AN RFMD® REFERENCE MANUAL

RF205x Calibration User Guide

Integrated Configurable Components from RFMD Multi-Market Products Group

CONTENTS

1. INTRODUCTION

The basic philosophy behind the RF205x product family is to offer a high-linearity broadband mixer along with frequency generation capability to support a RF frequency range of approximately 50MHz to 2500MHz, and an IF frequency range of approximately 50MHz to 2500MHz.

While many users of the devices will not need to cover the entire frequency range at once (for whom automatic calibration will work perfectly well), some will; this guide is aimed at those users.

To reliably cover the Local Oscillator frequency range of 300MHz to 2400MHz it is necessary to calibrate the voltage controlled oscillators (VCOs) to maintain the loop bandwidth characteristics. This document explains how the different calibration mechanisms included on the chips work to achieve this.

Two calibration mechanisms are provided on the chip, both can be operated either in an automatic mode or under user control. In the automatic mode operation is completely transparent to the user. The first mechanism is Coarse Tune calibration (CT Cal) designed to ensure the VCO tank circuit is tuned to the correct frequency. The second calibration mechanism is loop filter correction designed to tune out the effect of VCO tuning slope variations (KV Cal).

A tab[1] has been provided in the graphical user interface software provided with the evaluation board to enable users to investigate these features and perform the necessary calculations.

[1] *The "Calibration" tab.*

2. COARSE TUNING CALIBRATION

Coarse tuning calibration is required to ensure the VCO operates on the correct frequency. By default this calibration will occur every time the device is switched from standby into an operating mode.

2.1 VCO DESCRIPTION

The on-chip VCO actually consists of three separate VCOs covering the following ranges[2]:

VCO#	Frequency range (approx)
VCO1 (VCOSEL = 0)	1800MHz to 2500MHz
VCO2 (VCOSEL = 1)	1500MHz to 2100MHz
VCO3 (VCOSEL = 2)	1150MHz to 1650MHz[3]

The user must select the correct VCO for the frequency of operation, this task is not performed automatically by the chip but must be programmed into PLL1x0 and/or PLL2x0 registers[4]. It should also be remembered that the oscillation frequency of VCO3 is determined by an external inductor and is therefore subject to change depending on the PCB layout.

To keep the tuning sensitivity of the VCOs within an acceptable range, each VCO has a series of switched capacitors (see figure below) which are used to set the oscillating frequency of the VCO to approximately the right value. This task is performed automatically if the CT calibration enable bits are set[5]; however, there is a small time penalty introduced, approximately 1500 phase detector clock cycles (50us to 60us at 26MHz phase detector frequency), into the frequency switching time to accomplish this task.

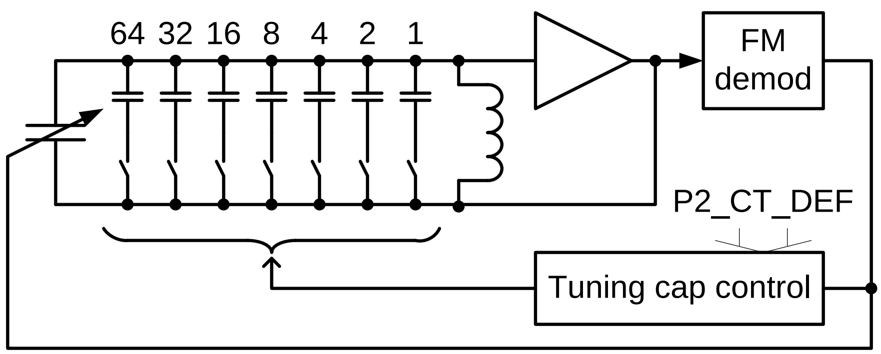

Figure 1. VCO Coarse Tuning

2.2 CALIBRATION METHOD

For the sake of simplicity, the following description will refer to the Path2 registers, but the same will apply to the Path1 if that is used.

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[2] The tuning range of each VCO is approximately +/-20% out of which some allowance has to be made for temperature effects.
[3] The tuning range of VCO3 depends on the external inductor value, the figures are taken from the RF2051 applications board.
[4] P1_VCOSEL and/or P2_VCOSEL respectively
[5] P1_CT_EN in PLL1x0 and P2_CT_EN in PLL2x0

2.2.1 Calibration Enabled

Automatic calibration is performed when the P2_CT_EN bits are set to 11 in the PLL2x0 register. A calibration is performed whenever the device is switched from standby to an active mode. The calibration mechanism uses a frequency-locked loop to switch the VCO capacitors to bring the varactor control voltage close to a predetermined level. This level is determined by the contents of P2_CT_V in the PLL2x5 register; the value is set to 1000 by default, ie mid-rail. Changing this value is not recommended without a careful analysis of the stability of the circuit operation with temperature, etc.

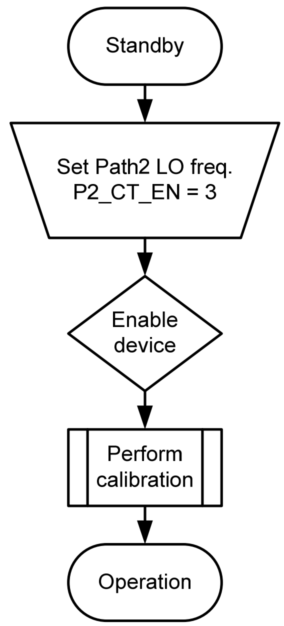

Figure 2. Coarse Tuning Autocalibration Flow

2.2.2 Manual Calibration Method

If P2_CT_EN is set to 00 then the user will have to load the correct coarse tune values into the P2_CT_DEF register when the frequency or VCO are changed. The following graph shows a typical variation of CT_DEF with frequency across the tuning range of the VCOs.

Since the P2_CT_DEF value changes when the frequency changes, if the VCO frequency is altered by more than a few MHz (the exact frequency being dependant on the VCO operating frequency) it would be advisable to program a new P2_CT_DEF value. From the graph it can be seen that for VCO2 the CT_CAL value varies from 0-127 over a frequency range of approximately 1400MHz to 2200MHz, corresponding to a change of CT_VAL every 6MHz on average.

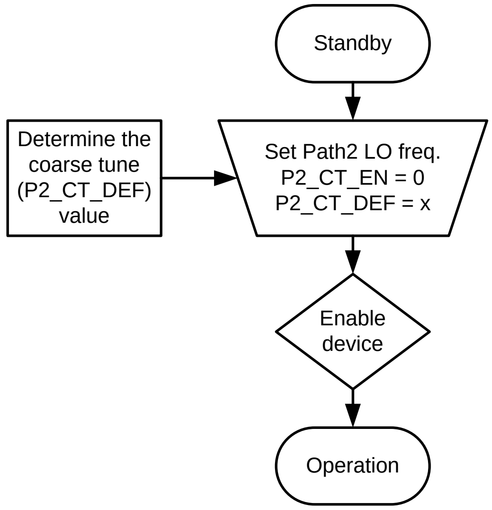

Figure 3. Coarse Tuning Manual Calibration

For a given value of P2_CT_DEF the varactor on the control input of the VCO will tune it by ±15MHz, again depending on the operating frequency and the choice of active or passive loop filter.

The easiest way to determine the required values for P2_CT_DEF is to perform an automatic calibration; once for a suitable number of frequencies, then to store the resulting values for later use. Since the curve is smooth it will be possible to perform an interpolation between frequency points to reduce the amount of storage required for the calibration data.

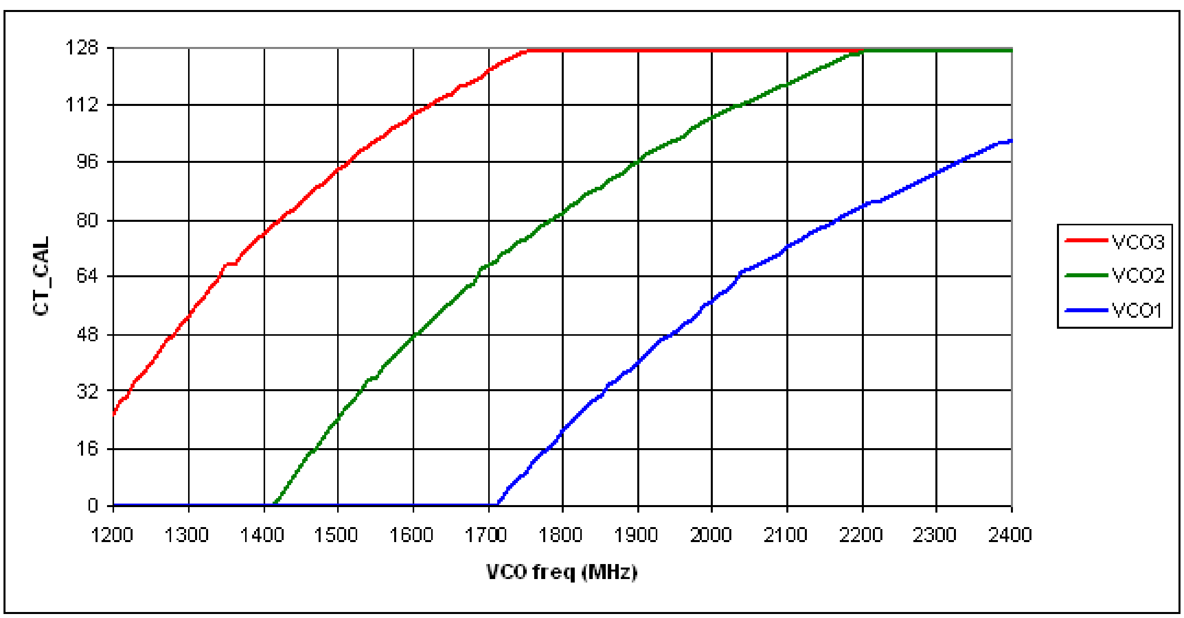

Figure 4. CT_CAL versus VCO Frequency (measured on RF2051 applications board at room temperature)

3. LOOP FILTER CALIBRATION

Loop filter calibration is required to ensure the loop filter frequency response is maintained over the operating frequency range of the application. In some applications requiring tight control over the loop filter characteristics it may be necessary to compensate for variations in VCO gain within the phase-locked loop. By default this calibration is disabled and in many applications it will not be necessary to enable it at all.

Also, in applications where a wide VCO frequency range is to be used, it may be necessary to account for the variation of the synthesizer divider ratio over the operating frequency range. Again this will not be required in many applications but if the full frequency range of the VCO's is utilised then it may be desirable. However it should be remembered that the device achieves its wide frequency range by using dividers in the LO path.[6]

For the sake of simplicity the following descriptions will refer to the path 2 registers, but the same will apply to the path 1 if that is used.

3.1 VCO GAIN CALIBRATION DESCRIPTION

An automatic method of determining the VCO gain is provided on the chip. To enable the VCO gain compensation algorithm it is necessary to set the P2_KV_EN bits. It is also necessary to set the device up to perform the calibration as discussed below.

3.1.1 Setting Up the Device for VCO Gain Calibration

Before a successful VCO gain calibration can be performed it is necessary to set up the device programming registers in the correct way:

- The NBR_KV_AVG bits in CFG2 are set to their maximum value (7). This sets the number of averages performed on the result to its maximum value for maximum accuracy. Reducing the number will speed up the calibration but reduce its accuracy.
- The TKV1 and TKV2 bits in CFG3 are set to their maximum (15). These set the settling time allowed for the frequency locked loop used in the calibration process. Reducing the number will speed up the calibration but reduce its accuracy.
- The P2_DN bits are calculated and programmed into the device. These bits set the frequency offset used to measure the VCO gain.
- The KV_RNG bit in CFG2 is left at 1. This sets the accuracy of the voltage measurement used in the calibration process to 9 bits. Setting the value to 0 will speed up the calibration but reduce its accuracy.
- The P2_KV_EN bits in register PLL1x0 are set to 11.
- The device enabled to perform the calibration.
- The result of the calibration is stored in the CP_CAL register.

An internal algorithm takes the contents of the CP_CAL register and uses it to adjust the charge pump current to compensate for the variation in VCO gain.

[6] *If the division ratio has to be changed to achieve the operating frequencies then the VCO frequency range will be 1200MHz to 2400MHz. For example if the operating frequency range is 1100MHz to 1300MHz this will be achieved using a VCO range of 2200MHz to 2400MHz and an LO division ratio of 2, plus a VCO range of 1200MHz to 1300MHz with an LO division ratio of 1.*

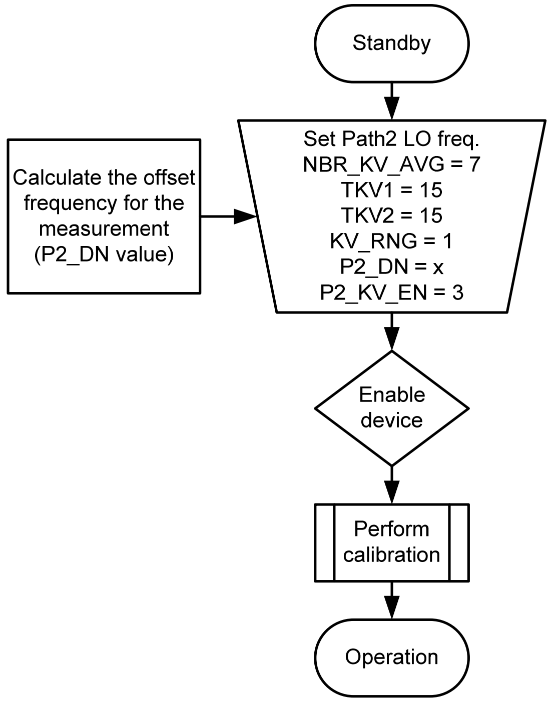

Figure 5. Automatic Charge Pump Calibration

As in the case of the coarse tuning calibration it is possible to turn off the calibration and manually set the required values. This is done by setting the P2_KV_EN bits to 00 and writing the calibration data to the P2_CP_DEF bits in the PLL2x0 register.

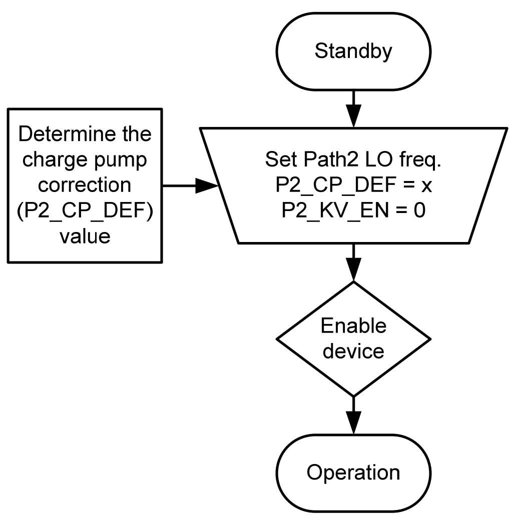

Figure 6. Manual Charge Pump Calibration

3.1.2 Determining the Required Frequency Offset

As discussed previously, the VCO gain calibration is performed by setting a frequency offset and measuring the change in VCO control voltage that results. This change is a measure of the VCO gain and is used to correct the charge pump current to maintain the loop filter gain.

It is therefore important to set the frequency shift to the correct value to ensure the measured voltage change, represented by CP_CAL, returns a value of 31 for the nominal VCO gain[7]:

$$P2\_DN = 75 * KV_{nom} / F_{pd}$$

where KV_{nom} is the VCO gain used to determine the loop filter components, in MHz/V
and F_{pd} is the phase detector frequency, in MHz

For the RF2051 applications board a typical value of P2_DN would be 75 * 20 / 26 = 56.

3.2 VCO OPERATING FREQUENCY COMPENSATION

A commonly used approximation to the loop filter response is given in the equation below:

$$F(s) = H(s) . K_{PD} . K_{VCO} / N$$

where H(s) is the open loop frequency response (determined by the loop filter components)
K_{PD} is the phase detector gain
K_{VCO} is the VCO gain and
N is the synthesizer divider ratio

The open loop frequency response is determined by the loop filter components and is therefore constant for any particular design of loop filter. However, K_{PD}, K_{VCO} and N can all vary.

In the previous section we described the internal algorithm for compensating for variations in the VCO gain by adjusting the charge pump current to keep the product of K_{PD} and K_{VCO} constant and hence F(s). This algorithm assumes that there has only been a small variation in N and is has been ignored since if the variation of N is small then further compensation will not be required.

However, if the frequency range of the VCO is large it may be desirable to compensate for the variation in division ratio. This may occur for two reasons:

1. The desired frequency range is large.
2. The desired frequency range requires the LO divider ratio to be changed. For example a frequency range of 1100MHz to 1300MHz will be covered by using VCO1 from 2200MHz to 2400MHz with an LO divider ratio of 2 and VCO3 from 1200MHz to 1300MHz with an LO divider ratio of 1. The VCO range is therefore 1200MHz to 2400MHz with its correspondingly wide divider ratio range.

In this case the CP_CAL correction value can be modified to account for the change in the N value.

The easiest way to achieve this is to determine the loop filter values for a nominal VCO value which would be the geometric mean of the minimum and maximum VCO frequencies. The CP_CAL value is then measured at the desired operating frequency and then scaled by the ratio $F_{nominal} / F_{wanted}$[8] as shown in the following formula:

$$CP\_CAL_{corrected} = CP\_CAL_{measured} * F_{nominal} / F_{wanted}$$

[7] *Typically 20MHz/V for the RF2051*
[8] *Note the CP_CAL value is, in fact, proportional to the reciprocal of the VCO gain*

A less accurate method would be to use the nominal CP_CAL value in the above calculation instead of measuring it at every frequency.

Alternatively the VCO gain could be measured at a few frequencies and the value interpolated. Care should be taken with this approach since there will be discontinuities in the shape of the VCO curve when the different VCO's are selected. It would be wise to make measurements of CP_CAL at the minimum and maximum frequencies used for each VCO required to cover the frequency range desired. Taking the previous example it would be wise to measure CP_CAL at 1200MHz and 1300MHz using VCO3, and 2200MHz and 2400MHz using VCO1.

4. USING THE CALIBRATION TAB IN THE GUI

The calibration tab in the graphical user interface software provides a convenient way of investigating the calibration of the RF205x.

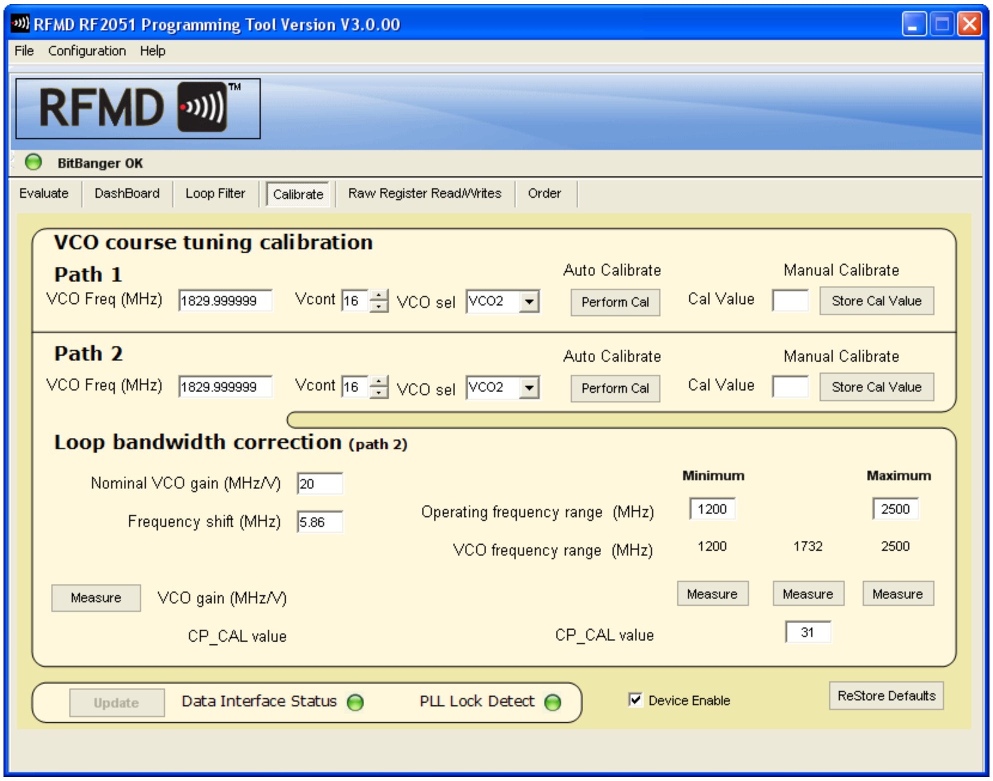

Figure 7. Calibrate Tab

A coarse tuning calibration is performed by clicking the “Perform cal” button. This will display the calibration value for the VCO frequency selected. The VCO select pull-down menu can be used to select an alternative VCO should this be desired. Should the user wish to change this value and save it to the device this is achieved by clicking the “Store cal value” button. This will set the device into manual CT calibration mode and save the value in the appropriate registers.

The VCO gain can be measured by setting the frequency for path 2 and clicking the “Measure” button having set the nominal VCO gain used to design the loop filter. The VCO gain and CP_CAL values are displayed.

If the user wishes to examine the effect of changing the VCO frequency the bottom right side of the GUI will facilitate this. By setting the minimum and maximum operating frequency the required VCO frequencies are displayed. Clicking on the “Measure” button will display the required CP_CAL value based upon the measured VCO gain and the divider ratio for the frequency concerned.