

# **TRF370417: Optimizing OIP3 Performance at Local Oscillator (LO) Frequencies Beyond 4.5 GHz**

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## **ABSTRACT**

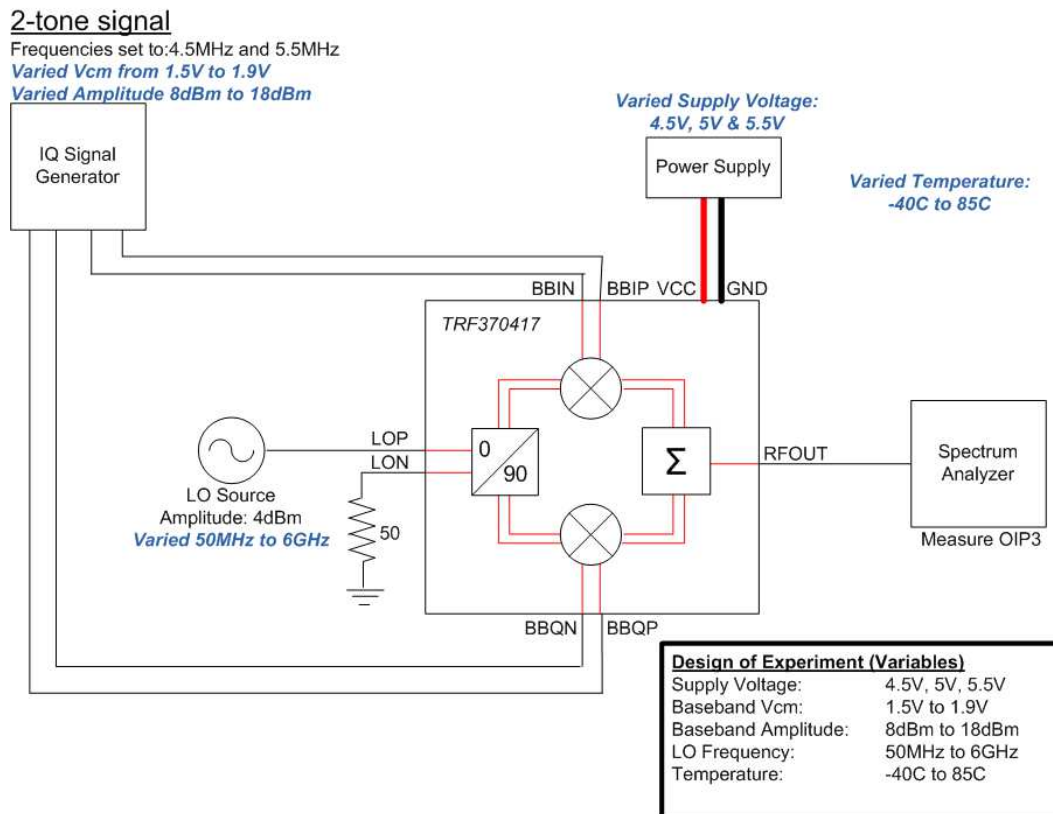
The TRF370417 is an industry-leading IQ modulator in terms of noise floor and OIP3 performance across a 50-MHz to 6-GHz local oscillator (LO) frequency range. At LO frequencies beyond 4.5 GHz, the OIP3 performance sensitivity increases with changes in supply voltage, temperature, common mode voltage (Vcm), process variation, and baseband input amplitude. This application note investigates the trends seen in OIP3 variation with respect to these sensitivities. In addition, recommendations are made for calibrating the TRF370417 for optimal OIP3 performance at LO frequencies beyond 4.5 GHz.

## **Contents**

1	Test Setup and Analysis .....	1
2	Optimal Vcm Setting – OIP3 Experimental Results .....	4
3	Single and Multiple LO Frequency OIP3 Calibration Recommendations and Summary .....	9
4	OIP3 Calibration Over Temperature .....	14
4.1	Summary .....	15

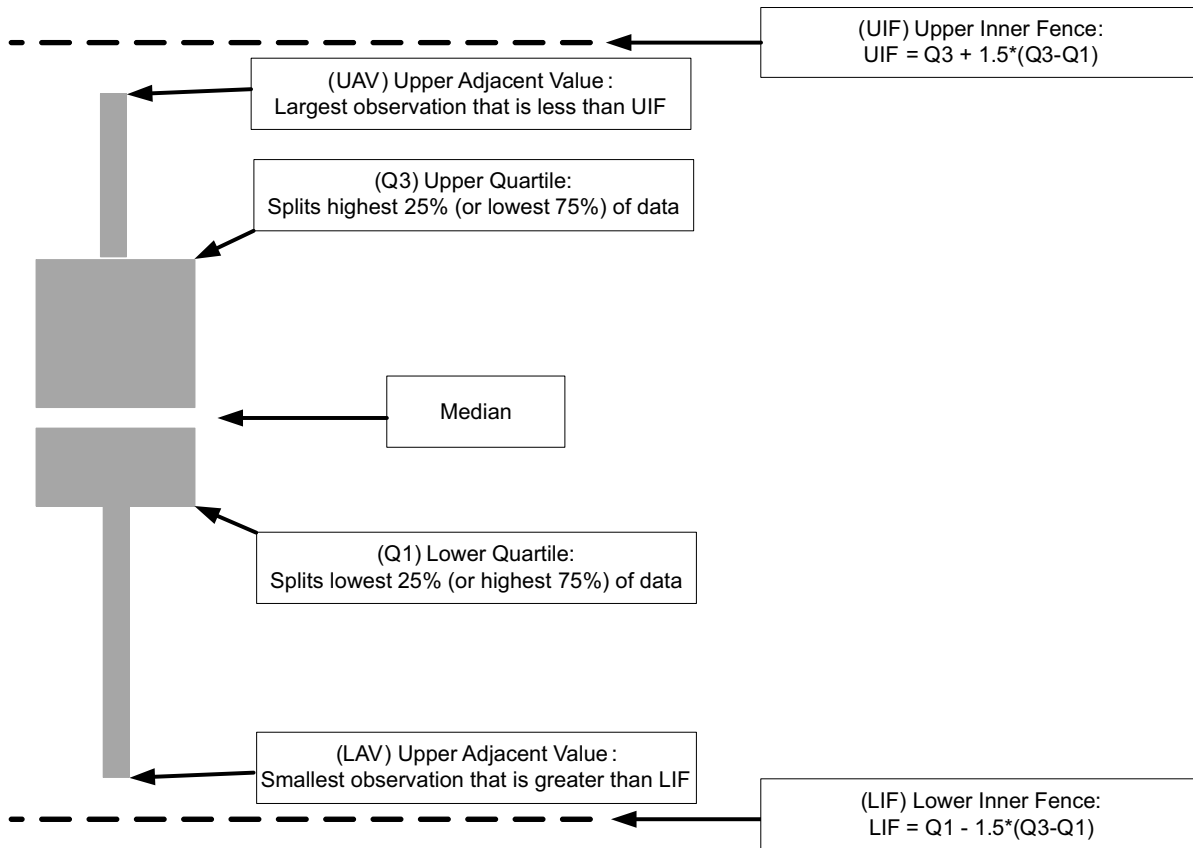
## **1 Test Setup and Analysis**

The TRF370417 test setup in [Figure 1](#) was used to create the results in this document. The table in [Figure 1](#) displays the test conditions varied for these experiments. Multiple TRF370417 units from three different wafer and package assembly lots were soldered onto TRF370417EVMs from 3 different EVM FAB lots accounting for process variation. A spectrum analyzer measured and stored the OIP3 results.



**Figure 1. TRF370417 Test Setup**

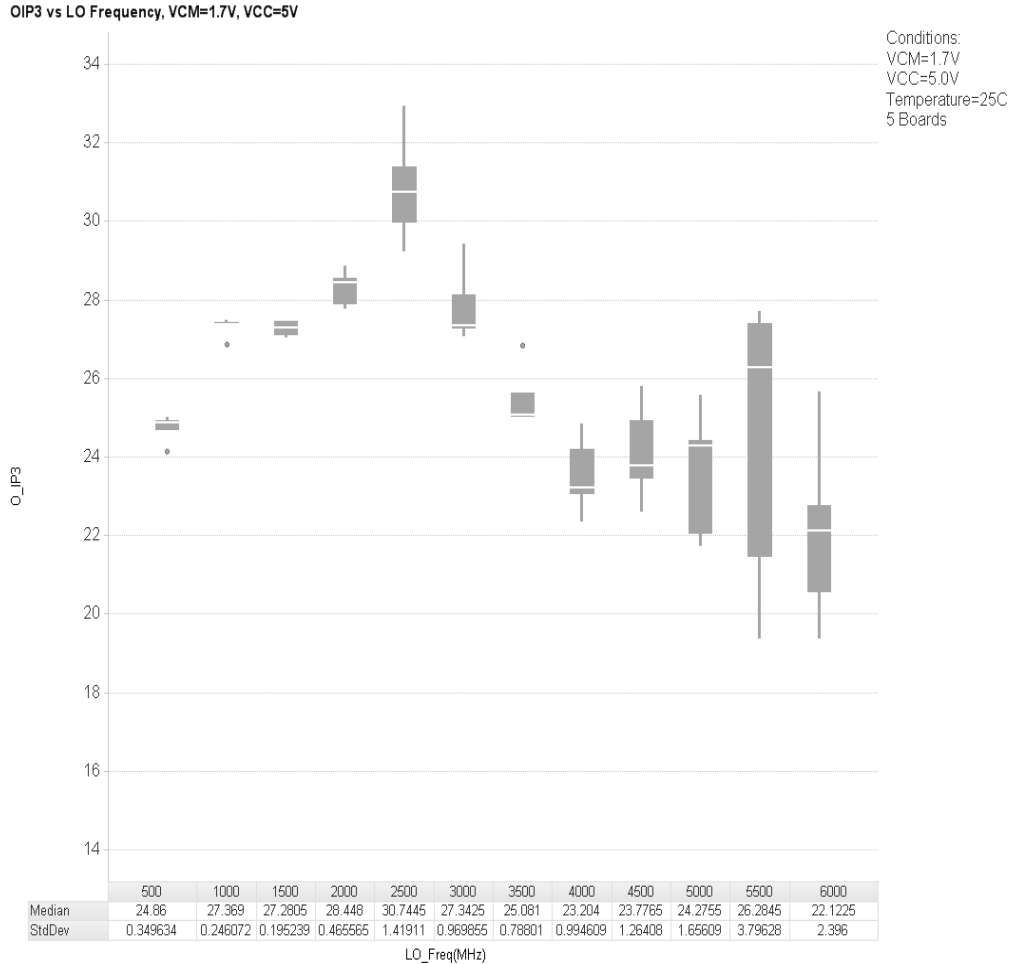
Several of the figures in this document display the data in boxplot form. [Figure 2](#) provides a review of the basic boxplot properties.



**Figure 2. Boxplot Properties**

## 2 Optimal Vcm Setting – OIP3 Experimental Results

Using the TRF370417 datasheet’s recommended baseband input Vcm of 1.7 V, [Figure 3](#) displays the OIP3 vs LO frequency performance curves for 5 units from 3 FAB lots. The significance of [Figure 3](#) is that with a small amount of process variation, LO frequencies beyond 4.5 GHz show OIP3 results 5 dB less than the datasheet typical of 25 dBm.



**Figure 3. OIP3 vs LO Frequency With Vcm = 1.7 V**

As a result of the data represented in [Figure 3](#), experiments on increasing optimization of OIP3 performance across the LO frequency range were developed. [Figure 4](#) displays OIP3 for Vcm levels varied from 1.5 V to 1.9 V in 10-mV steps across several LO frequencies. The significance of [Figure 4](#) is that for LO frequencies beyond 4.5 GHz there is a Vcm voltage providing datasheet-typical numbers for OIP3. However, as will be shown, this optimal Vcm voltage is not always 1.7 V as recommended in the datasheet.

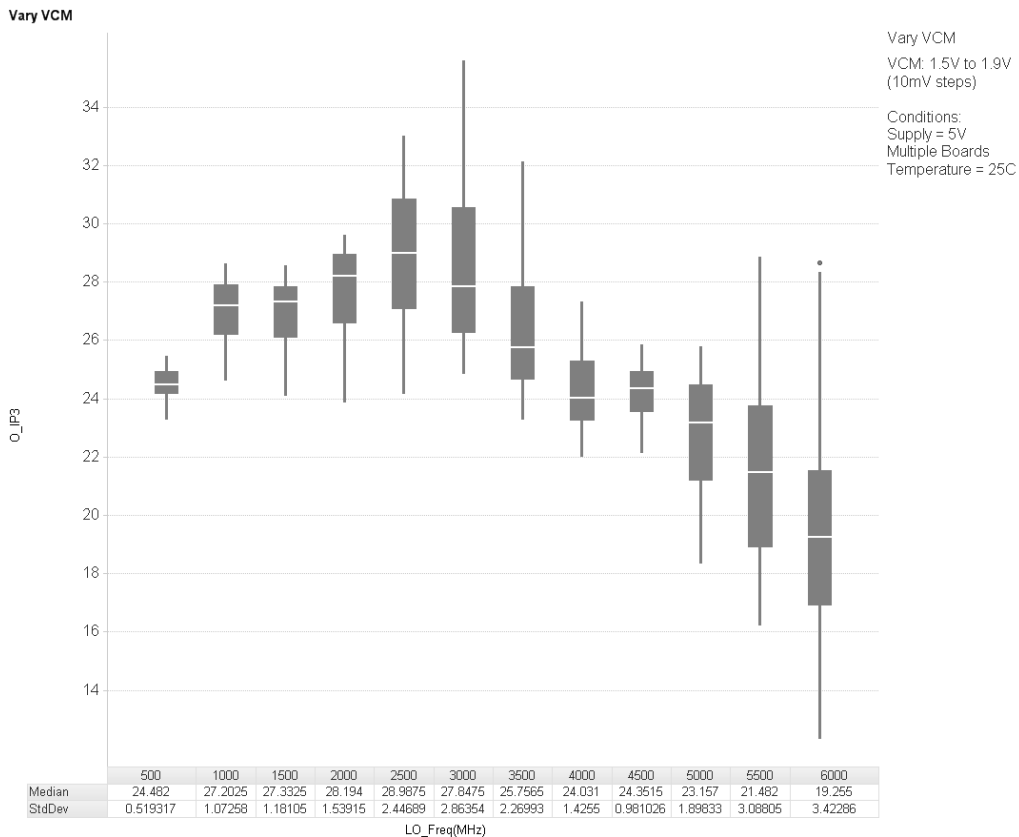
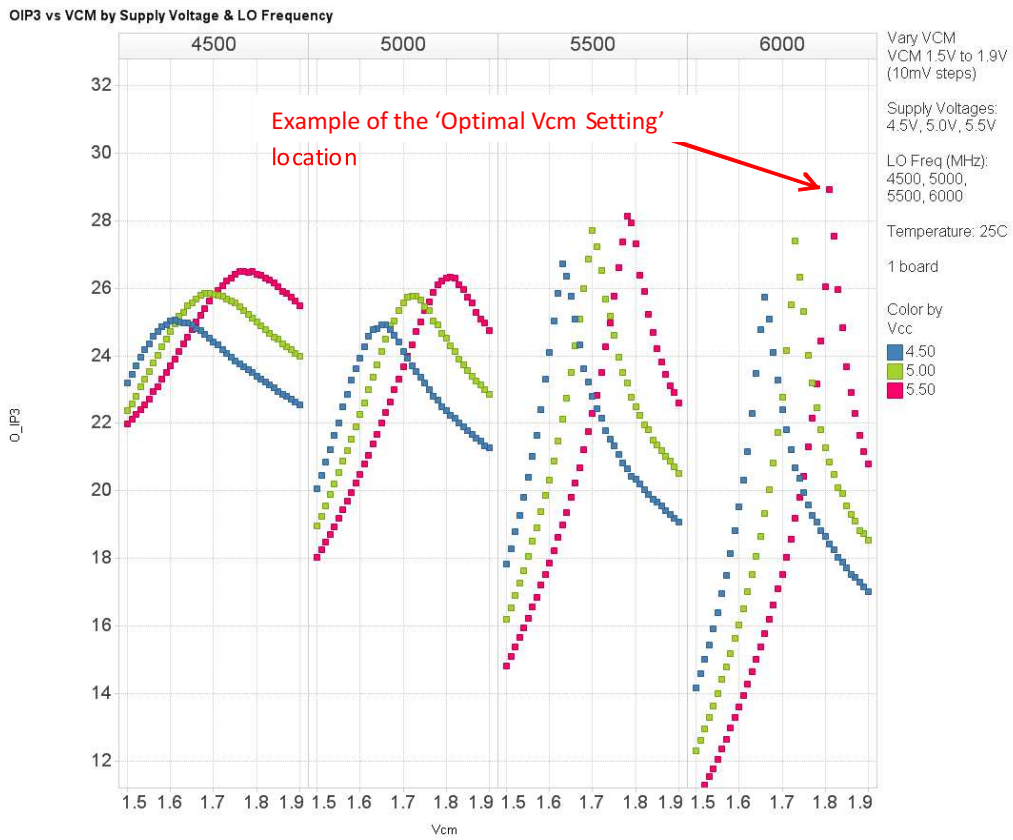


Figure 4. TRF3704 OIP3 vs LO Frequency Baseband Vcm Varied From 1.5 V to 1.9 V

The goal of Figure 5 through Figure 8 is to identify trends in the optimal Vcm setting vs supply voltage, temperature, process variation and baseband input voltage.

Figure 5 demonstrates a typical trend seen for OIP3 vs Vcm by supply voltage and LO frequency. In Figure 5, there are 4 LO frequencies plots: 4.5GHz, 5GHz, 5.5GHz and 6GHz. The optimal Vcm setting is defined as the maximum OIP3 value across a Vcm sweep for a fixed set of supply, LO frequency, temperature and baseband input voltage conditions. There are 2 trends seen in Figure 3. Trend 1 shows for higher supply voltages, the OIP3 value improves at the optimal Vcm setting. Trend 2 shows as the supply voltage increases, the Vcm voltage required to generate the optimal Vcm setting increases.

For LO frequencies beyond 4.5 GHz, these 2 trends imply that for an optimal OIP3 setup, a 5.5-V supply voltage and Vcm calibration are necessary. Vcm calibration techniques are discussed in Section 3. These trends also imply that a low-drift supply is required to limit unnecessary optimal Vcm setting drift.



**Figure 5. TRF370417 OIP3 vs Vcm at LO Frequencies (MHz) = 4500, 5000, 5500, 6000 at Supply Voltages (V) = 4.5, 5.0, 5.5**

Figure 6 demonstrates a typical trend seen for OIP3 vs Vcm by temperature and LO frequency. In Figure 6, there are 4 LO frequencies plots: 4.5 GHz, 5 GHz, 5.5 GHz, and 6 GHz. There are 2 trends seen in Figure 6. Trend 1 shows for lower temperatures, the OIP3 value improves at the optimal Vcm setting. Trend 2 shows as the temperature decreases, the optimal Vcm setting voltage increases.

For LO frequencies beyond 4.5 GHz, these 2 trends imply that for applications with a significant temperature range, knowledge of the calibration temperature and optimal Vcm setting temperature coefficient (TC) are necessary. Optimal Vcm setting TCs are provided in Section 4.

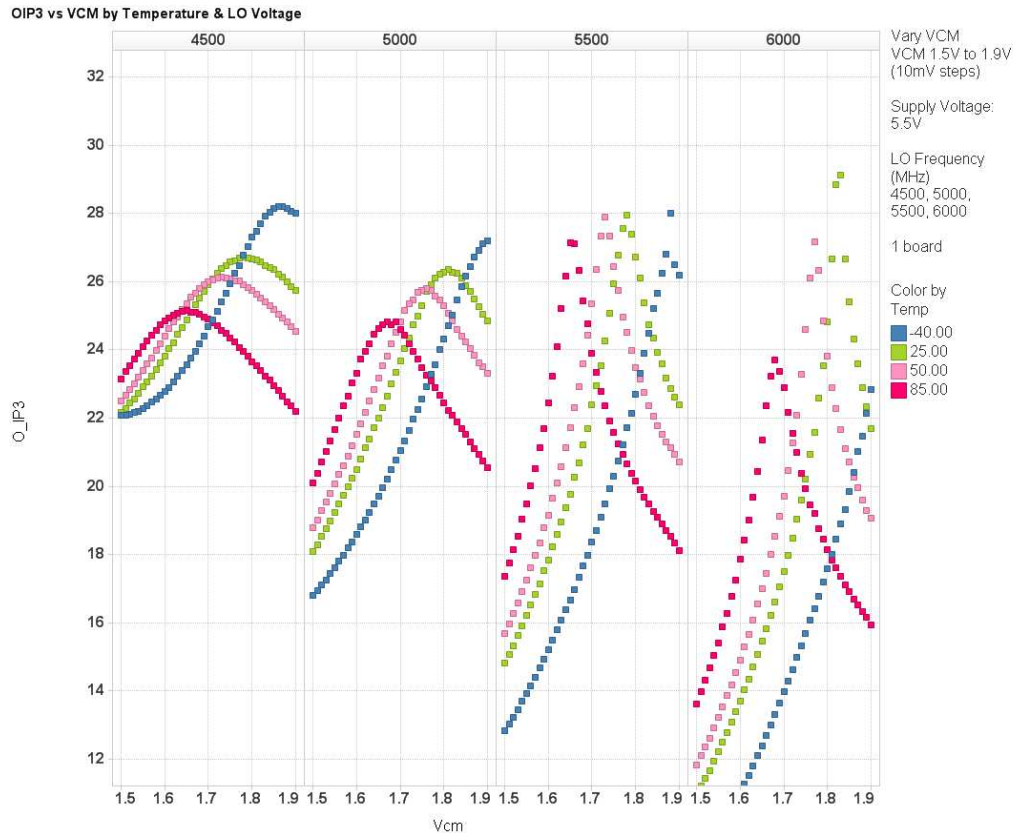


Figure 6. TRF370417 OIP3 vs Vcm at LO Frequencies (MHz) = 4500, 5000, 5500, 6000 at Temp (°C) = -40, 25, 50, 85

Figure 7 demonstrates that as the baseband input level varies, the optimal Vcm setting varies too. The important item regarding Figure 7 is that an obvious trend of the optimal Vcm setting vs baseband input level is not easily identified. Therefore, it is recommended to have a fixed baseband input level when using the TRF370417 at LO frequencies beyond 4.5 GHz. In this paper, all plots used a 2-tone baseband input signal, with each tone set to  $-14.0$  dBm by the signal generator. The signal generator assumed a  $50\text{-}\Omega$  termination in its dBm calculation. In a  $50\text{-}\Omega$  system, this calculates to  $265$  mVpp. However, the baseband inputs on the TRF370417EVM are unterminated. Therefore, the actual 2-tone signal amplitude at the TRF370417's baseband input pins is  $505$  mVpp. The table below can help decode Figure 7 dBm baseband amplitude settings from the signal generator.

dBm per Tone at Instrument	Vpp 2 Tone (mV) at Baseband Inputs
-8	1010
-10	800
-14	505
-18	317

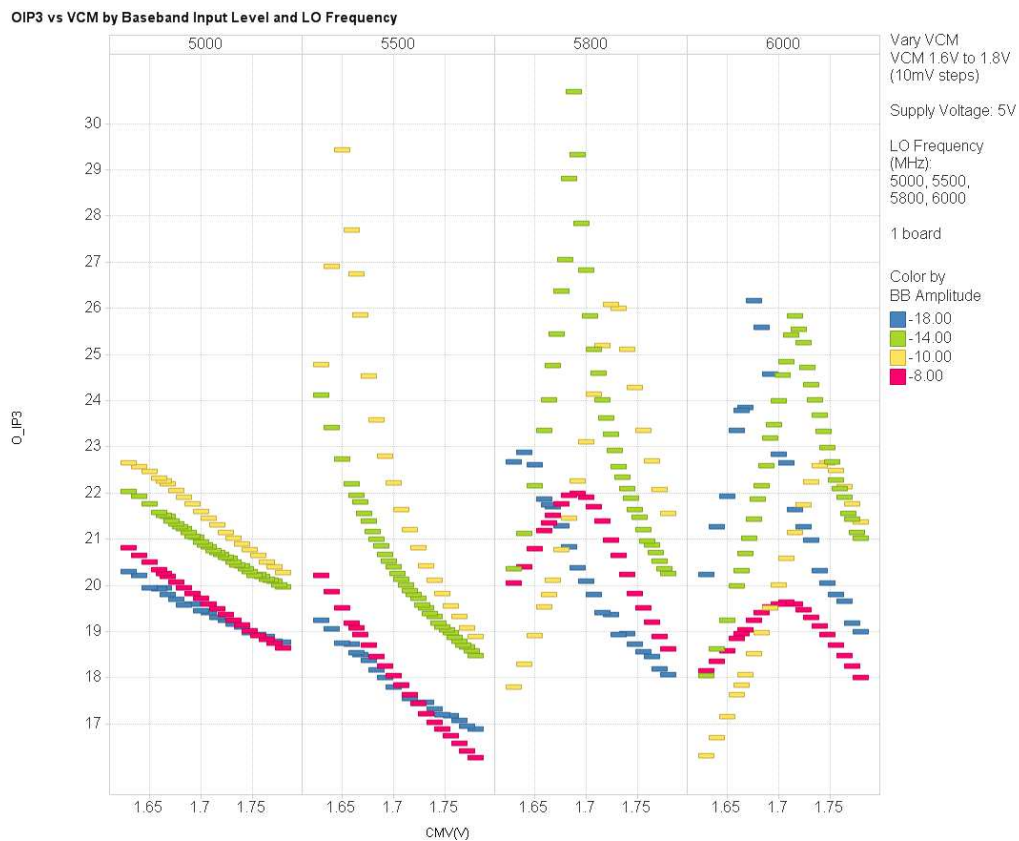


Figure 7. TRF370417 OIP3 vs Vcm at LO Frequencies (MHz) = 5000, 5500, 5800, 6000 at Baseband Input levels (dBm) =  $-8.0$ ,  $-10.0$ ,  $-14.0$ ,  $-18.0$



Figure 8 shows that the optimal Vcm setting varies with process variations. This implies that to obtain optimal OIP3 performance, perform a unique Vcm calibration on each unit.

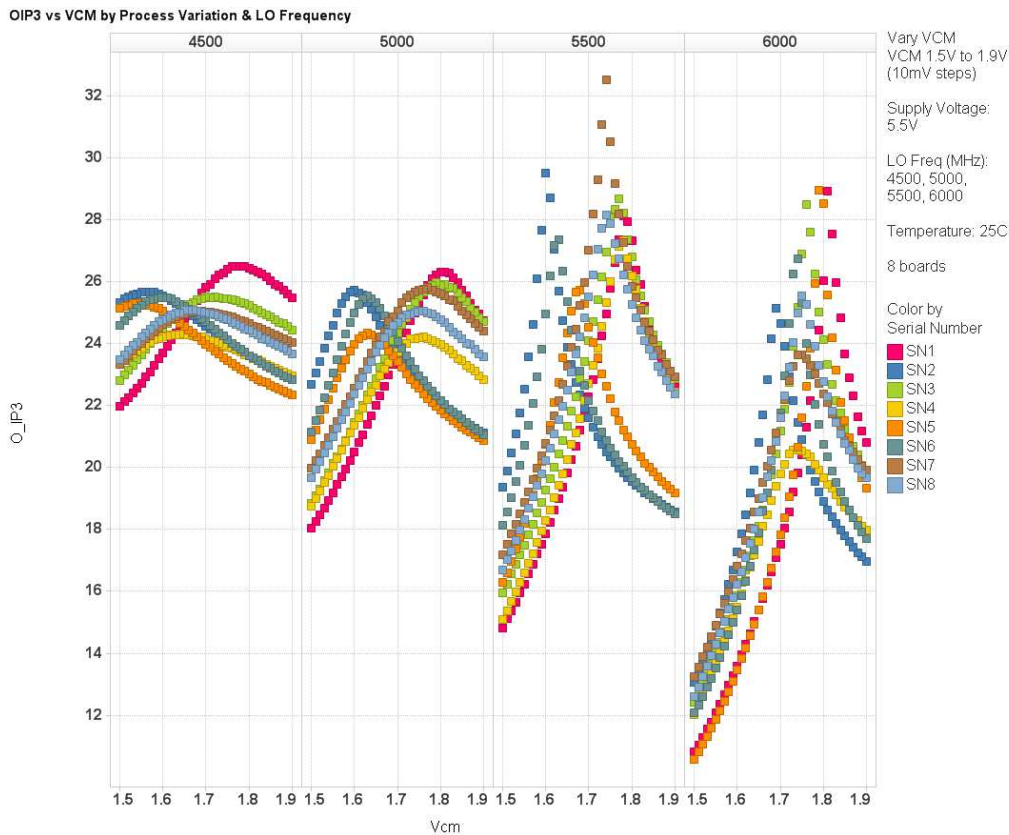


Figure 8. TRF370417 OIP3 vs Vcm - Process Variation at LO Frequencies (MHz) = 4500, 5000, 5500, 6000

Section 3 discusses recommendations for single LO frequency and multiple LO frequency calibration procedures. Section 4 provides the optimal Vcm temperature-setting coefficients for applications that have a wide operating temperature range.

### 3 Single and Multiple LO Frequency OIP3 Calibration Recommendations and Summary

Section 1 and Section 2 showed that OIP3 performance is improved by optimizing the Vcm level of the TRF370417's baseband inputs. It was also shown that this optimal Vcm setting varies with frequency, temperature, baseband input amplitude, process variation and supply voltage at LO frequencies beyond 4.5 GHz. The goal of this section is to compare a single and a multiple LO frequency OIP3 calibration procedure. The 8 EVM boards discussed in Figure 9 to Figure 12 include units from 3 FAB lots, 3 assembly lots and 3 EVM lots to account for process variation.

Figure 9 provides the baseline OIP3 response vs LO frequency without a Vcm calibration procedure. In Figure 9, Vcm is set to 1.7 V, as recommended by the datasheet.

For a single LO frequency Vcm calibration, calibrate at the fastest LO frequency that will be used in an application. As an example, if an application is specified up to 5.8 GHz, then it is recommended to measure OIP3 with a Vcm varied from 1.5 V to 1.9 V at a LO frequency equal to 5.8 GHz. This calibrated Vcm level at 5.8 GHz is then used for all other LO frequencies. Figure 10 and Figure 11 provide the calibrated OIP3 vs LO frequency response by performing calibrations at 5.8 GHz, and 6 GHz, respectively. The single LO frequency Vcm calibration provides OIP3 results equal to, or improved when compared to baseline OIP3 response shown in Figure 9. For LO frequencies less than 4.5 GHz, the user can set Vcm equal to 1.7 V, or to the calibrated Vcm voltage.

For applications that require optimal OIP3 performance at several LO frequencies, a multiple frequency Vcm calibration should be performed. Figure 12 provides the OIP3 results of calibrating Vcm at all LO frequencies.

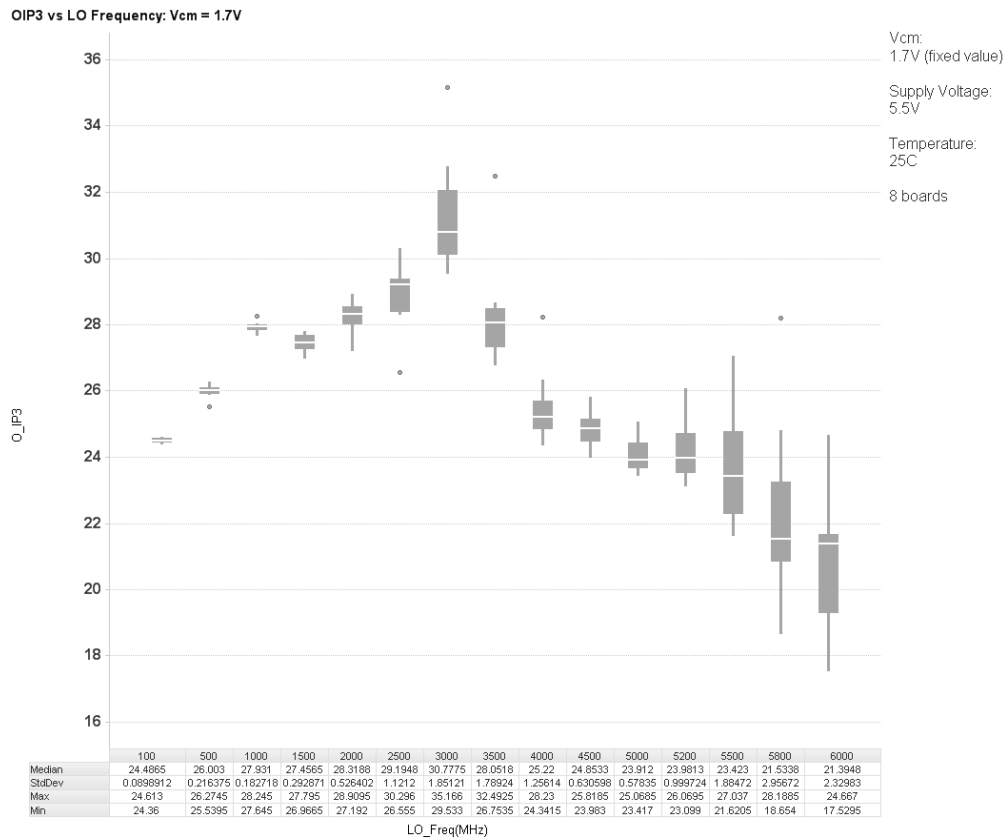
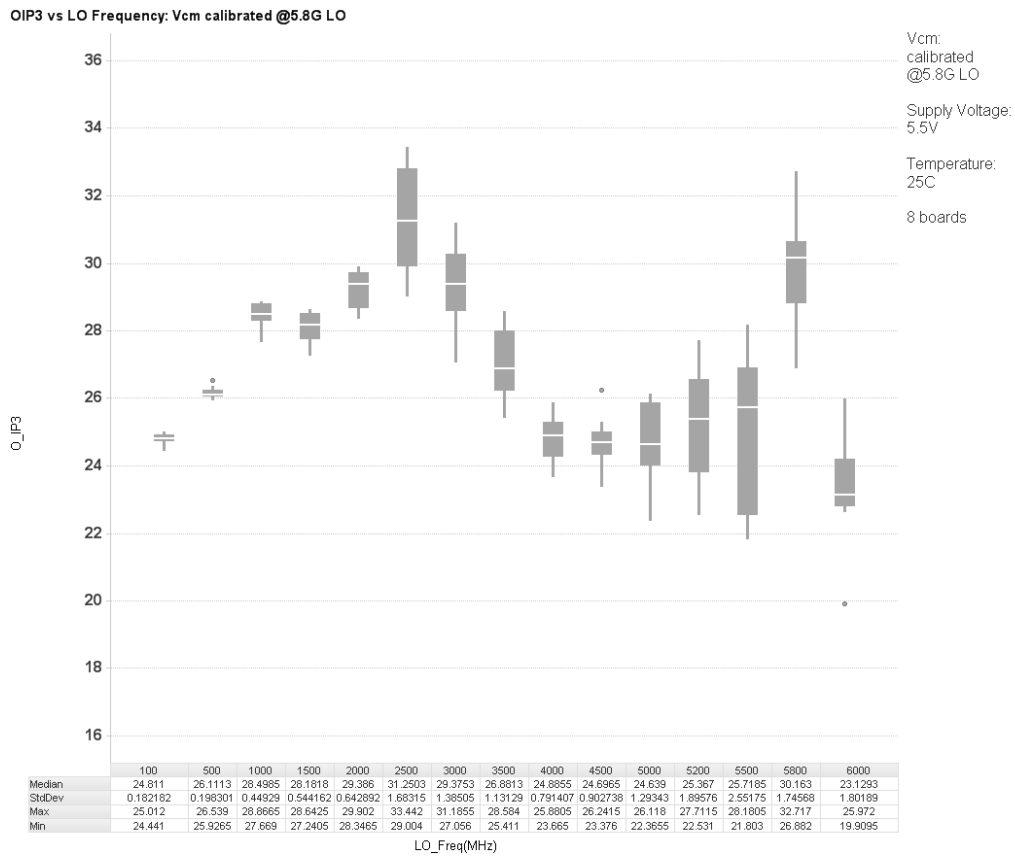


Figure 9. TRF370417 OIP3 vs LO Frequency – No Calibration Vcc = 5.5 V, Vcm = 1.7 V (Fixed – Datasheet Default)



**Figure 10. TRF370417 OIP3 vs LO Frequency – Single LO Frequency Calibration at 5.8 GHz, Vcc = 5.5 V, Vcm = Calibrated Result**

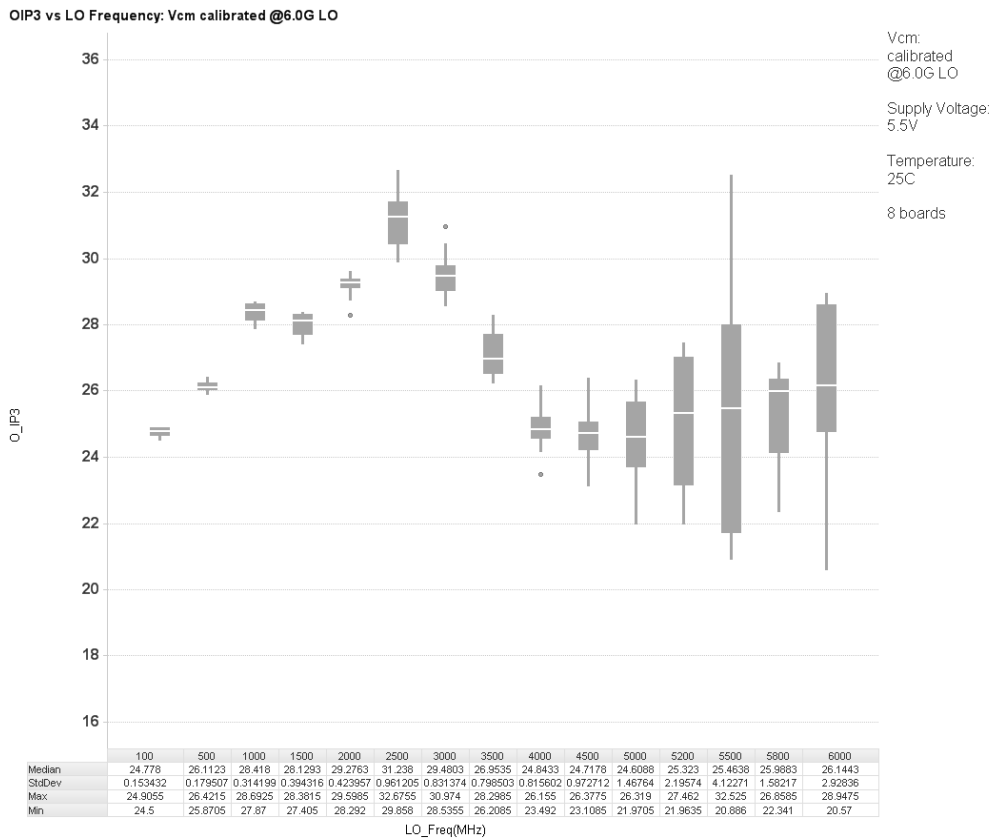


Figure 11. TRF370417 OIP3 vs LO Frequency – Single LO Frequency Calibration at 6.0 GHz, Vcc = 5.5V, Vcm = Calibrated Result

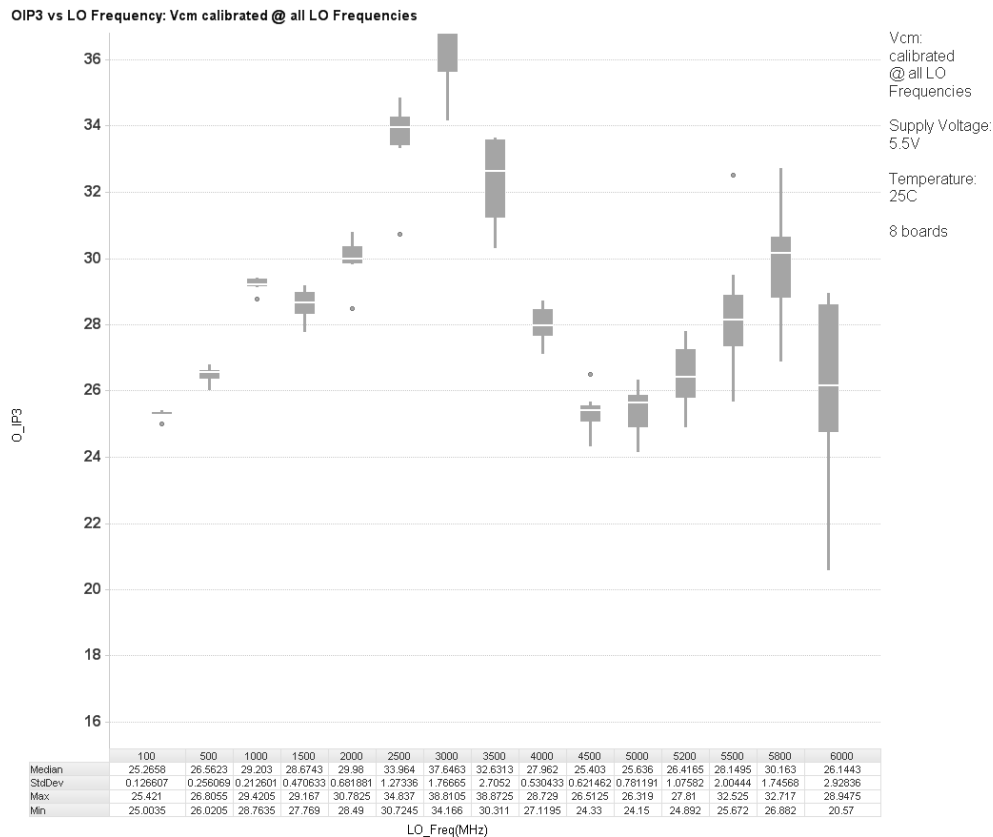


Figure 12. TRF370417 OIP3 vs LO Frequency – All Frequency Calibration, Vcc = 5.5 V, Vcm = Calibrated Result

Table 1 provides a statistical comparison of the OIP3 results for the three cases discussed above; 1) no calibration, 2) single LO frequency calibration, and 3) multiple LO frequency calibration.

Table 1. TRF370417 OIP3 Calibration Procedure Comparison at 25°C

OIP3 results (dBm)						
VCM = 1.7V						
LO(MHz)	4500	5000	5200	5500	5800	6000
Median	23.9	23.9	23.9	23.4	21.5	21.4
stdev	0.63	0.58	1	1.9	3	2.3
max	25.8	25	26	27	28.1	24.7
min	23.9	23.4	23.1	21.6	18.6	17.5
VCM calibrated at LO = 5.8GHz						
LO(MHz)	4500	5000	5200	5500	5800	6000
Median	24.7	24.6	25.4	25.7	30.1	23.1
stdev	0.9	1.3	1.9	2.5	1.7	1.8
max	26.2	26.1	27.7	28.2	32.7	26
min	23.4	23.4	22.5	21.8	26.8	19.9
VCM calibrated at LO = 6.0GHz						
LO(MHz)	4500	5000	5200	5500	5800	6000
Median	24.7	24.6	25.3	25.5	25.9	26.1
stdev	0.9	1.5	2.2	4.1	1.6	2.9
max	26.4	26.3	27.5	32.5	28.8	28.9
min	23.1	22	22	20.9	22.3	20.6
VCM calibrated at LO Frequencies						
LO(MHz)	4500	5000	5200	5500	5800	6000
Median	25.4	25.6	26.4	28.1	30.1	26.1
stdev	0.6	0.8	1	2	1.7	2.9
max	26.5	26.3	27.8	32.5	32.7	28.9
min	24.3	24.2	24.9	25.7	26.8	20.6

Figure 13 provides a rough idea of the TRF370417 optimal Vcm setting OIP3 minimums after a multiple LO frequency calibration. The dashes in Figure 13 represent the 5.5 V and 25°C optimal Vcm setting vs LO frequency for all 8 devices. SN4 was the worst-performing board at 5.5 V and 25°C. SN4 is represented by the yellow dashed curve. SN4's optimal Vcm setting's OIP3 measurements were repeated using the worst-case datasheet operating conditions of 4.5 V and 85°C, which is represented by the yellow circles in Figure 13.



Figure 13. TRF370417 OIP3 vs LO Frequency – All Frequency Calibration Comparing 4.5 V at 85°C to 5.5 V at 25°C

#### 4 OIP3 Calibration Over Temperature

Figure 6 shows that the optimal Vcm setting drifted over temperature based on a single unit trend. Many applications are not able to implement calibrations at more than one temperature due to cost and time constraints. Figure 14 plots the optimal Vcm setting TC by LO frequency. Figure 14 was generated from all 8 TRF370417 EVMs in this paper to determine process variation. For optimal OIP3 performance over temperature, the end user should calibrate the TRF370417 at a nominal temperature and use the information in Figure 14 for finding the optimal Vcm setting at other temperatures.

Figure 14 provides the average TC drift. For all units at a given frequency, the minimum and maximum TC value varied  $\pm 0.0004$  delta V/delta C from the average shown in Figure 14. This variation seen in TC from unit-to-unit is similar to the measurement repeatability of this experiment. A rough measurement repeatability of 0.0004 delta V/delta C can be calculated from the Vcm step size (10 mV) divided by the temperature range (85°C–50°C = 25°C). This result indicates the average TC drift shown in the plot is the best number to consider as it averages out the measurement repeatability error.

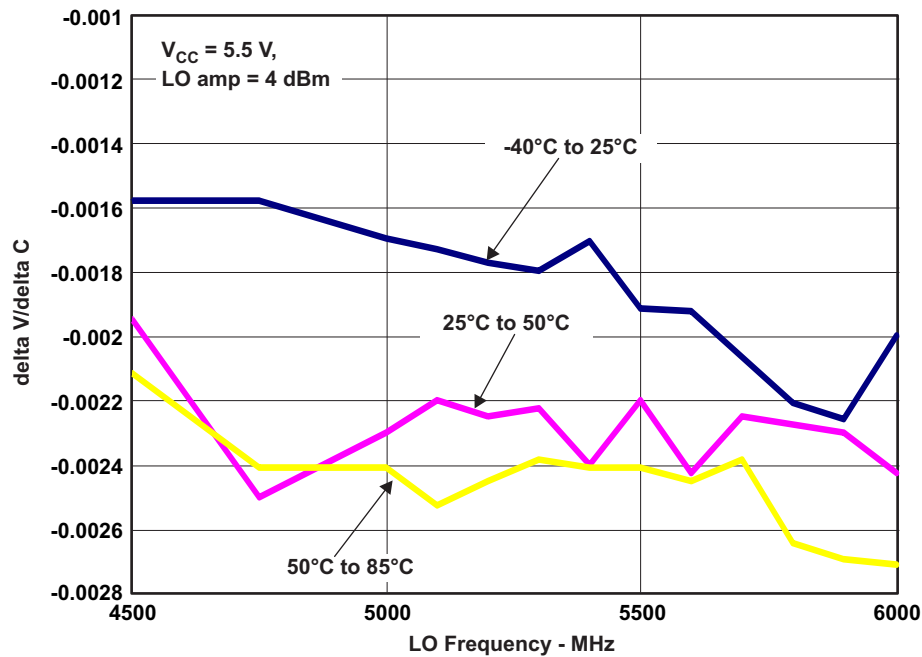


Figure 14. TRF370417 Optimal Vcm Setting TC vs LO Frequency

#### 4.1 Summary

In summary, to optimize the TRF370417 OIP3 for LO frequencies beyond 4.5 GHz it is recommended to:

1. Set  $V_{CC} = 5.5\text{ V}$ , see [Figure 5](#)
2. Power the TRF370417 with a low drift supply, see [Figure 5](#)
3. Set the baseband input level to a fixed amplitude, see [Figure 7](#)
4. Implement a OIP3/Vcm calibration procedure, see [Figure 5](#) to [Figure 8](#), and sections [Section 3](#) and [Section 4](#)

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