UHF ASK/FSK Industrial Transmitter ATA8401/ATA8402/ATA8403

ATA8401/ATA8402/ATA8403

Introduction

The ATA8401/ATA8402/ATA8403 are PLL transmitter ICs, which have been developed for the demands of RF low-cost transmission systems for industrial applications at data rates up to 50kBit/s ASK and 32kBit/s FSK modulation scheme. With these products Atmel® offers the solution for the PLL transmitter for industrial market covering frequency ranges 310MHz to 350MHz with ATA8401, 429MHz to 439MHz with ATA8402 and 868MHz to 928MHz with ATA8403. The purpose of this application note is firstly to summarize some important hints for the design using these transmitters and secondly to describe the Atmel demo boards as well as the evaluation with the demo software.

1. Application Hints

1.1 Antenna Design, Layout and Matching

Different applications and of course different operation frequency ranges need different antenna solutions. Short Range Device (SRD) in the ISM bands around 315MHz, 433.92MHz and 868MHz use mostly quarter-wave monopoles, helical antennas, or printed small loop antennas. Antenna characteristic such as directivity, gain, polarization, impedance, and bandwidth determine the system performance of the application. In addition to technical requirements, cost and the package are the most significant parameters to consider for mass-production. Choosing an antenna design is for the most part a compromise between cost, package, and technical requirements.

For the general application of hand-held wireless control transmitters, the printed "small" loop antenna is free of cost and its size is smaller than a whip antenna. The loop antenna performance satisfies most system requirements, and it also has the added benefit of hand-in sensitivity. A "small" loop antenna is an antenna with total loop length (circumference) of less than one fifth of a wavelength (λ/5). (The rule of thumb is approximately tenth of the wavelength (λ/10).) Atmel's demo board uses a small loop antenna. Therefore, the equations in this application note are only valid for the small loop antenna.

For radiation, a loop antenna needs a strong current flowing through it in order to generate a magnetic field as the loop antenna is a magnetic antenna. The radiation resistance of the antenna is a primary determiner of the antenna's transmitted power.

$$R_{Rad} \approx 31.2 \times 10^3 \left(\frac{A^2}{\lambda^4} \right) \qquad \text{Equation 1}$$

Notes: 1. A is the loop area in square meters

2. λ is the wavelength in meter

A second important parameter of the antenna's transmitted power is the loss of the loop antenna. This can be derived from the skin depth theory under the assumption that the trace width is much greater than trace's thickness, which is greater than the skin depth. The loss resistance for a copper trace can be calculated with the following equation:

$$R_{loss\_loop} \approx \frac{1}{2w} \times (2.59 \times 10^{-7}) \sqrt{f} \qquad \text{Equation 2}$$

Notes: 1. L is the total perimeter of the antenna in meters referring to the trace's centre

2. W is the trace width in meters

In order to estimate the transmit power using the loop antenna, it is necessary to determine the efficiency of the antenna. This is given by:

$$\eta = \frac{R_{Rad}}{R_{Rad} + R_{loss\_loop} + R_{loss\_cap}} \qquad \text{Equation 3}$$

Notes: 1. R_{Rad} is the radiation resistance of the antenna

2. R_{loss_loop} is the loss resistance of the loop's trace

3. R_{loss_cap} is the loss of the capacitors for the matching

The radiated power can be calculated, as follows:

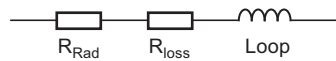$$P_{Rad} = (I_{loop})^2 \times R_{Rad} \qquad \text{Equation 4}$$

Note: I_{loop} is the current flow through the loop antenna

The relationship between the effective radiated power (ERP) and the IC's output power (Pout,IC) driving the antenna is:

$$ERP = \eta \times P_{out,IC} \qquad \text{Equation 5}$$

The equivalent circuit for the loop antenna is shown in .

Figure 1-1.   Equivalent Circuit of a Loop Antenna

An estimation of the loop inductance is necessary to match the loop antenna. This value can be determined using a formula for inductance of a polygon of general shape (Equation 6). This formula provides a result with 5% accuracy.

$$L \,=\, 2 \times 10^{-7} \times l \times \ln\!\left(\frac{8A}{lw}\right) \qquad \text{Equation 6}$$

Notes: 1.   L is the loop perimeter
2.   A is the loop area
3.   W is the trace width of the loop antenna

The Q factor of the loop antenna is given by

$$Q_{loop} \,=\, \frac{\omega L_{loop}}{R_{loss}} \qquad \text{Equation 7}$$

To optimize the performance of the loop antenna the following rules must be considered:
- The area enclosed by the loop has to be designed as large as possible and the ground area within the loop must be small.
- The field density increases towards the loop edges. Therefore, enough space must be provided near to the loop edges.
- The trace width of the loop antenna should not exceed 1.5 mm to avoid a large antenna Q factor.

Figure 1-2.   Layout Design of the Loop Antenna
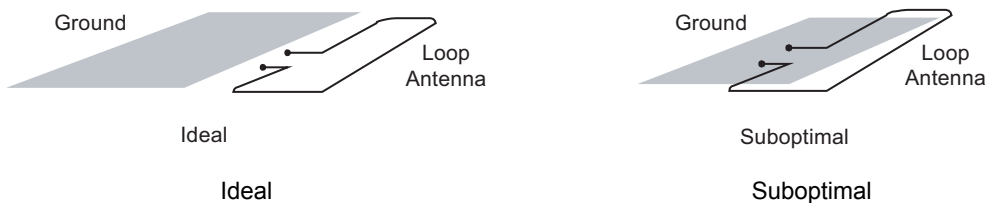
The Power Amplifier (PA) is an open collector output delivering a current pulse, which is nearly independent from the load impedance. Therefore, the output power can be controlled via the connected load impedance. To achieve the maximum output power, the PA's output capacitance has to be compensated for by the reactive part of the load impedance so that all the power will be delivered to the resistive load. The saturation of the PA's output transistor is the limitation of the voltage swing at matching. The PA's matching principle is illustrated in . The open collector output stage of the PA needs the DC current delivered by a low resistive path to the power supply (V_S). This low resistive path will be provided by connecting a feed inductor (RF choke) on the PA output (pin Ant1).

**Figure 1-3. Principle of Power Amplifier Matching**
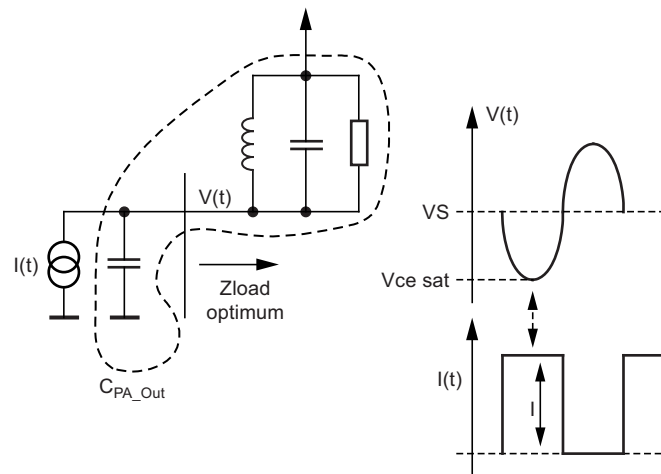
The simple matching method of the loop antenna to the power amplifier is illustrated in Figure 1-4. The capacitors Cmatch1 and Cmatch2 transform the parallel resonance impedance ($Z_{||}$) of the loop antenna to match the optimal load impedance of the transmitter, $Z_{load,opt}$. The optimum load impedance of each transmitter is:

ATA8401 requires $Z_{load,opt}$ of $(255 + j192)\Omega$

ATA8402 requires $Z_{load,opt}$ of $(166 + j223)\Omega$

ATA8403 requires $Z_{load,opt}$ of $(166 + j226)\Omega$

Figure 1-4. Matching Loop Antenna to the Power Amplifier
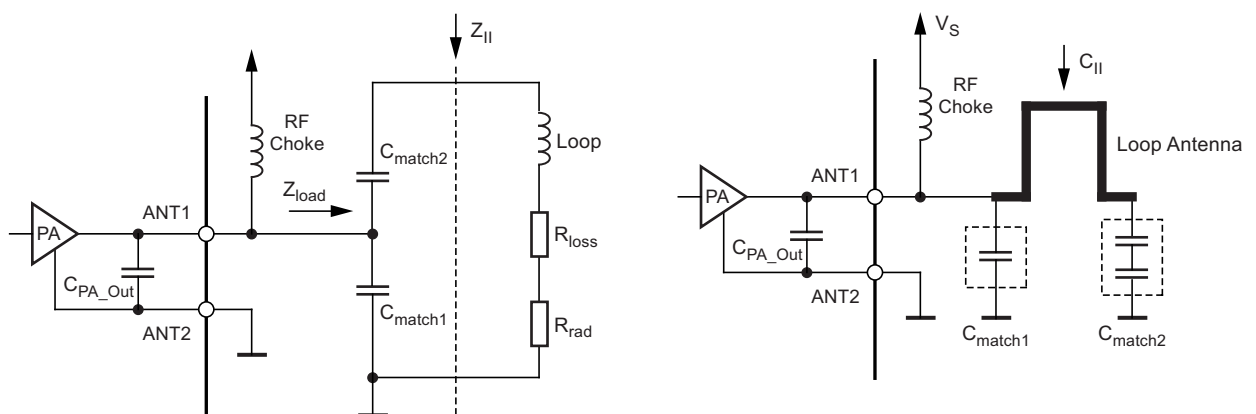
The parallel resonance impedance ($Z_{||}$) can be calculated by equation 8.

$$Z_{II} = Q_{loop}2\pi f L_{loop} \qquad \text{Equation 8}$$

The variable r in the equation 9 describes the transformation ratio of the matching structure ($C_{match1,2}$).

$$Z_{II} = r^2 Z_{load} \qquad \text{Equation 9}$$

$$C_{II} = \frac{1}{\omega^2 L_{loop}} = \frac{(C_{match1} + C_{PA\_Out})C_{match2}}{(C_{match1} + C_{PA\_Out}) + C_{match2}} \qquad \text{Equation 10}$$

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$$r = \frac{(C_{match1} + C_{PA\_Out}) + C_{match2}}{C_{match2}} \Rightarrow C_{match1} = r \times C_{II} - C_{PA\_Out} \qquad \text{Equation 11}$$

$$C_{match2} = \frac{C_{match1} + C_{PA\_Out}}{r - 1} \qquad \text{Equation 12}$$

In order to get lower influences of the capacitor's tolerance and to achieve an optimal matching with standard elements, two capacitor are used in series for C_{match2}. The C_{match1} has to be placed as close as possible to the IC to suppress the first harmonic. The connection of the pin ANT2 to ground must be designed properly. The best practical way is to place several vias direct to the ground plane of the board. This rule of ground connection is also valid for the ground connection of the matching elements.

If a higher harmonic rejection is needed, an additional low-pass filter has to be designed between the loop antenna and the transmitter. Figure 1-5 shows the principle schematic. The Cx must be placed as close as possible to the power amplifier output.

Figure 1-5. Matching Structure of the Loop Antenna with an Additional Harmonic Rejection
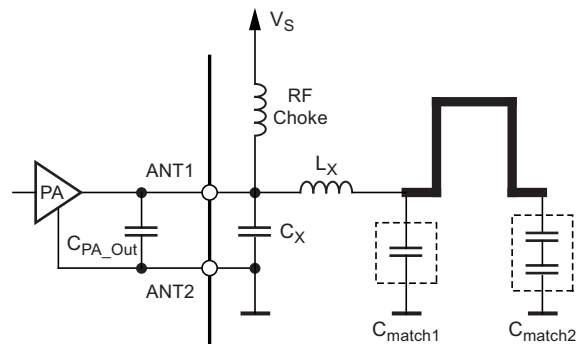
Caution: The formulas provide a theoretical start value for tuning of the real values on the application board.

1.2 Board Layout

The decoupling measure of the power supply is very important to minimize any disturbance in the internal circuit. It is recommended that a capacitor X7R with a value of 68nF is placed between VS (pin 6) and GND (pin 7) of the transmitter. The decoupling effect is better if the capacitor is placed as close as possible to the IC. The ground connection between the decoupling capacitor and ground plane must be design properly.
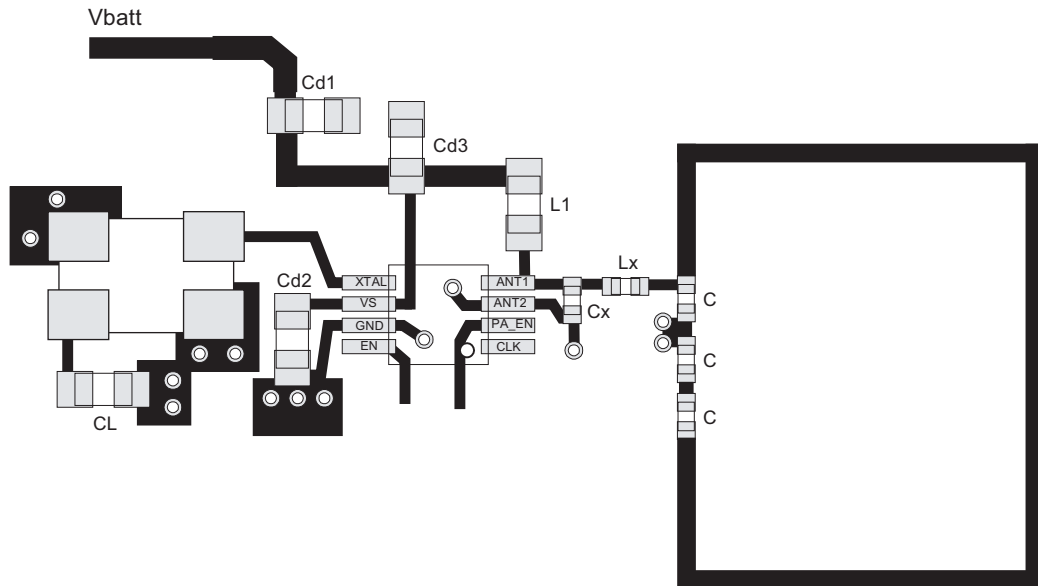
Figure 1-6. Example for a Board Layout

Figure 1-6 shows an example of an ideal layout. In this example, a crystal with a metal shielding is used. These types of crystals generally have four pads. The two ground pads of the crystal must be connected to the board's ground plane properly. The connection between the crystal and the pin XTO must be kept short. If the clock signal generated by the transmitter is needed for the microprocessor, the trace between the pin CLK and the microprocessor pin must be as short as possible. The layout in Figure 1-6 uses a discrete element as RF choke instead of the printed inductor as found on the demo board. The discrete inductor needs less space than the printed one.

Notes: 1.   L1 is the RF choke

2.   Cd1 is the decoupling capacitor near the battery

3.   Cd2 is the decoupling capacitor for the transmitter's power supply

4.   Cd3 is the capacitor to bypass the high-frequency coupling from the power amplifier output into the transmitter's power supply. This capacitor must be placed near to the RF choke.

In a practical application, there are different supply voltages on the board, for example for the microprocessor and for the transmitter. The different traces from the battery must be separated and decoupled to the ground.

1.3 The Setting of the Transmitter

Figure 1-7 shows the typical applications for the transmitters in ASK or FSK mode.

Figure 1-7. Typical Application Schematic

a) ASK mode   b) FSK mode
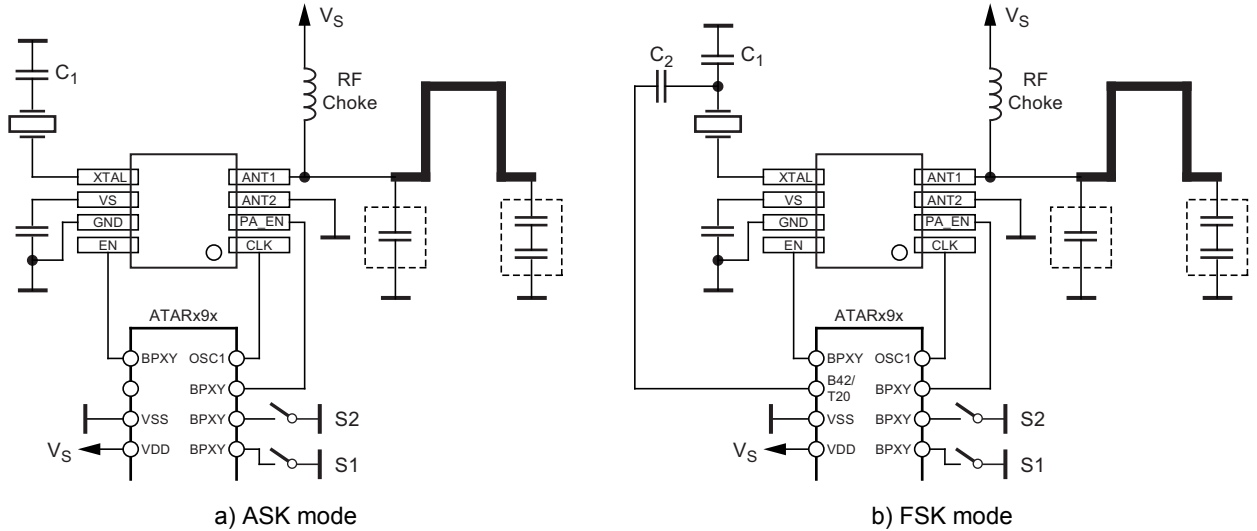
If ENABLE = Low and PA_ENABLE = Low, the circuit is in standby mode. To start the crystal oscillator (XTO), the pin ENABLE must be switched on. At the same time the Phase Locked Loop (PLL) and the Clock Driver are active. To activate the power amplifier, the pin PA_ENABLE must be set to high. After switching the pin ENABLE on, both the XTO circuit and the PLL need a maximum of 1ms to reach a stable condition. Therefore, the application software has to wait at least 1ms before switching the power amplifier on.

1.3.1 ASK (OOK) Transmission

The load capacitor of the crystal (C1 in Figure 1-7a) is used to adjust the desired RF transmit frequency. For ASK modulation, the PA_ENABLE will be switched alternating between high and low voltage due to the data to be transmitted. This results in the switching on and off of the power amplifier, which is known as OOK (On Off Keying).

1.3.2 FSK Transmission

The crystal pulling method is used for the FSK modulation (seeFigure 1-7b). An additional capacitor C2 will be used to modulate the crystal resonance frequency due to the data to be transmitted. For this purpose the capacitor C2 will be connected to the capacitor C1 related to the data. In practical terms this is a connection between capacitor C2 and the open drain port of a microprocessor. In the event of modulation, the microprocessor switches the capacitor C2 alternately between high impedance condition and ground. This method pulls the crystal's series resonance frequency between two values, which results in the RF operating frequency.

1.4 Crystal Oscillator

The crystal oscillator uses the crystal's series resonance frequency to generate the reference frequency. The series connection of the crystal and the load capacitor results in an impedance Z_{XTAL} seen from the pin XTAL (pin 5). According to the crystal's specification, the crystal will oscillate on the loaded resonance frequency f_L, in which the impedance Z_{XTAL} is real. This means the imaginer part of the impedance $Im\{Z_{XTAL}\}$ is 0Ω.

The impedance Z_{XTO} is the large signal input impedance of the XTO seen into the pin XTAL (pin 5) in steady state oscillation. For the oscillation start-up, the following conditions must be fulfilled (see Figure 1-8).

$Im\{Z_{XTO} + Z_{XTAL}\} = 0$ Equation 13

$Re\{Z_{XTO} + Z_{XTAL}\} < 0$ Equation 14

Figure 1-8. Condition for Oscillation Start Up
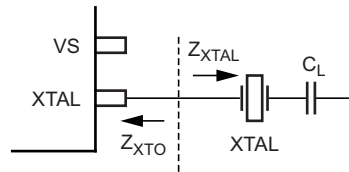
To achieve the condition described by equation 13 at the specified loaded crystal frequency, the capacitance CL can be determined as:

$$C_L = \frac{1}{2\pi f_L Im\{Z_{XTAL}\}}$$ Equation 15

With $Im\{Z_{XTAL}\} = -Im\{Z_{XTO}\}$

In real applications, there are stray capacitances on the board have to be taken into account when determining the load capacitance.

If FSK modulation is used, the crystal-loaded resonance frequency is pulled by two different capacitance values (CL1 and CL2) due to the data. Figure 1-9 shows the principle circuit for FSK modulation. The frequency deviation can be estimated using formula 16.

Figure 1-9. Circuitry for FSK Modulation
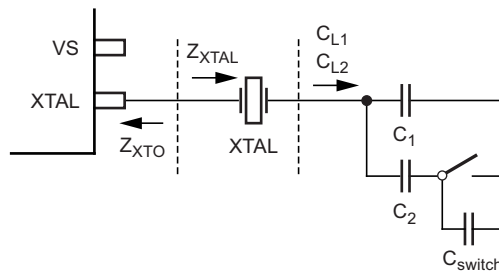
$$Im\{Z_{XTAL}\} = -Im\{Z_{XTO}\} - \frac{2\Delta f}{\pi f_L C_M}$$ Equation 16

Notes: 1. Δf is the ± frequency deviation in ppm
         2. C_M is the motional capacitance of the crystal.

When determining C1 and C2, C_{switch} of the microprocessor's pin must be considered. If the switch is open, the C_{switch} must be taken into account in the calculation of the series resonance resistance $Re\{Z_{XTAL}\}$. If the switch is closed, the on resistance of the modulating port of the microprocessor must be taken into account.

Caution: The formulas provide a theoretical start value for tuning of the real values on the application board.

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2. The Demo Board

2.1 Peripheral Interfaces

2.1.1 Clock Output

The transmitter provides a clock signal with a crystal accuracy, which can be used as reference for an external microprocessor. The frequency of the clock signal is:

$$f_{CLK} = \frac{f_{XTO}}{256} \qquad \text{Equation 17}$$

The clock output signal is CMOS-compatible if the load capacitance on the pin CLK (pin 1) is lower than 10pF. Hence, the trace connecting the pin CLK and the microprocessor port must be as short as possible.

Atmel's microprocessors M44C090, M44C890, and T48C893 have a special feature to take over an external clock signal. In real applications with the Atmel's transmitters, the microprocessor starts with a RC oscillator to switch the transmitter. After the clock signal has stabilized, the microprocessor takes over the clock signal as reference. The demo board ATAB8401, ATAB8402, and ATAB8403 use Atmel's microprocessor T48C893

2.1.2 Port Configuration of the Microprocessor

The transmitter pins EN and PA_EN must be connected to the CMOS-compatible output stage. To ensure that the transmitter is in power-down mode during the microprocessor reset, a pull-down resistor must be applied. For the switches on the demo board, a pull-up resistor is needed.

With FSK modulation, the modulating port of the microprocessor must be properly defined. The on resistance of the port must be very small so that the maximum series resonance of the crystal circuit does not exceed the defined value. Either a pull-up or pull-down resistor is needed for this port. The port must be set in an open-drain high-current configuration.

Table 2-1. Port Configuration of T48C893 on the Demo Board

| Port	Function	Output Driver	Pull-up/Pull-down Resistor
BP20/NTE	Programming	CMOS	Pull-down
BP21	Pin EN of the transmitter	CMOS	Pull-down
BP23	LED D1	CMOS	Pull-down
BP40/SC/INT3	Switch S3/programming	CMOS	Pull-up
BP42/T2O	FSK modulation switch/ programming	Open drain	None
BP43/SD/INT3	Programming	CMOS	Pull-down
BP50/INT6	Switch S2	CMOS	Pull-up
BP53/INT1	Switch S1	CMOS	Pull-up
BP60/T3O	Pin PA_EN of the transmitter	CMOS	Pull-down

2.2   DC Feed Inductor for the Power Amplifier

Atmel's demo boards use a printed inductor on PCB (L1) to reduce the cost of the external components. This inductor provides a DC current for the open collector stage of the power amplifier. The value of L1 must be between 50nH to 100nH. Formula 18 gives approximation of the inductance for a printed inductor (see Figure 2-1).

$$L = 49.2 \times n^2 \times r_m \qquad \text{Equation 18}$$

Notes: 1.   L is in nH

2.   N is number of turns

3.   Rm is mean radius in cm

Figure 2-1.   Printed Inductor
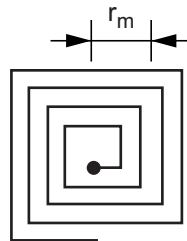
A printed inductor on PCB can be expressed as a parallel circuit of inductor, capacitor, and resistor. The printed inductor of the transmitter's demo board can be estimated as 90nH || 0.3pF || 2.8kΩ.

2.3   Schematic of the Demo Board

Figure 2-2.   The Schematic of the Demo Board
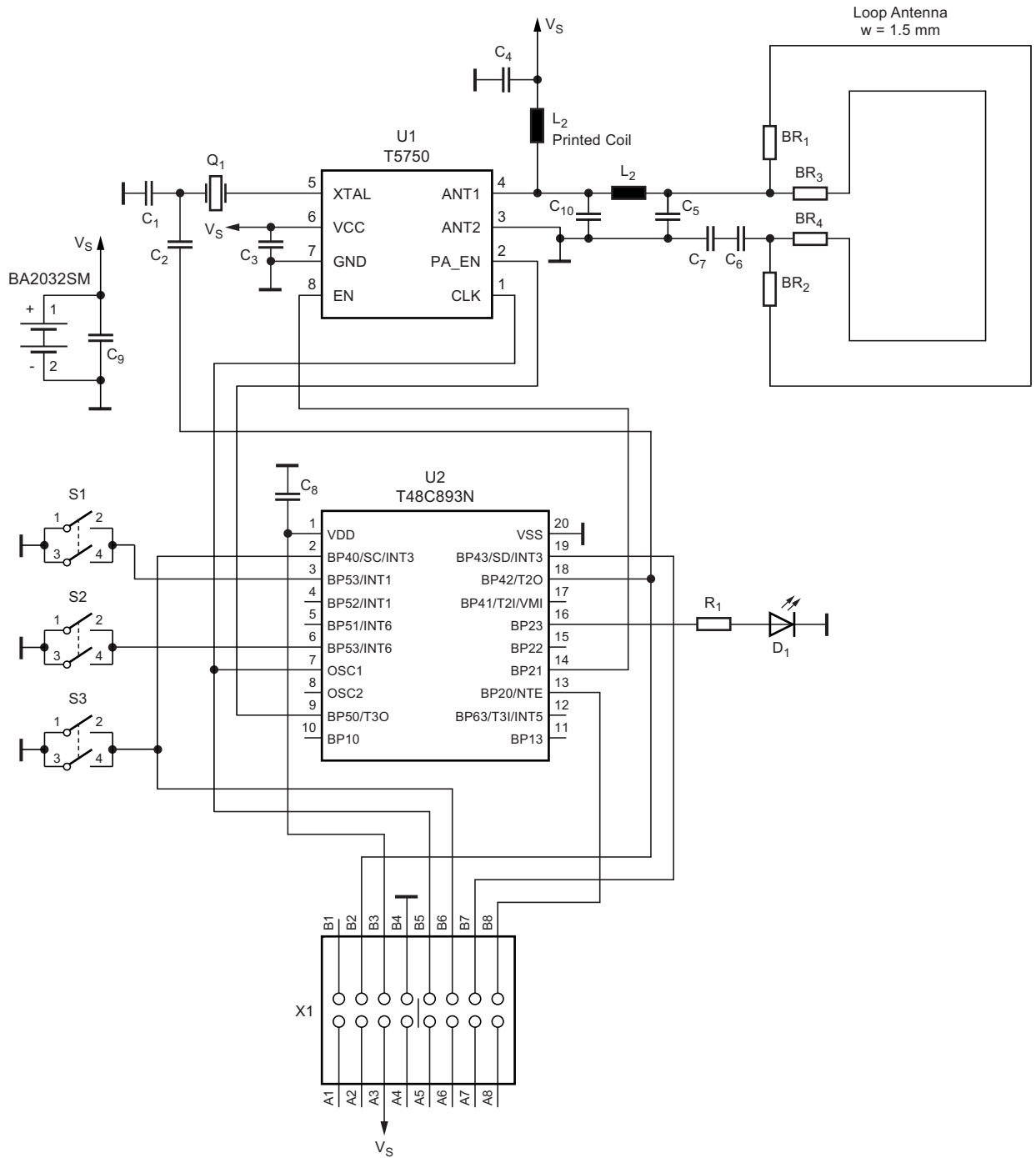
The demo board is designed for three different transmitters, T5750, T5753, T5754, ATA8401, ATA8402, and ATA8403. The smaller loop antenna is designed for radiating 868MHz and 915MHz Frequency.

2.4   Demo Board's Layout
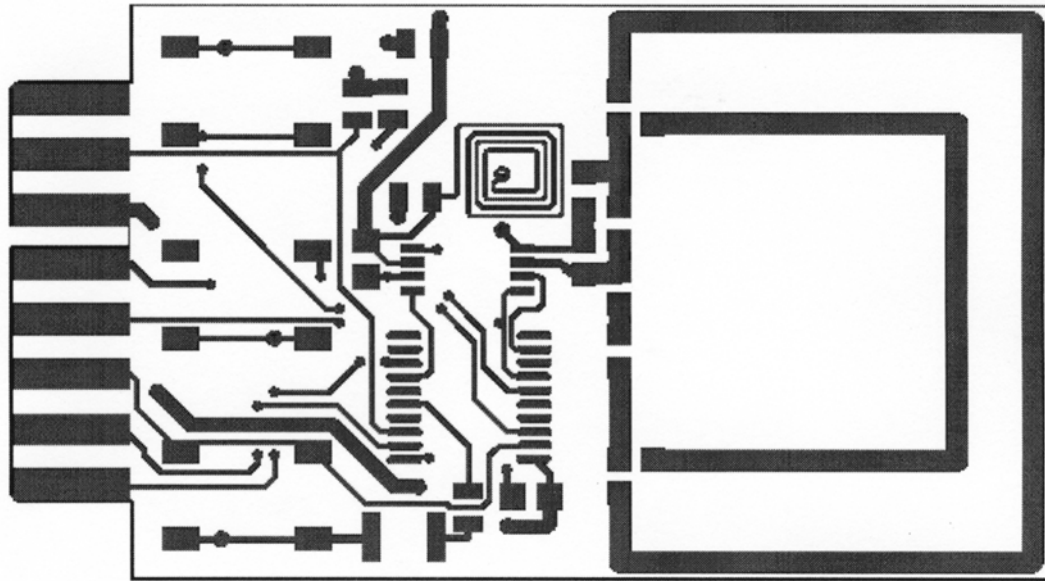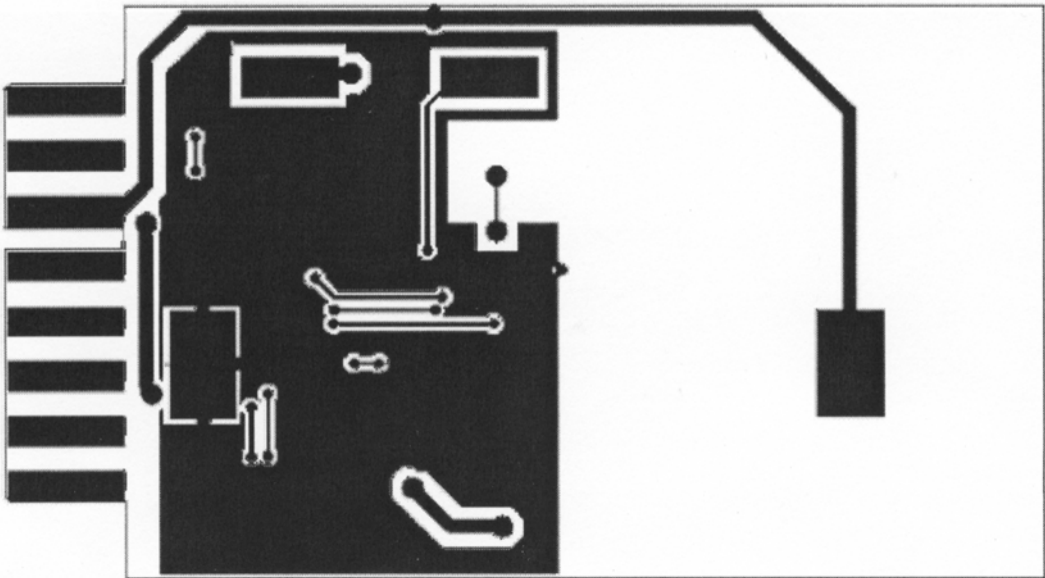
Figure 2-3.   Top Layer of the Demo Board

Figure 2-4.   Bottom Layer of the Demo Board

2.5 BOM List

Table 2-2. Bill of Materials of the Demo Board

Components	pcs	315Mhz	433.92Mhz	868.3MHz	915Mhz	Value	Tolerance	Material/Series	Housing	Manufacturer/Distributor
over			Components List Transmitter Application Board ATAB8401 (315MHz)/ATAB8402 (433.92MHz)/ATAB8403-8 (868.3MHz)/ATAB8403-9 (915MHz)							
U1	1	X	X	X	X	ATAB8401 ATAB8402 ATAB8403			TSSOP8	Atmel
U2	1	X	X	X	X	T48C893N			SSO20	Atmel
Q1	1	X	X	X	X	9.843750MHz 13.560000MHz 13.567187MHz 14.296875MHz		Order No.: 4730007881 Order No.: 4730007882 Order No.: 4730007557 Order No.: 4730007559	HC-49/U4B	ACAL
C1	1	X	X	X	X	4.7pF/50V 6.8pF/50V 8.2pF/50V	0.1pF 0.1pF 0.1pF	GRM1885C1H4R7B GRM1885C1H6R8B GRM1885C1H8R2B	Size 0603	muRata®
C2	1	X	X	X	X	12pF/50V 6.8pF/50V 4.7pF/50V	5% 0.1pF 0.1pF	GRM1885C1H120J GRM1885C1H6R8B GRM1885C1H4R7B	Size 0603	muRata
C3	1	X	X	X	X	68nF/25V	10%	GRM21BR71E683K	Size 0805	muRata
C4						n.m.				
C5	1	X	X	X	X	15pF/50V 6.8pF/50V 1.5pF/50V	5% 0.1pF 0.1pF	GRM1885C1H150J GRM1885C1H6R8B GRM1885C1H1R5B	Size 0603	muRata
C6	1	X	X	X	X	8.2pF/50V 3.9pF/50V 1.2pF/50V 1.0pF/50V	0.1pF 0.1pF 0.1pF 0.1pF	GRM1885C1H8R2B GRM1885C1H3R9B GRM1885C1H1R2B GRM1885C1H1R0B	Size 0603	muRata
C7	1	X	X	X	X	15pF/50V 6.8pF/50V 1.5pF/50V 1.0pF/50V	5% 0.1pF 0.1pF 0.1pF	GRM1885C1H150J GRM1885C1H6R8B GRM1885C1H1R5B GRM1885C1H1R0B	Size 0603	muRata
C8	1	X	X	X	X	100nF/25V	10%	GRM21BR71E104K	Size 0805	muRata
C9	1			X		1nF/50V	10%	GRM188R71H102K	Size 0603	muRata
C10	1	X	X	X	X	n.m. 0.3pF 0.5pF	0.05pF 0.05pF	04023j0R3ABW 04023j0R5ABW	Size 0402 Size 0402	AVX® AVX
L2	1	X	X	X	X	1.8nH 33nH 18Ω 0Ω bridge		LL1608-FS LL1608-FS	Size 0603 Size 0603	TOKO® TOKO
R1	1	X	X	X	X	1kΩ/0.1W	5%		Size 0603	e.g. Vishay®
D1	1	X	X	X	X	SMD LED red		TLMK3100	P-LCC-2	Vishay
BR1	1	X	X			0Ω bridge			Size 0603	e.g. Vishay
BR2	1	X	X			0Ω bridge			Size 0603	e.g. Vishay
BR3	1			X	X	0Ω bridge			Size 0603	e.g. Vishay
BR4	1			X	X	0Ω bridge			Size 0603	e.g. Vishay

Table 2-2. Bill of Materials of the Demo Board (Continued)

		315Mhz	433.92Mhz	868.3MHz	915Mhz					
Components List Transmitter Application Board ATAB8401 (315MHz)/ATAB8402 (433.92MHz)/ATAB8403-8 (868.3MHz)/ATAB8403-9 (915MHz)										
Components	**pcs**					**Value**	**Tolerance**	**Material/Series**	**Housing**	**Manufacturer/ Distributor**
S1, S2, S3	3	X	X	X	X	SMD switch		KSC 241J		ITT Cannon®/ Spoerle Electronic
VBatt1	1	X	X	X	X	Battery holder		BA2032SM		Roßmann Electronic
Lithium cell	1	X	X	X	X	3V/220mAh		CR2032		e.g. SONY®/ Roßmann Electronic
PCB jack	1	X	X	X	X	8 pins		MKFL13478-6-0808		Stocko®/ Hoppe Electronic
PCB	1	X	X	X	X	T5750/53/54 V4.0		FR4	Thickness 1.2mm	

3.   Operating of Transmitter Demo board with RF Design Kit

Transmitter demo boards ATAB8401/02/03 show the feature ISP (in system programmable) and can be used as an example of a stand-alone RF remote control transmitter that offers ASK and FSK modulation. To evaluate the transmitter, Atmel offers a microprocessor board ATAB-RFMB (ATAB-STKFlamingo) to configure the IC as well as the evaluation software RF Design Kit. This section provides some important information needed to start the evaluation with the microcontroller board. For the complete description of both RF Design Kit and ATAB-RFMB (ATAB-STKFlamingo), please refer to the application notes "ATAK57xx and ATAK862xx hardware description" and "ATAK57xx, ATAK57xx-F, ATAK862xx and ATAK862xx-F software description".

Technical features:

- Power supply: 3V Lithium cell (e.g. CR2032)
- Frequency deviation: approximately. 30kHz
- Printed loop antenna
- Three programmable buttons
- No hardware changing is necessary for the verification of two different modulation schemes.
- In-system configuration of the software setting to the EEPROM of the microcontroller T48C893N is possible using the programming adapter JP1
- The transmitter demo board is tested under the ETSI as well as FCC regulation. The test results show that the transmitter can be applied in real applications and pass the type approval

Configuration of the transmitter:

- Connect the microcontroller board (ATAB-RFMB or ATAB-STKFlamingo) to a PC using a serial link cable (RS232). Please use the free serial port (Com1 or Com2).
- Switch on the 12V power supply of the microcontroller board
- Start the RF Design Kit software (see Figure 3-1 on page 16)
- Select the transmitter drop-down menu to choose the setting of a transmitter. The setting software for T5750/53/54 is the same as for verification with ATA8401/ATA8402/ATA8403. (Figure 3-2 on page 16)
    - Choose T5753 (315MHz) for configuration of ATAB8401
    - Choose T5754 (315MHz) for configuration of ATAB8402
    - Choose T5750 (868MHz) for configuration of ATAB8403-8
    - Choose T5750 (915MHz) for configuration of ATAB8403-9
- Remove the lithium cell battery from the holder
- Plug the transmitter into the adapter PCB of the microcontroller board

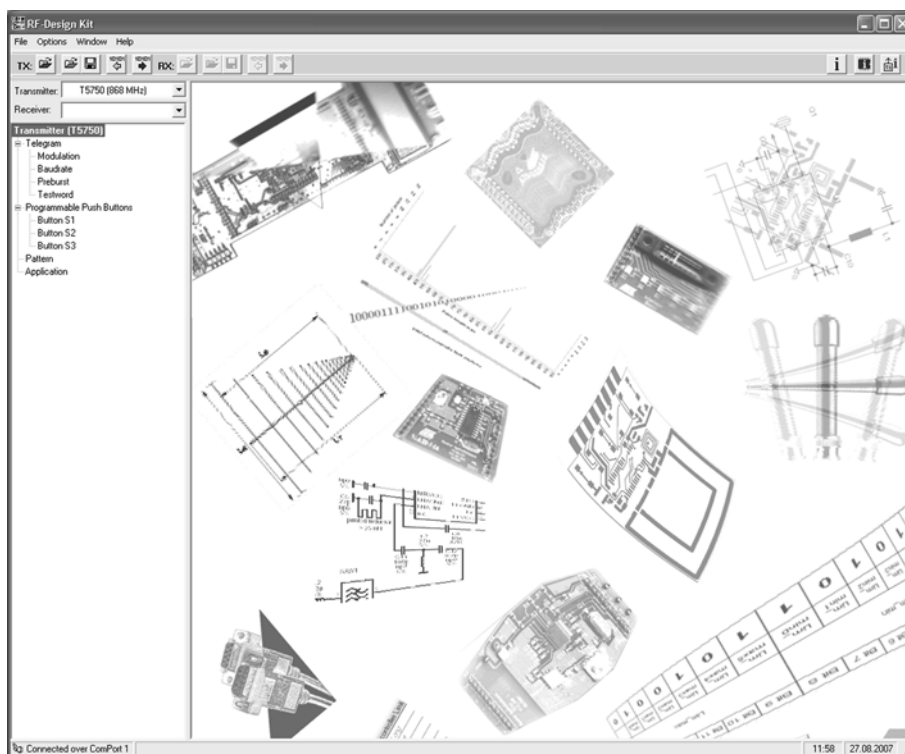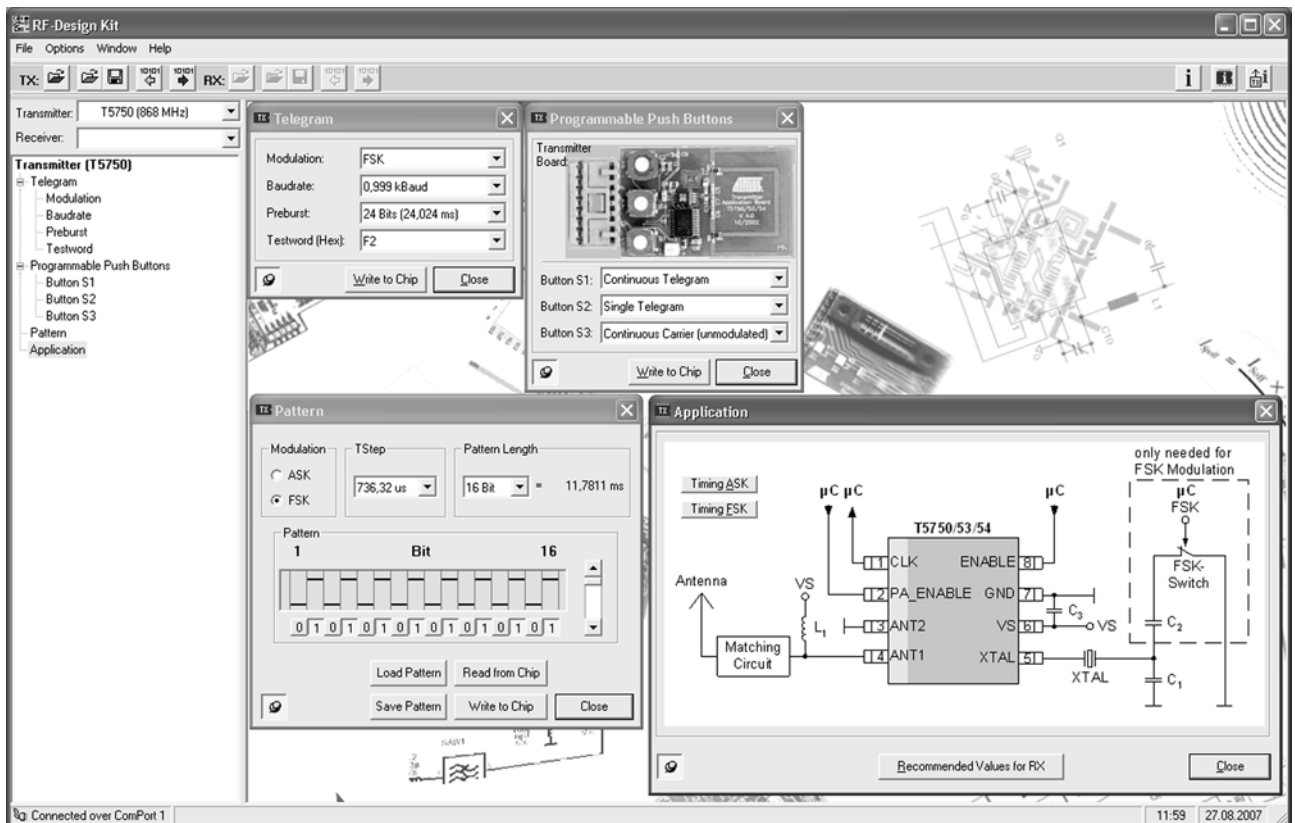**Figure 3-1.** **Windows Interface of RF Design Kit**
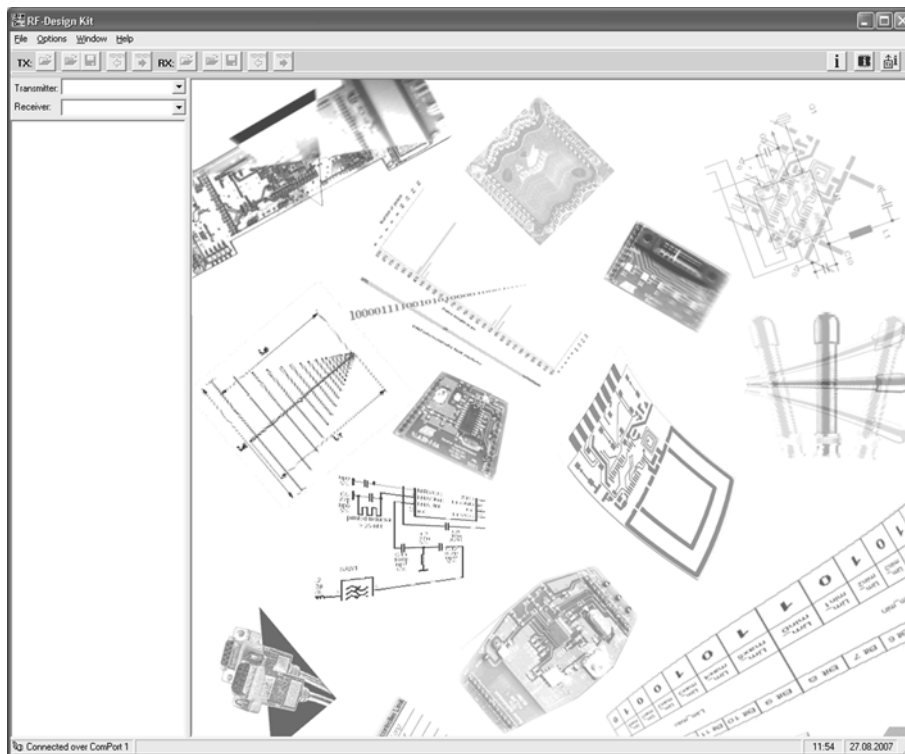
Figure 3-2. **Selecting the Setting of a Transmitter (Setting for ATAB5750-8 and ATAB8403-8)**

- Set the desired transmitter's setting (see Figure 3-2)
- Please follow the instructions below "Getting started evaluating the transmitter board"

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Figure 3-3. Several Setting Menu to Configure the Transmitter

Getting started evaluating the transmitter board:

- Insert the lithium cell battery into the holder.
- Activate the transmitter by the pushing the S1 or S2 button (without programming the transmitter board, the default setting will be activated)
- Activate one of the three buttons for the required function.
- The "continuous" transmission setting, the board will send the signal approximately 30s long.
- The start of each function and the end of the continuous function will be indicated by LED D1 switched on.

Default configuration:

- Modulation: FSK
- Data Rate: 1kBps
- Test word: F09AF09A
- Button functions:
    - S1 $\rightarrow$ continuous telegram
    - S2 $\rightarrow$ single telegram
    - S3 $\rightarrow$ continuous preburst
- Preburst length is set to the value matching the Polling setting of the suitable receiver.

Reference:

Constantine Balanis, *Antenna Theory, Analysis and Design*, Second Edition, John Wiley & Sons, 1997

Frederick Grover, *Inductance Calculations Working Formulas and Tables*, Dover Publications, 1946.

4. Revision History

Please note that the following page numbers referred to in this section refer to the specific revision mentioned, not to this document.

Revision No.	History
9115B-INDCO-07/15	• Put document in the latest template

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