



DATASHEET

AX8052F143

**SoC Ultra-Low Power RF-
Microcontroller for RF Carrier
Frequencies in the Range 70-
1050 MHz**

Version 1.2a

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1. Overview

1.1. Features

SoC Ultra-low power advanced narrow-band RF-microcontroller for wireless communication applications

- QFN40 package
- Supply range 1.8V - 3.6V
- -40°C to 85°C
- Ultra-low power consumption:
 - CPU active mode 150 μ A/MHz
 - Sleep mode with 256 Byte RAM retention and wake-up timer running 900 nA
 - Sleep mode 4 kByte RAM retention and wake-up timer running 1.5 μ A
 - Sleep mode 8 kByte RAM retention and wake-up timer running 2.2 μ A
 - Radio RX-mode 6.5 mA @ 169 MHz
 - Radio RX-mode 9.5 mA @ 868 MHz
 - Radio TX-mode 8 mA @ 0 dBm, 22 mA @ 10 dBm, 54 mA @ 15 dBm

AX8052

- Ultra-low power MCU core compatible with industry standard 8052 instruction set
- Down to 500 nA wake-up current
- 1 cycle/instruction for many instructions
- 64 kByte in-system programmable FLASH
- Code protection lock
- 8.25 kByte SRAM
- 3-wire (1 dedicated, 2 shared) in-circuit debug interface
- 3 16-bit timers with $\Sigma\Delta$ output capability
- 2 16-bit wakeup timers
- 2 input captures
- 2 output compares with PWM capability
- 10-bit 500 ksample/s analog-to-digital converter
- Temperature sensor
- 2 analog comparators
- 2 UARTs
- 1 general purpose master/slave SPI

- 2 channel DMA controller
- Multi-megabit/s AES encryption/decryption engine, supports AES-128, AES-192 and AES-256¹
- Ultra-low power 10 kHz/640 Hz wakeup oscillator, with automatic calibration against a precise clock
- Internal 20 MHz RC oscillator, with automatic calibration against a precise clock for flexible system clocking
- Low frequency tuning fork crystal oscillator for accurate low power time keeping
- Brown-out and power-on-reset detection

High performance narrow-band RF transceiver compatible to AX5043

- Receiver
 - Carrier frequencies from 70 to 1050 MHz
 - Data rates from 1 kbps to 115.2 kbps
 - High selectivity receiver with up to 43 dB adjacent channel rejection
 - 0 dBm maximum input power
 - Sensitivity down to -126 dBm @ 1.2 kbps
 - +/- 10% data-rate error tolerance
 - Support for antenna diversity with external antenna switch
 - Short preamble modes allow the receiver to work with as little as 16 preamble bits
- Transmitter
 - Data-rates from 1 kbps to 115.2 kbps
 - High efficiency, high linearity integrated power amplifier
 - Power level programmable in 0.5 dB steps from -10 dBm to 15 dBm
 - GFSK shaping with BT=0.3 or BT=0.5

¹ The AES engine requires software enabling and support. For more details please contact exportcontrol@axsem.com.

- Unrestricted power ramp shaping
- **RF Frequency Generation**
 - Configurable for usage in 70 MHz - 1050 MHz bands
 - RF carrier frequency and FSK deviation programmable in 1 Hz steps
 - Ultra fast settling RF frequency synthesizer for low-power consumption
 - Fully integrated RF frequency synthesizer with VCO auto-ranging and band-width boost modes for fast locking
 - Configurable for either fully integrated VCO, internal VCO with external inductor or fully external VCO
 - Configurable for either fully integrated or external synthesizer loop filter for a large range of bandwidths
 - Channel hopping up to 2000 hops/s
 - Automatic frequency control (AFC)
- **Flexible antenna interface**
 - Integrated RX/TX switching with differential antenna pins
 - Mode with differential RX pins and single-ended TX pin for usage with external PAs and for maximum PA efficiency at low output power
- **Wakeup-on-Radio**
 - 640 Hz or 10 kHz lowest power wake-up timer
 - Wake-up time programmable between 98 μ s and 102 s
- **Sophisticated radio controller**
 - Antenna diversity and RX/TX switch control
 - Fully automatic packet reception and transmission without micro-controller intervention
 - Supports HDLC, Raw, Wireless M-Bus frames and arbitrary defined frames
 - Automatic channel noise level tracking
 - μ s resolution timestamps for exact timing (eg. for frequency hopping systems)
 - 256 Byte micro-programmable FIFO, optionally supports packet sizes > 256 Bytes
- 3 matching units for preamble byte, sync-word and address
- Ability to store RSSI, frequency offset and data-rate offset with the packet data
- Multiple receiver parameter sets allow the use of more aggressive receiver parameters during preamble, dramatically shortening the required preamble length at no sensitivity degradation
- **Advanced Crystal Oscillator (RF reference oscillator)**
 - Fast start-up and lowest power steady-state XTAL oscillator for a wide range of crystals
 - Integrated tuning capacitors
 - Possibility of applying an external clock reference (TCXO)

1.2. Applications

70 – 1050 MHz licensed and unlicensed radio systems.

- AMR
- FCC Part 90 6.25 kHz, 12.5 kHz and 25 kHz channel width, FCC Part 15.245, EN 300 220 V2.3.1 including the narrow-band 6.25 kHz, 12.5 kHz, 20 kHz and 25 kHz definitions.
- Security applications
- Messaging / Paging
- Wireless Sensors
- Wireless M-Bus applications according to EN 13757-4

2. Block Diagram

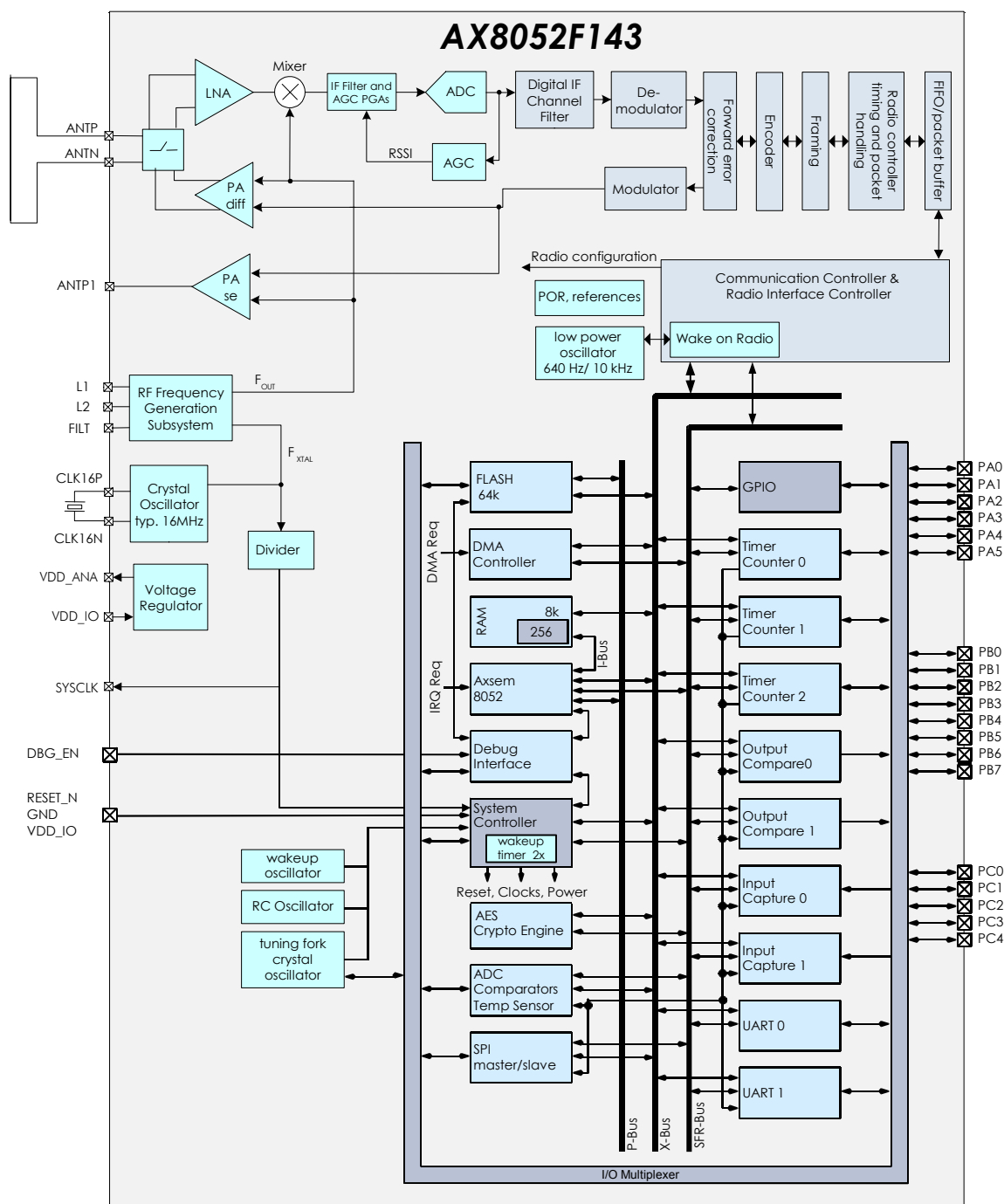


Figure 1 Functional block diagram of the AX8052F143

3. Pin Function Descriptions

Symbol	Pin(s)	Type	Description
VDD_ANA	1	P	Analog power output, decouple to neighboring GND
GND	2	P	Ground, decouple to neighboring VDD_ANA
ANTP	3	A	Differential antenna input/output
ANTN	4	A	Differential antenna input/output
ANTP1	5	A	Single-ended antenna output
GND	6	P	Ground, decouple to neighboring VDD_ANA
VDD_ANA	7	P	Analog power output, decouple to neighboring GND
GND	8	P	Ground
FILT	9	A	Optional synthesizer filter
L2	10	A	Optional synthesizer inductor
L1	11	A	Optional synthesizer inductor
SYSCLK	12	O	System clock output
PC4	13	I/O	General purpose IO
PC3	14	I/O	General purpose IO
PC2	15	I/O	General purpose IO
PC1	16	I/O	General purpose IO
PC0	17	I/O	General purpose IO
PB0	18	I/O	General purpose IO
PB1	19	I/O	General purpose IO
PB2	20	I/O	General purpose IO
PB3	21	I/O	General purpose IO
PB4	22	I/O	General purpose IO
PB5	23	I/O	General purpose IO
PB6	24	I/O	General purpose IO, DBG_DATA
PB7	25	I/O	General purpose IO, DBG_CLK
DBG_EN	26	I	In-circuit debugger enable
RESET_N	27	I	Optional reset pin If this pin is not used it must be connected to VDD_IO
GND	28	P	Ground
VDD_IO	29	P	Unregulated power supply
PA0	30	I/O/A	General purpose IO
PA1	31	I/O/A	General purpose IO
PA2	32	I/O/A	General purpose IO
PA3	33	I/O/A	General purpose IO
PA4	34	I/O/A	General purpose IO
PA5	35	I/O/A	General purpose IO
VDD_IO	36	P	Unregulated power supply
TST1	37	A	Do not connect
TST2	38	A	Do not connect

Symbol	Pin(s)	Type	Description
CLK16N	39	A	Crystal oscillator input/output (RF reference oscillator)
CLK16P	40	A	Crystal oscillator input/output (RF reference oscillator)
GND	Center pad	P	Ground on center pad of QFN, must be connected

A = analog signal

I = digital input signal

O = digital output signal

I/O = digital input/output signal

N = not to be connected

P = power or ground

All digital inputs are Schmitt trigger inputs, digital input and output levels are LVCMOS/LVTTL compatible. Port A Pins (PA0—PA7) must not be driven above VDD_IO, all other digital inputs are 5V tolerant.

3.1. Alternate Pin Functions

GPIO Pins are shared with dedicated Input/Output signals of on-chip peripherals. The following table lists the available functions on each GPIO pin.

GPIO	Alternate Functions				
PA0	T0OUT	IC1	ADC0		
PA1	T0CLK	OC1	ADC1		
PA2	OC0	U1RX	ADC2	COMPI00	
PA3	T1OUT		ADC3	LPXTALP	
PA4	T1CLK	COMPO0	ADC4	LPXTALN	
PA5	IC0	U1TX	ADC5	COMPI10	
PB0	U1TX	IC1	EXTIRQ0		
PB1	U1RX	OC1			
PB2	IC0	T2OUT			PWRAMP
PB3	OC0	T2CLK	EXTIRQ1	DSWAKE	ANTSEL
PB4	U0TX	T1CLK			
PB5	U0RX	T1OUT			
PB6	DBG_DATA				
PB7	DBG_CLK				
PC0	SSEL	T0OUT	EXTIRQ0		
PC1	SSCK	T0CLK	COMPO1		
PC2	SMOSI	U0TX			
PC3	SMISO	U0RX	COMPO0		
PC4	COMPO1	ADCTRIG	EXTIRQ1		

3.2. Pinout Drawing

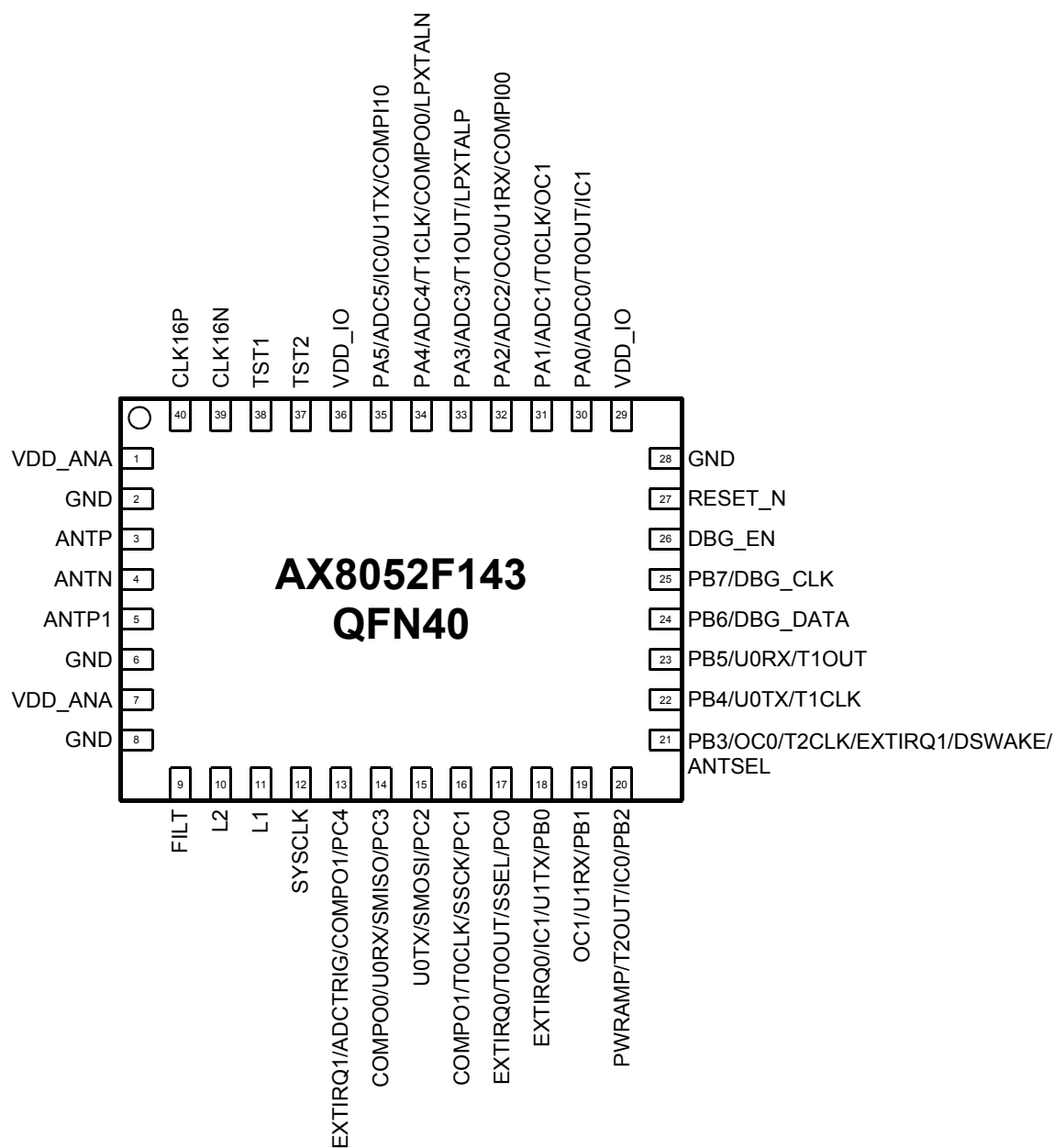


Figure 2: Pinout drawing (Top view)

4. Specifications

4.1. Absolute Maximum Ratings

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device.

This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied.

Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

SYMBOL	DESCRIPTION	CONDITION	MIN	MAX	UNIT
VDD_IO	Supply voltage		-0.5	5.5	V
IDD	Supply current			100	mA
P _{tot}	Total power consumption			800	mW
P _i	Absolute maximum input power at receiver input			15	dBm
I _{I1}	DC current into any pin except ANTP, ANT _N , ANTP1		-10	10	mA
I _{I2}	DC current into pins ANTP, ANT _N , ANTP1		-100	100	mA
I _O	Output Current			40	mA
V _{ia}	Input voltage ANTP, ANT _N , ANTP1 pins		-0.5	5.5	V
	Input voltage digital pins		-0.5	5.5	V
V _{es}	Electrostatic handling	HBM	-2000	2000	V
T _{amb}	Operating temperature		-40	85	°C
T _{stg}	Storage temperature		-65	150	°C
T _j	Junction Temperature			150	°C

4.2. DC Characteristics

Supplies

SYM	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
T _{AMB}	Operational ambient temperature		-40	27	85	°C
V _{IO}	I/O and voltage regulator supply voltage		1.8	3.0	3.6	V
V _{BOUT}	Brown-out threshold	Note 1		1.3		V
I _{DS}	Deep Sleep current			100		nA
I _{SL256P}	Sleep current, 256 Bytes RAM retained	Wakeup from dedicated pin		500		nA
I _{SL256}	Sleep current, 256 Bytes RAM retained	Wakeup Timer running at 640 Hz		900		nA
I _{SL4K}	Sleep current, 4.25 kBytes RAM retained	Wakeup Timer running at 640 Hz		1.5		μA
I _{SL8K}	Sleep current, 8.25 kBytes RAM retained	Wakeup Timer running at 640 Hz		2.2		μA
I _{RX}	Current consumption RX RF frequency generation subsystem: Internal VCO and internal loop-fiter	868 MHz, datarate 6 kbps		9.5		mA
		169 MHz, datarate 6 kbps		6.5		
		868 MHz, datarate 100 kbps		11		
		169 MHz, datarate 100 kbps		7.5		
I _{TX-DIFF}	Current consumption TX differential	868 MHz, 16 dBm, FSK, Note 2, RF frequency generation subsystem: Internal VCO and internal loop-filter Antenna configuration: Differential PA, internal RX/TX switch		51		mA
I _{RX-SE}	Current consumption TX single ended	868 MHz, 0 dBm, FSK, estimated, RF frequency generation subsystem: Internal VCO and internal loop-filter Antenna configuration: Single ended PA, internal RX/TX switching		8		mA
I _{MCU}	Microcontroller running power consumption	All peripherals disabled		150		μA/ MHz
I _{VSUP}	Voltage supervisor	Run and standby mode		85		μA
I _{LPXTAL}	Crystal oscillator current (RF reference oscillator)	16 MHz		160		μA
I _{LFXTAL}	Low frequency crystal oscillator current	32 kHz		700		nA
I _{RCOSC}	Internal oscillator current	20 MHz		210		μA
I _{LPOSC}	Internal Low Power Oscillator current	10 kHz		650		nA
		640 Hz		210		nA
I _{ADC}	ADC current	311 kSample/s, DMA 5 MHz		1.1		mA
I _{WOR}	Typical wake-on-radio duty cycle current	1s, 100 kbps		6		μA

Notes: 1. Digital circuitry is functional down to typically 1 V.
2. Measured with matching network V1.

For information on current consumption in complex modes of operation tailored to your application, see the software AX-RadioLab.

Note on current consumption in TX mode

To achieve best output power the matching network has to be optimized for the desired output power and frequency. As a rule of thumb a good matching network produces about 50% efficiency with the **AX8052F143** power amplifier although over 90% are theoretically possible. A typical matching network has between 1 dB and 2 dB loss (P_{loss}). The theoretical efficiencies are the same for the single ended PA (ANTP1) and differential PA (ANTP and ANTEN) therefore only one current value is shown in the table below. We recommend to use the single ended PA for low output power and the differential PA for high power. The differential PA is multiplexed with the LNA on pins ANTP and ANTEN. Therefore constraints for the RX matching have to be considered for the differential PA matching.

The current consumption can be calculated as

$$I_{TX}[mA] = 1/PA_{efficiency} * 10^{((P_{out}[dBm] + P_{loss}[dB])/10)/1.8V} + I_{offset}$$

I_{offset} is about 6 mA for the fully integrated VCO at 400 MHz to 1050 MHz, and 3 mA for the VCO with external inductor at 169 MHz. The following table shows calculated current consumptions versus output power for $P_{loss} = 1$ dB, $PA_{efficiency} = 0.5$, $I_{offset} = 6$ mA at 868 MHz and $I_{offset} = 3.5$ mA at 169 MHz.

Pout [dBm]	I _{txcalc} [mA]	
	868 MHz	169 MHz
0	7.5	4.5
1	7.9	4.9
2	8.4	5.4
3	9.0	6.0
4	9.8	6.8
5	10.8	7.8
6	12.1	9.1
7	13.7	10.7
8	15.7	12.7
9	18.2	15.2
10	21.3	18.3
11	25.3	22.3
12	30.3	27.3
13	36.7	33.7
14	44.6	41.6
15	54.6	51.6

Both **AX8052F143** power amplifiers run from the regulated VDD_ANA supply and not directly from the battery. This has the advantage that the current and output power do not vary much over supply voltage and temperature.

Logic

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
DIGITAL INPUTS						
V_{T+}	Schmitt trigger low to high threshold point	$V_{DD_IO} = 3.3V$		1.55		V
V_{T-}	Schmitt trigger high to low threshold point			1.25		V
V_{IL}	Input voltage, low				0.8	V
V_{IH}	Input voltage, high		2.0			V
V_{IPA}	Input voltage range, Port A		-0.5		V_{DD_IO}	V
V_{IPBC}	Input voltage range, Ports B, C		-0.5		5.5	V
I_L	Input leakage current		-10		10	μA
R_{PU}	Programmable Pull-Up Resistance			65		$k\Omega$
DIGITAL OUTPUTS						
I_{OH}	Output Current, high Ports PA, PB and PC	$V_{OH} = 2.4V$	8			mA
I_{OL}	Output Current, low Ports PA, PB and PC	$V_{OL} = 0.4V$	8			mA
I_{OH}	Output Current, high Pin SYSCLK	$V_{OH} = 2.4V$	4			mA
I_{OL}	Output Current, low Pin SYSCLK	$V_{OL} = 0.4V$	4			mA
I_{OZ}	Tri-state output leakage current		-10		10	μA

4.3. AC Characteristics

Crystal Oscillator (RF reference oscillator)

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
f_{XTAL}	Crystal or frequency	Note 1, 2	10	16	50	MHz
gm_{osc}	Oscillator transconductance range	Self-regulated see note 3	0.2		20	mS
C_{osc}	Programmable tuning capacitors at pins CLK16N and CLK16P	AX5043_XTALCAP=0x00 default		3		pF
		AX5043_XTALCAP=0x01		8.5		pF
		AX5043_XTALCAP=0xFF		40		pF
$C_{osc-lsb}$	Programmable tuning capacitors, increment per LSB of AX5043_XTALCAP	AX5043_XTALCAP = 0x01 – 0xFF		0.5		pF
f_{ext}	External clock input (TCXO)	Note 4, 5	10	16	50	MHz
RIN_{osc}	Input DC impedance		10			k Ω
$NDIV_{SYSCLK}$	Divider ratio $f_{SYSCLK} = F_{XTAL} / NDIV_{SYSCLK}$		2^0	2^4	2^{10}	

Notes

1. Tolerances and start-up times depend on the crystal used. Depending on the RF frequency and channel spacing the IC must be calibrated to the exact crystal frequency using the readings of the register AX5043_TRKFREQ.
2. The choice of crystal oscillator frequency depends on the targeted regulatory regime for TX, see separate documentation on meeting regulatory requirements.
3. The oscillator transconductance is regulated for fastest start-up time during start-up and for lowest power during steady state oscillation. This means that values depend on the crystal used.
4. If an external clock or TCXO is used, it should be input via an AC coupling at pin CLK16P with the oscillator powered up and AX5043_XTALCAP=000000
5. The choice of crystal oscillator frequency depends on the targeted regulatory regime for TX, see separate documentation on meeting regulatory requirements.

Low-power Oscillator (Transceiver Wake on Radio Clock)

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
$f_{osc-slow}$	Oscillator frequency slow mode LPOS FAST=0 in AX5043_LPOSCONFIG register	No calibration	480	640	800	Hz
		Internal calibration vs. crystal clock has been performed	630	640	650	
$f_{osc-fast}$	Oscillator frequency fast mode LPOS FAST=1 in AX5043_LPOSCONFIG register	No calibration	7.6	10.2	12.8	kHz
		Internal calibration vs. crystal clock has been performed	9.8	10.2	10.8	

RF Frequency Generation Subsystem (Synthesizer)

SYM	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
f _{REF}	Reference frequency		10	16	50	MHz
Dividers						
NDIV _{ref}	Reference divider ratio range	Controlled directly with bits REFDIV in register AX5043_PLLVCODIV	2 ⁰		2 ³	
NDIV _m	Main divider ratio range	Controlled indirectly with register AX5043_FREQ	4.5		66.5	
NDIV _{RF}	RF divider range	Controlled directly with bit RFDIV in register AX5043_PLLVCODIV	1		2	
Charge Pump						
I _{CP}	Charge pump current	Programmable in increments of 8.5 μA via register AX5043_PLLCPI	8.5		2168	μA
Internal VCO (VCOSEL=0)						
f _{RF}	RF frequency range	RFDIV=1	400		525	MHz
		RFDIV=0	800		1050	
f _{step}	RF frequency step	RFDIV=1 f _{REF} = 16.000000 MHz		0.98		Hz
BW	Synthesizer loop bandwidth	The synthesizer loop bandwidth an start-up time can be programmed with the registers AX5043_PLLLOOP and AX5043_PLLCPI. For recommendations see the AX5043 Programming Manual, the AX-RadioLab software and AX5043 Application Notes on compliance with regulatory regimes.	50		500	kHz
T _{start}	Synthesizer start-up time if crystal oscillator and reference are running		5		25	μs
PN868	Synthesizer phase noise 868 MHz f _{REF} = 48 MHz	10 kHz from carrier		-95		dBc/Hz
		1 MHz from carrier		-120		
PN433	Synthesizer phase noise 433 MHz f _{REF} = 48 MHz	10 kHz from carrier		-105		dBc/Hz
		1 MHz from carrier		-120		
VCO with external inductors (VCOSEL=1, VCO2INT=1)						
f _{RFmg_lo}	RF frequency range	RFDIV=1	70		262	MHz
f _{RFmg_hi}	For choice of L _{ext} values as well as VCO gains see Figure 3 and Figure 4	RFDIV=0	140		525	
PN169	Synthesizer phase noise 169 MHz L _{ext} =47 nH (wire wound 0603) AX5043_RFDIV=0, f _{REF} = 16 MHz Note: phase noises can be improved with higher f _{REF}	10 kHz from carrier		-97		dBc/Hz
		1 MHz from carrier		-115		
External VCO (VCOSEL=1, VCO2INT=0)						
f _{RF}	RF frequency range fully external VCO	Note: The external VCO frequency needs to be 2xf _{RF}	70		1000	MHz
V _{amp}	Differential input amplitude at L1, L2 terminals			0.7		V
V _{inL}	Input voltage levels at L1, L2 terminals		0		1.8	V
V _{ctrl}	Control voltage range	Available at FILT in external loop filter mode	0		1.8	V

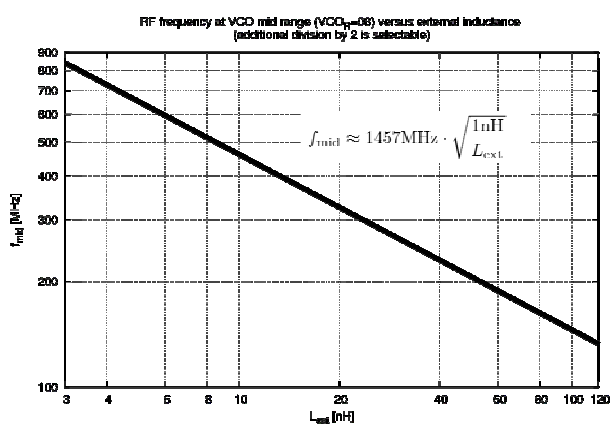


Figure 3 VCO with external inductors: frequency vs L_{ext}

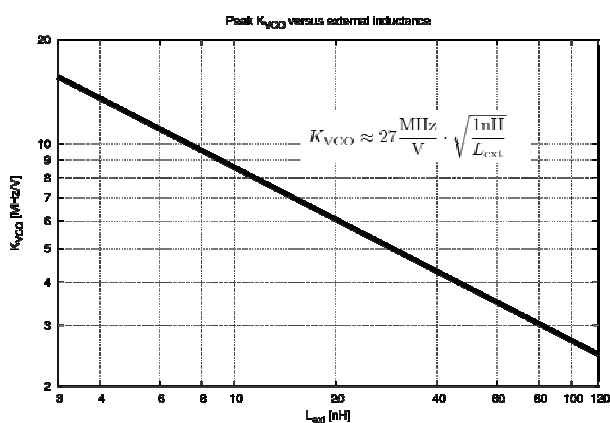


Figure 4 VCO with external inductors: K_{VCO} vs L_{ext}

The following table shows the typical frequency ranges for frequency synthesis with external VCO inductor for different inductor values.

Lext [nH]	Freq [MHz]		PLL Range
	RFDIV=0	RFDIV = 1	
8.2	482	241	0
8.2	437	219	15
10	432	216	0
10	390	195	15
12	415	208	0
12	377	189	15
15	380	190	0
15	345	173	15
18	345	173	0
18	313	157	15
22	308	154	0
22	280	140	14
27	285	143	0
27	258	129	15
33	260	130	0
33	235	118	15
39	245	123	0
39	223	112	14
47	212	106	0
47	194	97	14
56	201	101	0
56	182	91	15
68	178	89	0
68	161	81	15
82	160	80	1
82	146	73	14
100	149	75	1
100	136	68	14
120	136	68	0
120	124	62	14

For tuning or changing of ranges a capacitor can be added in parallel to the inductor.

Transmitter

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
SBR	Signal bit rate		1		115.2	kbps
PTX ₈₆₈	Transmitter power @ 868 MHz		-10		15	dBm
PTX _{868-step}	Programming step size output power	Note 1			0.5	dB
dTX _{temp}	Transmitter power variation vs. temperature	-40 °C to +85 °C Note 2		+/- 0.5		dB
dTX _{Vdd}	Transmitter power variation vs. VDD_IO	1.8 to 3.6 V Note 2		+/- 0.5		dB
Padj	Adjacent channel power GFSK BT=0.5, 500 Hz deviation, 1.2 kbps, 25 kHz channel spacing, 10 kHz channel BW	868 MHz		-44		dBc
		433 MHz		-51		
PTX _{868-harm2}	Emission @ 2 nd harmonic	868 MHz, Note 2		-40		dBc
PTX _{868-harm3}	Emission @ 3 rd harmonic			-60		
PTX _{433-harm2}	Emission @ 2 nd harmonic	433 MHz, Note 2		-40		dBc
PTX _{433-harm3}	Emission @ 3 rd harmonic			-40		

Notes

- $$P_{out} = \frac{AX5043_TXPWR_COEF \cdot B}{2^{l^2} - 1} \cdot P_{max}$$
- Additional low-pass filtering was applied to the antenna interface, see Applications section.

Receiver

SYM	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
SBR	Signal bit rate		1		115.2	kbps
IS _{BER868}	Input sensitivity at BER = 10 ⁻³ for 868 MHz operation, continuous data	FSK, h = 0.5, 100 kbps		-105		dBm
		FSK, h = 0.5, 10 kbps		-116		
		FSK, 500 Hz deviation, 1.2 kbps		-126		
IS _{PER868}	Input sensitivity at PER = 1% for 868 MHz operation, 144 bit packet data	FSK, h = 0.5, 100 kbps		-103		dBm
		FSK, h = 0.5, 10 kbps		-115		
		FSK, 500 Hz deviation, 1.2 kbps		-125		
IS _{WOR868}	Input sensitivity at PER = 1% for 868 MHz operation, WOR-mode	FSK, h = 0.5, 100 kbps		-102		dBm
IL	Maximum input level				10	dBm
CP _{1dB}	Input referred compression point	2 tones separated by 100 kHz		-35		dBm
RSSIR	RSSI control range	FSK, 500 Hz deviation, 1.2 kbps	-126		-36	dB
RSSIS ₁	RSSI step size	Before digital channel filter; calculated from register AX5043_AGCCOUNTER		0.625		dB
RSSIS ₂	RSSI step size	Behind digital channel filter; calculated from registers AX5043_AGCCOUNTER, AX5043_TRKAMPL		0.1		dB
RSSIS ₃	RSSI step size	Behind digital channel filter; reading register AX5043_RSSI		1		dB
SEL ₈₆₈	Adjacent channel suppression	FSK 4.8 kbps, h = 0.5, 25 kHz channels Note 1		40		dB
BLK ₈₆₈	Blocking at +/- 10MHz offset	Note 2		78		dB
R _{AFC}	AFC pull-in range	The AFC pull-in range can be programmed with the AX5043_MAXRFOFFSET registers. The AFC response time can be programmed with the AX5043_FREQGAIN register.	+/- 15			%
R _{DROFF}	Bitrate offset pull-in range	The bitrate pull-in range can be programmed with the AX5043_MAXDROFFSET registers.	+/- 10			%

Notes

1. Interferer/Channel @ BER = 10⁻³, channel level is +3 dB above the typical sensitivity, the interfering signal is CW; channel signal is modulated with shaping
2. Channel/Blocker @ BER = 10⁻³, channel level is +3 dB above the typical sensitivity, the blocker signal is CW; channel signal is modulated with shaping

Low Frequency Crystal Oscillator

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
f_{LPXTAL}	Crystal frequency			32	150	kHz
$gm_{I_{pxosc}}$	Transconductance oscillator	LPXOSCGM=00110		3.5		μS
		LPXOSCGM=01000		4.6		
		LPXOSCGM=01100		6.9		
		LPXOSCGM=10000		9.1		
$RIN_{I_{pxosc}}$	Input DC impedance		10			$M\Omega$

Internal Low Power Oscillator

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
f_{LPOSC}	Oscillation Frequency	LPOSCFAST=0 Factory calibration applied. Over the full temperature and voltage range	630	640	650	Hz
		LPOSCFAST=1 Factory calibration applied Over the full temperature and voltage range	10.08	10.24	10.39	kHz

Internal RC Oscillator

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
F_{FRCOSC}	Oscillation Frequency	Factory calibration applied. Over the full temperature and voltage range	19.8	20	20.2	MHz

Microcontroller

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
T_{SYSCLKL}	SYSCLK Low		27			ns
T_{SYSCLKH}	SYSCLK High		21			ns
T_{SYSCLKP}	SYSCLK Period		47			ns
T_{FLWR}	FLASH Write Time	2 Bytes		20		μs
T_{FLPE}	FLASH Page Erase	1 kBytes		2		ms
T_{FLE}	FLASH Secure Erase	64 kBytes		10		ms
T_{FLEND}	FLASH Endurance: Erase Cycles		10 000	100 000		Cycles
$T_{\text{FLRETRoom}}$	FLASH Data Retention	25°C See Figure 5 for the lower limit set by the memory qualification	100			Years
T_{FLREThot}		85°C See Figure 5 for the lower limit set by the memory qualification	10			

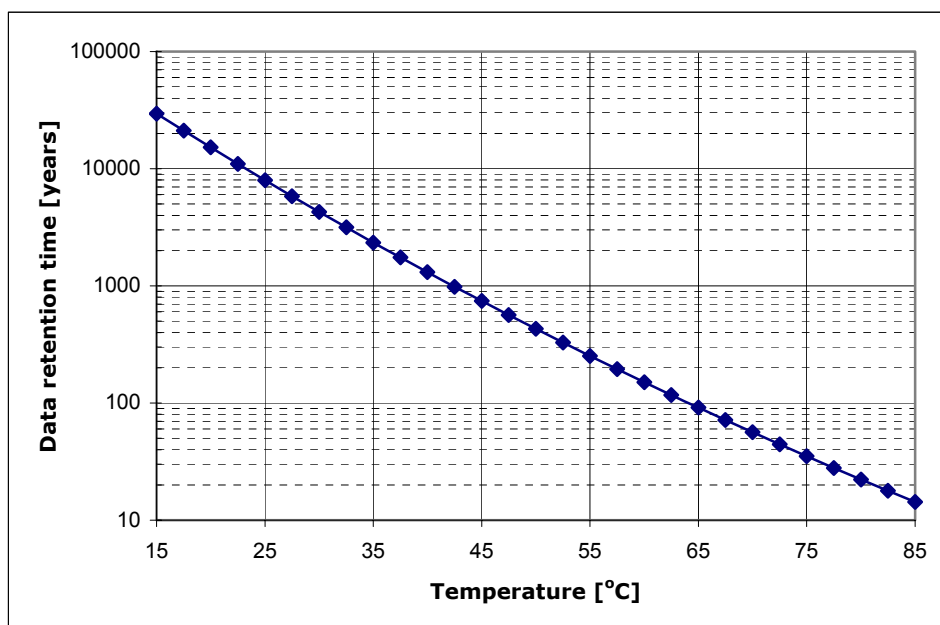


Figure 5 FLASH memory qualification limit for data retention after 10k erase cycles

ADC / Comparator / Temperature Sensor

SYMBOL	DESCRIPTION	CONDITION	MIN	TYP	MAX	UNIT
ADCSR	ADC sampling rate GPADC mode		30		500	kHz
ADCSR_T	ADC sampling rate temperature sensor mode		10	15.6	30	kHz
ADCRES	ADC resolution			10		Bits
V _{ADCREF}	ADC reference voltage & comparator internal reference voltage		0.95	1	1.05	V
Z _{ADC00}	Input capacitance				2.5	pF
DNL	Differential nonlinearity				+/- 1	LSB
INL	Integral non inearity			+/- 1		LSB
OFF	Offset			3		LSB
GAIN_ERR	Gain error			0.8		%
ADC in Differential Mode						
V _{ABS_DIFF}	Absolute voltages & common mode voltage in differential mode at each input		0		VDD_IO	V
V _{FS_DIFF01}	Full swing input for differential signals	Gain x1	-500		500	mV
V _{FS_DIFF10}		Gain x10	-50		50	mV
ADC in Single Ended Mode						
V _{MID_SE}	Mid code input voltage in single ended mode			0.5		V
V _{IN_SE00}	Input voltage in single ended mode		0		VDD_IO	V
V _{FS_SE01}	Full swing input for single ended signals	Gain x1	0		1	V
Comparators						
V _{COMP_ABS}	Comparator absolute input voltage		0		VDD_IO	V
V _{COMP_COM}	Comparator input common mode		0		VDD_IO-0.8	V
V _{COMPOFF}	Comparator input offset voltage				20	mV
Temperature Sensor						
TRNG	Temperature range		-40		85	°C
TRES	Temperature resolution			0.1607		°C/LSB
T _{ERR_CAL}	Temperature	Factory calibration applied	-2		+2	°C

5. Circuit Description

The **AX8052F143** is a true single chip narrow-band, ultra-low power RF-microcontroller SoC for use in licensed and unlicensed bands ranging from 70 MHz to 1050 MHz. The on-chip transceiver consists of a fully integrated RF front-end with modulator and demodulator. Base band data processing is implemented in an advanced and flexible communication controller that enables user friendly communication.

The **AX8052F143** contains a high speed microcontroller compatible to the industry standard 8052 instruction set. It contains 64 kBytes of FLASH and 8.25 kBytes of internal SRAM.

The **AX8052F143** features 3 16-bit general purpose timers with $\Sigma\Delta$ capability, 2 output compare units for generating PWM signals, 2 input compare units to record timings of external signals, 2 16-bit wakeup timers, a watchdog timer, 2 UARTs, a Master/Slave SPI controller, a 10-bit 500 kSample/s A/D converter, 2 analog comparators, a temperature sensor, a 2 channel DMA controller, and a dedicated AES crypto controller. Debugging is aided by a dedicated hardware debug interface controller that connects using a 3-wire protocol (1 dedicated wire, 2 shared with GPIO) to the PC hosting the debug software.

While the radio carrier/LO synthesizer can only be clocked by the crystal oscillator (carrier stability requirements dictate a high stability reference clock in the MHz range), the microcontroller and its peripherals provide extremely flexible clocking options. The system clock that clocks the microcontroller, as well as peripheral clocks, can be selected from one of the following clock sources: the crystal oscillator, an internal high speed 20MHz oscillator, an internal low speed 640 Hz/10 kHz oscillator, or the low frequency crystal oscillator. Prescalers offer additional flexibility with their programmable divide by a power of two capability. To improve the accuracy of the internal oscillators, both oscillators may be slaved to the crystal oscillator.

AX8052F143 can be operated from a 1.8 V to 3.6 V power supply over a temperature range of -40°C to 85°C , it consumes 7 - 51 mA for transmitting, depending on the output power, 9 - 11 mA for receiving.

The **AX8052F143** features make it an ideal interface for integration into various battery powered solutions such as ticketing or as transceiver for telemetric applications e.g. in sensors. As primary application, the transceiver is intended for UHF radio equipment in accordance with the European Telecommunication Standard Institute (ETSI) specification EN 300 220-1 and the US Federal Communications Commission (FCC) standard Title 47 CFR part 15 as well as Part 90. Additionally **AX8052F143** is suited for systems targeting compliance with Wireless M-Bus standard EN 13757-4:2005. Wireless M-Bus frame support (S, T, R) is built-in.

The **AX8052F143** sends and receives data in frames. This standard operation mode is called Frame Mode. Pre and post ambles as well as checksums can be generated automatically.

AX8052F143 supports any data rate from 1 kbps to 115.2 kbps for FSK, MSK, 4-FSK, GFSK, GMSK and ASK modulations. To achieve optimum performance for specific data rates and modulation schemes several register settings to configure the **AX8052F143** are necessary, they are outlined in the following, for details see the AXSEM RadioLab software which calculates the necessary register settings and the AX5043 Programming Manual.

The receiver supports multi-channel operation for all data rates and modulation schemes.

5.1. Microcontroller

The AX8052 microcontroller core executes the industry standard 8052 instruction set. Unlike the original 8052, many instructions are executed in a single cycle. The system clock and thus the instruction rate can be programmed freely from DC to 20MHz.

Memory Architecture

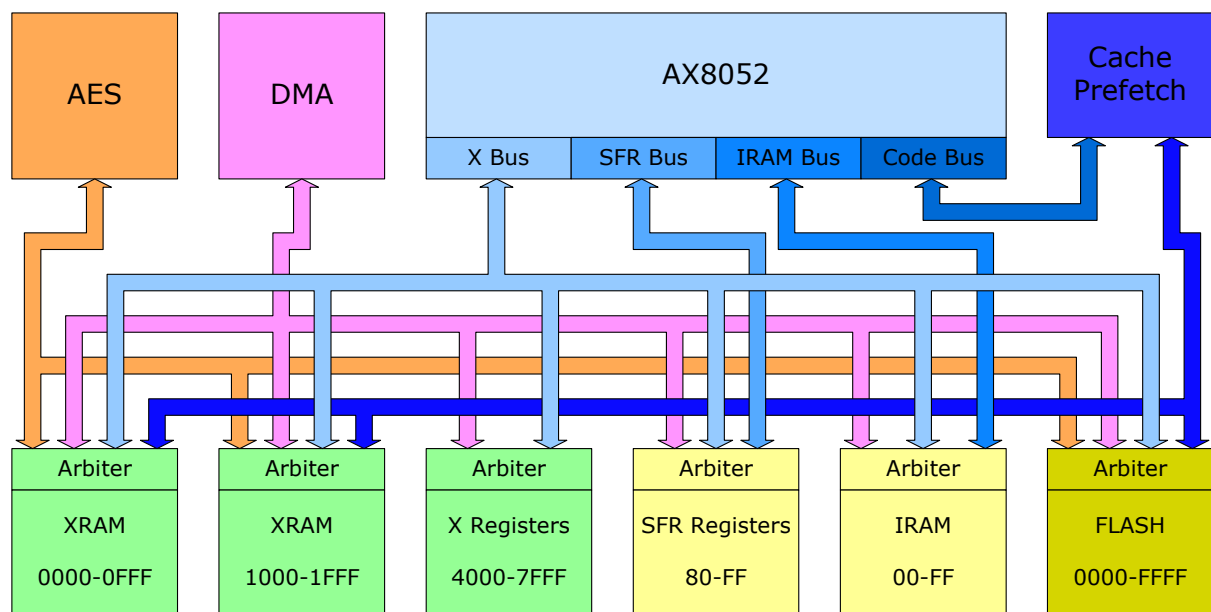


Figure 6 AX8052 Memory Architecture

The **AX8052F143** Microcontroller features the highest bandwidth memory architecture of its class. Figure 6 shows the memory architecture. Three bus masters may initiate bus cycles:

- The AX8052 Microcontroller Core
- The Direct Memory Access (DMA) Engine
- The Advanced Encryption Standard (AES) Engine

Bus targets include:

- Two individual 4 kBytes RAM blocks located in X address space, which can be simultaneously accessed and individually shut down or retained during sleep mode
- A 256 Byte RAM located in internal address space, which is always retained during sleep mode
- A 64 kBytes FLASH memory located in code space.
- Special Function Registers (SFR) located in internal address space accessible using direct address mode instructions
- Additional Registers located in X address space (X Registers)

The upper half of the FLASH memory may also be accessed through the X address space. This simplifies and makes the software more efficient by reducing the need for generic pointers².

SFR Registers are also accessible through X address space, enabling indirect access to SFR registers. This allows driver code for multiple identical peripherals (such as UARTs or Timers) to be shared.

The 4 word × 16 bit fully associative cache and a pre-fetch controller hide the latency of the FLASH.

The AX8052 Memory Architecture is fully parallel. All bus masters may simultaneously access different bus targets during each system clock cycle. Each bus target includes an arbiter that resolves access conflicts. Each arbiter ensures that no bus master can be starved.

Both 4 kBytes RAM blocks may be individually retained or switched off during sleep mode. The 256 Byte RAM is always retained during sleep mode.

The AES engine accesses memory 16 bits at a time. It is therefore slightly faster to align its buffers on even addresses.

Memory Map

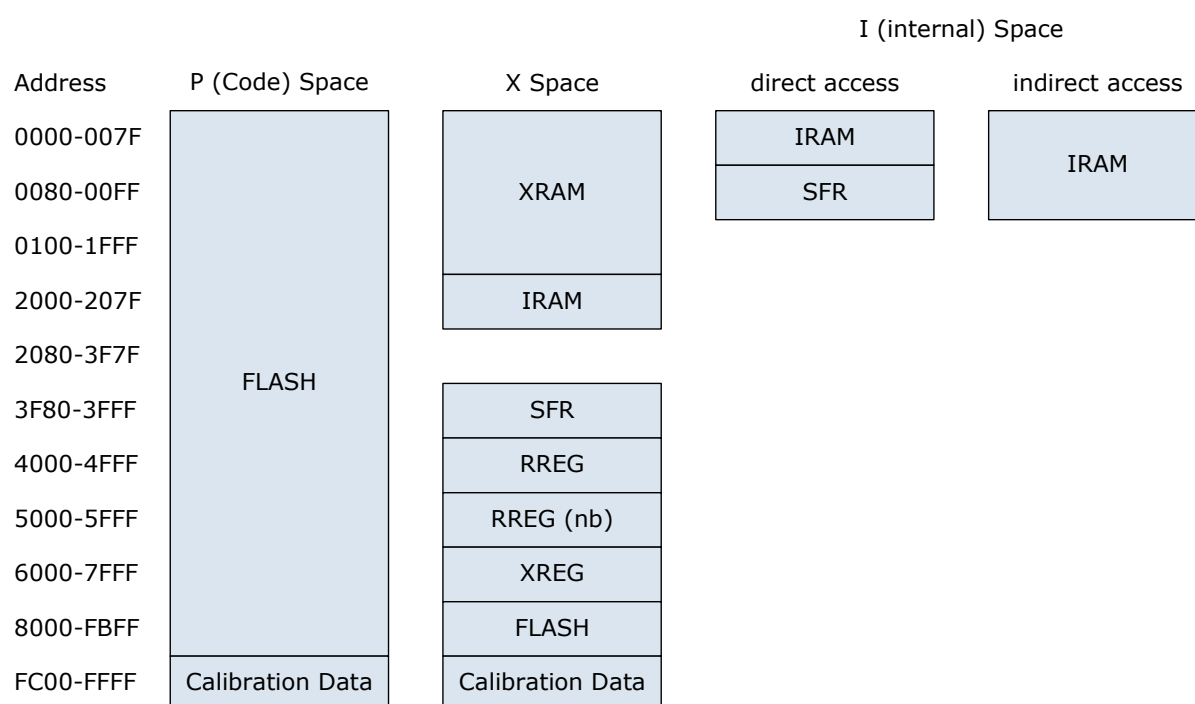


Figure 7 AX8052 Memory Map

The AX8052, like the other industry standard 8052 compatible microcontrollers, uses a Harvard architecture. Multiple address spaces are used to access code and data. Figure 7 shows the AX8052 memory map.

² Generic pointers include, in addition to the address, an address space tag.

The AX8052 uses P or Code Space to access its program. Code space may also be read using the MOVC instruction.

Smaller amounts of data can be placed in the Internal³ or Data Space. A distinction is made in the upper half of the Data Space between direct accesses (MOV reg,addr; MOV addr,reg) and indirect accesses (MOV reg,@Ri; MOV @Ri,reg; PUSH; POP); Direct accesses are routed to the Special Function Registers, while indirect accesses are routed to the internal RAM.

Large amounts of data can be placed in the External or X Space. It can be accessed using the MOVX instructions. Special Function Registers, as well as additional Microcontroller Registers (XREG) and the Radio Registers (RREG) are also mapped into the X Space.

Detailed documentation of the Special Function Registers (SFR) and additional Microcontroller Registers can be found in the AX8052 Programming Manual.

The Radio Registers are documented in the AX5043 Programming Manual. Register Addresses given in the AX5043 Programming Manual are relative to the beginning of RREG, i.e. 0x4000 must be added to these addresses. It is recommended that the AXSEM provided ax8052f143.h header file is used; Radio Registers are prefixed with AX5043_ in the ax8052f143.h header file to avoid clashes of same-name Radio Registers with AX8052 registers.

Normally, accessing Radio Registers through the RREG address range is adequate. Since Radio Register accesses have a higher latency than other AX8052 registers, the AX8052 provides a method for non-blocking access to the Radio Registers. Accessing the RREG (nb) address range initiates a Radio Register access, but does not wait for its completion. The details of mechanism is documented in the Radio Interface section of the AX8052 Programming Manual.

The FLASH memory is organized as 64 pages of 1 kBytes each. Each page can be individually erased. The write word size is 16 Bits. The last 1 kByte page is dedicated to factory calibration data and should not be overwritten.

³ The origin of Internal versus External (X) Space is historical. External Space used to be outside of the chip on the original 8052 Microcontrollers.

Power Management

The microcontroller power mode can be selected independently from the transceiver. The microcontroller supports the following power modes:

PCON register	Name	Description
00	RUNNING	The microcontroller and all peripherals are running. Current consumption depends on the system clock frequency and the enabled peripherals and their clock frequency.
01	STANDBY	The microcontroller is stopped. All register and memory contents are retained. All peripherals continue to function normally. Current consumption is determined by the enabled peripherals. STANDBY is exited when any of the enabled interrupts become active.
10	SLEEP	The microcontroller and its peripherals, except GPIO and the system controller, are shut down. Their register settings are lost. The internal RAM is retained. The external RAM is split into two 4kByte blocks. Software can determine individually for both blocks whether contents of that block are to be retained or lost. SLEEP can be exited by any of the enabled GPIO or system controller interrupts. For most applications this will be a GPIO or wakeup timer interrupt.
11	DEEPSLEEP	The microcontroller, all peripherals and the transceiver are shut down. Only 4 bytes of scratch RAM are retained. DEEPSLEEP can only be exited by tying the PB3 pin low.

Clocking

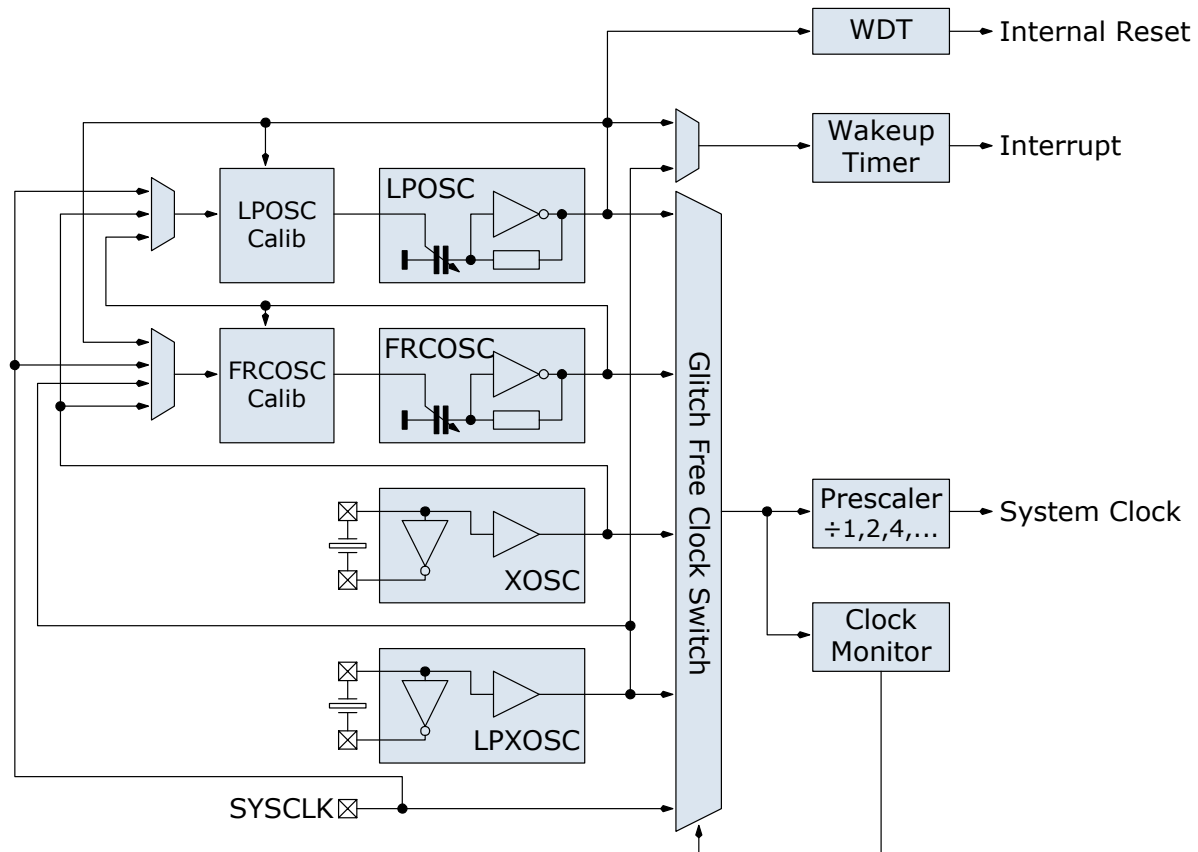


Figure 8 Clock System Diagram

The system clock can be derived from any of the following clock sources:

- The crystal oscillator (RF reference oscillator, typically 16 MHz, via SYSCLK)
- The low speed crystal oscillator (typical 32 kHz tuning fork)
- The internal high speed RC (20 MHz) oscillator
- The internal low power (640 Hz/10 kHz) oscillator

An additional pre-scaler allows the selected oscillator to be divided by a power of two. After reset, the microcontroller starts with the internal high speed RC oscillator selected and divided by two. I.e. at start-up, the microcontroller runs with $10 \text{ MHz} \pm 10\%$. Clocks may be switched any time by writing to the **CLKCON** register. In order to prevent clock glitches, the switching takes approximately $2 \cdot (T_1 + T_2)$, where T_1 and T_2 are the periods of the old and the new clock. Switching may take longer if the new oscillator first has to start up. Internal oscillators start up instantaneously, but crystal oscillators may take a considerable amount of time to start the oscillation. **CLKSTAT** can be read to determine the clock switching status.

A programmable clock monitor resets the **CLKCON** register when no system clock transitions are found during a programmable time interval, thus reverts to the internal RC oscillator.

Both internal oscillators can be slaved to one of the crystal oscillators to increase the accuracy of the oscillation frequency. While the reference oscillator runs, the internal oscillator is slaved to the reference frequency by a digital frequency locked loop. When the reference oscillator is switched off, the internal oscillator continues to run unslaved with the last frequency setting.

Reset and Interrupts

After reset, the microcontroller starts executing at address 0x0000. Several events can lead to resetting the microcontroller core:

- POR or hardware RESET_N pin activated and released
- Leaving SLEEP or DEEPSLEEP mode
- Watchdog Reset
- Software Reset

The reset cause can be determined by reading the **PCON** register.

The microcontroller supports 22 interrupt sources. Each interrupt can be individually enabled and can be programmed to have one of two possible priorities. The interrupt vectors are located at 0x0003, 0x000B, ..., 0x00AB.

Debugging

A hardware debug unit considerably eases debugging compared to other 8052 microcontrollers. It allows to reliably stop the microcontroller at breakpoints even if the stack is smashed. The debug unit communicates with the host PC running the debugger using a 3 wire interface. One wire is dedicated (DBG_EN), while two wires are shared with GPIO pins (PB6, PB7). When DBG_EN is driven high, PB6 and PB7 convert to debug interface pins and the GPIO functionality is no longer available. A pin emulation feature however allows bits PINB[7:6] to be set and PORTB[7:6] and DIRB[7:6] to be read by the debugger software. This allows for example switches or LEDs connected to the PB6, PB7 pins to be emulated in the debugger software whenever the debugger is active.

In order to protect the intellectual property of the firmware developer, the debug interface can be locked using a developer-selectable 64-bit key. The debug interface is then disabled and can only be enabled with the knowledge of this 64-bit key. Therefore, unauthorized persons cannot read the firmware through the debug interface, but debugging is still possible for authorized persons. Secure erase can be initiated without key knowledge; secure erase ensures that the main FLASH array is completely erased before erasing the key, reverting the chip into factory state.

The DebugLink peripheral looks like an UART to the microcontroller, and allows exchange of data between the microcontroller and the host PC without disrupting program execution.

5.2. Timer, Output Compare and Input Capture

The **AX8052F143** features three general purpose 16-bit timers. Each timer can be clocked by the system clock, any of the available oscillators, or a dedicated input pin. The timers also feature a programmable clock inversion, a programmable prescaler that can divide by powers of two, and an optional clock synchronization logic that synchronizes the clock to the system clock. All three counters are identical and feature four different counting modes, as well as a $\Sigma\Delta$ mode that can be used to output an analog value on a dedicated digital pin only employing a simple RC lowpass filter.

Two output compare units work in conjunction with one of the timers to generate PWM signals.

Two input capture units work in conjunction with one of the timers to measure transitions on an input signal.

For software timekeeping, two additional 16-bit wakeup timers with 4 16-bit event registers are provided, generating an interrupt on match events.

5.3. UART

The **AX8052F143** features two universal asynchronous receiver transmitters. They use one of the timers as baud rate generator. Word length can be programmed from 5 to 9 bits.

5.4. SPI Master/Slave Controller

The **AX8052F143** features a master/slave SPI controller. Both 3 and 4 wire SPI variants are supported. In master mode, any of the on-chip oscillators or the system clock may be selected as clock source. An additional prescaler with divide by two capability provides additional clocking flexibility. Shift direction, as well as clock phase and inversion, are programmable.

5.5. ADC, Analog Comparators and Temperature Sensor

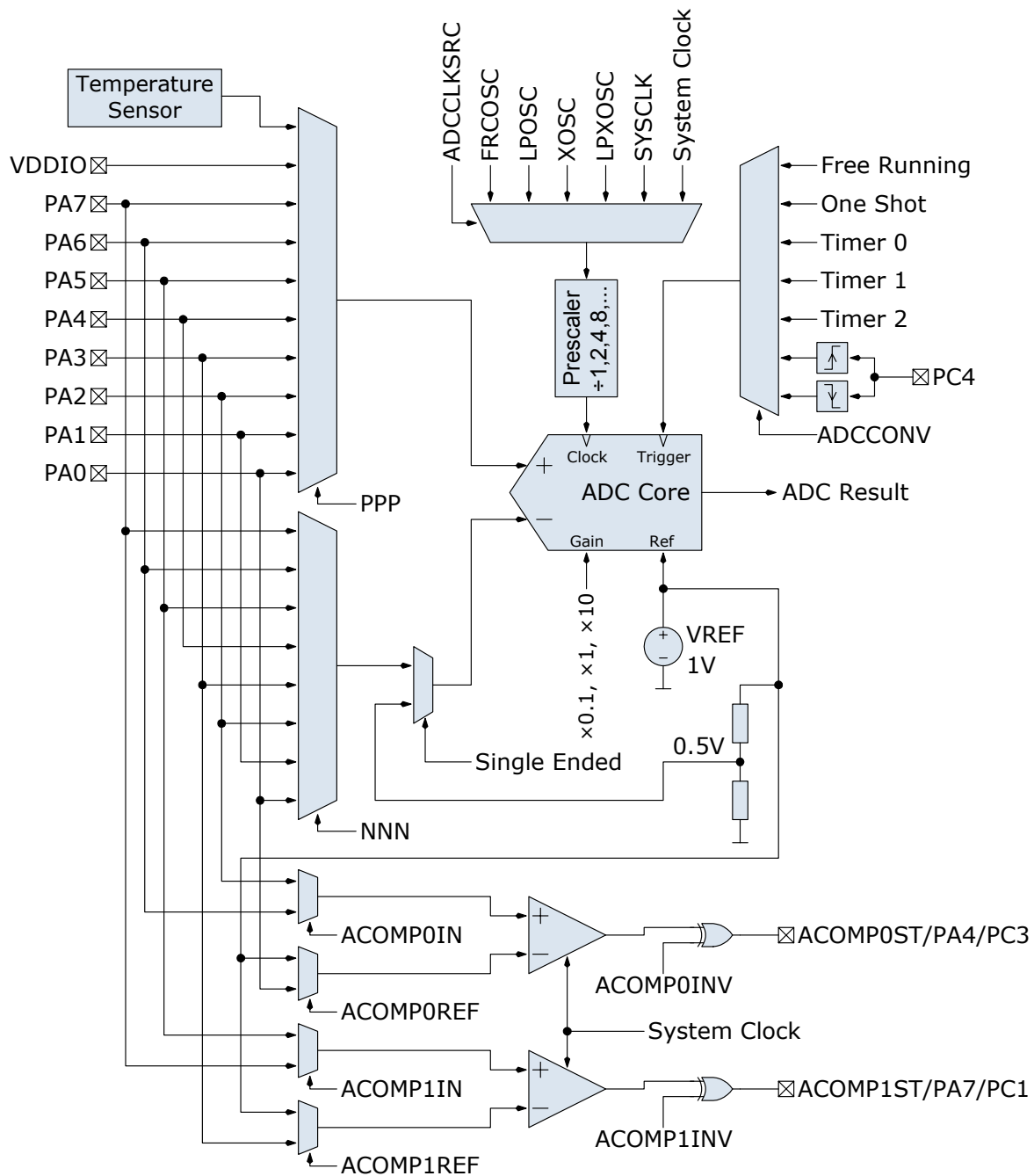


Figure 9 ADC Block Diagram

The **AX8052F143** features a 10-bit, 500 kSample/s Analog to Digital converter. Figure 9 shows the block diagram of the ADC. The ADC supports both single ended and differential measurements. It uses an internal reference of 1 V. $\times 1$, $\times 10$ and $\times 0.1$ gain modes are provided. The ADC may digitize signals on PA0...PA7, as well as VDD_IO and an internal temperature sensor. The user can define four channels which are then converted sequentially and stored in four separate result registers. Each channel configuration consists of the multiplexer and the gain setting.

The **AX8052F143** contains an on-chip temperature sensor. Built-in calibration logic allows the temperature sensor to be calibrated in °C, °F or any other user defined temperature scale.

The **AX8052F143** also features two analog comparators. Each comparator can either compare two voltages on dedicated PA pins, or one voltage against the internal 1V reference. The comparator output can be routed to a dedicated digital output pin or can be read by software. The comparators are clocked with the system clock.

5.6. DMA Controller

The **AX8052F143** features a dual channel DMA engine. Each DMA channel can either transfer data from XRAM to almost any peripheral on chip, or from almost any peripheral to XRAM. Both channels may also be cross-linked for memory-memory transfers. The DMA channels use buffer descriptors to find the buffers where data is to be retrieved or placed, thus enabling very flexible buffering strategies.

The DMA channels access XRAM in a cycle steal fashion. They access XRAM whenever XRAM is not used by the microcontroller. Their priority is lower than the microcontroller, thus interfering very little with the microcontroller. Additional logic prevents starvation of the DMA controller.

5.7. AES Engine

The **AX8052F143** contains a dedicated engine for the government mandated Advanced Encryption Standard (AES). It features a dedicated DMA engine and reads input data as well as key stream data from the XRAM, and writes output data into a programmable buffer in the XRAM. The round number is programmable; the chip therefore supports AES-128, AES-192, and AES-256, as well as higher security proprietary variants. Keystream (key expansion) is performed in software, adding to the flexibility of the AES engine. ECB (electronic codebook), CFB (cipher feedback) and OFB (output feedback) modes are directly supported without software intervention.

5.8. Crystal Oscillator (RF reference oscillator)

The **AX8052F143** is normally operated with an external TCXO, which is required by most narrow-band regulation with a tolerance of 0.5 ppm to 1.5 ppm depending on the regulation. The on-chip crystal oscillator allows the use of an inexpensive quartz crystal as the RF generation subsystem's timing reference when possible from a regulatory point of view.

A wide range of crystal frequencies can be handled by the crystal oscillator circuit. As the reference frequency impacts both the spectral performance of the transmitter as well as the current consumption of the receiver, the choice of reference frequency should be made according to the regulatory regime targeted by the application. Application Notes for usage of AX5043 in compliance with various regulatory regimes also apply to **AX8052F143**.

The oscillator circuit is enabled by programming the **AX5043_PWRMODE** register. At power-up it is enabled.

To adjust the circuit's characteristics to the quartz crystal being used, without using additional external components, the tuning capacitance of the crystal oscillator can be programmed. The transconductance of the oscillator is automatically regulated, to allow for fastest start-up times together with lowest power operation during steady-state oscillation.

The integrated programmable tuning capacitor bank makes it possible to connect the oscillator directly to pins CLK16N and CLK16P without the need for external capacitors. It is programmed using bits XTALCAP[5:0] in register **AX5043_XTALCAP**.

To synchronize the receiver frequency to a carrier signal, the oscillator frequency could be tuned using the capacitor bank however, the recommended method to implement frequency synchronization is to make use of the high resolution RF frequency generation sub-system together with the Automatic Frequency Control, both are described further down.

Alternatively a single ended reference (TXCO, CXO) may be used. The CMOS levels should be applied to CLK16P via an AC coupling with the crystal oscillator enabled.

5.9. Low Power Oscillator and Wake on Radio (WOR) Mode

The **AX8052F143** transceiver features an internal lowest power fully integrated oscillator. In default mode the frequency of oscillation is 640 Hz +/- 1.5%, in fast mode it is 10.2 kHz +/- 1.5%.

If Wake on Radio Mode is enabled, the receiver wakes up periodically at a user selectable interval, and checks for a radio signal on the selected channel. If no signal is detected, the receiver shuts down again. If a radio signal is detected, and a valid packet is received, the microcontroller is alerted by asserting an interrupt.

5.10. SYSCLK Output

The SYSCLK pin outputs the RF reference clock signal divided by a programmable integer. Divisions from 1 to 2048 are possible. For divider ratios > 1 the duty cycle is 50%. Bits SYSCLK[3:0] in the **AX5043_PINCFG1** register set the divider ratio. The SYSCLK output can be disabled.

5.11. Power-on-reset (POR) and RESET_N Input

AX8052F143 has an integrated power-on-reset block. No external POR circuit is required.

After POR or reset all registers are set to their default values.

If the RESET_N pin is not used it must be tied to VDD_IO.

The **AX8052F143** can be reset by software as well. The microcontroller is reset by writing 1 to the SWRESET bit of the **PCON** register. The transceiver can be reset by first writing 1 and then 0 to the RST bit in the **AX5043_PWRMODE** register.

5.12. Ports

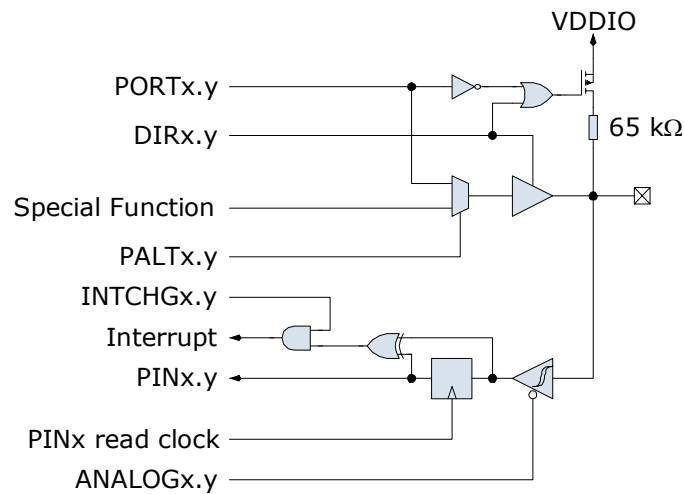


Figure 10: Port pin schematic

Figure 10 shows the GPIO logic. The **DIR** register bit determines whether the port pin acts as an output (1) or an input (0).

If configured as an output, the **PALT** register bit determines whether the port pin is connected to a peripheral output (1), or used as a GPIO pin (0). In the latter case, the **PORT** register bit determines the port pin drive value.

If configured as an input, the **PORT** register bit determines whether a pull-up resistor is enabled (1) or disabled (0). Inputs have schmitt-trigger characteristic. Port A inputs may be disabled by setting the **ANALOGA** register bit; this prevents additional current consumption if the voltage level of the port pin is mid-way between logic low and logic high, when the pin is used as an analog input.

Port A, B and C pins may interrupt the microcontroller if their level changes. The **INTCHG** register bit enables the interrupt. The **PIN** register bit reflects the value of the port pin. Reading the **PIN** register also resets the interrupt if interrupt on change is enabled.

PWRAMP and ANTSEL

PWRAMP functionality is available on PB2 if **PALTRADIO** bit 6 and **DIRB** bit 2 are set. ANTSEL functionality is available on PB3 if **PALTRADIO** bit 7 and **DIRB** bit 3 are set. If these pins should be set to high-impedance, it must be done by clearing the corresponding **DIRB** bit, not by setting **AX5043_PINFUNC_PWRAMP** or **AX5043_PINFUNC_ANTSEL** to Z.

6. Transceiver

The transceiver block is controllable through its registers, which are mapped into the X data space of the micro-controller. The transceiver block features its own 4 word × 10 bit FIFO. The microcontroller can either be interrupted at a programmable FIFO fill level, or one of the DMA channels can be instructed to transfer between XRAM and the transceiver FIFO.

6.1. RF Frequency Generation Subsystem

The RF frequency generation subsystem consists of a fully integrated synthesizer, which multiplies the reference frequency from the crystal oscillator to get the desired RF frequency. The advanced architecture of the synthesizer enables frequency resolutions of 1 Hz, as well as fast settling times of 5 – 50 μs depending on the settings (see section 4.3: AC Characteristics). Fast settling times mean fast start-up and fast RX/TX switching, which enables low-power system design.

For receive operation the RF frequency is fed to the mixer, for transmit operation to the power-amplifier.

The frequency must be programmed to the desired carrier frequency.

The synthesizer loop bandwidth can be programmed, this serves three purposes:

1. Start-up time optimization, start-up is faster for higher synthesizer loop bandwidths
2. TX spectrum optimization, phase-noise at 300 kHz to 1 MHz distance from the carrier improves with lower synthesizer loop bandwidths
3. Adaptation of the bandwidth to the data-rate. For transmission of FSK and MSK it is required that the synthesizer bandwidth must be in the order of the data-rate.

VCO

An on-chip VCO converts the control voltage generated by the charge pump and loop filter into an output frequency. This frequency is used for transmit as well as for receive operation. The frequency can be programmed in 1 Hz steps in the **AX5043_FREQ** registers. For operation in the 433 MHz band, the RFDIV bit in the **AX5043_PLLVCODIV** register must be programmed.

The fully integrated VCO allows to operate the device in the frequency ranges 800 – 1050 MHz and 400 – 520 MHz.

The carrier frequency range can be extended to 140 – 525 MHz and 70 – 262 MHz by using an appropriate external inductor between device pins L1 and L2. The bit VCO2INT in the **AX5043_PLLVCODIV** register must be set high to enter this mode.

It is also possible to use a fully external VCO by setting bits VCO2INT=0 and VCOSEL=1 in the **AX5043_PLLVCODIV** register. A differential input at a frequency of double the desired RF frequency must be input at device pins L1 and L2. The control voltage for the VCO can be output at device pin FILT when using external filter mode. The voltage range of this output pin is 0 – 1.8 V. This mode of operation is recommended for special applications where the phase noise requirements are not met when using the fully internal VCO or the internal VCO with external inductor.

VCO Auto-Ranging

The **AX8052F143** has an integrated auto-ranging function, which allows to set the correct VCO range for specific frequency generation subsystem settings automatically. Typically it has to be executed after power-up. The function is initiated by setting the RNG_START bit in the **AX5043_PLLRANGINGA** or **AX5043_PLLRANGINGB** register. The bit is readable and a 0 indicates the end of the ranging process. Setting RNG_START in the **AX5043_PLLRANGINGA** register ranges the frequency in **AX5043_FREQA**, while setting RNG_START in the **AX5043_PLLRANGINGB** register ranges the frequency in **AX5043_FREQB**. The RNGERR bit indicates the correct execution of the auto-ranging. VCO auto-ranging works with the fully integrated VCO and with the internal VCO with external inductor.

Loop Filter and Charge Pump

The **AX8052F143** internal loop filter configuration together with the charge pump current sets the synthesizer loop band width. The internal loop-filter has three configurations that can be programmed via the register bits FLT[1:0] in registers **AX5043_PLLLOOP** or **AX5043_PLLLOOPBOOST** the charge pump current can be programmed using register bits PLLCPI[7:0] in registers **AX5043_PLLCPI** or **AX5043_PLLCPIBOOST**. Synthesizer bandwidths are typically 50 - 500 kHz depending on the **AX5043_PLLLOOP** or **AX5043_PLLLOOPBOOST** settings, for details see the section 4.3: AC Characteristics.

The **AX8052F143** can be setup in such a way that when the synthesizer is started, the settings in the registers **AX5043_PLLLOOPBOOST** and **AX5043_PLLCPIBOOST** are applied first for a programmable duration before reverting to the settings in **AX5043_PLLLOOP** and **AX5043_PLLCPI**. This feature enables automated fastest start-up.

Setting bits FLT[1:0]=00 bypasses the internal loop filter and the VCO control voltage is output to an external loop filter at pin FILT. This mode of operation is recommended for achieving lower bandwidths than with the internal loop filter and for usage with a fully external VCO.

Registers

Register	Bits	Purpose
AX5043_PLLLOOP AX5043_PLLLOOPBOOST	FLT[1:0]	Synthesizer loop filter bandwidth and selection of external loop filter, recommended usage is to increase the bandwidth for faster settling time, bandwidth increases of factor 2 and 5 are possible.
AX5043_PLLCPI AX5043_PLLCPIBOOST		Synthesizer charge pump current, recommended usage is to decrease the bandwidth (and improve the phase-noise) for low data-rate transmissions.
AX5043_PLLVCODIV	REFDIV	Sets the synthesizer reference divider ratio.
	RFDIV	Sets the synthesizer output divider ratio.
	VCOSSEL	Selects either the internal or the external VCO
	VCO2INT	Selects either the internal VCO inductor or an external inductor between pins L1 and L2
AX5043_FREQA, AX5043_FREQB		Programming of the carrier frequency
AX5043_PLLRANGINGA, AX5043_PLLRANGINGB		Initiate VCO auto-ranging and check results

6.2. RF Input and Output Stage (ANTP/ANTN/ANTP1)

The **AX8052F143** has two main antenna interface modes:

1. Both RX and TX use differential pins ANTP and ANTN. RX/TX switching is handled internally. This mode is recommended for highest output powers, highest sensitivities and for direct connection to dipole antennas. Also see Figure 15.
2. RX uses the differential antenna pins ANTP and ANTN. TX uses the single ended antenna pin ANTP1. RX/TX switching is handled externally. This can be done either with an external RX/TX switch or with a direct tie configuration. This mode is recommended for low output powers at high efficiency Figure 18 and for usage with external power amplifiers Figure 17.

Pin PB2 can be used to control an external RX/TX switch when operating the device together with an external PA (Figure 17). Pin PB3 can be used to control an external antenna switch when receiving with two antennas (Figure 19).

When antenna diversity is enabled, the radio controller will, when not in the middle of receiving a packet, periodically probe both antennas and select the antenna with the highest signal strength. The radio controller can be instructed to periodically write both RSSI values into the FIFO. Antenna diversity mode is fully automatic.

LNA

The LNA amplifies the differential RF signal from the antenna and buffers it to drive the I/Q mixer. An external matching network is used to adapt the antenna impedance to the IC impedance. A DC feed to GND must be provided at the antenna pins.

PA

In TX mode the PA drives the signal generated by the frequency generation subsystem out to either the differential antenna terminals or to the single ended antenna pin. The antenna terminals are chosen via the bits TXDIFF and TXSE in register **AX5043_MODECFGA**.

The output power of the PA is programmed via the register **AX5043_TXPWRCOEFFB**.

The PA can be digitally pre-distorted for high linearity.

The output amplitude can be shaped (raised cosine), this mode is selected with bit AMPLSHAPE in register **AX5043_MODECFGA**. PA ramping is programmable in increments of the bit time and can be set to 1 – 8 bit times via bits SLOWRAMP in register **AX5043_MODECFGA**.

Output power as well as harmonic content will depend on the external impedance seen by the PA.

6.3. Digital IF Channel Filter and Demodulator

The digital IF channel filter and the demodulator extract the data bit-stream from the incoming IF signal. They must be programmed to match the modulation scheme as well as the data-rate. Inaccurate programming will lead to loss of sensitivity.

The channel filter offers bandwidths of 995 Hz up to 221 kHz.

The AXSEM RadioLab Software calculates the necessary register settings for optimal performance. An overview of the registers involved is given in the following table as reference, for details see the AX5043 Programming Manual. The register setups typically must be done once at power-up of the device.

Registers

Register	Remarks
AX5043_DECIMATION	This register programs the bandwidth of the digital channel filter.
AX5043_RXDATARATE2... AX5043_RXDATARATE0	These registers specify the receiver bit rate, relative to the channel filter bandwidth.
AX5043_MAXDROFFSET2... AX5043_MAXDROFFSET0	These registers specify the maximum possible data rate offset
AX5043_MAXRFOFFSET2... AX5043_MAXRFOFFSET0	These registers specify the maximum possible RF frequency offset
AX5043_TIMEGAIN, AX5043_DRGAIN	These registers specify the aggressiveness of the receiver bit timing recovery. More aggressive settings allow the receiver to synchronize with shorter preambles, at the expense of more timing jitter and thus a higher bit error rate at a given signal-to-noise ratio.
AX5043_MODULATION	This register selects the modulation to be used by the transmitter and the receiver, i.e. whether ASK, FSK should be used.
AX5043_PHASEGAIN, AX5043_FREQGAINA, AX5043_FREQGAINB, AX5043_FREQGAINC, AX5043_FREQGAIND, AX5043_AMPLGAIN	These registers control the bandwidth of the phase, frequency offset and amplitude tracking loops.
AX5043_AGC_GAIN	This register controls the AGC (automatic gain control) loop slopes, and thus the speed of gain adjustments. The faster the bit-rate, the faster the AGC loop should be.
AX5043_TXRATE	These registers control the bit rate of the transmitter.
AX5043_FSKDEV	These registers control the frequency deviation of the transmitter in FSK mode. The receiver does not explicitly need to know the frequency deviation, only the channel filter bandwidth has to be set wide enough for the complete modulation to pass.

6.4. Encoder

The encoder is located between the Framing Unit, the Demodulator and the Modulator. It can optionally transform the bit-stream in the following ways:

- It can invert the bit stream.
- It can perform differential encoding. This means that a zero is transmitted as no change in the level, and a one is transmitted as a change in the level.
- It can perform Manchester encoding. Manchester encoding ensures that the modulation has no DC content and enough transitions (changes from 0 to 1 and from 1 to 0) for the demodulator bit timing recovery to function correctly, but does so at a doubling of the data rate.
- It can perform spectral shaping (also known as whitening). Spectral shaping removes DC content of the bit stream, ensures transitions for the demodulator bit timing recovery, and makes sure that the transmitted spectrum does not have discrete lines even if the transmitted data is cyclic. It does so without adding additional bits, i.e. without changing the data rate. Spectral Shaping uses a self synchronizing feedback shift register.

The encoder is programmed using the register **AX5043_ENCODING**, details and recommendations on usage are given in the AX5043 Programming Manual.

6.5. Framing and FIFO

Most radio systems today group data into packets. The framing unit is responsible for converting these packets into a bit-stream suitable for the modulator, and to extract packets from the continuous bit-stream arriving from the demodulator.

The Framing unit supports two different modes:

- Packet modes
- Raw modes

The microcontroller communicates with the framing unit through a 256 byte FIFO. Data in the FIFO is organized in Chunks. The chunk header encodes the length and what data is contained in the payload. Chunks may contain packet data, but also RSSI, Frequency offset, Timestamps, etc.

The **AX8052F143** contains one FIFO. Its direction is switched depending on whether transmit or receive mode is selected.

The FIFO can be operated in polled or interrupt driven modes. In polled mode, the microcontroller must periodically read the FIFO status register or the FIFO count register to determine whether the FIFO needs servicing.

In interrupt mode EMPTY, NOT EMPTY, FULL, NOT FULL and programmable level interrupts are provided. Interrupts are acknowledged by removing the cause for the interrupt, i.e. by emptying or filling the FIFO.

To lower the interrupt load on the microcontroller, one of the DMA channels may be instructed to transfer data between the transceiver FIFO and the XRAM memory. This way, much larger buffers

can be realized in XRAM, and interrupts need only be serviced if the larger XRAM buffers fill or empty.

Packet Modes

The **AX8052F143** offers different packet modes. For arbitrary packet sizes HDLC is recommended since the flag and bit-stuffing mechanism. The **AX8052F143** also offers packet modes with fixed packet length with a byte indicating the length of the packet.

In packet modes a CRC can be computed automatically.

HDLC⁴ Mode is the main framing mode of the **AX8052F143**. In this mode, the **AX8052F143** performs automatic packet delimiting, and optional packet correctness check by inserting and checking a cyclic redundancy check (CRC) field.

The packet structure is given in the following table.

Flag	Address	Control	Information	FCS	(Optional Flag)
8 bit	8 bit	8 or 16 bit	Variable length, 0 or more bits in multiples of 8	16 / 32 bit	8 bit

HDLC packets are delimited with flag sequences of content 0x7E.

In **AX8052F143** the meaning of address and control is user defined. The Frame Check Sequence (FCS) can be programmed to be CRC-CCITT, CRC-16 or CRC-32.

The receiver checks the CRC, the result can be retrieved from the FIFO, the CRC is appended to the received data.

In Wireless M-Bus Mode⁵, the packet structure is given in the following table.

Preamble	L	C	M	A	FCS	Optional Data Block (optionally repeated with FCS)	FCS
variable	8 bit	8 bit	16 bit	48 bit	16 bit	8 – 96 bit	16 bit

For details on implementing a HDLC communication as well as Wireless M-Bus please use the AXSEM RadioLab software and see the AX5043 Programming Manual.

⁴ **Note:** HDLC mode follows High-Level Data Link Control (HDLC, ISO 13239) protocol.

⁵ **Note:** Wireless M-Bus mode follows EN13757-4

RAW Modes

In Raw mode, the **AX8052F143** does not perform any packet delimiting or byte synchronization. It simply serializes transmit bytes and de-serializes the received bit-stream and groups it into bytes. This mode is ideal for implementing legacy protocols in software.

Raw mode with preamble match is similar to raw mode. In this mode, however, the receiver does not receive anything until it detects a user programmable bit pattern (called the preamble) in the receive bit-stream. When it detects the preamble, it aligns the de-serialization to it.

The preamble can be between 4 and 32 bits long.

6.6. RX AGC and RSSI

AX8052F143 features three receiver signal strength indicators (RSSI):

1. RSSI before the digital IF channel filter.
The gain of the receiver is adjusted in order to keep the analog IF filter output level inside the working range of the ADC and demodulator. The register **AX5043_AGCCOUNTER** contains the current value of the AGC and can be used as an RSSI. The step size of this RSSI is 0.625 dB. The value can be used as soon as the RF frequency generation sub-system has been programmed.
2. RSSI behind the digital IF channel filter.
The register **AX5043_RSSI** contains the current value of the RSSI behind the digital IF channel filter. The step size of this RSSI is 1 dB.
3. RSSI behind the digital IF channel filter high accuracy.
The demodulator also provides amplitude information in the **AX5043_TRK_AMPLITUDE** register. By combining both the **AX5043_AGCCOUNTER** and the **AX5043_TRK_AMPLITUDE** registers, a high resolution (better than 0.1dB) RSSI value can be computed at the expense of a few arithmetic operations on the micro-controller. The AXSEM RadioLab Software calculates the necessary register settings for best performance.

6.7. Modulator

Depending on the transmitter settings the modulator generates various inputs for the PA:

Modulation	Bit = 0	Bit = 1	Main Lobe Bandwidth	Max. Bitrate
ASK	PA off	PA on	BW=BITRATE	100 kBit/s
FSK/MSK/GFSK/GMSK	$\Delta f = -f_{\text{deviation}}$	$\Delta f = +f_{\text{deviation}}$	$BW = (1+h) \cdot \text{BITRATE}$	100 kBit/s

h = modulation index. It is the ratio of the deviation compared to the bit-rate;
 $f_{\text{deviation}} = 0.5 \cdot h \cdot \text{BITRATE}$, **AX8052F143** can demodulate signals with $h < 32$.

ASK = amplitude shift keying

FSK = frequency shift keying

MSK = minimum shift keying; MSK is a special case of FSK, where $h = 0.5$, and therefore $f_{\text{deviation}} = 0.25 \cdot \text{BITRATE}$; the advantage of MSK over FSK is that it can be demodulated more robustly.

All modulation schemes, except 4-FSK, are binary.

Amplitude can be shaped using a raised cosine waveform. Amplitude shaping will also be performed for constant amplitude modulation ((G)FSK, (G)MSK) for ramping up and down the PA. Amplitude shaping should always be enabled.

Frequency shaping can either be hard (FSK, MSK), or Gaussian (GMSK, GFSK), with selectable $BT=0.3$ or $BT=0.5$.

Modulation	DiBit = 00	DiBit = 01	DiBit = 11	DiBit = 10	Main Lobe Bandwidth	Max. Bitrate
4-FSK	$\Delta f = -3f_{\text{deviation}}$	$\Delta f = -f_{\text{deviation}}$	$\Delta f = +f_{\text{deviation}}$	$\Delta f = +3f_{\text{deviation}}$	$BW = (1+3h) \cdot \text{BITRATE}$	100 kBit/s

4-FSK Frequency shaping is always hard.

6.8. Automatic Frequency Control (AFC)

The **AX8052F143** features an automatic frequency tracking loop which is capable of tracking the transmitter frequency within the RX filter band width. On top of that the **AX8052F143** has a frequency tracking register **AX5043_TRKRFFREQ** to synchronize the receiver frequency to a carrier signal. For AFC adjustment, the frequency offset can be computed with the following formula:

$$\Delta f = \frac{\text{AX5043_TRKRFFREQ}}{2^{32}} f_{\text{XTAL}}$$

6.9. PWRMODE Register

The **AX8052F143** transceiver features its own independent power management, independent from the microcontroller. While the microcontroller power mode is controlled through the **PCON** register, the **AX5043_PWRMODE** register controls which parts of the transceiver are operating.

AX5043_PWRMODE register	Name	Description
0000	POWERDOWN	All digital and analog functions, except the register file, are disabled. The core supply voltages are switched off to conserve leakage power. Register contents are preserved. Access to the FIFO is not possible and the contents are not preserved. POWERDOWN mode is only entered once the FIFO is empty.
0001	DEEPSLEEP	The transceiver is fully turned off. All digital and analog functions are disabled. All register contents are lost. To leave DEEPSLEEP mode the pin SEL has to be pulled low. This will initiate startup and reset of the transceiver. Then the MISO line should be polled, as it will be held low during initialization and will rise to high at the end of the initialization, when the chip becomes ready for operation. It is recommended to use the functions ax5043_enter_deepsleep() and ax5043_wakeup_deepsleep() provided in libmf
0101	STANDBY	The crystal oscillator and the reference are powered on; receiver and transmitter are off. Register contents are preserved and accessible. Access to the FIFO is not possible and the contents are not preserved. STANDBY is only entered once the FIFO is empty.
0110	FIFO	The reference is powered on. Register contents are preserved and accessible. Access to the FIFO is possible and the contents are preserved.
1000	SYNTHRX	The synthesizer is running on the receive frequency. Transmitter and receiver are still off. This mode is used to let the synthesizer settle on the correct frequency for receive.
1001	FULLRX	Synthesizer and receiver are running.
1011	WOR	Receiver wakeup-on-radio mode. The mode the same as POWERDOWN, but the 640 Hz internal low power oscillator is running.
1100	SYNTHTX	The synthesizer is running on the transmit frequency. Transmitter and receiver are still off. This mode is used to let the synthesizer settle on the correct frequency for transmit.
1101	FULLTX	Synthesizer and transmitter are running. Do not switch into this mode before the synthesizer has completely settled on the transmit frequency (in SYNTHTX mode), otherwise spurious spectral transmissions will occur.

A typical **AX5043_PWRMODE** sequence for a transmit session :

Step	PWRMODE	Remarks
1	POWERDOWN	
2	STANDBY	The settling time is dominated by the crystal used, typical value 3ms.
3	FULLTX	Data transmission
4	POWERDOWN	

A typical **AX5043_PWRMODE** sequence for a receive session :

Step	PWRMODE[3:0]	Remarks
1	POWERDOWN	
2	STANDBY	The settling time is dominated by the crystal used, typical value 3ms
3	FULLRX	Data reception
4	POWERDOWN	

6.10. Voltage Regulator

The **AX8052F143** transceiver uses its own dedicated on-chip voltage regulator system to create stable supply voltages for the internal circuitry from the primary supply VDD_IO. The I/O level of the digital pins is VDD_IO.

Pins VDD_ANA are supplied for external decoupling of the power supply used for the on-chip PA.

The voltage regulator system must be set into the appropriate state before receive or transmit operations can be initiated. This is handled automatically when programming the device modes via the **AX5043_PWRMODE** register.

Register **AX5043_POWSTAT** contains status bits that can be read to check if the regulated voltages are ready (bit SVIO) or if VDD_IO has dropped below the brown-out level of 1.3V (bit SSUM).

In power-down mode the core supply voltages for digital and analog functions are switched off to minimize leakage power. Most register contents are preserved but access to the FIFO is not possible and FIFO contents are lost.

In deep-sleep mode all supply voltages are switched off. All digital and analog functions are disabled. All register contents are lost.

7. Application Information

7.1. Typical Application Diagrams

Connecting to Debug Adapter

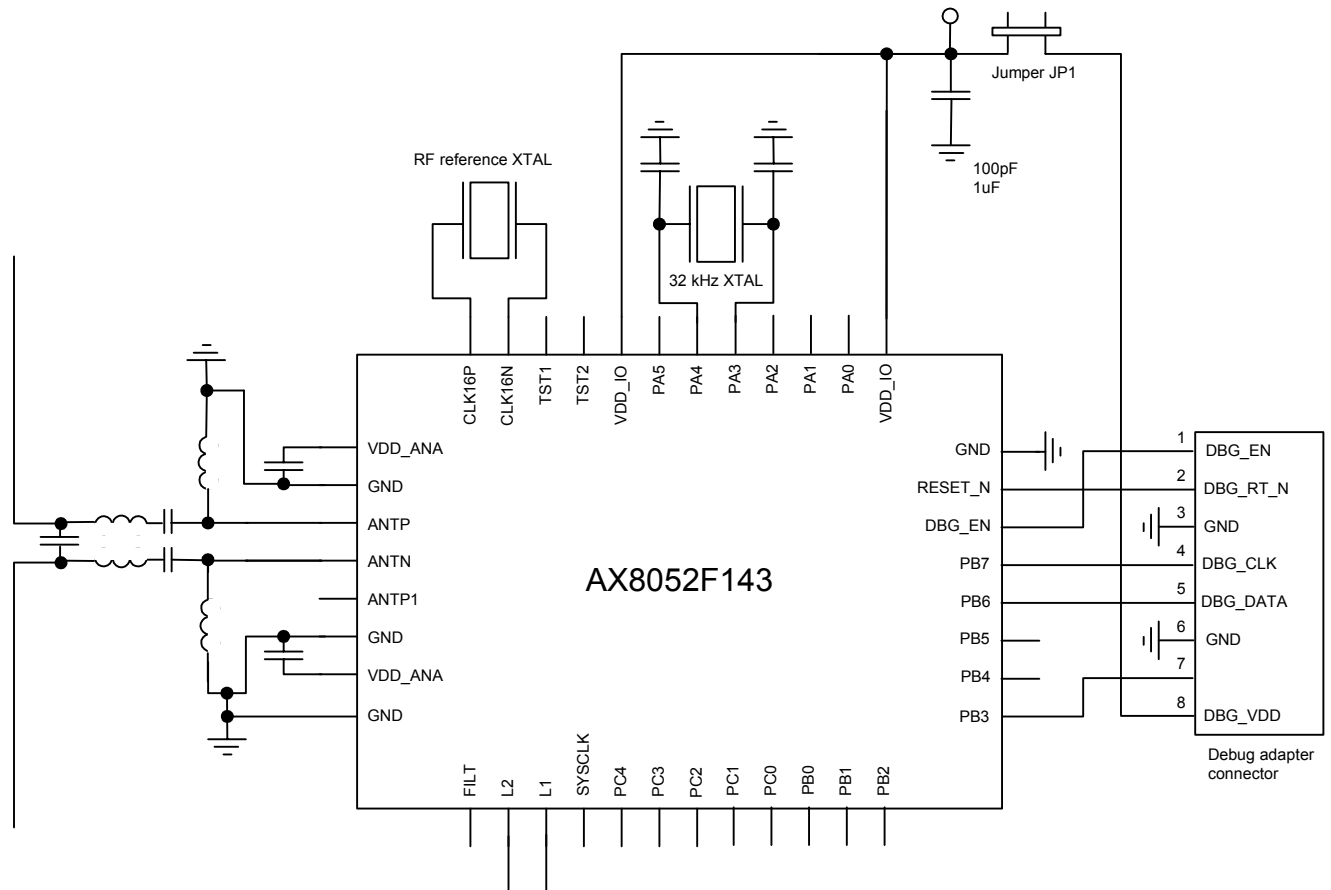


Figure 11 Typical application diagram with connection to the debug adapter

Short Jumper JP1-1 if it is desired to supply the target board from the Debug Adapter (50mA max). Connect the bottom exposed pad of the **AX8052F143** to ground.

If the debugger is not running, PB6 and PB7 are not driven by the Debug Adapter. If the debugger is running, the PB6 and PB7 values that the software reads may be set using the Pin Emulation feature of the debugger.

PB3 is driven by the debugger only to bring the **AX8052F143** out of Deep Sleep. It is high impedance otherwise.

The 32 kHz crystal is optional, the fast crystal at pins CLK16N and CLK16P is used as reference frequency for the RF RX/TX. Crystal load capacitances should be chosen according to the crystal's datasheet. At pins CLK16N and CLK16P they the internal programmable capacitors may be used, at pins PA3 and PA4 capacitors must be connected externally.

Match to 50 Ohm for differential antenna pins (868/433 MHz RX/TX operation)

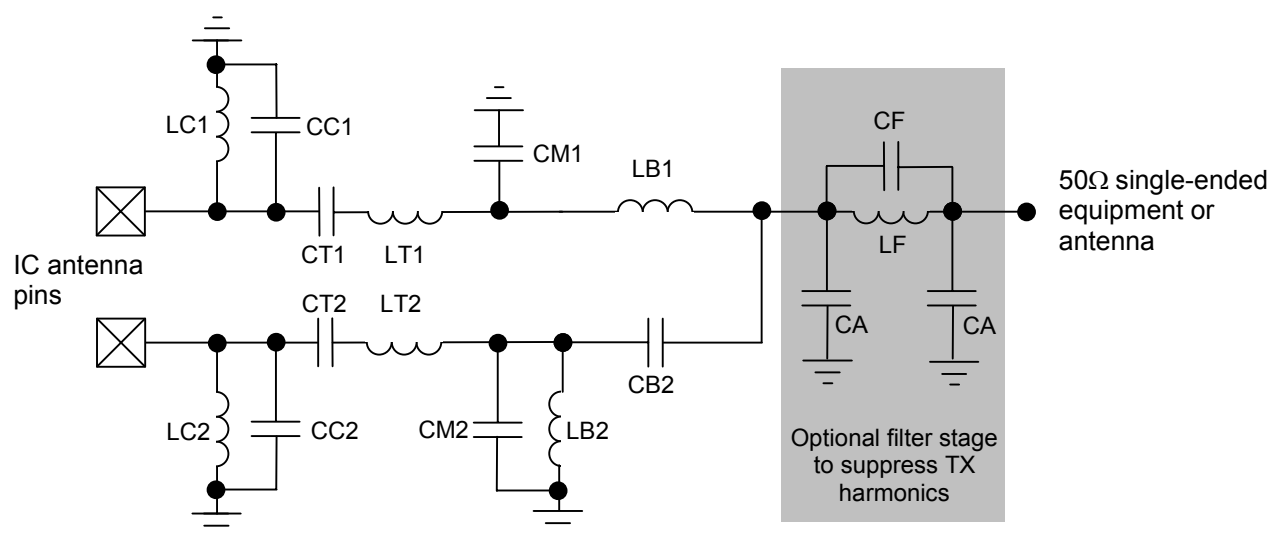


Figure 12 Structure of the differential antenna interface for TX/RX operation to 50 Ω single-ended equipment or antenna

Frequency Band	LC1,2 [nH]	CC1,2 [pF]	CT1,2 [pF]	LT1,2 [nH]	CM1 [pF]	CM2 [pF]	LB1,2 [nH]	CB2 [pF]	CF [pF] optional	LF [nH] optional	CA [pF] optional
868 / 915 MHz	18	nc	2.7	18	6.2	3.6	12	2.7	nc	0 OHM	nc
433 MHz	68	4.3	4.3	47	12	8.2	27	5.1	nc	0 OHM	nc

Match to 50 Ohm for differential antenna pins (169 MHz RX/TX operation)

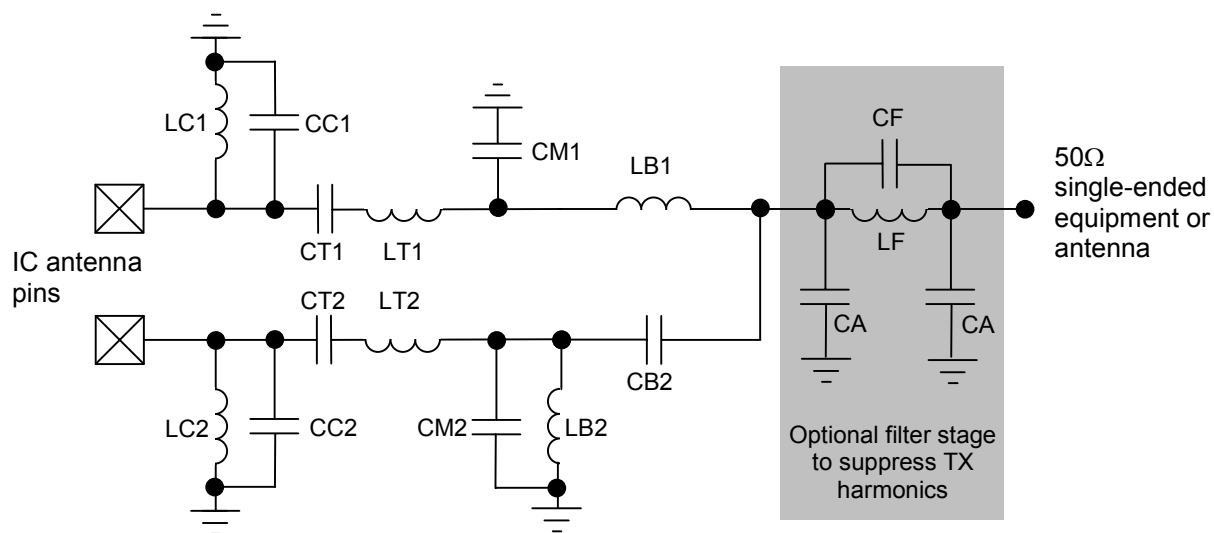


Figure 13 Structure of the differential antenna interface for RX/TX operation to 50 Ω single-ended equipment or antenna

Frequency Band	LC1,2 [nH]	CC1,2 [pF]	CT1,2 [pF]	LT1,2 [nH]	CM1 [pF]	CM2 [pF]	LB1,2 [nH]	CB2 [pF]	CF [pF] optional	LF [nH] optional	CA [pF] optional
169 MHz	150	4.3	10	120	12	nc	68	12	6.8	30	27

Match to 50 Ohm for single-ended antenna pin (169 MHz TX operation)

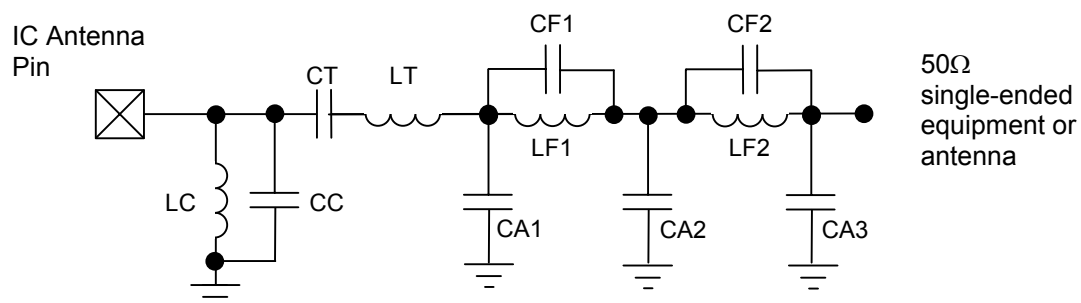


Figure 14 Structure of the single-ended antenna interface for TX operation to 50 Ω single-ended equipment or antenna

Frequency Band	LC [nH]	CC [pF]	CT [pF]	LT [nH]	CF1 [pF]	LF1 [nH]	CF2 [pF]	LF2 [nH]	CA1 [pF]	CA2 [pF]	CA3 [pF]
169 MHz	150	2.2	22	120	4.7	39	1.8	47	33	47	15

Using a Dipole Antenna and the internal TX/RX Switch

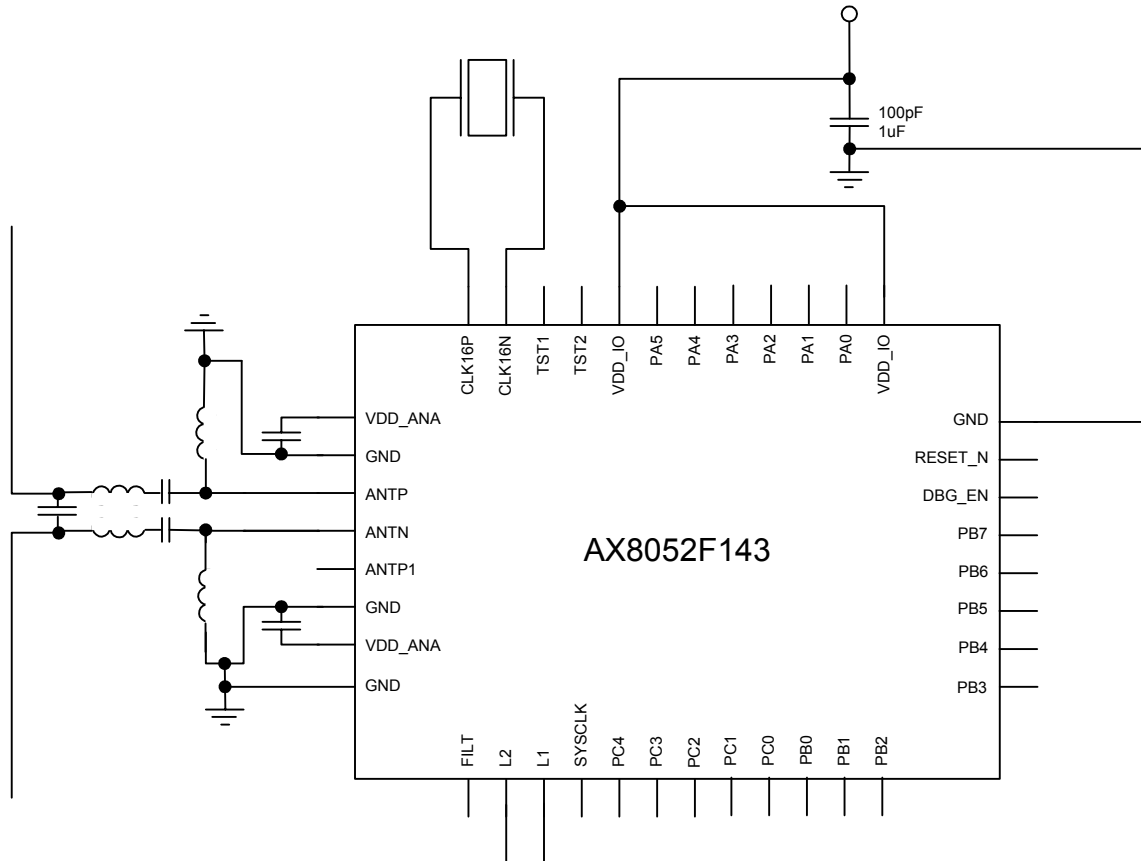


Figure 15 Typical application diagram with dipole antenna and internal TX/RX switch

Using a single-ended Antenna and the internal TX/RX Switch

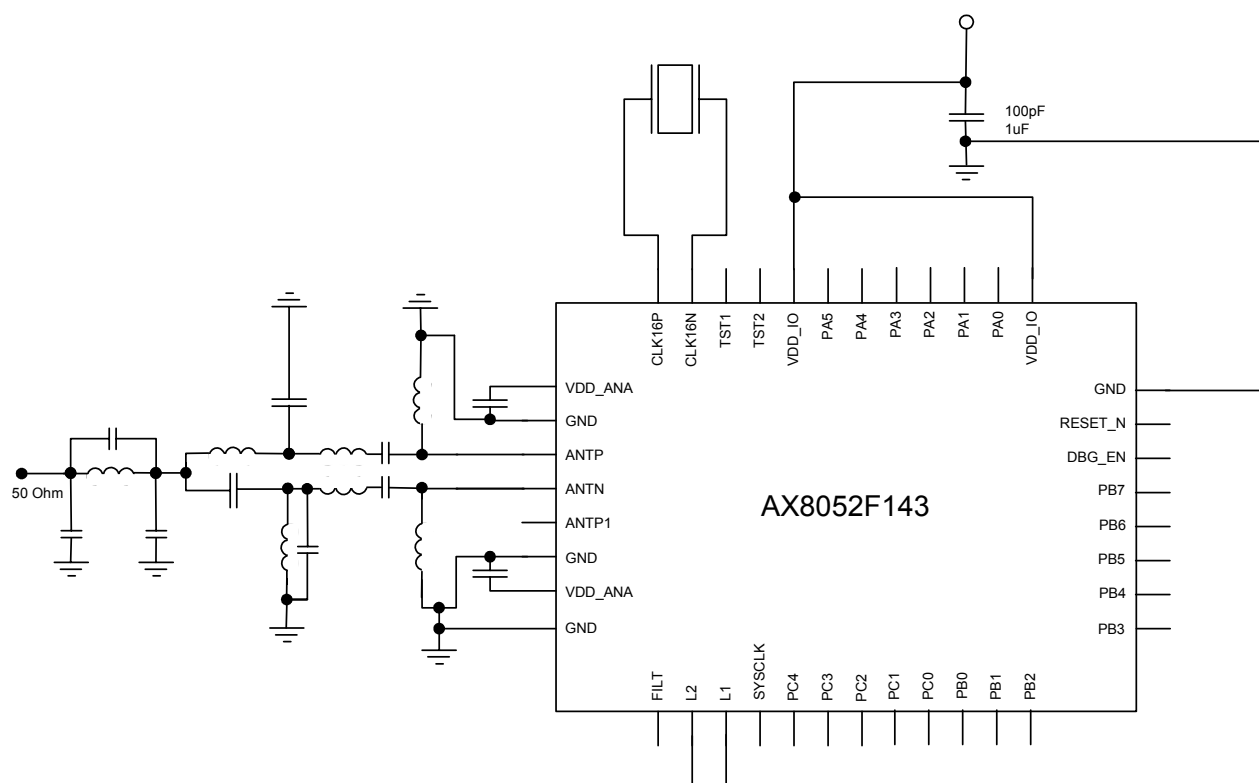


Figure 16 Typical application diagram with single-ended antenna and internal TX/RX switch

Using an external high-power PA and an external TX/RX Switch

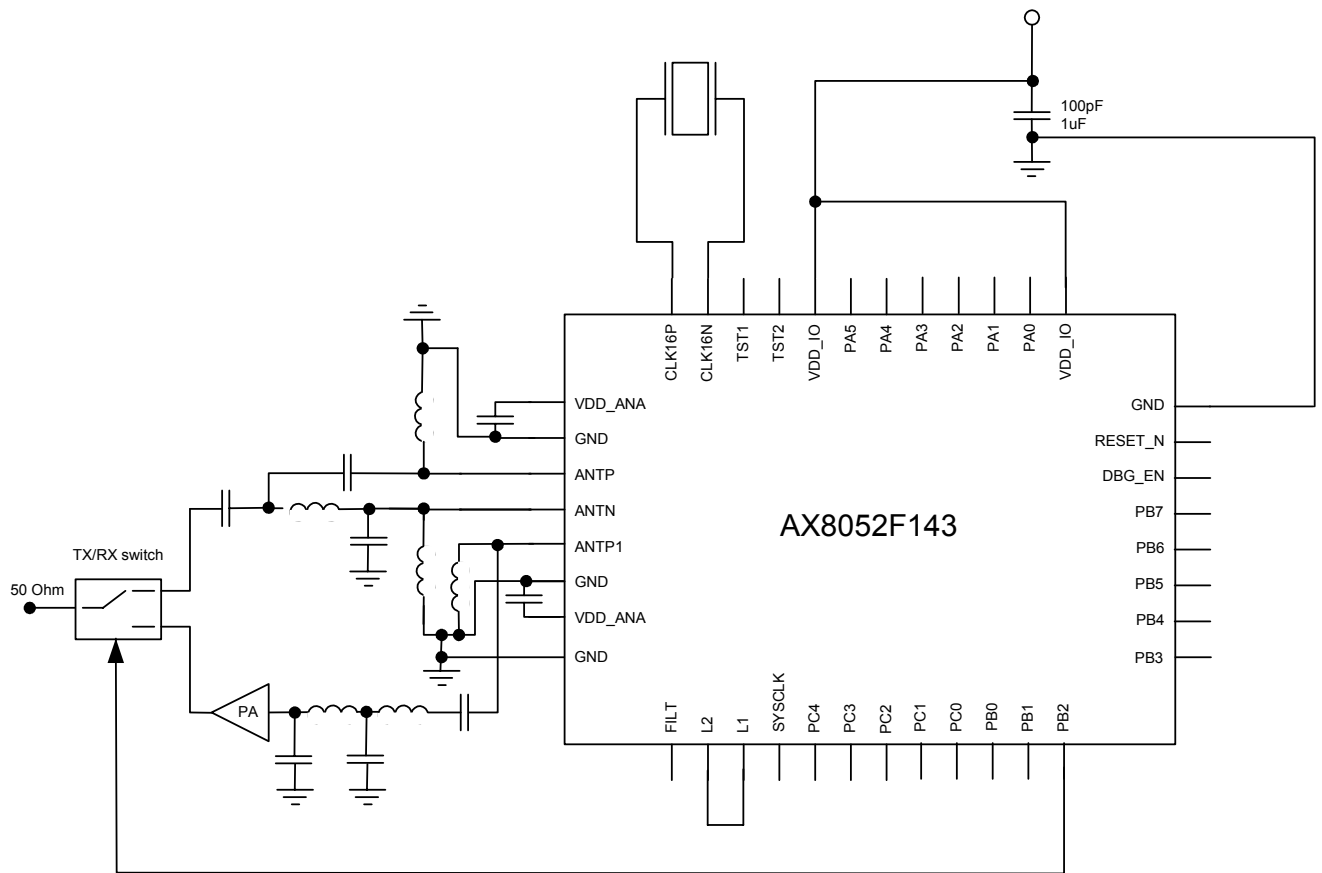


Figure 17 Typical application diagram with single-ended antenna , external PA and external antenna switch

Using the single-ended PA

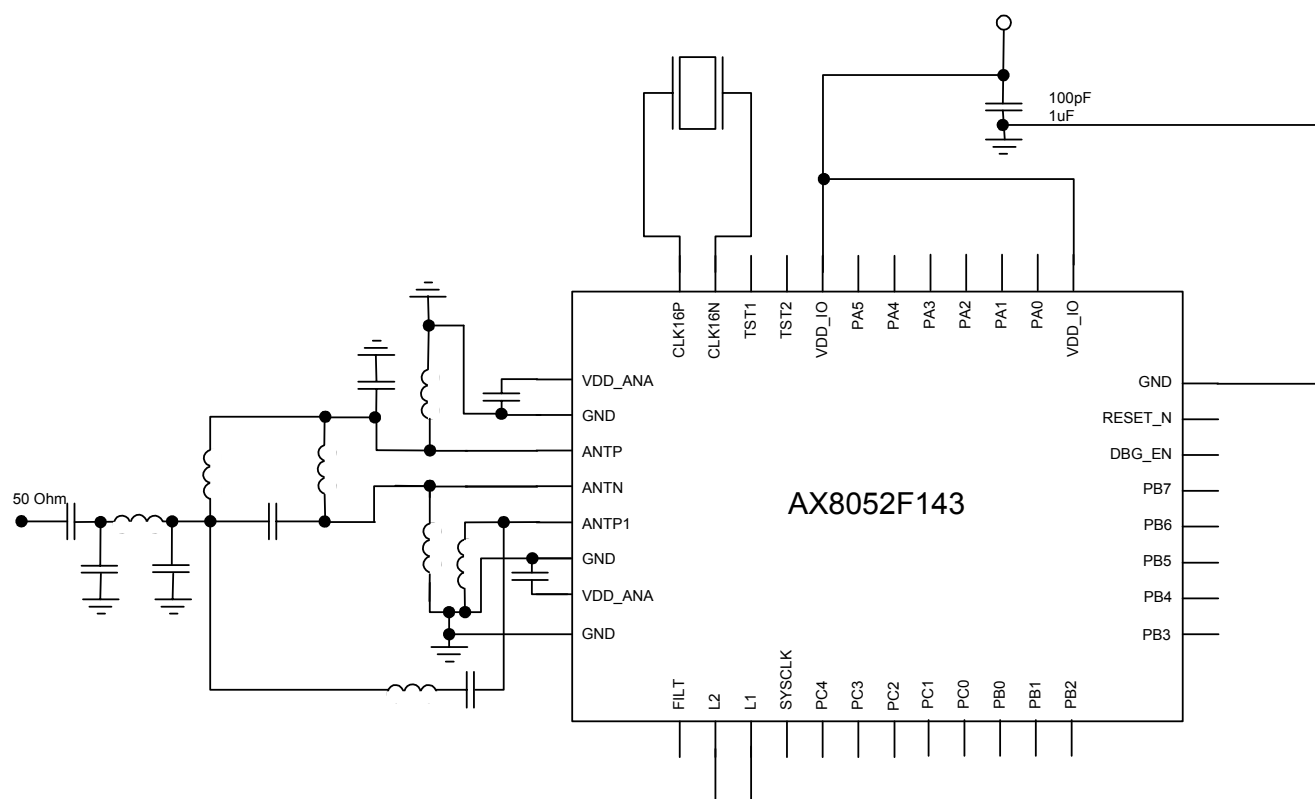


Figure 18 Typical application diagram with single-ended antenna, single ended internal PA, without RX/TX switch

Using two Antenna

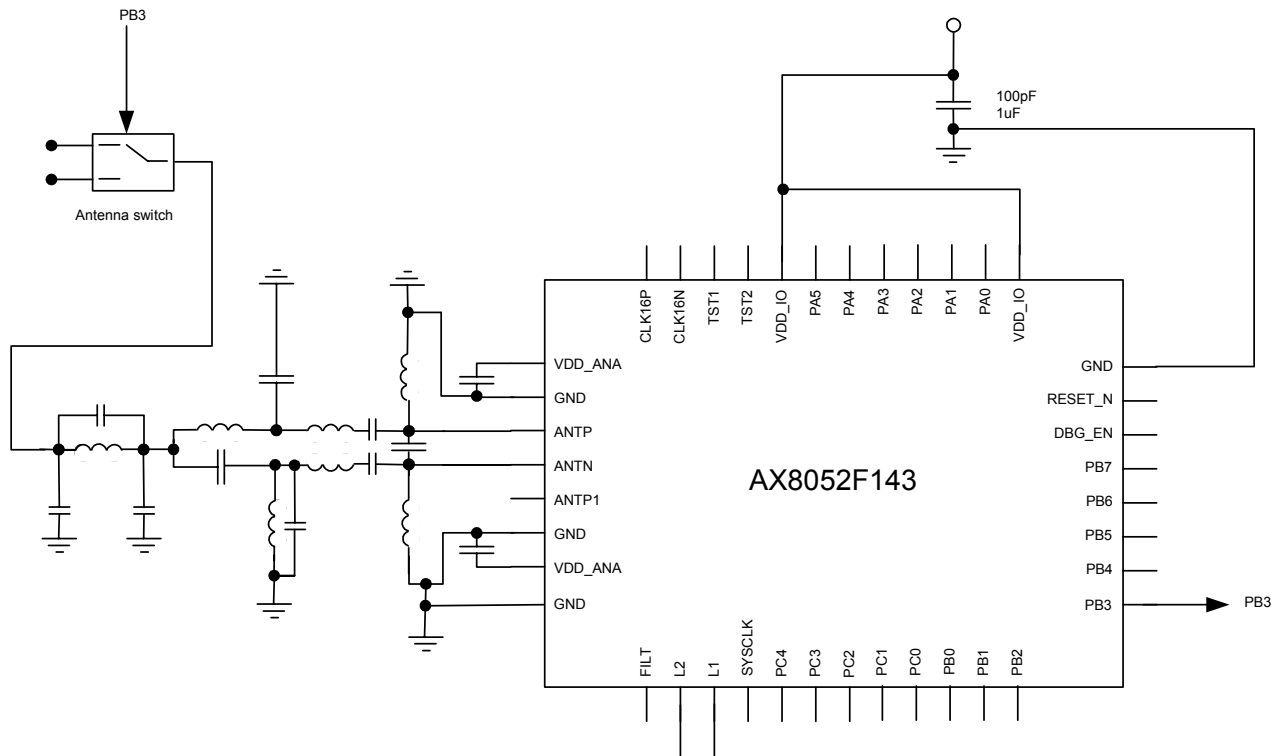


Figure 19 Typical application diagram with two single-ended antenna and external antenna switch

Using an external VCO inductor

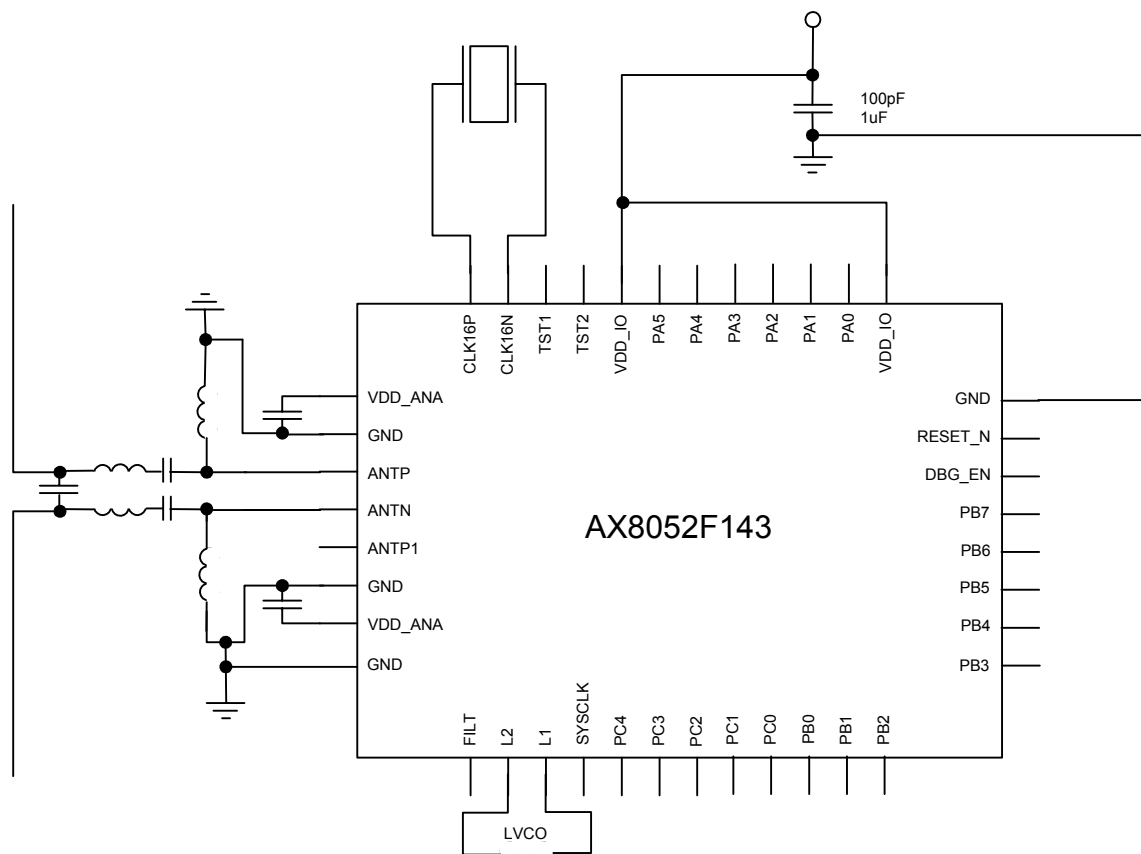


Figure 20 Typical application diagram with external VCO inductor

Using an external VCO

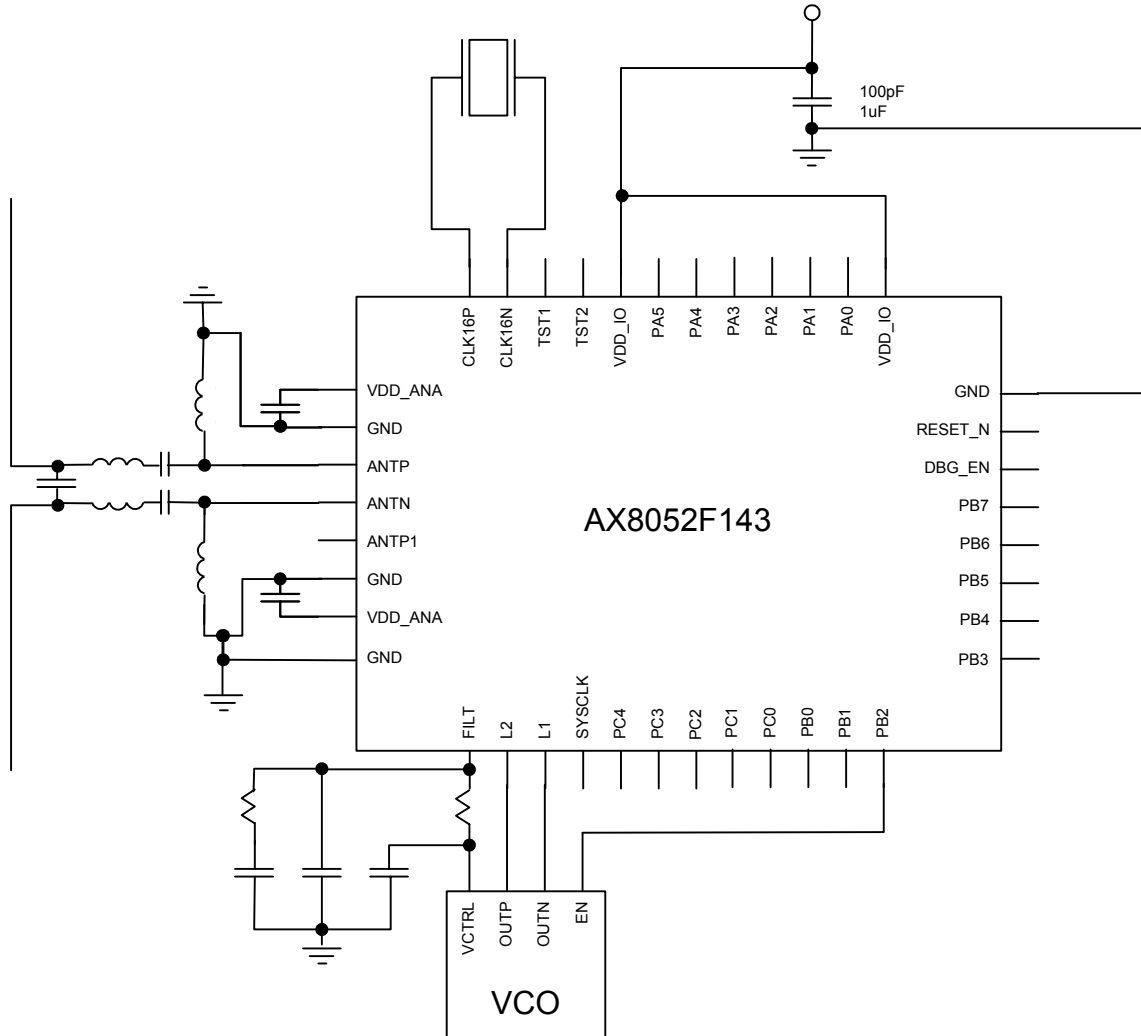


Figure 21 Typical application diagram with external VCO

Using a TCXO

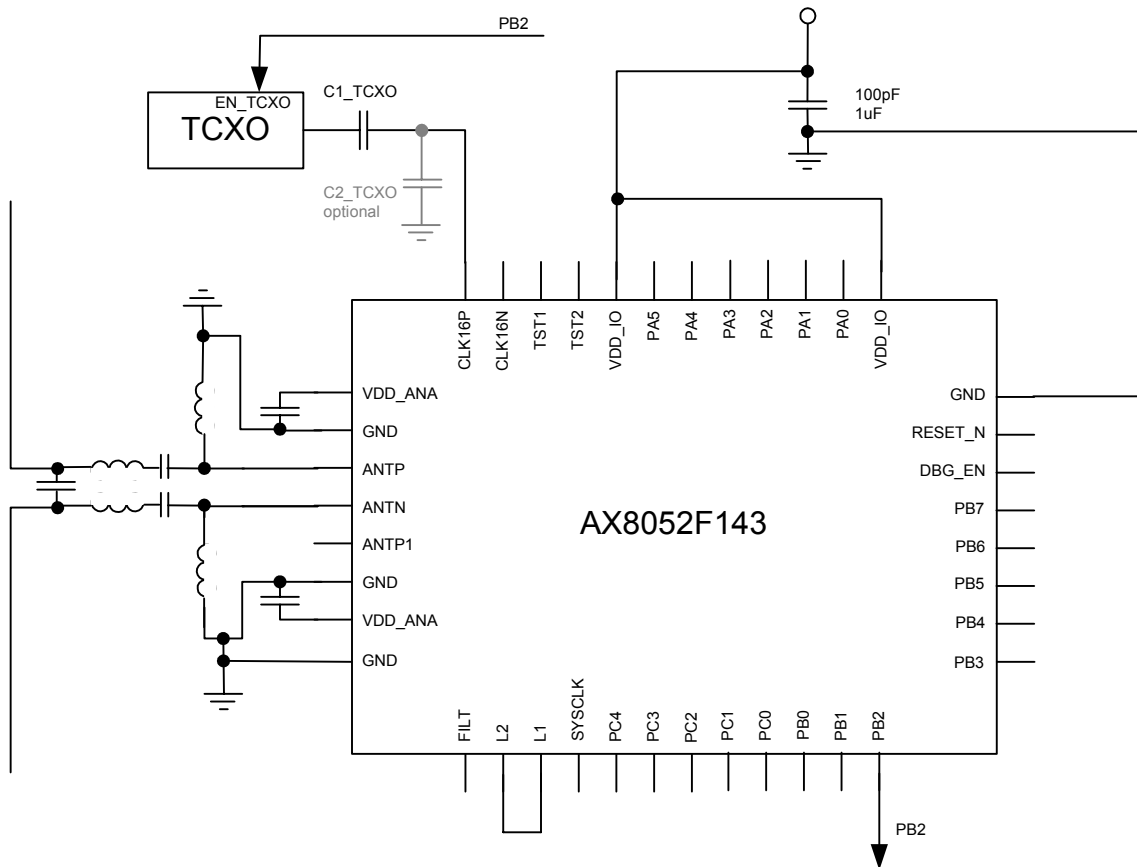
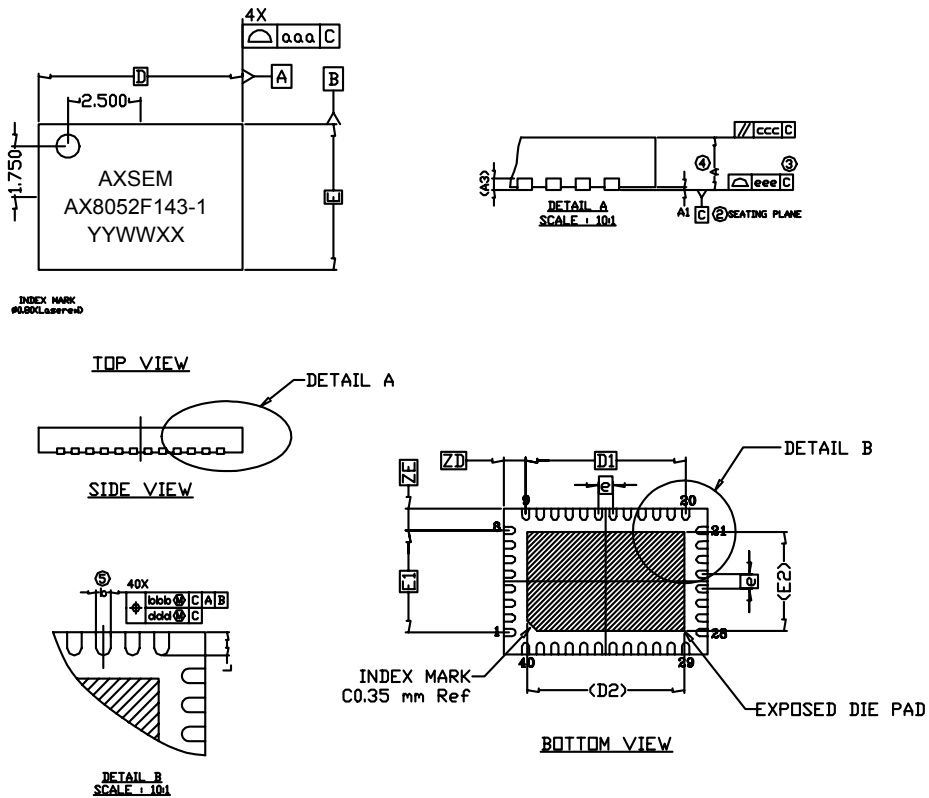


Figure 22 Typical application diagram with a TCXO

8. QFN40 Package Information

8.1. Package Outline QFN40 5x7mm



DIMENSIONAL REFERENCES			
REF.	Min.	Nom.	Max.
A	0.80	0.90	1.00
A1	0	0.02	0.05
A3	0.20 Ref		
D	7.00 BSC		
D1	5.50 BSC		
E	5.00 BSC		
E1	3.50 BSC		
e	0.50 BSC		
ZD	0.75 BSC		
ZE	0.75 BSC		

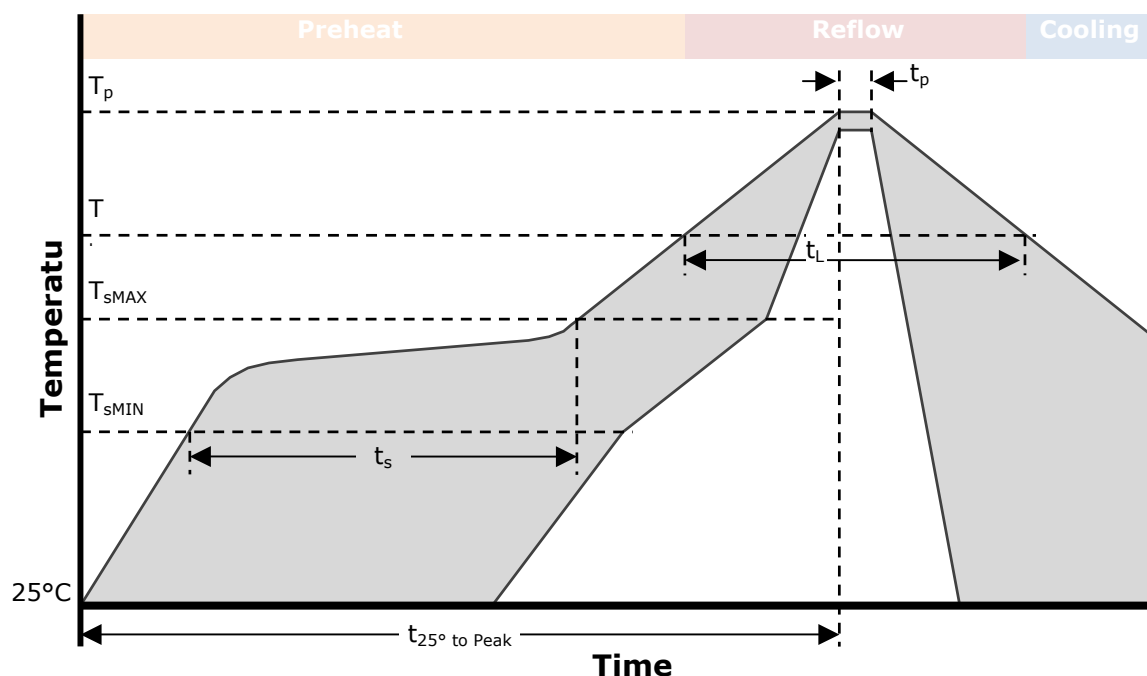
TOLERANCE OF FORM AND POSITION	
REF.	Units: mm
aaa	0.15
bbb	0.10
ccc	0.10
ddd	0.05
eee	0.08

Units: mm				
LF REF#.	Symbol	Min	Nom	Max
FR9020	b	0.18	0.25	0.30
	L	0.30	0.40	0.50
	D2	5.30	5.40	5.50
	E2	3.30	3.40	3.50

Notes

- 'e' represents the basic terminal pitch
- Datum 'C' is the mounting surface with which the package is in contact.
- '3' specifies the vertical shift of the flat part of each terminal from the mounting surface.
- Dimension 'A' includes package warpage.
- Dimension 'b' applies to the metallised terminal and is measured between 0.15 to 0.30 mm from the terminal tip. If the terminal has the optional radius on the other end of the terminal, the dimension 'b' should not be measured in the radius are
- Package dimension take reference from JEDEC MO-220
- YYWWXXX is the packaging lot code
- RoHS

8.2. QFN40 Soldering Profile



Profile Feature		Pb-Free Process
Average Ramp-Up Rate		3 °C/sec max.
Preheat Preheat		
Temperature Min	T_{sMIN}	150°C
Temperature Max	T_{sMAX}	200°C
Time (T_{sMIN} to T_{sMAX})	t_s	60 – 180 sec
Time 25°C to Peak Temperature	$T_{25^\circ \text{ to Peak}}$	8 min max.
Reflow Phase		
Liquidus Temperature	T_L	217°C
Time over Liquidus Temperature	t_L	60 – 150 sec
Peak Temperature	t_p	260°C
Time within 5°C of actual Peak Temperature	T_p	20 – 40 sec
Cooling Phase		
Ramp-down rate		6°C/sec max.

Notes:

All temperatures refer to the top side of the package, measured on the package body surface.

8.3. QFN40 Recommended Pad Layout

1. PCB land and solder masking recommendations are shown in Figure 23.

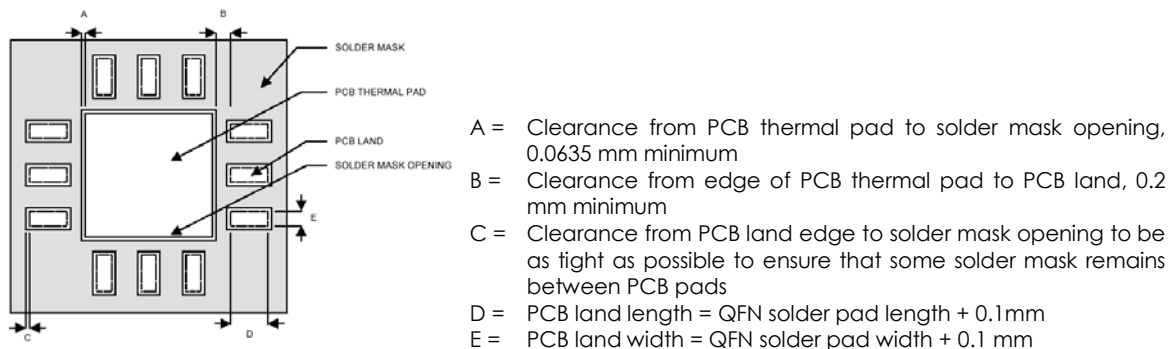


Figure 23: PCB land and solder mask recommendations

2. Thermal vias should be used on the PCB thermal pad (middle ground pad) to improve thermal conductivity from the device to a copper ground plane area on the reverse side of the printed circuit board. The number of vias depends on the package thermal requirements, as determined by thermal simulation or actual testing.
3. Increasing the number of vias through the printed circuit board will improve the thermal conductivity to the reverse side ground plane and external heat sink. In general, adding more metal through the PC board under the IC will improve operational heat transfer, but will require careful attention to uniform heating of the board during assembly.

8.4. Assembly Process

Stencil Design & Solder Paste Application

1. Stainless steel stencils are recommended for solder paste application.
2. A stencil thickness of 0.125 – 0.150 mm (5 – 6 mils) is recommended for screening.
3. For the PCB thermal pad, solder paste should be printed on the PCB by designing a stencil with an array of smaller openings that sum to 50% of the QFN exposed pad area. Solder paste should be applied through an array of squares (or circles) as shown in Figure 24.
4. The aperture opening for the signal pads should be between 50-80% of the QFN pad area as shown in Figure 25.
5. Optionally, for better solder paste release, the aperture walls should be trapezoidal and the corners rounded.
6. The fine pitch of the IC leads requires accurate alignment of the stencil and the printed circuit board. The stencil and printed circuit assembly should be aligned to within + 1 mil prior to application of the solder paste.
7. No-clean flux is recommended since flux from underneath the thermal pad will be difficult to clean if water-soluble flux is used.

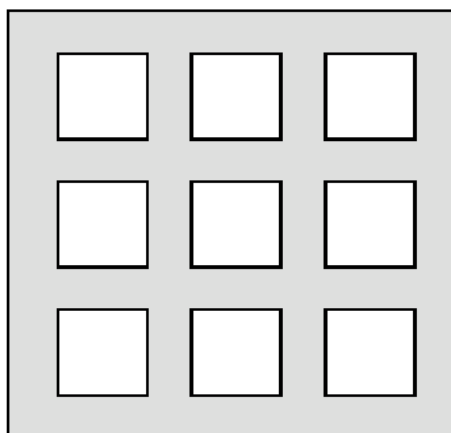


Figure 24: Solder paste application on exposed pad

**Minimum
50% coverage**

62% coverage

**Maximum
80% coverage**

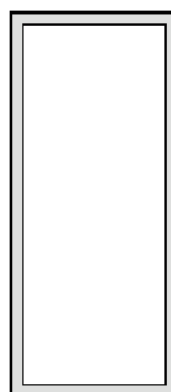
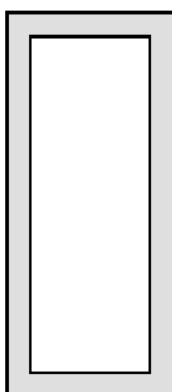
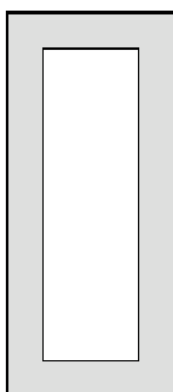


Figure 25: Solder paste application on pins

9. Life Support Applications

This product is not designed for use in life support appliances, devices, or in systems where malfunction of this product can reasonably be expected to result in personal injury. AXSEM customers using or selling this product for use in such applications do so at their own risk and agree to fully indemnify AXSEM for any damages resulting from such improper use or sale.

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