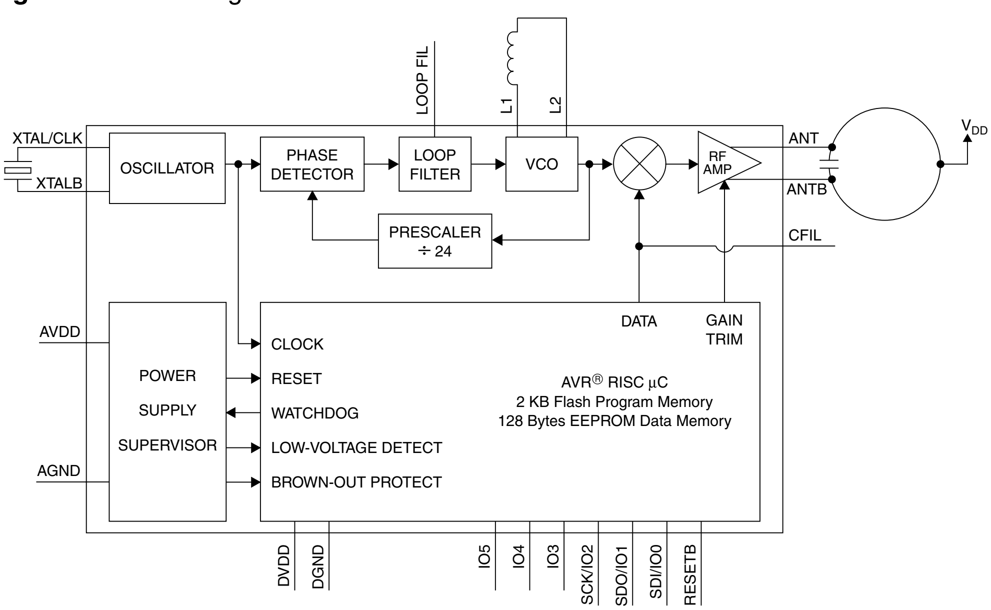
AT86RF401-EK1 Smart RF MicroTransmitter Evaluation Kit Application Note

The AT86RF401-EK1 evaluation kit was developed to familiarize the user with the features of the AT86RF401 MicroTransmitter and to provide all the tools needed to develop an application based on this device. Sample code is provided in the evaluation kit in order to speed development with this device. Additionally, software tools included on the CD-ROM allow the user to evaluate RF parameters without having to write software.

Functional Description

The AT86RF401 evaluation kit comes with software that causes the transmitter to generate a continuous wave (CW) RF signal when one of four buttons is pressed. This is achieved by programming the integral AVR microcontroller with the appropriate instructions that directly control the Phase-Locked Loop (PLL) RF transmitter. The program memory (2 Kbytes) and data memory (128 bytes) are nonvolatile, retaining their values even after the power is removed. Additional features include in-system programming capability, low battery detection, Voltage Controlled Oscillator (VCO) switched capacitor tuning array, and programmable power attenuation. See Figure 1 for a system block diagram.

Figure 1. Block Diagram



Smart RF

AT86RF401-EK1

Application Note

5028A–RKE–1/03

Transmitter Hardware

The transmitter hardware consists of a PCB with the AT86RF401, push buttons, battery holder, printed trace antenna, programming header, and some discrete components. See Figure 2 on page 3 for a schematic representation of the transmitter.

VCO Inductor

Placement of L2, the VCO inductor, must be taken into consideration when designing with the AT86RF401. The long axis of the inductor should be placed parallel with the leads of the TSSOP package to help prevent the RF signal, radiating from the antenna, from coupling back into the VCO/PLL. The AT86RF401 contains an internal switched capacitor array in parallel with the external VCO inductor. This is used to fine-tune the VCO control voltage for optimal performance. See *VCO Switch Cap Tuning* on page 4 for a more detailed explanation. The inductor should be placed as close to the AT86RF401 as possible, but the distance can be lengthened (which adds parasitic inductance) in order to obtain a nonstandard inductor value and center the tuning range of the VCO.

Printed Trace Antenna Design

Designing a differential loop antenna should be approached with symmetry in mind. The loop should be matched with respect to the two antenna pins. The AT86RF401 requires that the antenna be biased to V_{DD}. It is recommended that the tap to V_{DD} be centered between the two antenna pins and include a bypass capacitor connected to ground. For more detailed information, refer to the application note *AT86RF401 RF Wireless MicroTransmitter: PCB Trace Antenna Design Considerations and Implementation Guidelines.*

Antenna Tuning

For maximum power output, the antenna impedance must match the output impedance of the AT86RF401. This is accomplished on the evaluation board by modifying the value of the external capacitor in the loop. The optimal value of the capacitor varies according to the inductance of the printed trace antenna. The three capacitors connected in series are used to provide greater flexibility in obtaining the optimal equivalent capacitance required for impedance matching. For more detailed information, refer to the application note *AT86RF401 RF Wireless MicroTransmitter: PCB Trace Antenna Design Considerations and Implementation Guidelines.*

In-system Programming

In-system programming is possible via the Serial Peripheral Interface (SPI). This makes code development or code changes easy to implement any time, even after the device is soldered into its target application. The SPI uses six wires to communicate with the AT86RF401. The SPI programming header traces should be routed carefully to minimize the number of loop areas created. These loop areas, specifically the V_{DD} and ground trace loop, can couple energy back into the VCO and pull the RF output off frequency.

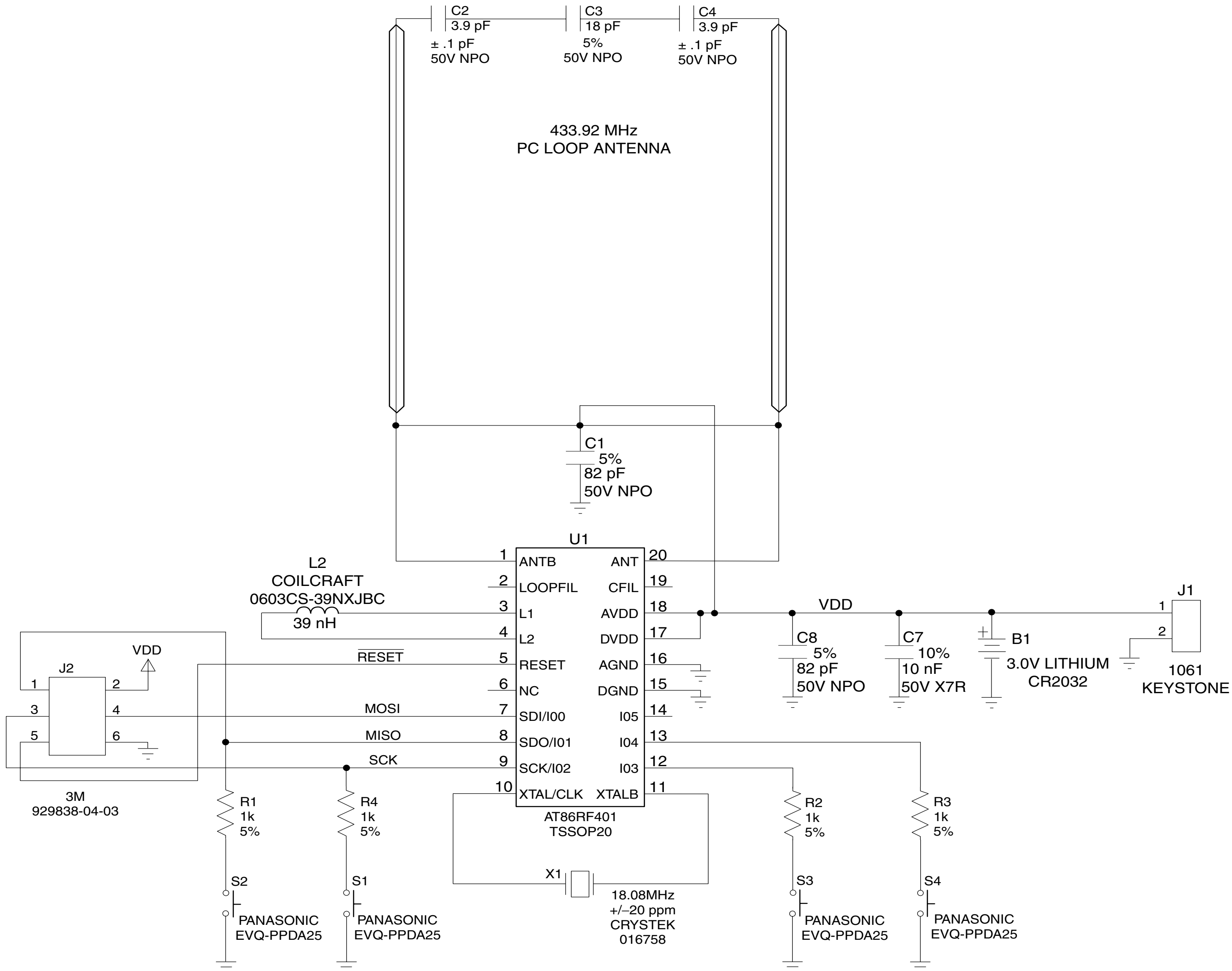
Push Button Inputs

The evaluation board contains four push button switches that can be used to bring the AT86RF401 out of sleep mode. The switches are normally open and pulled high by the internal pull-up resistor in the AT86RF401. When a button is pressed, the resulting logic low level causes an I/O (if so configured) to generate a wake-up interrupt and initiate the execution of software.

Crystal Oscillator

The AT86RF401 crystal oscillator requires both pins of the crystal to be connected to the AT86RF401. The AT86RF401 provides internal 40 pF load capacitors to each end of the crystal. By integrating load capacitors for the crystal, external components are minimized. The crystal should be an AT-cut, series-resonant crystal.

Figure 2. Schematic Representation



Transmitter Software

The transmitter sample code can be found on the CD contained in the evaluation kit. The evaluation kit is shipped with the sample transmitter preprogrammed with the CW mode software.

Sleep Mode

The CW mode software places the AT86RF401 in a low current sleep mode after the button is released in order to extend battery life. Sleep mode is achieved by configuring the appropriate registers. See *Button Input Detection* on page 5 for a more detailed description. The current draw is less than 0.5 uA while in this mode.

Low-battery Detect

The AT86RF401 has a register programmable low-battery detector. This allows the programmer to set a voltage threshold in software and detect whether the battery level (V_{DD}) is above or below that voltage. The low-battery detector only returns the status of the battery to a bit in the BL_CONFIG register. It is left to the programmer to poll this bit to check the status of the battery.

A similar but different feature called brownout protection also exists on this device. It consists of an internal fixed reference voltage, typically 1.8 volts. When the supply voltage drops below the brownout protection level, normal device operation is suspended until the supply returns to an acceptable level.

VCO Switch Cap Tuning

Tuning the VCO with external components can be difficult due to large tolerance and limited selection of standard values. In the AT86RF401, this process has been simplified with the use of an internal switched capacitor array. An external inductor is still required but its tolerance is not critical. Furthermore, the resolution of the switched capacitor array is 0.03 pF/step (spanning a range of 0 to 0.93 pF). *This level of resolution cannot be obtained with an external discrete capacitor.* The fine VCO tuning capacitor resolution available to the user enables precise tuning of the VCO.

The tuning process utilizes two integral comparators with fixed reference voltages corresponding to the lower and upper VCO control limits, typically 0.7 volts and 1.4 volts, respectively. By monitoring the states of these comparators, one can determine when the VCO is tuned for optimal performance.

The optimal tuning window determined in software does not mean that the PLL will unlock if the control voltage is outside this window. In fact, the PLL will stay locked outside of this range. The VCO tuning range should be evaluated over voltage and temperature to insure that the VCO tuning cap selection properly centers the VCO performance over all operating conditions.

Contained in the CW mode software is the VCO tuning routine that operates by sweeping the switched capacitor array values while monitoring the corresponding comparator outputs (all of which are accessible in the VCOTUNE register). When the comparators indicate a “valid” tuning, the value of the switched capacitor array can be saved in non-volatile EEPROM data memory. VCO tuning does not need to be performed prior to every transmission. It is possible to develop an adaptive algorithm in the user’s application software that repeats the VCO tuning periodically based on number of transmissions or on the supply voltage.

Note that if an external inductance is too large or too small, the switch capacitors will not be able to compensate. If this is the case, the external inductor value must adjusted accordingly.

Power Attenuation

A useful feature of the AT86RF401 is its ability to place output power attenuation under software control. The output power can be attenuated in 36 steps, from full output power to 35 dB below full power. The control of these steps is selectable with three bits of "coarse" tune and three bits of "fine" tune in the PWR_ATTEN register. Note that the steps reduce current to the power amplifier in a linear fashion. Consequently, the power attenuation steps are logarithmic.

Button Input Detection

When a button is pressed on the evaluation board, it causes an I/O pin to be driven to a logic low level. This will bring the AT86RF401 out of sleep if the I/O affected was configured as a button input. The button press instance is latched into the B_DET register and must be cleared by software. This allows a momentary button press to be retained even if the I/O is no longer at a logic low level. The current logic level of the I/O is contained in the IO_DATIN register. An I/O pin in normal input mode will not latch a button press into the B_DET register.

CW Mode Output

The CD contains sample software that outputs a continuous wave (CW) RF signal while a button is being pressed. The software first sets the I/O pins to button inputs and calls a VCO tune routine before placing the part in sleep mode. This allows the AT86RF401 to draw less current and only wake up when a button is pressed. When this occurs, the software turns on the PLL and power amp, resulting in the generation of an RF signal. The software then checks to see if the button is still pressed and continues transmitting until the button is released. When the button is released, the PLL and power amp are turned off and the AT86RF401 is put back to sleep until the next button press. Control of the PLL and power amp is done through the TX_CNTL register.

Delay Loop Modulation

On-off key (OOK) modulation is possible by using a simple delay loop. When sending an RF signal for a specific time period the software should turn on the PLL and power amp, enter a loop that decrements a counter until it reaches "0", and then turn off the power amp. The same loop can be used to time the "off" period.

Development Software Tools

The AT86RF401 Evaluation CD contains software to aid in development. These software programs provide easy-to-use tools to evaluate the AT86RF401 as well as assist in software development.

AT86RF401 SPI Controller

The SPI controller allows real-time control of the RF section of the AT86RF401 without the need to write code. This means that the device can be evaluated quickly upon receiving the evaluation kit. Control of the AT86RF401 in real-time is possible by use of the In-system programming (ISP) capability. The SPI controller uses the parallel port of a PC to read and write to the I/O register space of the AT86RF401. Several quick preset functions are available for use in evaluation. Also included in the SPI controller program is the ability to read and write the memory of the device. It can be used to load compiled code or to read from the program or data memory locations. More information regarding this software tool is available in the *SPI controller.doc* file included on the CD.

AT86RF401 Simulator

The AT86RF401 simulator is based on AVR Studio 2.0 and allows debugging of code through hardware emulation. The simulator provides feedback to assembled code with responses similar to running code on the AT86RF401. It is possible to step through code and watch the reaction of specific registers in the AT86RF401. Functions like the button presses, low battery detect, and power attenuation are observable through the simulator. The simulator also outputs a VCD file with visual responses to the executed code. This file can be viewed using the GTKWave software included on the CD. More detailed instructions on using the simulator can be found in the *AT86RF401 Simulator.doc* file on the evaluation CD.

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