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LMS6002 – Wide Band Multi Standard Radio Chip
- Programming and Calibration Guide -

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Contents

Revision History

Version 1.0r0
Released: Mar 16, 2010
Initial version constructed from new SPI and old 6002D programming guide documents.

Version 1.0r1
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Unnoticed change in 0x5F register documented

Version 1.1r0
Released: Oct 27, 2010
FREQSEL table updated. Calibration diagrams updated. VCOCAP selection algorithm added.

Version 1.1r1
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Diagram 4.3 corrected.

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Diagram 4.9 Updated.

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Register map updated. VCO selection algorithm added. Updated general DC calibratin procedure. Updated correction and Measurement functions Implemented in BB section.

Version 1.1r5
Released: Jan 15, 2014
Corrected register 0x42 and 0x43.

1

Serial Port Interface

1.1 Description

The functionality of LMS6002 transceiver is fully controlled by a set of internal registers which can be accessed through a serial port interface. Both write and read operations are supported. The serial port can be configured to run in 3 or 4 wire mode with the following pins used:

- SEN   serial port enable, active low;
- SCLK   serial clock;
- SDIO   serial data in/out in 3 wire mode, serial data input in 4 wire mode;
- SDO   serial data out in 4 wire mode, don't care in 3 wire mode.

Serial port key features:

- 16 serial clock cycles are required to complete write operation;
- 16 serial clock cycles are required to complete read operation;
- Multiple write/read operations are possible without toggling serial enable signal.

All configuration registers are 8-bit wide. Write/read sequence consists of 8-bit instruction followed by 8-bit data to write or read. MSB of the instruction bit stream is used as SPI command where CMD = 1 for write and CMD = 0 for read. Next 3 bits represent block address since LMS6002 configuration registers are divided into eight logical blocks as shown in Table 1. Remaining 4 bits of the instruction are used to address particular registers within the block as described in Section 2. Use address values from the tables.

Write/read cycle waveforms are shown in   Figure 1.1, Figure 1.2 and Figure 1.3. Note that write operation is the same for both 3-wire and 4-wire modes. Although not shown in the figures, multiple byte write/read is possible by repeating instruction/data sequence while keeping SEN low.
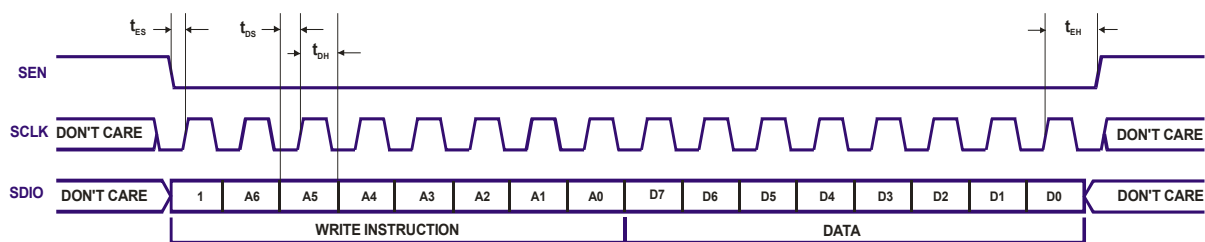
Figure 1.1: SPI write cycle, 3-wire and 4-wire modes
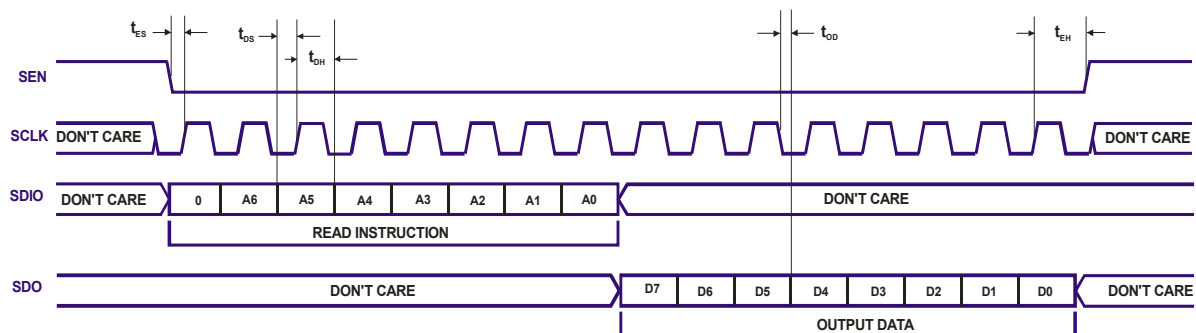
Figure 1.2: SPI read cycle, 4-wire mode (default)
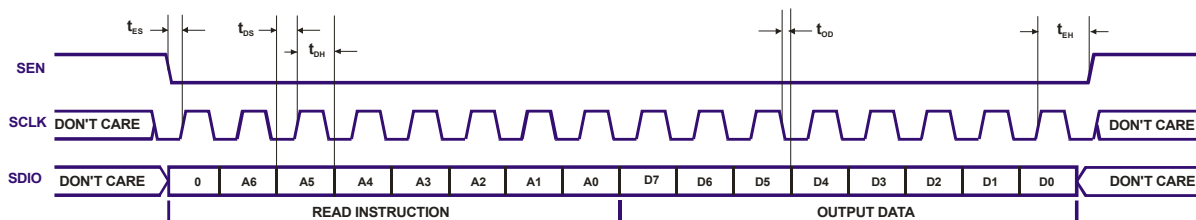
Figure 1.3: SPI read cycle, 3-wire mode

2

LMS6002Dr2 Memory Map Description

2.1 LMS6002Dr2 Memory Map

Table 1: LMS6002Dr2 memory map

Address (7 bits)	Description
x000:xxxx	Top level configuration (as in Table 2, Table 3, Table 4, Table 5)
x001:xxxx	TX PLL configuration (as in Table 6, Table 7, Table 8)
x010:xxxx	RX PLL configuration (as in Table 6, Table 7, Table 8)
x011:xxxx	TX LPF modules configuration (as in Table 9, Table 10)
x100:xxxx	TX RF modules configuration (as in Table 15, Table 17, Table 17)
x101:xxxx	RX LPF, DAC/ADC modules configuration (as in Table 9, Table 10, Table 103, Table 104)
x110:xxxx	RX VGA2 configuration (as in Table 18, Table 19)
x111:xxxx	RX FE modules configuration (as in Table 20, Table 21, Table 22)

2.2   Top Level Configuration

Table 2: Top level configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x00	7–6 5–0	Not used DC_REGVAL[5:0]: Value from DC calibration module selected by DC_ADDR. **Read Only.**

0x01	7–5
	
	4–2
	
	1
	
	0
		RCCAL_LPFCAL[2:0]: Value of the cal_core block in the LPF which calibrates the RC time constant.
		DC_LOCK[2:0]: Lock pattern register.
		      Locked, when register value is not "000" nor "111".
		DC_CLBR_DONE : indicates calibration status.
		    1 – calibration in progress;
		    0 – calibration is done.
		DC_UD: Value from DC module comparator, selected by DC_ADDR
		    1 – Count Up;
		    0 – Count Down.
		Read Only.

0x02	7–6 5–0	Not used DC_CNTVAL[5:0] : Value to load into selected (by DC_ADDR) DC calibration module. **Default: 00011111**

0x03	7–6
	5
	
	4
	
	3
	
	2–0
		Not used
		DC_START_CLBR: Start calibration command of the module, selected by DC_ADDR
		    1 – Start Calibration;
		    0 – Deactivate Start Calibration command. (**default**)
		DC_LOAD: Load value from DC_CNTVAL to module, selected by DC_ADDR
		    1 – Load Value;
		    0 – Deactivate Load Value command. (**default**)
		DC_SRESET: resets all DC Calibration modules
		    1 – Reset inactive; (**default**)
		    0 – Reset active.
		DC_ADDR[2:0]: Active calibration module address.
		    000 – LPF tuning module.
		    001-111 – Not used.
		Default: 00001000

0x04	7–4 3–0	VER[3:0]: Chip version REV[3:0]: Chip revision **Read only**. Default: 00100010

0x05	7
	
	6
	5
	
	4
	
	3
	
	2
	
	1
	
	0
		DECODE:
		    0 – decode control signals (**default**)
		    1 – use control signals from test mode registers.
		Not used
		SRESET: DSM soft reset
		    0 – reset state
		    1 – inactive (**default**)
		EN: Top modules enable
		    EN =0 – Top modules powered down
		    EN =1 – Top modules enabled (**default**)
		STXEN: Soft transmit enable
		    STXEN=0 – Transmitter powered down (**default**)
		    STXEN=1 – Transmitter enabled
		SRXEN: Soft receive enable
		    SRXEN=0 – Receiver powered down (**default**)
		    SRXEN=1 – Receiver enabled
		TFWMODE: Serial port mode
		    TFWMODE=0 – three wire mode
		    TFWMODE=1 – four wire mode (**default**)
		Not used
		Default: 00110010

Table 3: Top level configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description
0x06	7-4	Not used

	3	CLKSEL_LPFCAL: Select the clock for LPF tuning module
		    0 – 40 MHz clock generated from TX PLL output
		    1 – use PLL reference clock **(default)**

	2	PD_CLKLPFCAL: Power down on chip LPF tuning clock generation block
		    0 – powered up
		    1 – powered down **(default)**

	1	ENF_EN_CAL_LPFCAL: Enables the enforce mode. Passes FORCE_CODE_CAL_LPFCAL to RCCAL_LPFCAL.
		    0 – enforce mode disabled **(default)**
		    1 – enforce mode enabled

	0	RST_CAL_LPFCAL: Reset signal used at the beginning of calibration cycle. Reset signal needs to be longer than 100ns.
		    0 – normal state
		    1 – reset state **(default)**
		Default: 00001101

0x07	7	EN_CAL_LPFCAL: Enable signal. If =1--> the block is enabled. Should be enabled only during the RC calibration algorithm running.
		    0 – Block disabled (**default**)
		    1 – Block enabled

	6–4	FORCE_CODE_CAL_LPFCAL[2:0]: Input code coming from software. Will be passed to the output if ENF_EN_CAL_LPFCAL=1. 000 (**default**)

	3–0	BWC_LPFCAL[3:0]: LPF bandwidth control (Set this code to RXLPF BWC if RXLPF and TXLPF have different cut-off frequencies).
		    code Bandwidth [MHz]
		    =======================
		    0000 14 (**default**)
		    0001 10
		    0010 7
		    0011 6
		    0100 5
		    0101 4.375
		    0110 3.5
		    0111 3
		    1000 2.75
		    1001 2.5
		    1010 1.92
		    1011 1.5
		    1100 1.375
		    1101 1.25
		    1110 0.875
		    1111 0.75
		Default: 00000000

0x08	7	Reserved 0 – **default** value.
	6	LBEN_LPFIN: BB loopback enable. If =1, TX BB loopback signal is connected to RXLPF input. If enabled, RXTIA should be disabled (powered down) 0 – **default** value.
	5	LBEN_VGA2IN: BB loopback enable. If =1, TX BB loopback signal is connected to RXVGA2 input. If enabled, LPF should be disabled (powered down). 0 – **default** value.
	4	LBEN_OPIN: BB loopback enable. If =1, TX BB loopback signal is connected to the RX output pins. If enabled, RXLPF and RXVGA2 should be disabled (powered down) 0 – **default** value.

	3–0	LBRFEN[3:0]: RF loop back control. When activated, LNAs should be disabled (powered down).
		    0 RF loopback disabled (**default**)
		    1 TXMIX output connected to LNA1 path
		    2 TXMIX output connected to LNA2 path
		    3 TXMIX output connected to LNA3 path
		    4-15 Reserved. Not valid for settings.
		Default: 00000000

Table 4: Top level configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description
0x09	7	RXOUTSW: RX out/ADC in high-Z switch control
		0 – switch open (RX output/ADC input chip pins disconnected) **(default)**
		1 – switch closed, RXVGA2 should be powered off first
	6–0	CLK_EN[6:0]: Clock distribution control
	6	CLK_EN [6]: 1 – PLLCLKOUT enabled (**default**)
		0 – PLLCLKOUT disabled
	5	CLK_EN [5]: 1 – LPF CAL clock enabled
		0 – LPF CAL clock disabled (**default**)
	4	CLK_EN [4]: 1 – Rx VGA2 DCCAL clock enabled
		0 – Rx VGA2 DCCAL clock disabled (**default**)
	3	CLK_EN [3]: 1 – Rx LPF DCCAL clock enabled
		0 – Rx LPF DCCAL clock disabled (**default**)
	2	CLK_EN [2]: 1 – Rx DSM SPI clock enabled
		0 – Rx DSM SPI clock disabled (**default**)
	1	CLK_EN [1]: 1 – Tx LPF SPI DCCAL clock enabled
		0 – Tx LPF SPI DCCAL clock disabled (**default**)
	0	CLK_EN [0]: 1 – Tx DSM SPI clock enabled
		0 – Tx DSM SPI clock disabled (**default**)
		Default: 01000000
0x0A	7-2	Not used
	1	FDDTDD: Frequency/Time division duplexing selection
		0 – FDD mode **(default)**
		1 – TDD mode
	0	TDDMOD: TDD mode selection if FDDTDD=1
		0 – TDD Transmit mode **(default)**
		1 – TDD Receive mode
		Default: 00000000

Table 5: Top level configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x0B	7–5	Not used
	4	PDXCOBUF: XCO buffer power down
		0 – buffer powered up **(default)**
		1 – buffer powered down
	3	SLFBXCOBUF: XCO buffer self-biasing control
		0 – self biasing disabled
		1 – self biasing enabled **(default)**
	2	BYPXCOBUF: XCO buffer bypass
		0 – buffer active **(default)**
		1 – buffer bypassed
	1–0	PD[1:0]: Power down control for top modules:
		PD[1]: 1 – PD_DCOREF_LPFCAL powered down
		0 – PD_DCOREF_LPFCAL powered up **(default)**
		PD[0]: 1 – RF loop back switch powered up
		0 – RF loop back switch powered down **(default)**
		Default: 00001000
0x0E	5-0	00000001 – v1
		Read only
0x0F	7–0	SPARE1[7:0]: Spare configuration register.
		Default: 00000000

2.3   TX/RX PLL Configuration

Table 6: TX/RX PLL configuration memory map (user mode)

Address (7 bits)	Bits	Description
Tx: 0x10, Rx: 0x20	7–0	NINT[8:1]: Integer part of the divider (MSBs).* **Default:** "01000001"**0**, NINT=130.
Tx: 0x11, Rx: 0x21 Tx: 0x12, Rx: 0x22 Tx: 0x13, Rx: 0x23	7 6–0 7–0 7–0	NINT[0]: Integer part of the divider (LSB).* NFRAC[22:16]: Fractional part of the divider* NFRAC[15:8] * NFRAC[7:0] * **Default: 0**"010…0", NFRAC=0.25, f_{VCO}=130.25*40MHz=5.21GHz.
Tx: 0x14, Rx: 0x24	7 6–4 3 2 1 0	DITHEN: Dithering control 0 – disabled 1 – enabled (**default**) DITHN[2:0]: How many bits to dither if DITHEN=1 000 – 1 bit (**default**) 001 – 2 bits 010 – 3 bits … 111 – 8 bits EN: PLL enable 0 – PLL powered down 1 – PLL enabled (**default**) AUTOBYP: Delta sigma auto bypass when NFRAC = 0 0 – disabled **(default)** 1 – enabled DECODE: 0 – decode power down/enable signals (**default**) 1 – use power down/enable signals from test mode registers Reserved 0 – (**default**) **Default: "10001000"**
Tx: 0x15, Rx: 0x25	7-4 4-2 1-0	SELVCO[2:0]: VCO selection 000 – All VCOs powered down 100 – Low frequency VCO (vco4) 101 – Mid low frequency VCO (vco3) (**default**) 110 – Mid high frequency VCO (vco2) 111 – High frequency VCO (vco1) FRANGE[2:0]: PLL output frequency range selection 000 – All dividers powered down 100 – Fvco/2 (2-4GHz range) (**default**) 101 – Fvco/4 (1-2GHz range) 110 – Fvco/8 (0.5-1GHz range) 111 – Fvco/16 (0.25-0.5GHz range) SELOUT[1:0]: Select output buffer in RX PLL, not used in TX PLL 00 – All output buffers powered down 01 – First buffer enabled for LNA1 path (**default**) 10 – Second buffer enabled for LNA2 path 11 – Third buffer enabled for LNA3 path **Default**: "10110001"

* Shadow registered

Table 7: TX/RX PLL configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description

Tx: 0x16, Rx: 0x26	7	EN_PFD_UP: Enable PFD UP pulses
		    0 – disabled
		    1 – enabled **(default)**

	6	OEN_TSTD_SX:
		    0 – Test signal output buffer disabled **(default)**
		    1 – Test signal output buffer enabled

	5	PASSEN_TSTOD_SD:
		    0 – Test signal pass disabled **(default)**
		    1 – Test signal pass enabled

	4–0	ICHP[4:0]: Charge pump current. Binary coded, LSB = 100uA:
		    00000 – 0uA
		    00001 – 100uA
		
		    ...
		    11000 – 2400uA
		    ... – 2400 uA
		Default: "10001100", ICHP = 1.2mA

Tx: 0x17, Rx: 0x27	7	BYPVCOREG: Bypass VCO regulator
		    0 – not bypassed
		    1 – regulator bypassed **(default)**

	6	PDVCOREG: VCO regulator power down.
		    0 – regulator powered up
		    1 – regulator powered down **(default)**

	5	FSTVCOBG: VCO regulator band gap settling time control. Shorts the resistor in band gap to speed up charging for faster response. After the initial charge up, it should be disabled.
		    1 – resistor shorted **(default)**
		    0 – switch open

	4–0	OFFUP[4:0]: Charge pump UP offset current. Binary coded, LSB = 10uA:
		    00000 – 0uA
		    00001 – 10uA
		
		    ...
		    11000 – 240uA
		    ... – 240uA
		Default: "11100000" = 0mA

Tx: 0x18, Rx: 0x28	7–5	VOVCOREG[3:1]: VCO regulator output voltage control, 3 MSBs.
		LSB=100mV, VOVCOREG[3:0] coded as below
		    0000 – 1.4V, min output
		
		    ...
		    0101 – 1.9V **(default)**
		
		    ...
		    1100 – 2.6V, max output
		    1101, 1110, 1111, not valid codes

	4–0	OFFDOWN[4:0]: Charge pump DOWN offset current. Binary coded, LSB = 10uA:
		    00000 – 0uA
		    00001 – 10uA
		
		    ...
		    11000 – 240uA
		    ... – 240uA
		Default: "01000000" = 0mA

Tx: 0x19, Rx: 0x29	7	VOVCOREG[0]: VCO regulator output voltage control, LSB
	6	Not used

	5–0	VCOCAP[5:0]: Switch capacitance programming. Binary coded.
		    000000 (max capacitance, min frequency)
		    010100 **(default)**
		    111111 (min capacitance, max frequency)
		Default: "10010100", VCOCAP=20

Table 8: TX/RX PLL configuration memory map (test mode)

Address (7 bits)	Bits	Description
Tx: 0x1A, Rx: 0x2A	7 6 5–0	VTUNE_H (**Read Only**): Value from Vtune comparator VTUNE_L (**Read Only**): Value from Vtune comparator Reserved 000011 – **(default)** **Default:** "00000011"

Tx: 0x1B, Rx: 0x2B	7–4
	
	3
	
	2
	
	1
	
	0
		Reserved
		      0111 – **(default)**
		PD_VCOCOMP_SX: VCO Comparator Enable
		      0 – enabled (powered up) **(default)**
		      1 – disabled (powered down)
		Reserved
		      1 –**(default)**
		Reserved
		      1 – **(default)**
		Reserved
		      0 – **(default)**
		Default: "01110110", A value = 0, (N=130).

Tx: 0x1C, Rx: 0x2C	7-0	Reserved **Default**: "00111000"
Tx: 0x1D, Rx: 0x2	7-0	Reserved **Read only**
Tx: 0x1E, Rx: 0x2E	7-0	Reserved **Read only**
Tx: 0x1F, Rx: 0x2F	7-0	Reserved **Read only**

2.4   TX LPF Modules Configuration

Table 9: TX LPF configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x30	7–6	Not used
	5–0	DC_REGVAL[5:0]: Value from DC calibration module selected by DC_ADDR. **Read Only.**
0x31	7–5	Not used
	4–2	DC_LOCK[2:0]: Lock pattern register. Locked, when register value is not "000" nor "111".

	1	DC_CLBR_DONE : indicates calibration status.
		        1 – calibration in progress;
		        0 – calibration is done.

	0	DC_UD: Value from DC module comparator, selected by DC_ADDR
		        1 – Count Up;
		        0 – Count Down.
		Read only.

0x32	7–6	Not used
	5–0	DC_CNTVAL[5:0] : Value to load into selected (by DC_ADDR) DC calibration module. **Default: 00011111**
0x33	7–6	Not used

	5	DC_START_CLBR: Start calibration command of module selected by DC_ADDR
		        1 – start calibration;
		        0 – deactivate start calibration command. (**default**)

	4	DC_LOAD: Load value from DC_CNTVAL to module, selected by DC_ADDR
		        1 – Load Value;
		        0 – Deactivate Load Value command. (**default**)

	3	DC_SRESET: resets all DC Calibration modules
		        1 – Reset inactive; (**default**)
		        0 – Reset active.

	2–0	DC_ADDR[2:0]: Active calibration module address.
		        000 – I filter.
		        001 – Q filter.
		        010 – 111 Not used.
		Default: 00001000

0x34	7–6	Not used

	5–2	BWC_LPF[3:0]: LPF bandwidth control:
		        code Bandwidth [MHz]
		        =======================
		        0000 14 (**default**)
		        0001 10
		        0010 7
		        0011 6
		        0100 5
		        0101 4.375
		        0110 3.5
		        0111 3
		        1000 2.75
		        1001 2.5
		        1010 1.92
		        1011 1.5
		        1100 1.375
		        1101 1.25
		        1110 0.875
		        1111 0.75

	1	EN : LPF modules enable
		        0 – LPF modules powered down
		        1 – LPF modules enabled (**default**)

	0	DECODE:
		        0 – decode control signals (**default**)
		        1 – use control signals from test mode registers
		Default: 00000010

0x35 DCO_DACCAL_LPF renamed, no action required	7	Not used

	6	BYP_EN_LPF: LPF bypass enable
		        1 – bypass switches will bypass the LPF
		        0 – normal operation (**default**)

	5–0	DCO_DACCAL[5:0]: Resistor calibration control for the DC offset cancellation DAC. 001100 (**default**) **Default: 00001100**

Table 10: TX LPF configuration memory map (test mode)

Address (7 bits)	Bits	Description

0x36	7	TX_DACBUF_PD: TX data DAC buffers power down
		    0 – enabled (**default**)
		    1 – powered Down

	6–4	RCCAL_LPF[2:0]: Calibration value, coming from TRX_LPF_CAL module. 011 – (**default**)
	3	Not used.

	2	PD_DCODAC_LPF: Power down for the DAC in the DC offset cancellation block.
		    1 – Powered Down
		    0 – Enabled (**default**)

	1	PD_DCOREF_LPF: Power down signal for the dc_ref_con3 block.
		    1 – Powered Down
		    0 – Enabled (**default**)

	0	PD_FIL_LPF: Power down for the filter.
		    1 – Powered Down
		    0 – Enabled (**default**)
		Default: 00110000

0x3E	7-0	SPARE0[7:0]: Spare configuration register. **Default:** 00000000

0x3F	7	PD_DCOCMP_LPF: Power down DC offset comparators in DC offset cancellation block. Should be powered up only when DC offset cancellation algorithm is running.
		    1 – Powered Down
		    0 – Enabled (**default**)

	6-0	SPARE1[6:0]: Spare configuration register. **Default:** 00000000

2.5   RX LPF, ADC and DAC Modules Configuration

Table 11: RX LPF configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x50	7–6	Not used
	5–0	DC_REGVAL[5:0]: Value from DC Calibration module, selected by DC_ADDR. **Read Only**.
0x51	7–5	Not used
	4–2	DC_LOCK[2:0]: Lock pattern register. Locked, when register value is not "000" nor "111".
	1	DC_CLBR_DONE : indicates calibration status. 1 – calibration in progress; 0 – calibration is done.
	0	DC_UD: Value from DC module comparator, selected by DC_ADDR 1 – Count Up; 0 – Count Down. **Read Only.**
0x52	7–6	Not used
	5–0	DC_CNTVAL[5:0] : Value to load into selected (by DC_ADDR) DC calibration module. **Default: 00011111**
0x53	7–6	Not used
	5	DC_START_CLBR: Start calibration command on module, selected by DC_ADDR 1 – Start Calibration; 0 – Deactivate Start Calibration command. (**default**)
	4	DC_LOAD: Load value from DC_CNTVAL to module, selected by DC_ADDR 1 – Load Value; 0 – Deactivate Load Value command. (**default**)
	3	DC_SRESET: resets all DC Calibration modules 1 – Reset inactive; (**default**) 0 – Reset active.
	2–0	DC_ADDR[3:0]: Active calibration module address. 000 – I filter.(**default**) 001 – Q filter. 010 – 111 Not used. **Default: 00001000**
0x54	7–6	Not Used
	5–2	BWC_LPF[3:0]: LPF bandwidth control: code Bandwidth [MHz] ======================= 0000 14 **(default)** 0001 10 0010 7 0011 6 0100 5 0101 4.375 0110 3.5 0111 3 1000 2.75 1001 2.5 1010 1.92 1011 1.5 1100 1.375 1101 1.25 1110 0.875 1111 0.75
	1	EN_LPF : LPF modules enable 0 – LPF modules powered down 1 – LPF modules enabled (**default**)
	0	DECODE: 0 – decode control signals (**default**) 1 – use control signals from test mode registers **Default: 00000010**
0x55	7	Not Used
	6	BYP_EN_LPF: LPF bypass enable 1 – bypass switches will bypass the LPF 0 – normal operation (**default**)
	5–0	DCO_DACCAL[5:0]: Resistor calibration control for the DC offset cancellation DAC. 001100 (**default**) **Default: 00001100**

Table 12: RX LPF configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description
0x56	7	Not used.
	6–4	RCCAL_LPF[2:0]: Calibration value, coming from TRX_LPF_CAL module. 011 – (**default**)
	3	Not used.
	2	PD_DCODAC_LPF: Power down for the DAC in the DC offset cancellation block. 1 – Powered Down 0 – Enabled (**default**)
	1	PD_DCOREF_LPF: Power down signal for the dc_ref_con3 block. 1 – Powered Down 0 – Enabled (**default**)
	0	PD_FIL_LPF: Power down for the filter. 1 – Powered Down 0 – Enabled (**default**) **Default: 00110000**
0x57	7	EN_ADC_DAC : ADC/DAC modules enable 0 – ADC/DAC modules powered down 1 – ADC/DAC modules enabled (**default**)
	6	DECODE: 0 – decode ADC/DAC enable signals (**default**) 1 – use ADC/DAC enable signals from MISC_CTRL[4:0] register.
	5–3	TX_CTRL1[6:4]. DAC Internal Output Load Resistor Control Bits 111 – 50 Ohms 110 – 100 Ohms 101 – 66 Ohms 100 – 200 Ohms 011 – 66 Ohms 010 – 200 Ohms (**default**) 001 – 100 Ohms 000 – Open Circuit
	2	TX_CTRL1[3]. DAC Reference Current Resistor: 1 – External (**default**) 0 – Internal
	1–0	TX_CTRL1[1:0]. DAC Full Scale Output Current Control (single-ended): 11 – Iout FS=5ma 10 – Iout FS=2.5ma 01 – Iout FS=10ma 00 – Iout FS=5ma (**default**) **Default: 10010100**
0x58	7–6	RX_CTRL1[7:6]. Reference bias resistor adjust: 11 – 15uA 10 – 10uA 01 – 40uA 00 – 20uA (**default**)
	5–4	RX_CTRL1[5:4]. Reference bias UP: 11 – 2.5X 10 – 2.0X 01 – 1.5X 00 – 1.0X (**default**)
	3–0	RX_CTRL1[3:0]. Reference bias DOWN: 1111 – Min Bias … 0000 – Max Bias (**default**) **Default: 00000000**

Table 13 RX LPF configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description
0x59	7	Not Used
	6–5	RX_CTRL2[7:6]. Reference Gain Adjust: 11 – 1.25V 10 – 1.00V 01 – 1.75V 00 – 1.50V **(default)**
	4–3	RX_CTRL2[5:4]. Common Mode Adjust: 11 – 790mV 10 – 700mV 01 – 960mV 00 – 875mV **(default)**
	2–1	RX_CTRL2[3:2]. Reference Buffer Boost: 11 – 2.5X 10 – 2.0X 01 – 1.5X 00 – 1.0X **(default)**
	0	RX_CTRL2[0]. ADC Input Buffer Disable: 1 – Disabled **(default)** 0 – Enabled **Default: 00000001**
0x5A	7	MISC_CTRL[9]. Rx Fsync Polarity, frame start: 1 – 1 0 – 0 **(default)**
	6	MISC_CTRL[8]. Rx Interleave Mode: 1 – Q,I 0 – I,Q **(default)**
	5	MISC_CTRL[7]. Dac Clk Edge Polarity: 1 – negative **(default)** 0 – positive
	4	MISC_CTRL[6]. Tx Fsync Polarity, frame start: 1 – 1 0 – 0 **(default)**
	3	MISC_CTRL[5]. Tx Interleave Mode: 1 – Q,I 0 – I,Q **(default)**
	2	RX_CTRL3[7]. ADC Sampling Phase Select: 1 – falling edge 0 – rising edge **(default)**
	1–0	RX_CTRL3[1:0]. Clock Non-Overlap Adjust: 11 – +300ps 10 – +150ps 01 – +450ps 00 – Nominal **(default)** **Default: 00100000**
0x5B	7–6	RX_CTRL4[7:6] ADC bias resistor adjust: 11 – 15uA 10 – 10uA 01 – 40uA 00 – 20uA **(default)**
	5–4	RX_CTRL4[5:4]. Main bias DOWN: 11 – Min Bias 10 – 01 – 00 – Nominal **(default)**
	3–2	RX_CTRL4[3:2]. ADC Amp1 stage1 bias UP: 11 – 15uA 10 – 10uA 01 – 40uA 00 – 20uA **(default)**
	1–0	RX_CTRL4[1:0]. ADC Amp2-4 stage1 bias UP: 11 – 15uA 10 – 10uA 01 – 40uA 00 – 20uA **(default)** **Default: 00000000**

Table 14 RX LPF configuration memory map (user/test mode) (continued)

Address (7 bits)	Bits	Description

0x5C	7–6	RX_CTRL5[7:6] ADC Amp1 stage2 bias UP:
		    11 – 15uA
		    10 – 10uA
		    01 – 40uA
		    00 – 20uA **(default)**

	5–4	RX_CTRL5[5:4]. ADC Amp2-4 stage2 bias UP:
		    11 – 15uA
		    10 – 10uA
		    01 – 40uA
		    00 – 20uA **(default)**

	3–2	RX_CTRL5[3:2]. Quantizer bias UP:
		    11 – 15uA
		    10 – 10uA
		    01 – 40uA
		    00 – 20uA **(default)**

	1–0	RX_CTRL5[1:0]. Input Buffer bias UP:
		    11 – 15uA
		    10 – 10uA
		    01 – 40uA
		    00 – 20uA **(default)**
		Default: 00000000

0x5D	7–4	REF_CTRL0[7:4]. Bandgap Temperature Coefficient Control:
		    0111 – Max
		    0000 – Nominal **(default)**
		    1000 – Min

	3–0	REF_CTRL0[3:0]. Bandgap Gain Control:
		    0111 – Max
		    0000 – Nominal **(default)**
		    1000 – Min
		Default: 00000000

0x5E	7–6	REF_CTRL1[7:6]. Reference Amps bias adjust
		    11 – 15uA
		    10 – 10uA
		    01 – 40uA
		    00 – 20uA **(default)**

	5–4	REF_CTRL1[5:4]. Reference Amps bias UP:
		    11 – 2.5X
		    10 – 2.0X
		    01 – 1.5X
		    00 – 1.0X **(default)**

	3–0	REF_CTRL1[3:0]. Reference Amps bias DOWN:
		    1111 – Min Bias
		    …
		    0000 – Max Bias **(default)**
		Default: 00000000

0x5F	7	PD_DCOCMP_LP: Power down DC offset comparators in the DC offset cancellation block. Should be powered up only when DC offset cancellation algorithm is running.
		    1 – Powered Down
		    0 – Enabled (**default**)

	6–5	SPARE00[6:5]: Spare configuration bits. 00 – **(default)**

	4	MISC_CTRL[4]. Enable DAC:
		    1 – Enable **(default)**
		    0 – Off

	3	MISC_CTRL[3]. Enable ADC1 (I Channel):
		    1 – Enable **(default)**
		    0 – Off

	2	MISC_CTRL[2]. Enable ADC2 (Q Channel):
		    1 – Enable **(default)**
		    0 – Off

	1	MISC_CTRL[1]. Enable ADC reference:
		    1 – Enable **(default)**
		    0 – Off

	0	MISC_CTRL[0]. Enable master reference:
		    1 – Enable **(default)**
		    0 – Off
		Default: 00011111

2.6   TX RF Modules Configuration

Table 15: TX RF modules configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x40	7–2	Not used

	1	EN : TXRF modules enable
		        0 – TXRF modules powered down
		        1 – TXRF modules enabled (**default**)

	0	DECODE:
		        0 – decode control signals (**default**)
		        1 – use control signals from test mode registers

		Default: 00000010
0x41	7–5	Not used

	4–0	VGA1GAIN[4:0]: TXVGA1 gain, log-linear control
		LSB=1dB, encoded as shown below:
		
		        code Gain [dB]
		        ======================
		        00000 -35
		        00001 -34
		        …
		        10101 -14 (**default**)
		
		        11110 -5
		        11111 -4

		Default: 00010101

0x42	7–0	VGA1DC_I[7:0]: TXVGA1 DC shift control, LO leakage cancellation
		LSB=0.0625mV, encoded as shown below:
		        code DC Shift [mV]
		        ======================
		        00000000 -16
		
		        …
		        01111111 -0.0625
		        10000000 0 (**default**)
		        10000001 0.0625
		
		        …
		        11111111 15.9375

		Default: 10000000

0x43	7–0	VGA1DC_Q[7:0]: TXVGA1 DC shift control, LO leakage cancellation
		LSB=0.0625mV, encoded as shown below:
		        code DC Shift [mV]
		        ======================
		        00000000 -16
		
		        …
		        01111111 -0.0625
		        10000000 0 (**default**)
		        10000001 0.0625
		
		        …
		        11111111 15.9375

		Default: 10000000
0x44	7-5	Not used

	4-3	PA_EN[2:0]: VGA2 power amplifier (TX output) selection
		        PA_EN[2:1] PA1 PA2
		        =============================
		        00 OFF OFF
		        01 ON OFF **(default)**
		        10 OFF ON
		        11 OFF OFF

	2	PA_EN[2]: AUXPA, auxiliary (RF loop back) PA power down
		        0 – powered up **(default)**
		        1 – powered down

	1-0	Not used.
		Default: 00001011

Table 16: TX RF modules configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description

0x45	7-3	VGA2GAIN[4:0]: TXVGA2 gain control, log-linear control
		LSB=1dB, encoded as shown below:
		      code Gain [dB]
		      =====================
		      00000 0 **(default)**
		      00001 1
		      11001 25 ...
		      11111 25

	2-0	ENVD[2:0]: Controls envelop/peak detector analogue MUX
		  ENVD[2]: Selects the signal for AC coupling, MUX provides
		        0 – reference DC generated inside the selected detector **(default)**
		        1 – average of the selected detector output
		  ENVD[1:0]: Detector select, MUX provides
		        00 – AUXPA envelop detector output **(default)**
		        01 – AUXPA peak detector output
		        10 – PA1 envelop detector output
		        11 – PA2 envelop detector output
		Default: 00000000

0x46	7-4	PKDBW[3:0]: Controls the bandwidth of the envelop and peak detectors
		        0000 – Minimum bandwidth, envelop ~1MHz, peak 30kHz **(default)**
		        1111 – Maximum bandwidth, envelop ~15MHz, peak ~300KHz

	3-2	LOOPBBEN[1:0]: Base band loop back switches control
		        00 – Switch open **(default)**
		        11 – Switch closed.

	1	FST_PKDET: Shorts the resistor in the envelop/peak detector to speed up charging for faster response. After the initial charge up, it should be disabled to achieve a LPF function.
		        0 – switch open, LPF function in effect **(default)**
		        1 – resistor shorted (no LPF function)

	0	FST_TXHFBIAS: Bias stage of high frequency TX part has large resistors to filter the noise. However, they create large settling time. This switch can be used to short those resistors during the initialization and then it may be needed to open it to filter the noise, in case the noise is too high.
		        0 – switch open (noise filtering functional) **(default)**
		        1 – resistors shorted (short settling - no noise filtering)
		Default: 00000000

0x47	7-4	ICT_TXLOBUF[3:0]: Controls the bias current of the LO buffer. Higher current will increase the linearity. LSB=5/6mA.
		        0000 – minimum current
		        0110 – TXMIX takes 5mA for buffer **(default)**
		        1111 – maximum current

	3-0	VBCAS_TXDRV[3:0]: The linearity of PAs depends on the bias at the base of the cascode npn's in the PA cells. Increasing the VBCAS will lower the base of the cascode npn.
		        0000 – maximum base voltage **(default)**
		        1111 – minimum base voltage
		Default: 01100000

0x48	7-5	Not used

	4-0	ICT_TXMIX[4:0]: Controls the bias current of the mixer. Higher current will increase the linearity. LSB=1mA.
		        00000 – 0 mA
		        01100 – TXMIX takes 12mA for each cell **(default)**
		        11111 – 31 mA
		Default: 00001100

0x49	7-5	Not used

	4-0	ICT_TXDRV[4:0]: Controls the bias current of the PAs. Higher current will increase the linearity. LSB=1mA.
		        00000 – 0 mA
		        01100 – PAs take 12mA for each cell **(default)**
		        11111 – 31 mA
		Default: 00001100

Table 17: TX RF modules configuration memory map (test mode)

Address (7 bits)	Bits	Description

0x4A	7-5
	4
	
	3
	
	2
	
	1
	
	0
		Not used
		PW_VGA1_I: VGA1, I channel power control
		       0 – powered down
		       1 – powered up **(default)**
		PW_VGA1_Q: VGA1, Q channel power control
		       0 – powered down
		       1 – powered up **(default)**
		PD_TXDRV: Power down for PAs and AUXPA.
		       0 – PA1, PA2 and AUXPA can be separately controlled **(default)**
		       1 – PA1, PA2 and AUXPA all disabled
		PD_TXLOBUF: Power down for TXLOBUF
		       0 – powered up **(default)**
		       1 – powered down
		PD_TXMIX: Power down for TXMIX
		       0 – powered up **(default)**
		       1 – powered down
		Default: 00011000

0x4B	7–0	VGA1GAINT[7:0]: TXVGA1 gain control, raw access
		LSB=1dB, encoded as shown below:
		    code Gain [dB]
		    =====================
		    00000110 -35
		    00000111 -34
		    …
		    01010000 -14 **(default)**
		    …
		    11100011 -5
		    11111111 -4
		Default: 01010000

0x4C	7–0	G_TXVGA2[8:1]: Controls the gain of PA1, PA2 and AUXPA, raw access For PA1, PA2: Gain=20*log10(0.038*G_TXVGA2[8:0]) For AUXPA: Only 4 LSB's are used, max gain ~22dB **Default**: 00000000, 0dB gain
0x4D	7 6-0	G_TXVGA2[0]: Controls the gain of PA1, PA2 and AUXPA, LSB Not used **Default**: 00000000

0x4E	7
	
	6-0
		PD_PKDET: Power down for envelop/peak detectors.
		       0 – powered up **(default)**
		       1 – powered down
		SPARE0[6:0]: Spare configuration register.
		Default: 00000000

0x4F	7–0	SPARE1[7:0]: Spare configuration register. **Default**: 00000000

2.7 RX VGA2 Configuration

Table 18: RX VGA2 configuration memory map (user mode)

Address (7 bits)	Bits	Description
0x60	7–6 5–0	Not used DC_REGVAL[5:0]: Value from DC Calibration module selected by DC_ADDR. **Read Only.**

0x61	7–5
	4–2
	
	1
	
	0
		Not used
		DC_LOCK[2:0]: Lock pattern register.
		     Locked, when register value is not "000" nor "111".
		DC_CLBR_DONE : indicates calibration status.
		     1 – calibration in progress;
		     0 – calibration is done.
		DC_UD: Value from DC module comparator, selected by DC_ADDR
		     1 – Count Up;
		     0 – Count Down.
		Read Only.

0x62	7–6 5–0	Not used DC_CNTVAL[5:0] : Value to load into selected (by DC_ADDR) DC calibration module. **Default: 00011111**

0x63	7–6
	5
	
	4
	
	3
	
	2–0
		Not used
		DC_START_CLBR: Start calibration command on module, selected by DC_ADDR
		     1 – Start Calibration;
		     0 – Deactivate Start Calibration command. (**default**)
		DC_LOAD: Load value from DC_CNTVAL to module, selected by DC_ADDR
		     1 – Load Value;
		     0 – Deactivate Load Value command. (**default**)
		DC_SRESET: resets all DC Calibration modules
		     1 – Reset inactive; (**default**)
		     0 – Reset active.
		DC_ADDR[3:0]: Active calibration module address.
		     000 – DC reference module.
		     001 – First gain stage (VGA2A), I channel.
		     010 – First gain stage (VGA2A), Q channel.
		     011 – Second gain stage (VGA2B), I channel.
		     100 – Second gain stage (VGA2B), Q channel.
		     101 – 111 Not used.
		Default: 00001000

0x64	7–6
	5-2
	
	1
	
	0
		Not used
		VCM[3:0]: RXVGA2 output common mode voltage control. VCM[3] – sign, VCM[2:0] – magnitude, LSB=40mV.
		<pre>code Voltage [V] code Voltage [V] code Voltage [V]
		============= ============= =============
		0000 1.18 0110 0.94 1100 0.78
		0001 1.14 0111 0.90 (def)1101 0.82
		0010 1.10 1000 0.62 1110 0.86
		0011 1.06 1001 0.66
		0100 1.02 1010 0.70
		0101 0.98 1011 0.74</pre>EN : RXVGA2 modules enable
		     0 – RXVGA2 modules powered down
		     1 – RXVGA2 modules enabled (**default**)
		DECODE:
		     0 – decode control signals (**default**)
		     1 – use control signals from test mode registers
		Default: 00011110

0x65	7–5
	4–0
		Not used
		VGA2GAIN[4:0]: RXVGA2 gain control
		LSB=3dB, encoded as shown below:
		<pre>code Gain [dB]
		=====================
		00000 0
		00001 3 (default)
		…
		01001 27
		01010 30
		…
		10100 60</pre>Not recommended to be used above 30dB
		Default: 00000001

Table 19: RX VGA2 configuration memory map (test mode)

Address (7 bits)	Bits	Description
0x66		PD[9:0]: Power down different modules:
	7-6	Not used
	5	PD[9] - DC current regulator
		1 – powered down
		0 – powered up (**default**)
	4	PD[8] - DC calibration DAC for VGA2B
		1 – powered down
		0 – powered up (**default**)
	3	Not used.
	2	PD[6] - DC calibration DAC for VGA2A
		1 – powered down
		0 – powered up (**default**)
	1	Not used.
	0	PD[4] - Band gap
		1 – powered down
		0 – powered up (**default**)
		Default: 00000000
0x67	7-4	Not used
	3	PD[3] – Output buffer in both RXVGAs
		1 – powered down
		0 – powered up (**default**)
	2	PD[2] - RXVGA2B
		1 – powered down
		0 – powered up (**default**)
	1	PD[1] - RXVGA2A
		1 – powered down
		0 – powered up (**default**)
	0	PD[0] - Current reference
		1 – powered down
		0 – powered up (**default**)
		Default: 00000000
0x68	7–4	VGA2GAINB: Controls the gain of second VGA2 stage (VGA2B) LSB=3dB, encoded as shown below:
		Code Gain [dB]
		======================
		0000 0 (**default**)
		0001 3
		…
		1001 27
		1010 30
	3–0	VGA2GAINA: Controls the gain of first VGA2 stage (VGA2A) LSB=3dB, encoded as shown below:
		Code Gain [dB]
		======================
		0000 0
		0001 3 (**default**)
		…
		1001 27
		1010 30
		Default: 00000001
0x6E	7	PD[7] - DC calibration comparator for VGA2B
		1 – powered down
		0 – powered up (**default**)
	6	PD[6] - DC calibration comparator for VGA2A
		1 – powered down
		0 – powered up (**default**)
	5-0	SPARE0[5:0]: Spare configuration register.
		Default: 00000000
0x6F	7–0	SPARE1[7:0]: Spare configuration register.
		Default: 00000000

2.8 RX FE Modules Configuration

Table 20: RX FE modules configuration memory map (user mode)

Address (7 bits)	Bits	Description

0x70	7–2
	1
	
	0
		Not used
		DECODE:
		    0 – decode control signals **(default)**
		    1 – use control signals from test mode registers
		EN: RXFE modules enable
		    EN =0 – Top modules powered down
		    EN =1 – Top modules enabled **(default)**
		Default: 00000001

0x71	7
	
	6–0
		IN1SEL_MIX_RXFE: Selects the input to the mixer
		    1 – input 1 is selected, shorted on-chip to LNA internal output **(default)**
		    0 – input 2 is selected, connected to pads.
		DCOFF_I_RXFE[6:0]: DC offset cancellation, I channel.
		    Code is Sign(<6>)-Magnitude(<5:0>), signed magnitude format.
		    0000000 – **(default)**
		Default: 10000000

0x72	7
	
	6–0
		INLOAD_LNA_RXFE: To select the internal load for the LNA .
		    1 – internal load is active **(default)**
		    0 – internal node is disabled.
		DCOFF_Q_RXFE[6:0]: DC offset cancellation, Q channel.
		    Code is Sign(<6>)-Magnitude(<5:0>), signed magnitude format.
		    0000000 – **(default)**
		Default: 10000000

0x73	7
	
	6–0
		XLOAD_LNA_RXFE: To select the external load for the LNA .
		    1 – external load is active
		    0 – external node is disabled **(default)**
		IP2TRIM_I_RXFE[6:0]: IP2 cancellation, I channel.
		    Code is Sign(<6>)-Magnitude(<5:0>), signed magnitude format.
		    0000000 – **(default)**
		Default: 00000000

0x74	7
	6–0
		Not used
		IP2TRIM_Q_RXFE[6:0]: IP2 cancellation, Q channel.
		    Code is Sign(<6>)-Magnitude(<5:0>), signed magnitude format.
		    0000000 – **(default)**
		Default: 00000000

0x75	7–6
	
	5–4
	
	3–0
		G_LNA_RXFE[1:0]: LNA gain mode control.
		    11 – max gain (all LNAs) **(default)**
		    10 – mid gain (all LNAs)
		    01 – LNA bypassed (LNA1 and LNA2)
		    00 – max gain (LNA3)
		LNASEL_RXFE[1:0]: Selects the active LNA.
		    00 – all LNA's disabled
		    01 – LNA1 active **(default)**
		    10 – LNA2 active
		    11 – LNA3 active
		CBE_LNA_RXFE[3:0]: Controls the capacitance parallel to the BE of the input NPN transistors. To be used at lower frequencies for easier matching. For LNA1 and LNA2 only.
		    0000 – **(default)**
		Default: 11010000

0x76	7
	6–0
		Not used
		RFB_TIA_RXFE[6:0]: Feedback resistor control of the TIA (RXVGA1) to set the mixer gain.
		    If =120 --> mixer gain = 30dB **(default)**
		    If =102 --> mixer gain = 19dB
		    If = 2 --> mixer gain = 5dB
		Default: 01111000

Table 21: RX FE modules configuration memory map (user mode) (continued)

Address (7 bits)	Bits	Description

0x77	7
	6–0
		Not used
		CFB_TIA_RXFE[6:0]: Feedback capacitor for the TIA (RXVGA1) to limit the BW.
		  If =0, min cap --> BW~45MHz for gain of 30dB. **(default)**
		  If = 19 --> BW=2.5MHz for MixGain=30dB and at TT.
		This cap is supposed to be set according to the RC time constant to have almost constant BW over the corners for optimum CDMA performance. Software will control it using the information from the LPF calibration circuit.
		
		Default: 00000000

0x78	7–6 5–0	Not used RDLEXT_LNA_RXFE[5:0]: Controls the on-chip LNA load resistor for the external load mode of the LNA. In practice, this will be set to high value, the output will be ac coupled, and the actual load is defined on PCB. 011100– **(default)** **Default: 00011100**
0x79	7–6 5–0	Not used RDLINT_LNA_RXFE[5:0]: Controls the on-chip LNA load resistor for the internal load mode of the LNA, LNA1 and LNA2. 011100– **(default)** **Default: 00011100**

0x7A	7–4
	
	3–0
		ICT_MIX_RXFE[3:0]: Control for tweaking the bias current for mixer.
		  0000 - 0 bias current
		  0111 - nominal bias current **(default)**
		  1111 - 2.1 x nominal bias current
		ICT_LNA_RXFE[3:0]: Control for tweaking the bias current for LNA.
		  0000 - 0 bias current
		  0111 - nominal bias current **(default)**
		  1111 - 2.1 x nominal bias current
		Default: 01110111

0x7B	7–4
	
	3–0
		ICT_TIA_RXFE[3:0]: Control for tweaking the bias current for TIA (RXVGA1).
		  0000 - 0 bias current
		  0111 - nominal bias current **(default)**
		  1111 - 2.1 x nominal bias current
		ICT_MXLOB_RXFE[3:0]: Control for tweaking the bias current for mixer LO buffer.
		  0000 - 0 bias current
		  0111 - nominal bias current **(default)**
		  1111 - 2.1 x nominal bias current
		Default: 01110111

0x7C	7
	6–3
	
	2
	
	1–0
		Not used
		LOBN_MIX_RXFE[3:0]: Tweak for the LO bias of the mixer for optimum linearity.
		  0000 – minimum bias voltage
		  0011 – **(default)**
		  1111 – maximum bias voltage
		RINEN_MIX_RXFE: Termination resistor on external mixer input enable
		  1 – Active
		  0 – Inactive **(default)**
		G_FINE_LNA3_RXFE[1:0]: LNA3 fine gain adjustment
		  00 – +0 dB (**default**)
		  01 – +1 dB
		  10 – +2 dB
		  11 – +3 dB
		Default: 00011000

Table 22: RX FE modules configuration memory map (test mode)

Address (7 bits)	Bits	Description
0x7D	7–4	Not used
	3	PD_TIA_RXFE: TIA (RXVGA1) power down.
		0 – block active (**default**)
		1 – block inactive
	2	PD_MXLOB_RXFE: Mixer LO buffer power down.
		0 – block active (**default**)
		1 – block inactive
	1	PD_MIX_RXFE: Mixer power down.
		0 – block active (**default**)
		1 – block inactive
	0	PD_LNA_RXFE: LNA power down.
		0 – block active (**default**)
		1 – block inactive
		Default: 00000000
0x7E	7-0	SPARE0[7:0] **Default:** 00000000
0x7F	7-0	SPARE1[7:0] **Default:** 00000000

3

Control Block Diagrams

3.1 SPI READ/WRITE Pseudo Code

```
//--------------------------------------------------------------------------
// Write command, SPI module address, register address
// Read data
//--------------------------------------------------------------------------
void SPI_Read(BYTE COMMAND)
{
        BYTE DATA;      //We will read data there

        //Write Command and Address (MSB First)
        //First 1 bit (MSB)  = Command
        //Next 3 bits  = SPI memory block address
        //Next 4 (LSBs) bits = Register Address
        for(int i=7; i>=0; i--)
        {
                if(i'th bit in COMMAND is '1')
                {
                        Set Data Output line to '1';
                }
                else
                {
                        Set Data Output line to '0';
                };
                Apply Rising and Falling CLK signal edges to CLK line;
        };

        //Read Data (MSB First)
        //Note: At this point we have data MSB valid from the chip.
        for(int i=7; i>=0; i--)
        {
                if(there is '1' at the Data Input Line)
                {
                        Set i'th bit in DATA '1';
                }
                else
                {
                        Set i'th bit in DATA '0';
                };
                Apply Rising and Falling CLK signal edges to CLK line;
        };
};
```

```
//------------------------------------------------------------------------------
// Write data to the chip:
// First byte: Command, SPI module address, register address
// Second byte: Data
//------------------------------------------------------------------------------
void SPI_Write(BYTE COMMAND, BYTE DATA)
{
        //Write Command, Address
        for(int i=7; i>=0; i--)
        {
                if(i'th bit in COMMAND is '1')
                {
                        Set Data Output line to '1';
                }
                else
                {
                        Set Data Output line to '0';
                };
                Apply Rising and Falling CLK signal edges to CLK line;
        };

        //Write Data
        for(int i=7; i>=0; i--)
        {
                if(i'th bit in DATA is '1')
                {
                        Set Data Output line to '1';
                }
                else
                {
                        Set Data Output line to '0';
                };
                Apply Rising and Falling CLK signal edges to CLK line;
        };
};
```

3.2 Loopback and Bypass Modes
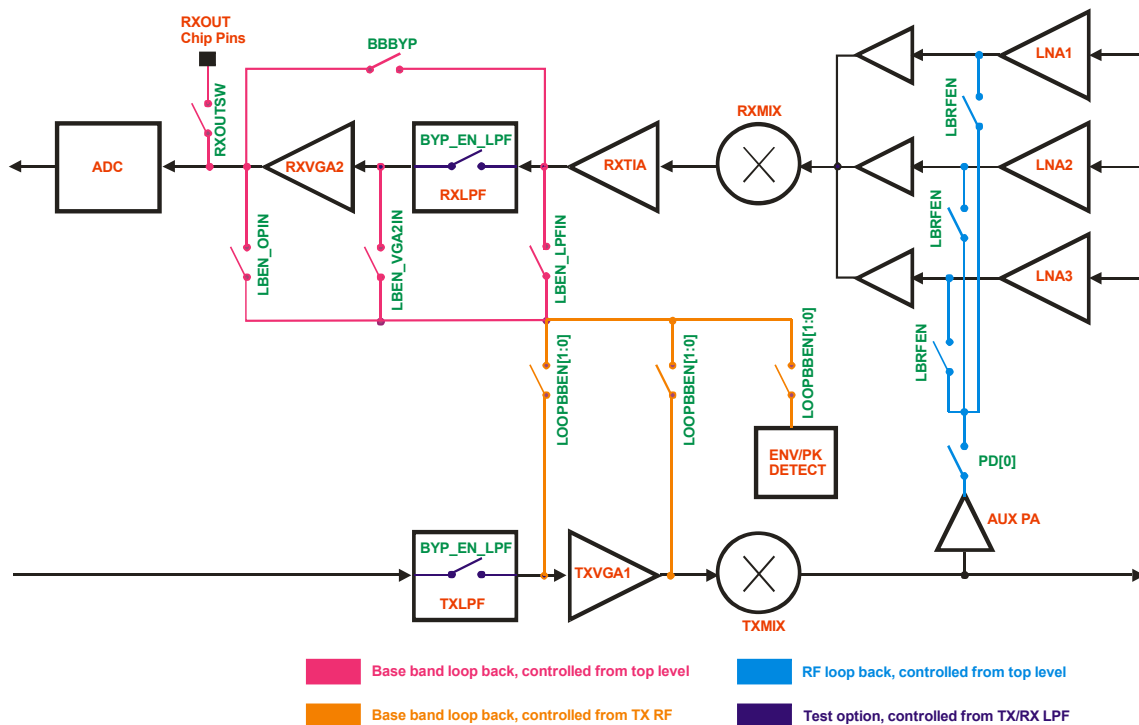
Figure 3.1: Loop back and test options

3.3 Envelop and Pick Detector Multiplexer
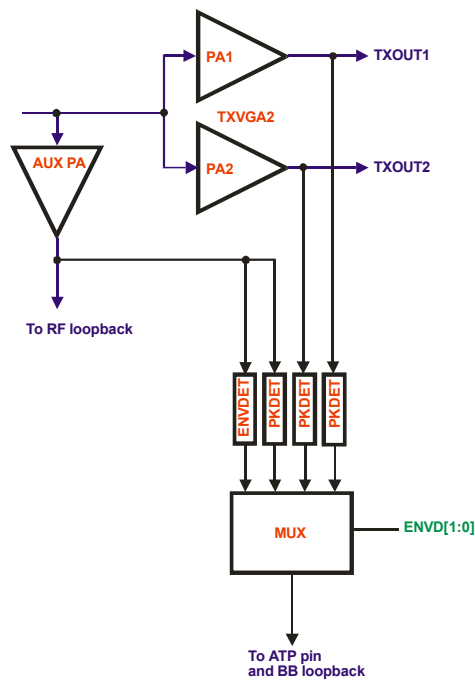
Figure 3.2: Envelop/pick detector analogue MUX

3.4 TX/RX PLL

The frequency setting for both TX and RX PLLs is the same as described here. TX PLL SPI registers are at x001xxxx and TX PLL registers are at x010xxxx.

To configure the PLL there are a number of variables which need to be set.

- Integer and fractional part of the divider
- FRANGE value
- VCO CAP, charge pump current (Icp) and charge pump offset current (Ioff)

This assumes the given loop filter value with a loop BW of 100kHz is used.

3.4.1 FREQSEL

To simplify the TX/RX PLL register setup the FRANGE and SELVCO register are combined to FREQSEL register. The frequency range and FREQSEL[5:0] value table showed below:

FREQSEL[5:0]:		
Frequency Range (GHz)		**Value**
0.2325	0.285625	100111
0.285625	0.336875	101111
0.336875	0.405	110111
0.405	0.465	111111
0.465	0.57125	100110
0.57125	0.67375	101110
0.67375	0.81	110110
0.81	0.93	111110
0.93	1.1425	100101
1.1425	1.3475	101101
1.3475	1.62	110101
1.62	1.86	111101
1.86	2.285	100100
2.285	2.695	101100
2.695	3.24	110100
3.24	3.72	111100

For example, UMTS Band I centre frequency 2140MHz is in range 1.86 to 2.285GHz hence FREQSEL = 100100 (0x24).

3.4.2 Integer and Fractional Part of the Divider

For wanted LO frequency f_{LO} and given PLL reference clock frequency f_{REF}, calculate integer and fractional part of the divider as below.

First, find temporary variable x from the 3 least significant bits of the FREQSEL value:

$$x = 2^{FREQSEL[2:0]-3}$$

Use x to calculate NINT and NFRAC:

$$NINT = \left\lfloor \frac{x * f_{LO}}{f_{REF}} \right\rfloor,$$

$$NFRAC = \left\lfloor 2^{23} \left[\frac{x * f_{LO}}{f_{REF}} - NINT \right] \right\rfloor,$$

and store the values in NINT/NFRAC registers at address 0x10-0x13 for TXPLL and 0x20-0x23 for RX PLL.

For example f_{LO} is band 1 centre frequency of 2140MHz, and f_{REF} = 30.72MHz:

$$FREQSEL[5:0] = 100100, FREQSEL[2:0] = 100 = 0x4 = 4$$

$$x = 2^{FREQSEL[2:0]-3} = 2^{4-3} = 2^1 = 2$$

$$NINT = \left\lfloor \frac{x * f_{LO}}{f_{REF}} \right\rfloor = \left\lfloor \frac{2 * 2140}{30.72} \right\rfloor = 139$$

$$NFRAC = \left\lfloor 2^{23} \left[\frac{x * f_{LO}}{f_{REF}} - NINT \right] \right\rfloor = \left\lfloor 2^{23} \left[\frac{2 * 2140}{30.72} - 139 \right] \right\rfloor = 2708821$$

3.4.3 VCO Capacitor, Icp and Ioff Selection

For the PLL loop filter implemented on evaluation board, loop bandwidth of 100kHz and optimum PLL phase noise performance, the following charge pump current setup is recommended:

- Charge pump current Icp=1200uA (default)
- Charge pump current offset up Ioff up = 30uA.
- Charge pump current offset down Ioff down = 0uA (default).

Regarding VCOCAP selection, an flexible algorithm, based on monitoring on chip Vtune comparators state, is developed as described below.
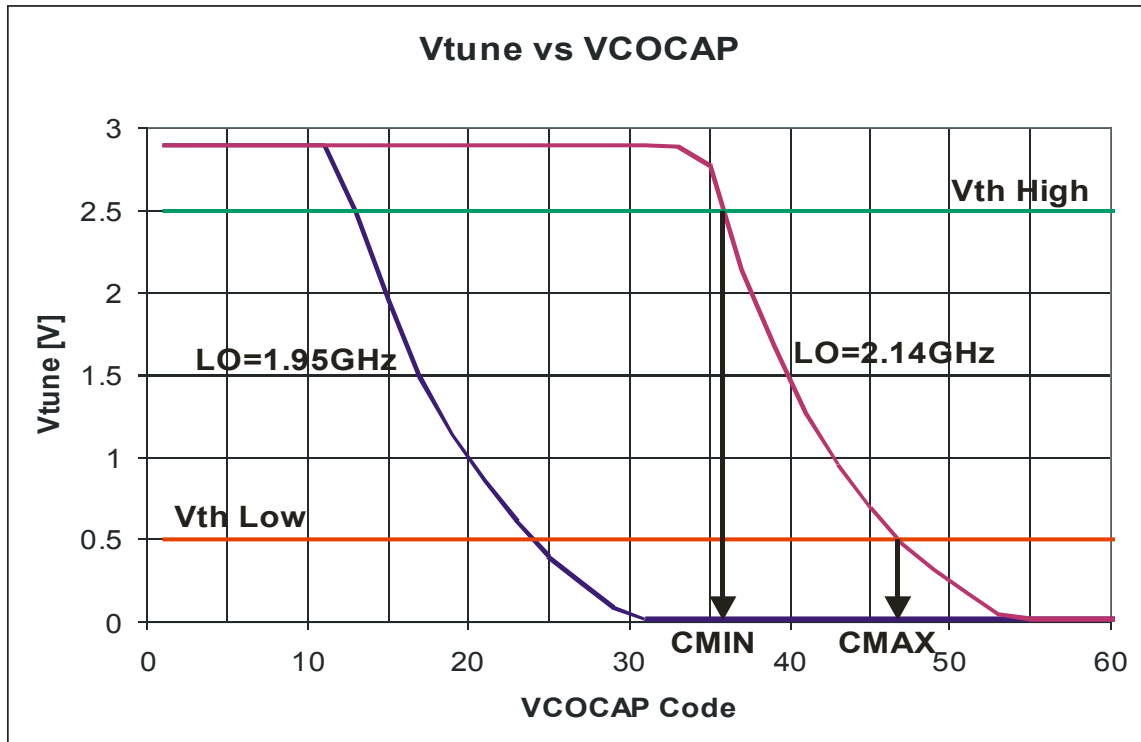
Figure 3.3: VCO capacitance selection

Figure 3.3 shows typical measured Vtune variation with the VCOCAP codes for the two target LO frequencies, 1.95GHz and 2.14GHz. Obviously, Vtune is changing from 2.9V down

to 0V. However, PLL lock is guaranteed only when Vtune is in the range 0.5V-2.5V. Also, for the best phase noise performance, Vtune should be kept around the middle of the range i.e. 1.5V.

There are two on chip Vtune comparators per PLL as shown in Figure 3.4. Their threshold voltages are set to Vth Low=0.5V and Vth High=2.5V. The state of the comparators can be obtained by powering them up (register 0x1B for TXPLL or 0x2B for RXPLL, bit 3) and reading the register 0x1A for TXPPLL or 0x2A for RXPLL, bits 7-6. True table is given below.

VTUNE_H	VTUNE_L	Status
0	0	OK, Vtune in range
1	0	Vtune is high (> 2.5V), PLL lock not guaranteed.
0	1	Vtune is Low (< 0.5V), PLL lock not guaranteed.
1	1	Not possible, check SPI connections.

These can be used to choose VCOCAP code. All we need to find is the code CMIN when comparators change the state from "10" to "00" and the code CMAX when the comparators change the state from "00" to "01". Optimum VCOCAP code is then the middle one between CMIN and CMAX. For LO=2.4GHz, this is illustrated in Figure 3.3. In this case, optimum code is around 41.

The algorithm is summarised as below.

1. Select correct FREQSEL as explained in section 3.4.1.

2. Set target LO frequency (NINT, NFRAC) as explained in section 3.4.2.

3. Sweep VCOCAP codes from 0-63. Monitor the state of Vtune comparators.
    3.a. Record the code CMIN when Vtune comparators state changes from "10" to "00" (PLL enters 'in range' state).

    3.b. Record the code CMAX when Vtune comparators state changes from "00" to "01" (PLL leaves 'in range' state).

    3.c. Select the middle code between CMIN and CMAX (C=(CMIN+CMAX)/2).

Note that faster search algorithm (replacement for step 3 above) can be implemented as shown in Section 4.6.

Once the PLL is set, Vtune comparators can also be used as lock (in range) indication.

3.4.4 PLL Control
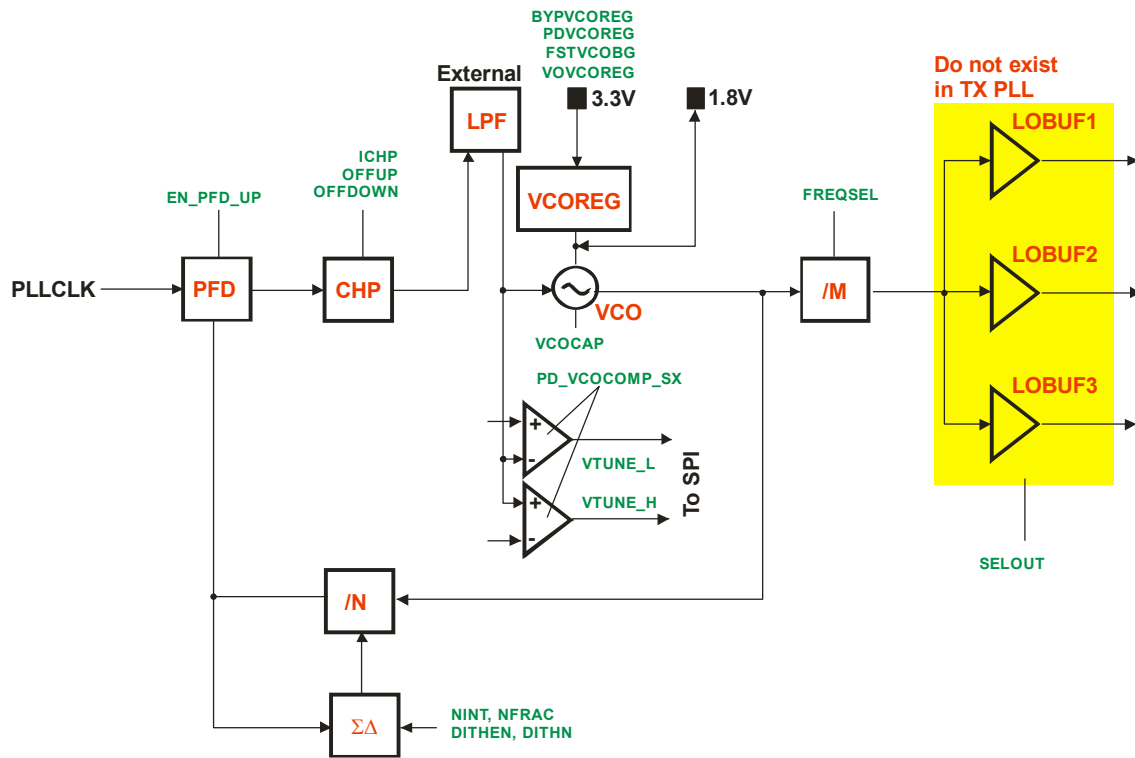
Figure 3.4: PLL control

3.5 TX/RX LPF
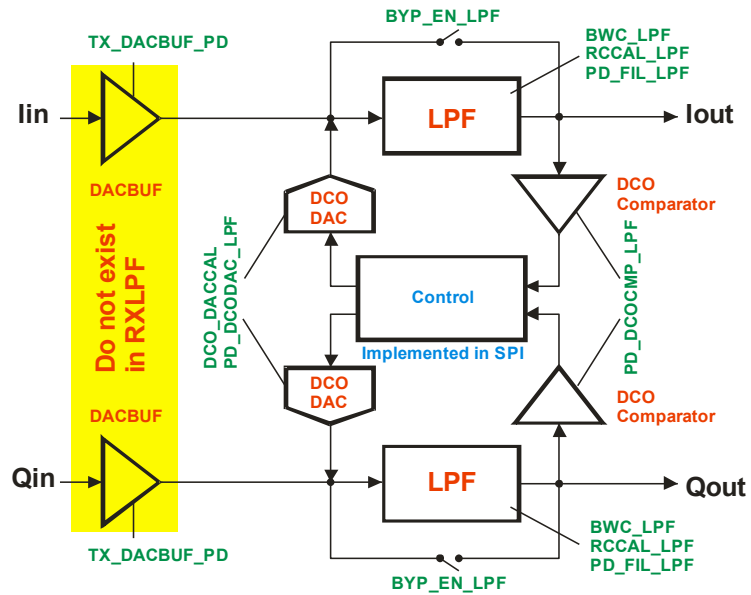
Figure 3.5: TX/RX LPF control

3.6 TX RF
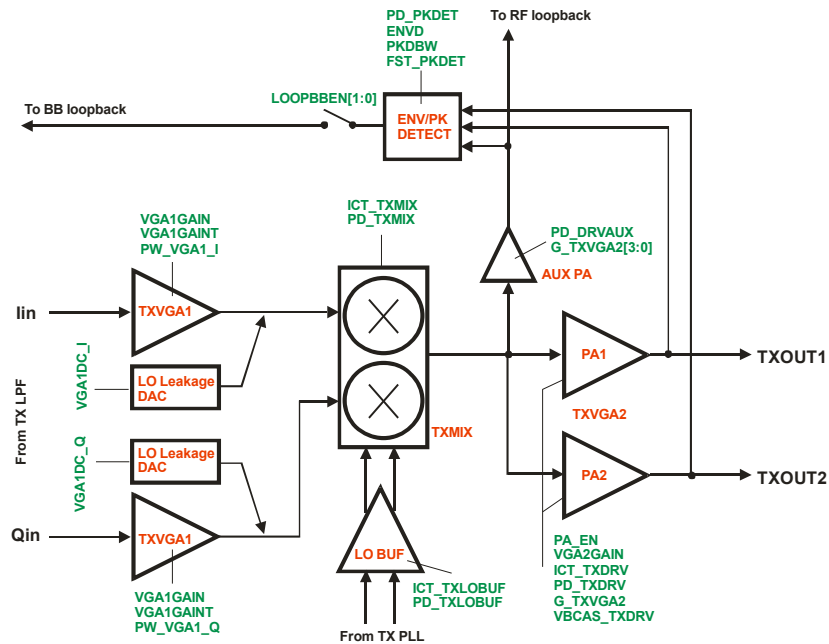
Figure 3.6: TX RF control

3.7 RX VGA2
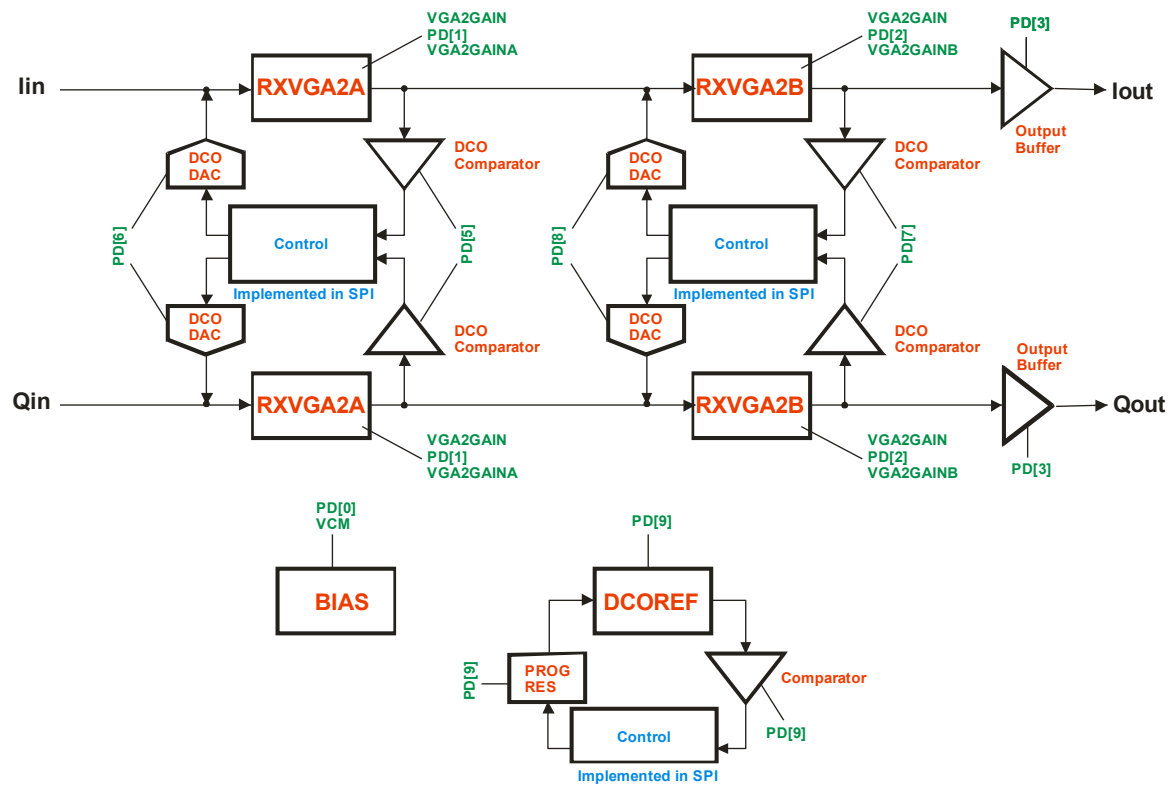
Figure 3.7: RXVGA2 control

3.8   RX FE
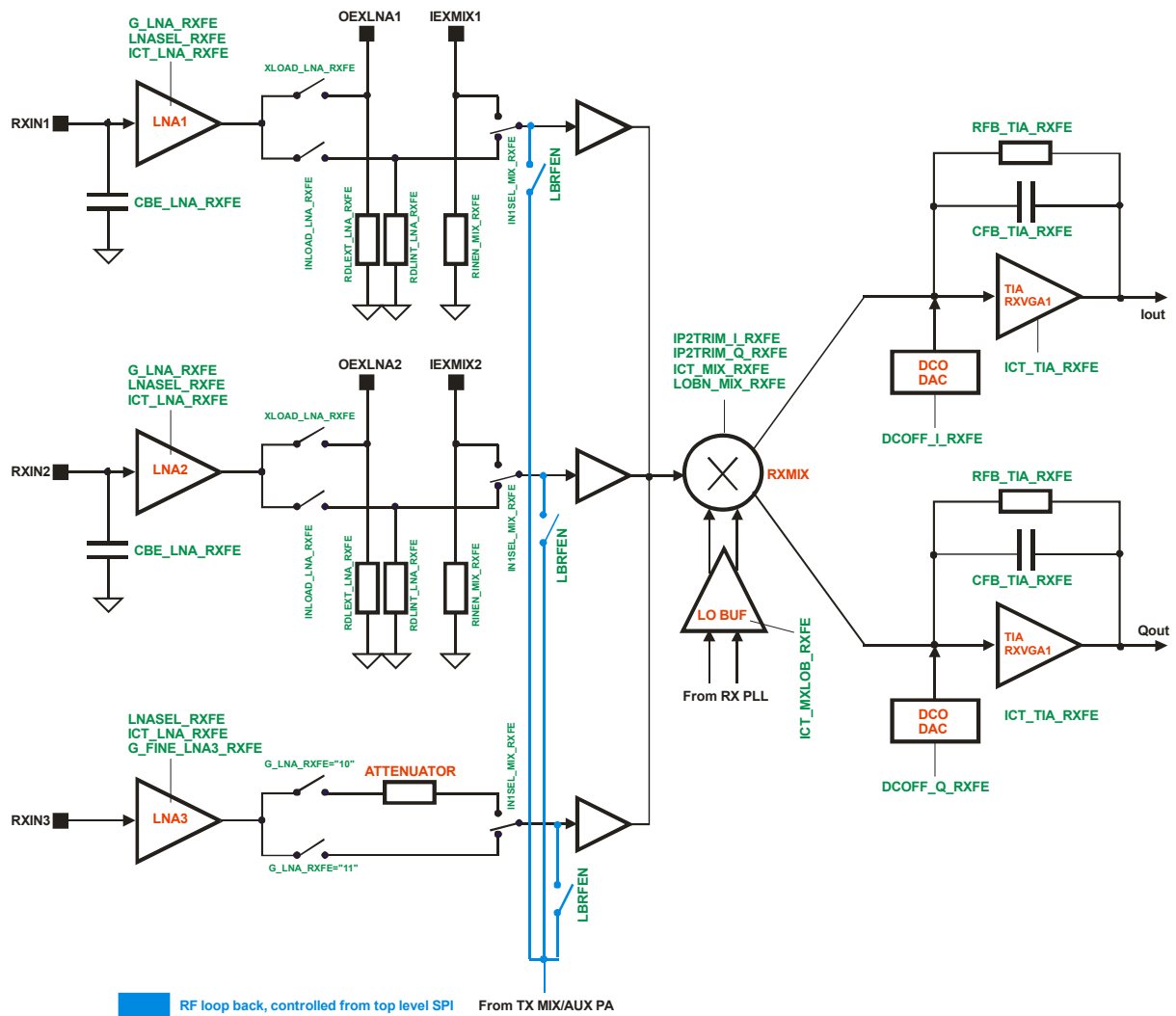
Figure 3.8: RX FE control

4

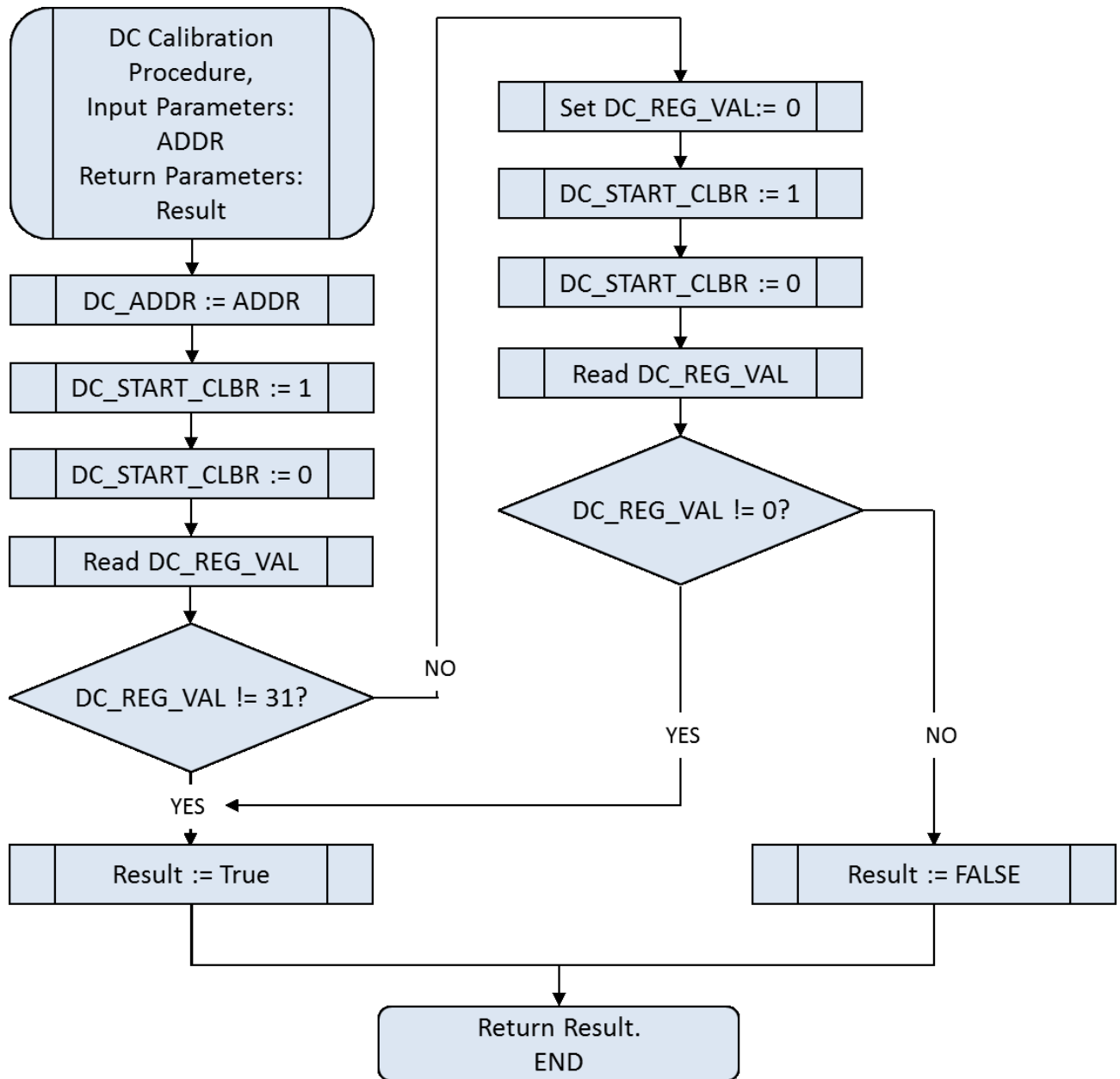# Calibration Flow Charts

4.1 General DC Calibration Procedure

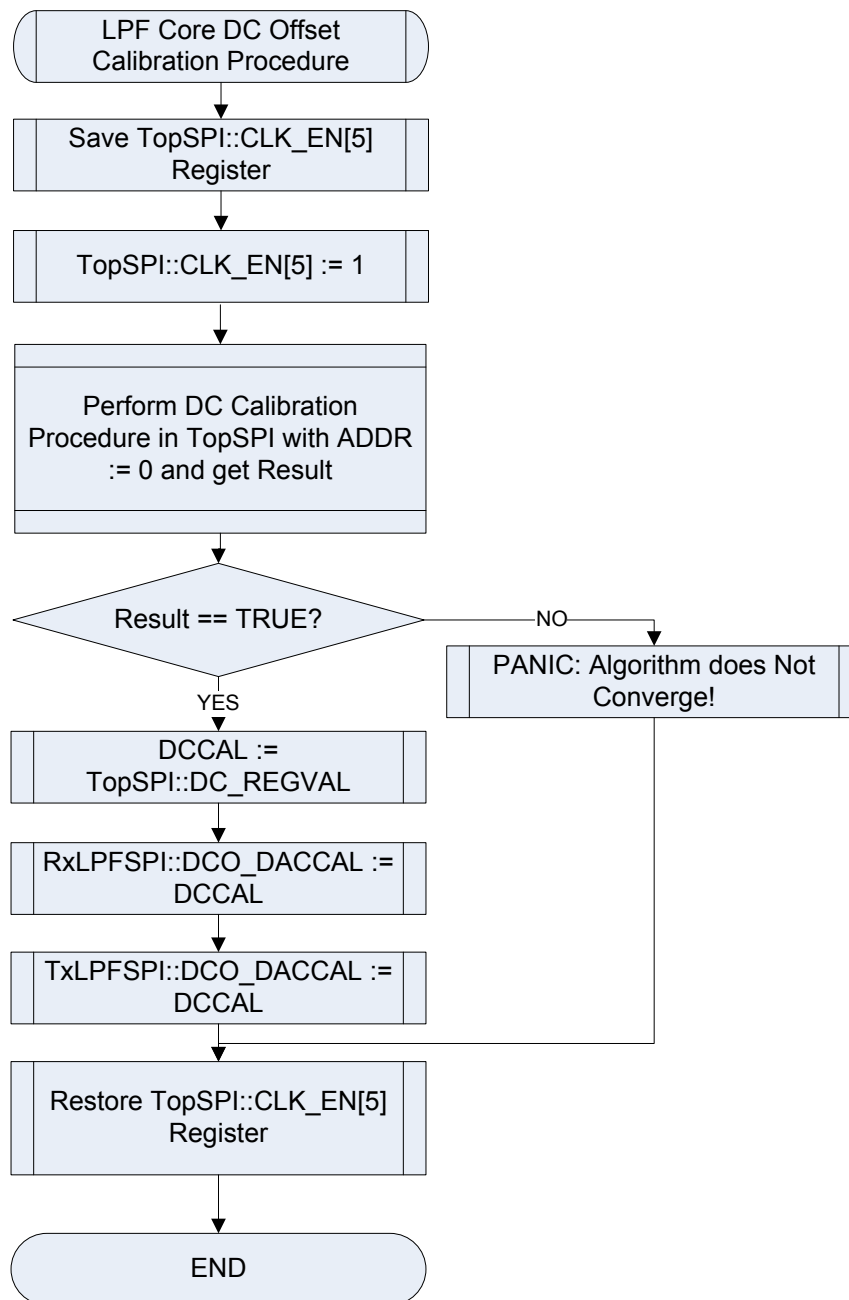Figure 4.1

4.2   DC Offset Calibration of LPF Tuning Module
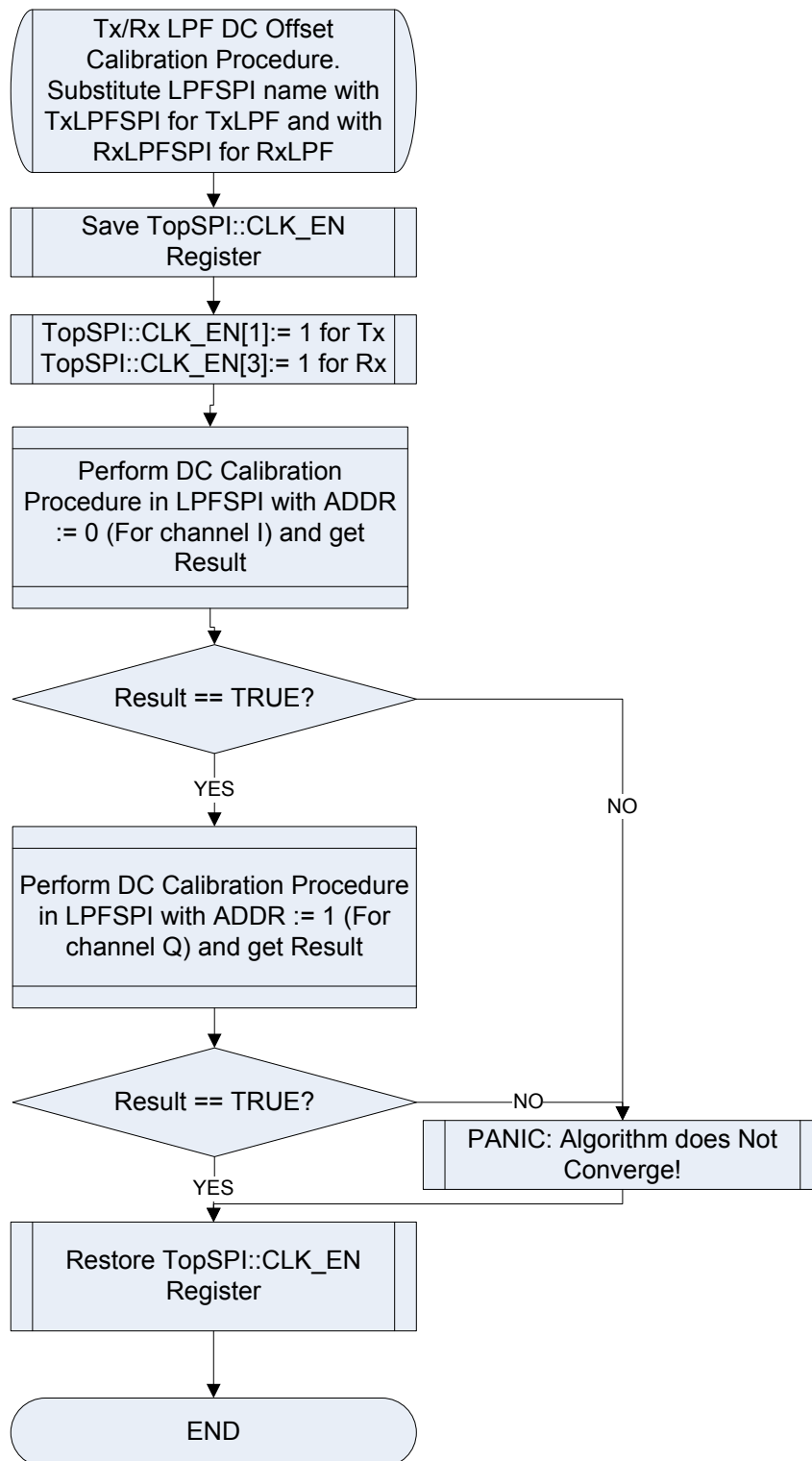

Figure 4.2

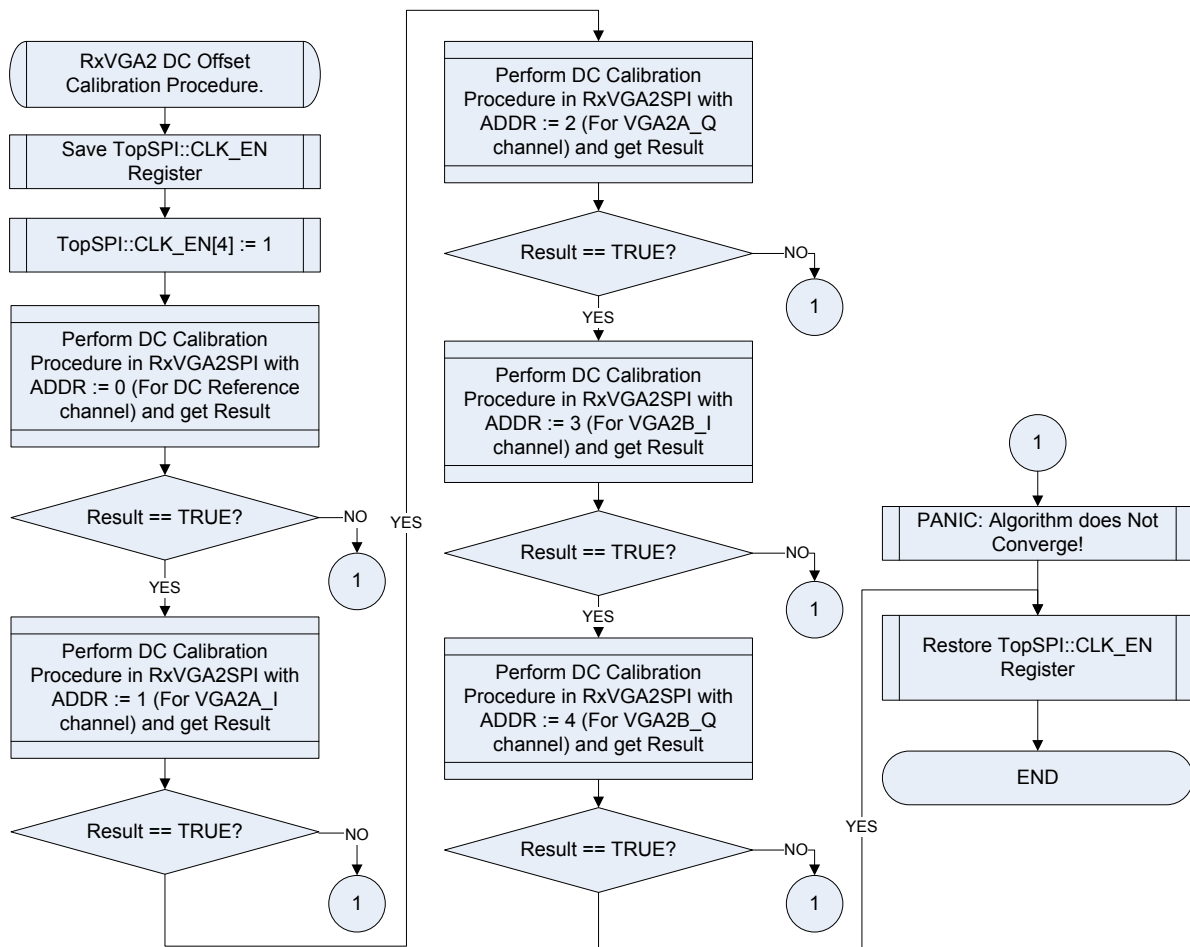## 4.3 TX/RX LPF DC Offset Calibration

Figure 4.3

4.4 RXVGA2 DC Offset Calibration

Figure 4.4

4.5 LPF Bandwidth Tuning
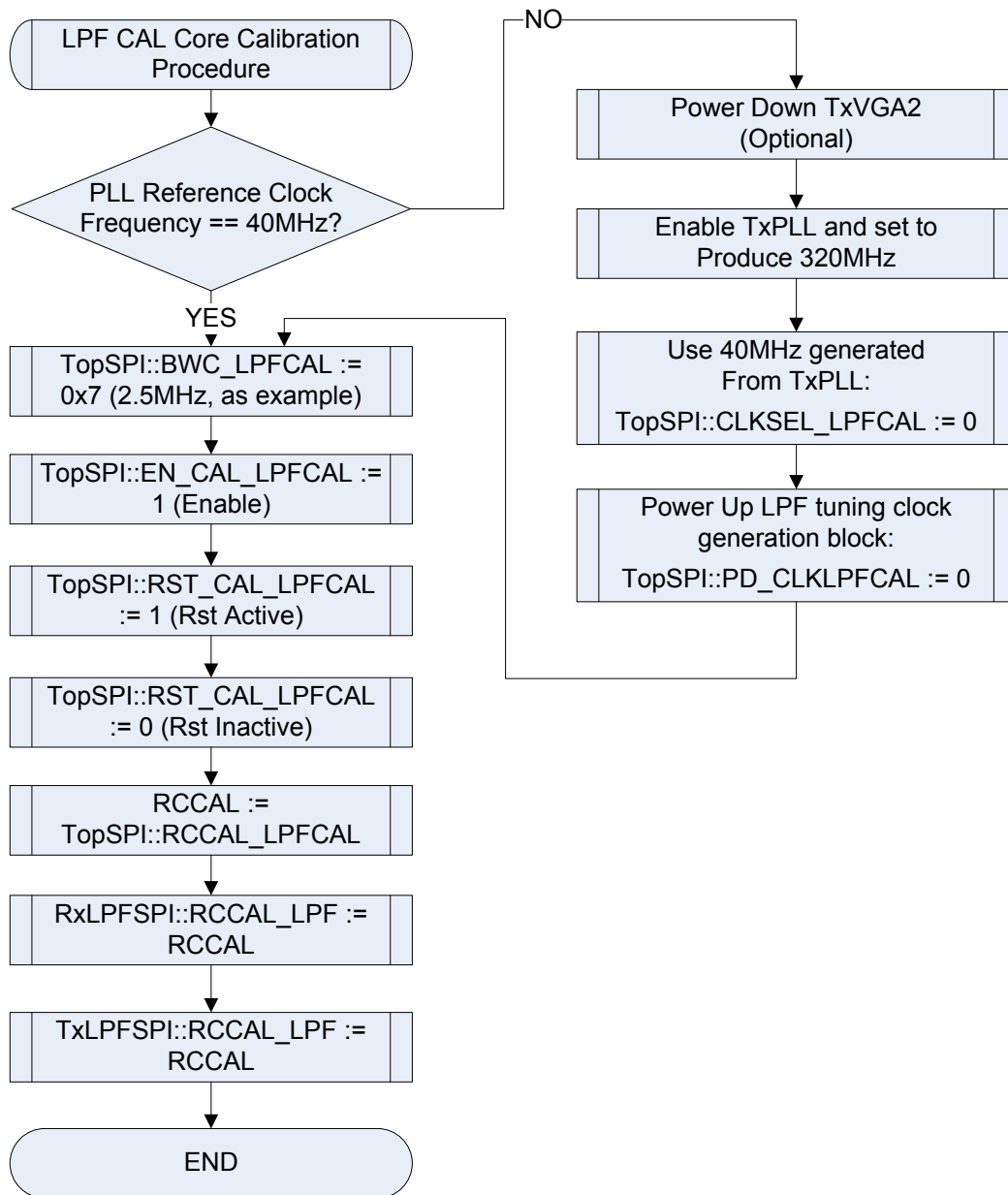
Figure 4.5

4.6   VCO and VCOCAP Code Selection Algorithm
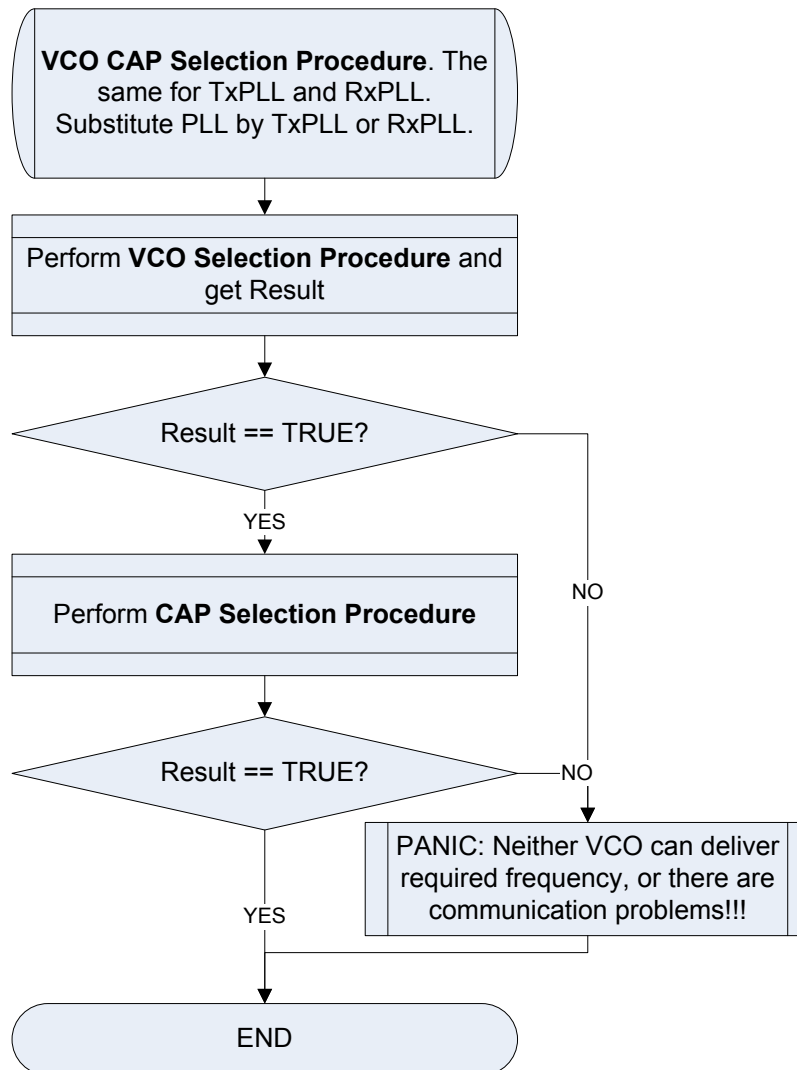
Figure 4.6 General procedure
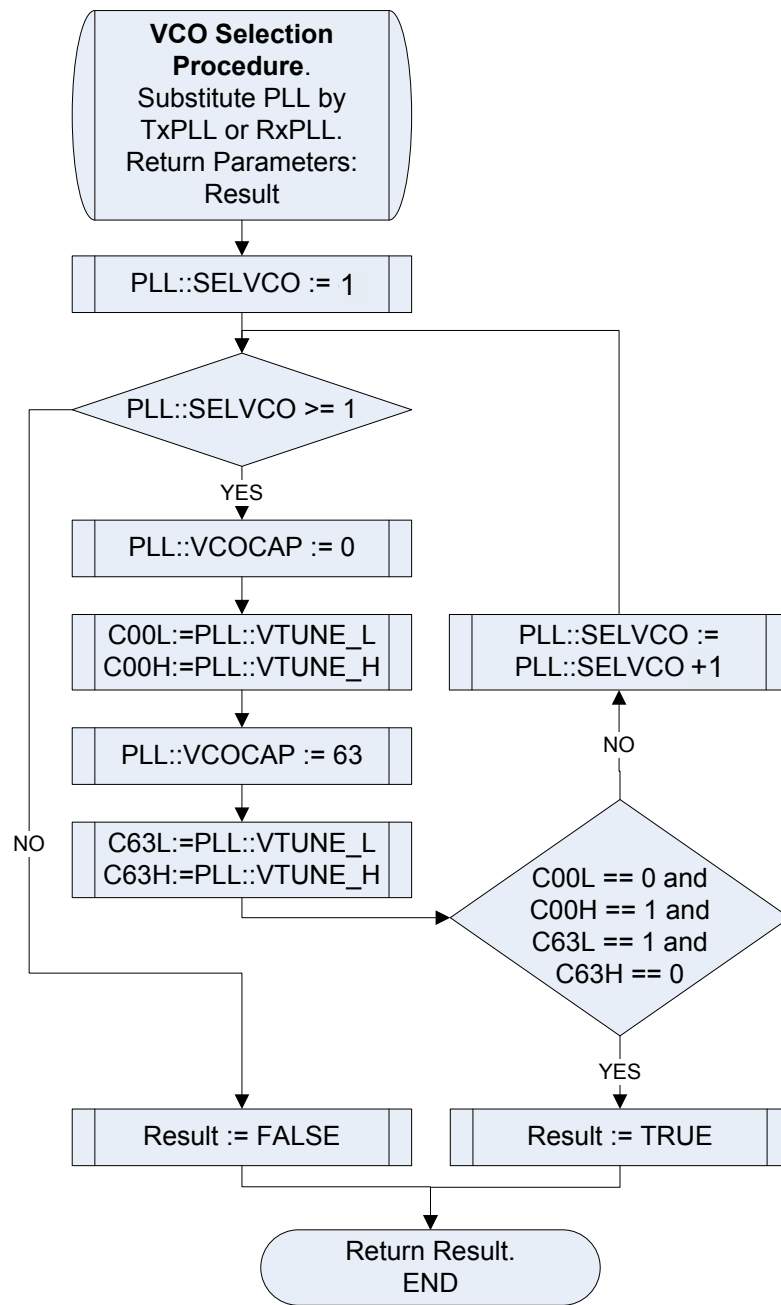
Figure 4.7 VCO selection
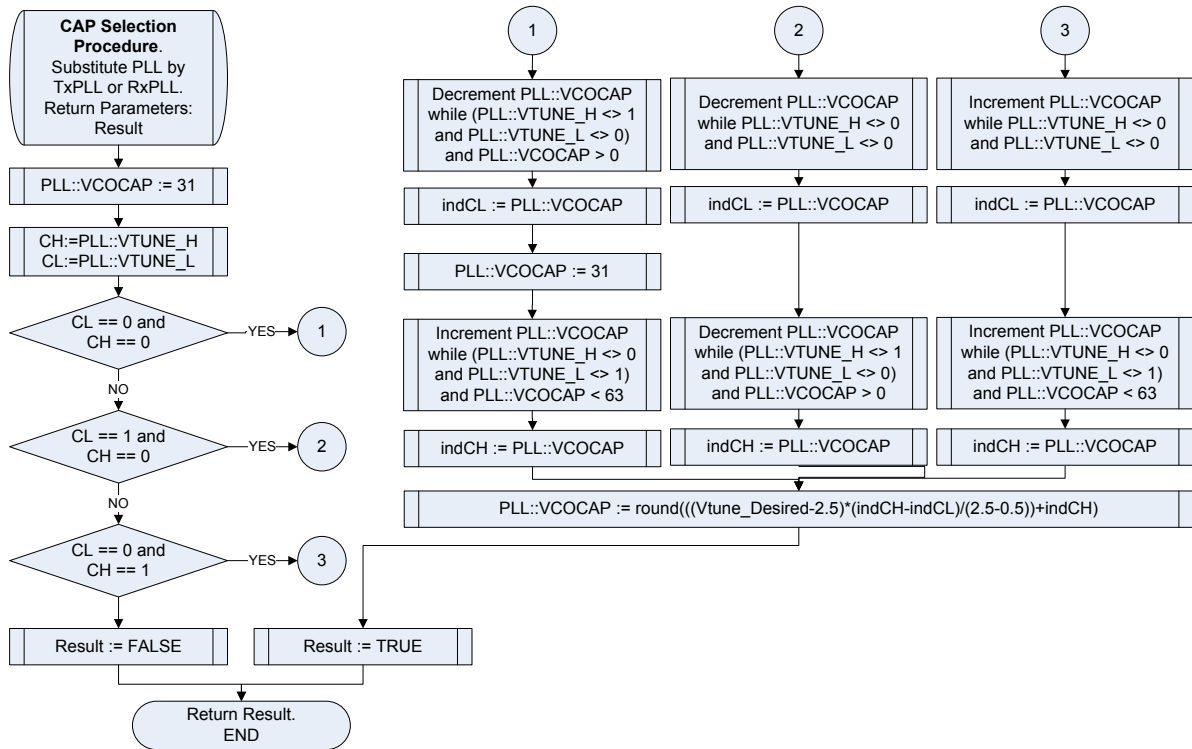
Figure 4.7 VCOCAP selection

4.7 Auto Calibration Summary

The following is recommended auto calibration sequence.

1. DC offset cancellation of the LPF tuning module, Figure 4.2.
2. LPF bandwidth tuning, Figure 4.5.
3. DC offset cancellation of the TXLPF, Figure 4.3.
4. DC offset cancellation of the RXLPF, Figure 4.3.
5. DC offset cancellation of the RXVGA2, Figure 4.4.

Please note, while executing DC calibration procedures, no TX/RX inputs should be applied.

LMS6002D has on-chip DACs for TX LO leakage calibration. Those DACs have been designed to provide around -50/-60dBc LO leakage cancellation.

4.8   Correction and Measurement Functions Implemented in BB

4.8.1   Applying IQ Gain Offset to Baseband Signals

Software in baseband initially applies course gain variation on the I or Q channel and measures the loop backed signal via the LMS6002D receiver to measure the optimum value. The example block for gain correction shown in figure 4.8.
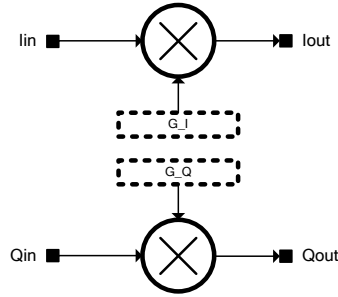

Figure 4.8 IQ gain correction implantation in BB.

This block implements the following equation:

$$Iout = Iin * G\_I$$
$$Qout = Qin * G\_Q$$

G_I and *G_Q* are programmable correction factors which are altered by BB modem to minimize unwanted side band component.

4.8.2   Applying IQ Phase Offset Baseband Signals

The baseband S/W applies a course phase multiplier on the I or Q channel and measures the loop backed signal via the LMS6002D receiver to measure the optimum value. The process is then repeated using a finer control step to ascertain the optimum phase and gain offset value to be applied. The example block for gain correction shown in figure 4.9.
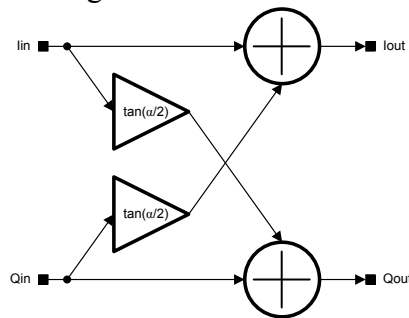

Figure 4.9 IQ phase correction implantation in BB.

IQ phase correction is in fact equivalent to vector rotation. If quadrature phase error is α then I and Q vectors are both rotated by $\alpha/2$ but in opposite directions hence IQ outputs of the corrector are 90$^\text{o}$ phase shifted. IQ phase correction equations are given below:

$$Iout = Iin + Qin * \tan\left(\frac{\alpha}{2}\right) .$$

$$Qout = Qin + Iin * \tan\left(\frac{\alpha}{2}\right)$$

The value of tan$(\alpha/2)$ is used as programmable correction parameter. BB modem should alter this value to minimize unwanted side band component.

4.8.3   Correcting RX I and Q DC Levels

Software in the receiver baseband is required to calibrate the DC level on the I and Q channel received. The process of applying DC level adjustment to the I & Q channel is an optional requirement required for fine tuning purposes only. The methodology of correcting the DC levels is shown in the diagram below.
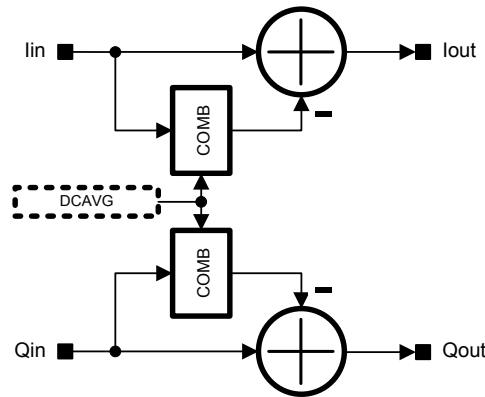

Figure 4.10: Correcting DC level on I and Q channels in the baseband received signal

The averaging (COMB) filter calculates the DC of the corrector input and that DC is subtracted to cancel it. The loop is running all the time so any change of the RX DC due to the signal level change, RX gain change or temperature will be tracked and cancelled automatically. The loop only programmable parameter is DCAVG which defines averaging window size.