AK2401A
Direct Conversion Transceiver

1. General Description

The AK2401A is a direct conversion transceiver that provides high performance narrow-band radio communication. The receiver block of the AK2401A integrates a LNA, I/Q demodulator, PGA and 24-bit delta-sigma ADC, and realizes both performances of high sensitivity and high tolerance to adjacent channel interference, intermodulation and blocking. Digital filter that is able to support channel selection for multiple radio systems, enabling simple system designing for a radio platform. The AK2401A also integrates a delta-sigma Fractional-N synthesizer that composes a high performance PLL with an external VCO. The transmission block has a DAC and a driver amplifier. The AK2401A is housed in a small QFN package (7mm x 7mm), realizing to downsize wire-less applications.

2. Features

- ☐ Operating Frequency: 29MHz to 960MHz
- ☐ Power Supply: 2.7 to 3.3V (DVDD : (1.7 to 1.9V) or (2.7 to 3.3V))
- ☐ Operational Temperature: -40 to +85ºC
- ☐ LNA: Gain 15dB, NF 1.5dB, IIP3 +7dBm
- ☐ High Linearity Direct Conversion I/Q Demodulator
- ☐ 24-bit ΔΣ A/D Converter: up to 150kHz Output Sampling Frequency (TCXO=19.2MHz)
- ☐ Band Changeable Digital Filter (Bandwidth can be set arbitrarily)
- ☐ Automatic Gain Control (AGC) function for LNA and PGA
- ☐ Real-time DC Offset Canceller (RDOC) Function
- ☐ RSSI Function: Data read by SPI communication
- ☐ 18-bit ΔΣ Fractional-N PLL Synthesizer
- ☐ Digital Frequency Modulation (FM/FSK) by Frequency Offset Function
- ☐ Fast Lock Function reduces Lock-up Time
- ☐ 12-bit D/A Converter: 200kHz Max. Sampling Frequency, S/N 72dB
- ☐ Transmission Driver Amplifier: −6 to +4 dBm Output
- ☐ Local Signal Dividing Circuit
- ☐ TCXO Frequency: 18.432MHz / 19.2MHz are recommended
- ☐ Package: 52-pin QFN (7×7×0.85mm 0.4 mm pitch)

3. Application

- Narrow Band Radio Communication: 6.25kHz/7.5kHz/12.5kHz/15kHz/20kHz/25kHz/ 50kHz/100kHz/150kHz / etc.
- Modulation Method: FM/2FSK/4FSK/QPSK/π/4 DQPSK /16QAM/64QAM (Modulation / demodulation needs to be done externally. Modem function is not installed.)
- Analog/Digital Dual Mode Transceiver
- Digital Radio System for Industrial Use
- Public safety and Community/Emergency Radio System
- Convenience Transceiver
- Marine/Mobile Communication System
- Low power / Telemeter Transmitter
- Amateur Radio System

4. Table of Contents

1. General Description 1
2. Features 1
3. Application 1
4. Table of Contents 2
5. Block Diagram and Functions 5
 5.1. Block Diagram 5
 5.2. Functions 5
6. Pin Configurations and Functions 7
 6.1. Pin Configurations 7
 6.2. Pin Functions 8
 6.3. Handling of Unused Pins 10
7. Absolute Maximum Ratings 11
8. Recommended Operating Conditions 11
9. Digital Characteristics 12
 9.1. DC Characteristics 12
 9.2. System Reset 12
 9.3. Serial Interface Timing for Register Access 13
 9.4. Serial Interface Timing for Programmable FIR Filter Coefficient Setting 14
 9.5. Serial Interface Timing for ADC Data Readout 15
 9.6. Serial Interface Timing for DAC Data Write 16
10. Analog Characteristics 17
 10.1. Receiving Characteristics 17
  10.1.1. LNA 17
  10.1.2. MIXER+PGA+AAF+ADC 17
  10.1.3. LOCAL BUFFER+LOCAL DIVIDER (RX) 19
  10.1.4. PLL SYNTHESIZER 19
  10.1.5. RSSI 20
 10.2. Transmission Characteristics 21
  10.2.1. DAC+SMF 21
  10.2.2. LOCAL BUFFER+LOCAL DIVIDER(TX)+DRIVER AMP 21
 10.3. Current Consumption 22
11. Typical Performance Characteristics 23
12. Operation Sequence 23
 12.1. Power-up Sequence 23
 12.2. Power-up Sequence of PLL Synthesizer 24
 12.3. Power-down Sequence of PLL Synthesizer 25
 12.4. DC Offset Calibration Sequence 26
13. Functional Descriptions 27
 13.1. Power Management 27
 13.2. Operation Mode Setting 29
 13.3. Level Diagram 30
  13.3.1. Level Diagram of Analog Receiving Circuit 30
  13.3.2. Level Diagram of Digital Receiving Circuit 31
 13.4. Analog Receiving Circuit (LNA) 32
 13.5. Analog Receiving Circuit (MIXER, PGA, AAF) 34
  13.5.1. MIXER 34
  13.5.2. Analog Filter Frequency Characteristics 35
  13.5.3. Output Path Selection of Analog Baseband Signal 36
 13.6. LOCAL BUFFER, LOCAL DIVIDER 37
  13.6.1. LOCAL BUFFER 37
  13.6.2. LOCAL DIVIDER 37
  13.6.3. Phase Calibration 37
 13.7. PLL SYNTHESIZER 39
  13.7.1. CHARGE PUMP, LOOP FILTER 39
  13.7.2. Frequency Setting 40

13.7.3. Frequency Offset Adjustment 40
13.7.4. Fast Lock Function 43
13.7.5. Lock Detection 44
13.8. Digital Receiving Circuit (ADC, DIGITAL FILTER, RSSI, AGC, ADC P/S IF) 46
13.8.1. ADC 46
13.8.2. Digital Filter Frequency Characteristics 46
13.8.3. Programmable FIR Filter 49
13.8.4. High-Pass Filter 54
13.8.5. DC Offset Calibration 56
13.8.6. RDOC Function 58
13.8.7. AGC Function 59
13.8.8. AGC_KEEP Function 63
13.8.9. RSSI Function 65
13.8.10. Output Sampling Rate 67
13.8.11. ADC P/S IF 68
14. Register Map 69
15. Register Definitions 72
15.1. <0x01-0x03>FRAC 72
15.2. <0x04-0x06>MOD 72
15.3. <0x07-0x08>INT 72
15.4. <0x09>RDIV 72
15.5. <0x0A-0x0B>CP 73
15.6. <0x0C>SYNTH 74
15.7. <0x0D-0x0E>FAST TIME 74
15.8. <0x0F-0x11>FREQ OFFSET1 75
15.9. <0x12>LOCAL 75
15.10. <0x13>TX 76
15.11. <0x14>RX 77
15.12. <0x15-0x16>PGA GAIN 78
15.13. <0x17-0x18>CAL START 79
15.14. <0x19-0x1E>CH_DC OFST 80
15.15. <0x1F-0x21, 0x47-048>AGC 80
15.16. <0x22, 0x51>CH FILTER 84
15.17. <0x23>PROG FILTER 85
15.18. <0x24-0x25, 0x4E-0x50>HPF 85
15.19. <0x26-0x28, 0x44-0x46, 0x4C-0x4D>RDOC 86
15.20. <0x29-0x2B>FREQ OFFSET2 88
15.21. <0x2C>RSSI 88
15.22. <0x2D>FIR COEF 89
15.23. <0x2E>PD 90
15.24. <0x2F-0x30>READ PGA 90
15.25. <0x31-0x36>READ OFST 90
15.26. <0x37-0x39>READ COEF 91
15.27. <0x3A>READ RSSI 91
15.28. <0x3B-0x3E>ANA DC OFST 91
15.29. <0x3F-0x40>LDCNT 92
15.30. <0x41-0x43>PHASE CAL 92
15.31. <0x49>PRE TESTEN 93
15.32. <0x4A>CH FILTER2 94
15.33. <0x4B>STATUS 94
15.34. <0x5F>SOFT RESET 94
16. Recommended External Circuits 95
16.1. Recommended External Circuits 95
16.2. List of Parts 95
16.3. Power Supply/Ground Pin 96
16.4. PCB Design 97
16.5. PCB Layout 98

17. LSI Interface Circuit 99
18. Package 101
18.1. Outline Dimensions 101
18.2. Marking 101
19. Revision History 102

5. Block Diagram and Functions

5.1. Block Diagram

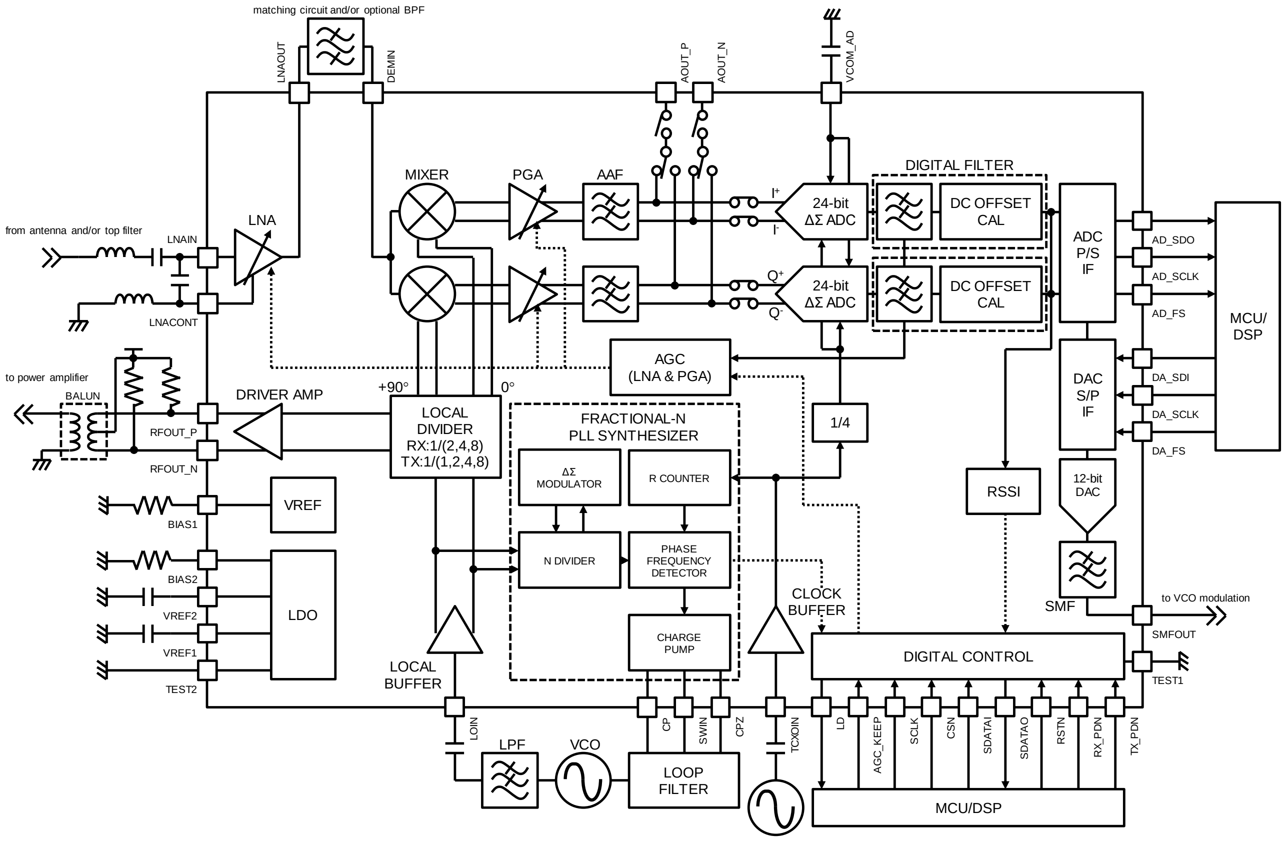


Figure 1. AK2401A Block Diagram

5.2. Functions

The AK2401A consists of the Analog Receiving Circuit 1 (LNA), the Analog Receiving Circuit 2 (MIXER, PGA and AAF), the Digital Receiving Circuit (ADC, DIGITAL FILTER, RSSI, AGC and ADC P/S IF), the Local Oscillation Circuit (PLL SYNTHESIZER, LOCAL BUFFER, LOCAL DIVIDER and CLOCK BUFFER), the Transmitting Data Generation Circuit (DAC S/P IF, DAC and SMOOTHING FILTER), the Transmitting Driver Amplifier Circuit (DRIVER AMP), the Reference Voltage Generation Circuit (VREF), the Internal Low Voltage Generation Circuit (LDO) and the Digital Control Circuit (DIGITAL CONTROL).

- Analog Receiving Circuit 1 (LNA: Low Noise Linear Amplifier)
  Amplify received RF signal in low noise. An automatic gain controlling (AGC) function that automatically switches operation mode according to the input signal level is implemented to prevent degradation of distortion characteristics in strong input environment. An external matching circuit is needed at input/output of the LNA. An external filter can be added between the LNA and the MIXER blocks depending on the Image suppression characteristic demands.

- Analog Receiving Circuit 2 (MIXER, PGA, AAF)
  The direct conversion type MIXER down coverts RF signal that is amplified by LNA. The MIXER is operated by two local signals with 90 degrees phase difference, and it generates Ich/Qch baseband signal. A matching circuit is necessary at the MIXER input. The PGA (programmable gain amplifier) is composed by a first-order low-pass filter that is able to change the gain by register settings. It amplifies the dynamic range by keeping the input level of the ADC after this block. The PGA has an AGC function that changes PGA gain automatically according to input signal level. The AAF is composed by a third-order low-pass filter (F_c=100kHz). It is an anti-aliasing filter that prevents aliasing at the ADC after this block. An analog filter is composed by the PGA and the AAF reducing blocking signals on ADC input.

- Digital Receiving Circuit (ADC, DIGITAL FILTER, RSSI, AGC, ADC P/S IF)
  The 24-bit delta-sigma A/D converter converts an analog baseband signal that is generated at the analog receiving circuit to a digital baseband signal. The digital filter is composed by a decimation filter and a channel filter for removing adjacent channel interference and blocking. The channel filter is selected from 10 types standard channel filters that have different frequency characteristics and FIR filter that can be set the coefficient arbitrary. The narrowest pass band of the standard channel filters is 2 kHz and the widest is 60 kHz. The output sampling frequency differs depending on the type of selected channel filter, and it will be 150 kHz at maximum when using a 19.2 MHz reference clock. A DC OFFSET CAL block is composed of a real-time DC offset canceller (RDOC) and a DC offset calibrator. It cancels DC offset that is superimposed to a baseband signal. The RSSI outputs a signal-strength level of the DC OFFSET CAL output. It can be confirmed by register read on SPI. The parallel interface for ADC outputs digital baseband signals.

- Local Generation Circuit (PLL SYNTHESIZER, LOCAL BUFFER, LOCAL DIVIDER, CLOCK BUFFER)
  The FRACTIONAL-N PLL is composed by a PLL SYNTHESIZER, external LOOP FILTER and VCO. It generates a local frequency signal by multiplying the reference clock from the TCXOIN pin by “N”, and converts to a local frequency by dividing the signal by “N” (N=2, 4, 8) at LOVAL DIVIDER. At the same time, two local signals that have 90 degree phase difference are generated.

- Transmitting Data Generation Circuit (DAC S/P IF, DAC, SMF)
  The 12-bit D/A converter converts a digital baseband signal that is input to a serial/parallel interface for DAC to an analog baseband signal. The SMF (SMOOTHING FILTER) is a low-pass filter (fc=20kHz) that smoothing the DAC output. These circuits are used for generating an audio signal of transmission and connected to voltage control pin of an external VCO. In other case, it is able to be used as a general purpose 12-bit DAC.

- Transmitting Driver Amplifier Circuit (DRIVER AMP)
  This circuit amplifies a signal that is divided by “N” by the LOCAL DIVIDER and outputs. It is assumed to use as a transmitting signal output when modulating the signal directly by an external VCO.

- Reference Voltage Generation Circuit (VREF)
  Generate reference voltage for each block.

- Internal Low Voltage Generation Circuit (LDO)
  Generate a 2.0V power from external 3V power (SYNVDD). This internal power supply is supplied to the digital receiving circuit, the digital control circuit and a part of local oscillation circuit.

- Digital Control Circuit (DIGITAL CONTROL)
  • Register Write/Read by 4-wire Serial Interface
    (CSN, SCLK, SDATAI, SDATAO pins)
  • Hardware Reset Signal Input (RSTN pin)
  • AGC Function Control Signal Input (AGC_KEEP pin)
  • PLL Status Output (LD pin)
  • Power Management by Pins (RX_PDN, TX_PDN pins)

6. Pin Configurations and Functions

6.1. Pin Configurations

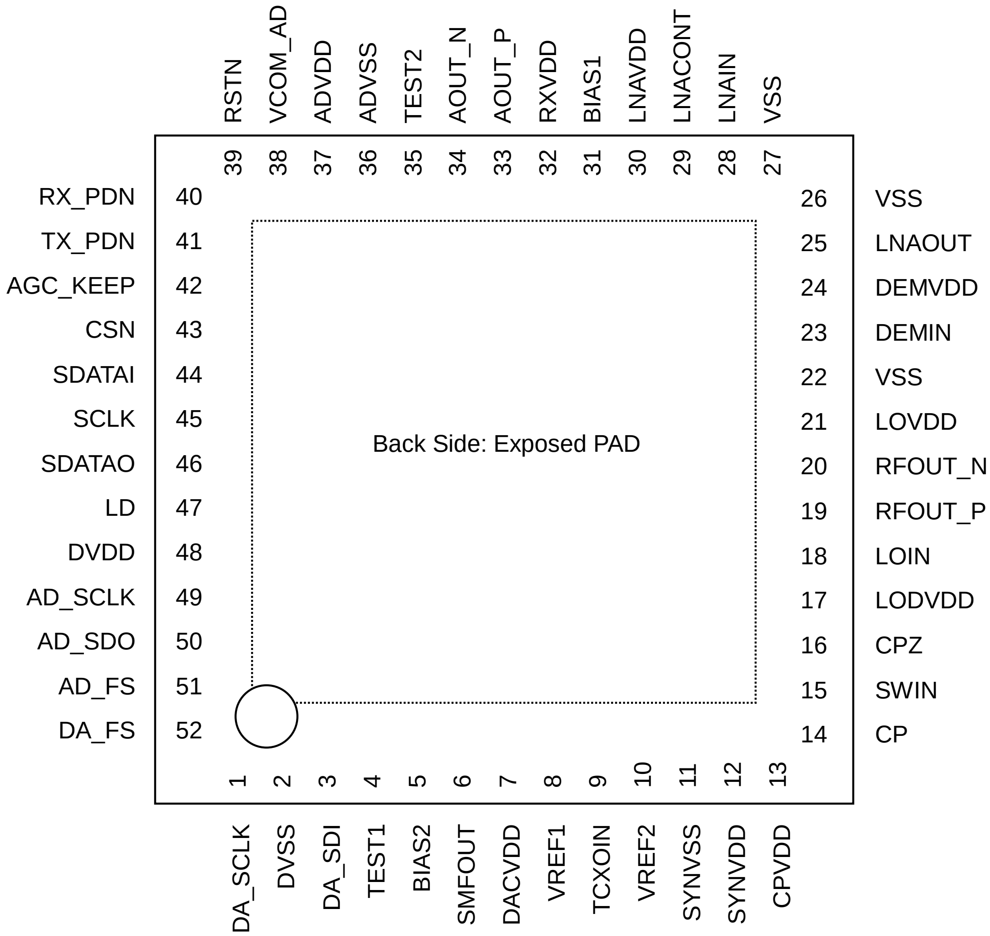


Figure 2. Pin Configurations (52-pin QFN0707, Top View)

6.2. Pin Functions

AI: Analog Input Pin, AO: Analog Output Pin, DI: Digital Input Pin, DO: Digital Output Pin,
P: Power Supply Pin, G: Ground Pin
All digital input pins must not be allowed to float.

No.	Pin Name	Type	Power Down Status	Function
1	DA_SCLK	DI	Hi-Z	Serial Data Clock Input for DAC
2	DVSS	G	-	Digital Ground for Interface Circuit.
3	DA_SDI	DI	Hi-Z	DAC Serial Data Input
4	TEST1	DI	100kΩ Pull down	Test Pin. Connect to VSS.
5	BIAS2	AI	Hi-Z	Resistance Pin for setting charge pump output current
6	SMFOUT	AO	Hi-Z	Smoothing Filter Output
7	DACVDD	P	-	Analog Power Supply for DAC
8	VREF1	AO	-	LDO Reference Connect a capacitor to stabilize LDO reference voltage
9	TCXOIN	AI	25kΩ Pull down	Reference Clock Input
10	VREF2	AO	-	Reference Voltage Pin Connect a capacitor to stabilize reference voltage.
11	SYNVSS	G	-	Analog Ground for Synthesizer
12	SYNVDD	P	-	Analog Power Supply for Synthesizer
13	CPVDD	P	-	Analog Power Supply for Charge Pump
14	CP	AO	Hi-Z	Charge Pump Output
15	SWIN	AI	* 1	Connect a resistor for Fast Lock
16	CPZ	AI	* 1	Connect a capacitor for Loop Filter
17	LODVDD	P	-	Analog Power Supply for Local Divider and Local Buffer
18	LOIN	AI	50Ω Pull down	Local Input
19	RFOUT_P	AO	Hi-Z * 2	Driver Amplifier Positive Output
20	RFOUT_N	AO	Hi-Z * 2	Driver Amplifier Negative Output
21	LOVDD	P	-	Analog Power Supply for Local Amplifier and Driver Amplifier
22	VSS	G	* 3	Ground
23	DEMIN	AI	H-Z * 4	MIXER Input
24	DEMVDD	P	-	Analog Power Supply for MIXER
25	LNAOUT	AO	Hi-Z * 2	LNA Output
26	VSS	G	* 3	Ground
27	VSS	G	* 3	Ground
28	LNAIN	AI	100kΩ Pull down	LNA Input
29	LNACONT	AI	Hi-Z * 4	LNA Matching Adjustment Pin
30	LNAVDD	P	-	Analog Power Supply for LNA
31	BIAS1	AI	Hi-Z	Connect a resistor for current adjustment
32	RXVDD	P	-	Analog Power Supply for PGA, AAF and VREF
33	AOUT_P	AO	Hi-Z	RX Positive Analog Output
34	AOUT_N	AO	Hi-Z	RX Negative Analog Output
35	TEST2	DI	100kΩ Pull down	Test Pin. Connect to VSS.
36	ADVSS	G	-	Ground for ADC
37	ADVDD	P	-	Analog Power Supply for ADC

38	VCOM_AD	AO	VSS	Connect a capacitor to stabilize reference voltage for ADC
39	RSTN	DI	Hi-Z	Hardware Reset Pin
40	RX_PDN	DI	Hi-Z	Power Down Pin for Receiving Block Refer to 13.1. Power Management section for details.
41	TX_PDN	DI	Hi-Z	Power Down Pin for Transmitting Block Refer to 13.1. Power Management section for details.
42	AGC_KEEP	DI	Hi-Z	AGC ON/OFF Control Pin Refer to 13.8.8 AGC_KEEP section for details.
43	CSN	DI	Hi-Z	Register Serial Data Chip Select Pin
44	SDATAI	DI	Hi-Z	Register Serial Data Input
45	SCLK	DI	Hi-Z	Register Serial Data Clock Input
46	SDATAO	DO	Low	Register Serial Data Output
47	LD	DO	Low	Lock Detection Output Pin
48	DVDD	P	-	Digital Power Supply for Interface Circuit
49	AD_SCLK	DO	Low	Clock Output for ADC Serial Data
50	AD_SDO	DO	Low	Serial Data Output for ADC
51	AD_FS	DO	Low	Frame Synchronized Output for ADC Serial Data
52	DA_FS	DI	Hi-Z	Frame Synchronized Input for DAC Serial Data
-	TAB	G	-	Exposed pad on the bottom surface of the package should be connected to VSS.

Notes:
* 1. When PD_SYNTH_N bit = “0”, the switch of loop filter selector is OFF. Refer to 13.7.1 CHARGE PUMP, LOOP FILTER.
* 2. Power supply must be supplied via an inductor since this pin is open drain/corrector pin.
* 3. Internally connected to the TAB.
* 4. This pin must be connected to VSS via an inductor since it is source input pin.

6.3. Handling of Unused Pins

Unused I/O pins must be connected appropriately.

■ In the case of that PLL SYNTHESIZER is not used

No.	Pin Name	Type	Handling	Note
5	BIAS2	AI	Open	
11	SYNVSS	G	Connect to VSS	
12	SYNVDD	P	Supply Voltage	
13	CPVDD	P	Supply Voltage	
14	CP	AO	Open	
15	SWIN	AI	Open	The same handling is also adopted in the case of PLL SYNTHESIZER is used but the fast lock function is not used.
16	CPZ	AI	Open	Refer to “13.7.1 CHARGE PUMP, LOOP FILTER” in the case of PLL SYNTHESIZER is used but the fast lock function is not used.
47	LD	DO	Open	Including the case of not using lock detection function

* The power must be supplied to the SYNVDD/CPVDD pin even when not using the PLL SYNTHESIZER.
* In the case of not using PLL SYNTHESIZER, RDOC can not be used. Use of an external PLL is not recommended.

■ In the case of that DAC is not used

No.	Pin Name	Type	Handling	Note
1	DA_SCLK	DI	Connect to VSS	
3	DA_SDI	DI	Connect to VSS	
6	SMFOUT	AO	Open	
7	DACVDD	P	Supply Voltage	
52	DA_FS	DI	Connect to VSS	

* The power must be supplied to the DACVDD pin even when not using the DAC.

■ In the case of that DRIVER AMP is not used

No.	Pin Name	Type	Handling	Note
19	RFOUT_P	AO	Open	In the case of single-ended output, connect unused pin to VDD.
20	RFOUT_N	AO	Open	
21	LOVDD	P	Supply Voltage	

* The power must be supplied to the LOVDD pin even when not using the DRIVER AMP.

■ In the case of that the corresponding function is not used

No.	Pin Name	Type	Handling	Note
33	AOUT_P	AO	Open	
34	AOUT_N	AO	Open	

42	AGC_KEEP	DI	“L” fixed	

7. Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit
Supply Voltage	LNAVDD pin, DEMVDD pin, ADVDD pin , SYNVDD pin, LODVDD pin, LOVDD pin, RXVDD pin DACVDD pin CPVDD pin	VDD1	-0.3	+3.6	V
	DVDD pin	DVDD	-0.3	+3.6	V
Ground Level * 5		VSS	0	0	V
Applied Analog Input Voltage		V_{AIN}	-0.3	VDD1+0.3	V
Applied Digital Input Voltage		V_{DIN}	-0.3	DVDD+0.3	V
Applied Input Current (except Power Supply pins)		I_{IN}	-10	+10	mA
Maximum LNAIN Input Level * 6		V_{LNAIN}		2.4	Vpp
Maximum DEMIN Input Level	DEMIN Input < 100MHz	DEMPOW1		+15	dBm
	DEMIN Input ≥ 100MHz	DEMPOW2		+10	dBm
Maximum LOIN Input Level		LOPOW		+14	dBm
Storage Temperature Range		T_{stg}	-55	125	ºC

Note:
* 5. VSS, SYNVSS, DVSS and ADVSS pins. All voltages are with respect to ground (VSS).
* 6. AC level that does not include DC bias in LNAIN pin.
* Operation at or beyond these limits may result in permanent damage to the device. Normal operation is not guaranteed at these extremes.

8. Recommended Operating Conditions

Parameter	Symbol	Min.	Typ.	Max.	Unit
Operating Temperature Range	Ta	-40		85	ºC
Power Supply Voltage	VDD1	2.7	3.0	3.3	V
	DVDD* 7	2.7	3.0	3.3	V
		1.7	1.8	1.9	

Note:
* 7. DVDD is power supply for interface circuits.
  If DVDD=2.7 to 3.3V, <Address0x4A> DO_MODE bit=”0”;
  If DVDD=1.7 to 1.9V, <Address0x4A> DO_MODE bit=”1”.

9. Digital Characteristics

9.1. DC Characteristics

Parameter		Symbol	Min.	Typ.	Max.	Unit
High Level Input Voltage	* 8	V_{IH}	0.8DVDD			V
Low Level Input Voltage	* 8	V_{IL}			0.2DVDD	V
High Level Input Current	V_{IH}=DVDD, * 8	I_{IH1}			+10	µA
Low Level Input Current	V_{IL}=0V, * 8	I_{IL1}	-10			µA
High Level Output Voltage	I_{OH}=+0.2mA * 9	V_{OH}	DVDD-0.4		DVDD	V
Low Level Output Voltage	I_{OL}=-0.4mA * 9	V_{OL}	0.0		0.4	V

Regarding the INPUT current, the direction in which the current flows into the IC is defined as + and the direction in which the current flows out from the IC is defined as -.
Regarding the OUTPUT current, the direction in which the current flows out from the IC is defined as + and the direction in which the current flows into the IC is defined as -.

Notes:
* 8. RSTN, CSN, SDATAI, SCLK, DA_SCLK, DA_SDI, DA_FS, AGC_KEEP, RX_PDN and TX_PDN pins
* 9. SDATAO, LD, AD_SCLK, AD_SDO and AD_FS pins

9.2. System Reset

■ Hardware Reset

Parameter		Symbol	Min.	Typ.	Max.	Unit
Hardware Reset Signal Input Width	RSTN pin	t_{RSTN}	1			µs

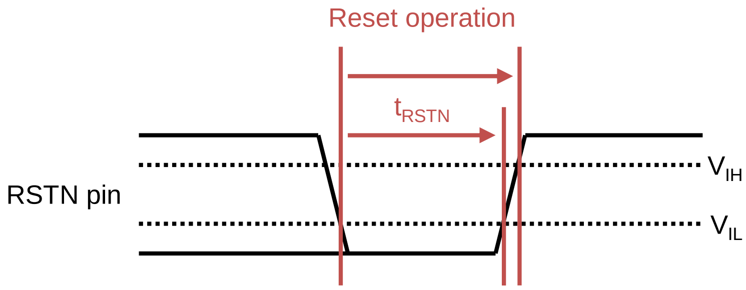


Figure 3. Hardware Reset

Hardware reset is executed by inputting “L” for 1µs or longer to the RSTN pin. All internal statuses are initialized by the hardware reset. Therefore all operational settings should be made after this reset.
For a certain reset of the device, inputs of the SCLK, the SDATAIN and the CSN pins should be fixed to “L” or “H” during reset and reset release timings. (Recommend) SCLK pin: “L”, SDATAIN pin: “L”, CSN pin: “H”.

■ Software Reset

Software reset is executed by writing <Address:0x5F> SRST[7:0] bits = “10101010”. All internal statuses are initialized by this reset same as hardware reset. Therefore all operational settings should be made after this reset. SRST[7:0] bits will be set to “00000000” automatically after software reset is completed.

9.3. Serial Interface Timing for Register Access

Register write and read are executed via serial interface pins (CSN, SCLK, SDATAI and SDATAO pins). A serial data input to the SDATAI pin consists of 1 bit Read/Write instruction, 7 bits address (MSB first, A6 to A0) and 8 bits data (MSB first, D7 to D0) in one frame (16 bits).

■ Write Access (Write Command)

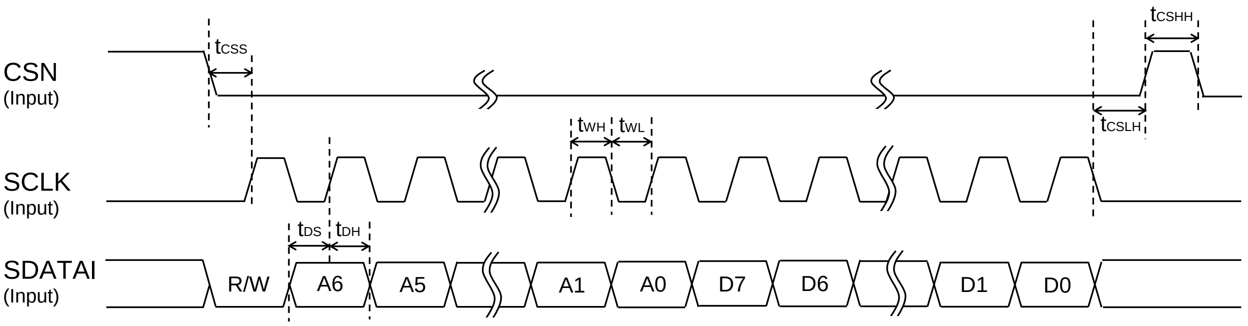


Figure 4. Interface Timing for Serial Register Write

■ Read Access (Read Command)

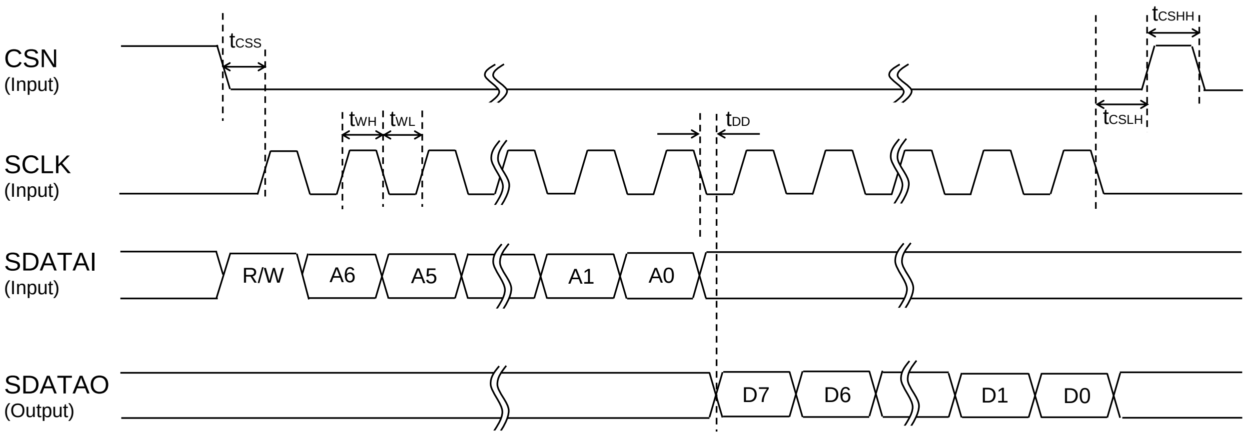


Figure 5. Interface Timing for Serial Register Read

R/W: Instruction bit controls the operation that writes data to the AK2401A or reads out data from the AK2401A. When this bit is “0”, a write operation is executed. When this bit is “1”, a read operation is executed.

A6 to A0: Register address to be accessed

D7 to D0: Write or Read data

(1) The CSN pin should be set to “H” when not accessing to the registers. The serial interfaces will be activated by setting the CSN pin to “L”.

(2) During the CSN pin = “L”, register write is executed in synchronization to a rising edge of the SCLK clock that is 16 cycles. A serial data is input to the SDATAI pin in the order of address and data. The input data is latched on the 16th rising edge of the SCLK. The CSN pin must be set to “H” every time data write is finished (note that input data will be invalid if the CSN pin becomes “H” before 16th SCLK crock count).

(3) In read operation, instruction and address bits are received in synchronization to rising edges of first 8 SCLK clocks and the data is read out in synchronization to falling edge of the last 8 SCLK clocks. The CSN pin must be set to “H” every time data read is finished since a consecutive reading is not supported.

DVDD= 2.7 to 3.3V (<Address0x4A> DO_MODE bit="0")

Parameter		Symbol	Min.	Typ.	Max.	Unit
CSN setup time		t_{CSS}	40			ns
SDATAIN setup time		t_{DS}	20			ns
SDATAIN hold time		t_{DH}	20			ns
SCLK high time		t_{WH}	40			ns
SCLK low time		t_{WL}	40			ns
CSN low hold time		t_{CSLH}	20			ns
CSN high hold time		t_{CSHH}	40			ns
SCLK to SDATA output delay time.	20pF load	t_{DD}			30	ns

DVDD= 1.7 to 1.9V (<Address0x4A> DO_MODE bit="1")

Parameter		Symbol	Min.	Typ.	Max.	Unit
CSN setup time		t_{CSS}	50			ns
SDATAIN setup time		t_{DS}	25			ns
SDATAIN hold time		t_{DH}	25			ns
SCLK high time		t_{WH}	50			ns
SCLK low time		t_{WL}	50			ns
CSN low hold time		t_{CSLH}	25			ns
CSN high hold time		t_{CSHH}	50			ns
SCLK to SDATA output delay time.	20pF load	t_{DD}			45	ns

* Digital Input and output timings refer to a rising/falling signal of 0.5 DVDD.

9.4. Serial Interface Timing for Programmable FIR Filter Coefficient Setting

By setting COEF_ST bit = "1" <Address 0x2D>, the AK2401A will enter coefficient setting mode for programmable FIR filter from register writing mode. Write 16 bits coefficient data sequentially according to the [CSN], [SCLK] and [SDATAI] timings shown below. Refer to "13.8.3. Programmable FIR Filter" for details. AC timings such as clock speed and setup/hold timings are the same as the serial interface for register access.

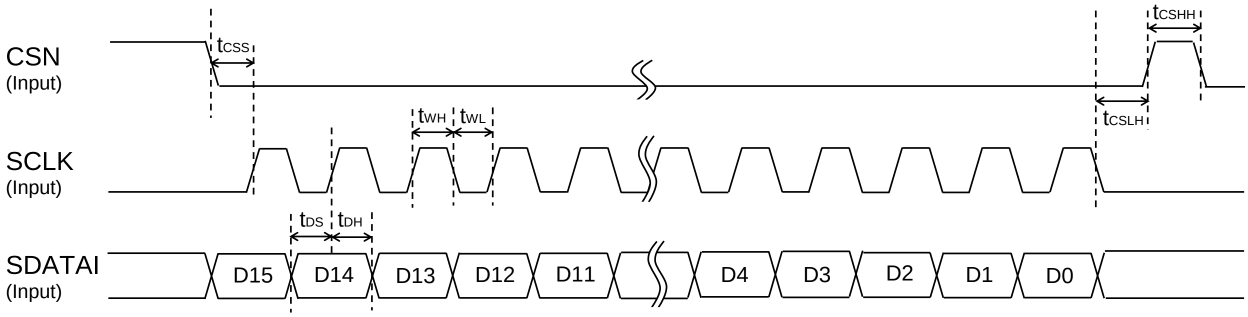


Figure 6. Interface Timing for Programmable FIR Digital Filter Coefficient

9.5. Serial Interface Timing for ADC Data Readout

ADC data is readout via serial interface that is configured with the AD_FS, AD_SCLK and AD_SDO pins. A 64-bit serial data is output from the AD_SDO pin in synchronization with a falling edge of the AD_SCLK pin. The I channel serial data is output when the AD_FS pin = "H" and the Q channel serial data is output when the AD_FS pin = "L" as 32-bit data for each channel. SDATAI signal does not include data and output "0" on the first rising edge of the AD_SCLK. Following the "0" output, 24-bit receiving data after ADC and digital filter processes is output in 2's complement format (MSB data will be fixed on the second rising edge of AD_SCLK pin). The AD_SDO pin outputs internal status bits for 7clocks after the last data of "D[0]". Refer to "13.8.11 ADC P/S IF" for details.

The maximum clock frequency of the AD_SCLK output is 9.6MHz (when TCXO = 19.2MHZ). The AD_SCLK signal frequency can be switched by setting the channel filter (DFIL_SEL[3:0] bits) <Address 0x22> and the sampling frequency (DFIL_SR[1:0] bits) <Address 0x22>. Refer to "13.8.10 Output Sampling Rate" for details.

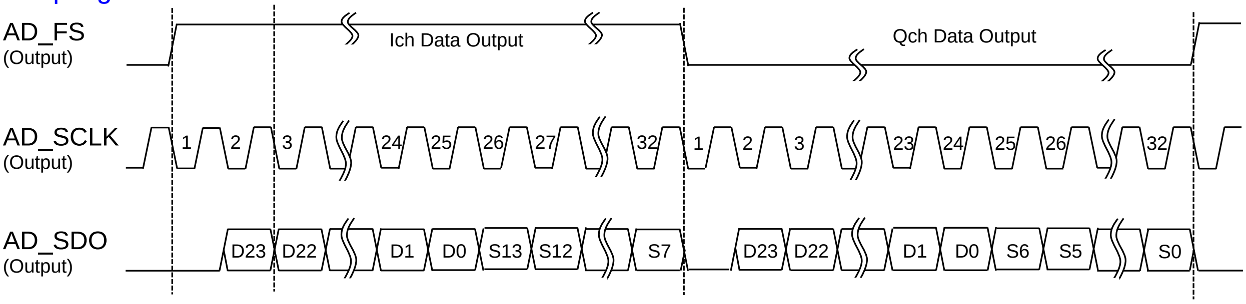


Figure 7. Interface Timing for ADC Data Read

DVDD= 2.7 to 3.3V (<Address0x4A> DO_MODE bit="0")
DVDD= 1.7 to 1.9V (<Address0x4A> DO_MODE bit="1")

Parameter		Symbol	Min.	Typ.	Max.	Unit
AD_SCLK Frequency		tCLK		* 10		MHz
AD_SCLK High Pulse Width	20pF load	tHI	0.4 / tCLK			µs
AD_SCLK Low Pulse Width	20pF load	tLO	0.4 / tCLK			µs

Note:
* Digital output timings refer to a rising/falling signal of 0.5 DVDD. (DVDD= (1.7 to 1.9V) or (2.7 to 3.3V))
* 10. AD_SCLK frequency will be different according to the channel filter setting <Address 0x22> DFIL_SEL[3:0] bits. When F0-F3 of the channel filter is selected, the output is at the frequency of TCXO/2; when F4-F8 is selected, the output is at the frequency of TCXO/4; when F9 is selected, the output is at the frequency of TCXO/8. Refer to "13.8.10 Output Sampling Rate" for details.

9.6. Serial Interface Timing for DAC Data Write

Data write to the DAC is executed via serial interface that is configured with the DA_FS, DA_SCLK and DA_SDI pins. The DAC interface has shift register, and the data is written to the DA_SDI pin (MSB first) in a synchronization with a DA_SLCK rising edge. Parallel converted data is sent to the DAC on a rising edge of the DA_FS pin and analog converted data is output to the SMFOUT pin. The maximum operational frequency of the DAC is 200kHz. The D/A data consists of 12 bits. Data input format is MSB first, 2's complement. Input a 12-cycle clock during a period from a rising edge of the DA_FS pin to a next rising edge of the DA_FS pin according the timing chart below. First 12 bits data is valid when 12 bits or more clock and data are input.

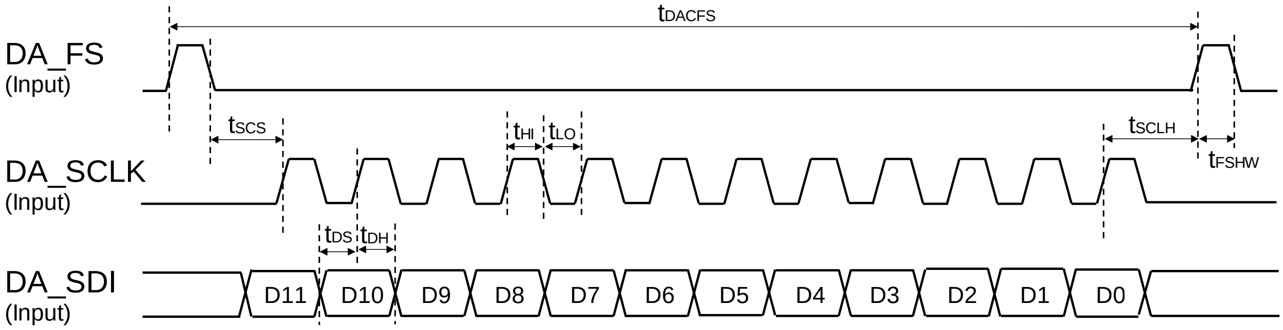


Figure 8. Interface Timing for DAC Data Write

DVDD= 2.7 to 3.3V (<Address0x4A> DO_MODE bit="0")
DVDD= 1.7 to 1.9V (<Address0x4A> DO_MODE bit="1")

Parameter	Symbol	Min.	Typ.	Max.	Unit
DAC_FS Cycle Time	t_{DACFS}	5			µs
DA_FS High Pulse Width	t_{FSHW}	100			ns
DA_SCLK High Pulse Width	t_{HI}	100			ns
DA_SCLK Low Pulse Width	t_{LO}	100			ns
DA_SDI Hold Time	t_{DH}	50			ns
DA_SDI Setup Time	t_{DS}	50			ns
DA_SCLK Low Hold Time	t_{SCLH}	100			ns
DA_SCLK Setup Time	t_{SCS}	100			ns

10. Analog Characteristics

Refer to "13.2 Operation Mode Setting" for settings of each operation mode (xxx Mode).
Specifications that are guaranteed by design are not tested.

10.1. Receiving Characteristics

VDD1= 2.7 to 3.3V, DVDD= (1.7 to 1.9V) or (2.7 to 3.3V), Ta= -40 to 85ºC,
LNA Input=MIXER RF Input=450MHz, LOIN Input=900MHz, <Address0x12>DIVSEL[1:0] bits="01" (Divide by 2), Normal Gain Mode; Unless otherwise specified

10.1.1. LNA

Parameter		Min.	Typ.	Max.	Unit	Description
Operating Frequency Range		29		960	MHz	
Gain	Normal Power Mode	12	15	18	dB	Normal Gain Mode
	Low Power Mode	12	15	18	dB	
	Normal Power Mode	-1	4	9	dB	Low Gain Mode LNA Input=-10dBm
	Low Power Mode	0	5	10	dB	
Noise Figure	Normal Power Mode		1.5	2.1	dB	Guaranteed by Design
	Low Power Mode		1.5	2.1	dB	
IIP3	Normal Power Mode	2	7		dBm	450.025MHz & 450.047MHz Input Observed 450.003MHz
	Low Power Mode	-7	-2		dBm	

10.1.2. MIXER+PGA+AAF+ADC

I channel and Q channel are specified independently.

Maximum PGA Gain:
I Channel: <Address0x15>PGAGAIN_I[5:0] bits="000000"(+28dB)
Q Channel: <Address0x16>PGAGAIN_Q[5:0] bits="000000"(+28dB)
Middle PGA Gain:
I Channel: <Address0x15>PGAGAIN_I[5:0] bits= "011100"(0dB)
Q Channel: <Address0x16>PGAGAIN_Q[5:0] bits= "011100"(0dB)
Minimum PGA Gain:
I Channel: <Address0x15>PGAGAIN_I[5:0] bits="110000"(-20dB)
Q Channel: <Address0x16>PGAGAIN_Q[5:0] bits="110000"(-20dB)

Parameter		Min.	Typ.	Max.	Unit	Description
Operating Frequency Range		29		960	MHz	
Max. Gain	Normal Power Mode	38	42	46	dB	
	Low Power Mode	37	41	45	dB	
Min. Gain	Normal Power Mode	-10	-6	-2	dB	
	Low Power Mode	-11	-7	-3	dB	
Gain Control Range			48		dB	
Gain Control Step		0.7	1	1.3	dB	
Noise Figure	Normal Power Mode		17.5	21.5	dB	Maximum PGA Gain * 11
	Low Power Mode		18.5	22.5	dB	

IIP3	Normal Power Mode	15	19		dBm	Middle PGA Gain 25kHz & 47kHz offset Observed 3kHz
	Low Power Mode	7	11		dBm	
IIP2 (In-band)	Normal Power Mode	55	76		dBm	Middle PGA Gain 5.25kHz & 7.25kHz offset Observed 2kHz
	Low Power Mode	55	76		dBm	
IIP2 (Out-band)	Normal Power Mode	53	72		dBm	Maximum PGA Gain 1MHz & 1.002MHz offset Observed 2kHz
	Low Power Mode	53	72		dBm	
Input P1dB	Normal Power Mode	-28	-22		dBm	Maximum PGA Gain
	Low Power Mode	-28	-22		dBm	
Local Leak at DEMIN pin			-90		dBm	LOIN Input=0dBm
I/Q Gain Imbalance				0.5	dB	
I/Q Phase Imbalance				2.75	deg	LOIN Input=0dBm
Phase Adjust Range		5.5		10	deg	
Phase Adjust Step Size		0		1	deg	
Frequency Attenuation Characteristics (Normalized at 1kHz) Low Cutoff Mode * 12	10kHz	-1	0	+1	dB	Maximum PGA Gain
	100kHz	-18	-9	-3	dB	
	1MHz	-97	-86	-75	dB	
	10kHz	-1	0	+1	dB	Middle PGA Gain
	100kHz	-9	-2	+1	dB	
	1MHz	-72	-62	-52	dB	
	10kHz	-1	0	+1	dB	Minimum PGA Gain
	100kHz	-9	-2	+1	dB	
	1MHz	-68	-60	-50	dB	
Frequency Attenuation Characteristics (Normalized at 1kHz) High Cutoff Mode * 12	10kHz	-1	0	+1	dB	Maximum PGA Gain
	100kHz	-14	-5	0	dB	
	1MHz	-91	-81	-69	dB	
	10kHz	-1	0	+1	dB	Middle PGA Gain
	100kHz	-9	-1.6	+1	dB	
	1MHz	-69	-60	-50	dB	
	10kHz	-1	0	+1	dB	Minimum PGA Gain
	100kHz	-9	-2	+1	dB	
	1MHz	-68	-59	-50	dB	

Notes:

* 11. Calculated from an integration value of (300Hz to 4kHz) output noise.
* 12. Frequency Attenuation Characteristics means MIXER+PGA+AAF. It does not include ADC characteristics.

10.1.3. LOCAL BUFFER+LOCAL DIVIDER (RX)

Parameter		Min.	Typ.	Max.	Unit	Description
LOIN Input Sensitivity		-5	0	5	dBm	
Output Frequency Range	2 div	50		960	MHz	3levels by <Address0x12> DIVSEL[1:0] bits
	4 div	29		480	MHz	
	8 div	29		240	MHz	

10.1.4. PLL SYNTHESIZER

BIAS2 pin=27kΩ

Parameter	Min.	Typ.	Max.	Unit	Description
N DIVIDER					
Operating Frequency Range	100		1920	MHz	
CLOCK BUFFER					
TCXOIN Input Sensitivity	0.4		2	Vpp	
Operating Frequency Range	10	19.2 or 18.432	25	MHz	* 13
PHASE FREQUENCY DETECTOR(PFD)					
Phase Detector Frequency(F_{PFD})			25	MHz	
CHARGE PUMP(CP)					
CP Current Adjust	22	27	33	kΩ	Connect to BIAS2 pin
Maximum CP Current		2560		μA	32 levels by <Address0x0A, 0x0B>
Minimum CP Current		80		μA	
I_{CP} TRI-STATE Leak Current		1		nA	$0.6 \le V_{CPO} \le$ (CPVDD - 0.7) (V_{CPO}:CP pin Voltage)
Sink/Source Current Mismatch * 14			10	%	V_{CPO} = CPVDD/2 Ta = 25ºC
I_{CP} vs V_{CPO} * 15			15	%	$0.5 \le V_{CPO} \le$ (CPVDD - 0.5) Ta = 25ºC
NOISE CHARACTERISTICS					
Normalized Phase Noise		-210		dBc/Hz	* 16

Notes:

* 13. In the case of using a TCXO other than 18.432MHz/19.2MHz, the cutoff frequency of the standard channel filter change. Also note that the output sampling rate of the ADC is related to the TCXO frequency. Refer to 13.8.2 Digital Filter Frequency Characteristics and 13.8.10 Output Sampling Rate for details.
* 14. Sink/Source Current Mismatch: $[(|I_{SINK}|-|I_{SOURCE}|)/\{(|I_{SINK}|+|I_{SOURCE}|)/2\}]\times100$ [%]
* 15. I_{CP} vs V_{CPO}: $[\{1/2*(|I_1|-|I_2|)\}/\{1/2*(|I_1|+|I_2|)\}]\times100$ [%]
* 16. It is calculated by the following formula with measuring in-band phase noise when PLL loop is locked. TCXOIN=19.2MHz, F_{PFD}=19.2MHz. This specification is not tested.
  ($PN_{TOTAL} = PN_{SYNTH} - 10 \text{ Log } F_{PFD} - 20 \text{ Log } N$)
  PN_{TOTAL}: Normalized Phase Noise, PN_{SYNTH}: In-band Phase Noise

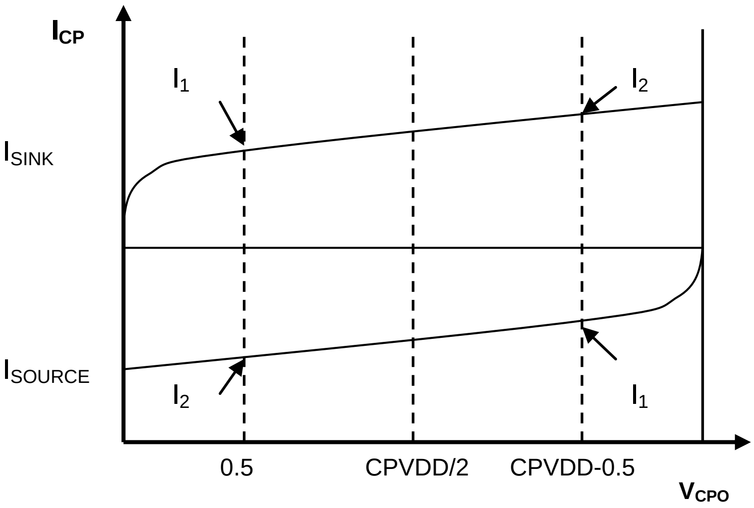


Figure 9. Charge Pump Characteristics - Voltage vs. Current

10.1.5. RSSI

Parameter		Min.	Typ.	Max.	Unit	Description
RSSI Output code <Address0x3A> RSSI[7:0] bits Read Back	LNA Input=-120dBm	0	14	28	Dec	Normal Gain Mode <Address0x1F> AGCOFF bit= “0” <Address0x2C> RSSI_LOW bit= “00”
	LNA Input=-50dBm	140	154	168	Dec	

10.2. Transmission Characteristics

VDD1=2.7 to 3.3V, DVDD= (1.7 to 1.9V) or (2.7 to 3.3V), Ta = -40 to 85ºC,
LOIN Input = 0dBm; Unless otherwise specified

10.2.1. DAC+SMF

Parameter		Min.	Typ.	Max.	Unit	Description
Resolution			12		bit	
Sampling Frequency				200	kHz	
Load Resistance (R_L)		10	100		kΩ	
Load Capacitance (C_L)			50	100	pF	
Output Level		1.15	1.35	1.55	Vpp	RL= 100kΩ, CL= 50pF Integrated Noise BW : 300Hz to 48kHz, fs= 96kHz, fout= 1kHz sine Observed SMFOUT pin
Reference Level		1.35	1.45	1.55	V	
S/N			72		dB	
SINAD			65		dB	
SMF Frequency Characteristics	@1kHz		0		dB	
	@20kHz		-4		dB	
	@100kHz		-44		dB	

10.2.2. LOCAL BUFFER+LOCAL DIVIDER(TX)+DRIVER AMP

Parameter		Min.	Typ.	Max.	Unit	Description
LOIN Input Sensitivity		-5	0	5	dBm	
Output Frequency Range	no div	100		960	MHz	4levels by <Address0x12> DIVSEL[1:0] bits
	2 div	100		960	MHz	
	4 div	100		480	MHz	
	8 div	100		240	MHz	
Output Power@450MHz			+4		dBm	4 levels by <Address0x13> TXOLV[1:0] bits
			+2		dBm	
			0		dBm	
			-6		dBm	

10.3. Current Consumption

VDD1= 2.7 to 3.3V, DVDD= (1.7 to 1.9V) or (2.7 to 3.3V), Ta=-40 to 85ºC; Unless otherwise specified
Refer to "13.1. Power Management" for block numbers shown in Description columns.
Current Consumption includes the drive current of the digital output pin.

■ Current Consumption of Each Function

Parameter		Min.	Typ.	Max.	Unit	Description
BIAS CIRCUIT			1.3	1.8	mA	[10], [11]
PLL SYNTHESIZER			10	15	mA	[5], [6]
RX TOTAL (2 div)	Normal Power Mode		73	96	mA	[1], [2], [3], [5], [7], [8]
	Low Power Mode		52	70	mA	
TX TOTAL (2 div, 0dBm)			24	31	mA	[4], [7], [8], [9]

■ Current Consumption of Each Block (Guaranteed by Design)

Parameter		Min.	Typ.	Max.	Unit	Description
LNA	Normal Power Mode		18		mA	[1]
	Low Power Mode		5		mA	
MIXER+PGA+AAF	Normal Power Mode		34		mA	[2]
	Low Power Mode		26		mA	
ADC+DIGITAL			13		mA	[3]
CLOCK BUFFER			1		mA	[5]
LOCAL BUFFER			2.5		mA	[7]
LOCAL DIVIDER(RX)	2 div		4.5		mA	[8]
	4 div		5.5		mA	
	8 div		6.5		mA	
VREF			0.4		mA	[11]
DAC			5		mA	[4]
LOCAL DIVIDER(TX)	No div		2		mA	[8]
	2 div		3		mA	
	4 div		4		mA	
	8 div		5		mA	
DRIVER AMP	+4dBm		28		mA	[9]
	+2dBm		19		mA	
	0dBm		13.5		mA	
	-6dBm		7		mA	

11. Typical Performance Characteristics

Evaluation data assuming various wireless communication standards is prepared as an application note.
Contact us separately.

12. Operation Sequence

12.1. Power-up Sequence

The AK2401A needs to be initialized by hardware reset (RSTN pin = "L") upon power-up. The RSTN pin must be held to "L" until VREF1 pin output is stabilized after power up each power supply (VDD1 and DVDD). The stabilization time of VREF1 pin depends on external capacitance of the VREF1 pin and VREF2 pin. The maximum VREF1 pin stabilization time is 10ms when connecting a 100pF and 10μF capacitors in parallel to the VREF1 pin and 0.47μF capacitors to the VREF2 pin. (VDD1: LNAVDD, DEMVDD, ADVDD, SYNVDD, LODVDD, LOVDD, RXVDD, CPVDD, DACVDD pins)

*AKM assumes no responsibility for the usage with a power-up sequence other than in this datasheet.

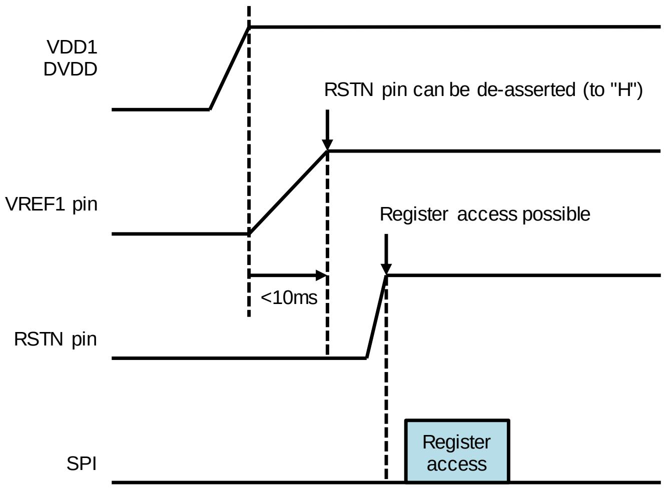


Figure 10. AK2401A Power-up Sequence

1. Set the RSTN pin to "L" and power up the power supplies (VDD1 and DVDD). DVDD must be powered up before or at the same time with SYNVDD. Except DVDD and SYNVDD, power-up sequences between those power supplies are not critical. In addition, it is recommended to start all the power supplies at the same time. Supply voltage to unused blocks and use registers for powering down. The internal LDO (VREF1 pin) will be powered up when SYNVDD is powered up.

2. The internal node (VREF1) will be risen with 10ms (max.) interval after power up the power supplies (VDD1 and DVDD).

3. Register write is enabled by bringing the RSTN pin = "H".

4. Write desired register values. According to 13.1 Power Management, PD_REF_N bit must be started before PD_RXR_N bit. In addition, it is necessary to set phase calibration. Refer to 13.6.3 Phase Calibration.

The polarity of the TX_PDN and RX_PDN pins at power-up is not critical.

12.2. Power-up Sequence of PLL Synthesizer

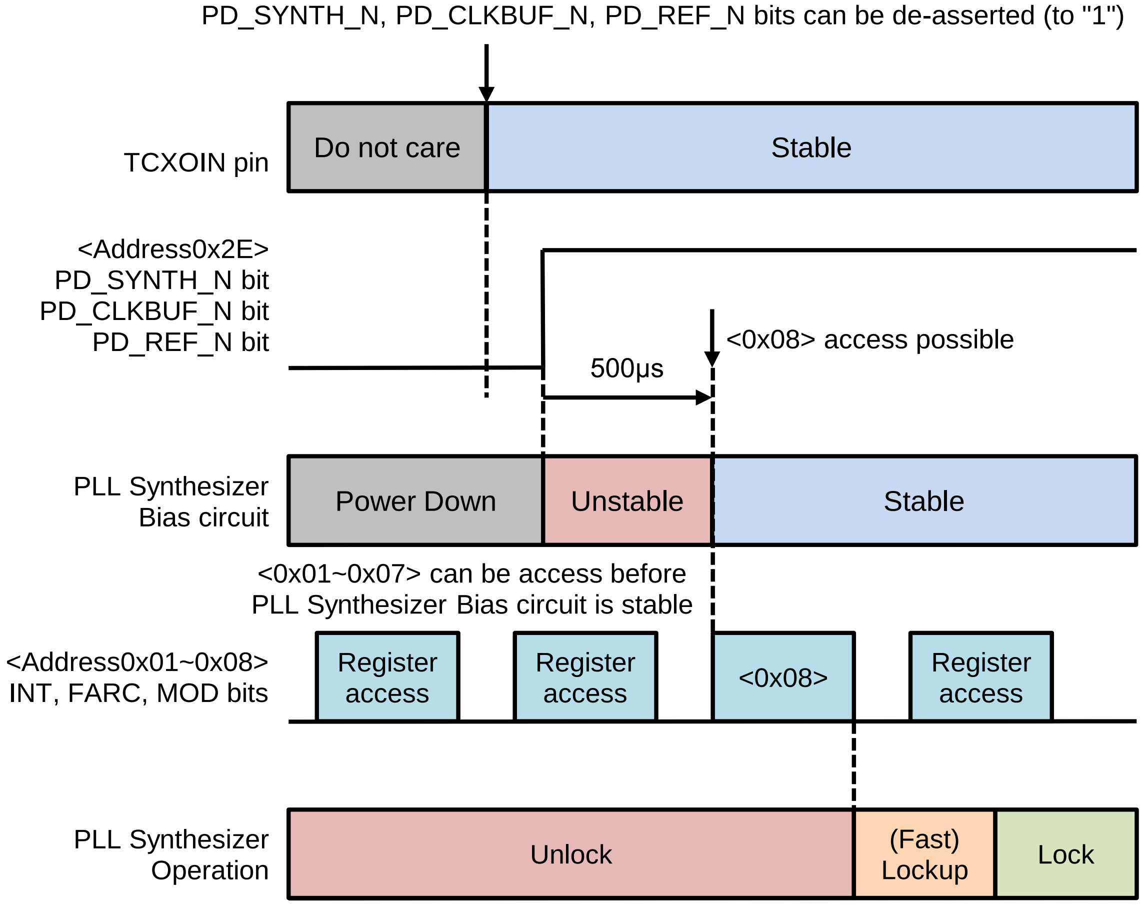


Figure 11. Power-up Sequence of PLL Synthesizer

Write data to the registers in <Address 0x01-0x08>, synthesizer frequency settings will be valid when writing to the last address “0x08” of the setting.

The synthesizer, clock buffer and reference circuits should be powered up when writing to the <Address 0x08>. Set PD_SYNTH_N, PD_CLKBUF_N and PD_REF_N bits = “1” in <Address 0x2E> to power on these circuits with a stable TCXO input before setting synthesizer frequency. (Refer to “13.1. Power Management” for details)

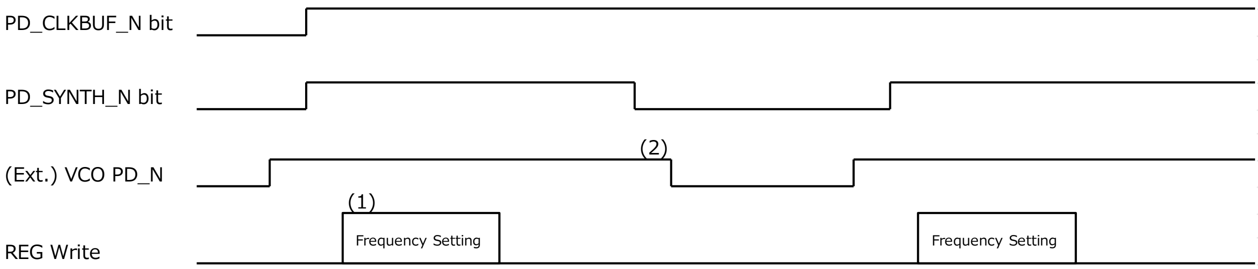
Wait 500μs to stabilize the internal circuit after power on these circuits and execute register write to the <Address 0x08> to set synthesizer frequency. Writing to the <Address 0x08> will be a trigger of frequency change of the synthesizer. Fast Lock-up mode is enabled when the <Address 0x0C> FASTEN bit = “1”. Refer to “13.7.4. Fast Lock Function” for details of the mode.

12.3. Power-down Sequence of PLL Synthesizer

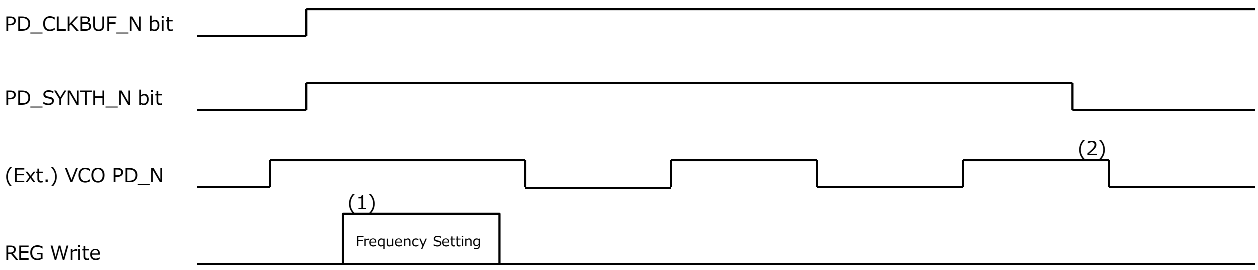
One of the following controls should be executed to power down the PLL Synthesizer.

- Controlling the power-up/power-down of PD_CLKBUF_N and PD_SYNTH_N bit at the same time
- The power-down control by following sequence

■ A sequence for power-down control of external VCO and PLL Synthesizer



■ A sequence for power-down control of only external VCO



(1) The frequency setting (<Address 0x01-0x08>) must be executed after writing PD_SYNTH_N bit = “1”.
(2) The power-down of external VCO must be executed at the same time or later of writing PD_SYNTH_N bit = “0”.

When the PLL Synthesizer is power-down, the frequency setting in the PLL Synthesizer is initialized though <Address 0x01-0x08>INT, FRAC, MOD bits keep their values. Therefore, the frequency setting of PLL Synthesizer should be executed again at next powering up of the PLL Synthesizer. (If the frequency is not changed, it is only required to write the final address <Address 0x08>.)

It is forbidden to power down the PLL Synthesizer (PD_SYNTH_N bit = “0”) in the following three states.

During PD_CLKBUF_N bit = “1”

1. In the state that the frequency setting is not executed after writing PD_SYNTH_N bit = “1” (including that INT and R bits are not set properly.)
2. In the state that the clock of external VCO is not input when PD_SYNTH_N bit = “1”
3. In the state that the clock of TCXO is not input when PD_SYNTH_N bit = “1” (* 17)

* 17. It is not normally assumed to operate TCXO intermittently.

Set PD_CLKBUF_N bit = “0” or initialize the AK2401A by system reset using RSTN pin or SRST bit when the PLL Synthesizer is powered down in the above three states.

12.4. DC Offset Calibration Sequence

DC offset calibration starts by writing “1” to <Address 0x17> OFSCAL1 and OFSCAL2 bits (or OFSCAL3 and OFSCAL4 bits). When executing the calibration separately, it should be applied to the analog bock (OFSCAL1) first and to the digital block (OFSCAL2) second. To stabilize the internal circuits, wait 1.5 ms before starting digital calibration after analog calibration. If OFSCAL1 and OFSCAL2 bits are set to “1” simultaneously, analog calibration is executed first ant the digital calibration is executed next automatically. Figure 12 shows the operation sequence of the DC offset calibration. Refer to 13.8.5 DC Offset Calibration for details about CAL time(2).

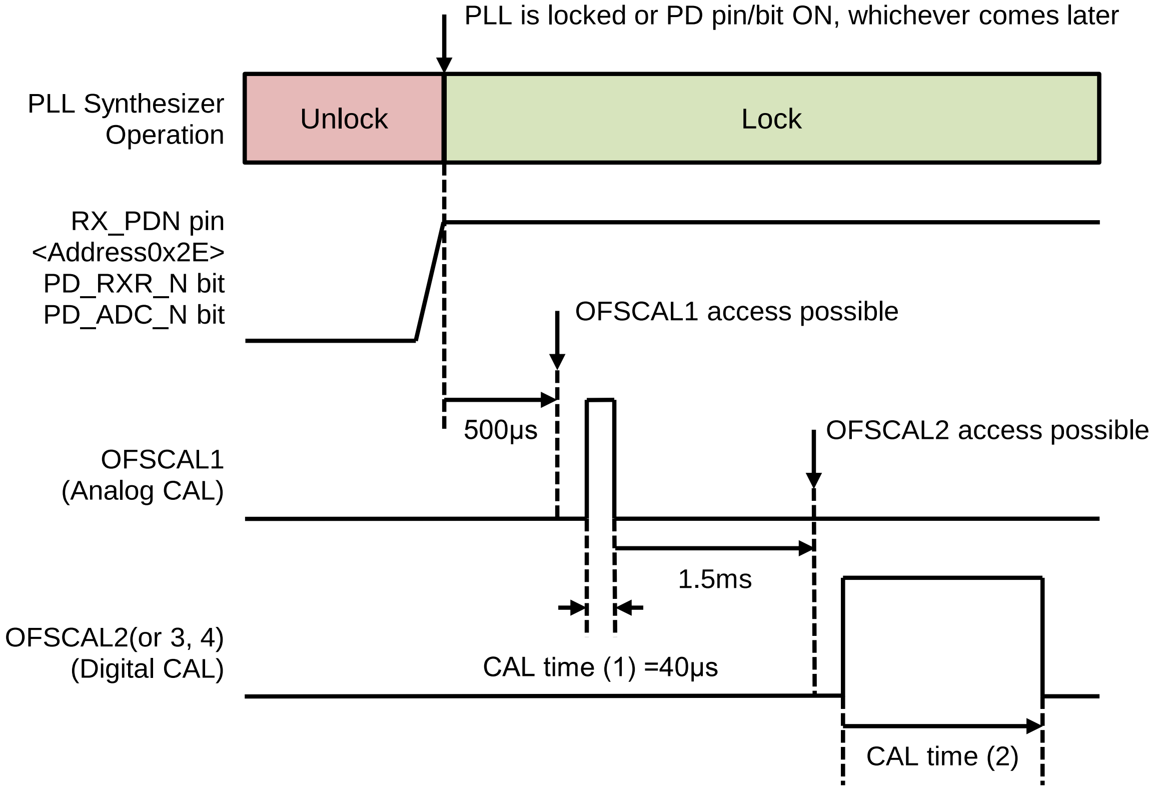


Figure 12. DC Offset Calibration Sequence

13. Functional Descriptions

13.1. Power Management

Power management of the AK2401A is controlled by the RX_PDN and the TX_PDN pins and <Address 0x2E> power down register. Figure 13 shows 11 blocks that are controlled by these settings.

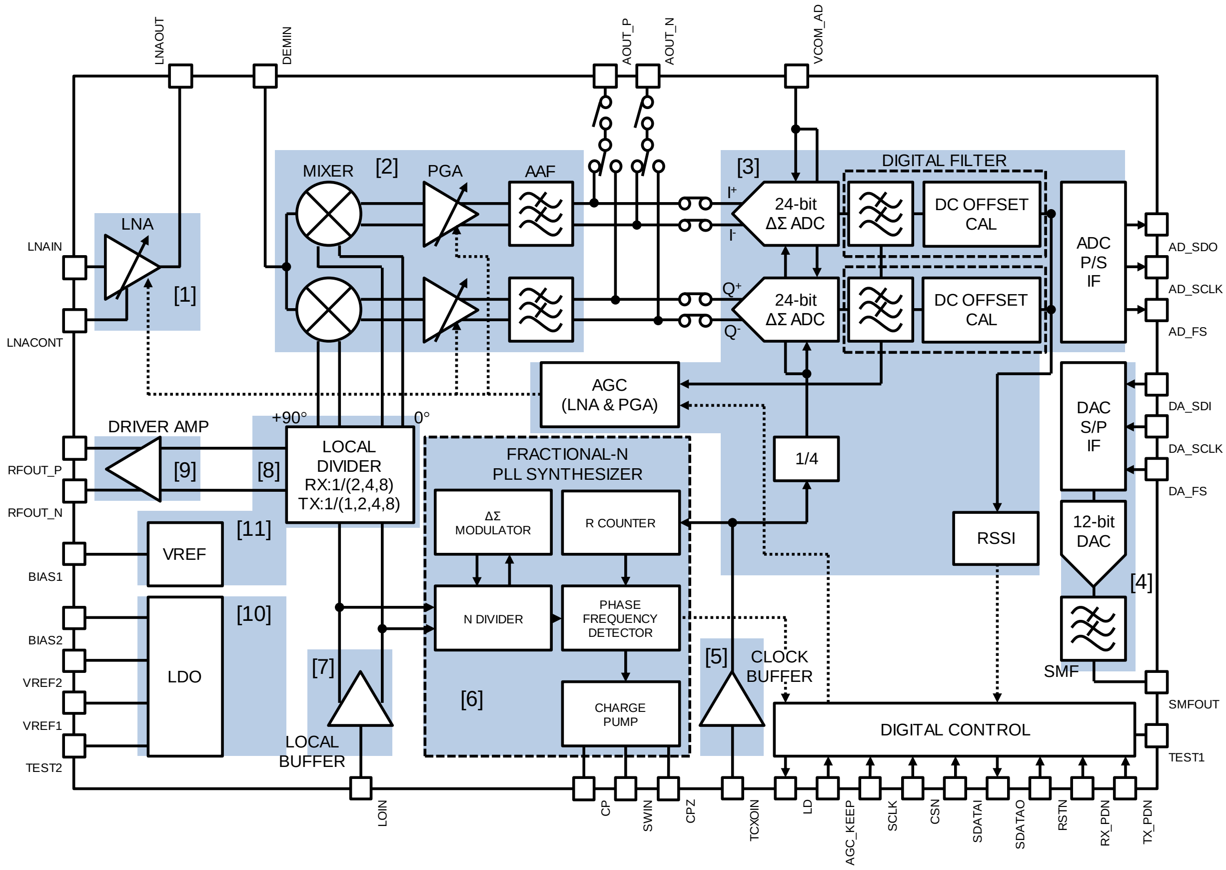


Figure 13. Power Management Block

No.	Management Blocks
[1]	LNA
[2]	MIXER, PGA, AAF
[3]	ADC, DIGITAL FILTER, RSSI, AGC, ADC P/S IF
[4]	DAC S/P IF, DAC, SMF
[5]	CLOCK BUFFER
[6]	PLL SYNTHESIZER
[7]	LOCAL BUFFER
[8]	LOCAL DIVIDER
[9]	DRIVER AMP
[10]	LDO
[11]	VREF

Table 1 shows blocks that are powered on by the power management pins and register. The power management pins are powered on by setting to "H" and the power management register is powered on by setting "1".

Table 1. Power-ON Management Block

	Control Method	Name	Power Management Block											Note
			[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	
Power Up	Pin	SYNVDD pin										●		
Receiving	Pin	RX_PDN pin	●	●	●				●	●				* 18
	Register	PD_LNA_N bit	●											
		PD_RXR_N bit		●					●	●				
		PD_ADC_N bit			●									
Transmitting	Pin	TX_PDN pin				★			★	★	★			* 19
	Register	PD_TXR_N bit							★	★	★			
		PD_DAC_N bit				★								
Other	Register	PD_SYNTH_N bit						◆	◆					
		PD_CLKBUF_N bit					◆							
		PD_REF_N bit											◆	* 20

Note:

* 18. There are no power control limitations for the TX_PDN pin polarity while the receiving block is in operation. However, in order to enable OFST2 bit, it is necessary to control the TX_PDN pin. Refer to "13.7.3. Frequency Offset Adjustment" for details.
* 19. The DAC block [4] can be excluded from TX_PDN pin powered down by setting <Address 0x13> DACCNT bit = "0" (the default value is "1"). Then, control is performed only with PD_DAC_N bit.
* 20. The power management block [2] (MIXER, PGA, AAF) should be powered up when the power management block [11] is powered up. In the same manner, the power management block [11] must be powered down when the power management block [2] is powered down.
* ●, ★ and ◆ indicate blocks that are powered on.

Power management of receiving block is controlled by the RX_PDN pin, PD_LNA_N bit, PD_RXR_N bit and PD_ADC_N bit. The register settings are ANDed. (e.g. It is necessary to set the RX_PDN pin = "H" and PD_LNA_N bit = "1" to power up the LNA block [1].) In the same manner, the settings of the TX_PDN pin, PD_TXR_N bit and PD_DAC_N bit are ANDed.

Power Management Sequence of Transmitting/Receiving Block is shown below.

■ Power Management with the RX_PDN and the TX_PDN Pins

1. Power up the AK2401A according to "12.1 Power-up Sequence" section and put the device in the state that register setting is available.
2. Fix the RX_PDN and TX_PDN pins to "L" and set power management registers of desired blocks to "1".
3. Set the RX_PDN or/and TX_PDN pins to "H" to start transmitting and receiving.

■ Power Management with Registers

1. Power up the AK2401A according to "12.1 Power-up Sequence" section and put the device in the state that register setting is available.
2. Fix the RX_PDN and TX_PDN pins to "H". (It does not matter even if "H" at power-up.)
3. Set power management registers of desired blocks to "1" to start transmitting and receiving.

* The power management block [7] (LOCAL BUFFER) is controlled by ORed result of transmitting and receiving blocks and PD_SYNTH_N bit.
  [7] Power ON: (RX_PDN pin *AND* PD_RXR_N bit) *OR* (TX_PDN pin *AND* PD_TXR_N bit) *OR* PD_SYNTH_N bit
* [8] LOCAL DIVIDER is controlled by ORed result of transmitting and receiving blocks. It will be in operation by power up either transmitting or receiving block.
  [8] Power ON: (RX_PDN pin *AND* PD_RXR_N bit) *OR* (TX_PDN pin *AND* PD_TXR_N bit)

13.2. Operation Mode Setting

Operation modes and control registers of the AK2401A are shown in Table 2.

Table 2. Operation Mode and Control Register

Operation Mode	Control Register	Polarity	Controlled Block
Normal Power Mode	<Address0x14> LPMODE_LNA bit	0	[1]LNA
Low Power Mode		1	
Normal Power Mode	<Address0x14> LPMODE_DEM bit	0	[2]MIXER
Low Power Mode		1	
Normal Gain Mode	<Address0x20> LNA_LGMODE bit	0	[1]LNA
Low Gain Mode		1	
Low Cutoff Mode	<Address0x14> RXLPF_FC bit	0	[2]PGA
High Cutoff Mode		1	
High Level Mode		1	

13.3. Level Diagram

13.3.1. Level Diagram of Analog Receiving Circuit

Level diagram of analog receiving circuit when <Address 0x1F>AGC_OFF bit="0"(during AGC operation) is shown in Figure 14. AGC operates so that the ADC input level becomes the set value of <Address 0x20> AGCTGT bits, and the dynamic range of the overall system is widened by changing the PGA gain. The value of PGA Gain with respect to the LNA input level varies depending on the setting value of AGCTGT bits, here, the level diagram at the time of AGCTGT bits ="011"(+6dBm) setting is stated.

The Low Gain Mode of LNA improves the distortion characteristics of the overall system by reducing the input level to MIXER at the time of strong input. In the Low Gain Mode of LNA that is expected to be used in exceeding IP1dB, the linearity of LNA self-confidence deteriorates compared to Normal Gain Mode. Therefore, when LNA is switched from Normal Gain Mode to Low Gain Mode at strong input, the distortion of the LNA output increases and the distortion of the MIXER output decreases. We expect that the distortion component of 3 * RF frequency output from LNA by exceeding IP1dB of LNA will be attenuated by external BPF between LNA and MIXER. For simplicity, it is assumed that there is no insertion loss of the external BPF between LNA and MIXER.

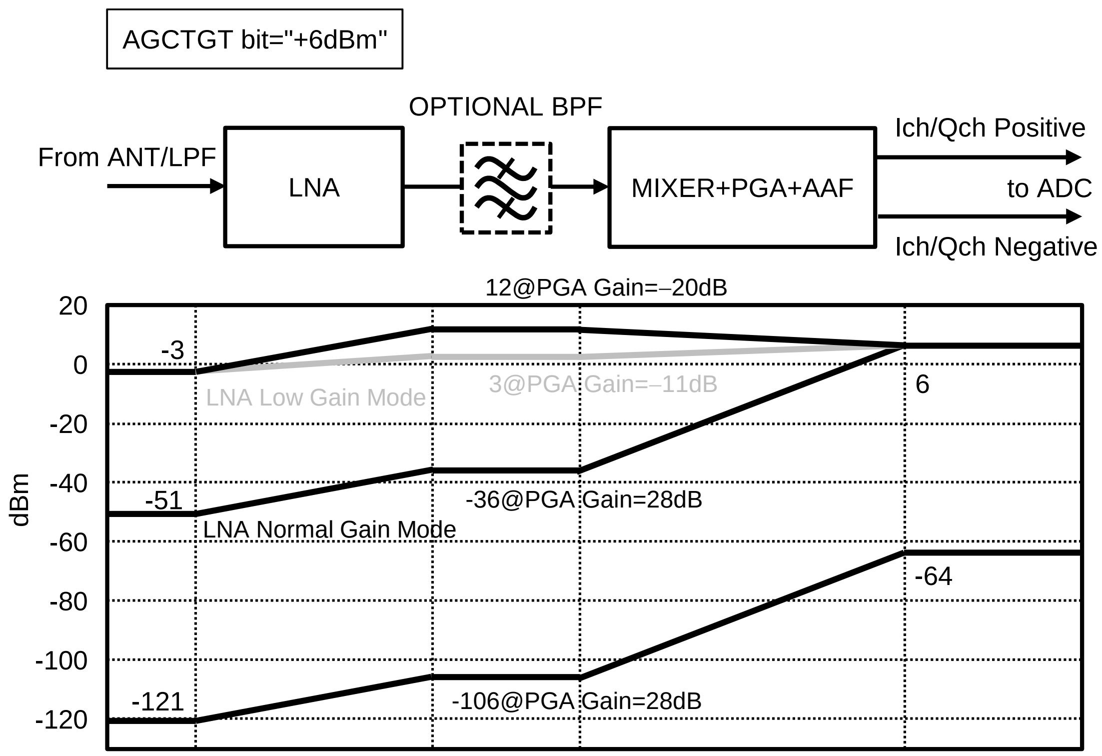


Figure 14. Level Diagram of Analog Receiving Circuit

13.3.2. Level Diagram of Digital Receiving Circuit

Level diagram of digital receiving circuit is shown in Figure 15. The maximum input level of delta-sigma block is 18dBm (=1.7 × VDD1[Vpp]), and -7dBFS at 24-bit full scale delta-sigma modulator. It will be clipped if the input level exceeds this maximum level. Received signal is attenuated 6dB in the decimation filter block. It will be output increasing by 6dB if using F0-F9 filter for channel filter. Therefore, the total gain of the digital filter will be 0dB. When using the programmable filter for channel filter, coefficient and bit adjustment should be executed in consideration of 6dB attenuation by the decimation filter. Refer to "13.8.3. Programmable FIR Filter" for details.

RDOC (Real-time DC Offset Canceller) is optimized for a condition that the total gain of the digital filter is 0dB. It is recommended to design the DC gain of a programmable FIR filter to 6dB when using RDOC and a programmable FIR filter for a channel filter.

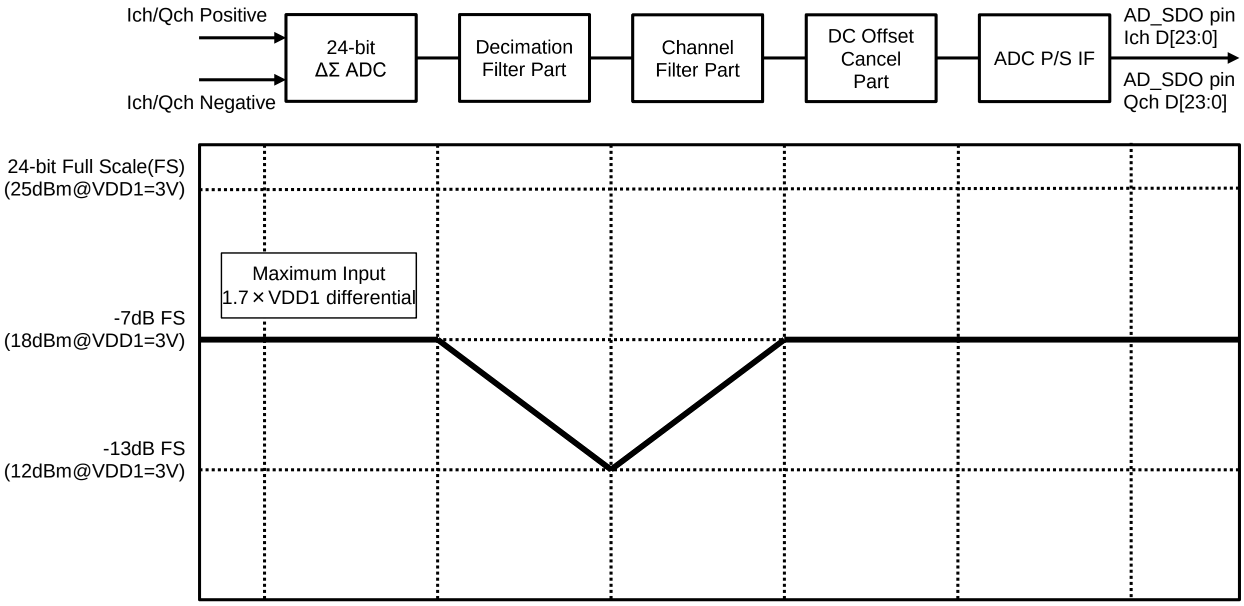


Figure 15. Level Diagram of Digital Receiving Circuit

13.4. Analog Receiving Circuit (LNA)

This is a Low Noise Amplifier (LNA) that gains receiving RF signal while keeping noise low. An impedance matching circuit is necessary for the input/output of the LNA.

The LNA has two operation modes that have different analog characteristics and power consumptions. Normal power mode and low power mode are selected by LPMODE_LNA bit in <Address0x14>. In low power mode, power consumption can be kept low although linearity will be degraded.

It also has normal gain mode and low gain mode to prevent characteristics degradation in high input environment. These modes are selected by LNA_LGMODE bit <Address0x20>. In low gain mode, although linearity and noise will be degraded, gain level can be kept low. In addition, the LNA has automatic gain control (AGC) function that switches operation mode automatically according to input signal level. Refer to "13.8.7. AGC" for details of the AGC function.

An equivalent circuit at the LNA Input is shown in Figure 16. An AC coupling capacitor (C1) is needed since the LNAIN pin is DC biased internally. The LNACONT pin should be connected to the ground via a source inductor (LS). C2 and LG are matching elements for impedance conversion.

Constant of the matching elements can be changed according to the following sequence and expressions if using the AK2401A in a different frequency condition that is shown in "16. Recommended External Circuits".

$$Z_{in} = sL_S + sL_G + \frac{1}{sC_2} + \frac{L_S g_m}{C_2}$$

$$\therefore \mathrm{Re} : \frac{L_S g_m}{C_2} = 50[\Omega] \qquad \cdots(1)$$

$$\therefore \mathrm{Im} : \omega_0 L_S + \omega_0 L_G - \frac{1}{\omega_0 C_2} = 0[\Omega] \qquad \cdots(2)$$

ω_0: Central Angle Frequency

by (1)

$$C_2 = \frac{L_S g_m}{50} \qquad \cdots(3)$$

by (2)

$$L_G = \frac{1}{\omega_0^2 C_2} - L_S \qquad \cdots(4)$$

Determine the source inductor (LS) value first. If the value of LS increases, gain will be decreased. If the value of LS decreases, gain will be increased. Refer to constants written in "16. Recommended External Circuits" for the default value. C2 value can be calculated by determining LS value by expression (3). Adjust C2 value by measuring S11 to have real part as 50Ω. LG value can be calculated by determining LS and C2 by expression (4). Adjust LG value by measuring S11 to have the imaginary part as 0Ω. These values should be determined on a sufficient evaluation since there are some influences by stray capacitances of the printing board and components.

g_m indicates transfer conductance of the internal transistor. The g_m value will be decreased when changing the operation mode to low power mode from normal power mode.

Use a protection diode to limit input amplitude as written in "7. Absolute Maximum Ratings" if the input amplitude at the LNAIN pin exceeds 2.4 Vpp. Connect a LD as needed. It is an inductor that cancels the difference of input impedance caused by a stray capacity of the diode.

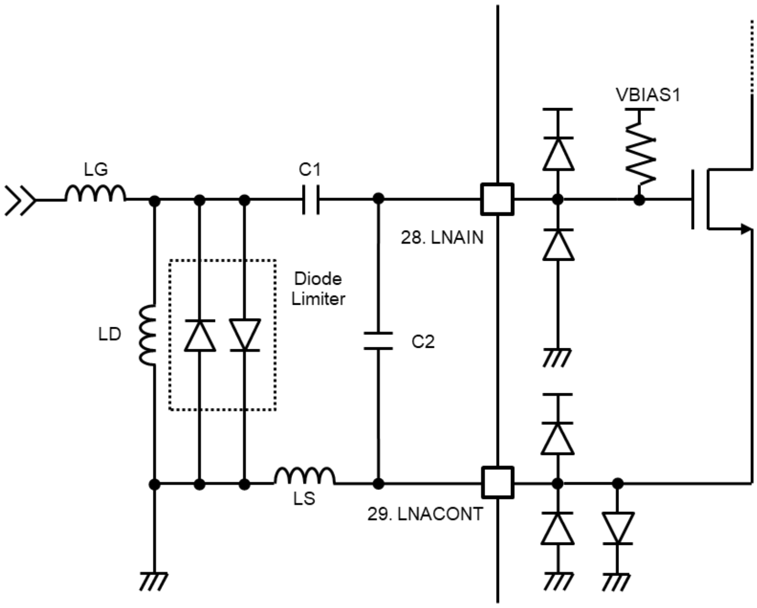


Figure 16. Equivalent Circuit for LNA Input Block

An equivalent circuit at the LNA output is shown in Figure 17. The LNAOUT pin is an open drain pin. Connect the LNAOUT pin to VDD1 via an L1 inductor to supply DC voltage. A load resistance RL should also be connected to the LNAOUT pin in parallel with the L1. The load resistance value can be changed if necessary. Normally, electric characteristics of the AK2401A are assuming to connect a 200Ω load resistance. The C4 is an AC coupling capacitor. The L1 and C4 also work as matching elements for impedance conversion.

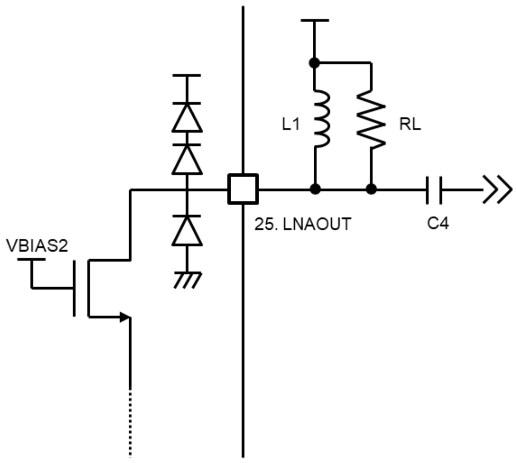


Figure 17. Equivalent Circuit for LNA Output Block

An external filter can be connected between the LNA and MIXER pins according to a desired image rejection characteristic.

13.5. Analog Receiving Circuit (MIXER, PGA, AAF)

RF signal that is gained by LNA is down converted to a baseband signal by the MIXER with direct conversion method. The MIXER is operated by two local signals that have a 90-degree phase difference and generates Ich/Qch baseband signals.

A PGA consists of a first order low-pass filter (Fc= 45 kHz or 90 kHz) that gain is changeable by register settings. It gains the dynamic range by keeping input level constant for the ADC that is disposed in the output stage of the PGA. The AK2401A has the AGC function that changes PGA gain automatically according to the input signal level. Refer to “13.8.7 AGC” for details of AGC function.

An AAF consists of a third order low-pass filter (Fc=100kHz). It is an anti-aliasing filter of the following ADC. An analog filter is composed by the PGA and AAF attenuating blocking signal that is over 100kHz into the ADC.

13.5.1. MIXER

The polarity of I/Q demodulator is shown below (Figure 18). It is designed to have 90 degrees phase difference between the Ich and Qch.

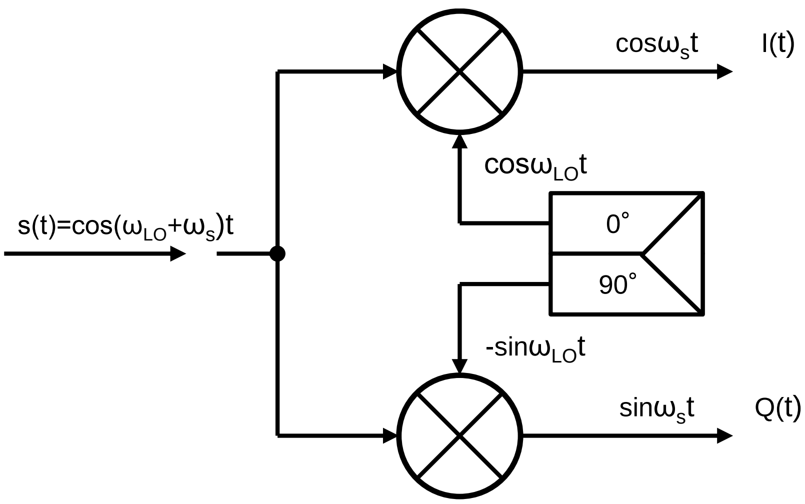


Figure 18. I/Q Demodulator Polarity

The MIXER has two operation modes that have different analog characteristics and power consumptions. Normal power mode and low power mode are selected by LPMODE_DEM bit in <Address0x14>. In low power mode, power consumption can be kept low although gain and linearity will be degraded.

An equivalent circuit is needed at the input of the MIXER (Figure 19). The DEMIN pin must be connected to the ground via L2 choke inductor to settle the DC voltage. C5 and L3 are matching elements for impedance conversion.

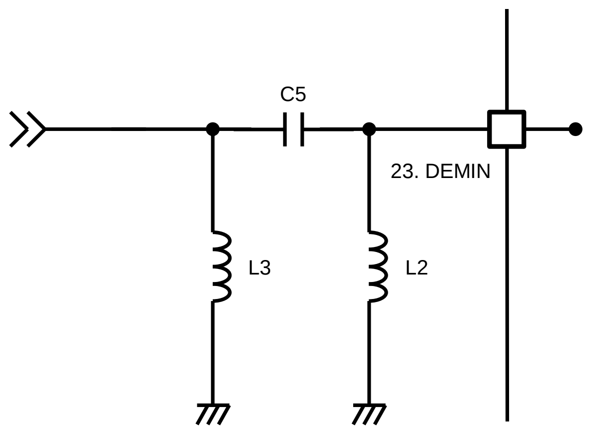


Figure 19. Equivalent Circuit for MIXER Input Block

13.5.2. Analog Filter Frequency Characteristics

Analog block frequency characteristics are shown in Figure 20. The low-pass filter of the analog block is composed by a PGA (programmable gain amplifier) and an AAF (anti-aliasing filter). The cutoff frequency (Fc) of the PGA can be switched by RXLPF_FC bit <Address 0x14>. FC = 45 kHz when RXLPF_FC bit = "0", and Fc = 90 kHz when RXLPF_FC bit = "1". The cutoff frequency (Fc) of the AAF is Fc = 100 kHz.
RXLPF_FC bit should be set according to digital channel filter settings. Refer to "13.8.2. Digital Filter Frequency Characteristics" for details.

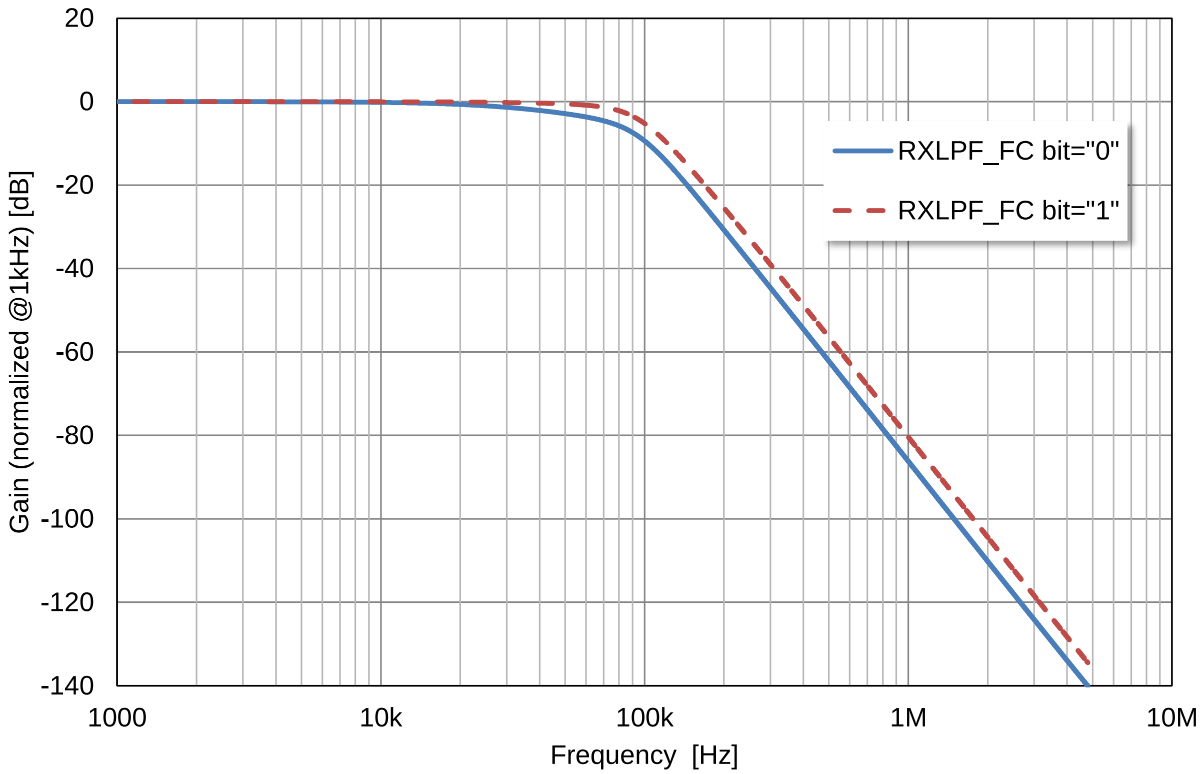


Figure 20. Analog Filter Frequency Characteristics (Maximum PGA Gain Setting)

13.5.3. Output Path Selection of Analog Baseband Signal

The signal path of the AAF output is controlled with IQ_SEL, ANA_PATH and MAIN_PATH bits <Address0x14>. Normally, the path between AAF and ADC is shorten by setting MAIN PATH bit = "1" and the paths between AAF and the AOUT_P pin, and AAF and the AOUT_N pin are open by setting ANA_PATH bit = "0". In this case, the AOUT_P pin and the AOUT_N pin must be opened.

Receiving analog baseband signal can be output in differential format by setting ANA_PATH bit = "1" shortening the paths between AAF and the AOUT_P pin, and AAF and the AOUT_N pin. In this case, IQ_SEL bit selects the output channel from Ich and Qch. Connect AC coupling capacitors to the AOUT_P and AOUT_N pins since these pins are internally DC biased. Connect them to an external device and they will output Hi-z signals.

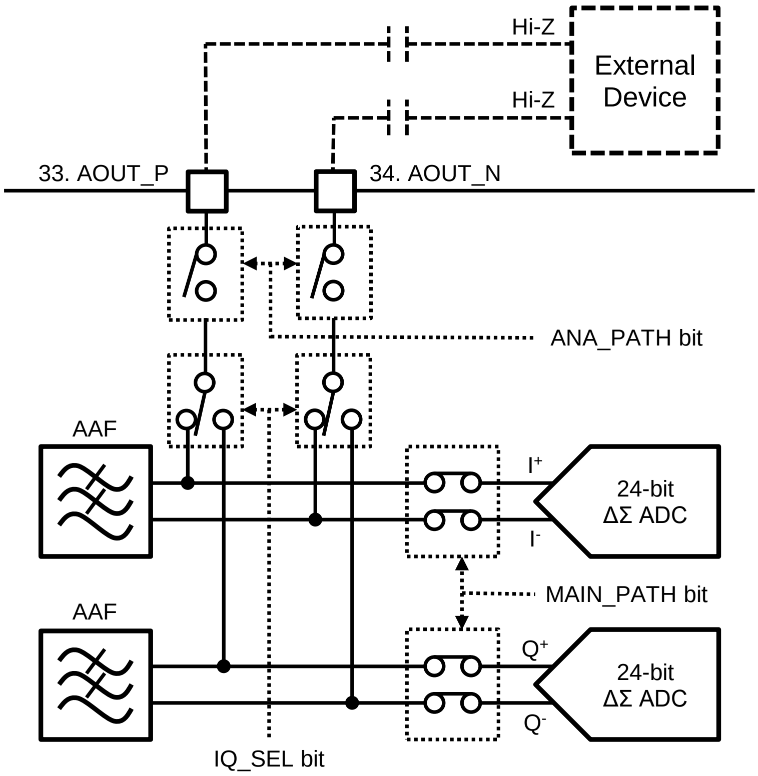


Figure 21. Output Path Selection of Analog Baseband Signal

13.6. LOCAL BUFFER, LOCAL DIVIDER

13.6.1. LOCAL BUFFER

It is a buffer amplifier that amplifies the frequency of external local signal by multiplying by N (N=2, 4, 8). The LOIN pin is internally matched to 50Ω. Input a signal to this pin via an AC coupling capacitor since it is DC biased internally.

13.6.2. LOCAL DIVIDER

LOCAL DIVIDER consists of a local divider and a 90 degrees phase shifter. It converts a local signal that is multiplied by the LOCAL BUFFER to a local frequency by dividing the signal by N (N=2, 4, 8). It also generates two local signals that have 90 degrees phase difference.

Operation frequency of the LOCAL DIVIDER will be different in receiving and transmitting modes. Refer to "10.1.3 LOCAL BUFFER+LOCAL DIVIDER (RX)" and "10.2.2 LOCAL BUFFER+LOCAL DIVIDER(TX)+DRIVER AMP" for details.

13.6.3. Phase Calibration

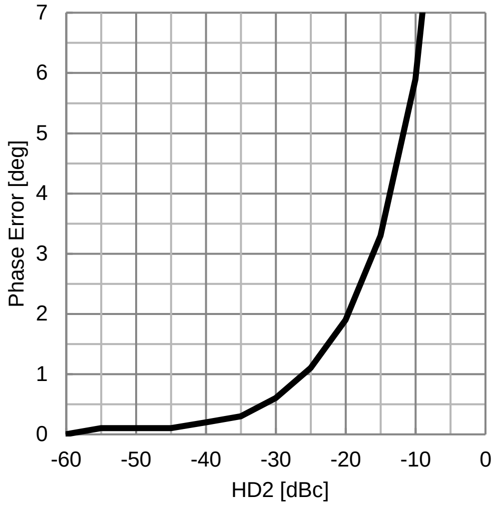
The AK2401A has a calibration function that corrects orthogonal difference of 90 degrees phase shifter. The orthogonality of the 90-degree phase shifter changes depending on local input frequency, Local signal level, and Local HD2. A phase unbalance may be improved by phase calibration with <Address0x14> PH_ADJ[4:0] bits.

Figure 22 shows the effect of the second harmonic of the local signal on the orthogonality. (a) is a graph showing the phase imbalance for the local second harmonic when adjusting the phase unbalance with an ideal local signal (Local HD2 : < -60dB). (b) shows the output S/N ratio (Hum & Noise Ratio) after FM demodulation for phase imbalance. If the IQ phase orthogonality is not sufficient, the S/N ratio will degrade. Therefore, it is recommended to keep the phase imbalance to 1 degree or less.

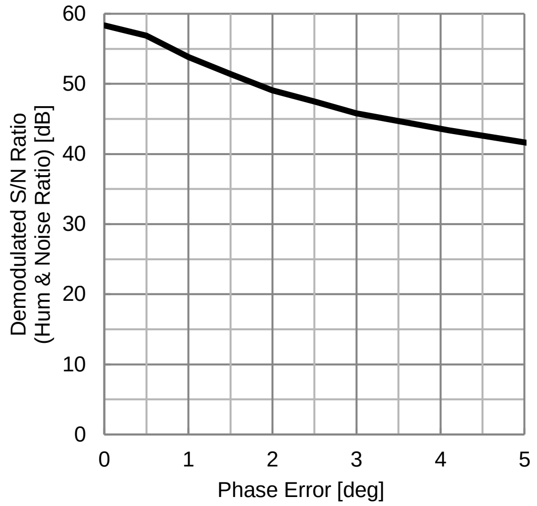
(c) and (d) are graphs comparing the phase imbalance for the input signal power of the local signal between the case where the second harmonic of the local signal is -50 dBc and the case of -20 dBc. (e) and (f) are graphs comparing the phase imbalance for the input frequency of local signal between the case where the second harmonic of the local signal is -50 dBc and the case of -20 dBc. As shown in the graph, by minimizing the second harmonic of the local signal, the variation in phase imbalance for various parameters is reduced.

■ How to determine the calibration value set by the register

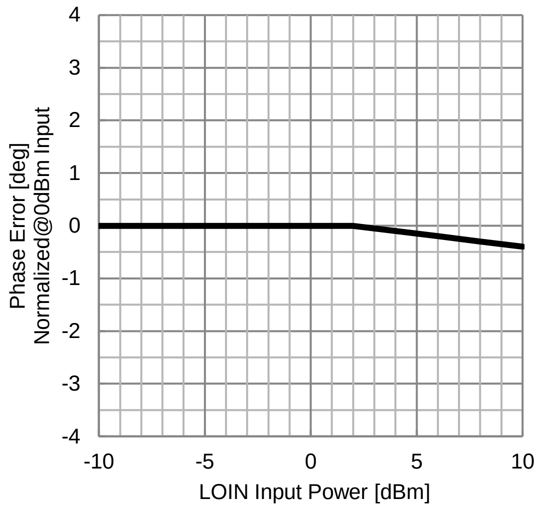
1. At first, insert a LPF that attenuates the second harmonic between VCO and the LOIN pin. It is recommended to suppress HD2 to -40dBc or less.
2. Set the LOIN input level and LOIN input frequency to the usage conditions and determine the calibration value. One way to measure the phase imbalance is to set AK2401A to output CW and measure it. Measure the phase difference of the I/Q output while inputting the CW signal of LO+1kHz to RF and decide the calibration value closet to 90 degrees.



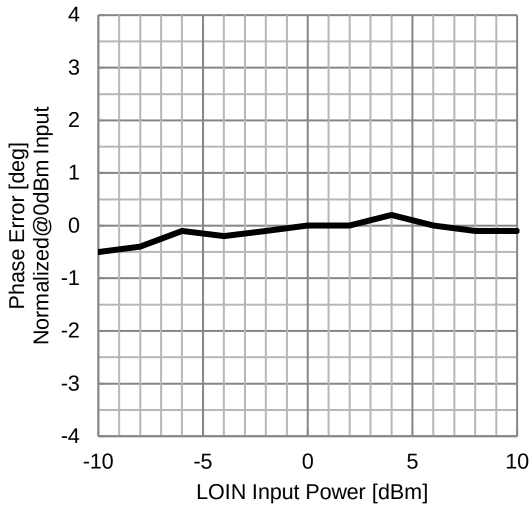
(a) LOIN=900MHz, 0dBm



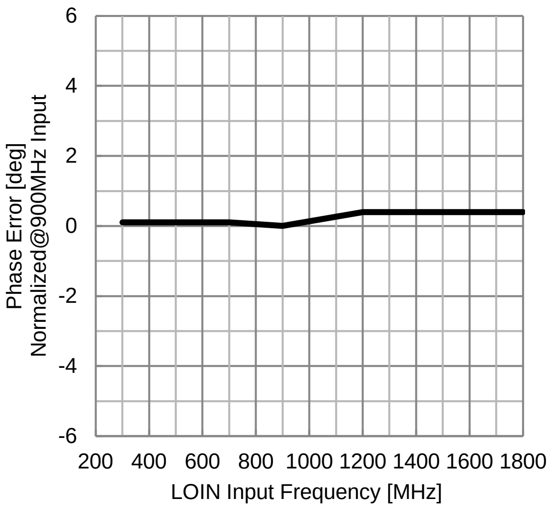
(b) LOIN=900MHz, 0dBm



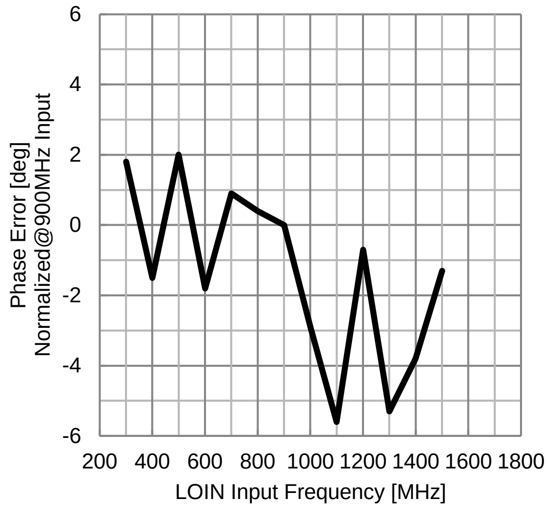
(c) LOIN=900MHz, HD2=-50dBc



(d) LOIN=900MHz, HD2=-20dBc



(e) LOIN=0dBm, HD2=-50dBc



(f) LOIN=0dBm, HD2=-20dBc

Figure 22. Measurement example of the orthogonality of the I/Q phases and various parameters (Divide by 2)

13.7. PLL SYNTHESIZER

The delta-sigma fractional-N PLL synthesizer block integrates an 18-bit delta-sigma modulator, a divider for reference clock, a phase frequency detector, a charge pump and an N-divider, composing a PLL with an external loop filter and VCO.

13.7.1. CHARGE PUMP, LOOP FILTER

Two levels of charge pump current can be set to the AK2401A. CPFINE[4:0] bits <Address 0x0A> set the current for normal operation and CPFAST[4:0] bits <Address 0x0B> set the current for fast lock-up mode. The PLL Fast Lockup mode is realized by switching these charge pump current by a timer for external loop filter. The AK2401A integrates a switch for loop filter changing and operates the switch by the internal timer.

Figure 23 shows the charge pump circuit and loop filter configuration example. The external loop filter must be connected to the CP, SWIN and CPZ pins. The CPZ pin must be connected to the intermediate node of the R2 resistor and the C2 capacitor even when not using the fast lock-up mode. In this case, the R2 resistor should be connected to the CP pin and the C2 capacitor should be connected to the ground.
In fast lock-up mode, The R2 and R'2 resistors are connected in parallel internally by the internal switch. The loop band and phase margin of fast lock-up mode should be calculated from the resistances of R2 and R'2.

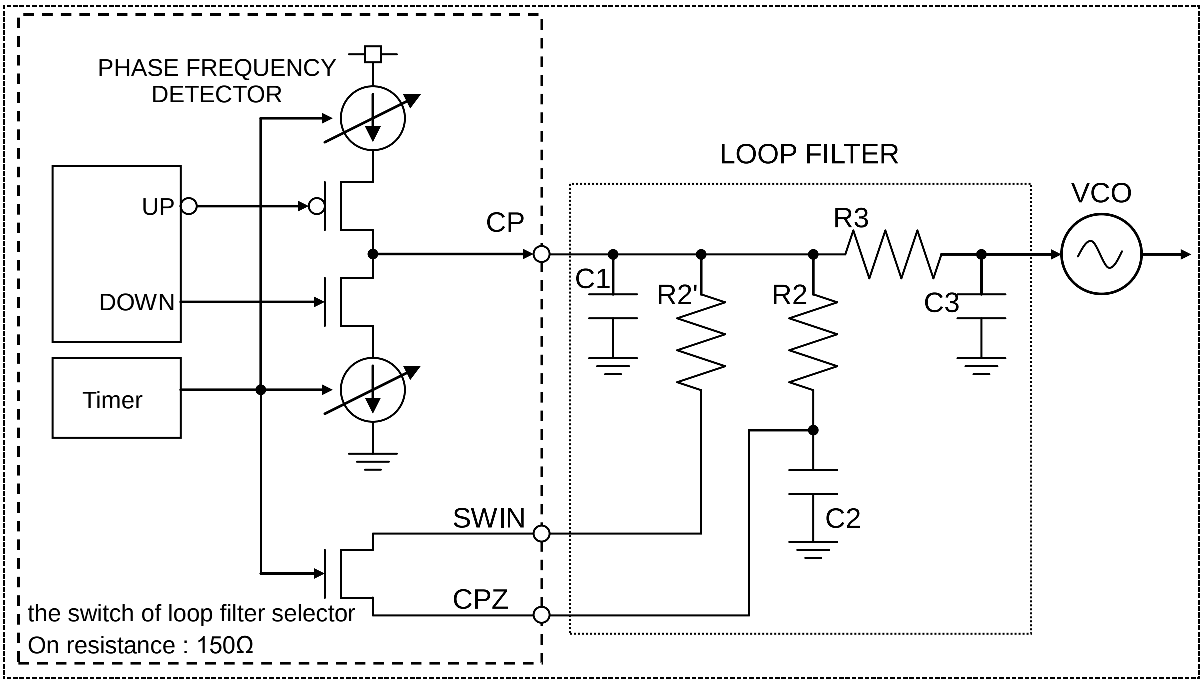


Figure 23. Charge Pump and External Loop Filter Circuit Example

13.7.2. Frequency Setting

The frequency of the AK2401A is calculated as shown below.

$$\text{Frequency Setting} = \text{PFD Frequency} \times \left(\text{INT} + \frac{\text{FRAC}}{\text{MOD}}\right)$$

PFD Frequency: Phase Comparison Frequency
INT: Settign for Integer Dividing Number (<Address0x07-0x08> Refer to “15.3 <0x07-0x08>INT”)
FRAC: Setting for Numerator of Fractional Divider (<Address0x01-0x03> Refer to “15.1 <0x01-0x03>FRAC”)
MOD: Setting for Denominator of Fractional Divider (<Address0x04-0x06> Refer to “15.2 <0x04-0x06>MOD”)

INT[11:0] bits must be set in the range of 35 ≤ INT ≤ 4091 (dec).
FRAC[17:0] bits must be set in the range of 0 ≤ FRAC ≤ (MOD-1).
MOD[17:0] bits must be set in the range of 2 ≤ MOD ≤ 262143 (dec). Since it is possible to set a fine frequency with a larger value, normally set it to the maximum value 262143 (dec).

■ Calculation Example of Setting Value
To achieve 910.0375MHz setting frequency with PFD Frequency = 4.8MHz,
Set values as below.
INT = 189 (dec)
FRAC = 154965 (dec)
MOD = 262143 (dec)

Frequency Setting = 4.8 × (189 + 154965 / 262143) = 910.037504… [MHz]

13.7.3. Frequency Offset Adjustment

The AK2401A has an offset adjustable register that can tune the carrier frequency. The frequency is recalculated by the timing mentioned later after setting OFST1[17:0] bits in <Address 0x0F-0x11> and OFST2[17:0] bits in <Address 0x29-0x2B>. The recalculated frequency is used at the delta-sigma modulator and N-Divider. When using the frequency offset function, be sure to set <Address 0x0C> DSMON bit = "1".

OFST1 is assumed to use for AFC (Auto Frequency Control) and DFM (Digital Frequency Modulation). OFST2 is necessary when using the real-time DC offset canceller (RDOC). Refer to “13.8.6 RDOC” for the relationship between OFST2 and RDOC.

OFST1[17:0] bits or OFST2[17:0] bits are selected by RDOC_FM bit <Address 0x28> and the TX_PDN pin settings as shown below.

RDOC_FM bit	TX_PDN pin	Offset Frequency
0	0	OFST1
0	1	OFST1
1	0	OFST2
1	1	OFST1

Selected offset frequency setting will be valid and the recalculation timings of the PLL synthesizer frequency of each case are described below.

- OFST1
  - When OFST1[7:0] bits <Address 0x11> are written while OFST1 is valid. (<Address 0x0F, 0x10> become valid when <Address 0x11> is written.)
  - When the offset frequency setting is changed to OFST1 from OFST2 by changing RDOC_FM bit or the TX_PDN pin.

- OFST2
  - When OFST[7:0] bits <Address 0x11> are written while OFST2 is valid. (Note that OFST2 is not valid when writing to the register <Address0x2B> although frequency offset setting register of OFST2 are <Address 0x29-0x2B>.)
  - When the offset frequency setting is changed to OFST2 from OFST1 by changing RDOC_FM bit or the TX_PDN pin.

PLL synthesizer frequency that considers offset frequency is calculated as shown below. Setting values of OFST1 and OFST2 are in 2's complement fromat and the MSB will be the sign bit. On the other hand, FRAC and MOD are in straight binary code. In the expression below, OFST means either OFST1 or OFST2.

$$\text{Frequency Setting} + \text{Offset Frequency} = \text{PFD Frequency} \times \left(\text{INT}+\frac{\text{FRAC+OFST}}{\text{MOD}}\right)$$

When (FRAC+OFST)/MOD ≥ 1, (FRAC+OFST-MOD)/MOD will be a fraction since the integer number of frequency dividing INT is added and becomes (INT+1) by internal processing. When (FRAC+OFST)/MOD < 0, (FRAC+OFST+MOD)/MOD will be a fraction since the integer number of frequency dividing INT is subtracted and becomes (INT-1) by internal processing.

The expression to calculate the OFST register setting value from desired offset frequency is as below.

$$\text{OFST} = \frac{\text{Offset Frequency}}{\text{PFD Frequency}} \times \text{MOD}$$

It will be closer to the desired offset frequency when the OFST value is near to an integer and the MOD value is higher. Example 1 and Example 2 are expressing the same setting frequency but it can obtain closer value of desired offset frequency with Example 2.

○ Calculation Examples

Example 1) When offset frequency is positive value (1):
If Frequency Setting= 490.0375MHz, PFD Frequency = 2.4MHz
INT =204, FRAC=8015 and MOD= 43968,
Frequency Setting = 2.4 × (204 + 8015 / 43968) = 490.037500000… [MHz]

To obtain 100Hz Offset Frequency,
OFST = 100 / 2400000 × 43968 = 1.832
The setting value will be 2(dec) by rounding off OFST.
Therefore, the actual Offset Frequency is as follows
Offset Frequency = 2400000 × 2 / 43968 = 109.2 [Hz]
In this case, offset error is 9.2Hz.

Example2) When offset frequency is positive value (2):
If Frequency Setting = 490.0375MHz, PFD Frequency = 2.4MHz
INT=204, FRAC= 47775 and MOD= 262080,
Frequency Setting = 2.4 × (204 + 47775 / 262080) = 490.037500000… [MHz]

To obtain 100Hz Offset Frequency,
OFST = 100 / 2400000 × 262080 = 10.92
The setting value will be 11(dec) = 0x0000B(hex) by rounding off OFST
Therefore, the actual Offset Frequency is as follows
Offset Frequency = 2400000 × 11 / 262080 = 100.7 [Hz]
In this case, offset error is 0.7Hz.

Example3) When offset frequency is negative value:
If Frequency Setting = 490.0375MHz, PFD Frequency = 2.4MHz
INT=204, FRAC= 47775 and MOD= 262080,
Frequency Setting = 2.4 × (204 + 47775 / 262080) = 490.037500000… [MHz]

To obtain 100Hz Offset Frequency,
OFST = -100 / 2400000 × 262080 = -10.92
The setting value will be -11(dec) = 0x3FFF5(hex) by rounding off OFST
Therefore, the actual Offset Frequency is as follows
Offset Frequency = 2400000 × (-11) / 262080 = -100.7 [Hz]
In this case, offset error is 0.7Hz.

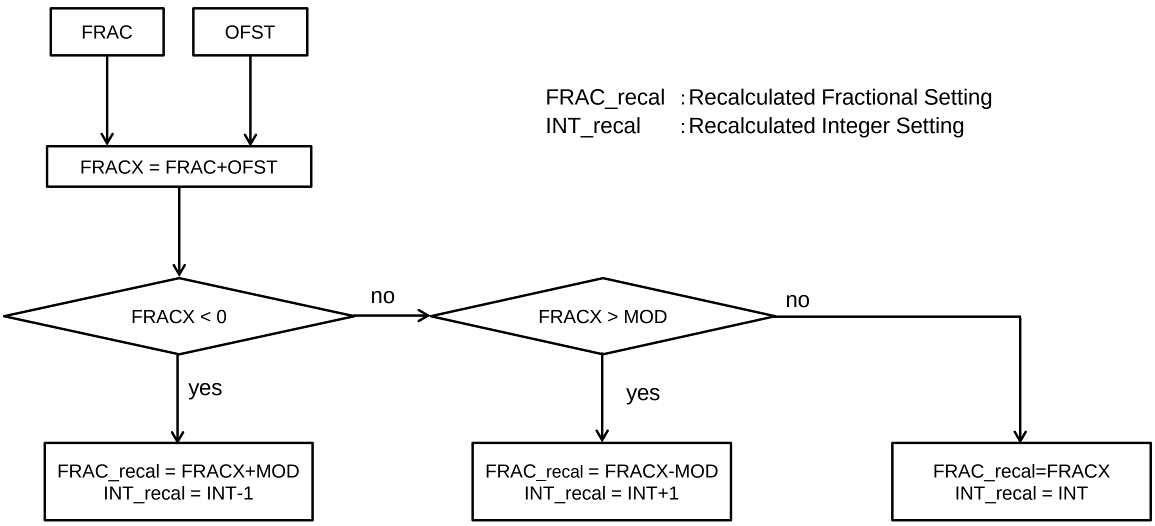


Figure 24. Frequency Recalculation Flow Chart with OFST Register Setting

13.7.4. Fast Lock Function

Fast lock function of the AK2401A is enabled by setting FASTEN bit = “1” <Address 0x0C>. The timer of fast lock operation will start when accessing to the <Address 0x08> for changing the frequency.

The loop filter switch is on for the timer period set by FAST_TIME[12:0] bits <Address 0x0D, 0x0E> and the charge pump current for fast lock function set by CPFAST[4:0] bits <Address 0x0B> is supplied. After the timer period is finished the loop filter switch is turned off and the normal charge pump current set by CPFINE[4:0] bits <Address 0x0A> is enabled. The timing chart of the fast lock function is shown Figure 25. The following formula is used to calculate the period of fast lock function.

Timer Period = Phase Frequency Detector Frequency Cycle x FAST_TIME[12:0] bits

The charge pump current is variable in 32 steps for both normal and fast lock operations. The charge pump current is determined by the resistance connected to the BIAS2 pin, CPFINE[4:0] bits <Address 0x0A> setting and CPFAST[4:0] bits <Address 0x0B> setting for normal and fast lock operations, respectively. The followings show the relationships between resistance, register settings and current.

Minimum Current of Charge Pump (I_{CP_MIN}) [μA] = 2160 / resistor value [kΩ] of the BIAS2 pin
Charge Pump Current [μA] = I_{CP_MIN} × (CPFINE[4:0] bits or CPFAST[4:0] bits + 1)

The external resistor of the BIAS pin should be selected in the range of (22 to 33) kΩ. Refer to the CP in “15.5 <0x0A-0x0B>CP” for details of the setting.

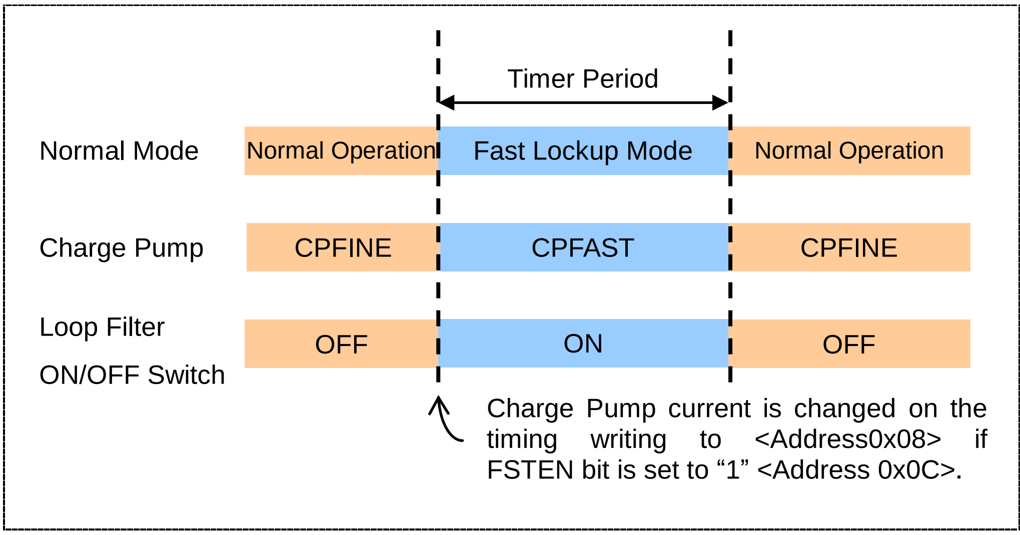


Figure 25. Fast Lock Function Sequence

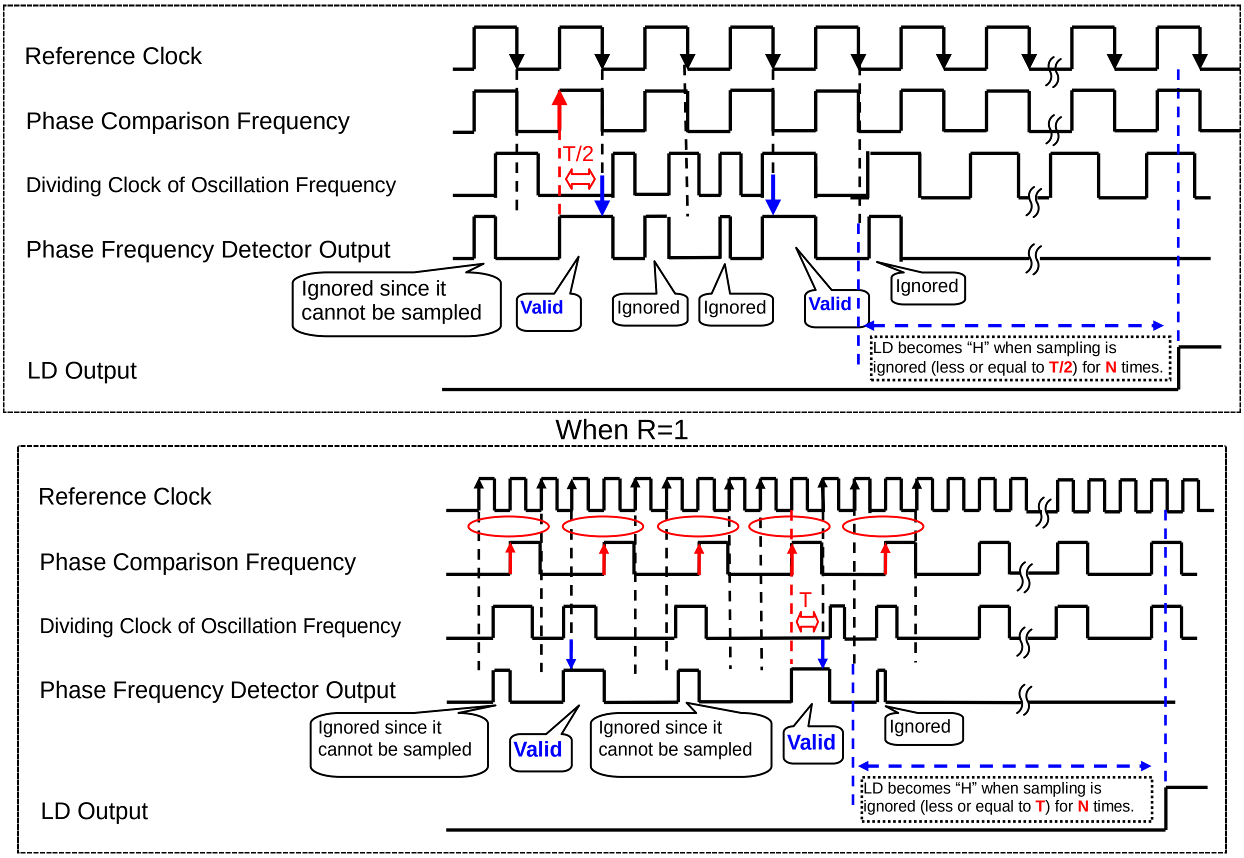
13.7.5. Lock Detection

The AK2401A has a lock detection function to determine PLL lock/unlock state. The lock detection function is enabled by setting LD bit = “0” <Address0x0C> and PLL lock detection signal is output from the LD pin according to the internal logic. It is called digital lock detection.

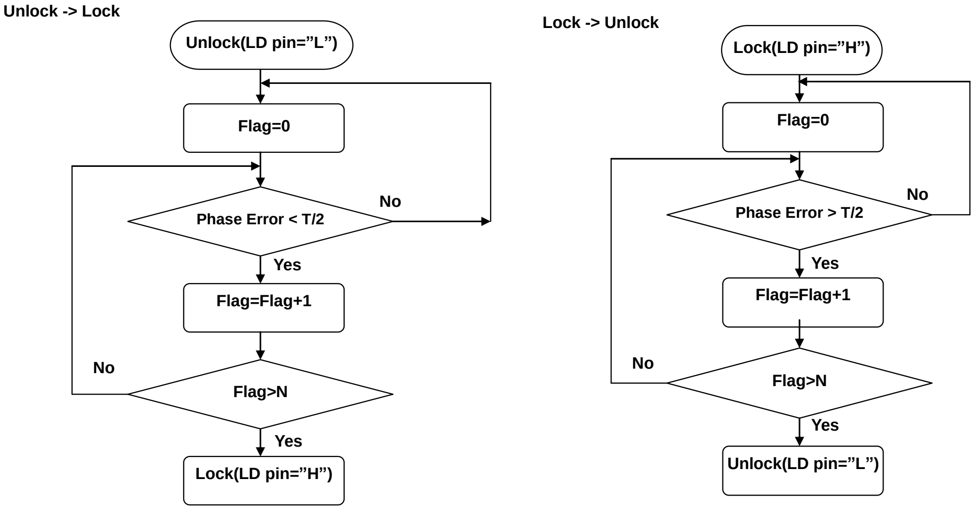
The followings show the digital lock detection method. The LD pin outputs Low while the AK2401A is unlock status after executing system reset. When R=1, if the phase error is detected as less than half a cycle of the reference clock N times in succession from the LD pin "L", it is determined to be in a "lock" state and the LD pin outputs "H". When R>1, if the phase error is detected as less than a cycle of the reference clock N times in succession from the LD pin "L", it is determined to be in a "lock" state and the LD pin outputs "H".The lock detection counter “N” is set by LD_LOCKCNT[7:0] bits <Address 0x3F>. If the phase error that is more than “T” is detected for “N” times continuously during lock status, the AK2401A detects unlock status and “L” signal is output from the LD pin. The unlock detection counter “N” is set by LD_UNLOCKCNT[7:0] bits <Address 0x40>.

In addition, the lock detection function has the constraint that the TCXO frequency f_{TCXO} and the LOIN input frequency fLO must be $f_{LO} / f_{TCXO} > 11$. Please note that if used under frequency conditions outside these constraints, the lock detection function will not operate correctly. For details on other frequency conditions, see chapter 13.7.2 Frequency Settings.
Setting values of LD_LOCKCNT[7:0] bits and LD_UNLOCKCNT[7:0] bits will be the count number “N” for phase lock and unlock detection, respectively.
Do not set LD_LOCKCNT bits = “00000000” nor LD_UNLOCKCNT bits = “00000000”.

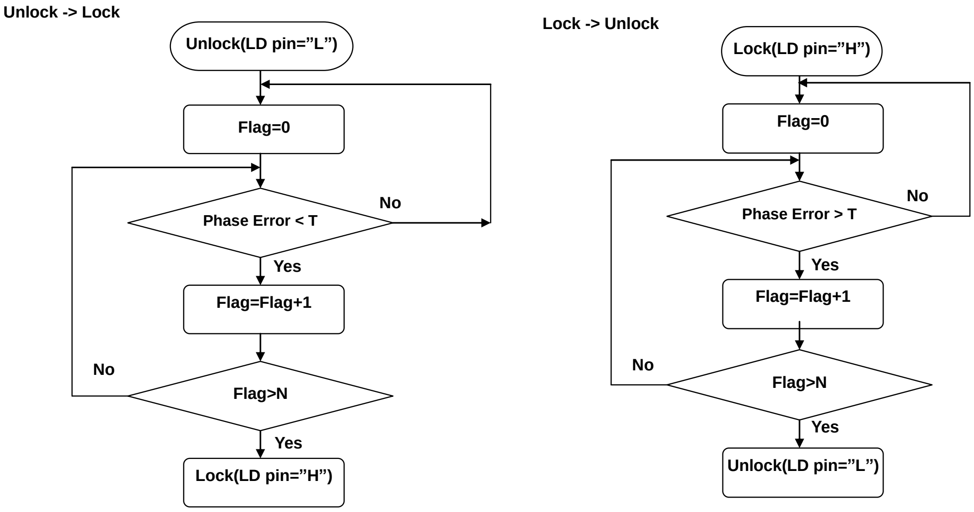
Timing chart of lock detection is shown in Figure 26.
Lock detection algorithm is shown in Figure 27.



When R > 1
Figure 26 Digital Lock Detect Operations



When R=1



When R > 1

Figure 27. Flow Chart of PLL Lock Detection Function

13.8. Digital Receiving Circuit (ADC, DIGITAL FILTER, RSSI, AGC, ADC P/S IF)

A block diagram of digital receiving circuit is shown in Figure 28. An analog baseband signal that is generated in the analog receiving circuit is over sampled by delta-sigma modulator by 64 times and converted to digital data. Then the digital data is decimated with attenuating delta-sigma noise and input to the channel filter.

Signal level setting after the channel filter is stored to registers by RSSI function. It can be confirmed by register readback function on SPI. A parallel-serial interface for the ADC outputs digital baseband signals. The output sampling rate differs depending on a selected channel filter type.

Select either set of High-pass Filter or RDOC function in addition to DC offset calibration to cancel DC offset that is superimposed to the baseband signals.

RDOC function should be selected normally. However, the RDOC function is not effective when receiving a signal that is modulated by a method with large amplitude variations like QPSK and QAM. Select High-pass Filter function for DC offset cancellation when receiving such signals.

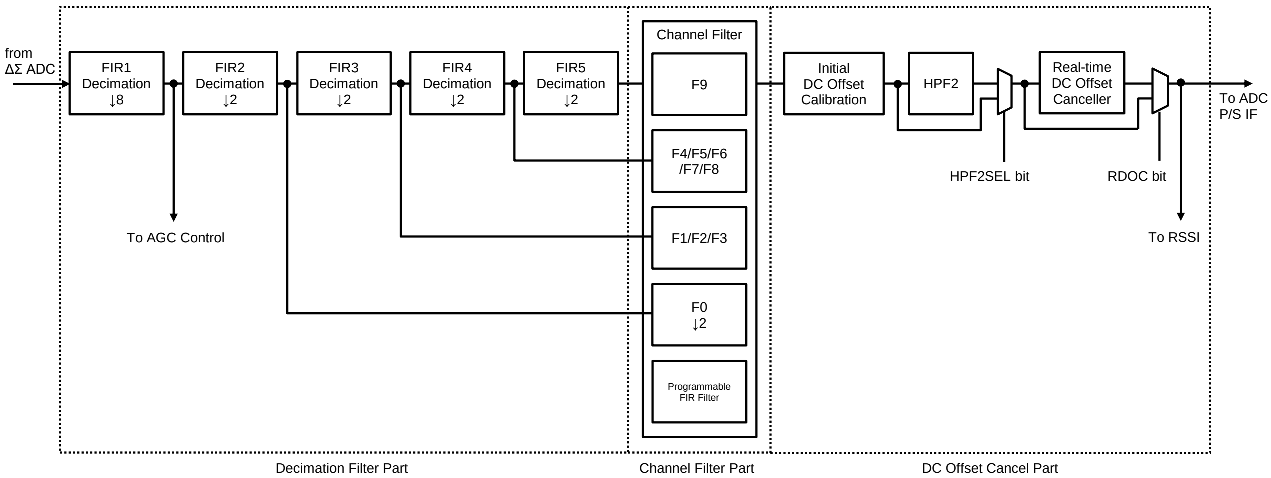


Figure 28. Digital Receiving Circuit

13.8.1. ADC

The ADC is a 24-bit delta-sigma A/D converter. ADC operation clock is generated by dividing a reference clock that is input to the TCXOIN pin by four.

13.8.2. Digital Filter Frequency Characteristics

The channel filter characteristics can be selected from F0 to F9, or select a FIR filter that can be programmed coefficient freely according to user preference. DFIL_SEL[3:0] bits in <Address 0x22> select the filter. The programmable FIR filter can be selected by setting DFIL_PROG bit = “1”.

Two types of TCXO: 19.2 MHz and 18.432 MHz are recommended as standards characteristics for the AK2401A. Set DFIL_CLK bit = “0” <Address 0x22> when using 19.2MHz clock, and set DFIL_CLK bit = “1” <Address 0x22> when using 18.432 MHz clock. FIR filter coefficients are adjusted to obtain same attenuation characteristics at F0-F9 filters with these two types of clocks. The filter characteristics are shown in Table 3. The frequency characteristics are shown in Figure 29.

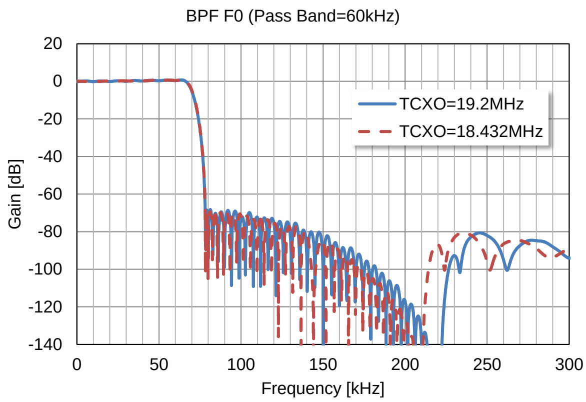
It is recommended to use a FIR filter that can change coefficients freely when using a reference clock with a frequency except 19.2MHz and 18.432MHz since the cut-off frequency varies.

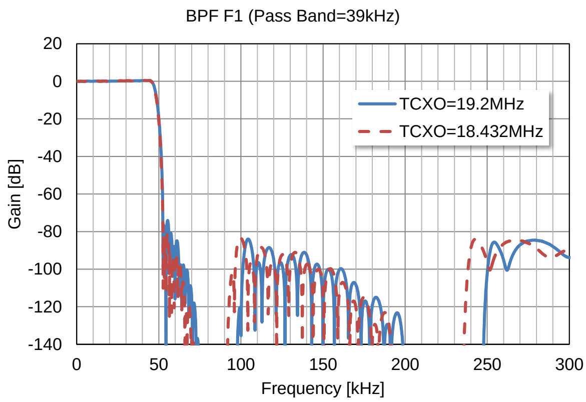
* None of channel filters of the AK2401A have root-raised cosine characteristics. Therefore, an external root-raised cosine filter should be connected when demodulating the data. Insufficient attenuation amount for ACS (Adjacent Channel Selectivity) should be compensated by a root-raised cosine filter if using a F3 channel filter for a TETRA (Terrestrial Trunked Radio) system since the attenuation amount of adjoining channels is only 50dB.

Table 3. Standard Channel Filter Frequency Characteristics

Filter Name	DFIL_PROG	DFIL_SEL [3:0](hex)	Pass Band [kHz]	Stop Band [kHz]	Pass Band Ripple [kHz]	Recommended Applications	RXLPF_FC Recommended Setting
F0	0	0	60	74	±0.7	TETRA 150kHz channel	1
F1	0	1	39	53	±0.5	TETRA 100kHz channel	1
F2	0	2	19.2	25.2	±0.2	TETRA 50kHz channel	1
F3	0	3	11	16.3	±0.1	TETRA 25kHz channel	0
F4	0	4	10	14	±0.2	Wide 25kHz channel (D)	0
F5	0	5	7.5	11.5	±0.2	Wide 25kHz channel (E)	0
F6	0	6	6	10	±0.2	Wide 25kHz channel (F)	0
F7	0	7	4.5	8.5	±0.2	Narrow 12.5kHz channel (G)	0
F8	0	8	3	7	±0.2	Narrow 12.5kHz channel (H)	0
F9	0	9-F	2	4	±0.2	Very Narrow 6.25kHz channel (J)	0
Programmable FIR Filter	1	X	-	-	-	-	-

(X: Do not care)





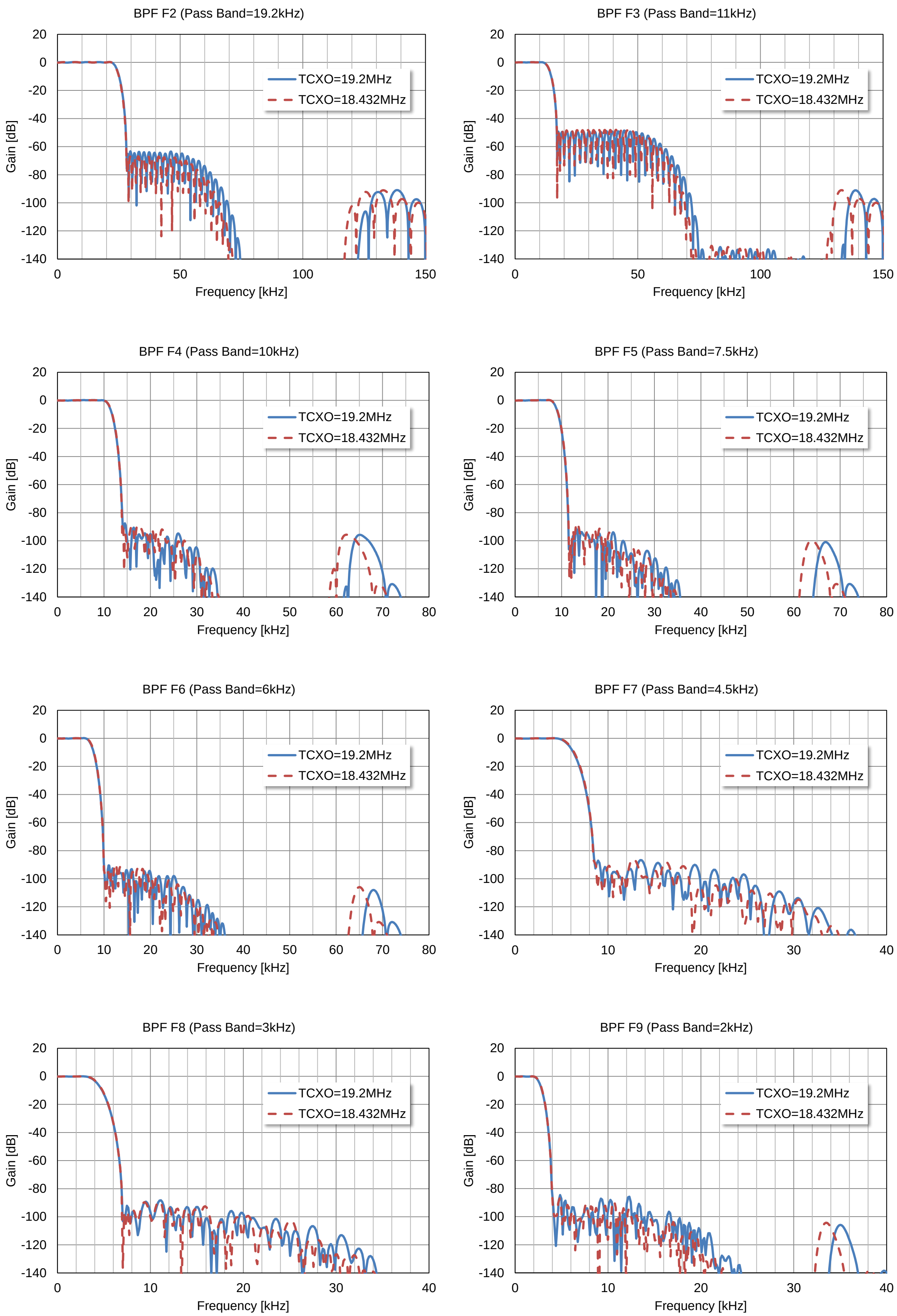
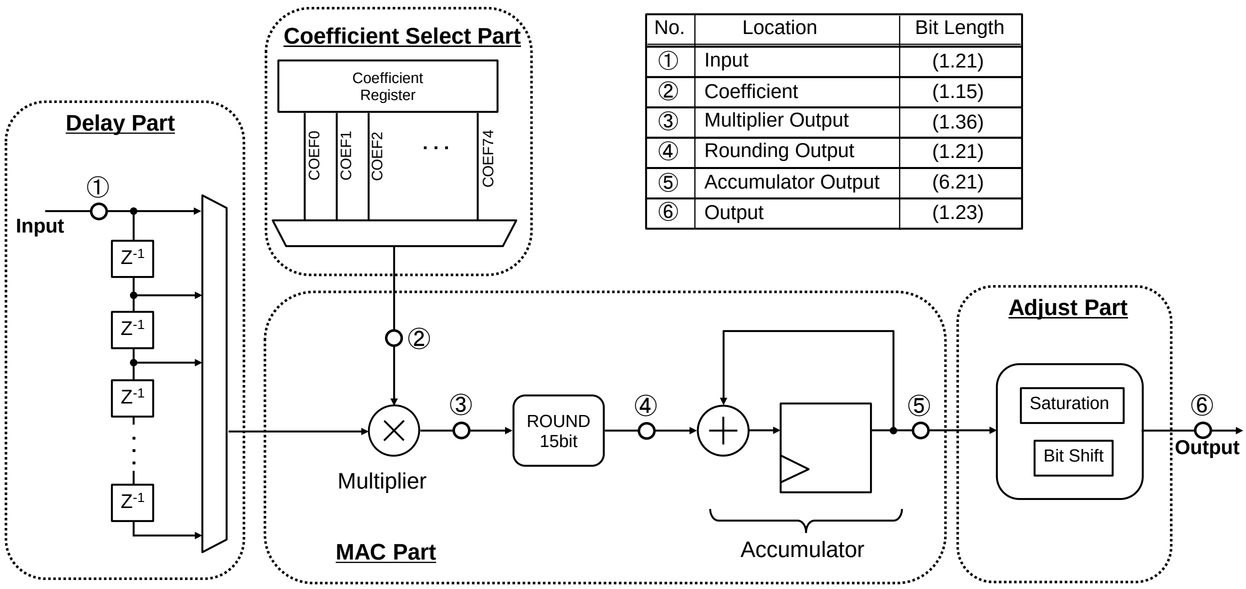


Figure 29. Digital Filter Frequency Characteristics

13.8.3. Programmable FIR Filter

The AK2401A has a programmable FIR filter that can be set a coefficient arbitrary. This FIR filter is disposed in channel filter block (Figure 30), and enabled by setting DFIL_PROG bit to “1” <Address 0x22> instead of F0-F9 fixed channel filters that are set by DFIL_SEL[3:0] bits.

Figure 30 shows a block diagram of the programmable FIR filter block. This filter is composed by delay block, coefficient selection block, MAC (Multiplier & Accumulator) block and bit adjustment blocks. The table in Figure 30 shows bit length of each numbered point in the diagram. For example, bit length (1.21) indicates 1 bit to left and 21 bits to the right, in total 22 bits configuration. All internal calculations are executed by 2’s complement expression.



No.	Location	Bit Length
①	Input	(1.21)
②	Coefficient	(1.15)
③	Multiplier Output	(1.36)
④	Rounding Output	(1.21)
⑤	Accumulator Output	(6.21)
⑥	Output	(1.23)

Figure 30. Programmable FIR Filter Block

■ **Coefficient Limits**

Coefficient limits are shown here.

Bit Number	Bit	16
Input Range	Dec	+32767 to -32767
	Hex	7FFFh to 8001h (* 21)
Maximum Total Coefficient Value	Dec	524288
Absolute Maximum Total Coefficient Value	Dec	1048576

Note:
* 21. Do not set 0x8000(hex). It is a prohibited setting.

The input maximum tap number is controlled by DFIL_SEL[3:0] bits <Address 0x22> as below.

DFIL_SEL[3:0]	Maximum Tap Number
0h to 1h	64 (TAP0 to TAP63)
4h to Fh	75 (TAP0 to TAP74)

If the coefficient accuracy is less than 16 bits, input “0” to the LSB side to make the input data 16-bit. It is necessary to keep the accuracy when rounding the data as shown in Figure 30. Setting examples are shown in the next page.

e.g.) When Input 12-bit 10TAP Coefficient

Coefficient Accuracy 12-bit		Input Value 16-bit	
Dec	Bin	Bin	Hex
-37	1111 1101 1011	1111 1101 1011 **0000**	FDB0
20	0000 0001 0100	0000 0001 0100 **0000**	0140
351	0001 0101 1111	0001 0101 1111 **0000**	15F0
948	0011 1011 0100	0011 1011 0100 **0000**	3B40
1449	0101 1010 1001	0101 1010 1001 **0000**	5A90
1449	0101 1010 1001	0101 1010 1001 **0000**	5A90
948	0011 1011 0100	0011 1011 0100 **0000**	3B40
351	0001 0101 1111	0001 0101 1111 **0000**	15F0
20	0000 0001 0100	0000 0001 0100 **0000**	0140
-37	1111 1101 1011	1111 1101 1011 **0000**	FDB0

■ Bit Adjustment Block

After the accumulator, calculations for saturation process and bit shift can be applied by the programmable FIR filter. PFIL_SAT[2:0] bits <Address0x23> control saturation process and PFIL_SIFT[2:0] bits control bit shift operation. The output bit length is adjusted to 24-bit by saturation process. Data process is executed in the order of saturation process and bit shifting.

Saturation Process

PFIL_SAT[2:0] bits <Address0x23> control the saturation process. The saturation process is applied the accumulator 27-bit output (6.21). The output data will be adjusted to 24-bit since bit length is changed after saturation process. If the bit length is over 24 bits, excess bits are rounded. If the bit length is less than 24 bits, “0” data is added to the LSB to make data 24-bit.

PFIL_SAT			Saturation Process	Output Bit Length
[2]	[1]	[0]		
0	0	0	0-bit	(6.21) 27-bit
0	0	1	1-bit	(5.21) 26-bit
0	1	0	2-bit	(4.21) 25-bit
0	1	1	3-bit	(3.21) 24-bit
1	0	0	4-bit	(2.21) 23-bit
1	0	1	5-bit	(1.21) 22-bit
1	1	0	6-bit	(0.21) 21-bit
1	1	1	7-bit	(0.20) 20-bit

* 0-bit setting (PFIL_SEL[2:0] bits = “000”) indicates there is no change in output bit length. Even in this case, the saturation process is executed.

Bit Shit

Bit shift setting is made by PFIL_SIFT[2:0] bits <Address0x23>. Bit shift is executed after the saturation process and 24-bit adjustment. The bit length will not be changed after bit shift operation. “0” data is added to the LSB for left shift, and “0” data is added to the MSB for right shift.

PFIL_SIFT			Bit Shift
[2]	[1]	[0]	
0	1	1	Left 3-bit Shift
0	1	0	Left 2-bit Shift
0	0	1	Left 1-bit Shift
0	0	0	No Shift
1	1	1	Right 1-bit Shift
1	1	0	Right 2-bit Shift
1	0	1	Right 3-bit Shift
1	0	0	Do Not Set

■ Calculation Sequence

The following is a calculation sequence example with an actual setting.

Calculation Example 1) F9 Filter Characteristics

[Coefficient Limits]

Bit Number	Bit	16
DC Gain	Times	3.9529
Max Coefficient	Dec	19113
Total Coefficient	Dec	129529
Absolute Maximum Total Coefficient	Dec	204505
PFIL_SAT[2:0]	Bin	100 (4-bit)
PFIL_SIFT[2:0]	Bin	000 (No Shift)

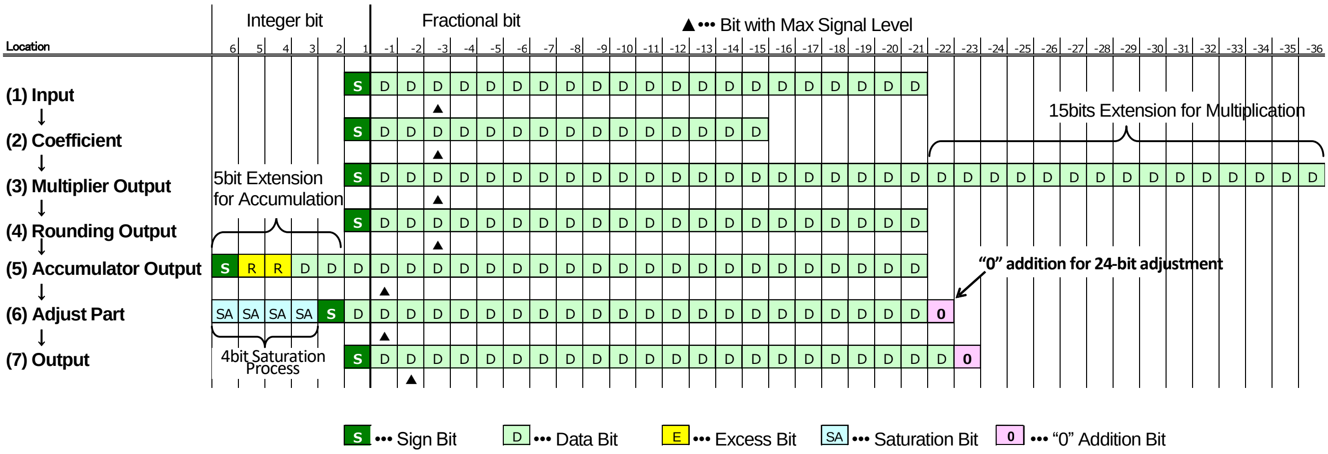


Figure 31. Programmable FIR Filter Calculation Example 1

An example of the F9 filter of the AK2401A is shown here. In this example, a bit adjustment is executed on the last step to make the total gain of digital filter -0dB (-7dBFS).

(1) Input bit length is (1.21). The maximum input signal level of programmable FIR filter is -13dBFS at full scale range (Figure 15). Therefore, the maximum signal is at -3 Fractional bit (▲) in Figure 31.
(2) Coefficient written by register setting. It has (1.15) bit length.
(3) Multiplication result of (1) and (2). Input signal is extended 15 bits for the bit length of the maximum coefficient.
(4) Round the data off to 21 bits to reduce the circuit size.
(5) Higher 5 bits are extended for accumulation. In this case, there are 2 excess bits although it is extended 5 bits according to the absolute maximum total coefficient. Since the filter DC gain is 4 times larger (+12dB), the maximum signal bit is shifted 2 bits to the left.
(6) Execute saturation process. In this case, 4-bit saturation process is executed to make the maximum signal level bit is higher second bit as total gain of the digital filter should be 0dB (-7dBFS). Bit length becomes 23-bit by executing 4-bit saturation process. Therefore, add "0" data to the LSB for 1 bit to make the data 24 bits.
(7) At final output, the decimal point is shifted 1-bit to the left and the data becomes (1.23). It expresses that the input signal is increased by 6dB, and the digital filter total gain is 0dB (-7dBFS).

Calculation Example 2) Maximum Coefficient Setting

[Coefficient Limits]

Bit Number	Bit	16
DC Gain	Times	16
Max Coefficient	Dec	32767
Total Coefficient	Dec	524288
Absolute Maximum Total Coefficient	Dec	1048576
PFIL_SAT[2:0]	Bin	001 (1-bit)
PFIL_SIFT[2:0]	Bin	111 (1-bit Shift to Right)

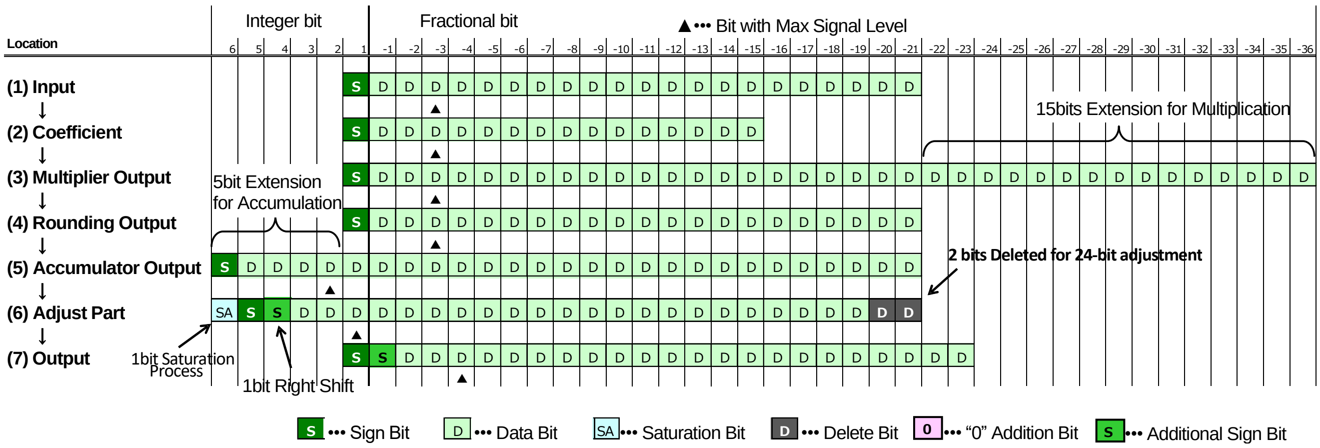


Figure 32. Programmable FIR Filter Calculation Example 2

A calculation example when input the maximum coefficient is shown here. In this example, a bit adjustment is executed on the last step to make the total gain of digital filter -12dB (-19dBFS).

(1) Input bit length is (1.21). As shown in Figure 15, level diagram, the maximum input signal level of programmable FIR filter is -13dBFS at full scale range. Therefore, the maximum signal is at -3 Fractional bit (▲) in Figure 32.
(2) Coefficient written by register setting. It has (1.15) bit length.
(3) Multiplication result of (1) and (2). Input signal is extended 15 bits according to the bit length of the maximum coefficient.
(4) Round the data off to 21 bits to reduce the circuit size.
(5) Higher 5 bits are extended for accumulation. In this case, there is no excess bit since the maximum value of the absolute total coefficient is input. The maximum signal bit is shifted 2 bits to the left because the filter DC gain is 16 times larger (+24dB).
(6) Execute saturation process. In this example, 1-bit saturation process is executed. LSB 2 bits are deleted to make the bit length to 26-bits after the saturation process. The data is shifted 1 bit to the right and added "0" to the MSB as PFIL_SIFT[2:0] bits are set to "111".
(7) At final output, the decimal point is shifted 1-bit to the left and the data becomes (1.23). It expresses that the input signal is decreased by 6dB, and the digital filter total gain is -12dB (-19dBFS).

■ Coefficient Write

A coefficient is written to the programmable FIR filter via the CSN, SCLK and SDATAI pins. COEF_ST bit = “1” <Address 0x2D> sets these three pins to programmable FIR filter coefficient write mode. During the coefficient write mode, COEF_ST bit is kept to “1” and 16-bit coefficient data is written sequentially for the number of time set by COEF_NUM[6:0] bits. COEF_ST bit returns to “0” automatically and coefficient write mode is finished after writing the coefficient for designated number of times. Normal register access will be available when the coefficient write mode is finished.

If the setting value of COEF_NUM[6:0] bits is smaller than the maximum tap number, rest of the tap coefficient will be filled by “0”. If the setting value of COEF_NUM[6:0] bits is larger than the maximum tap number, internal limit process is executed automatically. Therefore, coefficient write can not be executed more than the maximum tap number. When COEF_NUM[6:0] bits are set to “0000000”, the AK2401A will not enter coefficient write mode even if COEF_ST bit is set to “1”.

Programmable FIR filter setting example and write sequence are shown below (Figure 33).

(1) Write a start register of the coefficient write. The following shows the setting of this example. {W/R, Address, COEF_NUM[6:0], COEF_ST} = {0010 0100 1000 0011} TAP0 to TAP64, coefficient will be written 65 taps in total since COEF_NUM[6:0] bits are set to 65(dec).
(2) Register interface becomes coefficient write mode after writing the start bit (1). In this example, 65 coefficients are written sequentially. From a coefficient only register TAP0 until TAP64, 16-bit data are written sequentially and the coefficient write mode will be finished. COEF_ST bit will return to “0” automatically when the coefficient write mode is finished.
(3) It is recommended to set COEF_NUM[6:0] bits “0000000” after writing coefficient to prevent unintended change of the setting.
(4) After the coefficient write mode, the AK2401A enters normal register write mode. A written coefficient can be readback in normal register access. Access to <Address 0x38 to 0x39> to readback the register values. First, coefficient TAP that is desired to readback must be set to TAP_NUM[6:0] bits <Address 0x37>. In this case, TAP_NUM[6:0] bits = “1000000”= 64(dec), therefore the coefficient of TAP64 is readout. Higher 8-bit of the assigned TAP coefficient is readback to R_COEF[15:8] bits <Address 0x38> and lower 8-bit is readback to R_COEF[7:0] bits <Address 0x39>.

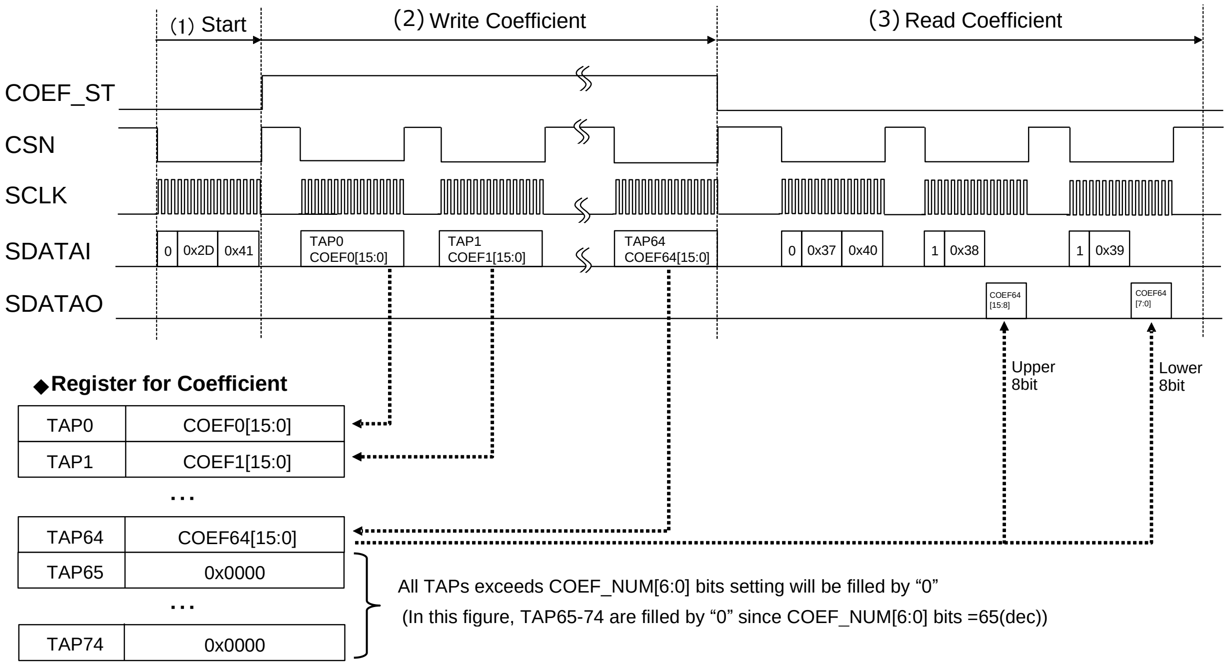


Figure 33. Programmable FIR Filter Write Example

13.8.4. High-Pass Filter

A high-pass filter will be enabled after the channel filter by setting HPF2SEL bit to “1” <Address0x4E>. This high-pass filter can not be used with the Real-time DC Offset Canceller (RDOC). Set RDOC bit to “0” <Address 0x26> when using the high-pass filter.

The high-pass filter consists of first order IIR filter. HPF2_FC[3:0] bits <Address 0x4E> control the cutoff frequency of the filter. The characteristics of the high-pass filter are shown in Table 4. The frequency characteristics of the high-pass filter when using 19.2 MHz clock are shown in Figure 34. Since the operating frequency of the high-pass filter changes according to the channel filter to be selected, the cutoff frequency will change depending on the setting value of <Address0x22>DFIL_SEL [3:0] bits.

Table 4. High-Pass Filter Frequency Characteristics

HPF2_FC				Gain [dB]	Cutoff Frequency						Unit
					TCXO=19.2MHz			TCXO=18.432MHz			
[3]	[2]	[1]	[0]		F0-F3	F4-F8	F9	F0-F3	F4-F8	F9	
0	0	0	0	0.0	0.7	0.4	0.2	0.7	0.4	0.2	Hz
0	0	0	1	0.0	1.5	0.7	0.4	1.4	0.7	0.3	
0	0	1	0	0.0	2.9	1.5	0.7	2.8	1.4	0.7	
0	0	1	1	0.0	5.8	2.9	1.5	5.6	2.8	1.4	
0	1	0	0	0.0	11.7	5.8	2.9	11.2	5.6	2.8	
0	1	0	1	0.0	23.3	11.7	5.8	22.4	11.2	5.6	
0	1	1	0	0.0	46.7	23.3	11.7	44.8	22.4	11.2	
0	1	1	1	0.0	93.4	46.7	23.3	89.7	44.8	22.4	
1	0	0	0	0.0	187	93.5	46.7	179	89.7	44.9	
1	0	0	1	0.1	376	188	94	361	180	90	
1	0	1	0	0.1	758	379	189	728	364	182	
1	0	1	1	0.3	1540	770	385	1478	739	370	
1	1	X	X	0.6	3178	1589	795	3051	1526	763	

(X: Do not care)

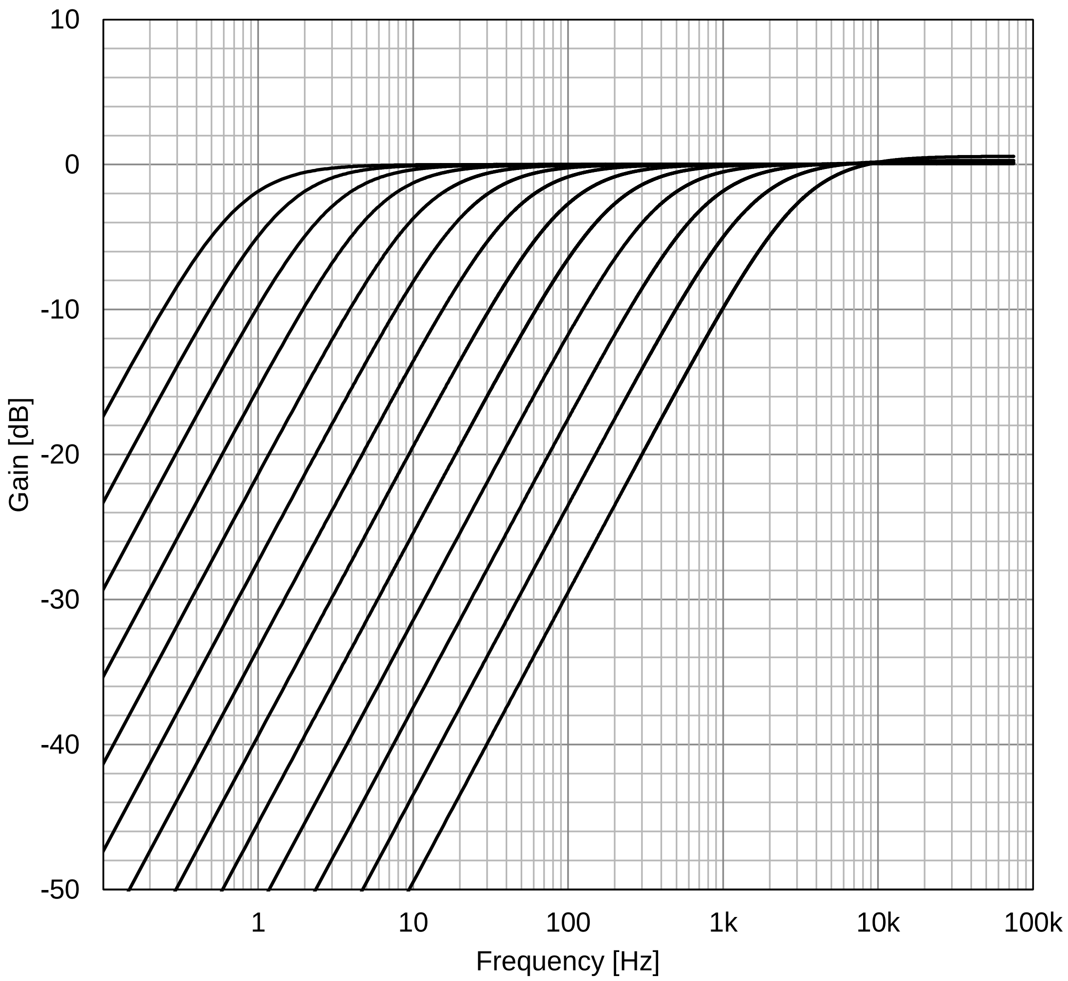


Figure 34. High-Pass Filter Frequency Characteristics
(TCXOIN Input=19.2MHz, DFIL_SEL[3:0] bits=”0100”(F4))

13.8.5. DC Offset Calibration

A DC offset calibration is performed in the analog and the digital receiving circuits independently. The DC offset calibration for the analog receiving circuit is executed by the MIXER. In the digital receiving circuit, DC offset calibrations are executed in the channel filter and the AGC that where the signal path is bifurcated before the channel filter. Normally these calibrations are executed at the same time. However, it is possible to execute these calibrations independently.

Refer to "12.4 DC Offset Calibration Sequence" for DC offset calibration sequence.

■ Analog Block (MIXER) DC Offset Calibration
DC offset calibration of the analog block is executed by the MIXER. The calibration starts by setting OFSCAL1 bit to "1" <Address 0x17> and ends after 40µs (CAL Time (1)). OFSCAL1 bit automatically returns to "0" after the calibration is finished. The calibration result will be initialized by hardware or software reset.

■ Digital Block (Channel Filter and AGC) DC Offset Calibration
DC calibrations for digital block are executed by the channel filter block and the AGC block. The calibration starts by setting OFSCAL2 bit to "1" <Address 0x17>. In the calibration, moving averages of the channel filter output and the AGC input are calculated and the calibration result is reduced from the receiving data. The calibration time is shown in Table 5 and Table 6 (CAL Time (2)). OFSCAL2 bit automatically returns to "0" after the calibration is finished.

The calibration result of the channel filter block can be readout from R_OFST_I[23:0] bits <Address 0x31-0x33> and R_OFST_Q[23:0] bits <Address 0x34-0x36> when OFST_RSEL[1:0] bits are set to "00" <Address 0x28>. And the calibration result of the AGC block can be readout from the same registers when OFST_RSEL[1:0] bits are set to "11" <Address 0x28>. The calibration is calculated against each PGA gain. Therefore, the readback result will be the value for the setting gain at the time. The calibration result will be initialized by hardware or software reset.

■ Digital Block (Channel Filter block only) DC Offset Calibration
A DC offset calibration for digital block is executed only at the cannel filter block by setting OFSCAL3 bit to "1" <Address 0x17>. OFSCAL3 bit automatically returns to "0" after the calibration is finished.

■ Digital Block (AGC block only) DC Offset Calibration
DC offset calibrations are executed only at the AGC block by setting OFSCAL4 bit to "1" <Address 0x17>. OFSCAL4 bit automatically returns to "0" after the calibration is finished.

OFSCAL3 bit and OFSCAL4 bit should be written independently when executing calibrations with these bits. It is prohibited to set "1" to OFSCAL1 bit and OFSCAN2 bit simultaneously.

Normally, use OFSCAL1 and OFSCAL2 bits.

DC Offset Calibration Time for Digital Block (CAL Time(2))
A DC offset calibration is executed at the channel filter and the AGC blocks at the same time in digital block. In this case, the calibration time (CAL Time (2)) will be longer period if only the channel filter block is calibrated (OFSCAL3 bit) or both channel filter and AGC blocks (OFSCAL2 or OFSCAL3 bit and OFSCAL4 bit) are calibrated. When only the AGC block is calibrated (OFSCAL4 bit), the calibration time (CAL Time (2)) will be the AGC calibration time.

Calibration Time for Digital Block (Channel Filter)
The calibration time of channel filter block will be different according to the filter that is selected by DFIL_SEL[3:0] bits <Address 0x22>. The calibration times (CAL Time(2)) when using 18.432MHz or 19.2MHz reference clock are shown below.

Table 5. Calibration Time for Digital Block (Channel Filter)

Filter Selected by DFIL_SEL[3:0] bits	CHOFS_AVE		CAL Time(2)		
	[1]	[0]	18.432MHz	19.2MHz	Unit
F0-F3	0	0	1.9 (default)	1.9 (default)	ms
	0	1	2.4	2.4	
	1	0	3.3	3.2	
	1	1	5.1	4.9	
F4-F8	0	0	2.4 (default)	2.4 (default)	
	0	1	3.3	3.2	
	1	0	5.1	4.9	
	1	1	8.6	8.3	
F9	0	0	3.3 (default)	3.2 (default)	
	0	1	5.1	4.9	
	1	0	8.6	8.3	
	1	1	15.7	15.2	

Calibration Time for Digital Block (AGC)
The calibration times (CAL Time(2)) of AGC block when using 18.432MHz or 19.2MHz reference clock are shown below.

Table 6. Calibration Time for Digital Block (AGC)

AGCOFS_AVE		CAL Time(2)		
[1]	[0]	18.432MHz	19.2MHz	Unit
0	0	131 (default)	127 (default)	µs
0	1	242	233	
1	0	464	447	
1	1	909	873	

13.8.6. RDOC Function

The AK2401A has a real-time DC offset cancellation (RDOC) function that follows real-time DC offset fluctuation and executes DC offset cancellation consistently. RDOC is enabled by setting RDOC bit = “1” <Address0x26>. RDOC is effective for receiving a signal without amplitude fluctuation such as FM and FSK.

■ RDOC Setting
Following registers are RDOC operation registers. These registers must be in the default setting.

Register	Address	Initial Value
RDOC_1	0x26 D7	“0”
RDOC_2	0x26 D6	“1”
RDOC_3	0x26 D4-D3	“10”
RDOC_4	0x26 D2-D1	“01”
RDOC_5	0x27 D6-D4	“010”
RDOC_6	0x27 D3-D2	“00”
RDOC_7	0x27 D1-D0	“11”
RDOC_8	0x28 D6-D5	“11”
RDOC_9	0x28 D1-D0	“00”
RDOC_10	0x44 D6-D5	“00”
RDOC_11	0x44 D4-D3	“00”
RDOC_12	0x44 D2-D0	“101”
RDOC_13	0x45 D7-D0	“00000001”
RDOC_14	0x46 D7-D6	“11”
RDOC_15	0x46 D5-D4	“00”
RDOC_16	0x46 D3-D2	“00”
RDOC_17	0x46 D1-D0	“00”
RDOC_18	0x27 D7	“0”
RDOC_19	0x4D D7	“0”
RDOC_20	0x4D D6	“0”
RDOC_21	0x4D D5-D4	“00”
RDOC_22	0x4D D3-D2	“00”
RDOC_23	0x4D D1-D0	“00”

■ Local frequency offset (OFST2) control function
Set <Address0x28>RDOC_FM bit =”1” when receiving non-modulated signal (CW) such as an FM radio. It is automatically controlled so that frequency offset is added to the local signal. It is recommended to set the frequency offset (OFST2 bits) to become 150Hz after divided by the local divider. It is necessary to enable OFST2 during receiving, and the polarity of TX_PDN pin is related to the condition that enables OFST2. Refer to 13.7.3 Frequency Offset Adjustment.

The operation status of this function can be output from LD pin or R_RDOC bit, but it is not normally used. Here, the operation status output from the LD pin is output only when <Address 0×0C>LD bit = "1", and in that case the lock detection output is not output.

This function can be OFF by setting RDOC_FM bit = “0” and OFST2 bits = all “0” if not receiving a non-modulated signal (CW) such as a digital FSK radio.

13.8.7. AGC Function

Figure 35 shows block diagram of AGC function. In AGC operation, the total gain of I and Q channels is detected by decimating the received signal to 1/8 after FIR1 filter, LNA gain mode setting value and PGA gain are calculated to converge the signal to the target level. DC offset influences on the total power of I and Q channels is removed by reducing the initial digital DC offset calibration result.

AGC function is enabled as shown in Table 7 by setting AGCOFF bit <Address0x1F> and LNA_AGCOFF bit <Address0x20>.

Table 7. AGC Operation Setting

AGCOFF	LNA_AGCOFF	Description	
		PGA	LNA
0	0	AGC	AGC
0	1	AGC	Manual Setting
1	0	Manual Setting	PGA Manual Setting
1	1	Manual Setting	Manual Setting

Figure 36 shows AGC circuit flow chart. AGC operation starts by setting AGC_OFF bit = “0” (default “1”) <Address 0x1F>. Following registers are AGC relative registers. AGC operation is executed according to these settings. (Refer to “15.12 <0x15-0x16>PGA GAIN” and “15.15 <0x1F-0x21, 0x47-048>AGC” for setting details)

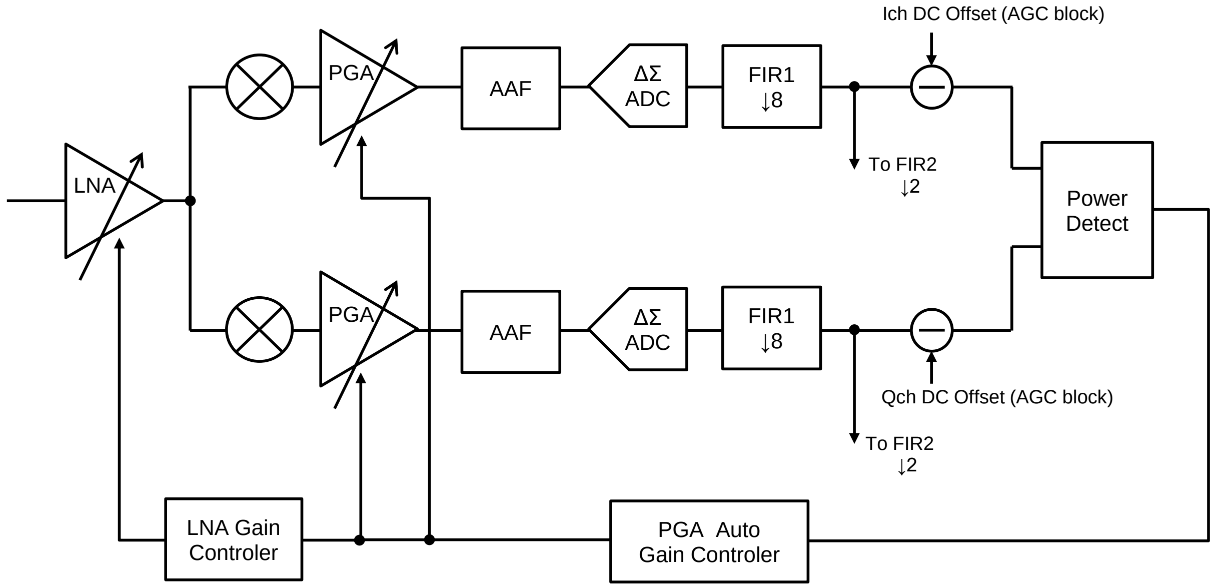


Figure 35. AGC Block Diagram

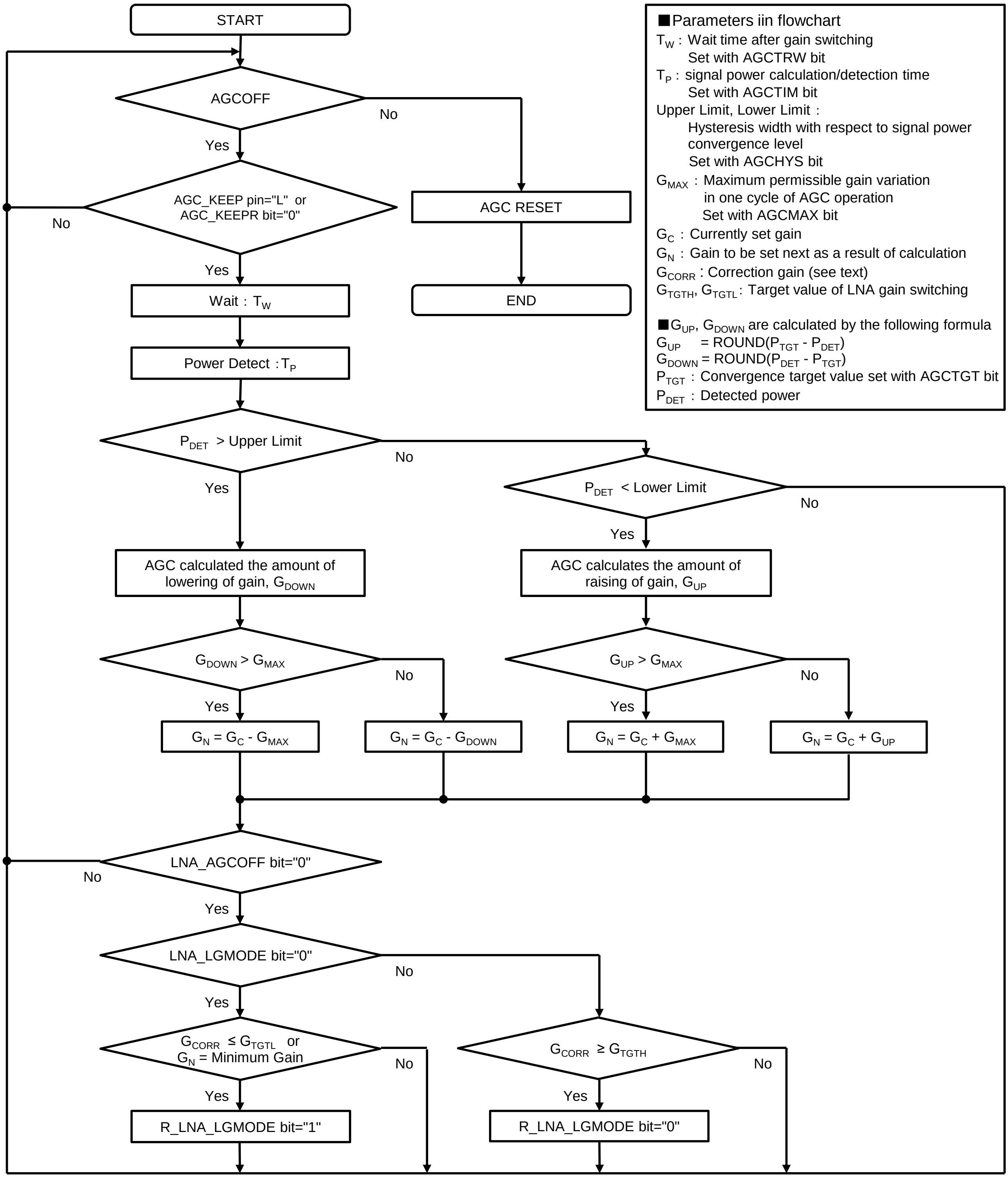


Figure 36. AGC Flow Chart

AGC relative registers are shown below.

PGA Control

<Address0x15> PGAGAIN_I[5:0] bits: PGA Ich Gain Setting
<Address0x16> PGAGAIN_Q[5:0] bits: PGA Qch Gain Setting
<Address0x1F> AGCOFF bit : AGC ON/OFF Setting
<Address0x1F> AGCHYS[1:0] bits: Hysteresis Width for Signal Power Convergence Level
<Address0x1F> AGCTIM[2:0] bits: Calculation/Detection Interval for Signal Power
<Address0x20> AGCTGT[2:0] bits: Target Value for Signal Power Convergence Level
<Address0x20> AGCMAX[2:0] bits: Maximum Gain Changing Amount in a Single AGC Operation
<Address0x21> AGCTRW[2:0] bits: Wait Time after Changing Gain

LNA Control

<Address0x20> LNA_AGCOFF bit: AGC ON/OFF setting of LNA
<Address0x20> LNA_LGMODE bit: Low Gain Mode Manual Setting of LNA
<Address0x47> LNA_TGT_H[5:0] bits: LNA Gain Switching Target (High)
<Address0x48> LNA_TGT_L[5:0] bits: LNA Gain Switching Target (Low)

PGA gain is set by PGAGAIN_I[5:0] bits and PGAGAIN_Q[5:0] bits manually when AGC_OFF bit =“1”. When setting AGC_OFF bit = “1” → “0”, AGC operation will be executed using PGAGAIN_I[5:0] bits setting as a default value. Ich and Qch gain settings will be the same during AGC operation.

Signal power is detected for every period set by AGCTIM bit after the wait time set by AGCTRW bit when the AGC is in operation. Upper and lower limits of detection value are determined by AGCHYS bits against signal power convergence target that is set by AGCTGT bits. AGC decreases the PGA gain if the detected power is larger than the upper limit, and increases the PGA gain if the detected power is lower than lower limit.

Adjustment amount of PGA gain is calculated by comparing detected power and target power to obtain the closest detected power to the target. This calculation result of gain adjustment amount will be limited by AGCMAX bits setting. After changing the PGA gain, next detection will be executed with an interval of wait time set by AGCTRW bits and AGCTIM bits.

When detected power is in the limit range of (lower limit < detected power < upper limit), AGC stops changing gain adjustment. After AGC operation is stopped, power detection is executed in every wait time set by AGCTRW bits and AGCTIM bits. Therefore, if the detected power becomes out of the limit range again, AGC resume the operation.

LNA has normal gain and low gain modes. When LNA_AGCOFF bit = “0”, LNA gain is changed interlocked with the PGA gain change. LNA gain switching is executed by comparing a correction gain (G_{CORR}) that is calculated by AGCTGT bits with setting values of LNA_TGT_H[2:0] bits and LNA_TGT_L[5:0] bits.

G_{CORR}[dB] = G_N[dB] - TGT_CORR[dB]

Table 8. Correction Value for LNA_TGT_H/L

AGCTGT			TGT_CORR	Unit
[2]	[1]	[0]		
0	1	1	6	dB
0	1	0	4 (default)	
0	0	1	2	
0	0	0	0	
1	1	1	-2	
1	1	0	-4	
1	0	1	-6	
1	0	0	-8	

* G_N takes a processing result of the AGC circuit when AGCOFF bit="0", and it takes setting value of PGAGAIN_I[5:0] bits <Address0x15> when AGCOFF bit = "1". In this document, "G_N" indicates gain value that unit is [dB]. Note that it does not indicating register values. A saturation process will be executed when G_{CORR} result is greater than 28 dB (Maximum PGA Gain) to 28dB and a saturation process will be executed when G_{CORR} result is less than -20 dB (Minimum PGA Gain) to -20dB.

LNA gain mode switching conditions are shown below.

■ Normal Gain Mode to Low Gain Mode

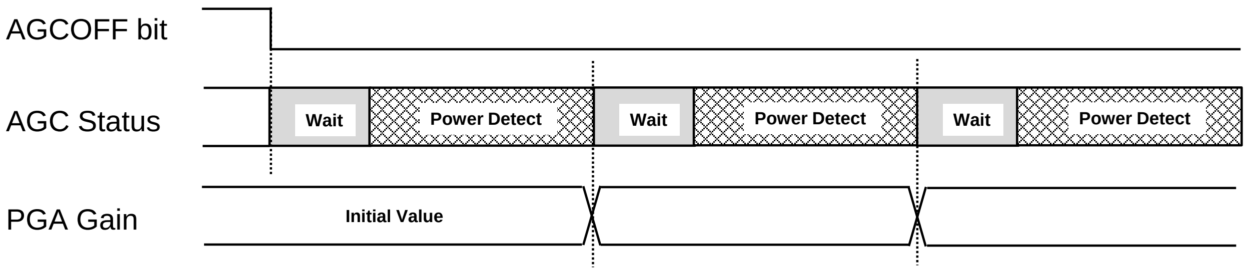
- When G_{CORR} becomes smaller than the threshold value set by LNA_TGT_L[5:0] bits.
- When PGA gain becomes the minimum value (-20dB).
  (There is a case that G_{CORR} will not become less than a threshold set by LNA_TGT_L bits if a convergence target level (AGCTGT bits) is set under -2dBm. This condition is for such a case.)

■ Low Gain Mode to Normal Gain Mode

- When G_{CORR} becomes greater than the value set by LNA_TGT_H[5:0] bits.

LNA gain mode can be read by R_LNA_LGMODE bit <Address0x2F>. The LNA is in normal gain mode when R_LNA_LGMODE bit is "0". It is in low gain mode when R_LNA_LGMODE bit is "1".
When LNA_AGCOFF bit = "0", AGC process result can be read by this bit. When LNA_AGCOFF bit = "1", LNA_LGMODE bits setting is readout.

If AGCOFF bit = "1" and LNA_AGCOFF bit = "0", PGA gain can be set manually and LNA gain mode is changed according to the PGA gain. Threshold calculations of PGA and AGC are the same. PGA can be set I channel and Q channel gain independently but I channel gain setting is used for both channels in LNA. LNA gain mode can be set manually by LNA_LGMODE bit when LNA_LGMODE bit = "1".



Wait	:	Period set by AGCTRW bit
Power Detect	:	Period AGCTIM bit
PGA Gain Initial Value	:	PGAGAIN_I, PGAGAIN_Q bits Setting

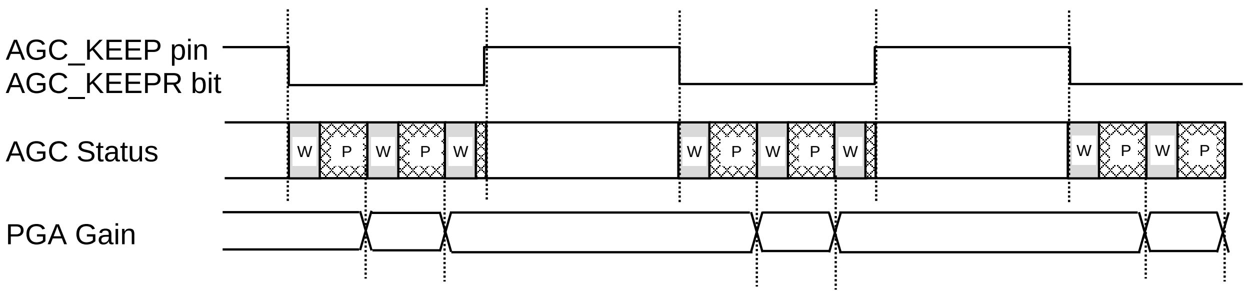
Figure 37. AGC Operation Timing Chart

13.8.8. AGC_KEEP Function

The AK2401A has a gain keep function. This function is controlled by the AGC_KEEP pin or AGC_KEEPR bits <Address 0x1F>. AGC_KEEP_SEL bits <Address 0x1F> switch register or pin controlling. The AGC KEEP function is ON by setting AGC_KEEP bit to “1” or the AGC_KEEP pin to “H”. The operation mode for this function can be set by AGCKP_MODE[1:0] bits <Address 0x21>. The details of AGCKP_MODE[1:0] bits settings are shown below.

■ AGCKP_MODE[1:0] bits= “00”

When the AGC KEEP function is OFF, a real-time PGA gain change is executed by detecting / calculating the signal power by AGC operation. When the AGC KEEP function is turned ON, the PGA gain value at the time will be kept. AGC operation is stopped and power detection/calculation is not executed while AGC_KEEP bit is “1” (AGC_KEEP pin is “H”). Time counters of AGCTIM bits and AGCTRW bits are also cleared in this time. AGC operation is resumed when the AGC KEEP function is turned OFF with the PGA gain that is kept by AGC KEEP function as initial value. Figure 38 is a timing chart of this mode.



W	:	Wait
P	:	Power Detect

Figure 38. AGC Operation when AGCKP_MODE[1:0] bits= “00”

■ AGCKP_MODE[1:0] bits= “01”

In this mode, PGA gain is changed only the timing when the AGC KEEP function is turned OFF. While the AGC KEEP function is OFF, only signal power detection is executed and the PGA gain is not changed. When the AGC KEEP function is turned ON, the AK2401A calculates the PGA gain from the detected value while the AGC KEEP function is OFF and keeps the calculated PGA gain. This value will be set to the PGA when the AGC KEEP function is turned OFF again. Figure 39 is a timing chart of this mode.

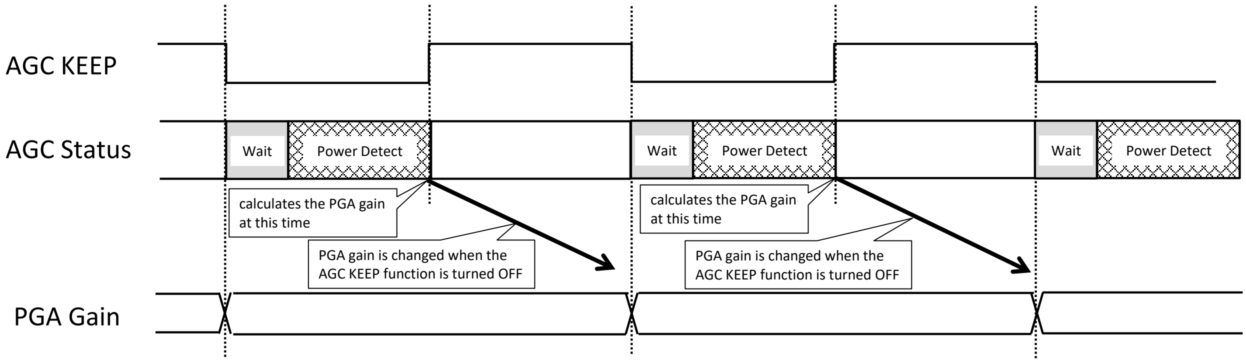


Figure 39. AGC Operation when AGCKP_MODE[1:0] bit= “01”

■ AGCKP_MODE[1:0] bits= “1x”

In this mode, the PGA gain is not kept even the AGC KEEP function is ON. The calculation result of RDOC function can be kept by inter locking with AGC_KEEP function when KEEP_RDOC bit = “1” <Address 0x26>. For example, only the DC offset value can be kept while the AGC operation is ON by setting AGCKP_MODE[1:0] bits to “1x”. It is not normally used.

Table 9. AGC_KEEP Operation

AGCKP_MODE		KEEP_RDOC	Description	
			PGA Gain Keeping	DC Offset Keeping
0	0	0	DO	DO NOT
0	1	0	DO	DO NOT
1	X	0	This setting is not used.	
0	0	1	DO	DO
0	1	1	DO	DO
1	X	1	DO NOT	DO

13.8.9.RSSI Function

The AK2401A has digital RSSI (Received Signal Strength Indicator) function. Figure 40 shows RSSI block diagram. Input level is detected by the power detection circuit and LOG converted code is output. (When DC offset calibration and RDOC functions are ON, RSSI processing is applied to the signal after these processes.) Then, the data is averaged by the output sampling rate of when DFIL_SR[1:0] bits = “00” <Address 0x22>. The number of sampling for averaging can be set by RSSIAVE[2:0] bits <Address 0x2C>.

The output code of the power detection circuit is a corresponding RSSI code that is added PGA gain code. Then, a correction value set by RSSI_LOW[1:0] bits <Address 0x> is subtracted. In this case, PGA gain code will be “0” at the maximum gain and the value of the code increases as the gain decrease. Therefore, RSSI code decreases corresponding to the PGA input level even if the input level of power detection circuit and ADC are kept stabled by AGC. The calculation result is stored to RSSI[7:0] bits <Address 0x3A>.

The relationship of the Input level and the output code, when the gain of each block is a typical value and normal power mode, is shown in the following expressions. Correct a gain difference of the output code as needed if each block gain is not typical value or low power mode. The following expressions are defined that the LNA is in normal gain mode; they do not cover the output correction of low gain mode. Correct gain difference of the output code as needed when using low gain mode. Input/output characteristics when RSSI_LOW bits “00” (18dB correction) is shown in Figure 41.

Output Code (dec) = 2 × (LNA Input Level [dBm] - RSSI_LOW bits Setting) + 290

LNA Input Level [dBm] = (Output Code (dec) - 290) ÷ 2 + RSSI_LOW bits Setting

(0.5dB resolution)

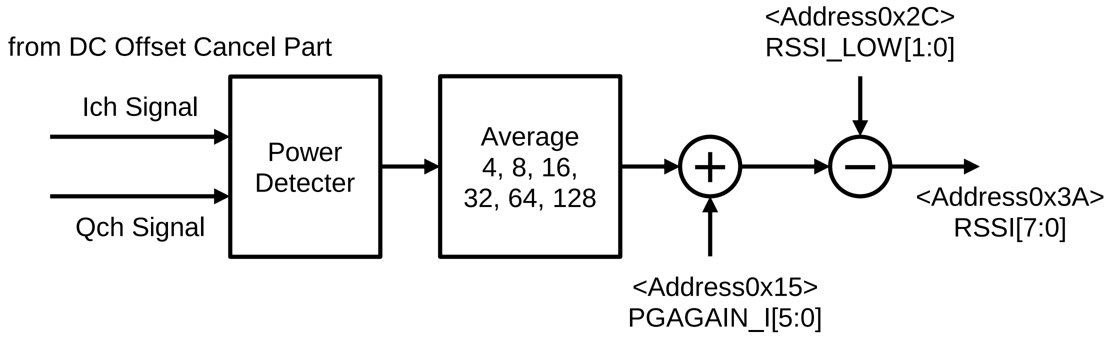


Figure 40. RSSI Block Diagram

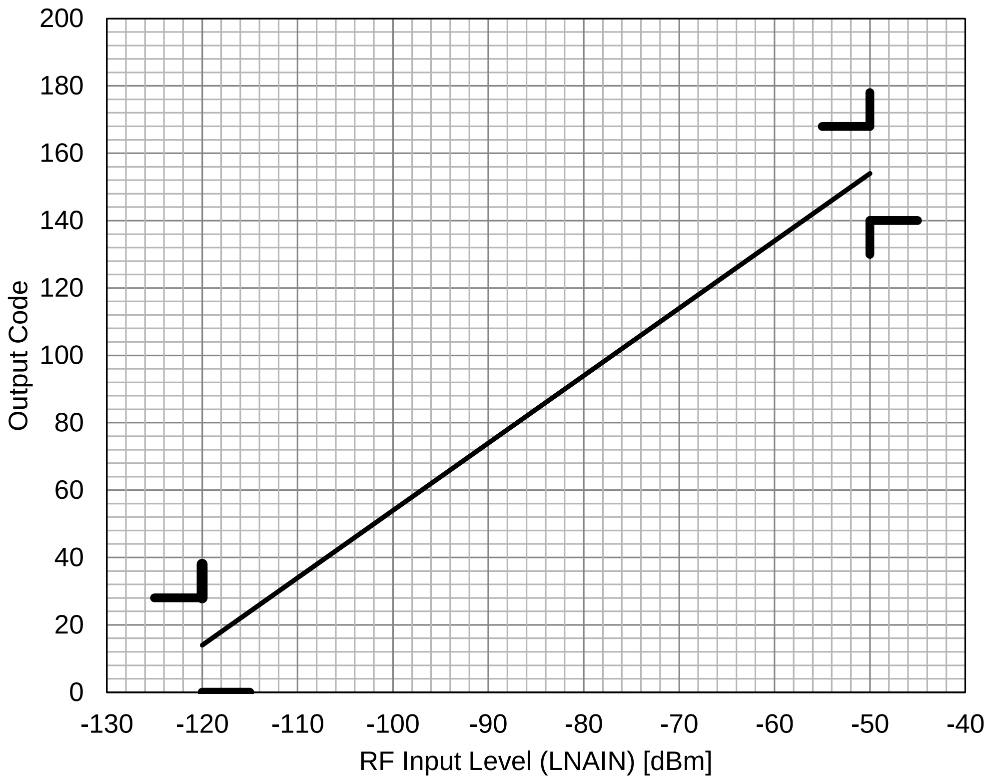


Figure 41. RSSI Characteristics

13.8.10. Output Sampling Rate

The output sampling rate of F0-F9 channel filters is shown in Table 10. Each filter operates with the frequency set to DFIL_SR[1:0] bits="00" <Address 0x22>. Also, by setting DFIL_SR[1:0] bits, the output sampling rate can be set to half or quarter rate of the original.

Signals will be output with the settings indicated as "Do not use" but their characteristics are not excellent because of aliasing noises.

Table 10. Output Sampling Rate

Filter	DFIL_PROG	DFIL_SEL				Output Sampling Rate		
		[3]	[2]	[1]	[0]	DFIL_SR=00 (default)	DFIL_SR=01 (1/2 rate)	DFIL_SR=1X (1/4 rate)
F0	0	0	0	0	0	TCXO/128	Do Not Use	Do Not Use
F1	0	0	0	0	1	TCXO/128	Do Not Use	Do Not Use
F2	0	0	0	1	0	TCXO/128	Do Not Use	Do Not Use
F3	0	0	0	1	1	TCXO/128	Do Not Use	Do Not Use
F4	0	0	1	0	0	TCXO/256	TCXO/512	TCXO/1024
F5	0	0	1	0	1	TCXO/256	TCXO/512	TCXO/1024
F6	0	0	1	1	0	TCXO/256	TCXO/512	TCXO/1024
F7	0	0	1	1	1	TCXO/256	TCXO/512	TCXO/1024
F8	0	1	0	0	0	TCXO/256	TCXO/512	TCXO/1024
	0	1	0	0	1			
F9	0	…				TCXO/512	TCXO/1024	TCXO/2048
	0	1	1	1	1			
Programmable FIR Filter	1	0	0	0	0	TCXO/128	Do Not Use	Do Not Use
	1	0	0	0	1	TCXO/128	Do Not Use	Do Not Use
	1	0	0	1	0	TCXO/128	Do Not Use	Do Not Use
	1	0	0	1	1	TCXO/128	Do Not Use	Do Not Use
	1	0	1	0	0	TCXO/256	TCXO/512	TCXO/1024
	1	0	1	0	1	TCXO/256	TCXO/512	TCXO/1024
	1	0	1	1	0	TCXO/256	TCXO/512	TCXO/1024
	1	0	1	1	1	TCXO/256	TCXO/512	TCXO/1024
	1	1	0	0	0	TCXO/256	TCXO/512	TCXO/1024
	1	1	0	0	1			
	1	…				TCXO/512	TCXO/1024	TCXO/2048
	1	1	1	1	1			

13.8.11. ADC P/S IF

The AK2401A outputs a data that is digitally processed by the ADC as a 64-bit serial signal. In the 64 bits, I channel's 24 bits and Q channel's 24 bits are used as data area and the rest of 16 bits can be applied as status bits for each function. Operational status of each function can be confirmed by the status bits. Serial interface output of the ADC that includes status bits are shown in Figure 42. Normally, each status bit is masked and outputs "0". It will start outputting the status by writing "1" to the corresponding register in the <Address0x4B>.

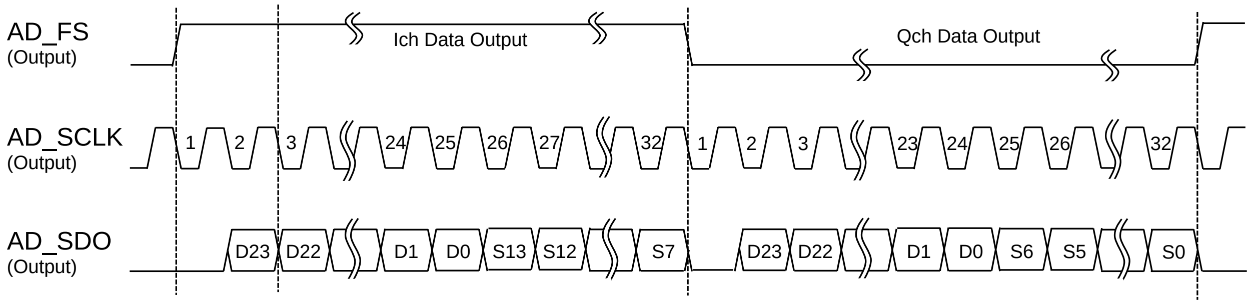


Figure 42. ADC Output Serial Interface Timing (Status Read)

S13-S10, S0: Operational Status of Internal Circuit Flag (Control Register: TEST_2-TEST_5, TEST_15 bits)

S13 to S10 and S0 are test function for AKM USE. Set TEST_2 to TEST_5, TEST_15 bits = "0" to invalid.

S9: LNA Low Gain Mode Operation Flag (Control Register: LNALG_STS bit)

This flag becomes "1" while LNA is in operation in Low Gain Mode. This flag is valid in both AGC and manual operations.

S8: AGC Gain Increment Flag (Control Register: AGC_STS bit)

This flag becomes "1" when PGA gain is increased during AGC operation. Flagging period is the same as one cycle of the output sampling rate. The timing of flag can be selected by AGCKP_MODE[1:0] bits <Address0x21>.

AGCKP_MODE[1:0] bits= "00"

This flag becomes "1" on the timing of a gain change in this setting.

AGCKP_MODE[1:0] bits= "01"

The flag becomes "1" on the timing of when the AGC_KEEP pin becomes "H" or AGC_KEEPR bit becomes "1" if a gain change is recognized. The gain change will be reflected to LNA gain mode and PGA gain setting on the timing when the AGC_KEEP pin become "L" or AGC_KEEPR bit become "0" next time.

S7: AGC Gain Decrement Flag (Control Register: AGC_STS bit)

This flag becomes "1" when PGA gain is decreased during AGC operation. Flagging period and the timing are the same as S8: AGC Gain Increment Flag.

S6-S1: RSSI Detection Value (Control Register: RSSI_STS bit)

Lower 6 bits of RSSI result that is read by setting RSSI bit <Address0x3A> are output in real-time. The output range of lower 6 bits is from -127dBm to -95.5dBm(Typical, RSSI_LOW bits="00") with a conversion to LNA input. All "1" is output after a saturation process if the output level exceeds -95.5 dBm of lower 6 bits. RSSI detection update timing is controlled by RSSIAVE bits <Address0x2C> settings.

14. Register Map

Name	Address	D7	D6	D5	D4	D3	D2	D1	D0
FRAC1	0x01	X	X	X	X	X	X	FRAC[17:16]	
FRAC2	0x02	FRAC[15:8]							
FRAC3	0x03	FRAC[7:0]							
MOD1	0x04	X	X	X	X	X	X	MOD[17:16]	
MOD2	0x05	MOD[15:8]							
MOD3	0x06	MOD[7:0]							
INT1	0x07	X	X	X	X	INT[11:8]			
INT2	0x08	INT[7:0]							
RDIV	0x09	R[7:0]							
CP1	0x0A	X	CPOF[1:0]		CPFINE[4:0]				
CP2	0x0B	X	X	X	CPFAST[4:0]				
SYNTH	0x0C	X	X	FASTEN	DUMMY1	CPHIZ	X	DSMON	LD
FAST TIME1	0x0D	FAST_TIME[15:8]							
FAST TIME2	0x0E	FAST_TIME[7:0]							
FREQ OFFSET1_1	0x0F	X	X	X	X	X	X	OFST1[17:16]	
FREQ OFFSET1_2	0x10	OFST1[15:8]							
FREQ OFFSET1_3	0x11	OFST1[7:0]							
LOCAL	0x12	X	X	X	X	I_LODIV	I_LOBUF	DIVSEL[1:0]	
TX	0x13	X	X	X	X	DACCNT	DUMMY2	TXOLV[1:0]	
RX	0x14	X	LPMODE _DEM	DUMMY3	RXLPF_ FC	IQ_SEL	ANA_ PATH	MAIN_ PATH	LPMODE _LNA
PGA GAIN_I	0x15	X	X	PGAGAIN_I[5:0]					
PGA GAIN_Q	0x16	X	X	PGAGAIN_Q[5:0]					
CAL START1	0x17	X	X	CAL LNAPD	OFS2REG	OFSCAL4	OFSCAL3	OFSCAL2	OFSCAL1
CAL START2	0x18	X	X	X	X	CHOFS_AVE[1:0]		AGCOFS_AVE[1:0]	
DC OFST I1	0x19	OFST_I[23:16]							
DC OFST I2	0x1A	OFST_I[15:8]							
DC OFST I3	0x1B	OFST_I[7:0]							
DC OFST Q1	0x1C	OFST_Q[23:16]							
DC OFST Q2	0x1D	OFST_Q[15:8]							
DC OFST Q3	0x1E	OFST_Q[7:0]							
AGC1	0x1F	AGCTIM[2:0]			AGCHYS[1:0]		AGC_ KEEP_SEL	AGC_ KEEPR	AGCOFF

Name	Address	D7	D6	D5	D4	D3	D2	D1	D0
AGC2	0x20	LNA_ AGCOFF	LNA_ LGMODE	AGCMAX[2:0]			AGCTGT[2:0]		
AGC3	0x21	X	X	FB_ RDOC	AGCKP_MODE[1:0]		AGCTRW[2:0]		
CH FILTER	0x22	DFIL_SR[1:0]		DFIL_ PROG	DFIL_ CLK	DFIL_SEL[3:0]			
PROG FILTER	0x23	X	X	PFIL_SAT[2:0]			PFIL_SIFT[2:0]		
HPF1_1	0x24	X	X	TEST_9	TEST_10[3:0]				TEST_11
HPF1_2	0x25	X	TEST_12[1:0]		TEST_13[1:0]		TEST_14[2:0]		
RDOC1	0x26	RDOC_1	RDOC_2	KEEP_ RDOC	RDOC_3[1:0]		RDOC_4[1:0]		RDOC
RDOC2	0x27	RDOC_18	RDOC_5[2:0]			RDOC_6[1:0]		RDOC_7[1:0]	
RDOC3	0x28	X	RDOC_8[1:0]		OFST_RSEL[1:0]		RDOC_ FM	RDOC_9[1:0]	
FREQ_O FST2_1	0x29	X	X	X	X	X	X	OFST2[17:16]	
FREQ_O FST2_2	0x2A	OFST2[15:8]							
FREQ_O FST2_3	0x2B	OFST2[7:0]							
RSSI	0x2C	X	X	X	RSSI_LOW[1:0]		RSSIAVE[2:0]		
FIR COEF	0x2D	COEF_NUM[6:0]							COEF_ST
PD	0x2E	PD_ CLKBUF_N	PD_ LNA_N	PD_ RXR_N	PD_ TXR_N	PD_ SYNTH_N	PD_ ADC_N	PD_ DAC_N	PD_ REF_N
READ PGA_I	0x2F	X	R_LNA_L GMODE	RPGA_I[5:0]					
READ PGA_Q	0x30	X	X	RPGA_Q[5:0]					
READ OFST_I1	0x31	R_OFST_I[23:16]							
READ OFST_I2	0x32	R_OFST_I[15:8]							
READ OFST_I3	0x33	R_OFST_I[7:0]							
READ OFST_Q1	0x34	R_OFST_Q[23:16]							
READ OFST_Q2	0x35	R_OFST_Q[15:8]							
READ OFST_Q3	0x36	R_OFST_Q[7:0]							
READ COEF1	0x37	X	TAPNUM[6:0]						
READ COEF2	0x38	R_COEF[15:8]							
READ COEF3	0x39	R_COEF[7:0]							
READ RSSI	0x3A	RSSI[7:0]							
DC_OFST CAL1H_I	0x3B	X	X	OFST1H_I[5:0]					
DC_OFST CAL1H_Q	0x3C	X	X	OFST1H_Q[5:0]					
DC_OFST CAL1L_I	0x3D	X	X	OFST1L_I[5:0]					
DC_OFST CAL1L_Q	0x3E	X	X	OFST1L_Q[5:0]					
LDCNT LOCK	0x3F	LD_LOCKCNT[7:0]							
LDCNT UNLOCK	0x40	LD_UNLOCKCNT[7:0]							

Name	Address	D7	D6	D5	D4	D3	D2	D1	D0
FUSE	0x41	X	X	X	X	X	X	X	DUMMY4
PHASE ADJ	0x42	X	X	PH_ADJ[5:0]					
R PHASE ADJ	0x43	X	X	R_PH_ADJ[5:0]					
RDOC4	0x44	R_RDOC	RDOC_10[1:0]		RDOC_11[1:0]		RDOC_12[2:0]		
RDOC5	0x45	RDOC_13[7:0]							
RDOC6	0x46	RDOC_14[1:0]		RDOC_15[1:0]		RDOC_16[1:0]		RDOC_17[1:0]	
AGC4	0x47	X	X	LNA_TGT_H[5:0]					
AGC5	0x48	X	X	LNA_TGT_L[5:0]					
PRE TESTEN	0x49	PRE_ TSTWE	X	X	X	X	X	X	X
CH FILTER2	0x4A	DO_MODE	TEST_6	TEST_7[1:0]		TEST_8	TEST_1	DFIL_ ACC	DFIL_ CLKG
STATUS	0x4B	TEST_2	TEST_3	TEST_4	TEST_5	LNALG_ STS	AGC_ STS	RSSI_ STS	TEST_15
RDOC7	0x4C	X	X	KEEP_RD_DLY[5:0]					
RDOC8	0x4D	RDOC_19	RDOC_20	RDOC_21[1:0]		RDOC_22[1:0]		RDOC_23[1:0]	
HPF2_1	0x4E	X	X	KEEP_ HPF2	HPF2_FC[3:0]				HPF2SEL
HPF2_2	0x4F	X	X	KEEP_HPF2_DLY_1[5:0]					
HPF2_3	0x50	X	X	KEEP_HPF2_DLY_2[5:0]					
CH FILTER2	0x51	X	X	X	X	X	X	X	TEST_16
SOFT RESET	0x5F	SRST [7:0]							

* X: Do not care
* Register values from the address 0x01 to 0x07 will be valid when writing to the address 0x08.
* Register values of the address 0x0D will be valid when writing to the address 0x0E.
* Register values of the address 0x0F and 0x10 will be valid when writing to the address 0x11.
* Register values of the address 0x15 will be valid when writing to the address 0x16.
* Register values of the address 0x19 will be valid when writing to the address 0x1A.
* Register values of the address 0x1C and 0x1D will be valid when writing to the address 0x1E.
* Register values of the address 0x29 and 0x2A will be valid when writing to the address 0x2B.

15. Register Definitions

15.1. <0x01-0x03>FRAC

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x01	X	X	X	X	X	X	FRAC[17:16]		R/W
Initial value							0	0	
0x02	FRAC[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x03	FRAC[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

FRAC[17:0]: Numerator Setting of Dividing Number for N-Divider

Set the numerator of dividing number for a frequency synthesizer. This value must be in a range of 0 ≤ FRAC ≤ (MOD-1). Delta-sigma modulator is stopped by setting this value “0”, and the N-Divider works as an integer dividing PLL.

This setting will be valid after writing to the Address 0x08.

15.2. <0x04-0x06>MOD

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x04	X	X	X	X	X	X	MOD[17:16]		R/W
Initial value							0	0	
0x05	MOD[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x06	MOD[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

MOD[17:0]: Denominator Setting of Dividing Number for N-Divider

Set the denominator of dividing number for a PLL synthesizer. This value must be in a range of 2 ≤ MOD ≤ 262143 (dec). Since it is possible to set a fine frequency with a larger value, normally set it to the maximum value 262143 (dec).
This setting will be valid after writing to the Address 0x08.

15.3. <0x07-0x08>INT

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x07	X	X	X	X	INT[11:8]				R/W
Initial value					0	0	0	0	
0x08	INT[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

INT[11:0]: Integer Dividing Number Setting for N-Divider

Set an integer dividing number for a PLL synthesizer. This value must be in a range of 35 ≤ INT ≤ 4091(dec).
This setting of the address 0x07 will be valid after writing to the address 0x08.

15.4. <0x09>RDIV

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x09	R[7:0]								R/W
Initial value	1	0	0	0	0	0	0	0	

R[7:0]: Dividing Setting of Reference Clock

This value must be in a range of 1 (Not Divided) ≤ RDIV ≤ 255 (Divide by 255).
* Do not set R[7:0] bits to “00000000”.

15.5. <0x0A-0x0B>CP

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x0A	X	CPOF[1:0]		CPFINE[4:0]					R/W
Initial value		0	0	0	0	0	0	0	
0x0B	X	X	X	CPFAST[4:0]					R/W
Initial value				0	0	0	0	0	

CPOF[1:0]: Phase Offset Adjustment by Frequency Phase Comparator

Phase noise characteristics and spurious characteristics are affected by adding an offset to the phase when the frequency of an input signal that is input to the frequency phase comparator is locked. These characteristics could be improved by this setting with optimized conditions. Percentages in the table below are normalized. Normally, CPOF[1:0] bits must be set to “00”.

CPOF		Phase Offset
[1]	[0]	
0	0	0% (default)
0	1	-11%
1	0	-20%
1	1	-27%

CPFINE[4:0]: Charge Pump Current Setting for Normal Operation
CPFAST[4:0]: Charge Pump Current Setting for First Lock Mode

The charge pump current can be calculated by the equations below.

Charge Pump Current [μA] = I_{CP_MIN} [μA] × (Setting Value + 1)
I_{CP_MIN} [μA] = 2160 / Resistor Connected to the [BIAS2] pin [kΩ]

Charge Pump Current (Typ.) Unit: μA

CPFAST[4:0] CPFINE[4:0]	BIAS2 Pin Connected Resistance		
	33kΩ	27kΩ	22kΩ
0	65	80	98
1	131	160	196
2	196	240	295
3	262	320	393
・・・	・・・		
n	2160 / BIAS2 Pin Resistance [kΩ]×(n+1)		
・・・	・・・		
28	1898	2320	2847
29	1964	2400	2945
30	2029	2480	3044
31	2095	2560	3142

15.6. <0x0C>SYNTH

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x0C	X	X	DUMMY1	LFMODE	CPHIZ	X	DSMON	LD	R/W
Initial value			0	0	0		0	0	

FASTEN: Fast Lock Mode Enable Setting

This bit controls Fast Lock mode for frequency convergence of the PLL synthesizer. Refer to “13.7.4 Fast Lock Function” for details.

0: Fast Lock Mode Disable
1: Fast Lock Mode Enable

DUMMY1: Dummy Register 1

This register must be in the default setting.

CPHIZ: TRI-STATE Charge Pump Output Setting

Charge pump output of the PLL synthesizer setting. Normally, CPHIZ bit should be set to “0”.

0: Normal Output
1: Tri-State

DSMON: Delta-sigma Modulator Setting

Set the operation of Delta-sigma modulator for integer dividing mode (FRAC=0).

The settings of OFST[17:0] bits <Address 0x0F-0x11> and OFST2[17:0] bits <Address 0x29-0x2B> are invalid when the Delta-sigma Modulator is not in operation. Normally, DSMON bit should be set to “1”.

0: Do Not Operate Delta-sigma Modulator in integer dividing mode (FRAC=0)
1: Operate Delta-sigma Modulator in integer dividing mode (FRAC=0)

LD: Lock Detection Function Mode Setting

A function of the LD (lock detection) pin of the PLL synthesizer is set. Refer to “13.7.5. Lock Detection” for the digital lock detection output when setting this bit to “0”. Refer to “13.8.6. RDOC Function” for the local frequency.

0: Digital Lock Detection Output
1: Operation Status of Local Frequency Offset Control Function

15.7. <0x0D-0x0E>FAST TIME

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x0D	FAST_TIME[15:8]								R/W
Initial value	0	0	0	1	0	0	0	0	
0x0E	FAST_TIME[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

FAST_TIME[15:0]: FAST Counter Time Setting

Set the valid period of fast lock mode for PLL synthesizer. The valid period is calculated as below. Do not set FAST_TIME[15:0] bits = 0x0000(hex) and 0x0001(hex).

Valid period = Phase Frequency Detector Frequency Cycle × FAST_TIME[15:0] bits

This setting <Address0x0D> becomes valid after writing to the <Address0x0E>.

15.8. <0x0F-0x11>FREQ OFFSET1

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x0F	X	X	X	X	X	X	OFST1[17:16]		R/W
Initial value							0	0	
0x10	OFST1[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x11	OFST1[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

OFST1[17:0]: Frequency Offset Setting 1

Set frequency offset for PLL synthesizer. Setting value is in 2’s complement format and MSB is the sign bit. Refer to “13.7.3. Frequency Offset Adjustment” for details of the frequency offset function. Set all “0” when not using the frequency offset function.

These settings <Address0x0F> and <Address0x10> will be valid after writing to the <Address0x11>.

15.9. <0x12>LOCAL

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x12	X	X	X	X	I_LODIV	I_LOBUF	DIVSEL[1:0]		R/W
Initial value					0	0	0	1	

I_LODIV: Current Adjustment with LOCAL DIVIDER

This bit increases the current consumption of LOCAL DIVIDER. When the noise of LOCAL DIVIDER affects the blocking characteristics, the blocking characteristics improve.

0: default

1: current increase

I_LOBUF: Current Adjustment with LOCAL DIVIDER

This bit increases the current consumption of LOCAL BUFFER. When the noise of LOCAL BUFFER affects the blocking characteristics, the blocking characteristics improve.

0: default

1: current increase

DIVSEL[1:0]: Local Divider Setting

Set the division number of LOCAL DIVIDER. Normally set to DIVSEL[1:0] bits="01" (divide by 2).

DIVSEL		Local Divider Setting	
[1]	[0]	RX PDN pin=”0”	RX PDN pin=”1”
0	0	Not Divide	Do Not Use
0	1	Divide by 2	Divide by 2
1	0	Divide by 4	Divide by 4
1	1	Divide by 8	Divide by 8

15.10. <0x13>TX

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x13	X	X	X	X	DACCNT	DUMMY2	TXOLV[1:0]		R/W
Initial value					1	0	0	0	

DACCNT: DAC Power Down Control for TX_PDN Reset

This setting selects whether power down the DAC or not by power down control of the transmission block by the TX_PDN pin. Refer to "13.1. Power Management" for details.

0: Do not control power down of the DAC by the TX_PDN pin
1: Control power down of the DAC by the TX_PDN pin

DUMMY2: Dummy Register 2

This register can be written / read, but it does not affect the operation.

TXOLV[1:0]: Driver Amplifier Output Power Setting

Set the output power of driver amplifier. Refer to "10.2. Transmission Characteristics" for details.

TXOLV		TX Output Power	Unit
[1]	[0]		
0	0	-6	dBm
0	1	0	
1	0	+2	
1	1	+4	

15.11. <0x14>RX

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x14	X	LPMODE_DEM	DUMMY3	RXLPF_FC	IQ_SEL	ANA_PATH	MAIN_PATH	LPMODE_LNA	R/W
Initial value		0	0	0	0	0	1	0	

DUMMY3: Dummy Register 3

This register can be written / read, but it does not affect the operation.

RXLPF_FC: Cutoff Frequency Setting

Set a cutoff frequency of the gain variable PGA that is composed by first order low-pass filter. Refer to ”13.5.2 Analog Filter Frequency Characteristics” for frequency characteristics. Refer to “13.8.2 Digital Filter Frequency Characteristics” for recommended settings.

0: Low Cutoff Mode
1: High Cutoff Mode

IQ_SEL: Receiving Analog Baseband Signal Output I/Q Setting

The output receiving analog baseband signal from the AOUT_P and AOUT_N pins when ANA_PATH bit= “1” is selected.

0: Ich
1: Qch

ANA_PATH: Output Function Enable for Receiving Analog Baseband Signal

Select the output of the AOUT_P and AOUT_N pins. Normally, ANA_PATH bit should be set to “0”.

0: AOUT_P, AOUT_N pins Hi-Z
1: AOUT_P, AOUT_N pins Output Receiving Analog Baseband Signal

MAIN_PATH: Output Setting of Receiving Analog Baseband Signal

Select connection of AAF output and ADC input. Normally, MAIN_PATH bit should be set to “1”.

0: AAF Output to ADC Input Not Connected
1: AAF Output to ADC Input Connected

LPMODE_LNA: Receiving Analog Circuit (LNA) Operation Mode

Select an operation mode of receiving analog circuit (LNA). Refer to “10.1.1 LNA” for receiving performance.

0: Normal Power Mode
1: Low Power Mode

LPMODE_DEM: Receiving Analog Circuit (MIXER) Operation Mode

Select an operation mode of receiving analog circuit (MIXER). Refer to “10.1.2 MIXER+PGA+AAF+ADC” for receiving performance.

0: Normal Power Mode
1: Low Power Mode

15.12. <0x15-0x16>PGA GAIN

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x15	X	X	PGAGAIN_I[5:0]						R/W
Initial value			0	0	0	0	0	0	
0x16	X	X	PGAGAIN_Q[5:0]						R/W
Initial value			0	0	0	0	0	0	

PGAGAIN_I[5:0]: Ich PGA Gain Setting
PGAGAIN_Q[5:0]: Qch PGA Gain Setting
Set Ich/Qch PGA gain independently.

■ AGCOFF bit= “1” <Address0x1F>
AGC function is OFF and the PGA gain settings are valid.

■ AGCOFF bit= “0” <Address0x1F>
AGC starts operation with the default value set by PGAGAIN_I[5:0] bits. Normally, PGAGAIN_I bits and PGAGAIN_Q bits should be set to “000000”.

PGAGAIN_I , PGAGAIN_Q						Gain	Unit
[5]	[4]	[3]	[2]	[1]	[0]		
0	0	0	0	0	0	28 (default)	dB
0	0	0	0	0	1	27	
0	0	0	0	1	0	26	
0	0	0	0	1	1	25	
・・・						・・・	
0	1	1	0	1	1	1	
0	1	1	1	0	0	0	
0	1	1	1	0	1	-1	
・・・						・・・	
1	0	1	1	1	1	-19	
1	1	0	0	0	0	-20	
1	1	0	0	0	1	Do Not Use	
1	1	0	0	1	0		
1	1	0	0	1	1		
1	1	0	1	0	0		
1	1	0	1	0	1		
1	1	0	1	1	0		
1	1	0	1	1	1		
1	1	1	X	X	X		

(X: Do not care)

15.13. <0x17-0x18>CAL START

<table>
<tr><th>Address</th><th>D7</th><th>D6</th><th>D5</th><th>D4</th><th>D3</th><th>D2</th><th>D1</th><th>D0</th><th>R/W</th></tr>
<tr><td>0x17</td><td rowspan="2">X</td><td rowspan="2">X</td><td>CAL LNAPD</td><td>OFS2REG</td><td>OFSCAL4</td><td>OFSCAL3</td><td>OFSCAL2</td><td>OFSCAL1</td><td rowspan="2">R/W</td></tr>
<tr><td>Initial value</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0x18</td><td rowspan="2">X</td><td rowspan="2">X</td><td rowspan="2">X</td><td rowspan="2">X</td><td colspan="2">CHOFS_AVE[1:0]</td><td colspan="2">AGCOFS_AVE[1:0]</td><td rowspan="2">R/W</td></tr>
<tr><td>Initial value</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Refer to “13.8.5. DC Offset Calibration” for detailed operation of DC offset calibration.

CALLNAPD: LNA Power Down Setting for DC Offset Calibration of Analog Block (MIXER)

This bit set ON/OFF of LNA power down function for initial DC offset calibration of the analog block. LNA is powered down during calibration by setting OFSCAL1 bit = “1” and powered up automatically after the calibration is finished. This setting is only valid when PD_LNA_N bit = “1” <Address 0x2E>. Normally, CALLNAPD bit should be set to “1”.

0: Do not power down the LNA during the DC offset calibration of the analog block (MIXER)
1: Power down the LNA during the DC offset calibration of the analog block (MIXER)

OFS2REG: External Input Setting for DC Offset Compensation Value

This bit selects DC offset compensation value source for the channel filter block. When it is “1”, setting value of I ch or Q ch <Address 0x19-0x1E> is used for offset compensation instead of using calibration result by OFSCAL2 bit. Normally, OFS3REF bit should be set to “0”.

0: Use Calibration Result for DC Offset Compensation for the Channel Filter
1: Use Register Settings for DC Offset Compensation for the Channel Filter

OFSCAL4: Start Trigger of DC Offset Calibration for Digital (AGC) Block

DC offset calibration for digital (AGC) block starts by writing “1” to this bit. This bit returns to “0” automatically after the calibration is finished.

OFSCAL3: Start Trigger of DC Offset Calibration for Digital (Channel Filter) Block

DC offset calibration for digital (Channel Filter) block starts by writing “1” to this bit. This bit returns to “0” automatically after the calibration is finished.

OFSCAL2: Start Trigger of DC Offset Calibration for Digital (Channel Filter + AGC) Block

DC offset calibration for digital (Channel Filter + AGC) block starts by writing “1” to this bit. This bit returns to “0” automatically after the calibration is finished.

OFSCAL1: Start Trigger of DC Offset Calibration for Analog Block (MIXER)

DC offset calibration for analog block (MIXER) starts by writing “1” to this bit. This bit returns to “0” automatically after the calibration is finished.

CHOFS_AVE[1:0]: Averaging Time of Calibration for Digital (Channel Filter) Block

Set the time of sampling data averaging process during the DC offset calibration of channel filter block.

AGCOFS_AVE[1:0]: Averaging Time of Calibration for Digital (AGC) Block

Set the time of sampling data averaging process during the DC offset calibration of AGC block.

15.14. <0x19-0x1E>CH_DC OFST

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x19	OFST_I[23:16]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x1A	OFST_I[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x1B	OFST_I[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x1C	OFST_Q[23:16]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x1D	OFST_Q[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x1E	OFST_Q[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

OFST_I[23:0]: Ich DC Offset Compensation Value
OFST_Q[23:0]: Qch DC Offset Compensation Value
Set these bits to define DC offset compensation value arbitrarily for the channel filter block. This setting will be valid instead of initial calibration value by setting OFS2REG bit = “1” <Address 0x17>.

The setting of <Address0x19> and <Address0x1A> will be valid when writing to the <Address0x1B>.
The setting of <Address0x1C> and <Address0x1D> will be valid when writing to the <Address0x1E>.

15.15. <0x1F-0x21, 0x47-048>AGC

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x1F	AGCTIM[2:0]			AGCHYS[1:0]		AGC_KEEPSEL	AGC_KEEPR	AGCOFF	R/W
Initial value	0	1	1	0	0	0	0	1	
0x20	LNA_AGC_OFF	LNA_LGMODE	AGCMAX[2:0]			AGCTGT[2:0]			R/W
Initial value	1	0	1	1	1	0	1	0	
0x21	X	X	FB_RDOC	AGCKP_MODE[1:0]		AGCTRW[2:0]			R/W
Initial value			0	0	0	0	1	1	
0x47	X	X	LNA_TGT_H[5:0]						R/W
Initial value			1	0	0	0	1	0	
0x48	X	X	LNA_TGT_L[5:0]						R/W
Initial value			1	0	1	1	1	0	

Note that <Address0x47> and <Address0x48> are written in this document in a reverse order.

Refer to “13.8.7 AGC” and “13.8.8 AGC_KEEP” for AGC operation related to these settings above

AGCTIM[2:0]: Calculation/Detection Time Setting of Signal Power

Set signal power calculation/detection time of AGC. The power calculation/detection time is calculated by the equation shown below. Power calculation/detection times in the case of using 18.432MHz and 19.2MHz reference clocks are shown in the table below.

Power Calculation/Detection Time = Reference Clock Cycle × 2048 ×2^N
*N: AGCTIM bits Setting Value

AGCTIM			Power Calculation/Detection Time		Unit
[2]	[1]	[0]	18.432MHz	19.2MHz	
0	0	0	0.11	0.11	ms
0	0	1	0.22	0.21	
0	1	0	0.44	0.43	
0	1	1	0.89 (default)	0.85 (default)	
1	0	0	1.79	1.71	
1	0	1	3.56	3.41	
1	1	0	7.11	6.83	
1	1	1	14.22	13.65	

AGCHYS[1:0]: Hysteresis Width of Signal Power Convergence Level

AGC (Automatic Gain Control) stops gain controlling when the current receiving level is within the range of this setting (convergence detection level) against the AGC convergence target level set by AGCTGT[2:0] bits <Address 0x20>.

AGCHYS		Convergence Detection Level	Unit
[1]	[0]		
0	0	< ±1 (default)	dB
0	1	< ±2	
1	0	< ±4	
1	1	< ±8	

AGC_KEEP_SEL: Control Method Setting for the AGC_KEEP Function

This bit selects register or pin control of the AGC_KEEP function.
0: Control by AGC_KEEPR bit
1: Control by the AGC_KEEP pin

AGC_KEEPR: ON/OFF Setting of the AGC KEEP Function

Set ON/OFF of the AGC KEEP function. This setting will only be valid when setting AGC_KEEP_SEL bit = “0” <Address 0x1F>
0: AGC KEEP Function OFF
1: AGC KEEP Function ON

AGCKP_MODE bit <Address 0x21> controls operation of the AGC KEEP function.

AGCOFF: ON/OFF Setting of AGC (Automatic Gain Control) Function

Set ON/OFF of the AGC function. AGC is performed in PGA and LNA blocks. LNA gain control can be applied to PGA by setting LNA_AGCOFF bit = “0” <Address0x20> when AGCOFF bit= “0”. Normally AGCOFF bit should be set to “0”.
0: AGC Function ON
1: AGC Function OFF

LNA_AGCOFF: LNA Gain Control Switching

LNA gain control can be applied to PGA gain setting. Normally, LNA_AGCOFF bit should be set to “0”

0: PGA gain is controlled by LNA gain control

1: PGA gain is not controlled by LNA gain control.

LNA_LGMODE: LNA Low Gain Mode

LNA low gain mode is available by setting LNA_LGMODE bit=“1”. This setting is only valid when LNA_AGCOFF bit= “1” <Address0x20>. LNA gain mode can be changed manually.

0: Normal Gain Mode

1: Low Gain Mode

AGCMAX[2:0]: Maximum Tolerate Gain Change Amount for Single AGC Operation

Set the maximum tolerate of gain change amount for single AGC operation.

AGCMAX			Max Tolerate Gain Change	Unit
[2]	[1]	[0]		
0	0	0	Do Not Use	dB
0	0	1	1	
0	1	0	2	
0	1	1	4	
1	0	0	8	
1	0	1	16	
1	1	0	32	
1	1	1	48 (default)	

AGCTGT[2:0]: Signal Power Convergence Target Level

Set the target level of AGC convergence.

AGCTGT			Convergence Level	Unit
[2]	[1]	[0]		
0	1	1	6	dBm
0	1	0	4 (default)	
0	0	1	2	
0	0	0	0	
1	1	1	-2	
1	1	0	-4	
1	0	1	-6	
1	0	0	-8	

FB_RDOC: Reflect RDOC Compensation Value to Digital (AGC) Block

DC offset value detected by RDOC will be reflected to Digital (AGC) block when FB_RDOC bit= “1”.

0: RDOC Compensation Value is not reflected to Digital (AGC) block.

1: RDOC Compensation Value is reflected to Digital (AGC) block.

LNA_TGT_H[5:0]: LNA Gain Mode Switching Threshold (High)
LNA_TGT_L[5:0]: LNA Gain Mode Switching Threshold (Low)

Set LNA gain mode switching threshold of when LNA_AGCOFF bit= “0”<Address0x20>. LNA gain switching is executed by comparing a correction gain (G_{CORR}) that is calculated by AGCTGT bits with setting values of LNA_TGT_H[2:0] bits and LNA_TGT_L[5:0] bits. The setting values must be LNA_TGT_H > LNA_TGT_L. In case of setting values such as LNA_TGT_H ≤ LNA_TGT_L, the same value set to LNA_TGT_L will be set to LNA_TGT_H. The difference between LNA_TGT_H and LNA_TGT_L should be bigger than LNA gain that is decreased by changing to Low gain mode. Here, LNA_TGT_H and LNA_TGT_L mean PGA gain threshold (dB) not register values.

<table>
<tr><th colspan="6">LNA_TGT_H, LNA_TGT_L</th><th rowspan="2">PGA Gain Threshold</th><th rowspan="2">Unit</th></tr>
<tr><th>[5]</th><th>[4]</th><th>[3]</th><th>[2]</th><th>[1]</th><th>[0]</th></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>28</td><td rowspan="25">dB</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>27</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>26</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>25</td></tr>
<tr><td colspan="6">・・・</td><td>・・・</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td><td>1</td><td>-1</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td><td>-2</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>-3</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>-4</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>-5</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>-6 (default, LNA_TGT_H)</td></tr>
<tr><td colspan="6">・・・</td><td>・・・</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>-18 (default, LNA_TGT_L)</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>-19</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>-20</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td rowspan="8">Do not use</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>X</td><td>X</td><td>X</td></tr>
</table>

(X: Do not care)

AGCKP_MODE[1:0]: AGC KEEP Function Operation

Select the operation mode of AGC KEEP function.
Refer to “13.8.8 AGC_KEEP” for details.

AGCTRW[2:0]: AGC Power Detection Wait Time

Set the wait time of power detection starts after PGA gain is changed in AGC operation. The wait time shown in the table is the time when 18.432MHz or 19.2MHz is used for the TCXO frequency.

AGCTRW			Wait Time	Unit
[2]	[1]	[0]		
0	0	0	0.125	ms
0	0	1	0.25	
0	1	0	0.5	
0	1	1	1 (default)	
1	0	0	2	
1	0	1	4	
1	1	0	8	
1	1	1	16	

15.16. <0x22, 0x51>CH FILTER

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x22	DFIL_SR[1:0]		DFIL_ PROG	DFIL_CLK	DFIL_SEL[3:0]				R/W
Initial value	0	0	0	0	0	0	0	0	
0x51	X	X	X	X	X	X	X	TEST_16	R/W
Initial value								0	

Note that <Address0x51> is written in this document in a reverse order.
<Address0x51>TEST_16 bit is test function for AKM USE. This register must be in the default setting.
Refer to "13.8.2 Digital Filter Frequency Characteristics", "13.8.3 Programmable FIR" and "13.8.10 Output Sampling Rate" for details of these settings.

DFIL_SR[1:0]: Output Sampling Rate

Select the sampling rate of digital filter outputs.

DFIL_PROG: Programmable FIR Filter Setting

Select normal channel filter or a programmable FIR Filter.

0: Use Normal Channel Filter set by DFIL_SEL[3:0] bits <Address 0x22>

1: Use a programmable FIR Filter set by <Address 0x2D> as Channel Filter

DFIL_CLK: Reference Clock Setting

Set reference clock that is input to the TCXOIN pin

0: 19.2MHz

1: 18.432MHz

DFIL_SEL[3:0]: Channel Filter Setting

Set Normal Channel Filter

15.17. <0x23>PROG FILTER

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x23	X	X	PFIL_SAT[2:0]			PFIL_SIFT[2:0]			R/W
Initial value			0	0	0	0	0	0	

PFIL_SAT[2:0]: Saturation Process Setting for Programmable FIR Filter Output

Set the number of bit for saturation process that is applied to the programmable FIR filter outputs.

PFIL_SIFT[2:0]: Bit Shift Setting for Programmable FIR Filter Output

Set the number of bit and sift direction (right or left) of bit shifting process that is applied to the programmable FIR filter outputs.

15.18. <0x24-0x25, 0x4E-0x50>HPF

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x24	X	X	TEST_9	TEST_10[3:0]				TEST_11	R/W
Initial value			0	0	0	0	0	0	
0x25	X	TEST_12[1:0]		TEST_13[1:0]		TEST_14[2:0]			R/W
Initial value		0	0	0	0	0	0	0	
0x4E	X	X	KEEP_ HPF2	HPF2_FC[3:0]				HPF2SEL	R/W
Initial value			0	0	0	0	0	0	
0x4F	X	X	KEEP_HPF2_DLY_1[5:0]						R/W
Initial value			1	0	1	1	1	1	
0x50	X	X	KEEP_HPF2_DLY_2[5:0]						R/W
Initial value			1	0	1	1	1	1	

<Address0x24-0x25>TEST_9 bit, TEST_10[3:0] bits, TEST_11 bit, TEST_12[1:0] bits, TEST_13[1:0] bits, TEST_14[2:0] bits are test function for AKM USE. These registers must be in the default setting.
Refer to "13.8.4. High-Pass Filter" for details of these settings.

KEEP_HPF2: Interlock Setting with AGC KEEP Function

The HPF2 function can be interlocked with the AGC KEEP function by setting this bit. If this bit is "1", the HPF2 function will be stopped when setting the AGC_KEEP pin = "H" or AGC_KEEPR = "1". In this time, the calculated internal value of HPF2 is kept. The HPF2 function will be enabled again when setting the AGC_KEEP pin = "L" or AGC_KEEPR bit = "0".

0: Do Not Interlock HPF2 Function with AGC KEEP Function
1: Interlock HPF2 Function with AGC KEEP Function

HPF2_FC[3:0]: Digital High-Pass Filter Cutoff Frequency

Set the HPF2 cutoff frequency

HPF2SEL: High-Pass Filter ON/OFF Setting

Set ON/OFF of HPF2.
0: HPF2 OFF
1: HPF2 ON
*This bit must not be set to "1" when <Address 0x26> RDOC bit = "1" <Address 0x26>.

KEEP_HPF2_DLY_1: Delay setting for Interlocking of HPF2 and AGC KEEP
KEEP_HPF2_DLY_2: Delay setting for Interlocking of HPF2 and AGC KEEP

Set the internal delay when KEEP_HPF2 bit = "1". The recommended value is shown in the table below.

Channel Filter (DFIL_SEL)	DFIL_PROG	KEEP_HPF2_DLY_1 KEEP_HPF2_DLY_2 Recommended (dec)
F0	0	18
F1-F3	0	43
F4-F8	0	47(default)
F9	0	44
F0	1	2 + (COEF_NUM/2)
F1-F3	1	11 + (COEF_NUM/2)
F4-F8	1	10 + (COEF_NUM/2)
F9	1	7 + (COEF_NUM/2)

15.19. <0x26-0x28, 0x44-0x46, 0x4C-0x4D>RDOC

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x26	RDOC_1	RDOC_2	KEEP_RDOC	RDOC_3[1:0]		RDOC_4[1:0]		RDOC	R/W
Initial value	0	1	0	1	0	0	1	0	
0x27	RDOC_18	RDOC_5[2:0]			RDOC_6[1:0]		RDOC_7[1:0]		R/W
Initial value	0	0	1	0	0	0	1	1	
0x28	X	RDOC_8[1:0]		OFST_RSEL[1:0]		RDOC_FM	RDOC_9[1:0]		R/W
Initial value		1	1	0	0	0	0	0	
0x44	R_RDOC	RDOC_10[1:0]		RDOC_11[1:0]		RDOC_12[2:0]			R/W
Initial value	0	0	0	0	0	1	0	1	
0x45	RDOC_13[7:0]								R/W
Initial value	0	0	0	0	0	0	0	1	
0x46	RDOC_14[1:0]		RDOC_15[1:0]		RDOC_16[1:0]		RDOC_17[1:0]		R/W
Initial value	1	1	0	0	0	0	0	0	
0x4C	X	X	KEEP_RD_DLY[5:0]						R/W
Initial value			1	0	1	1	1	1	
0x4D	RDOC_19	RDOC_20	RDOC_21[1:0]		RDOC_22[1:0]		RDOC_23[1:0]		R/W
Initial value	0	0	0	0	0	0	0	0	

Note that <Address0x44>, <Address0x45>, <Address0x46>, <Address0x4C> and <Address0x4D> are written in this document in a reverse order.

Refer to “13.8.6 RDOC” for details.

Following registers are RDOC operation registers. These registers must be in the default setting.

Register	Address	Initial Value
RDOC_1	0x26 D7	“0”
RDOC_2	0x26 D6	“1”
RDOC_3	0x26 D4-D3	“10”
RDOC_4	0x26 D2-D1	“01”
RDOC_5	0x27 D6-D4	“010”
RDOC_6	0x27 D3-D2	“00”
RDOC_7	0x27 D1-D0	“11”
RDOC_8	0x28 D6-D5	“11”
RDOC_9	0x28 D1-D0	“00”
RDOC_10	0x44 D6-D5	“00”
RDOC_11	0x44 D4-D3	“00”
RDOC_12	0x44 D2-D0	“101”
RDOC_13	0x45 D7-D0	“00000001”
RDOC_14	0x46 D7-D6	“11”
RDOC_15	0x46 D5-D4	“00”
RDOC_16	0x46 D3-D2	“00”
RDOC_17	0x46 D1-D0	“00”
RDOC_18	0x27 D7	“0”
RDOC_19	0x4D D7	“0”
RDOC_20	0x4D D6	“0”
RDOC_21	0x4D D5-D4	“00”
RDOC_22	0x4D D3-D2	“00”
RDOC_23	0x4D D1-D0	“00”

KEEP_RDOC: Interlock Setting with AGC KEEP Function

The RDOC function can be interlocked with the AGC KEEP function by setting this bit. If this bit is “1”, the RDOC cancellation function will be OFF when setting the AGC_KEEP pin = “H” or AGC_KEEPR = “1”. In this time, the calculated DC offset value is kept. The RDOC function will be enabled again when setting the AGC_KEEP pin = “L” or AGC_KEEPR bit = “0”.

0: Do Not Interlock RDOC Function with AGC KEEP Function
1: Interlock RDOC Function with AGC KEEP Function

RDOC: RDOC ON/OFF Setting

Set ON/OFF of RDOC.

0: RDOC OFF
1: RDOC ON

OFST_RSEL[1:0]: DC Offset Readback Data Select

Readback data of DC offset cancellation in 15.25 <0x31-0x36>READ OFST can be selected.

OFST_RSEL		Readback Data in 15.25 <0x31-0x36>READ OFST
[1]	[0]	
0	0	[1] Digital Block (Channel Filter) DC Offset Calibration Value
0	1	[2] RDOC Value
1	0	Total Value of [1] + [2]
1	1	Digital Block (AGC) DC Offset Calibration Value

RDOC_FM: RDOC setting for FM radio

Set RDOC_FM bit = “1” when receiving unmodulated (CW) signals such as FM radio with RDOC function. Refer to 13.8.6 RDOC Function for details.

R_RDOC: Operation Status Readback for RDOC Function

Current operation status can be read by R_RDOC bit. It is not normally used.

KEEP_RD_DLY: Delay setting for Interlocking of RDOC and AGC KEEP

Set the internal delay when KEEP_RDOC bit = "1". The recommended value is shown in the table below.

Channel Filter (DFIL_SEL)	DFIL_PROG	KEEP_RD_DLY recommended (dec)
F0	0	18
F1-F3	0	43
F4-F8	0	47(default)
F9	0	44
F0	1	2 + (COEF_NUM/2)
F1-F3	1	11 + (COEF_NUM/2)
F4-F8	1	10 + (COEF_NUM/2)
F9	1	7 + (COEF_NUM/2)

15.20. <0x29-0x2B>FREQ OFFSET2

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x29	X	X	X	X	X	X	OFST2[17:16]		R/W
Initial value							0	0	
0x2A	OFST2[15:8]								R/W
Initial value	0	0	0	0	0	0	0	0	
0x2B	OFST2[7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

OFST2[17:0]: Frequency Offset Setting 2

Set frequency offset for PLL synthesizer. Setting value is in 2’s complement format and MSB is the sign bit. Refer to “13.7.3. Frequency Offset Adjustment” for details of the frequency offset function. It is recommended to set the offset frequency (OFST2 bits) to become 150Hz after divided by the local divider. Set all “0” when not using the RDOC function. This setting is only valid when RDOC_FM bit = “1” <Address0x28>. Refer to “13.8.6. RDOC Function” for details.

The setting of <Address0x29> and <Address0x2A> will be valid when writing to the <Address0x2B>.

15.21. <0x2C>RSSI

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x2C	X	X	X	RSSI_LOW[1:0]		RSSIAVE[2:0]			R/W
Initial value				0	0	0	0	0	

Refer to “13.8.9. RSSI” for setting details.

RSSI_LOW[1:0]: RSSI Compensation

Set a compensation value of RSSI code. The RSSI function subtracts the RSSI compensation value from a detected signal level and outputs as RSSI code. The smaller the compensation value is the smaller signal level can be detected.

RSSI_LOW		Compensation Value [dB]
[1]	[0]	
0	0	18 (default)
0	1	12
1	0	6
1	1	0

RSSIAVE[2:0]: RSSI Averaging Setting

The signal from RSSI circuit is averaged by output sampling rate. Set the number of averaging operation by RSSIAVE bits. The setting of the output sampling rate is DFIL_SR[1:0] bits = “00” <Address0x22>.

RSSIAVE			Averaging [Times]
[2]	[1]	[0]	
0	0	0	4 (default)
0	0	1	8
0	1	0	16
0	1	1	32
1	0	0	64
1	0	1	128
1	1	0	
1	1	1	

15.22. <0x2D>FIR COEF

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x2D	COEF_NUM[6:0]							COEF_ST	W
Initial value	0	0	0	0	0	0	0	0	

Refer to “13.8.3. Programmable FIR” for setting details.

COEF_NUM[6:0]: TAP Number Setting for Programmable FIR Filter

Set the TAP number of programmable FIR filter. This setting must be in the range shown below. If the setting of COEF_NUM bits is more than 75, it will be recognized as 75 as the limit of the setting.

<Address0x22> DFIL_SEL[3:0] bits = 0-3(dec): 1 ≤ COEF_NUM ≤ 64
<Address0x22> DFIL_SEL[3:0] bits = 4-15(dec): 1 ≤ COEF_NUM ≤ 75

The AK2401A can not be in FIR filter coefficient write mode even if COEF_ST bit is set to “1” when COEF_NUM[6:0] bits are set to “0000000”. Therefore, it is recommended to set COEF_NUM[6:0] bits “0000000” after writing coefficient to prevent unintended change of the setting.

COEF_ST: Start Trigger of Coefficient Write Mode

When setting this bit to “1”, the serial interface for register writing enters FIR filter coefficient write mode. Write coefficient continuously for the number of times of the TAP number set by COEF_NUM[6:0] bits. COEF_ST bit returns to “0” automatically after finish writing the coefficient and normal register write becomes available.

15.23. <0x2E>PD

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x2E	PD_ CLKBUF_N	PD_ LNA_N	PD_ RXR_N	PD_ TXR_N	PD_ SYNTH_N	PD_ ADC_N	PD_ DAC_N	PD_ REF_N	R/W
Initial value	0	0	0	0	0	0	0	0	

Control each block power down. Refer to "13.1. Power Management" for details.

15.24. <0x2F-0x30>READ PGA

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x2F	X	R_LNA_ LGMODE	RPGA_I[5:0]						R
Initial value		0	0	0	0	0	0	0	
0x30	X	X	RPGA_Q[5:0]						R
Initial value			0	0	0	0	0	0	

R_LNA_LGMODE: LNA Gain Mode Readback (Readback Only)

Gain mode of the low noise amplifier is readback by writing the register addresses of this register. "0" indicates Normal Gain Mode and "1" indicates Low Gain Mode. AGC calculation result is readback when LNA_AGCOFF bit = "0". The setting value of LNA_LGMODE bit will be readback when LNA_AGCOFF bit = "1".

RPGA_I[5:0]: Ich PGA Gain Readback (Readback Only)
RPGA_Q[5:0]: Qch PGA Gain Readback (Readback Only)

Setting gain of programmable gain amplifier is readback by writing the register addresses of these settings above. AGC calculation result is readback when AGCOFF bit = "0" <Address 0x1E>. The setting values of PGAGAIN_I[5:0] bits <Address 0x15> and PGAGAIN_Q[5:0] bits <Address 0x16> will be readback when AGCOFF bit = "1".

15.25. <0x31-0x36>READ OFST

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x31	R_OFST_I[23:16]								R
Initial value	0	0	0	0	0	0	0	0	
0x32	R_OFST_I[15:8]								R
Initial value	0	0	0	0	0	0	0	0	
0x33	R_OFST_I[7:0]								R
Initial value	0	0	0	0	0	0	0	0	
0x34	R_OFST_Q[23:16]								R
Initial value	0	0	0	0	0	0	0	0	
0x35	R_OFST_Q[15:8]								R
Initial value	0	0	0	0	0	0	0	0	
0x36	R_OFST_Q[7:0]								R
Initial value	0	0	0	0	0	0	0	0	

R_OFST_I[23:0]: Ich DC Offset Calibration Result (Readback Only)
R_OFST_Q[23:0]: Qch DC Offset Calibration Result (Readback Only)

DC offset value set by OFST_RSEL[1:0] bits <Address 0x28> are readback.

15.26. <0x37-0x39>READ COEF

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x37	X	TAPNUM[6:0]							R/W
Initial value		0	0	0	0	0	0	0	
0x38	R_COEF[15:8]								R
Initial value	0	0	0	0	0	0	0	0	
0x39	R_COEF[7:0]								R
Initial value	0	0	0	0	0	0	0	0	

Refer to "13.8.3. Programmable FIR" for details of these setting.

TAPNUM[6:0]: TAP Specifying for Programmable FIR Filter Coefficient Readback

Specify the TAP when readback the coefficient set to the programmable FIR filter <Address 0x38, 0x39>.

R_COEF[15:0]: Programmable FIR Filter Coefficient Readback (Readback Only)

Readback the coefficient set to the programmable FIR filter.
The coefficient that is specified by <Address 0x37> TAPNUM[6:0] bits is readback.

15.27. <0x3A>READ RSSI

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x3A	RSSI[7:0]								R
Initial value	0	0	0	0	0	0	0	0	

RSSI[7:0]: RSSI Result (Readback Only)

Readback RSSI result. Refer to "13.8.9. RSSI" for details.

15.28. <0x3B-0x3E>ANA DC OFST

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x3B	X	X	OFST1H_I[5:0]						R/W
Initial value			1	0	0	0	0	0	
0x3C	X	X	OFST1H_Q[5:0]						R/W
Initial value			1	0	0	0	0	0	
0x3D	X	X	OFST1L_I[5:0]						R/W
Initial value			1	0	0	0	0	0	
0x3E	X	X	OFST1L_Q[5:0]						R/W
Initial value			1	0	0	0	0	0	

OFST1H_I[5:0]: DC Offset Calibration Result of Analog Block (Ich Normal Power Mode)
OFST1H_Q[5:0]: DC Offset Calibration Result of Analog Block (Qch Normal Power Mode)
OFST1L_I[5:0]: DC Offset Calibration Result of Analog Block (Ich Low Power Mode)
OFST1L_Q[5:0]: DC Offset Calibration Result of Analog Block (Qch Low Power Mode)

DC offset calibration result of the analog block that is executed by OFSCAL1 bit = “1” <Address 0x17> can be readout. The calibration result will be stored at <Address 0x3B and 0x3C> if the calibration mode is set to normal mode LPMODE_DEM bit = “0” <Address 0x14>. The calibration result will be stored at <Address 0x3D and 0x3E> if the calibration mode is set to low power mode LPMODE_DEM bit = “1” <Address 0x14>.
By writing to these registers, a register setting value can be used instead of the calibration result. Note that the calibration result will be over written in this case.

15.29. <0x3F-0x40>LDCNT

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x3F	LD_LOCKCNT[7:0]								R/W
Initial value	0	0	1	1	1	1	1	1	
0x40	LD_UNLOCKCNT[7:0]								R/W
Initial value	0	0	1	1	1	1	1	1	

LD_LOCKCNT[7:0]: Lock Detection Accuracy Setting
LD_UNLOCKCNT[7:0]: Unlock Detection Accuracy Setting
Set the number of detection time for digital lock/unlock detection mode. Refer to “13.7.5. Lock Detection” for details.

*Do not set LD_LOCKCNT bit= “00000000” or LD_UNLOCKCNT bit= “00000000”.

15.30. <0x41-0x43>PHASE CAL

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x41	X	X	X	X	X	X	X	DUMMY4	R/W
Initial value								0	
0x42	X	X	PH_ADJ[5:0]						R/W
Initial value			1	0	0	0	0	0	
0x43	X	X	R_PH_ADJ[5:0]						R
Initial value			1	0	0	0	0	0	

DUMMY4: Dummy Register 4
This register can be written / read, but it does not affect the operation.

PH_ADJ[5:0]: I/Q Orthogonal Phase Calibration Setting

Set I/Q orthogonal phase calibration value directly.

PH_ADJ						Ich	Qch	Unit
[5]	[4]	[3]	[2]	[1]	[0]			
0	0	0	0	0	X	-3.875	0	
0	0	0	0	1	0	-3.75	0	
0	0	0	0	1	1	-3.625	0	
・・・						・・・		
0	1	1	1	1	0	-0.25	0	
0	1	1	1	1	1	-0.125	0	
1	0	0	0	0	0	0	0	Δdeg
1	0	0	0	0	1	0	-0.125	
1	0	0	0	1	0	0	-0.25	
・・・						・・・		
1	1	1	1	0	1	0	-3.625	
1	1	1	1	1	0	0	-3.75	
1	1	1	1	1	1	0	-3.875	

(X: Do not care)

R_PH_ADJ[5:0]: I/Q Orthogonal Phase Adjustment Calibration Value Readback (Readback Only)

Readback the value written in PH_ADJ bit as it is.

* Refer to "15.19. <0x26-0x28, 0x44-0x46, 0x4C-0x4D>RDOC" for register description of <Address0x44>, <Address0x45> and <Address0x46>.
* Refer to "15.15. <0x1F-0x21, 0x47-048>AGC" for register description of <Address0x47> and <Address0x48>.

15.31. <0x49>PRE TESTEN

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x49	PRE_ TSTWE	X	X	X	X	X	X	X	R/W
Initial value	0								

PRE_TSTWE: Pre Test Register Enable

Register writing to the <Address0x4A> and <Address0x4B> become valid when setting PRE_TSTWE bit = "1".

15.32. <0x4A>CH FILTER2

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x4A	DO_MODE	TEST_6	TEST_7[1:0]		TEST_8	TEST_1	DFIL_ACC	DFIL_CLKG	R/W
Initial value	0	0	0	1	0	1	0	0	

TEST_1 bit, TEST_6 bit, TEST_7 [1:0] bits and TEST_8 bit are test bits. Write default value to these bits.

DO_MODE : Drive capacity setting of digital output buffer
Set the drive capacity of the digital output buffer. When DO_MODE bit="1" is set, the same driving performance as at 3V(typ.) can be obtained even when DVDD=1.8V(typ.). When DVDD=1.8V(typ.), set DO_MODE bit="1".

“0” : default
“1” : Drive capacity improvement of digital output buffer

DFIL_ACC : Digital Filter Accumulator Calculation Method Setting
Set the calculation method of the digital filter. Spurious of the operation frequency of the digital filter (such as TCXO/4) will be changed. Normally, DFIL_ACC bit must be set to “0”.

0: PRBS (default)
1: Homogenized

DFIL_CLKG : Digital Filter Clock Gating Setting
Set ON/OFF of the clock gating of the digital filter. Spurious of the operation frequency of the digital filter (such as TCXO/4) will be reduced. Normally, DFIL_CLKG bit must be set to “1”.

0: Clock Gating OFF (default)
1: Clock Gating ON (recommended)

15.33. <0x4B>STATUS

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x4B	TEST_2	TEST_3	TEST_4	TEST_5	LNALG_STS	AGC_STS	RSSI_STS	TEST_15	R/W
Initial value	0	0	0	0	0	0	0	0	

When writing “0” to this register, each status bit at ADC output serial interface is masked and outputs “0”. When writing “1” to this register, each status bit will output status of corresponding block.

Refer to “13.8.11. ADC P/S IF” for details.

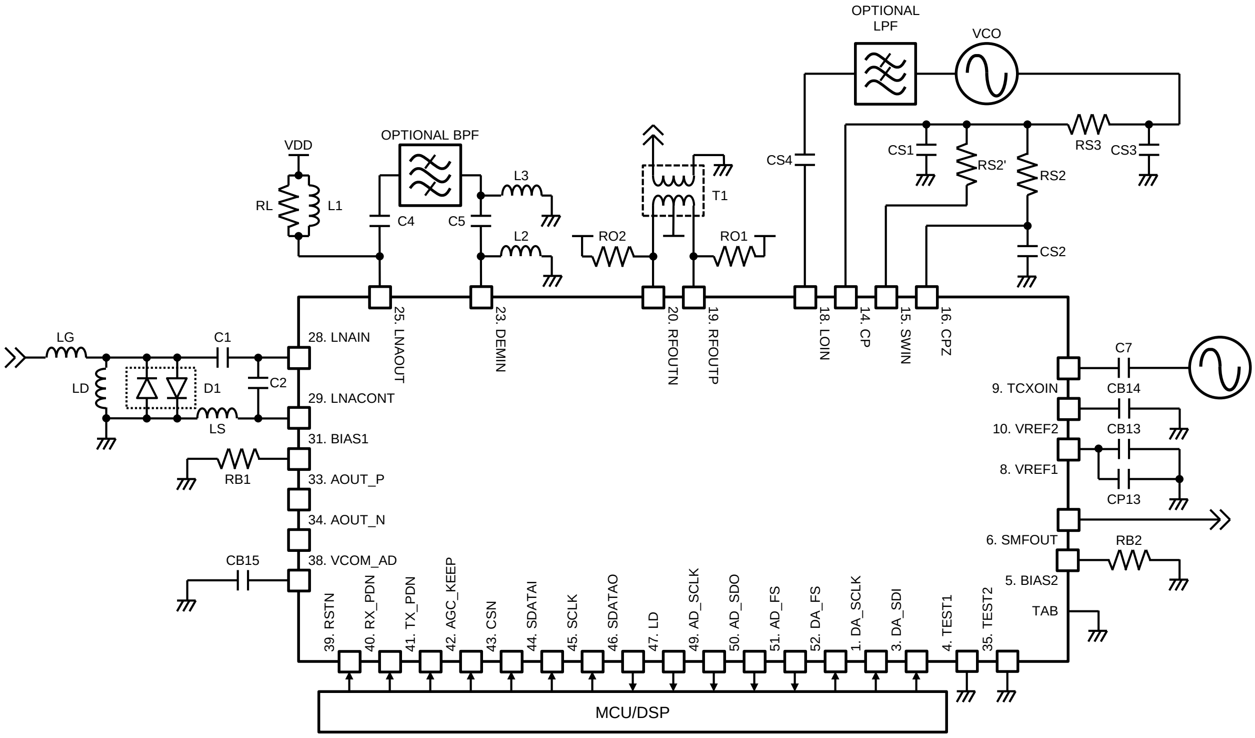
15.34. <0x5F>SOFT RESET

Address	D7	D6	D5	D4	D3	D2	D1	D0	R/W
0x5F	SRST [7:0]								R/W
Initial value	0	0	0	0	0	0	0	0	

SRST[7:0]: Software Reset
Software reset is executed by writing to SRST[7:0] bits = “10101010”. This register will return to “00000000” automatically when the software reset is completed. Refer to “9.2. System Reset” for details.

16. Recommended External Circuits

16.1. Recommended External Circuits



16.2. List of Parts

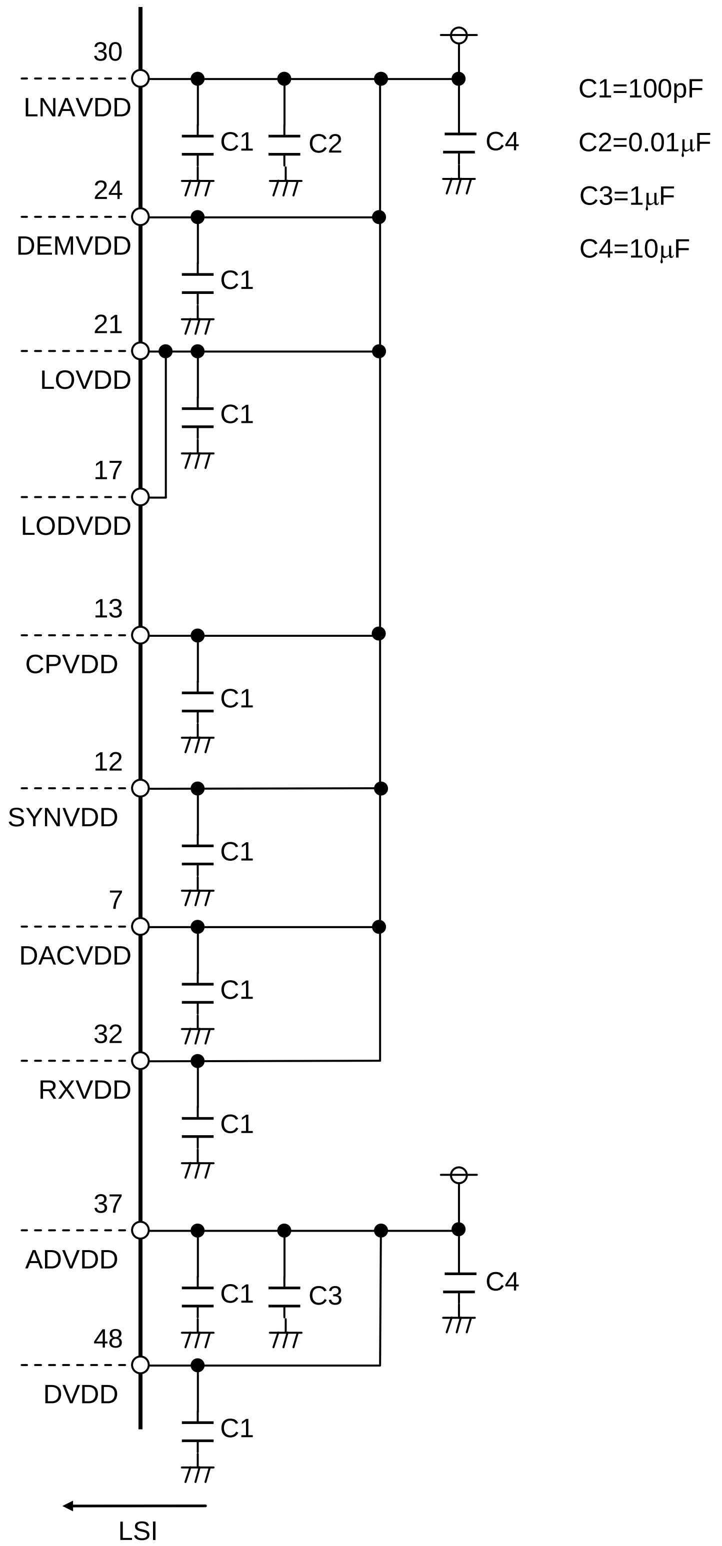
Table 11. Parts List for External Circuit Connection

Ref.	Value	Description	Ref.	Value	Description
LG	30nH	LNAIN=450MHz Normal Power Mode	T1	4:1	RFOUT=450MHz JTX-4-10T
LS	3.3nH		RO1	100Ω	
C2	3.6pF		RO2	100Ω	
C1	100pF		RS2	-	LOOP FILTER
LD	-		RS2’	-	
D1	-		RS3	-	
LG	47nH	LNAIN=450MHz Low Power Mode	CS1	-	
LS	3.3nH		CS2	-	
C2	1.3pF		CS3	-	
C1	100pF		CS4	1000pF	
LD	-		C7	100pF	
D1	-		CB13	10μF	
RL	200Ω	LNAOUT=450MHz	CP13	100pF	
L1	27nH		CB14	0.47μF	
C4	3.9pF		CB15	2.2μF	
L2	220nH	DEMIN=450MHz	RB1	47kΩ	±1% recommended
L3	22nH		RB2	27kΩ	±1% recommended
C5	20pF				

*Coil inductors are used on the AKM evaluation board.
*Matching circuit examples at frequencies other than 450 MHz are prepared as application notes. Contact us separately.
*DAN217UM is used for the diode LD on the AKM evaluation board.

16.3. Power Supply/Ground Pin

Connect capacitors between VDD and VSS pins to eliminate ripple and noise included in power supply.
For a maximum effect, the capacitors should be located at the shortest distance between these pins.

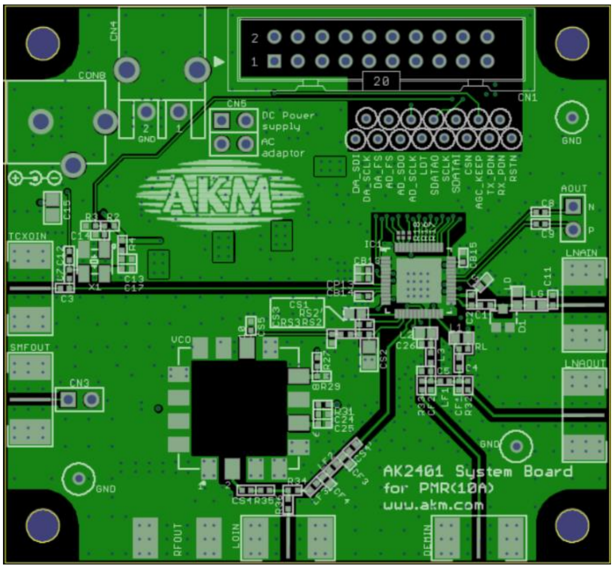


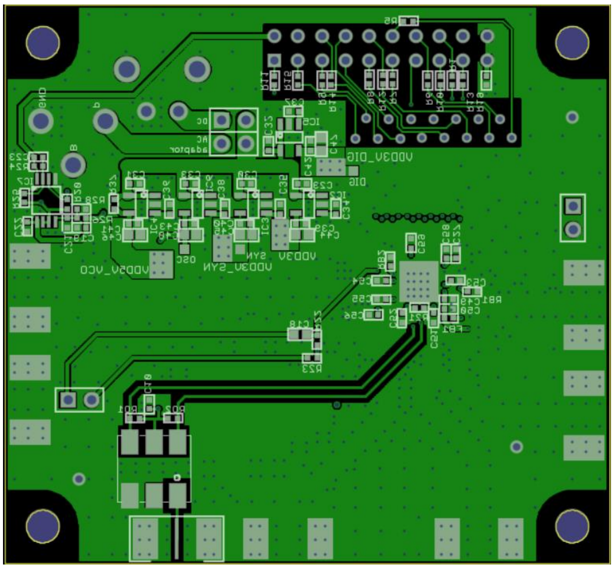
16.4. PCB Design

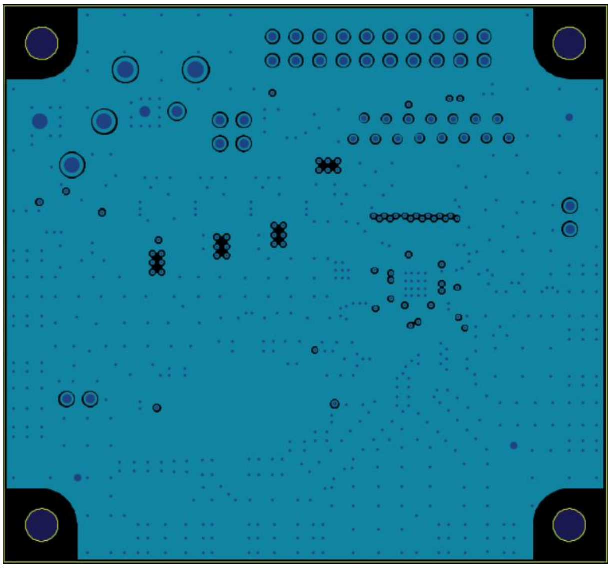
Below are board design guidelines confirmed by the conditions of our evaluation board and do not specify layout pattern of customer's board or guarantee the characteristics.

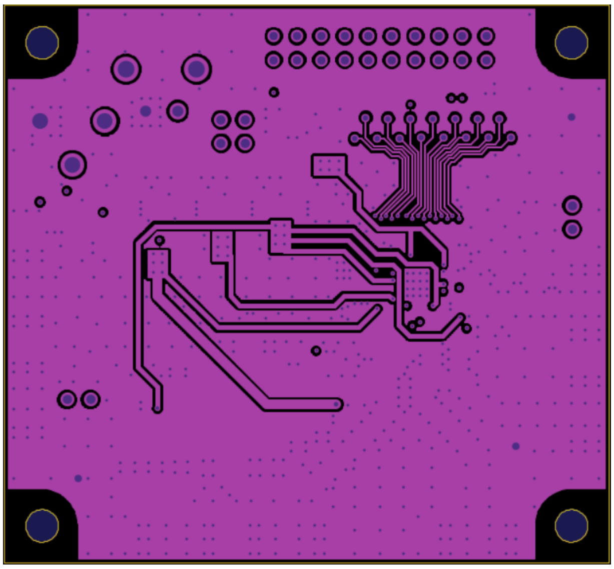
- Connect the exposed pad in the center of the back to the low impedance analog ground. If the exposed pad is not connected, the operation may become unstable.
- The ADC is a 24-bit delta-sigma A/D converter. ADC operation clock is generated by dividing a reference clock that is input to the TCXOIN pin by four. For this reason, since (TCXO/4) MHz and its harmonic components leak to the input part of the LNA, selecting that frequency as the RF frequency causes suppression of receiver sensitivity. Therefore, if customer's RF frequency is equal to multiplied by (TCXO/4) MHz, evaluate its performance with customer's board. On our evaluation board we confirm that the suppression of receiver sensitivity will be relaxed by paying attention to the guidelines described below.
- Each VSS is not separated and connected to the same analog ground.
- Spurious characteristics are improved by short-circuiting the exposed pad and each VSS pin with the TOP layer of the PCB.
- Power supply pins need to be careful not to go around LNA because ADVDD/DVDD is the main spurious source. In addition to connecting a 100pF decoupling capacitor to each power supply pin, 0.01μF is added to LNAVDD and 1μF is added to ADVDD. Be careful with the isolation between the digital signal line of AD_SCLK and the power supply line of LNAVDD.
- Each power supply pin is wired in low impedance from LDO etc. without connecting ferrite beads in series. Improvement of spurious characteristics may be occurring by connecting 1Ω in series only for LNAVDD.
- Spurious characteristics degrade due to high frequency noise of AD_SCLK, AD_SDO, AD_FS pins. Put 100Ω damping resistance in series. Fill the digital signal line in the inner layer.
- Connect decoupling capacitors, especially small capacitance ceramic capacitors as close to AK2401A as possible.
- Use a balun connected to RFOUT_P, RFOUT_N pins depending on the frequency band. Because it is an open collector pin, when using a balun without a center tap, it is necessary to supply the power supply voltage separately through an inductor.
- For VREF1, VREF2 pins capacitor connected to ground, stabilize the internal circuit, connect the specified value.
- All digital input pins must not be allowed to float.

16.5. PCB Layout

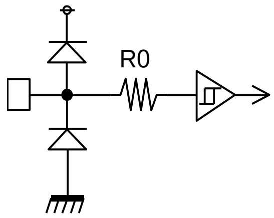
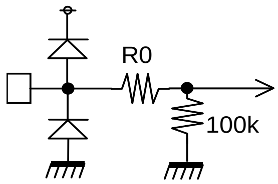
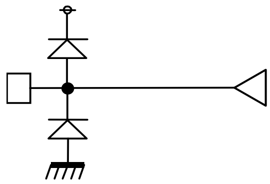
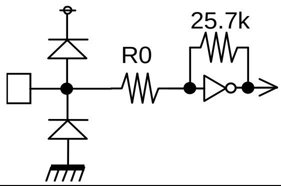
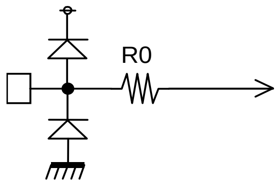
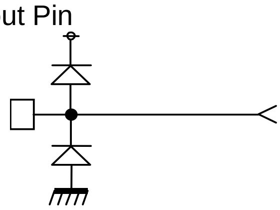
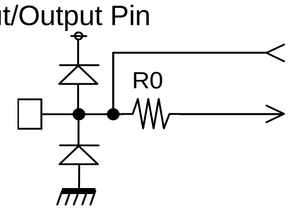


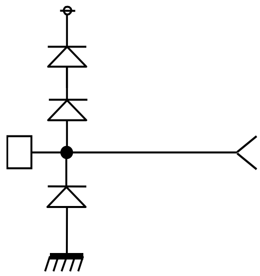
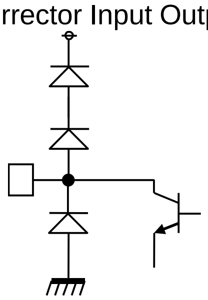
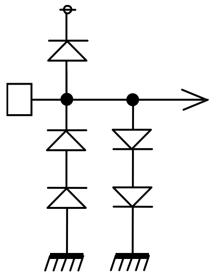
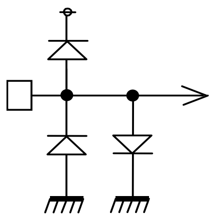
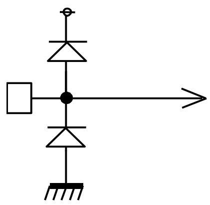






17. LSI Interface Circuit

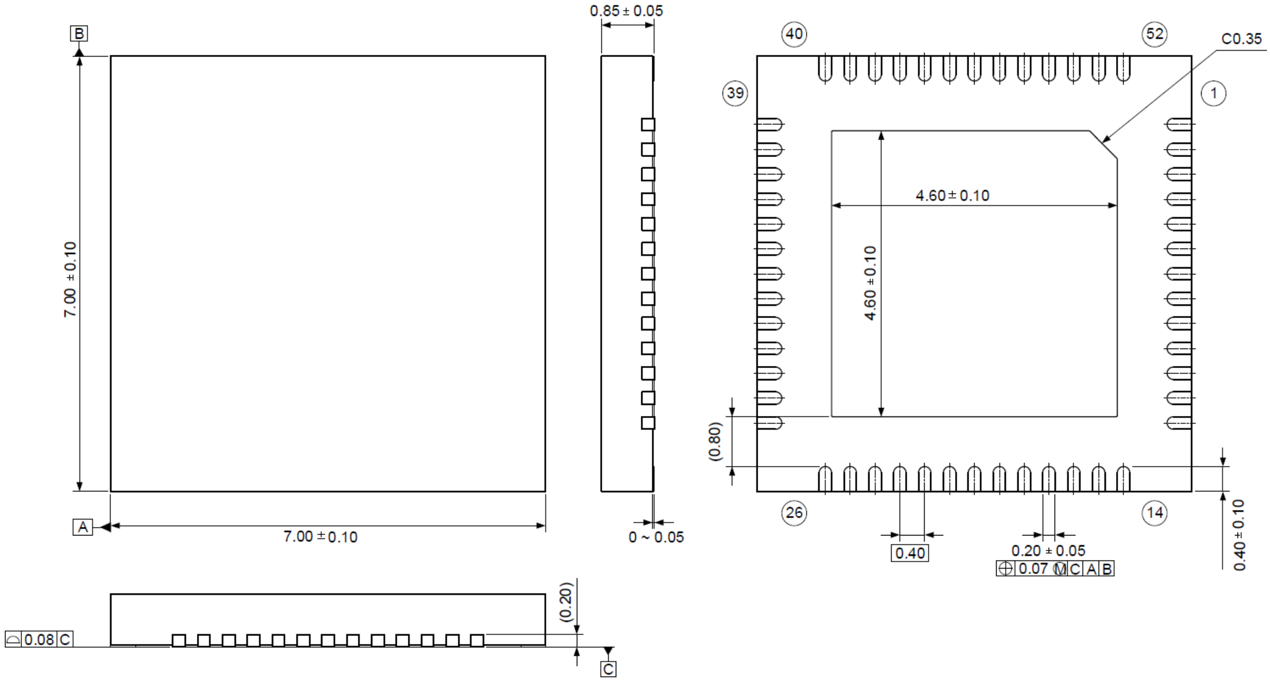
<table>
<tr><th>Pin#</th><th>Name</th><th>I/O</th><th>R0[Ω]</th><th>Function</th></tr>
<tr><td>1</td><td>DA_SCLK</td><td>I</td><td>300</td><td rowspan="10">Digital Input Pin
</td></tr>
<tr><td>3</td><td>DA_SDI</td><td>I</td><td>300</td></tr>
<tr><td>39</td><td>RST_N</td><td>I</td><td>300</td></tr>
<tr><td>40</td><td>RX_PDN</td><td>I</td><td>300</td></tr>
<tr><td>41</td><td>TX_PDN</td><td>I</td><td>300</td></tr>
<tr><td>42</td><td>AGC_KEEP</td><td>I</td><td>300</td></tr>
<tr><td>43</td><td>CSN</td><td>I</td><td>300</td></tr>
<tr><td>44</td><td>SDATAI</td><td>I</td><td>300</td></tr>
<tr><td>45</td><td>SCLK</td><td>I</td><td>300</td></tr>
<tr><td>52</td><td>DA_FS</td><td>I</td><td>300</td></tr>
<tr><td>4</td><td>TEST1</td><td>I</td><td>300</td><td rowspan="2">Digital Input Pin Pull-Down
</td></tr>
<tr><td>35</td><td>TEST2</td><td>I</td><td>300</td></tr>
<tr><td>46</td><td>SDATAO</td><td>O</td><td></td><td rowspan="5">Digital Output Pin
</td></tr>
<tr><td>47</td><td>LD</td><td>O</td><td></td></tr>
<tr><td>49</td><td>AD_SCLK</td><td>O</td><td></td></tr>
<tr><td>50</td><td>AD_SDO</td><td>O</td><td></td></tr>
<tr><td>51</td><td>AD_FS</td><td>O</td><td></td></tr>
<tr><td>9</td><td>TCXOIN</td><td>I</td><td>300</td><td>Analog Input Pin
</td></tr>
<tr><td>38</td><td>VCOM_AD</td><td>I</td><td>300</td><td>Analog Input Pin
</td></tr>
<tr><td>14</td><td>CP</td><td>O</td><td></td><td rowspan="3">Analog Output Pin
</td></tr>
<tr><td>33</td><td>AOUT_P</td><td>O</td><td></td></tr>
<tr><td>34</td><td>AOUT_N</td><td>O</td><td></td></tr>
<tr><td>5</td><td>BIAS2</td><td>I</td><td>300</td><td rowspan="7">Analog Input/Output Pin
</td></tr>
<tr><td>6</td><td>SMFOUT</td><td>O</td><td>300</td></tr>
<tr><td>8</td><td>VREF1</td><td>O</td><td>300</td></tr>
<tr><td>10</td><td>VREF2</td><td>O</td><td>300</td></tr>
<tr><td>15</td><td>SWIN</td><td>I</td><td>300</td></tr>
<tr><td>16</td><td>CPZ</td><td>I</td><td>300</td></tr>
<tr><td>31</td><td>BIAS1</td><td>I</td><td>300</td></tr>
</table>

25	LNAOUT	O		RF Output Pin 
19	RFOUT_P	O		RF Open Corrector Input Output PIN 
20	RFOUT_N	O		
18	LOIN	I		RF Input Pin 
23	DEMIN	I		RF Input Pin 
28	LNAIN	I		RF Input Pin 
29	LNACONT	I		

18. Package

18.1. Outline Dimensions

52-pin QFN (Unit: mm)



*The exposed pad on the bottom surface of the package must be connected to VSS.

18.2. Marking

a: Product number : AK2401A
b: Date code : YYWWTLU (7 digits)
YY : Lower 2 digits of calendar year (Year 2021 -> 21, 2022 -> 22 …)
WW : Week
T : Foundry identification (fixed)
L : Lot identification, given to each product lot which is made in the same week.
LOT ID is given in alphabetical order (A, B, C, …)
U : Assembly location identification (fixed)
c: 1 pin marking : Circle

19. Revision History

Date (Y/M/D)	Revision	Reason	Page	Contents
22/03/09	00	Initial Version		
25/11/10	01	1st version	44	Addition of LD normal operation constraint conditions

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