Application Note

Compensating IQ Mixer Imbalance in the SC2426

Number: SCT-AN19D5VC

Date: 2023-10-25

SIGNAL CRAFT TECHNOLOGIES

6815 – 8 Street NE, Suite 295
Calgary, AB T2E7H7 Canada
www.signalcraft.com

Revision History

Revision	Date	Author	Description
1.0	2023-10-25	W. Loo	Initial Release
1.1	2023-10-27	W. Loo	Formatting changes

Table of Contents

1. Overview

1.1 Introduction

The SC2426 RF Up/Down Converter is a stand-alone platform for use with signals in the 6 to 26 GHz range. A key component used in both the Transmit and Receive paths of the SC2426 is an IQ Mixer. This is highlighted in the block diagram of the SC2426 shown below:

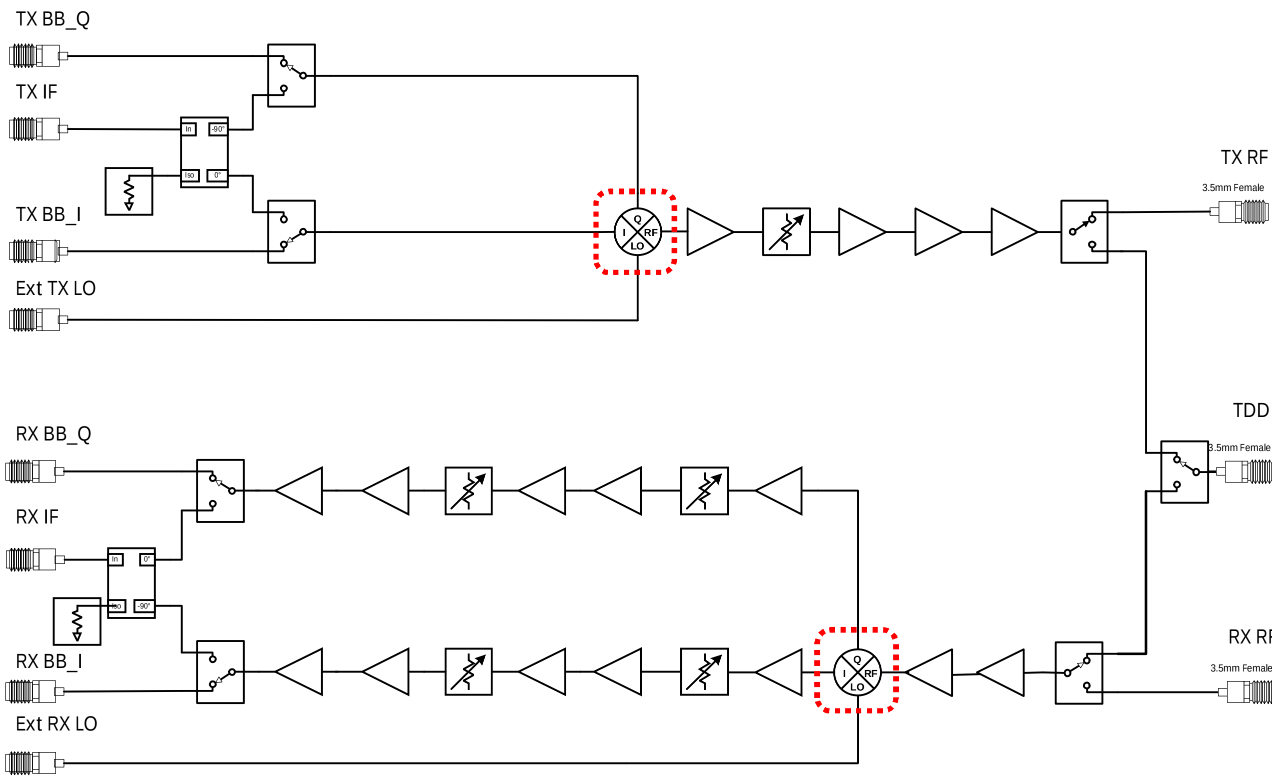

Figure 1 - Block Diagram of SC2426 RF paths

IQ mixers depend on phase and amplitude balance between the I and Q paths to achieve the best performance. Any IQ imbalance will result in LO feedthrough, RF/IF feedthrough and spurious products. However, due to manufacturing limitations, there will always be some degree of imbalance between the I and Q paths.

To compensate for these imbalances, a common technique is to apply independent DC bias voltages to each of the I and Q paths. By applying the appropriate DC bias voltage levels, the inherent imbalances can be greatly reduced and improve the performance of the system. The SC2426 provides a mechanism to apply the necessary independent DC bias voltages to the I and Q paths on the Transmit direction.
(NOTE: The mechanism is not available on the Receive direction. However, low pass filtering is applied on the Receive direction outputs that will largely eliminate the issue when the receive LO frequency is selected to be above the cutoff frequency of these filters.)

This document describes how to utilize the IQ DC bias feature of the SC2426 and a procedure to determine the suitable DC bias voltages to apply.

1.2 LO Leakage Characteristics

The following plot shows a typical LO leakage response when the adjustments are applied. (NOTE: In the plot, the DC I bias and Q bias adjustments are arbitrarily scaled. However negative values indicate negative bias voltage is being applied and positive values indicate the positive bias voltage is being applied).

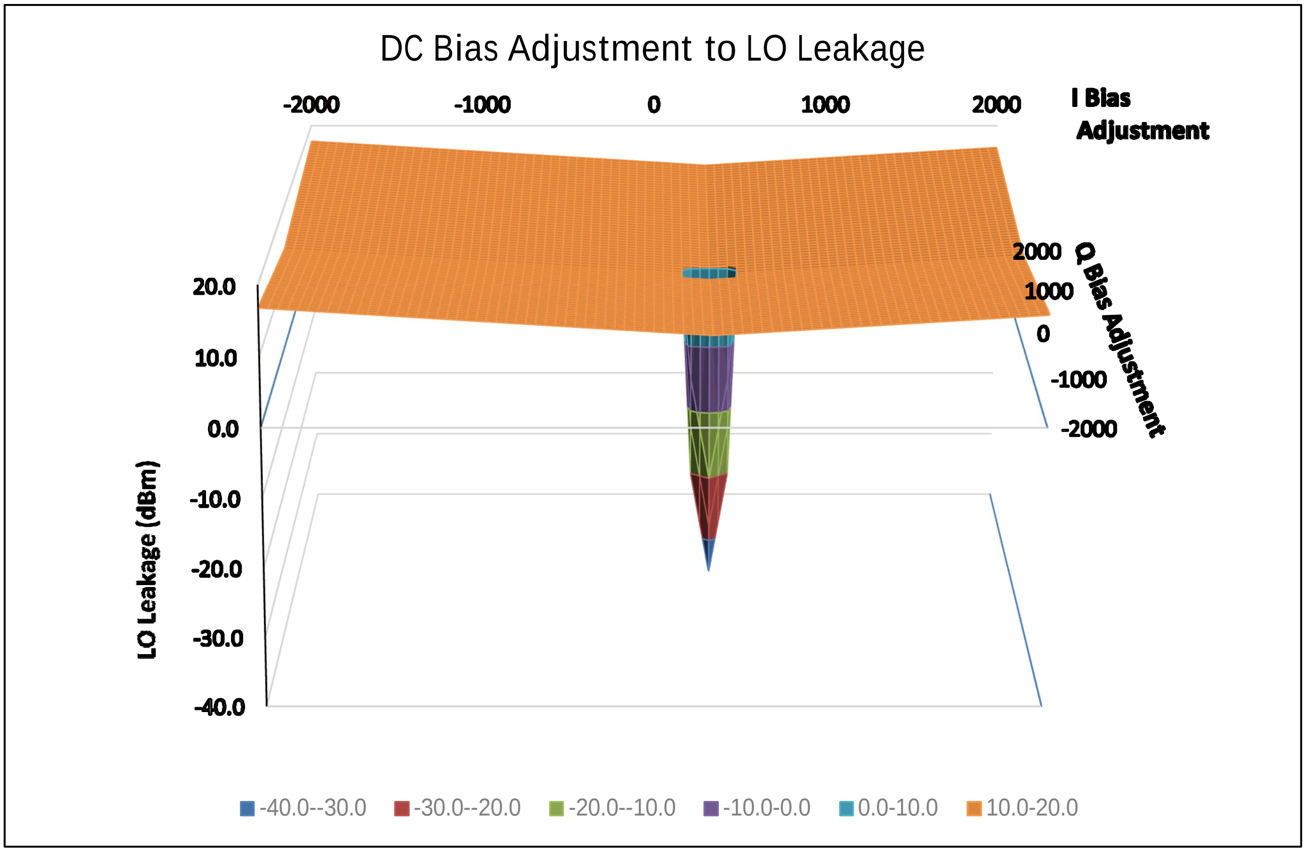

Figure 2 - DC Bias Adjustment Affect

A few observations can be noted:

1. Over most of the adjustment range, the LO leakage is relatively constant. In the above example, the typical nominal value is around +15dBm.

2. There is an ideal adjustment point where the LO leakage is at a minimum. This will vary greatly depending on the test conditions (LO frequency, LO input power and temperature). The ideal point can be as low as 60 dB below the nominal value. In the above example, it is 50dB below the nominal or around -35 dBm and is located at I Bias Adjustment = 300 and Q Bias Adjustment = -200.

3. The ideal adjustment point is in a very narrow spot and may be difficult to find. It may also vary over temperature making operation at the ideal point unrealistic. However, near the ideal point, the LO leakage will have a sharp roll off. Therefore, there is a relatively large region where there is at least a 30dB reduction from the nominal value. This area is large enough that it should be relatively easy to find and operate in.

Based on these characteristics, it is clear that the procedure for finding the I bias and Q bias adjustment is a 2-dimensional search for minima point (or an area reasonably close to the minima point).

2. Support Commands

2.1 Protocols

There are 2 protocols available to configure and control the SC2426:

- Console Protocol – An ASCII Protocol that operates over the USB and Control Port UART interfaces. This protocol is intended as a simple user-friendly interface for interactive control of the hardware.
- Binary Protocol – A Binary Protocol operates over the Expansion Control Port SPI Interface. This protocol is intended as an alternative suitable for interfacing with an external microcontroller or FPGA. Additionally, the SPI interface operates at higher speeds required for time-critical applications.

Both protocols are described in detail in the API specification, titled "SCT-SW19D5VC - SC2426 API Specification".

This document will focus on utilizing the Console Protocol. The equivalent commands for utilizing the Binary Protocol can be found in the API specification.

2.2 Console Protocol Commands

The 2 commands specifically related to the IQ DC bias adjustment are:

- IQPATH:DCBIAS - Sets the DC bias of the specified IQ path.
    - Syntax:
      IQPATH:DCBIAS <channel ID> <path> <I bias> <Q bias>
    - Arguments:
        - channel ID: <32 - 47>
        - path: <TX | RX>
            - TX – transmit/upconverter
            - RX – receive/downconverter
        - I bias: <-2048 to 2047> (default 0).
        - Q bias: <-2048 to 2047> (default 0)
    - Example Usage:
      > IQPATH:DCBIAS 32 TX -300 450
      OK

- IQPATH:DCBIAS? - Gets the DC bias adjustment for the specified IQ Path.
    - Syntax:
      IQPATH:DCBIAS? <channel ID> <path>
    - Arguments:
        - channel ID: <32 - 47>
        - path: <TX | RX>
            - TX – transmit/upconverter
            - RX – receive/downconverter
    - Example:
      > IQPATH:DCBIAS? 32 TX
      -300 450
      OK

It should be noted that the adjustment ranges are in arbitrarily scaled units. The relationship between the units and actual voltage may change with different iterations of the SC2426 hardware. The user should not be concerned about the absolute DC voltages that are actually being applied.

Additional commands are required to enable other SC2426 hardware elements as part of the compensation procedure. All commands are documented in the API specification.

3. Detailed Procedure

3.1 Overview

The overall procedure is an iterative search. The major steps after setup are summarized below:

1. Determine the nominal LO leakage level by sampling levels spread across the available I bias and Q bias range.
2. Set a starting point for the I bias and Q bias search.
3. While holding the Q bias value constant, vary the I bias value until a local minima is found for the LO leakage power level.
4. While holding the I bias value constant, vary the Q bias value until a local minima is found for the LO leakage power level.
5. Repeat steps 3 and 4 until the LO leakage power level has reduced from the nominal level from step 1 to a satisfactory level.

3.2 Required Equipment

- SC2426
- PC with USB interface to communicate with SC2426
- Signal generator for LO (the frequency range for the SC2426 is 6GHz to 26GHz).
- Spectrum Analyzer or Power Meter suitable for the LO frequency selected

3.3 Transmit Path Procedure

3.3.1 Setup

Using the “Config Port”, set the SC2426 to behave as a “Master” and set the ID bits 00. This will result in a channel ID of 32 for the unit.

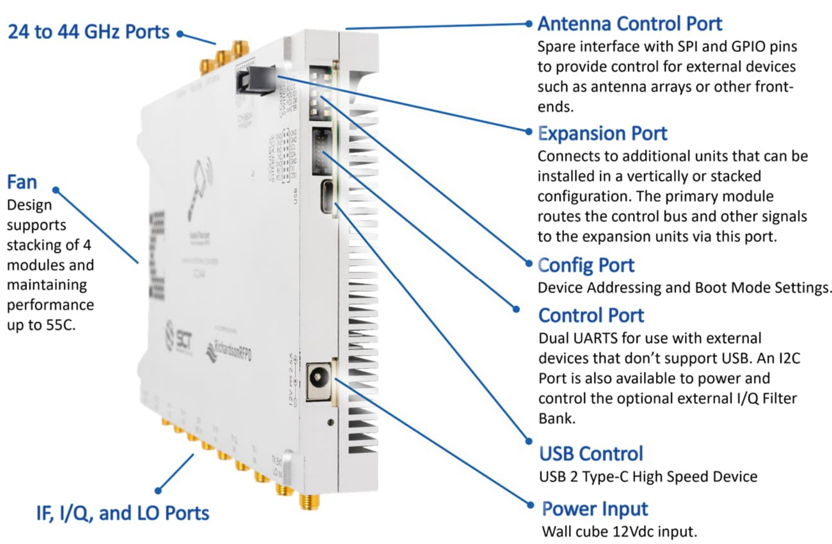

Figure 3 – SC2426 Hardware

Name	Description
Master/Slave	• Master Role = Down
Channel ID0/ID1	• Channel ID 32 = ID1 (Down), ID0 (Down)
BOOT0/1	Reserved. For normal operation, the switch positions must be as follows: • BOOT0 = Up • BOOT1 = Down

Table 1 - Configuration DIP Switch Settings

The basic setup is to inject the test LO signal from the signal generator into the “TX EXT LO IN” port and measure the output at the “TX FDD OUT” port. This is shown in the figure below. (NOTE: All unused ports should be terminated with 50R loads).

The power level for the LO signal injected into the “TX EXT LO IN” port should be around 0dBm. The LO leakage power level is then observed at the “TX FDD OUT” port.

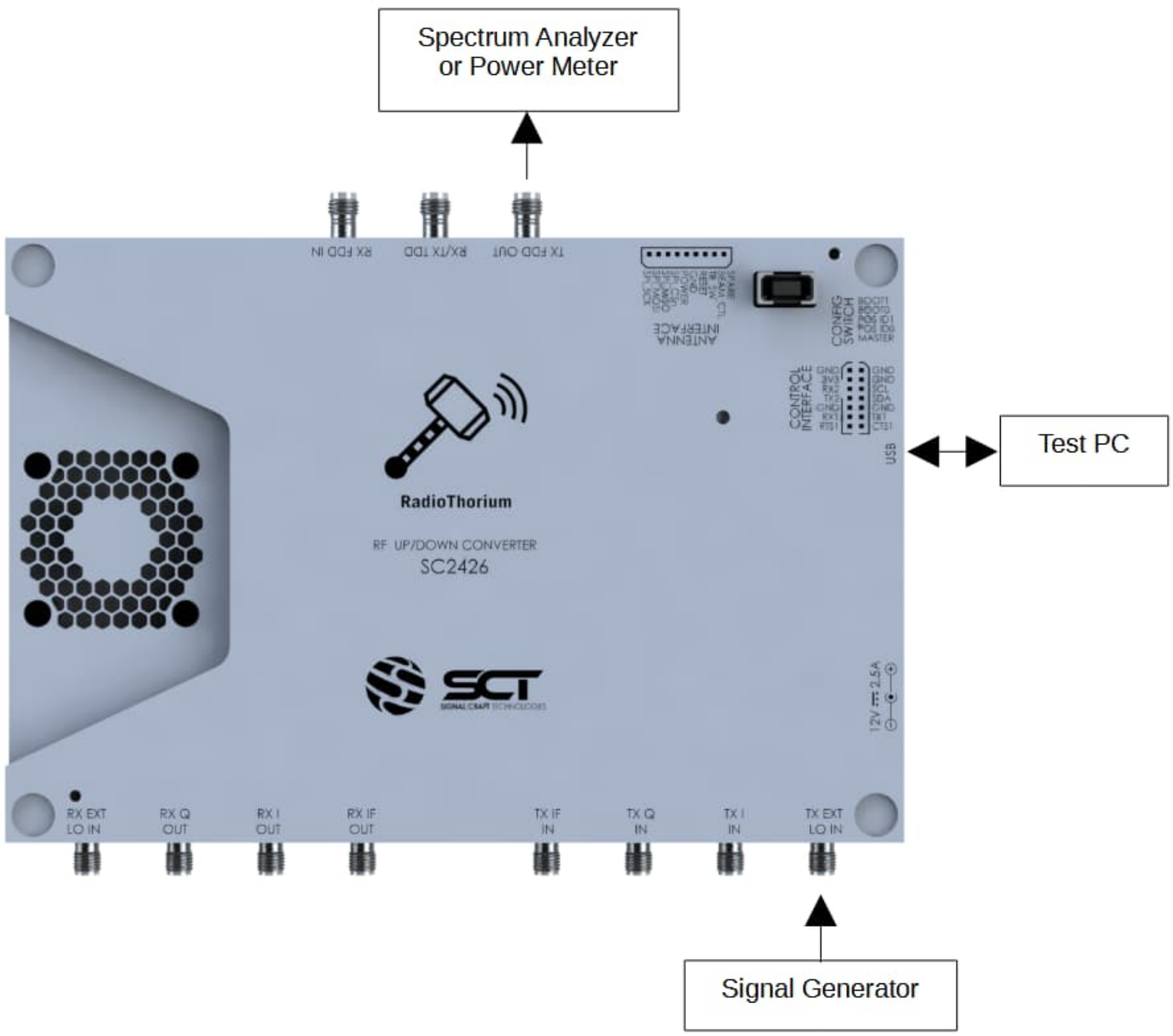

Figure 4 - Basic Test Setup

3.3.2 Initialization

The following commands are used on the console port to set the SC2426 into the required state for the search process.

```
// Turn on the internal PAs to enable signal outputs
BIAS:SEQ 32 1

// Set the TX RF path to FDD mode
RFPATH:PATH 32 TX FDD

// Set the TX RF path attenuators to 0
RFPATH:ATTN 32 TX 0
```

3.3.3 Search Process

Step 1: Determine the nominal LO leakage level

Poll 4 points spread out over the I bias an Q bias adjustment range to establish the nominal LO leakage level. The nominal value can be considered the highest LO leakage observed. The following commands are issued to get the 4 poll points.

```
BIAS:DAC 32 TX 1000 1000
BIAS:DAC 32 TX -1000 1000
BIAS:DAC 32 TX 1000 -1000
BIAS:DAC 32 TX -1000 -1000
```

Step 2: Set starting point

If all of the poll points from Step 1 are roughly the same, then a suitable starting point is to set I bias and Q bias as 0. However, if the poll results from Step 1 show one point that is substantially lower than the others, then that point can then be used as the starting point to reduce the search time.

A relatively coarse starting search step of 30 should be used in the following steps.

Step 3: I Bias Search

For this step, the Q bias level is held constant from the previous step.

- Establish the direction of the search by taking a reading with a positive search step and reading with a negative search step. The search direction will be whichever reading shows the LOWER LO leakage power level.

  NOTE: If the readings are too close (readings within 1dB may not be definitive), it may not obvious which direction should be taken. In that case, take additional readings in both directions at increasing multiples of the increment. (For example, if the first step readings are +/-30, then proceed to +/-60, +-/90 etc.) Repeat until the search direction is clear.

- One the direction is established, continue to take readings while adding/subtracting increasing multiples of the search step. Continue taking readings until the LO leakage power starts to INCREASE. Establish the I bias level as the one where the LO leakage power is at the lowest.

Step 4: Q Bias Search

For this step, the I bias level is held constant from the previous step.

- Establish the direction of the search by taking a reading with a positive search step and reading with a negative search step. The search direction will be whichever reading shows the LOWER LO leakage power level.

  NOTE: If the readings are too close (readings within 1dB may not be definitive), it may not obvious which direction should be taken. In that case, take additional readings in both directions at increasing multiples of the increment. (For example, if the first step readings are +/-30, then proceed to +/-60, +-/90 etc.) Repeat until the search direction is clear.

- One the direction is established, continue to take readings while adding/subtracting increasing multiples of the search step. Continue taking readings until the LO leakage power starts to INCREASE. Establish the Q bias level as the one where the LO leakage power is at the lowest.

Step 5: Evaluate and Adjust Increment

At this point, the I bias and Q bias levels will result in an LO leakage level that will be lower than the nominal established in Step 1. If the decrease is sufficient (a 30 dB reduction is reasonable), then the search can be terminated with the bias levels determined.

If the LO leakage level is not satisfactory, the search can continue. The search step should be reduced from the previous setting. A reasonable reduction in search steps is 30 -> 15 -> 5. There should be no need to search with a finer step size than 5 – however this can be further reduced to find a very precise operating point if desired.

Using the revised search step size and the last I bias and Q bias levels, Steps 3 and 4 can be repeated until the LO leakage level has been reduced to the target level.