current can be derived between:

$$I_{EVALUATED(MIN)}\ (A) = \frac{1.347V - 0.4V}{26V/V \times 0.39\Omega} = 0.0934A \quad \text{(Eq. 39)}$$

And

$$I_{EVALUATED(MAX)}\ (A) = \frac{1.482V - 0.4V}{26V/V \times 0.39\Omega} = 0.1067A \quad \text{(Eq. 40)}$$

Thus, the range of error in the measurement made by the microcontroller is ±6.7% at 100mA. This range does not take into account other errors in the ADC measurement such as reference error, quantization error, etc.

Related Parts		
MAX16946	Remote Antenna, Current-Sense and LDO/Switches	Free Samples
MAX16947	Remote Antenna, Current-Sense and LDO/Switches	Free Samples

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