# AVR2038: AT86RF231 Range Extension

8-bit AVR® Microcontrollers

Application Note

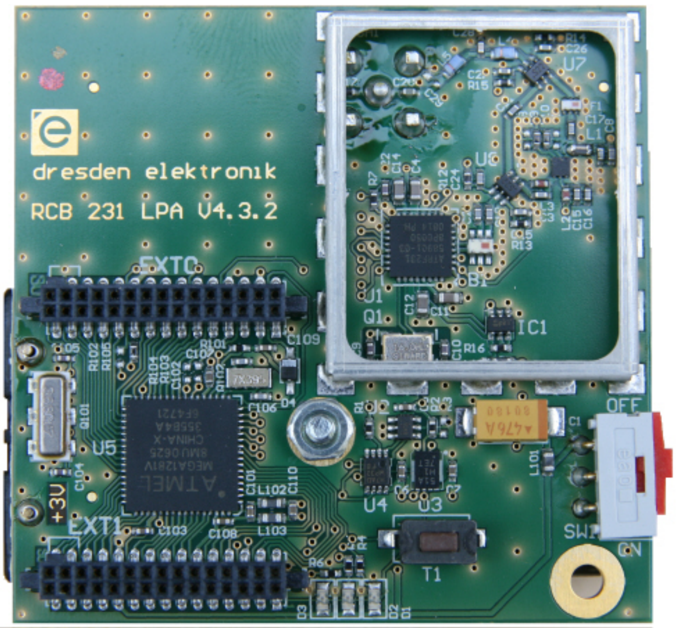
## Features

- High Performance RF-CMOS 2.4GHz Radio Transceiver for IEEE 802.15.4™, ZigBee®, ZigBee® RF4CE, 6LoWPAN, WirelessHART™ and ISM Applications
- Range Extension using High Output Transmitter
- Low Current Consumption
  - TRX_OFF = 0.4mA
  - RX_ON = 12.3mA
  - BUSY_TX = 105mA (at Transmitter Power of +18dBm)

## 1 Introduction

The application note describes the usage, design, and layout of the AT86RF231 *Range Extension*. An implementation is shown in Figure 1-1. The information provided is intended as a helping hand for hardware designers to make use of the AT86RF231 RF front-end control capabilities.

**Figure 1-1.** AT86RF231 – Range Extension.




Rev. 8340A-AVR-10/10

# 2 Disclaimer

Typical values contained in this application note are based on simulations and testing of individual examples.

# 3 Introduction

The AT86RF231 is a feature rich, low-power 2.4GHz radio transceiver designed for industrial and consumer ZigBee, ZigBee RF4CE, IEEE 802.15.4, 6LoWPAN and high data rate ISM applications.

While these application areas are typically low cost, low power standards, solutions supporting higher transmit output power are occasionally desirable. To simplify the control of an optional external RF front-end, the AT86RF231 provides a differential control pin pair to indicate a transmit operation. A detailed description, how to use and configure the RF front-end control, can be found in the AT86RF231 datasheet [1], section References.

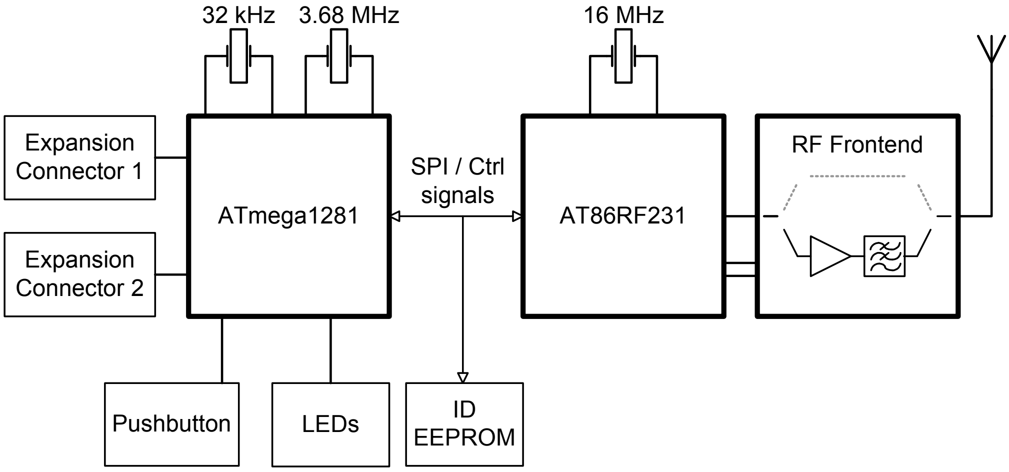
The control of an external RF front-end is done via digital control pins DIG3/DIG4. The function of this pin pair is enabled with register bit PA_EXT_EN (register 0x04, TRX_CTRL_1). While the transmitter is turned off, pin 1 (DIG3) is set to low level and pin 2 (DIG4) to high level. If the radio transceiver starts to transmit, the two pins change their polarity. This differential pin pair can be used to control PA, LNA, and RF switches.

If the AT86RF231 is not in a receive or transmit state, it is recommended to disable register bit PA_EXT_EN (register 0x04, TRX_CTRL_1) to reduce the power consumption or avoid leakage current of external RF switches and other building blocks, especially during SLEEP state. If register bits PA_EXT_EN = 0, output pins DIG3/DIG4 are both at logic low level.

# 4 Range Extension Board – Overview

Figure 4-1 illustrates the setup of the AT86RF231 *Range Extension* board. It mainly consists of three sections: the microcontroller ATmega1281/V and periphery, the radio transceiver AT86RF231 and the RF front-end with power amplifier and low-pass filtering.

**Figure 4-1.** Range Extension Board – Block Diagram.




The Atmel ATmega1281/V controls the AT86RF231 radio transceiver, and serves as an SPI master. The radio transceiver handles all actions concerning RF modulation/demodulation, signal processing, frame reception and transmission. MAC hardware acceleration functions are implemented in the radio transceiver, too. Further information about the radio transceiver and the microcontroller are available in the appropriate datasheets, refer to [1] and [2].

The RF front-end incorporates signal amplification and filtering of the transmit signal. The degree of filtering depends on operating conditions as well as regional aspects. Switching between reception and transmission is directly controlled by the radio transceiver. This allows the unlimited use of the radio transceiver MAC acceleration modes RX_AACK and TX_ARET, see [1], and reduces the microcontroller interaction significantly. The usage of a low-noise amplifier (LNA) is not demonstrated in this application note, even if it is possible by reusing already existing control signals.

All components are placed on one side of a four-layer, 1.5mm standard FR4 printed circuit board, giving a low cost manufacturing solution.

A schematic of the RCB can be found in Appendix A.1 - Schematic.

## 4.1 Power Supply

The board is powered by a single supply voltage in the range of 2.7V to 3.6V, which makes it possible to be powered by two 1.5V cells. Optionally the power can be supplied externally. All semiconductors are supplied by this power, reducing component count and power losses of voltage converters.

**Battery power**

For autonomous operation the AT86RF231 *Range Extension* board can be powered by two AAA batteries that are held by the battery clip on the back of the board. Use power switch SW1 to manually switch on/off the board.

**External power**

When used as a daughter board in a more complex system, the board can be powered through the expansion connectors. For pin mapping see Table 4-2. In this case the power switch has to be in OFF position to avoid unintentionally charging of the batteries, if they are applied.

## 4.2 Microcontroller

The Atmel ATmega1281/V is a low-power 8-bit microcontroller based on the AVR® enhanced RISC architecture. The non-volatile flash program memory of 128kB and 8kB of internal SRAM, supported by a rich set of peripheral units, makes it suitable for a full function sensor network node.

The microcontroller is capable of operating as a PAN-coordinator, a full function device (FFD) as well as a reduced function device (RFD), as defined by IEEE802.15.4 [3]. However, the AT86RF231 *Range Extension* board is not limited to this and can be programmed to operate other standards or ISM applications, too.

## 4.3 RF Section

The radio transceiver AT86RF231 contains all RF and BB critical components necessary to transmit and receive signals according to IEEE802.15.4 or proprietary ISM data rates.

In this application note, the RF front-end is used mainly to demonstrate the RX/TX indicator usage in order to control a power amplifier. A balun B1 performs the differential to single ended conversion to connect the AT86RF231 to the RF front-end. Two SPDT switches separate receive and transmit paths. The transmit path incorporates a power amplifier (PA) and low-pass filter (LPF). Both RF switches, and PA are directly controlled by the radio transceiver, for details refer to [1] in section References. Additional low pass filtering (L4/5, C28/29) between RX/TX switch U7 and antenna may be required to further suppress harmonics caused by the limited isolation of the 2/1 RF switch. The amount of harmonic filtering has to be aligned to regional requirements. For instance, operating the device according to ETSI EN 300 228 [6] or ARIB STD-T66 [7], the LPF can be removed. Furthermore, it has to be noted that ETSI EN 300 228 limits the transmitter output power to +10dBm/MHz ERP. The transmitter output power for boards operating under ARIB STD-T66 depends on the data rate selected.

Note - any modification in the PA RF path, including the LPF, requires a review of the RF front-end circuitry to ensure an optimum operating point of the PA. Any modification of components, PCB layout and shielding influences the performance of the circuitry.

A separate switched supply $V_{DD\_SW}$ for the RF front-end, see Figure A. 1-2, disconnects it from the main radio transceiver power supply $V_{DD}$ in case of no active transceiver operation. This ensures the lowest possible current consumption for all other operating modes. If this is not needed, IC1B and R16 are not required; $V_{DD\_SW}$ can be connected to $V_{DD}$ via L12.

An antenna has to be connected to the SMA connector for proper operation.

## 4.4 Clock Sources

### Radio Transceiver

The radio transceiver is clocked by the 16MHz reference crystal Q1. The 2.4GHz modulated signal is derived from this clock. Operating the node according to IEEE802.15.4 [3] the reference frequency should not exceed a deviation of ±40ppm. The absolute frequency is mainly determined by the external load capacitance of the crystal, which depends on the crystal type and is given in its datasheet.

The radio transceiver reference crystal Q1 is isolated from fast switching digital signals and surrounded by the ground plane to minimize disturbances of the oscillation.

The AT86RF231 *Range Extension* board uses a SIWARD crystal SX4025 with two load capacitors of 10pF. To compensate fabrication and environment variations the frequency can be tuned with the transceiver register “XOSC_CTRL (0x12)”, for more detailed information refer to [1], section References. An initial tuning is done during fabrication and stored in the onboard EEPROM, also carrying the board ID, see section 4.6.

**Microcontroller**

There are various clock source options for the microcontroller Atmel ATmega1281/V.

- 8MHz calibrated internal RC oscillator
- 128kHz internal RC oscillator
- 3.6872MHz ceramic resonator
- CLKM 1..16MHz (radio transceiver clock)

The 8MHz calibrated internal RC oscillator is used as the default clocking. The CLKM signal, generated by the transceiver, is connected to T1 (PD6) of the ATmega1281V and can be used as a symbol synchronous counter as well as a reference clock to calibrate the internal RC oscillator. Optionally, the microcontroller can be clocked directly from the CLKM signal, for this purpose the 0Ω resistor R105 has to be soldered to R102 and R104 has to be mounted. In this configuration Q101 and C104/5 are not required.

A 32kHz crystal is connected to the AVR pins (TOSC1, TOSC2) to be used as a low power real time clock. The connection of the SLP_TR pin of the radio transceiver to the OC2A pin (PB4) of the ATmega1281/V makes it possible to wake up both the microcontroller and the radio transceiver simultaneously from a *Timer 2 Output Compare Match* event.

This operation mode saves valuable time in a cycled sleep/wakeup network scenario.

## 4.5 On-Board Peripherals

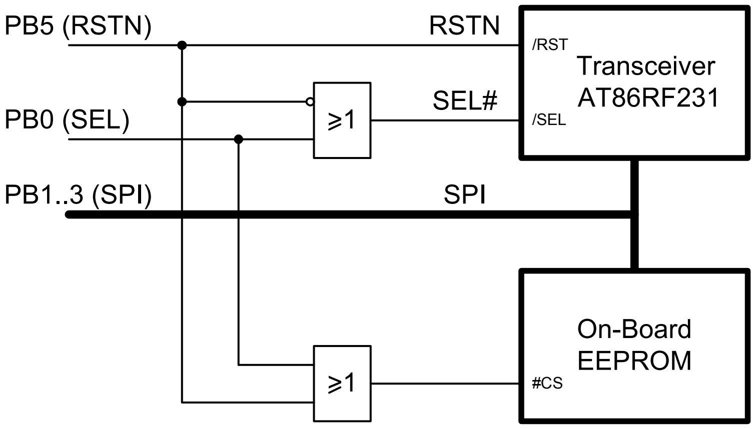
For simple applications, debugging purposes or just to deliver status information, a basic user interface is provided directly on the board, consisting of three LED’s and a pushbutton connected to Port E (PE2…PE4 and PE5).

## 4.6 ID EEPROM

To identify the board type by software, an optional identification EEPROM is populated. Information about the board, the node MAC address and production calibration values are stored here. An Atmel AT25010A with 128 x 8 bit organization and SPI interface is used because of its small package, and low voltage and low power operation.

For interfacing the EEPROM, the SPI bus is shared with the transceiver. The select signal for each of the SPI slave (EEPROM, radio transceiver) is decoded with the reset line RSTN of the transceiver. Therefore, the EEPROM is addressed when the radio transceiver is held in reset (RSTN = 0), see Figure 4-2.

**Figure 4-2.** EEPROM Access Decoding Logic.




The EEPROM data is written during board production test. A unique serial number; the MAC address[1] as well as calibration values, is stored. These can be used to optimize system performance.

Final products do not require this external ID EEPROM. All data can be stored directly in the microcontroller internal EEPROM. The following table gives the data structure of the EEPROM.

**Table 4-1.** ID EEPROM Mapping.

| **Address** | **Name** | **Type** | **Description** |
|---|---|---|---|
| 0x40 | MAC address | uint64 | MAC address [1] for the 802.15.4 node, little endian byte order |
| 0x48 | Serial Number | uint64 | Board serial number, little endian byte order |
| 0x50 | Board Family | uint8 | Internal board family identifier |
| 0x51 | Revision | uint8[3] | Board revision number ##.##.## |
| 0x54 | Feature | uint8 | Board features, coded into seven bits<br>7 – Reserved<br>6 – Reserved<br>5 – External LNA<br>4 – External PA<br>3 – Reserved<br>2 – Diversity<br>1 – Antenna<br>0 – SMA connector |
| 0x55 | Cal OSC 16MHz | uint8 | RF231 XTAL calibration value, register “XTAL_TRIM” |
| 0x56 | Cal RC 3.6V | uint8 | AVR internal RC oscillator calibration value @ 3.6V, register “OSCCAL” |
| 0x57 | Cal RC 2.0V | uint8 | AVR internal RC oscillator calibration value @ 2.0V, register “OSCCAL” |
| 0x58 | Antenna Gain | int8 | Antenna gain [1/10dBi] |
| 0x60 | Board Name | char[30] | Textual board description |

| Address | Name | Type | Description |
|---|---|---|---|
| 0x7E | CRC | uint16 | 16 Bit CRC checksum, standard ITU-T generator polynomial $G_{16}(x) = x^{16} + x^{12} + x^5 + 1$ |

Note: 1. MAC addresses used for this package are Atmel property. The use of these MAC addresses for development purposes is permitted.

### 4.7 External Peripherals

The RCB is equipped with two 50 mil connectors to place the board on a variety of expansion boards. The connectors provide access to all spare Atmel ATmega1281/V pins, including USART, TWI, ADC, PWM and external memory pins.

The detailed pin mapping is shown in Table 4-2.

**Table 4-2.** Expansion Connector Mapping.

| EXT0 | | | | EXT1 | | | |
|---|---|---|---|---|---|---|---|
| **Pin#** | **Function** | **Pin#** | **Function** | **Pin#** | **Function** | **Pin#** | **Function** |
| 1 | PB6 | 2 | PB7 | 1 | PB1 (SCK) | 2 | GND |
| 3 | #RESET | 4 | VCC | 3 | PE7 | 4 | PE6 |
| 5 | GND | 6 | XTAL2 | 5 | PE5 | 6 | PE4 |
| 7 | XTAL1 | 8 | GND | 7 | PE3 | 8 | PE2 |
| 9 | PD0 (SCL) | 10 | PD1 (SDA) | 9 | PE1 (PDO) | 10 | PE0 (PDI) |
| 11 | PD2 (RXD1) | 12 | PD3 (TXD1) | 11 | AGND | 12 | AREF |
| 13 | PD4 | 14 | PD5 | 13 | PF0 | 14 | PF1 |
| 15 | PD6 (CLKM) | 16 | PD7 | 15 | PF2 | 16 | PF3 |
| 17 | PG0 (#WR) | 18 | PG1 (#RD) | 17 | PF4 (TCK) | 18 | PF5 (TMS) |
| 19 | GND | 20 | GND | 19 | PF6 (TDO) | 20 | PF7 (TDI) |
| 21 | PC0 | 22 | PC1 | 21 | Vcc | 22 | GND |
| 23 | PC2 | 24 | PC3 | 23 | PA0 | 24 | PA1 |
| 25 | PC4 | 26 | PC5 | 25 | PA2 | 26 | PA3 |
| 27 | PC6 | 28 | PC7 | 27 | PA4 | 28 | PA5 |
| 29 | GND | 30 | PG2 (ALE) | 29 | PA6 | 30 | PA7 |

## 5 Programming

This RCB type of board provides all required programming interfaces through the two 50 mil connectors. Using an appropriate expansion board the interfaces are available as 100 mil connectors to connect for instances to a JTAGICE mkII.

# 6 Electrical Characteristics

## 6.1 Absolute Maximum Ratings

Absolute maximum ratings are dependent on the individual parts and their usage within the final design. For details about these parameters, refer to individual datasheets of the components used.

## 6.2 Recommended Operating Range

**Table 6-1.** Operating Range.

| No. | Symbol | Parameter | Condition | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|---|
| 6.2.1 | $T_{OP}$ | Operating temperature range (1) | | -20 | | +70 | °C |
| 6.2.2 | $f_{RF}$ | Operating frequency range | | 2400 | | 2483.5 | MHz |
| 6.2.3 | $V_{CC}$ | Supply voltage | | 2.7 (2) | 3.0 | 3.6 | V |

Notes:
1. Operating temperature range is limited by crystal only, other important components covering a range of -40…+85°C. For details refer individual datasheets.
2. Minimum value set by power amplifier specification. A lower value of the minimum supply voltage will affect the TX output power.

## 6.3 General RF Specifications

Test Conditions (unless otherwise stated):

$V_{DD}$ = 3.0V, $f_{RF}$ = 2.45GHz, $T_{OP}$ = 25°C

**Table 6-2.** RF Specifications.

| No. | Symbol | Parameter | Condition | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|---|
| 6.3.1 | $f_{RF}$ | Frequency range | As specified in [3] | 2405 | | 2480 | MHz |
| 6.3.2 | $f_{CH}$ | Channel spacing | As specified in [3] | | 5 | | MHz |
| 6.3.3 | $f_{HDR}$ | Header bit rate (SHR, PHR) | As specified in [3] | | 250 | | kb/s |
| 6.3.4 | $f_{PSDU\_Sym}$ | PSDU symbol rate | As specified in [3] | | 62.5 | | ks/s |
| 6.3.5 | $f_{PSDU\_Bit}$ | PSDU bit rate | As specified in [3]<br>OQPSK_DATA_RATE = 1<br>OQPSK_DATA_RATE = 2<br>OQPSK_DATA_RATE = 3 | | 250<br>500<br>1000<br>2000 | | kb/s<br>kb/s<br>kb/s<br>kb/s |
| 6.3.6 | $f_{CHIP}$ | Chip rate | As specified in [3] | | 2000 | | kchip/s |
| 6.3.7 | $f_{XTAL}$ | Crystal oscillator frequency | Reference oscillator (XTAL) | | 16 | | MHz |
| 6.3.8 | $f_{XTAL\_ACC}$ | XTAL frequency accuracy | | -40 (1) | | +40 | ppm |
| 6.3.9 | $t_{XTAL}$ | XTAL settling time | Leaving SLEEP state to clock available at pin 17 (CLKM) | | 330 | 1000 | µs |
| 6.3.10 | $B_{20dB}$ | 20dB bandwidth | | | 2.8 | | MHz |

Note: 1. A reference frequency accuracy of ±40ppm is required by [3].

## 6.4 Transmitter Characteristics

Test Conditions (unless otherwise stated):

$V_{CC}$ = 3.0V, $f_{RF}$ = 2.45GHz, $T_{OP}$ = 25°C

**Table 6-3.** Transmitter Characteristics.

| No. | Symbol | Parameter | Condition | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|---|
| 6.4.1 | $P_{TX}$ | TX Output power | Maximum configurable TX output power value (2)<br>Register bit TX_PWR = 0 | -4 (3) | +18 (1) | +21 (3) | dBm |
| 6.4.2 | $P_{RANGE}$ | Output power range | 16 steps, configurable in register 0x05 (PHY_TX_PWR) | | 15 | | dB |
| 6.4.3 | $P_{ACC}$ | Output power tolerance | | | | ±3 | dB |
| 6.4.4 | | EVM | | | 8 | | % rms |
| 6.4.5 | $P_{HARM}$ | Harmonics (FCC) (1)<br>2nd harmonic<br>3rd harmonic | Pout = Pmax<br>CW, no modulation | | <br>-42<br>-50 | | <br>dBm<br>dBm |
| 6.4.6 | $P_{SPUR}$ | Spurious Emissions<br>30 – ≤1000MHz<br>>1 – 12.75GHz<br>1.8 – 1.9GHz<br>5.15 – 5.3GHz | Complies with (1)<br>EN 300 328/440,<br>FCC-CFR-47 part 15,<br>ARIB STD-66, RSS-210 | | <br>-36<br>-30<br>-47<br>-47 | | <br>dBm<br>dBm<br>dBm<br>dBm |

Notes:
1. Note - the operation of devices using a high output power has to follow rules of the local regulatory bodies, like FCC [5], ETSI [6], ARIB [7] or other authorities.
2. According to EN 300 328 and STD-T66 (partly) the TX output power is limited to 10mW/MHz. The low-pass filter consisting of L4/5 and C28/29 is not required.
3. Min. and Max. are typical values for minimum output power at lowest supply voltage or maximum output power at maximum supply voltage, respectively.

## 6.5 Current Consumption Specifications

Test Conditions (unless otherwise stated) (1) (2)

$V_{DD}$ = 3.0V, $f_{RF}$ = 2.45GHz, $T_{OP}$ = 25°C, MCU off

**Table 6-4.** Current Consumption Specifications.

| No. | Symbol | Parameter | Condition | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|---|
| 6.5.1 | $I_{BUSY\_TX}$ | Supply current transmit state | $P_{TX,max}$ = +18dBm<br>$P_{TX,min}$ = +4dBm | | 105<br>36 | | mA<br>mA |
| 6.5.2 | $I_{RX\_ON}$ | Supply current RX_ON state | RX_ON state – high input level (3) | | 10.3 | | mA |
| 6.5.3 | $I_{RX\_ON}$ | Supply current RX_ON state | RX_ON state – high sensitivity | | 12.3 | | mA |
| 6.5.4 | $I_{RX\_ON\_P}$ | Supply current RX_ON state | RX_ON state, with register setting RX_PDT_LEVEL > 0 | | 11.8 | | mA |
| 6.5.5 | $I_{PLL\_ON}$ | Supply current PLL_ON state | PLL_ON state | | 5.6 | | mA |
| 6.5.6 | $I_{TRX\_OFF}$ | Supply current TRX_OFF state | TRX_OFF state | | 0.4 | | mA |
| 6.5.7 | $I_{SLEEP}$ | Supply current SLEEP state | SLEEP state | | | 0.02 | µA |

Notes:
1. Current consumption figures does not include microcontroller.
2. Current consumption for all operating modes is reduced at lower $V_{DD}$.
3. Current consumption for operating modes other than transmit are similar to radio transceiver only without RF front-end, see [1].

# 7 Typical Characteristics

## 7.1 TX Supply Current

The following charts each show a typical behavior of the AT86RF231 *Range Extension* Boards. These figures are examples only and not tested during manufacturing.

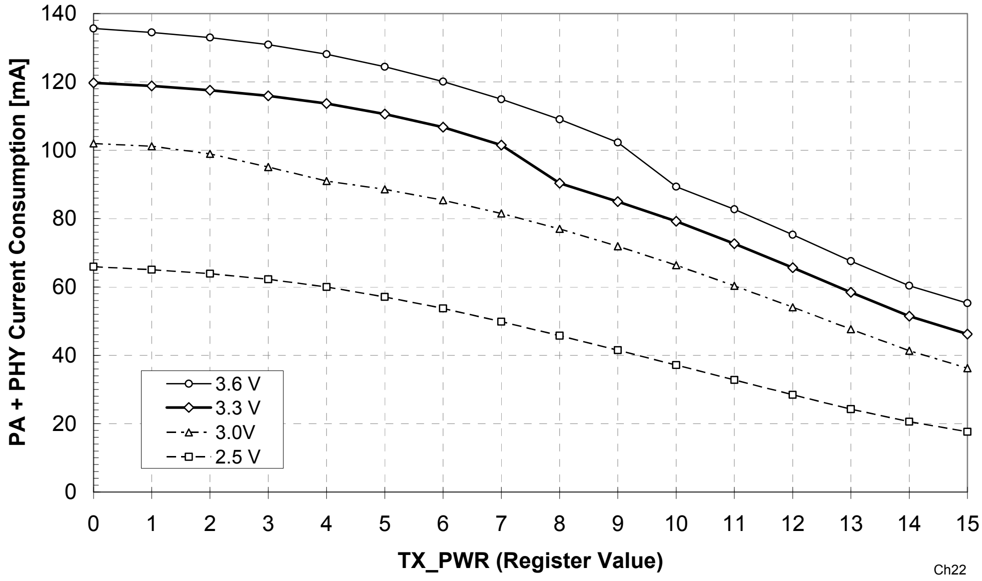
Power consumption of the microcontroller required to program the radio transceiver as well as power consumption of the LED's are not included in the measurement results.

The current consumption is a function of several factors such as: operating voltage, operating frequency, loading of I/O pins, switching rate of I/O pins, and ambient temperature. The dominating factors are operating voltage and ambient temperature.

If possible, measurement results are not affected by current drawn from I/O pins. Register, SRAM or Frame Buffer read or write accesses are not performed during current consumption measurements.

### 7.1.1 TX_BUSY state

**Figure 7-1.** Current Consumption vs. TX_PWR.




Note: Setting of AT86RF231 register bits TX_PWR are according to [1]. The highest radio transceiver output power of +3dBm is achieved by setting register bits TX_PWR = 0, and the lowest radio transceiver TX output power of -17dBm with TX_PWR = 0, respectively. For further details refer to [1], section References, and see Figure 7-4.

**Figure 7-2.** Current Consumption vs. TX Output Power.

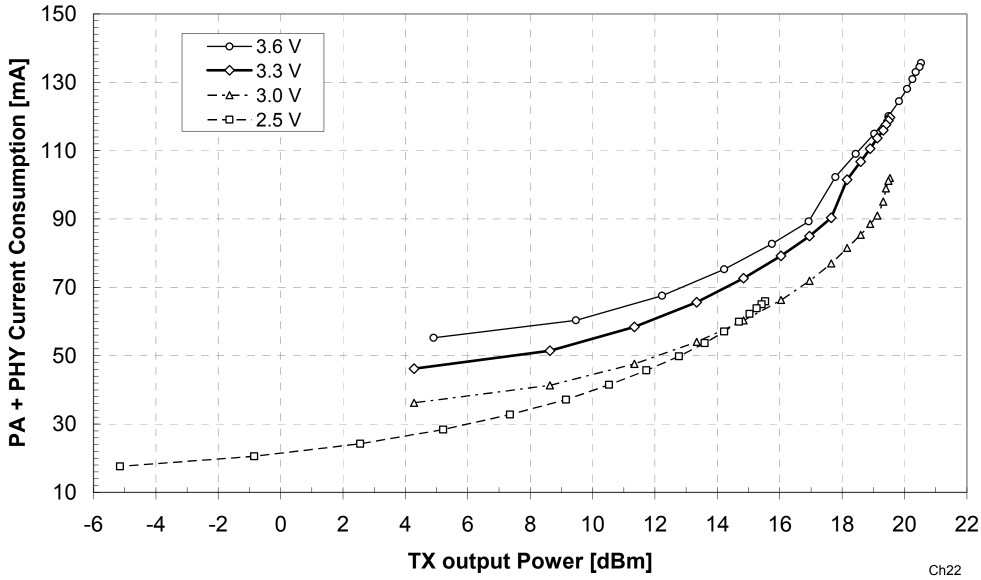
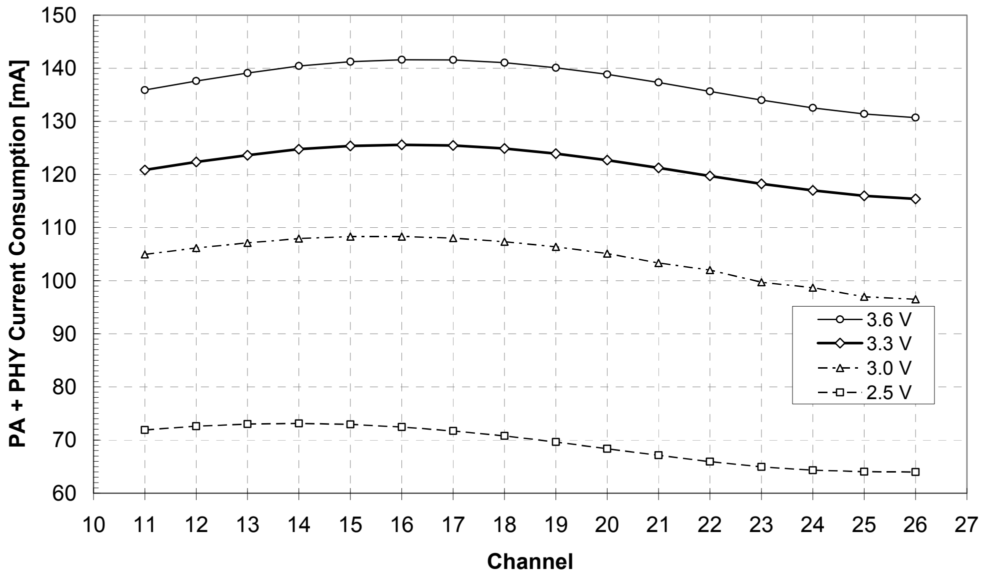


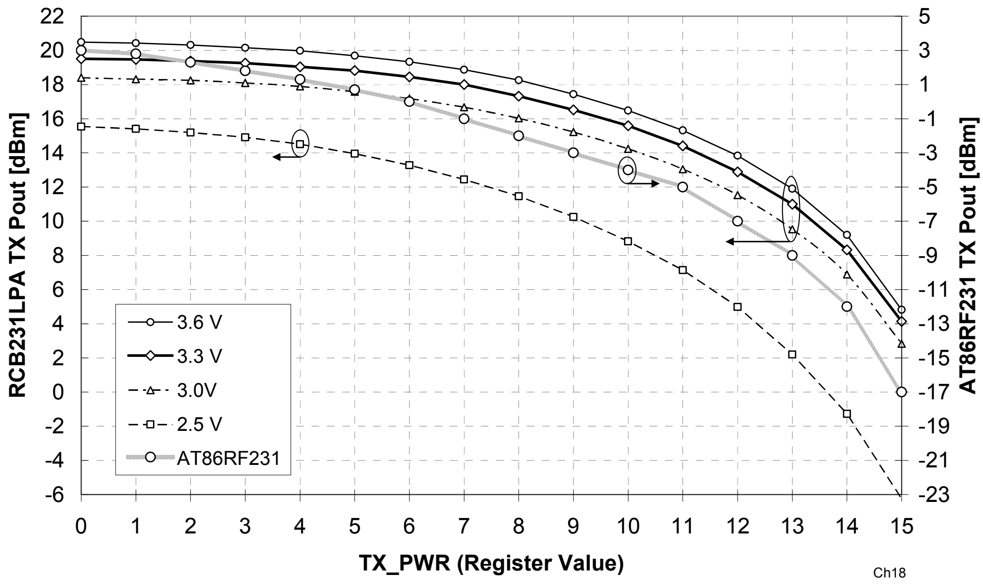

**Figure 7-3.** Current Consumption vs. Channel (TX_PWR = 0).



## 7.2 TX Performance

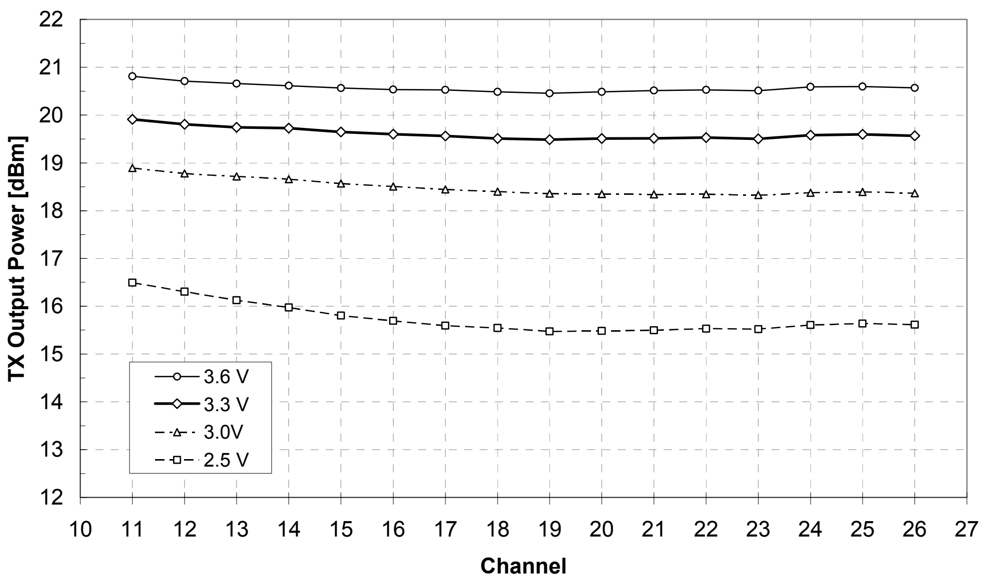
### 7.2.1 TX Output Power

**Figure 7-4.** TX Output Power vs. TX_PWR.




### 7.2.2 TX Output Power vs. IEEE802.15.4 Channel

**Figure 7-5.** TX Output Power vs. Channel (TX_PWR = 0).



### 7.2.3 TX Modulation Accuracy (EVM)

**Figure 7-6.** Error Vector Magnitude vs. TX Output Power.

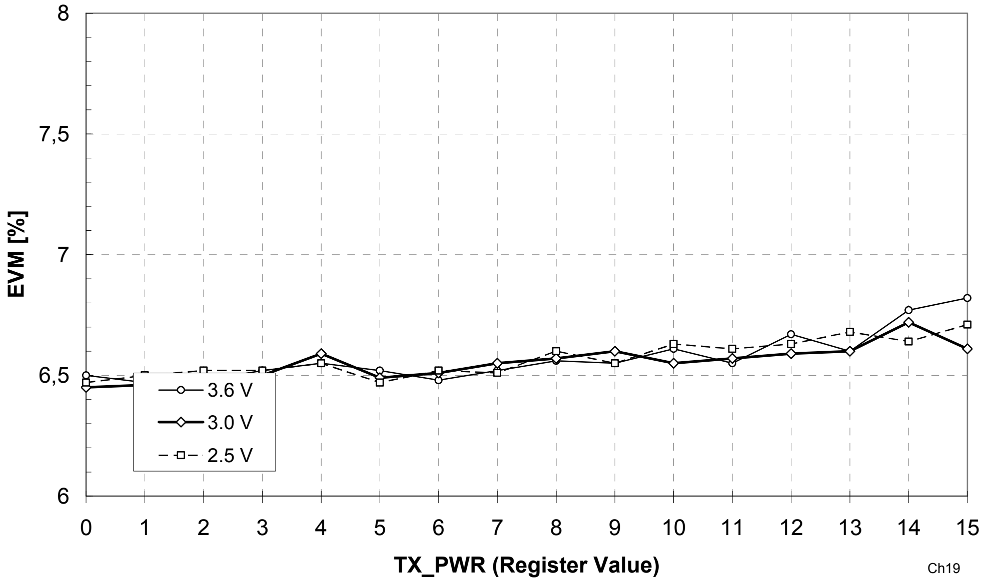
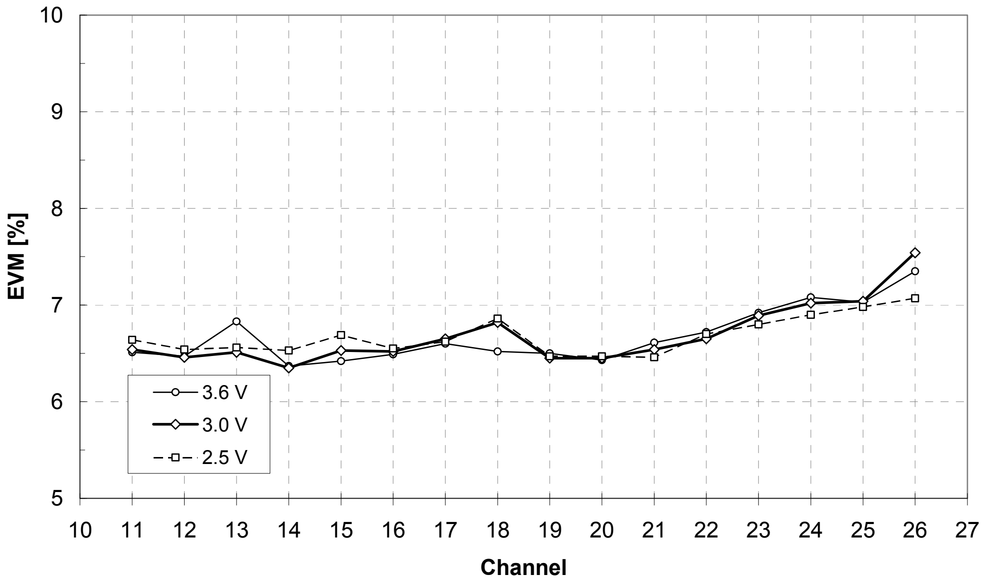
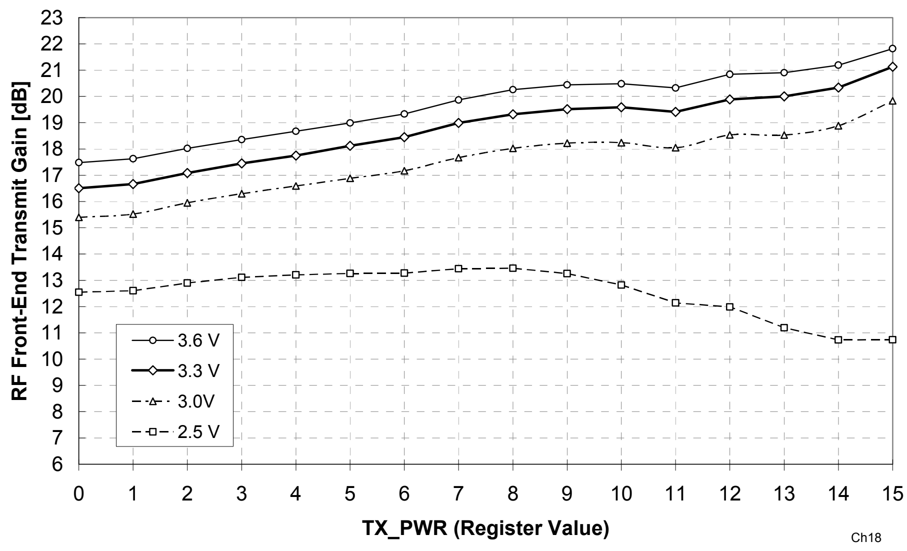



**Figure 7-7.** Error Vector Magnitude vs. IEEE802.15.4 Channel (TX_PWR = 0).



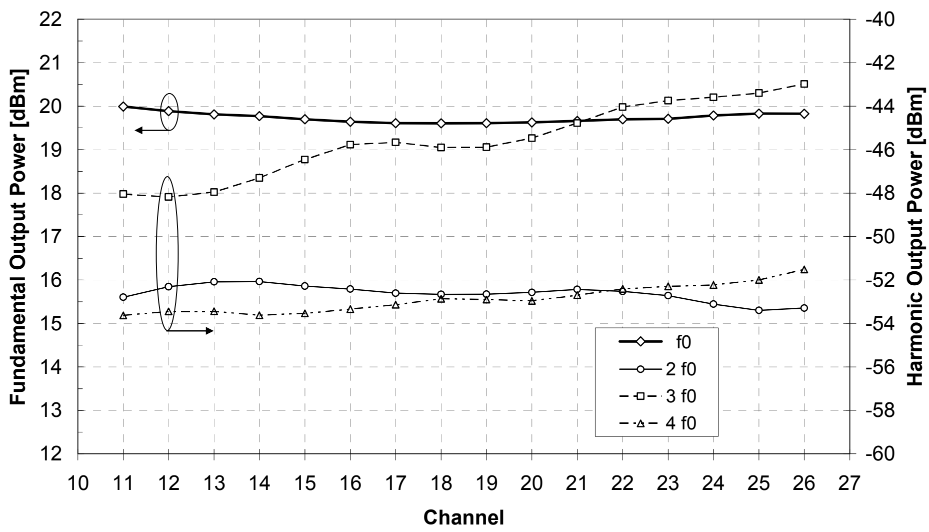
### 7.2.4 RF Front-End Transmit Gain

**Figure 7-8.** RF Front-End Overall Transmit Gain.




### 7.2.5 Harmonics

**Figure 7-9.** TX $P_{out}$ and Harmonics vs. IEEE802.15.4 Channel (TX_PWR = 0)




Note: Harmonic measurement results shown in this paper are derived using CW signals without modulation, and therefore illustrating a worst case scenario. Applying normal TX test mode operation using IEEE802.15.4 modulated signals, harmonic power is further reduced due to the relation of a limited measurement detector bandwidth and a wide modulation bandwidth.

### 7.2.6 Spurious Emissions – FCC

**Figure 7-10.** FCC Band Edge Spurious Emissions (conducted).

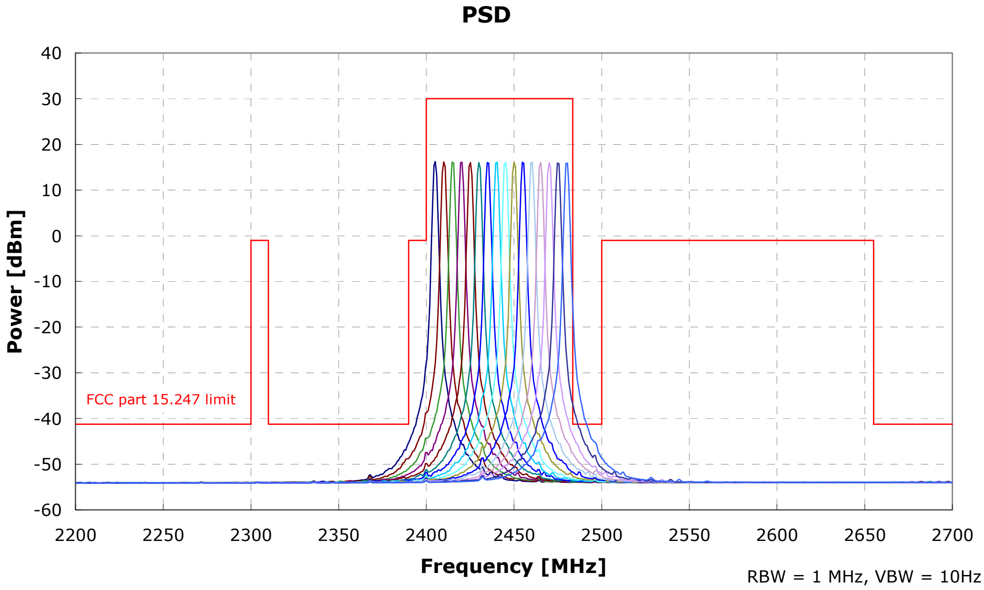



**Figure 7-11.** FCC Band Edge Spurious Emissions (conducted), Lower Band Edge.

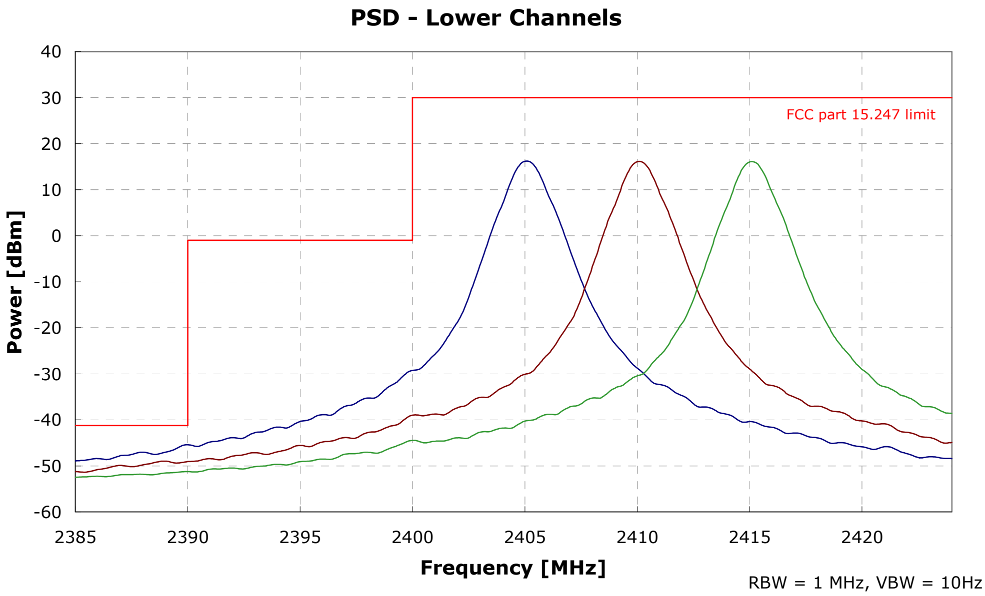
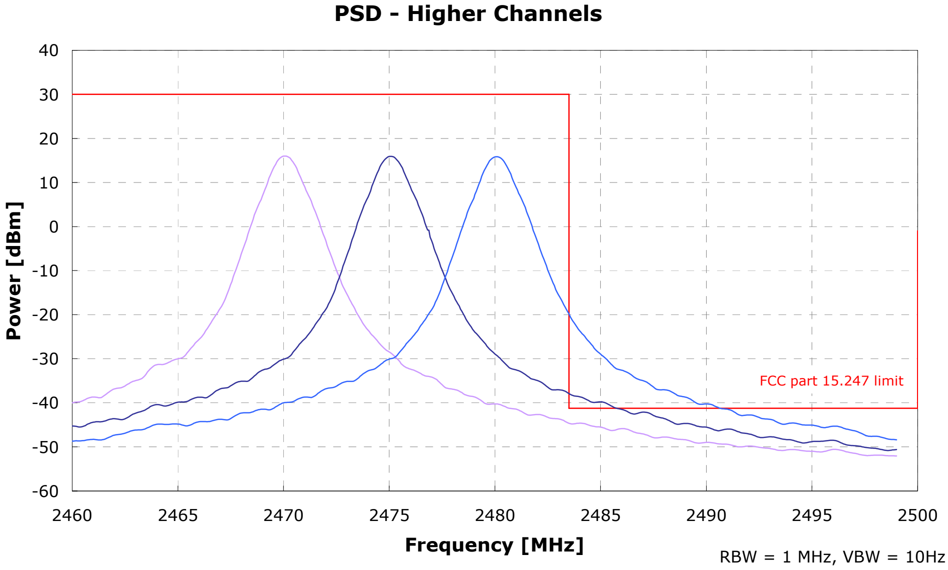


**Figure 7-12.** FCC Band Edge Spurious Emissions (conducted), Upper Band Edge.

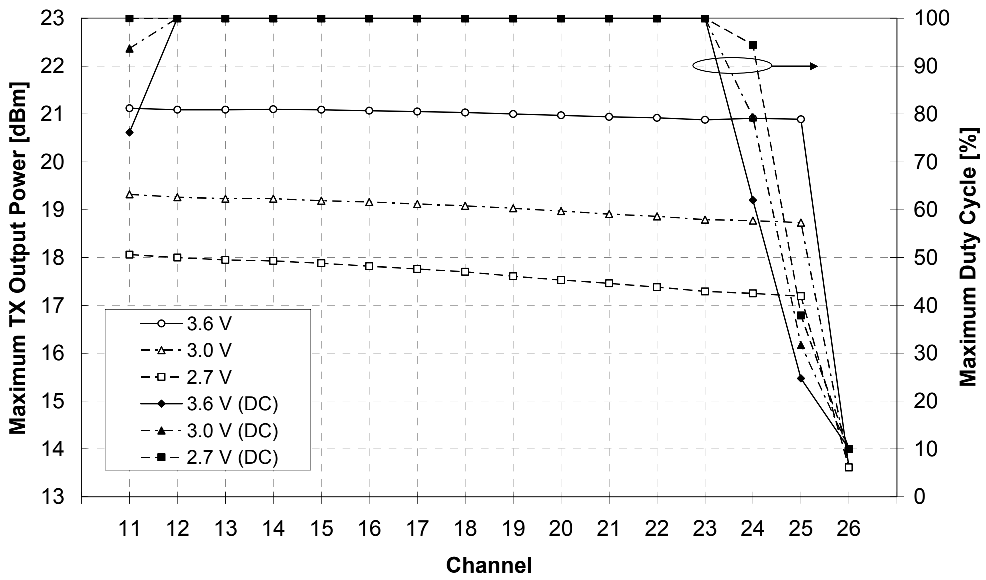



| | |
|---|---|
| Note: | Operating the AT86RF231 *Range Extension* in the United States, FCC regulates the usage of such devices intended for unlicensed operation in the 2.4GHz ISM band [5]. A summary is given in IEEE802.15.4-2006 [3]; refer to the informative Annex F, IEEE 802.15.4 regulatory requirements.<br><br>Harmonic requirements of Section 15.247 of FCC CFR47 are easily achieved using the low pass filter consisting of L4/5 and C28/29, even if $2^{nd}$ and $3^{rd}$ harmonics fall into restricted bands. Most critical areas are spurious emissions at lower and upper band edges. Especially the upper band edge requirement is hard to achieve for devices transmitting at higher output power. According to FCC Part 15.247, an IEEE802.15.4 compliant device using DSSS modulation is allowed to transmit up to +30dBm (conducted).<br><br>Referring to Figure 7-12, out-of band power from certain channels violates the requirements of FCC 15.247 in the restricted bands up to 2390MHz and starting from 2483.5MHz. To achieve this requirement, the output power of the affected channels has to be reduced and/or a duty cycle has to be introduced.<br><br>To investigate spurious emissions for frequencies above 1GHz, FCC CFR47 specifies peak and average limits in combination with specific detectors. The averaging limit is related to a 100ms reference period. The application of the average detector allows higher fundamental if the active on-air transmit time is less than the reference period. A relaxation factor can be calculated according to:<br><br>min{20 dB; 20log((TX on-air time)/100ms)}<br><br>This factor may be applied to the spurious emissions. In other words, if spurious emissions are above the average limit, duty cycle operation has to be introduced to fulfill specification. However, this can be applied to an average reading only, peak limits are to be fulfilled without exceptions. A peak limit violation requires TX output power back-off for the affected channel. |

In this example, assuming conducted measurements and taking no band-edge spur margin into account, a duty cycle and/or back-off is required for a few channels. The required duty cycle and/or back-off depend on the final implementation, in detail the achieved TX output power.

Conducted band-edge measurements, resulting in a certain duty-cycle and/or back-off requirements as shown in Figure 7-13, are derived following FCC recommendations published in FCC public notice DA00-705, also known as marker delta method.

**Figure 7-13.** AT86RF231 *Range Extension* Duty-Cycle and PA Back-Off.



# Appendix A – Design

## A.1 - Schematic

**Figure A.1-1.** RCB231LPA – RF Front-End Section.

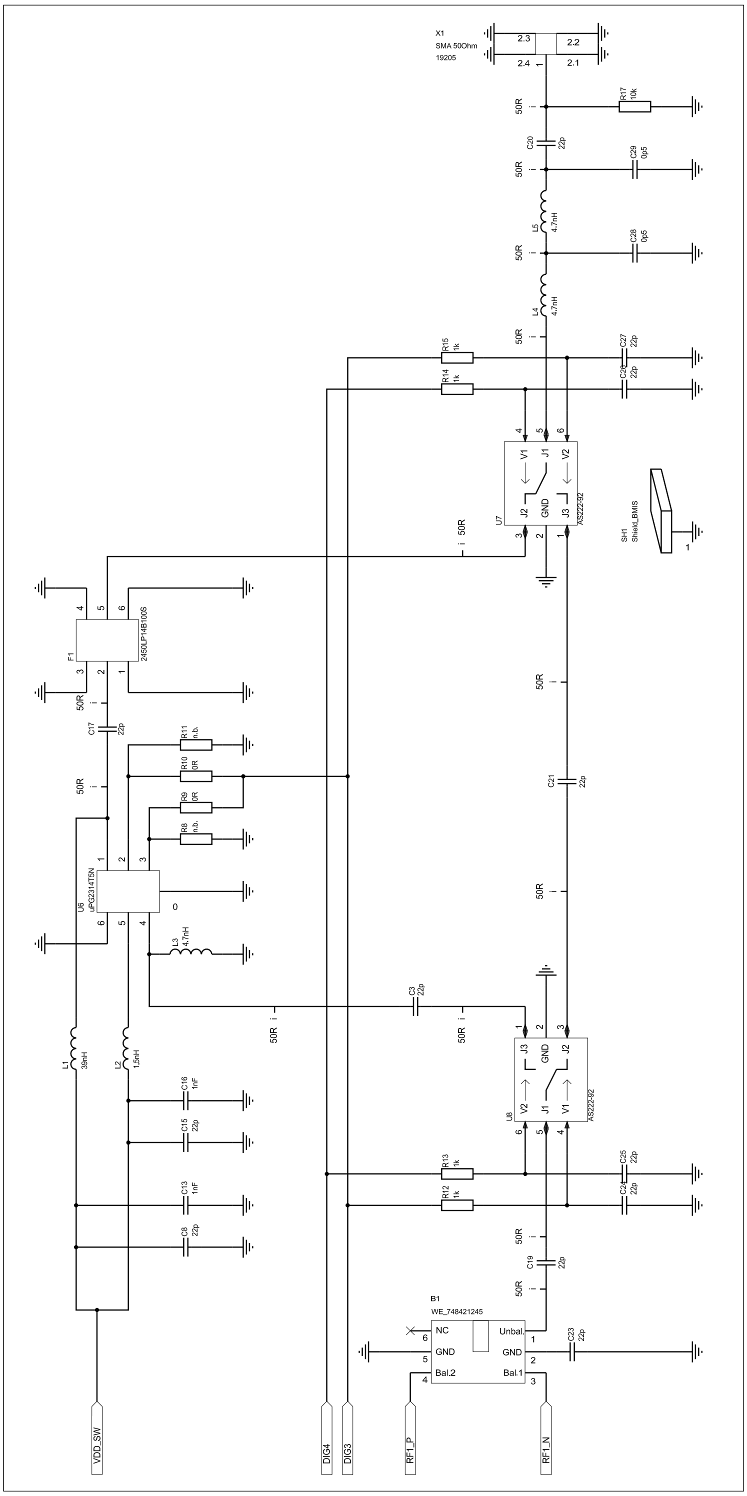


**Figure A. 1-2.** RCB231LPA – Transceiver Section.

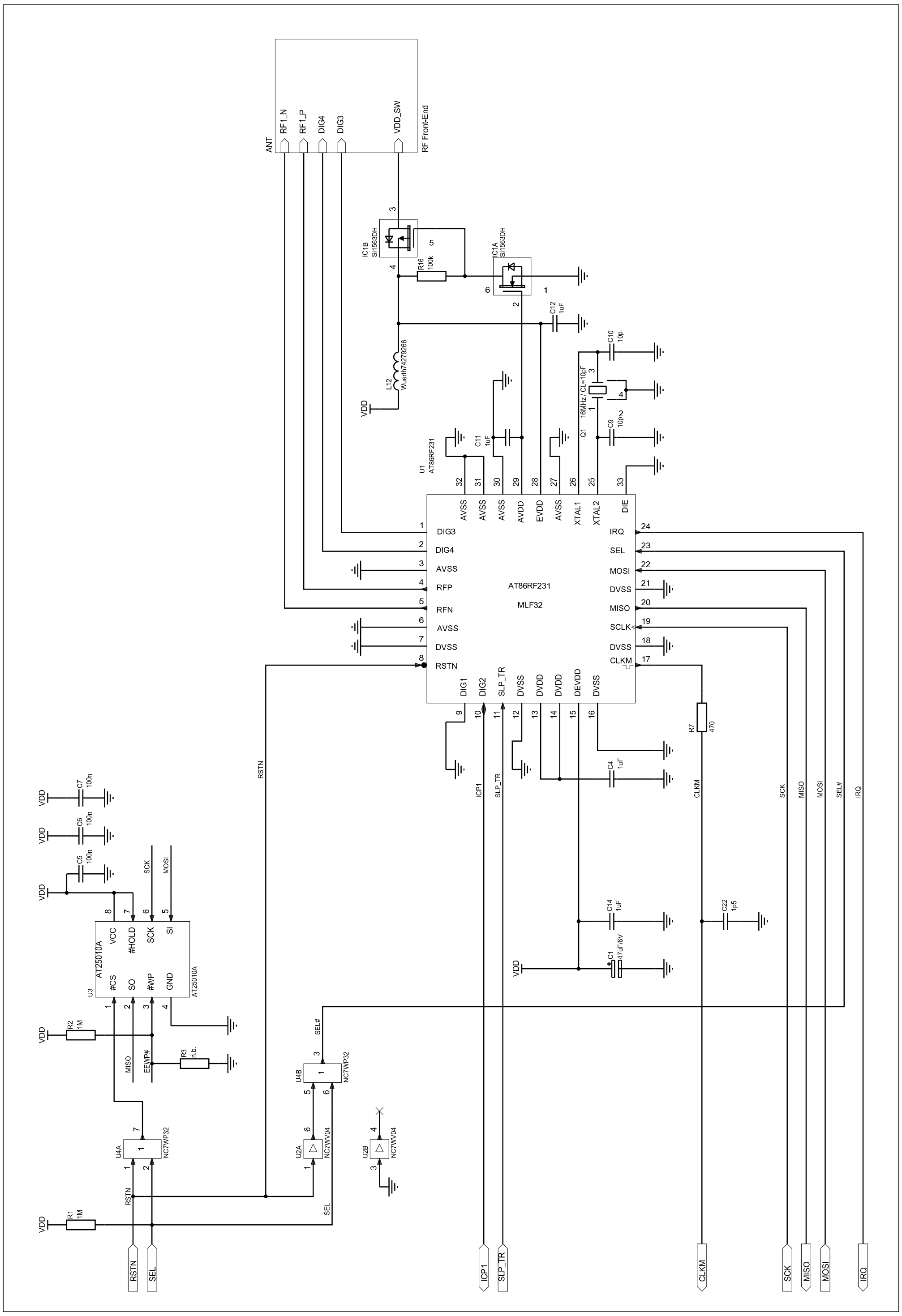
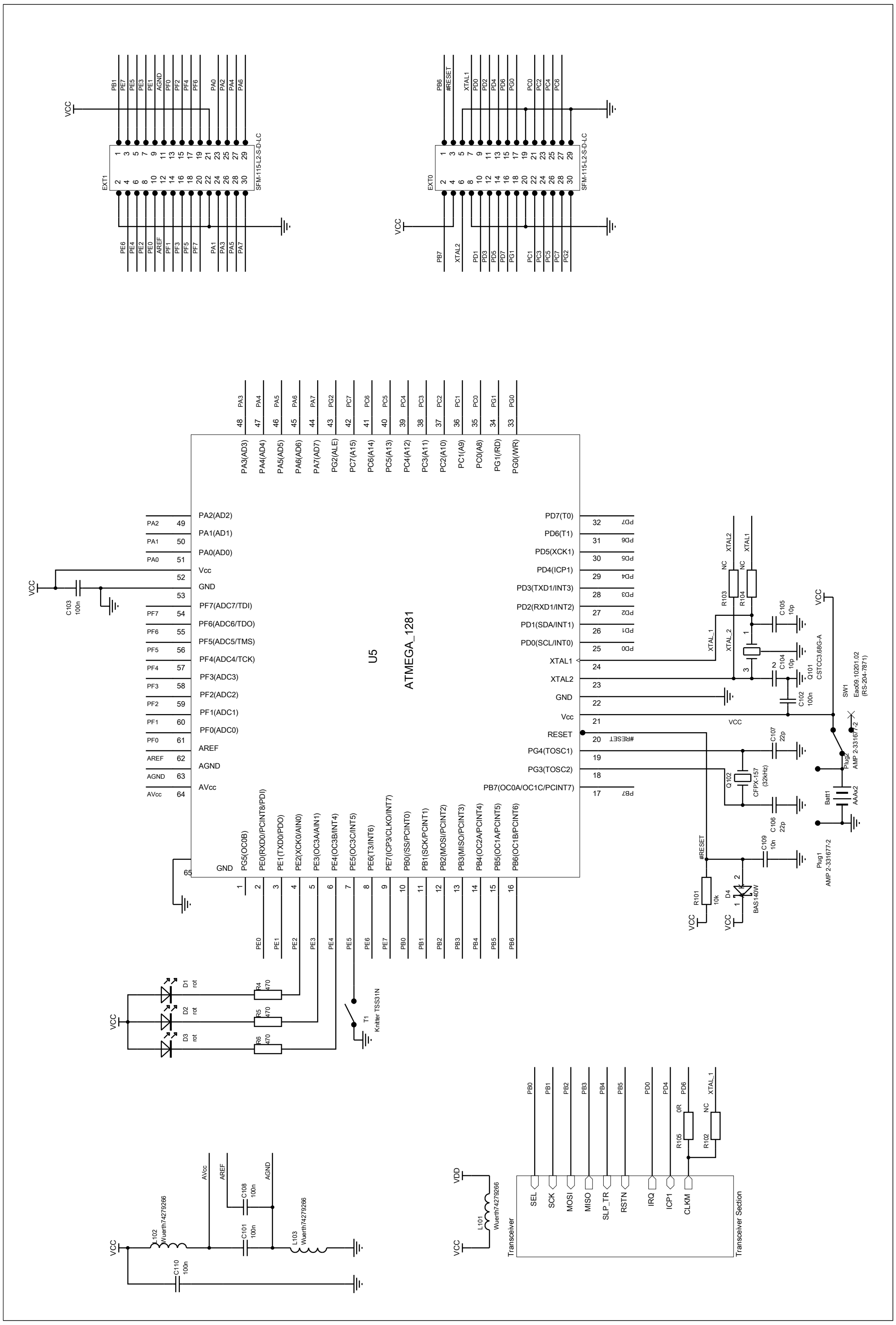
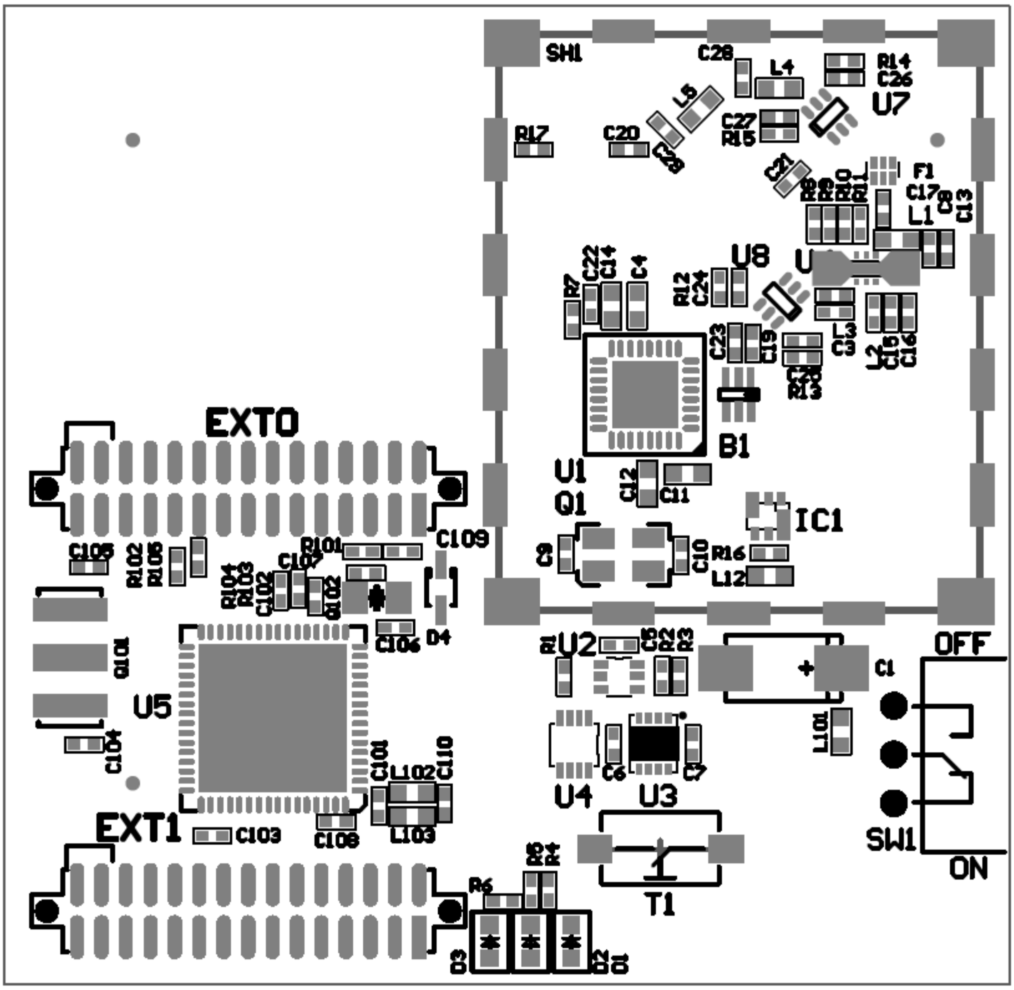


**Figure A. 1-3.** RCB231LPA – MCU Section.



## A.2 – Assembly Drawing

**Figure A. 2-4.** RCB231LPA – Assembly Drawing.






8340A-AVR-10/10

## A.3 – Bill of Material (BoM)

| Quantity | Comment | Description | Designator | Footprint |
|---|---|---|---|---|
| 1 | WE_748421245 | Balun Wuert 748421245 | B1 | BALUN0805 |
| 1 | AAAx2 | Battery | Batt1 | BH-421-3 |
| 1 | 47uF/6V | Electrolytic Capacitor | C1 | TANTAL_C |
| 14 | 22p | Capacitor | C3, C8, C15, C17, C19, C20, C21, C23, C24, C25, C26, C27, C106, C107 | 0402 |
| 4 | 1uF | Capacitor | C4, C11, C12, C14 | 0603 |
| 8 | 100n | Capacitor | C5, C6, C7, C101, C102, C103, C108, C110 | 0402 |
| 4 | 10p | Capacitor | C9, C10, C104, C105 | 0402 |
| 2 | 1nF | Capacitor | C13, C16 | 0402 |
| 1 | 1p5 | Capacitor | C22 | 0402 |
| 1 | 0p5 | Capacitor | C28 | 0402 |
| 1 | 0p5 | Capacitor | C29 | 0402 |
| 1 | 10n | Capacitor | C109 | 0402 |
| 3 | rot | | D1, D2, D3 | LED0603 |
| 1 | BAS140W | Schottky Diode | D4 | SOD-323 |
| 1 | SFM-115-L2-S-D-LC | Connector 15x2-pol. | EXT0 | SFM15 |
| 1 | SFM-115-L2-S-D-LC | | EXT1 | SFM15 |
| 1 | 2450LP14B100S | | F1 | 0603-6 |
| 1 | Si1563DH | MOSFET | IC1 | SOT-SC70/6-Dual Co |
| 1 | 39nH | Inductor | L1 | 0603 |
| 1 | 1,5nH | Inductor | L2 | 0402 |
| 1 | 4.7nH | Inductor | L3 | 0402 |
| 2 | 4.7nH | Inductor | L4, L5 | 0603 |
| 4 | Wuerth74279266 | | L12, L101, L102, L103 | 0603 |
| 1 | Logo 1 | | LG1 | LOGO solder |
| 1 | Logo 2 | | LG2 | LOGO solder |
| 1 | Nut | | NT1 | |
| 1 | M2,5x8 | | NT2 | |
| 2 | AMP 2-331677-2 | | Plug1, Plug2 | |
| 1 | 16MHz / CL=10pF | Crystal Siward A207-011 | Q1 | XTAL_4X2_5_small |
| 1 | CSTCC3.68G-A | | Q101 | CSTCC |
| 1 | CFPX-157 | Crystal | Q102 | CFPX |
| 2 | 1M | Resistor | R1, R2 | 0402 |
| 3 | n.b. | Resistor | R3, R8, R11 | 0402 |
| 4 | 470 | Resistor | R4, R5, R6, R7 | 0402 |
| 3 | 0R | Resistor | R9, R10, R105 | 0402 |
| 4 | 1k | Resistor | R12, R13, R14, R15 | 0402 |
| 1 | 100k | Resistor | R16 | 0402 |
| 2 | 10k | Resistor | R17, R101 | 0402 |
| 3 | NC | Resistor | R102, R103, R104 | 0402 |
| 1 | Shield_BMIS | | SH1 | LT08AD4303F |
| 1 | Eao09.10201.02 | Switch 1W | SW1 | EAO1XUM |
| 1 | Knitter TSS31N | Pushbutton 1P | T1 | Taster_ITT |
| 1 | AT86RF231 | 802.15.4 2.4GHz TRX | U1 | MLF-32 |
| 1 | NC7WV04 | 2x 2 Input Inverter | U2 | SC-70-6 |
| 1 | AT25010A | | U3 | Mini-Map-8 |
| 1 | NC7WP32 | 2x 2 Input OR Gatter | U4 | SC-70-8 |
| 1 | ATMEGA_1281 | 8-bit AVR uC | U5 | MLF64-M2 |
| 1 | uPG2314T5N | | U6 | TSON-6 |
| 2 | AS222-92 | | U7, U8 | SC-70/6 |
| 1 | SMA 50Ohm | | X1 | SMA_BU |

## Appendix B – Abbreviation

| | | |
|---|---|---|
| ADC | - | Analog-to-digital converter |
| BB | - | Base Band |
| CRC | - | Cyclic redundancy check |
| FCC | - | Federal Communication Commission |
| FFD | - | Full Functional Device |
| ISM | - | Industrial, Scientific, and Medical |
| LNA | - | Low Noise Amplifier |
| MAC | - | Medium Access Control |
| PA | - | Power Amplifier |
| PHR | - | PHY Header |
| PHY | - | Physical Layer |
| PSDU | - | PHY Service Data Unit |
| RCB | - | Radio Controller Board |
| PWM | - | Pulse Width Modulation |
| RF | - | Radio Frequency |
| RFD | - | Reduced Functional Device |
| RX | - | Receiver |
| TWI | - | 2-wire Serial Interface |
| TX | - | Transmitter |
| USART | - | Universal Asynchronous Receiver Transmitter |

# Appendix C – EVALUATION BOARD/KIT IMPORTANT NOTICE

This evaluation board/kit is intended for use for **FURTHER ENGINEERING, DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY.** It is not a finished product and may not (yet) comply with some or any technical or legal requirements that are applicable to finished products, including, without limitation, directives regarding electromagnetic compatibility, recycling (WEEE), FCC, CE or UL (except as may be otherwise noted on the board/kit). Atmel supplied this board/kit "AS IS," without any warranties, with all faults, at the buyer's and further users' sole risk. The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies Atmel from all claims arising from the handling or use of the goods. Due to the open construction of the product, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge and any other technical or legal concerns.

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# References

[1] AT86RF231; Low Power, 2.4 GHz Transceiver for ZigBee, IEEE 802.15.4, 6LoWPAN, RF4CE, SP100, WirelessHART and ISM Applications; Datasheet; Rev. 8111B-MCU Wireless-02/09; Atmel Corporation.

[2] ATmega1281/V; 8-bit Microcontroller with 128K Bytes In-System Programmable Flash; Datasheet; Rev. 2549L–AVR–08/07; Atmel Corporation.

[3] IEEE Std 802.15.4™-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).

[4] AT86RF231; Software Programming Model; Rev.2.0; Atmel Corporation.

[5] FCC Code of Federal Register (CFR); Part 47; Section 15.35, Section 15.205, Section 15.209, Section 15.231, Section 15.247, and Section 15.249. United States.

[6] ETSI EN 300 328, Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Wideband Transmission Systems; Data transmission equipment operating in the 2.4 GHz ISM band and using spread spectrum modulation techniques; Part 1-3.

[7] ARIB STD-T66, Second Generation Low Power Data Communication System/Wireless LAN System 1999.12.14 (H11.12.14) Version 1.0.

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