

# Improving the Output Accuracy Over Temperature for RMS Power Detectors

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## INTRODUCTION

Stable temperature performance is extremely important in base-station designs because the ambient temperature can vary widely depending on the surroundings and the location. Using high accuracy over temperature RMS detectors can improve the power efficiency of the base-station designs. The LTC5582 and the dual-channel LTC5583 are a family of RMS detectors that offer excellent stable temperature performance (from  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ) at any frequency up to 10GHz for LTC5582, and 6GHz for LTC5583. However, their temperature coefficients vary with frequency, and without temperature compensation, the error over temperature can be greater than 0.5dB. As a result, sometimes it is necessary to optimize the temperature compensation at different frequencies to improve the accuracy to  $<0.5\text{dB}$  of error. In addition, the temperature compensation can be implemented using only two off chip resistors, with no external circuitry required.

The change in output voltage is governed by the following equation:

$$\Delta V_{\text{OUT}} = \text{TC1} \cdot (T_A - t_{\text{NOM}}) + \text{TC2} \cdot (T_A - t_{\text{NOM}})^2 + \text{detV1} + \text{detV2} \quad (1)$$

Where TC1 and TC2 are the 1st and 2nd order temperature coefficients respectively.  $T_A$  is the actual ambient temperature, and  $t_{\text{NOM}}$  is the reference room temperature,  $25^{\circ}\text{C}$ . detV1 and detV2 are output voltage variation when  $R_{T1}$  and  $R_{T2}$  are not set to zero.

The method to calculate the resistor values for temperature compensation is the same for both LTC5582, and LTC5583. The two control pins are RT1, which sets TC1 (the 1st order temperature compensation coefficient), and RT2 which sets TC2 (the 2nd order temperature compensation coefficient). Shorting RT1 and RT2 to ground conveniently turns off the temperature compensation feature if not needed.

## LTC5583 Temperature Compensation Design

LTC5583 includes two additional pins, RP1 that controls the polarity of TC1, and RP2 which controls the polarity of TC2. However, the magnitude of the temperature coefficients are the same with a fixed  $R_{T1}$ , or  $R_{T2}$  value, only polarity is flipped. Both channel A and channel B share the compensation circuitry, therefore both channels are controlled together.

Figure 1 illustrates the change in  $V_{\text{OUT}}$  as a function of temperature from the 1st order temperature compensation. Only three resistor values are shown to illustrate that increasing resistor values causes an increase in the magnitude of the slope. The polarity of the slope is controlled by the RP1 pin.

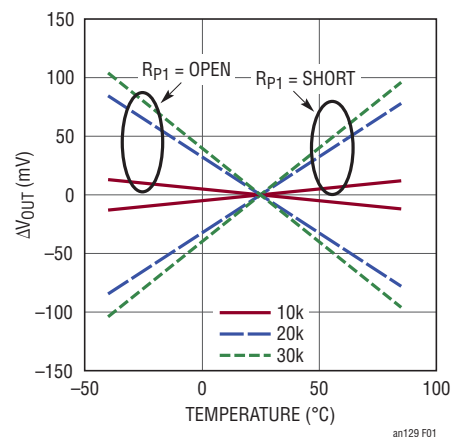


Figure 1. 1st Order  $\Delta V_{\text{OUT}}$  vs Temperature

Figure 4 illustrates the effect of 2nd order temperature compensation on  $V_{\text{OUT}}$ . The polarity of the curves is controlled by RP2. The curvature depends on the resistor values. The overall effect is the summation of the 1st order and 2nd order temperature compensation given by equation 1.

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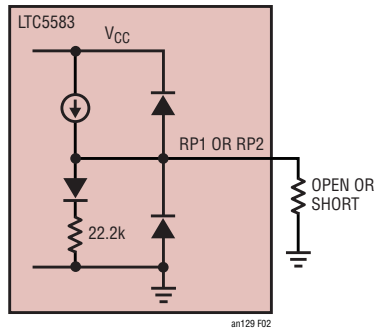


Figure 2. Simplified Schematic of Pins RP1 and RP2.

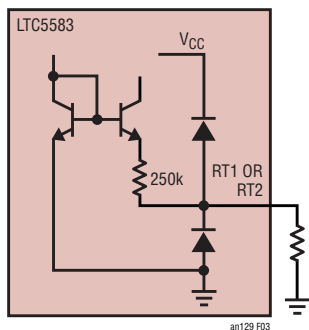


Figure 3. Simplified Schematic of Pins RT1, and RT2.

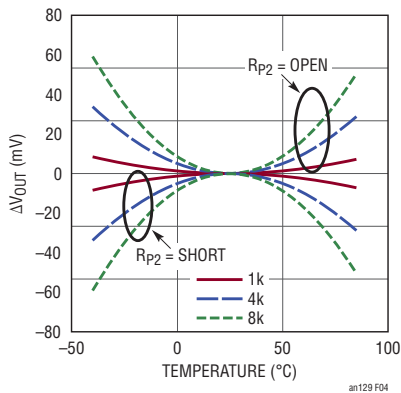


Figure 4. 2nd Order  $V_{OUT}$  vs Temperature

Take an LTC5583 as an example at 900MHz input. The first step is to measure the  $V_{OUT}$  over temperature without compensation. Figure 5 shows the uncompensated  $V_{OUT}$ . The Linearity error over temperature is referenced to the slope and intercept point at 25°C. To minimize the output voltage change with temperature, the linearity curve in red (85°C) needs to be shifted down, and the linearity curve in blue (-40°C) needs to be shifted up to align with the room temperature in green, and overlap as much as possible. What follows is a step by step design procedure.

Step 1. Estimate the temperature compensation needed in dB, from Figure 5. For example, read the plot at an input power of -25dBm, which is the middle of the dynamic range. Multiply the linearity error in dB by 30mV/dB (typical  $V_{OUT}$  slope) to convert to mV.

$$\text{Cold } (-40^{\circ}\text{C}) = 13\text{mV or } 0.43\text{dB}$$

$$\text{Hot } (85^{\circ}\text{C}) = -20\text{mV or } -0.6\text{dB}$$

This is the amount of output voltage adjustment required over temperature.

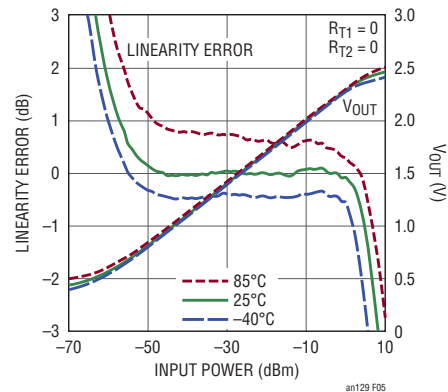


Figure 5. Uncompensated LTC5583 at 900MHz

Step 2. Determine RP1 and RP2, and the solutions for 1st and 2nd order compensation. To find the solutions, let a = 1st order term, and b = 2nd order term. Set them up so they satisfy the temperature compensation at -40°C and 85°C.

$$a - b = 13\text{mV} \quad (2)$$

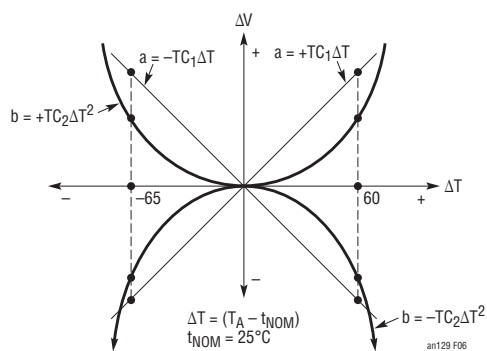
$$-a - b = -20\text{mV} \quad (3)$$

$$a = 16.5 \quad (1\text{st})$$

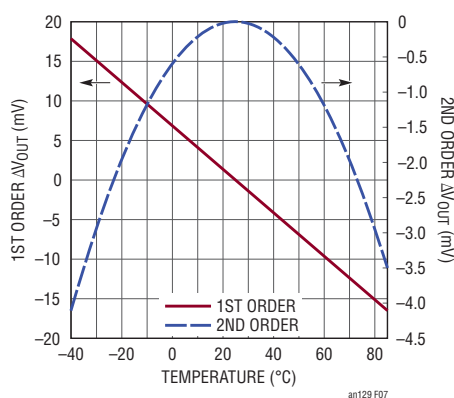
$$b = 3.5 \quad (2\text{nd})$$

The polarity of a and b in equation 2 and equation 3 are determined by the polarity of the 1st order term and the 2nd order term, such that their summation satisfy the 13mV at cold (-40°C), and -20mV at hot (85°C) adjustment. Refer to Figure 6. 1st order term and 2nd order term can be either positive or negative. So there are total of 4 combinations possible. In this case, only when both terms are negative will their sum satisfy the required compensation.

Figure 7 shows the 1st and 2nd order compensation required at -40°C and 85°C. Notice the polarity of the 1st order and 2nd order compensation are negative such that



**Figure 6. Polarity of 1st and 2nd Order Solutions**



**Figure 7. Solutions for the Temperature Compensation**

when both curves are added, their sum produces the required adjustment to  $V_{OUT}$ . Consequently,  $TC1$  and  $TC2$  are negative, and  $RP1$  and  $RP2$  are determined from Figure 8 and Figure 9. Notice the values of the two solutions add up to approximately 13mV at  $-40^{\circ}\text{C}$ , and  $-20\text{mV}$  at  $85^{\circ}\text{C}$ .

$$R_{P1} = \text{open}$$

$$R_{P2} = \text{short}$$

Step 3. Calculate the temperature coefficients at one of the temperature extremes and determine resistor values  $R_{T1}$  and  $R_{T2}$ , using Figures 8 and 9.

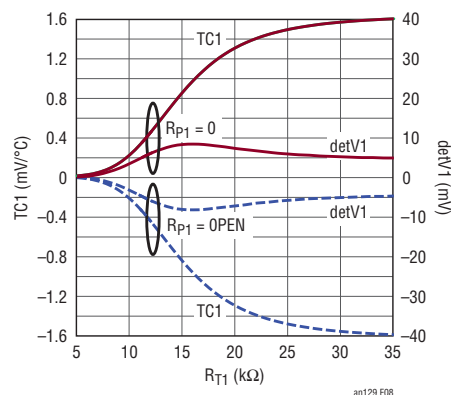
$$a = 16.5 = TC1 \cdot (85 - 25); TC1 = 0.275\text{mV}/^{\circ}\text{C}$$

$$R_{T1} = 11\text{k} \text{ (from Figure 8)}$$

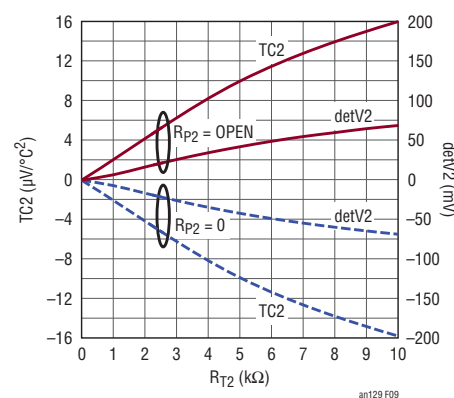
$$b = 3.5 = TC2 \cdot (85 - 25)^2; TC2 = 0.972\mu\text{V}/^{\circ}\text{C}^2$$

$$R_{T2} = 499\Omega \text{ (from Figure 9)}$$

Figure 10 shows the LTC5583 performance over temperature for one of the two output channels. Notice an improvement to the temperature performance from uncompensated  $V_{OUT}$ , from Figure 5. This may be satisfactory for most applica-



**Figure 8. 1st Order Temperature Compensation Coefficient  $TC1$  vs External  $RT1$  Values**



**Figure 9. 2nd Order Temperature Compensation Coefficient  $TC2$  vs External  $RT2$  Values**

tions. However, for some applications where even better accuracy is needed, a 2nd iteration can be performed to further improve the temperature performance. To simplify the calculation,  $\text{detV1}$  and  $\text{detV2}$  terms are ignored because they are not dependent on temperature. As a result, the solutions are not precise. However, it is very helpful in improving the accuracy over temperature, as shown here.

## 2nd Iteration Calculation

Step 1. Find the compensation needed from Figure 10, using the same method in first iteration.

$$\text{Cold } (-40^{\circ}\text{C}) = -3\text{mV or } -0.1\text{dB}$$

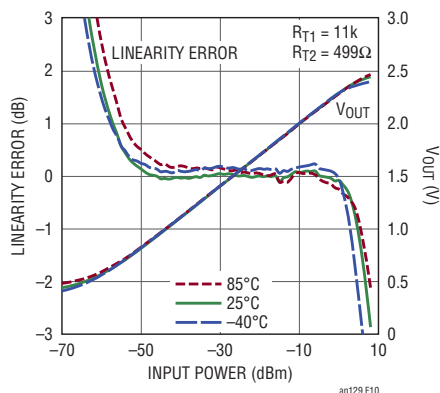
$$\text{Hot } (85^{\circ}\text{C}) = -3\text{mV or } -0.1\text{dB}$$

Add the new values to the 1st iteration

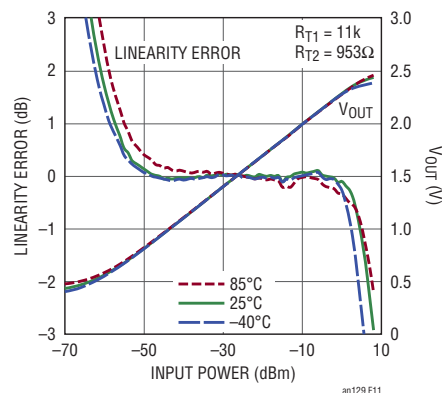
$$\text{Cold } (-40^{\circ}\text{C}) = -3\text{mV} + 13\text{mV} = 10\text{mV}$$

$$\text{Hot } (85^{\circ}\text{C}) = -3\text{mV} - 20\text{mV} = -23\text{mV}$$

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**Figure 10. Temperature Compensated LTC5583 Output After 1st Iteration**



**Figure 11. Temperature Compensated LTC5583 Output After 2 Iterations.**

Repeat steps 2 and 3 to calculate the  $R_{T1}$  and  $R_{T2}$  values.

$$R_{T1} = 11k$$

$$R_{T2} = 953\Omega$$

$$R_{P1} = \text{open}$$

$$R_{P2} = \text{short}$$

The performance results are shown in Figure 11 after two iterations. Over temperature, the dynamic range is 50dB with 0.2dB of linearity error, and 56dB of dynamic range with 1.0dB of linearity error. Refer to Table 1 for temperature compensation values at other frequencies.

**Table 1. Recommended Settings and Resistor Values for LTC5583 for Optimal Temperature Performance at Various Frequencies**

FREQUENCY (MHZ)	$R_{P1}$	$R_{P2}$	$R_{T1}$ (k $\Omega$ )	$R_{T2}$ (k $\Omega$ )
450	Open	0	11.5	1.13
880	Open	0	11.5	1.13
900	Open	0	11	0.953
1800	Open	0	12.1	1.5
2140	Open	0	9.76	1.1
2300	Open	0	10.5	1.43
2500	Open	0	10.5	1.43
2700	Open	0	8.87	1.21

This iteration process can be repeated over and over again to further increase the accuracy. This will allow the designer to dial in the compensation as accurately as needed for most applications.

## LTC5582 Single Detector

The method to calculate the LTC5582 compensation values for  $R_{T1}$  and  $R_{T2}$  is the same, only easier because

the polarity has been predetermined. Both TC1 and TC2 are negative. Refer to Table 2 for  $R_{T1}$  and  $R_{T2}$  values at other frequencies. The compensation coefficients shown in Figure 8 and Figure 9 are different for LTC5582. Refer to data sheet for additional information.

**Table 2. Recommended  $R_{T1}$  and  $R_{T2}$  Values of LTC5582 for Optimal Temperature Performance at Various Frequencies**

FREQUENCY (MHZ)	$R_{T1}$ (k $\Omega$ )	$R_{T2}$ (k $\Omega$ )
450	12	2
800	12.4	1.4
880	12	2
2000	0	2
2140	0	2
2600	0	1.6
2700	0	1.6
3000	0	1.6
3600	0	1.6
5800	0	3
7000	10	1.43
8000	10	1.43
10000	10	3

## Conclusion

LTC5582 and LTC5583 offer excellent temperature performance with only two external compensation resistors. The procedure to calculate the compensation resistors is simple, and can be reiterated for even better performance. The example shown here is for LTC5583 at 900MHz RF input, but the method can be applied to LTC5582 and LTC5583 at any frequency within the limits of the IC. The performance over temperature is fairly consistent from part to part. The resulting performance provides accuracy over temperature with less than 1% of output voltage.