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How to Improve Power Supply Output Regulation Accuracy with the LTpowerCAD Resistor Divider Tool

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Abstract

This article will demonstrate how to select the right power supply tolerances for a design. Specifically, the LTpowerCAD resistor divider toolbox will be used to show how to use component tolerances and estimate the corresponding errors in the output voltage. Armed with this information, designers can properly decide on what tolerance would be allowable for their application.

Introduction

Power supplies can be found in almost any circuit. From radio transceivers to microprocessors, FPGAs, and amplifiers, it's a guarantee that a power supply block exists somewhere, which makes one a vital part of any analog or digital circuit.

Like any other component, power supplies come in many shapes and forms. Different architectures, such as linear regulators or switching mode regulators present advantages and disadvantages, making one beneficial over the other in certain applications. In all these architectures, one common denominator is that the output is usually dictated by a combination of external parts, especially feedback resistors.

With the help of simulation tools, a power supply can be designed to fit the necessary specifications and come up with component values that meet them. Although simulation results show promise, limitations exist in real-life settings. One common example would be component tolerance. In reality, the rated value of components such as resistors or capacitors vary, and this variance is what tolerance describes. A simulated resistor combination of 57 kΩ and 23 kΩ resistors to output a 5 V signal would be different from a real-life combination of 57 kΩ and 23 kΩ, since the components will vary. This tolerance affects the accuracy of the DC output voltage as well, aside from inherent errors to the IC.

Regulator Output Calculation

Many Analog Devices voltage regulator ICs have an output feedback pin (FB or ADJ pin). Thus, the output voltage can be set with a pair of external resistors, R_{TOP} and R_{BOT}, where R_{TOP} connects to V_{OUT} and FB pin, and R_{BOT} connects the FB pin and IC signal ground pin. Usually, the standard IC data sheet equation is given as:

$$V_{OUT} = V_{REF} \times (1 + R_{TOP}/R_{BOT}) \quad (1)$$

Where V_{REF} is the IC internal reference voltage as an internal input of the feedback error amplifier. Let's take the output voltage formula for the LT3062 linear regulator as an example. Figure 1 shows its computed output voltage.

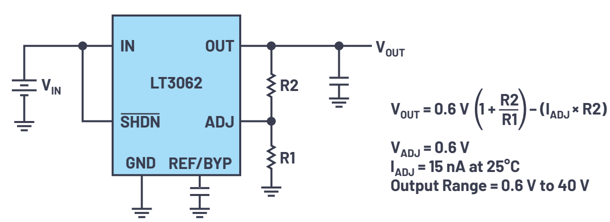

Figure 1. The output voltage for LT3062.

With an internally generated, and assumed to be accurate, voltage reference (V_{REF} = 0.6 V of the LT3062) the output voltage divider feedback network (R1 and R2) dictates the voltage level that the IC regulates. In the LT3062 equation, there is an additional term from I_{ADJ}, the unintended bias current flowing out from the ADJ pin. Its typical value is 15 nA, but can be as high as 60 nA, as shown in the electrical characteristics (EC) table, and it can cause additional V_{OUT} regulation error.

Table 1. LT3062 R1 and R2 Combinations for Common Voltage Output Levels

V_{OUT} (V)	R1 (kΩ)	R2 (kΩ)
1.2	118	118
1.5	121	182
1.8	124	249
2.5	115	365
3	124	499
3.3	124	562
5	115	845
12	124	2370
15	124	3010

If 1% tolerance of R1 and R2 is used, what is the total Vo error caused by the resistor divider—1% or 2%? Should we use 0.5% or 0.1% resistors for an application? Certain levels of accuracy in the output voltage might be needed, and choosing the right resistors plays a key role. You may not want to use resistors that have very low tolerance (which can be significantly expensive) if the target error can be reached with a higher tolerance resistor.

LTpowerCAD Resistor Divider Tool

To aid in the design, the LTpowerCAD® resistor divider tool can be used. LTpowerCAD is a complete power supply design program equipped with a toolbox of design assets including the resistor divider design tool. The resistor divider tool takes inputs such as the desired output voltage level V_{OUT} and the regulator's voltage reference V_{REF} (ADJ pin or FB pin voltage), then recommends commercially available standard resistor values, depending on the selected tolerance, to arrive at the desired voltage. Two errors are estimated with this tool: 1) Error caused by standard, discrete standard resistor values. Note: for a given V_{OUT} and V_{REF}, the tool automatically selects the best matching pair of standard resistor values to minimize this error, so the actual V_{OUT} is closest to the target value. 2) Error caused by resistor tolerance for a given V_{OUT} and V_{REF} combination. In fact, with a pair of 1% accurate resistor dividers, the effective divider tolerance becomes a function of the divider ratio, in the range from 1% to 2%. The LTpowerCAD resistor divider tool sums those two errors for the total R-divider tolerance. This makes it easy for an engineer to view the total error to decide which resistor tolerance level (0.1%, 0.5%, 1%, or 2%) will be necessary to meet the final target.

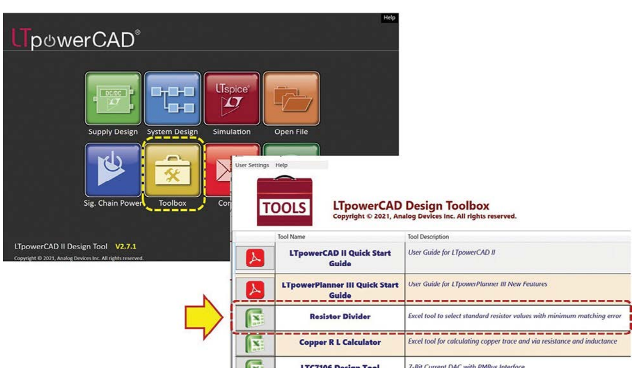

Figure 2. Open the resistor divider tool in the LTpowerCAD Toolbox.

The tool also has a provision to solve either the top or bottom resistor value when given the other resistance (user input) while also considering the target or allowable component tolerance.

Aside from the resistor value recommendations, the tool also shows the error computations associated with a component tolerance with respect to the ideal and actual V_{OUT}.

With these parameters, designers can get a glimpse of the expected voltage range, given the chosen component tolerances, and assess if it fits the target application.

Lastly, the tool also has a feature for finding standard value resistors for any given value to help simplify the component search.

Additional Errors and Considerations

It is necessary to point out that this resistor divider tool only estimates the DC error by the resistor divider. It does not include other DC errors that should be added up to the resistor divider error for the total power supply V_{OUT} regulation accuracy. These additional errors include 1) an IC internal reference V_{REF} error, which is typical in the range of 0.5% to 1.5% and can be found on the IC data sheet EC table; 2) power supply line and load regulation errors that can be found on the IC EC table as well; 3) ADJ or FB pin leakage current error, as in the LT3062 example, with a lower R_{BOT} value desired to reduce this error; and 4) additional errors caused by PCB resistance between the local IC and the remote load device, etc. All these errors should be considered for total error estimation while designing a power supply.

In addition, a high precision electronics system may also have a strict requirement of total supply output voltage tolerance, including DC error and AC ripples. For example, many high current ASICs and FPGAs require a ±2% or ±3% total tolerance window, including DC error and AC ripples. To meet this strict requirement, the power supply must be designed with fast transient response, as well as having large amount output capacitors to minimize V_{OUT} ripple during fast load step transients. In this case, it is critical to select an IC with tight V_{REF} tolerance. A regulator with remote voltage sensing is desired for high current rails. In addition, the space and cost saving of output capacitors will be much greater than the small cost increase of using a 0.5% or even a 0.1% resistor. It is also helpful to use an integrated module, such as an ADI LTM series μModule® regulator, that specifies the total DC regulation tolerance (including V_{REF}, line, and load regulation errors) of a complete high performance power supply solution.

Standard Resistor Divider Selection Program (Version 2.0)

This program selects the standard resistor divider pair and suggests the best matching of resistor pair values that give the smallest error on output voltage.
In case if multiple pairs give the same smallest error, only the first pair of standard value is given.

Values entered by user | Calculated values

Please enter voltage values Here:			
Desired output votlage, V_{OUT}=	12	V	
Internal reference voltage, V_{REF}=	0.6	V	
Voltage divider base value pair suggestion:			
Standard tolerance selection:	1% res		
Suggested R_{TOP}=	2150	Ω	
Suggested R_{BOT}=	113	Ω	
With accurate R_{TOP} & R_{BOT}, V_{OUT}=	12.01593	V	
Error of V_{OUT} (with accurate R_{TOP} & R_{BOT})=	0.13274	%	
Error of actual V_{OUT} due to resistors' tolerance (V_{OUTmax}, V_{OUTmin})=	1.91919	-1.88119	%
Worst case total error of V_{OUT} (V_{OUTmax}, V_{OUTmin})=	2.05462	-1.75107	%
Worst case actual V_{OUTmax}, V_{OUTmin}=	12.24655	11.78987	V

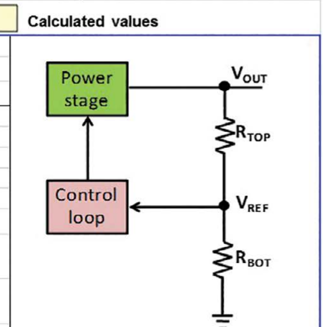

Figure 3. LTpowerCAD resistor divider tool: resistor pair recommendation.

If User Selected R_{TOP}:			
User select R_{TOP}=	5400		Ω
Standard tolerance selection:	1% res		
R_{TOP} standard value=	5360		Ω
R_{BOT} standard value=	280		Ω
With accurate R_{TOP} & R_{BOT}, V_{OUT}=	12.08571		V
Error of V_{OUT} (with accurate R_{TOP} & R_{BOT})=	0.71429		%
Error of actual V_{OUT} due to resistors' tolerance (V_{OUTmax}, V_{OUTmin})=	1.91919	-1.88119	%
Worst case total error of V_{OUT} (V_{OUTmax}, V_{OUTmin})=	2.64791	-1.18105	%
Worst case actual V_{OUTmax}, V_{OUTmin}=	12.31775	11.85827	V
If User Selected R_{BOT}:			
User select R_{BOT}=	111		Ω
Standard tolerance selection:	1% res		
R_{TOP} standard value=	2100		Ω
R_{BOT} standard value=	110		Ω
With accurate R_{TOP} & R_{BOT}, V_{OUT}=	12.05455		V
Error of V_{OUT} (with accurate R_{TOP} & R_{BOT})=	0.45455		%
Error of actual V_{OUT} due to resistors' tolerance (V_{OUTmax}, V_{OUTmin})=	1.91919	-1.88119	%
Worst case total error of V_{OUT} (V_{OUTmax}, V_{OUTmin})=	2.38292	-1.43564	%
Worst case actual V_{OUTmax}, V_{OUTmin}=	12.28595	11.82772	V

Figure 4. LTpowerCAD resistor divider tool: R_{TOP} or R_{BOTTOM} solver.

If User Selected R_{TOP}:			
User select R_{TOP}=	5400		Ω
Standard tolerance selection:	1% res		
R_{TOP} standard value=	5360		Ω
R_{BOT} standard value=	280		Ω
With accurate R_{TOP} & R_{BOT}, V_{OUT}=	12.08571		V
Error of V_{OUT} (with accurate R_{TOP} & R_{BOT})=	0.71429		%
Error of actual V_{OUT} due to resistors' tolerance (V_{OUTmax}, V_{OUTmin})=	1.91919	-1.88119	%
Worst case total error of V_{OUT} (V_{OUTmax}, V_{OUTmin})=	2.64791	-1.18105	%
Worst case actual V_{OUTmax}, V_{OUTmin}=	12.31775	11.85827	V
If User Selected R_{BOT}:			
User select R_{BOT}=	111		Ω
Standard tolerance selection:	1% res		
R_{TOP} standard value=	2100		Ω
R_{BOT} standard value=	110		Ω
With accurate R_{TOP} & R_{BOT}, V_{OUT}=	12.05455		V
Error of V_{OUT} (with accurate R_{TOP} & R_{BOT})=	0.45455		%
Error of actual V_{OUT} due to resistors' tolerance (V_{OUTmax}, V_{OUTmin})=	1.91919	-1.88119	%
Worst case total error of V_{OUT} (V_{OUTmax}, V_{OUTmin})=	2.38292	-1.43564	%
Worst case actual V_{OUTmax}, V_{OUTmin}=	12.28595	11.82772	V

Figure 5. LTpowerCAD resistor divider tool: voltage error computations.

Find a standard resistor for any given value:		
user enter resistor value=	503	Ω
Standard tolerance selection:	0.1% res	
Standard resistor value=	505	Ω

Figure 6. LTpowerCAD resistor divider tool: standard resistance finder.

Conclusion

Depending on the target application, certain levels of power supply V_{OUT} tolerance are required. A few millivolts of error might be a crucial aspect in different systems and so proper design considerations must be met.

One external and controllable factor in regulator accuracy is component tolerance. The difference between using resistors with 0.5% tolerance vs. 2% tolerance might have a significant impact on your system's performance, and choosing the right components lessens the possibility of errors. Selecting the right components also helps minimize cost and improve reliability since the need for changing components would be minimized or eliminated.

Using the LTpowerCAD resistor divider tool, engineers can observe the effects of component tolerance on their power supply design. By initially choosing a target output voltage and reference pin voltage, designers can: (1) get the best matching pair of standard resistors for the target voltage, (2) solve for either the top or bottom resistor, and (3) achieve the desired range of voltage error due to R-divider tolerance.

With the given features, plus the standard resistor finder, the resistor divider tool proves to be helpful in power supply design. It can especially help engineers who are beginners in power supply design get acquainted with it. Using this tool, an engineer can design power supplies that can match the specifications needed for the intended application and ensure the optimal performance and power delivered to different system blocks.

About the Author

Jose Ramon San Buenaventura is a system applications engineer based in Cavite, Philippines. He joined Analog Devices in 2018 and obtained his bachelor's degree in electronics and communications engineering from De La Salle University-Laguna. In his time at ADI, he's worked on different projects involving sensors and sensor analog front ends (AFEs), sensor fusion, and programming using different platforms such as MATLAB, C, Python, digital signal processing, and algorithms. He can be reached at jose.sanbuenaventura@analog.com.

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