AVR2023 - AT86RF231 PCB reference design for antenna diversity

Application Note

Features

- **802.15.4 compliant 2.4 GHz transceiver**
- **Hardware supported antenna diversity**
- **1.8 V to 3.6 V operation**
- **Low current consumption**
  - **Typ. 600 nA (Sleep)**
  - **Typ. 8 mA (TRX_OFF)**
  - **Typ. 22 mA (TX, output power +3 dBm)**

1 Introduction

The AT86RF231 diversity board demonstrates the capabilities of the 802.15.4 compliant 2.4 GHz radio transceiver AT86RF231. With the high performance ATmega1281V AVR microcontroller it serves as a full function network node that is capable of hosting a MAC implementation driven by two AAA batteries for more than one year. Two ceramic chip antennas increase the link budget in a typical indoor scenario with multipath fading effects.

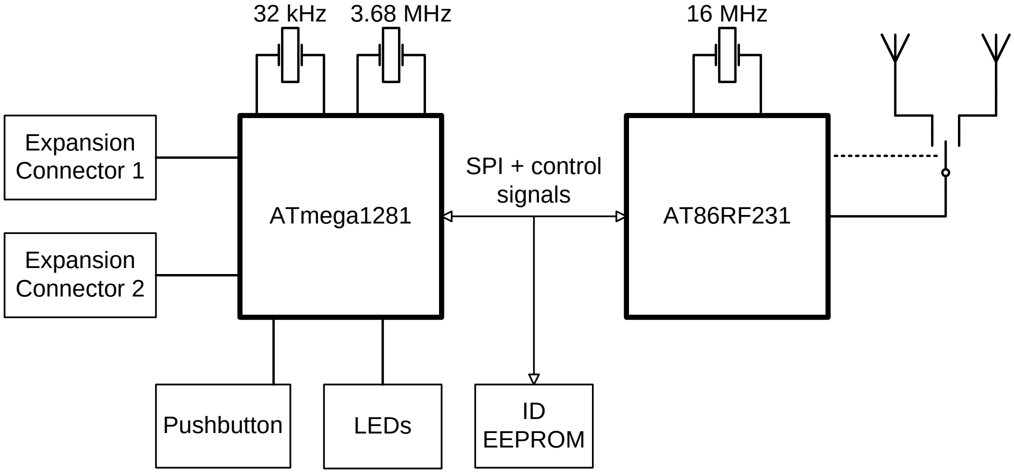
Figure 1-1. AT86RF231 – Antenna Diversity Board

Rev. 8182A-AVR-08/08

2 General

The board mainly consists of two sections: The microcontroller ATmega1281V and the radio transceiver AT86RF231.

Figure 2-1 AT86RF231 diversity board overview



The microcontroller ATmega1281V controls the 802.15.4 compliant radio transceiver AT86RF231 and serves as a SPI master. The transceiver handles all 802.15.4 actions concerning RF modulation/demodulation, signal processing and frame reception. Several MAC hardware acceleration functions are implemented in the transceiver. To increase the link budget in a multipath environment, two antennas serve as an antenna diversity system. The antenna switching can be configured to be automatically handled by the transceiver.

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

2.1 Power Supply

The board is powered by a single supply voltage in the range of 1.8 V – 3.6 V, which makes it possible to be powered by two 1.5 V 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 of the node the board can be powered by two AAA batteries that are held by the battery clip on the back of the board. To manually switch on/off the board, the power switch SW1 can be used.

The microcontroller software is responsible for appropriate sleep / wakeup cycles of the system to reach a reliable lifetime of the batteries. A small calculation example is given as follows.

For calculation of the battery lifetime in a typical 802.15.4 scenario, it can be assumed that the node is sleeping most of the time and is in active states (RX or TX) for a small slice of time. Assuming a sleep / wake cycle T_S of 8 seconds and an active time

t_a of 40 ms, which is sufficient for sending and receiving a frame, the battery lifetime of two AAA batteries (each of 1000 mAh) can be estimated as follows:

I_{active} = 22 mA, I_{sleep} = 1 uA (see Table 3-1)

T_s = 8 s, t_a = 40 ms

t_{Batt} = 1000 mAh / [(T_s – t_a)/T_s * 1 uA + t_a/T_s * 22 mA]

t_{Batt} = 9009.4 h > 1 year

The board can serve as an end device (RFD) for more than one year.

External power

When used as a daughter board in a more complex system, the board can be powered by the expansion connectors. For pin mapping see **Table 2-1**. In this case the power switch has to be in OFF position to avoid unintentionally charging of the batteries, if they are applied.

2.2 Microcontroller

The ATmega1281V is a low-power 8-bit microcontroller based on the AVR enhanced RISC architecture. The non-volatile flash program memory of 128 kB and 8 kB of internal SRAM, supported by a rich set of peripheral units, makes it suitable for a full function sensor network node.

The controller is capable of operating as a PAN-coordinator, a full function device (FFD) as well as a reduced function device (RFD), as defined in the standard IEEE 802.15.4.

2.3 RF Section

The transceiver AT86RF231 contains all RF critical components necessary to transmit and receive a 802.15.4 compliant modulated 2.4 GHz signal. External components are reduced to decoupling capacitors and the crystal. The differential 100 Ohm RF signal is converted into a single ended 50 Ohm signal by the balun (B1) and routed to the antennas via the RF switch (U5). The switch is controlled by the DIG1 pin. It can be set manually or be handled by the diversity decision algorithm of the transceiver, which detects the optimal antenna (see [3] for more details). The crystal is isolated from fast switching digital signals and surrounded by the ground plane to minimize disturbances of the oscillation.

2.4 Clock Sources

Radio Transceiver

The Radio Transceiver is clocked by the 16 MHz reference crystal Q1. The 2.4 GHz modulated signal is derived from this clock, therefore the frequency should not exceed a deviation of +/- 40 ppm, as specified in IEEE 802.15.4. The 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 AT86RF231 diversity board uses a SIWARD crystal SX4025 with two load capacitors of 10 pF. To compensate fabrication and environment variations the frequency can be tuned with the transceiver register “XOSC_CTRL (0x12)”, for more detailed information see [2].

Microcontroller

There are various clock source options for the microcontroller ATmega1281V.

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

The 8 MHz calibrated internal RC oscillator is used as the default clocking. The CLKM signal, generated by the transceiver, is connected to T1 (PD6) of the AVR and can be used as a symbol synchronous counter as well as a reference clock for calibration of the internal RC oscillator. Optionally the AVR can be clocked directly from the CLKM signal, for this purpose the 0 Ohm resistor R105 has to be soldered to R102.

A 32 kHz 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 transceiver to the OC2A pin (PB4) of the AVR makes it possible to wake up both the microcontroller and the transceiver simultaneously from a Timer 2 Output Compare Match. This saves valuable time in a cycled sleep / wakeup network scenario.

2.5 Antennas

Two ceramic chip antennas are placed at the top of the board in an orthogonal configuration. This results in diversification of space and polarization and can greatly reduce multipath fading effects (see performance results in section 3.2). The transceiver can be configured to select an antenna via register setting, or to automatically select the antenna depending on the receive signal.

The RF switch requires a complementary switching signal which is generated by a dual inverter (U6) whose input is the transceiver signal DIG1. To minimize sleep current, the inverter is supplied by DVDD - the output of the 1.8 V internal voltage regulator of the transceiver. This ensures the inverter to shut off when the transceiver goes to sleep mode. To reduce switching harmonics the switch control signals as well as the supply voltage of the dual inverter are filtered by RC combinations, see Appendix A Schematics.

2.6 Peripherals

For simple applications and debugging purposes, a basic user interface is mounted directly on the board, consisting of a pushbutton and three red LEDs. For more sophisticated applications, two Expansion connectors give access to all spare AVR pins, including USART, TWI, ADC, PWM and external memory pins.

Figure 2-2 Connection of the on-board peripherals

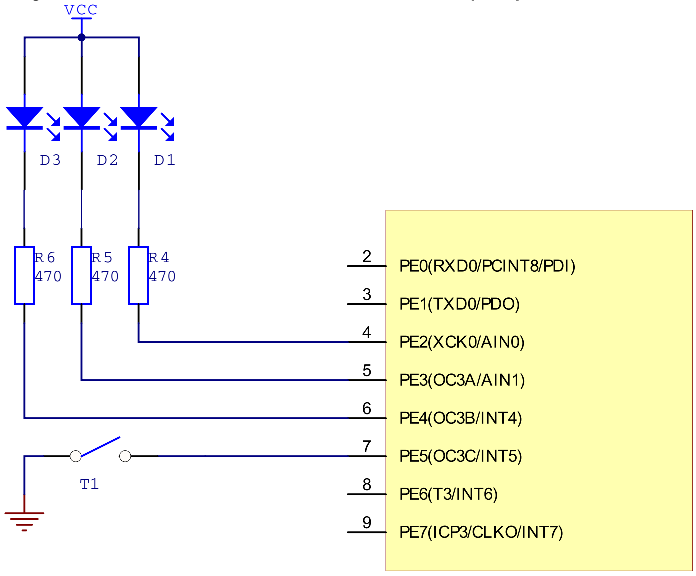


Table 2-1 Expansion Connector Mapping

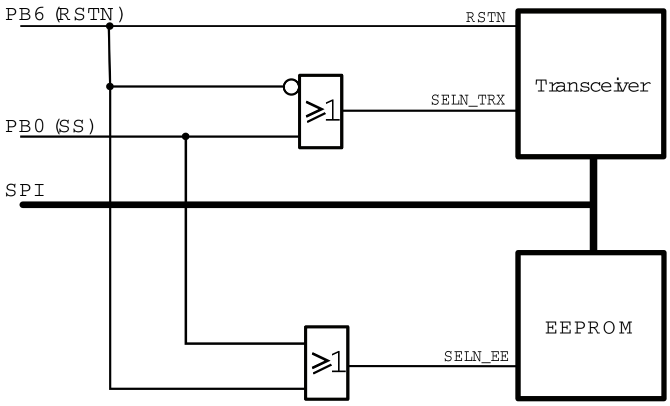
EXT0				**EXT1**			
Pin#	**Function**	**Pin#**	**Function**	**Pin#**	**Function**	**Pin#**	**Function**
1	PB6	2	PB7	1	PB1 (SCK)	2	GND
3	#RESET	4	VCC	3	PE7	4	PE6
5	GND	6	XTAL2	5	PE5	6	PE4
7	XTAL1	8	GND	7	PE3	8	PE2
9	PD0 (SCL)	10	PD1 (SDA)	9	PE1 (PDO)	10	PE0 (PDI)
11	PD2 (RXD1)	12	PD3 (TXD1)	11	AGND	12	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

2.7 ID EEPROM

To identify the board type by software an identification EEPROM is mounted. Information about the board, the node MAC address and production calibration values can be stored here. An Atmel AT25010A with 128x8 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, transceiver) is decoded with the reset line RSTN of the transceiver. Therefore, the EEPROM is addressed when the transceiver is held in reset (RSTN = 0), as shown in **Figure 2-3**.

Figure 2-3 EEPROM access decoding logic



The EEPROM data is written during board production test. A unique serial number, the MAC address as well as calibration values are stored. These can be used to optimize system performance. The following table gives the data structure of the EEPROM.

Table 2-2 ID EEPROM mapping

Address	Name	Type	Description
0x40	MAC address	uint64	MAC address 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 7 Bits 7 – Reserved 6 – Reserved 5 – External LNA 4 – External PA 3 – Reserved 2 – Diversity 1 – Antenna 0 – SMA connector
0x55	Cal OSC 16 MHz	uint8	RF231 XTAL calibration value, register “XTAL_TRIM”
0x56	Cal RC 3.6 V	uint8	AVR internal RC oscillator calibration value @ 3.6 V, register “OSCCAL”
0x57	Cal RC 2.0 V	uint8	AVR internal RC oscillator calibration value @ 2.0 V, register “OSCCAL”
0x58	Antenna Gain	int8	Antenna gain [1/10 dBi]

0x60	Board Name	char[30]	Textual board description
0x7E	CRC	uint16	16 Bit CRC checksum, standard ITU-T generator polynomial $G_{16}(x) = x^{16}+x^{12}+x^5+1$

3 Performance

3.1 Current consumption

Typical values for current consumption of the whole board in active states (no sleep / wakeup cycles).

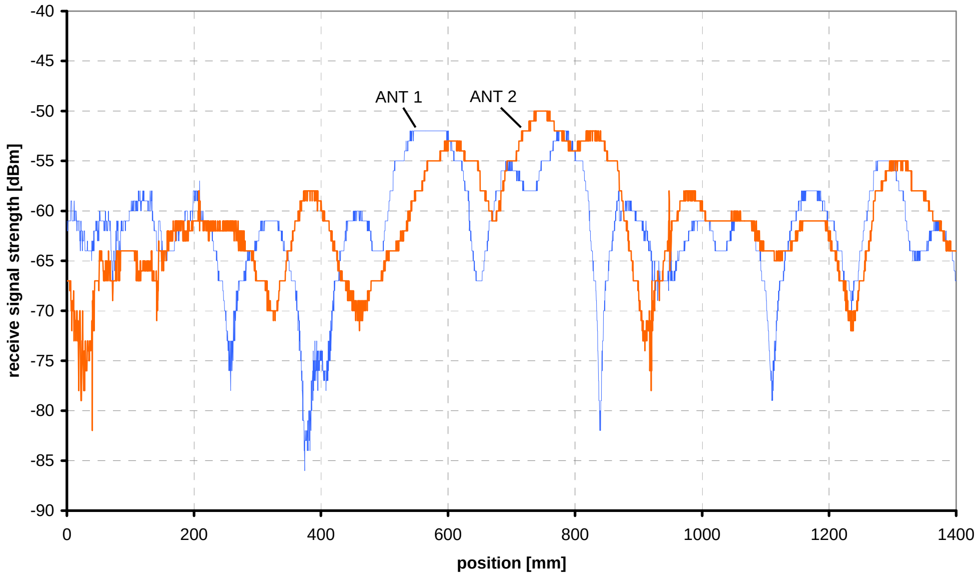
Table 3-1 Current consumption

Supply voltage [V]	TRX_OFF [mA]	RX [mA]	TX [mA]	SLEEP [uA]
1.8	5	17	19	0.2
3	8	21	23	0.6
3.6	12	24	26	1.2

3.2 Diversity Effect

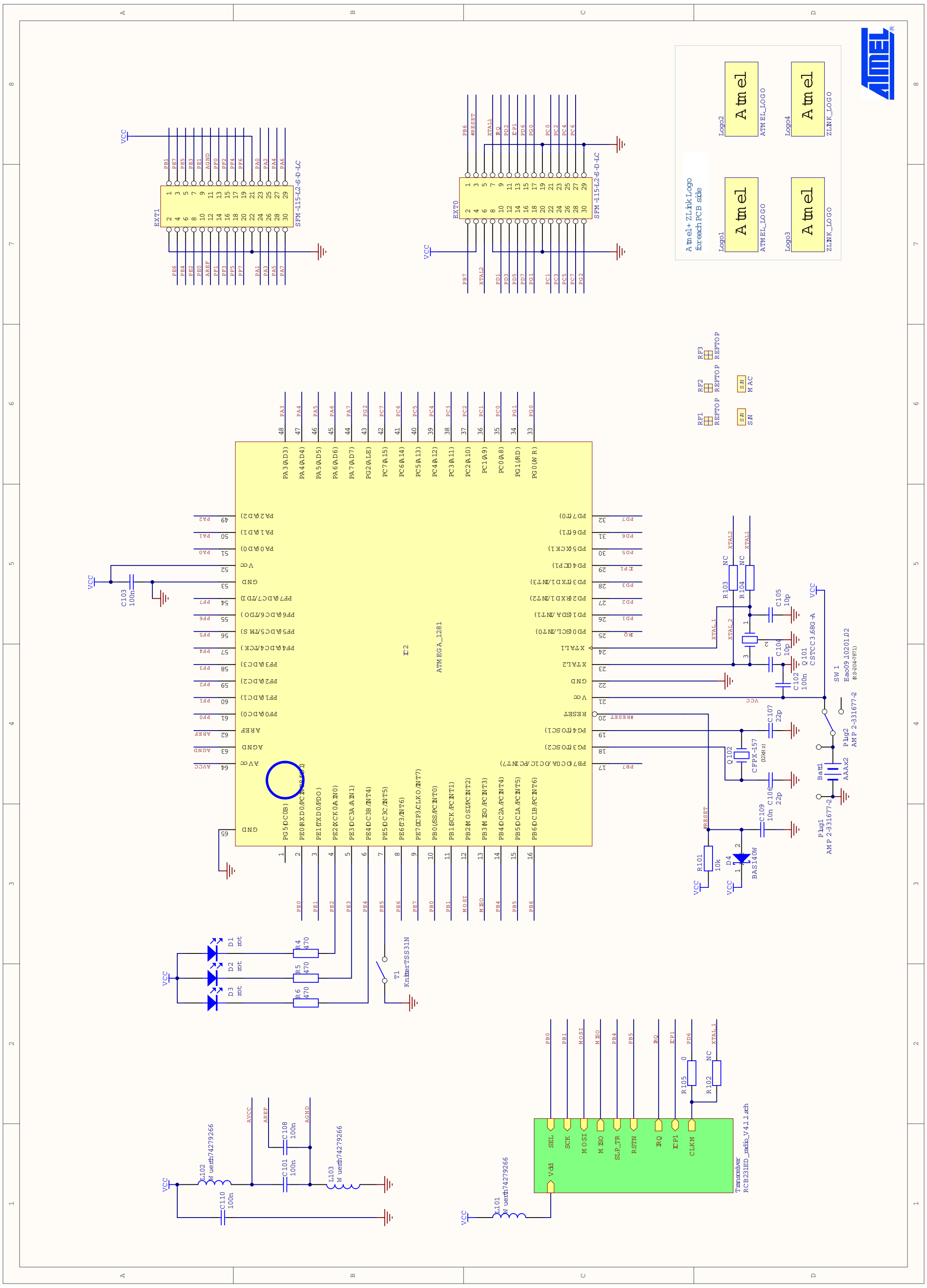
Due to multipath propagation interference effects between network nodes, the receive signal strength may strongly vary, even for small changes of the propagation conditions, affecting the link quality. These fading effects can result in an increased error floor or loss of the connection between devices.

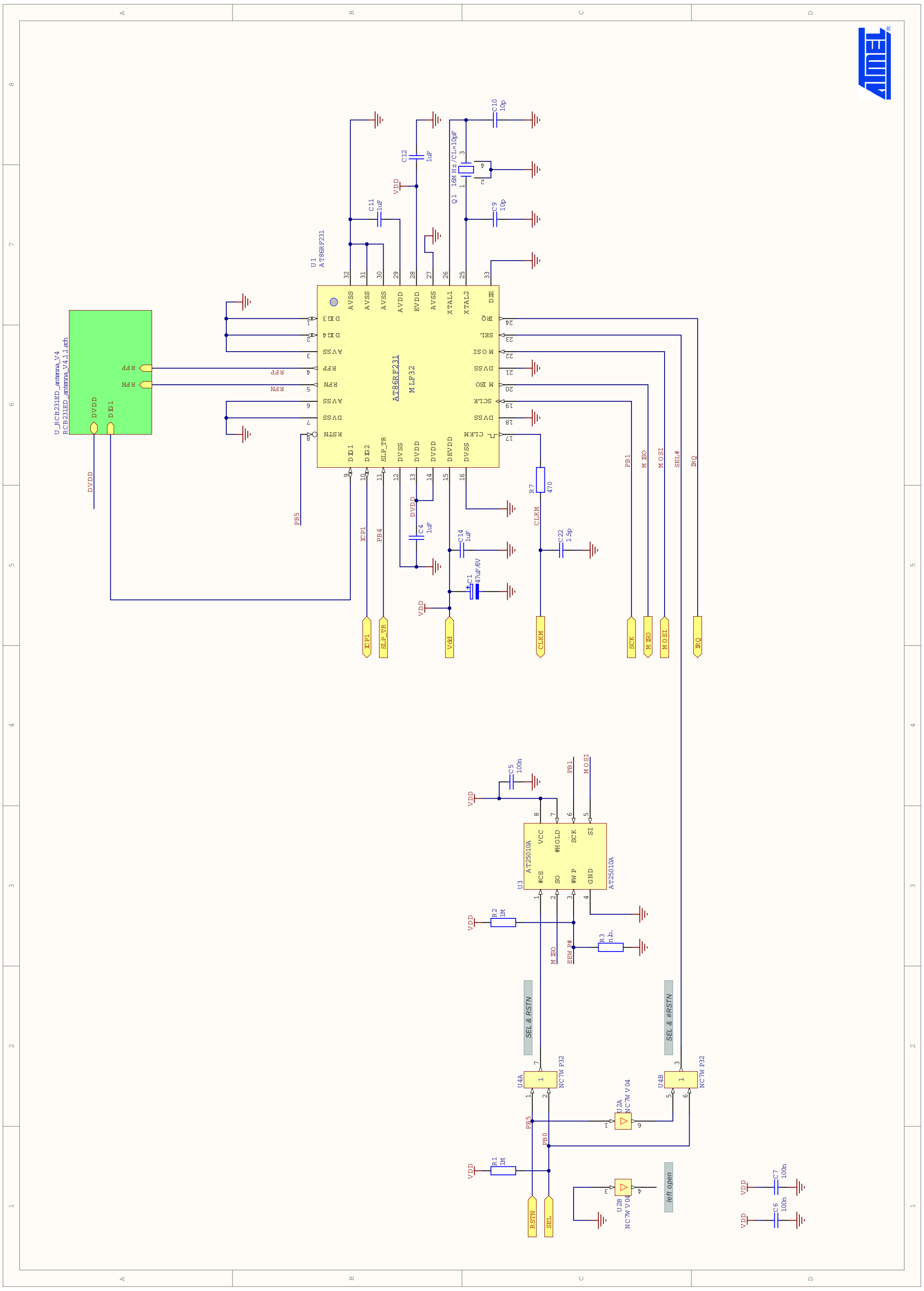
Figure 3-1 Receive level for each antenna in a multipath fading scenario

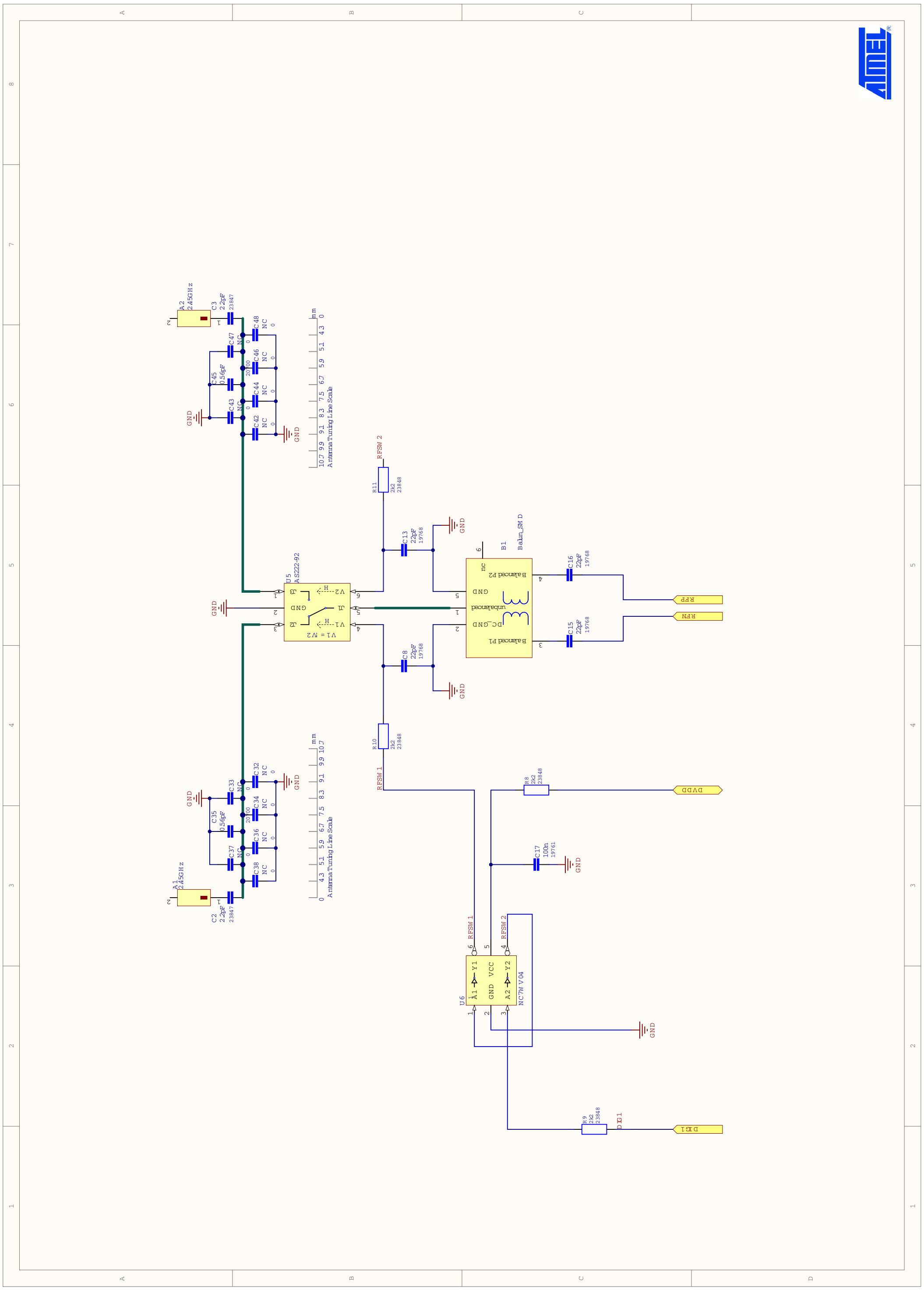


For a given position inside a network scenario with multipath fading effects, both antennas differ in their receive level (see **Figure 3-1**). This affects the packet error rate for small receive levels. Switching between both antennas and selecting the one that receives better can increase the reliability of a connection. For a detailed analysis see [3].

4 Appendix A Schematics

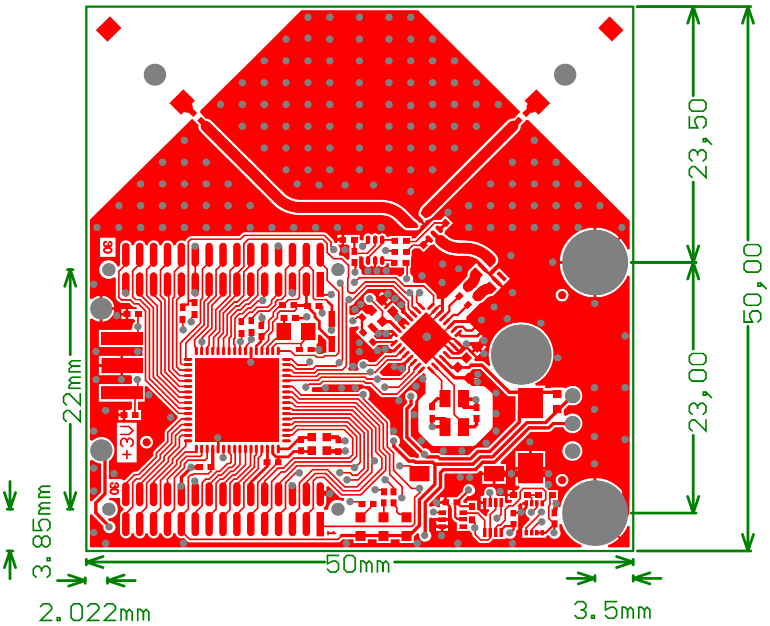




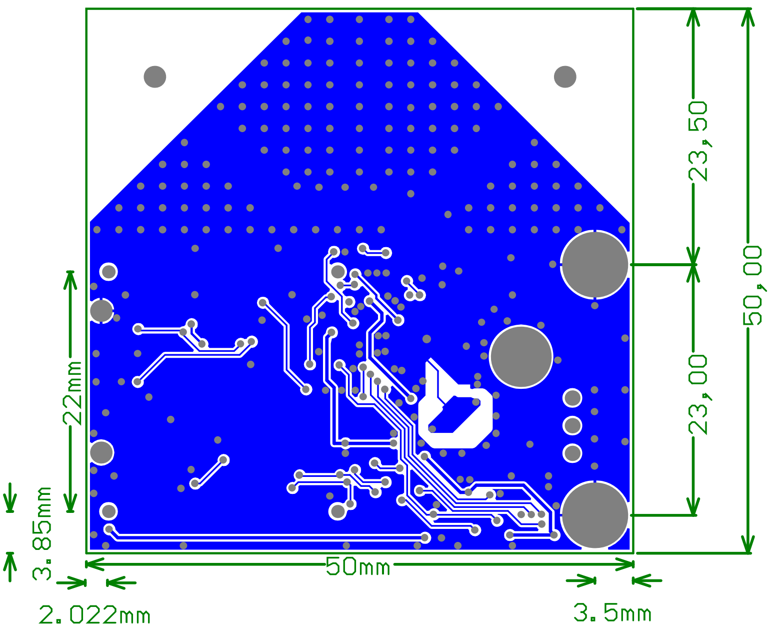


5 Appendix B Layout

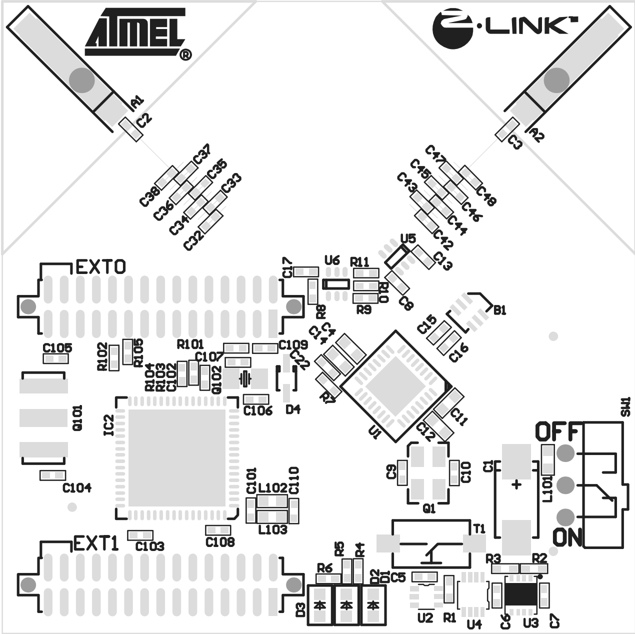
Copper Top Side



Copper Bottom Side



Assembly Drawing



6 Appendix C BOM

Quantity	Designator	Comment	Footprint	Description
9	C5, C6, C7, C17, C101, C102, C103, C108, C110	100n	0402A	Capacitor
6	C8, C13, C15, C16, C106, C107	22p, 22pF	0402A	Capacitor
4	C4, C11, C12, C14	1uF	0603H0.8	Capacitor
4	C9, C10, C104, C105	10p	0402A	Capacitor
4	R4, R5, R6, R7	470	0402, 0402A	Resistor
4	R8, R9, R10, R11	2k2	0402A	Resistor
3	D1, D2, D3	red	LED0603	LED, red
3	L101, L102, L103	Wuerth74279266	0603H0.8	Inductor
2	A1, A2	2.4GHz	ANT_AT45_45 deg	Ceramic Antenna
2	C2, C3	2.2pF	0402A	Capacitor

2	C35, C45	0.56pF	0402A	Capacitor
2	EXT0, EXT1	SFM-115-L2-S-D-LC	SFM15	Connector 15x2 pin
2	Plug1, Plug2	AMP 2-331677-2		Battery clip plug
2	R1, R2	1M	0402	Resistor
2	U2, U4	NC7WP32, NC7WV04	SC-70-6, SC-70-8	Dual 2 Input OR Gate
1	B1	Balun_SMD	0805-6	BALUN
1	Batt1	AAAx2	BH-421-3	Battery clip
1	C1	47uF/6V	TANTAL_C	Electrolytic Capacitor
1	C109	10n	0402A	Capacitor
1	C22	1.5p	0402	Capacitor
1	D4	BAS140W	SOD-323	Silicon AF Schottky Diode
1	IC2	ATMEGA_1281V	MLF64-M2	8-bit AVR uC
1	Q1	16MHz / CL=10pF	XTAL_4X2_5_small	Crystal Siward A207-011
1	Q101	CSTCC3.68G-A	CSTCC	Ceramic resonator
1	Q102	CFPX-157	CFPX	Crystal
1	R101	10k	0402A	Resistor
1	R105	0	0402A	Resistor
1	SW1	Eao09.10201.02	EAO1XUM	Switch 1W
1	T1	Knitter TSS31N	Taster_ITT	Miniature Button
1	U1	AT86RF231	MLF-32	802.15.4 2.4GHz Radio Transceiver
1	U3	AT25010A	Mini-Map-8	128 x 8 EEPROM Atmel
1	U5	AS222-92	SC-70/6	RF Switch Skyworks
1	U6	NC7WV04	SC-70/6	Dual inverter, ULP

7 References

[1] Datasheet ATmega1281V
[2] Datasheet AT86RF231
[3] AVR2021: AT86RF231 Antenna Diversity

8 EVALUATION BOARD/KIT IMPORTANT NOTICE

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