AN4971
Application note

Received signal strength indicator (RSSI) for ST25RU3993

Introduction

The ST25RU3993 UHF RFID reader comprises an integrated received signal strength indicator (RSSI) for the received I and Q signals. Thanks to this feature it is possible to measure the power level of an incoming transponder signal or to detect external RF signal levels in the vicinity of the VCO frequency, which could cause interferences.

The received signals (I, Q) are routed to two 4-bit logarithmic A/D converters. The two acquired logarithmic absolute values are proportional to the input power at the mixer input ports. The ratio between the I and Q values gives the phase relation between the local oscillator (VCO) phase and the incoming signal phase.

The ST25RU3993 datasheet, available on *www.st.com*, is to be considered as a reference for this document. Concerning notation, the 0x prefix indicates numbers in hexadecimal notation (example: 0x29), while binary numbers are followed by a b suffix (example: 00b).

Contents

List of tables

List of figures

1 External RF input signal power

A listen before talk (LBT) or similar field level sensing functionality can be implemented using either the differential RX ports or the single-ended RX port.

The sensitivity for differential RX pins ranges from -86 dBm to -22 dBm, and from -88 dBm to -32 dBm for the single-ended RX pin.

When the low power output is used, the ST25RU3993 local oscillator (LO) signal, internally used for the RX mixers, is connected to the RFOPX and RFONX pins. If the internal power amplifier is used the LO signal is tapped from the preamplifier (PA) stage. These are optimal points in case power transmission and signal reception are simultaneous, as in the case of RFID transponder operation.

To sense external signals (LBT) the power transmission should be disabled.

Depending on the TX port used in the application, there are two possible choices to prepare the LO signal using an external PA:

1. The low power output is enabled and used for the LO signal, but power transmission is disabled, on the external PSA, via:
   - power down
   - bias
   - supply
2. The low power output is disabled and the LO signal source is the internal PA stage (register 0x0C: 44).

Note: The TX ports of the internal PA can be left unconnected, but a 100 nF capacitor is required on the VDD_PA pin.

The internal PA output is disabled and the LO signal is connected to the low power output path (register 0x0C:01).

Note: Pins RFOPX and RFONX should be connected to VDD_B via two 100 Ω resistors.

In order to enable the enable RSSI measurement for external RF sources the following additional configurations should be set:

- In the Protocol Selection Register set the two bits rf_on and rec_on to “1”
- Set the dir_mode bit in the Protocol Selection Register to “1”
- Disable the no response interrupt in the Enable Interrupt Register 1 by setting the e_irq_noresp bit to “0”.
- The RSSI Display Register needs to be configured to show the Real time RSSI information through the Status Readout Page Setting Register (register 0x29: X[a]0)

To acquire the external signal level, check if the PLL is locked (pll_ok bit) and if the RF power is on (rf_ok bit), then send the direct command Enable RX (0x97), wait 500 μs, and read out the Real time RSSI from the RSSI Display Register (0x2B).

Using an external RF source the non coherent down-conversion ensures that both I and Q RSSI values have a similar level.

a. Don’t care.

The equations for calculating an approximation of the received input power are:

$$meanRSSI = [RSSI(I) + RSSI(Q)] / 2$$

$$Pin\ (in\ dBm) = 2.1 * meanRSSI - G$$

where:

- meanRSSI is the arithmetic mean value of the two RSSI(I) and RSSI(Q) values read-out from the RSSI Display Register
- Pin is the input power, expressed in dBm
- G is a constant depending on the settings of the RX Filter Settings Register and of the RX Mixer and Gain Register.

Components in RF path to the mixer input ports and PCB trace properties are contributing to G as well.

The above procedure assumes that the ST25RU3993 has been previously enabled, and that RX and TX are switched on (EN=1, stby=0, rf_on=1). If the reader device is disabled (EN=0) or in standby mode (stby=1), the MCU needs to wait 18 ms after enabling it and send the direct command Enable RX. If only TX and RX are disabled (rf_on=0), the MCU needs to wait 7 ms after setting rf_on=1 and sending Enable_RX.

It is recommended to check the calculated power against the actual input power and adjust the G constant accordingly for every PCB design.

1.1 Differential input mixer

Typical values for the G constant that are used to calculate an external signal (LBT) input power and available input signal ranges for the differential mixer are shown in *Table 1*.

Table 1. G values for different sensitivity settings - Differential mixer

Register settings 0x0A(1), 0x09(2)	G value (dB)	Available sensitivity range Min/Max (dBm)		Comments
0xC1, 0xFF	53	-50	-22	Internal attenuator on, minimal BB gain
0x01, 0xFF	62	-59	-31	Internal attenuator on, nominal BB gain
0x00, 0xFF	71	-68	-40	Internal attenuator off, nominal BB gain, hence nominal LBT sensitivity
0x02, 0xFF	80	-77	-49	Increased mixer gain, nominal BB gain
0xE2, 0xFF	89	-86	-58	Increased mixer gain, maximal BB gain, hence best LBT sensitivity

1. RX Mixer and Gain Register.
2. RX Filter Settings Register.

The G values in *Table 1* are valid for the detection of the signal with 50 kHz base-band (BB) frequency, and using filter setting 0x09: FF, appropriate for the LBT sensing of a 50 kHz offset.

To calculate the input signal power for backscatter link frequencies of 250 kHz (0x09: 34) or 320 kHz (0x09: 24) the G values should be increased by 2.5 dB (meaning higher gain and lower input power).

To calculate the input signal power for backscatter link frequencies of 160 kHz (0x09: 3F) or 640 kHz (0x09: 04) the G values should be increased by 1.5 dB.

Figure 1. Input power (dBm) vs. RSSI - Differential mixer - BB = 300 kHz

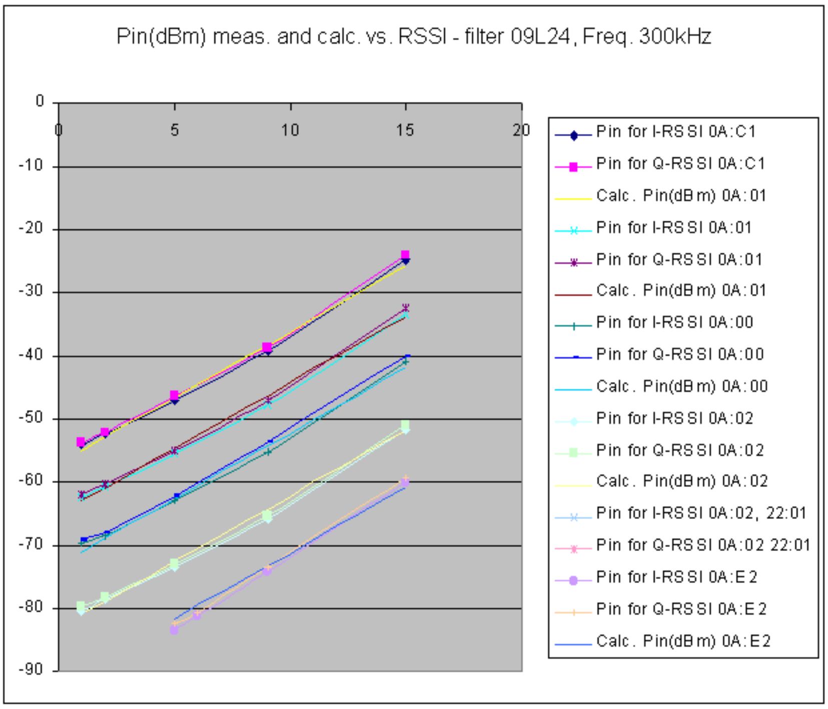


Figure 2. Input power (dBm) vs. RSSI - Differential mixer - BB = 50 kHz

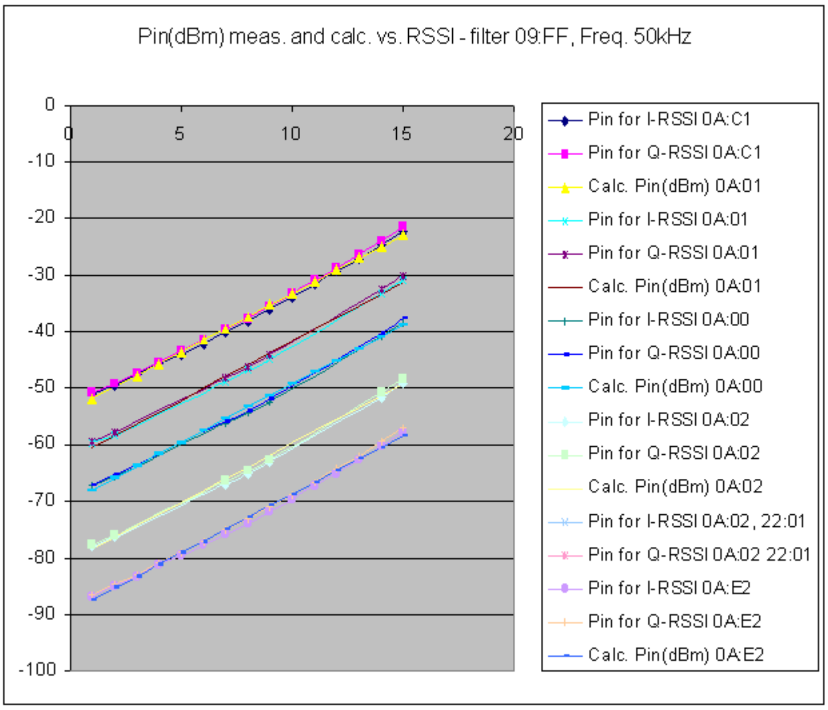


Figure 1 and *Figure 2* show the typical relation between RSSI readout value (code) and input signal power (dBm) for differential mixer inputs at, respectively, 300 kHz and 50 kHz BB signal frequencies, for the I and Q channels. Pin is calculated according to the equations above.

1.2 Single-ended input mixer

The typical values for the G constant used to calculate the external signal (LBT) input power and available input signal ranges for the single-ended mixer are shown in *Table 2*.

Table 2. G values for different sensitivity settings - Single-ended mixer

Register settings 0x0A(1), 0x22(2), 0x09(3)	G value (dB)	Available sensitivity range Min/Max (dBm)		Comments
0xC0, 0x14, 0xFF	63	-60	-32	Low mixer gain, minimal BB gain
0x00, 0x14, 0xFF	71	-68	-40	Low mixer gain, nominal BB gain, hence nominal LBT sensitivity
0x01, 0x12, 0xFF	77	-74	-46	Medium mixer gain, nominal BB gain
0x03, 0x11, 0xFF	83	-80	-52	High mixer gain, nominal BB gain
0xE3, 0x00, 0xFF	91	-88	-60	High mixer gain, maximal BB gain, hence best LBT sensitivity

1. RX Mixer and Gain Register.
2. RX Filter Settings Register.
3. Emitter-Coupled Mixer Options Register.

The G values in *Table 2* are valid for the detection of the signal at 50 kHz BB frequency while using filter setting 0x09: FF, appropriate for LBT sensing using a 50 kHz offset.

To calculate the input signal power at a backscatter link frequency of 250 kHz (0x09: 34) or 320 kHz (0x09:24) the G value should be increased by 2.5 dB (meaning higher gain and lower input power).

To calculate the input signal power at a backscatter link frequency of 160 kHz (0x09: 3F) or 640 kHz (0x09: 04) the G value should be increased by 1.5 dB.

Figure 3 and *Figure 4* show the typical relation between RSSI readout levels (code) and the input signal power (in dBm) for the single- ended mixer input for, respectively, 50 kHz and 300 kHz BB signal frequencies, for the I and Q channels. The corresponding RX filter settings are 0x09: FF and 0x09: 24.

Figure 3. Input power (dBm) vs. RSSI - Single-ended mixer - BB = 50 kHz

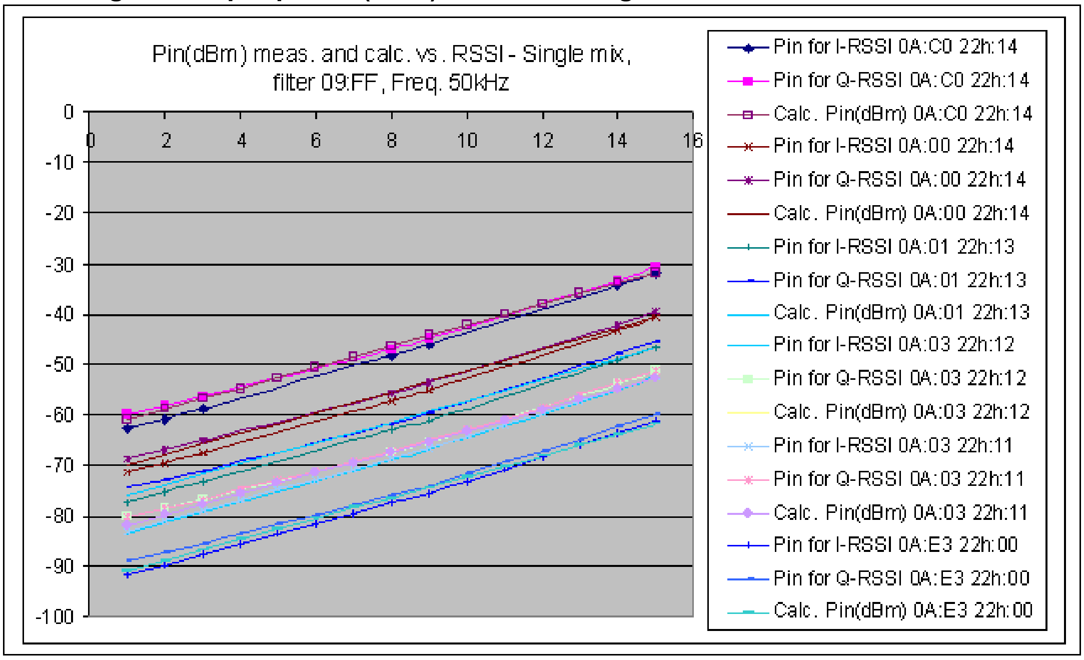
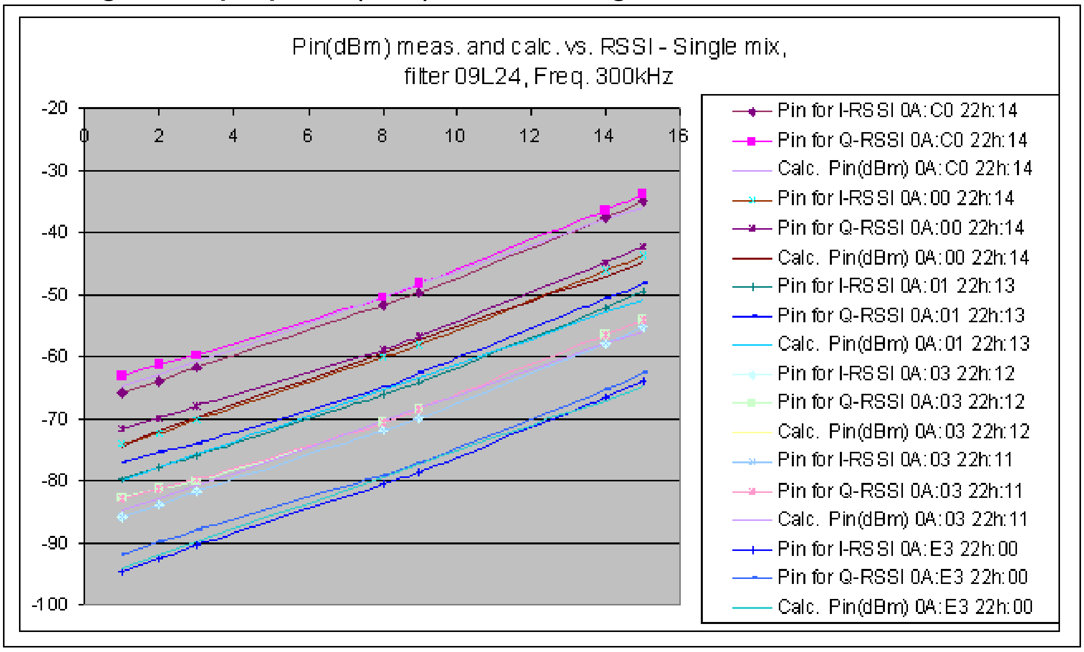


Figure 4. Input power (dBm) vs. RSSI - Single-ended mixer - BB = 300 kHz



2 Transponder input signal power

During the reception of the transponder signal the amplitudes of the I and Q channels are continuously monitored. During the pilot tone the RSSI level is measured and stored in a register. The display of RSSI-1-pilot (I, Q) values needs to be configured through the register 0x29: X[b]4 and can be read out from register 0x2B. The MCU can access the acquired RSSI-1-pilot (I) and RSSI-1-pilot (Q) values during data reception or after the end of the reception. They are valid until the start of the next data transmission.

The modulated transponder signal is coherent with the local oscillator (VCO). Consequently, the down-converted signal can be seen in the I and/or in the Q channel.

The following formulas can be used to calculate the received transponder signal level at the mixer input ports:

$$\text{highRSSI} = \max\,[\text{RSSI(I)}, \text{RSSSI(Q)}]$$

$$\text{deltaRSSI} = \text{abs}\,[\text{RSSI(I)} - \text{RSSSI(Q)}]$$

$$\text{Pin(dBm)} = 2.1 * \text{highRSSI} + 10 \log (1 + 10^{-\text{deltaRSSI}/10}) - G - 3$$

where

- highRSSI is the highest value between the RSSI(I) and RSSI(Q) values read from the RSSI Display Register
- deltaRSSI is the absolute value of the difference between the two RSSI values
- Pin(dBm) is the input signal power of the transponder at the mixer input ports in dBm
- G is a constant depending on register settings, components in the RX path to the ST25RU3993, and PCB traces. G values for different register settings are listed in *Table 1* and *Table 2*.

Since the contribution of deltaRSSI is relatively small, the calculation for Pin can be simplified (especially for the MCU) using the formula:

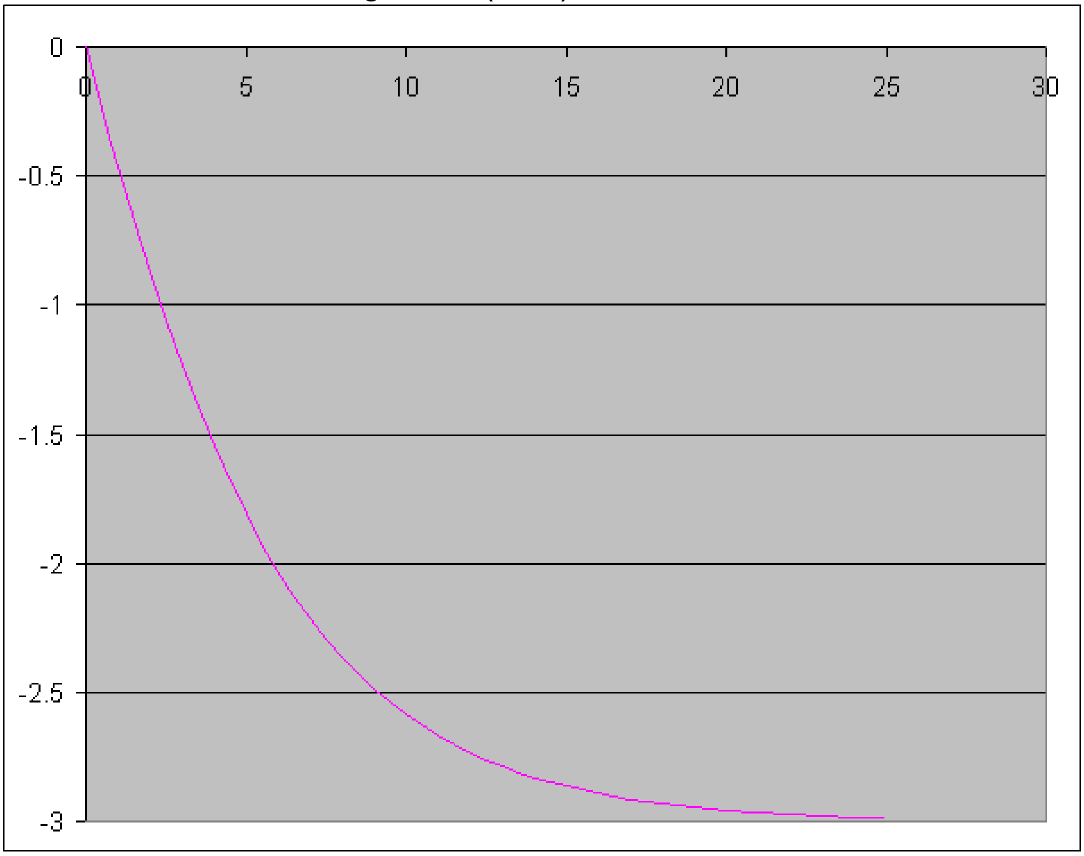
$$\text{Pin(dBm)} = 2.1 * \text{highRSSI} - G - C$$

where C is a constant depending upon deltaRSSI.

The behavior of C with respect to deltaRSSI is shown in *Figure 5*. Using a single C value of 1.5 the error contribution due to the simplified calculation can be up to 1.5 dB, using a set of C values Pin can be approximated with higher accuracy.

b. Don’t care.

Figure 5. C (in dB) vs. deltaRSSI



3 RSSI calculation using AGC

When AGC is enabled the calculation of the RSSI needs to be adapted.

AGC values 5, 6 and 7 are related to gain stages (3 dB each) in the RSSI and digitizer circuitry. The influence of the AGC can be seen on the BB tag signal (OAD and OAD2 outputs) and RSSI result.

Values 1 to 4 are related to the digitizer hysteresis. This part of the AGC action is seen on the sensitivity only.

To correctly calculate the signal input power with AGC enabled, in addition to the RSSI Display Register result, the AGC result from register 0x2A, bits agc<2:0> needs to be taken into account.

To calculate the RSSI of an external RF signal (LBT mode), the constant G value from *Table 1* and *Table 2* should be corrected according the following formulas:

$$G_{AGC} = G - 3\text{ dB} * (AGC - 4),\text{ if } AGC > 4$$

$$G_{AGC} = G,\text{ if } AGC \leq 4$$

where:

- AGC is the value of the status bits from register 0x2A
- G_{AGC} is the constant for the AGC based RSSI calculation
- G is the constant from *Table 1* and *Table 2*.

4 Conclusion

Thanks to the integrated RSSI measurement capability, the ST25RU3993 allows the user to measure the power level of an incoming transponder signal or to detect external RF signal levels close to the VCO frequency. The received signals (I, Q) are processed and an optimized gain is set by the internal AGC.

This application note provides the formulas to calculate the dBm level of the external RF carrier with the aid of a constant (G value), shown in a tabular format for both receiver types, to help the user select the correct value for a given receiver gain and filter configuration.

To optimize performance it is recommended to check the calculated power against the actual input power, and to adjust the G constant accordingly for every PCB design.

5 Revision history

Table 3. Document revision history

Date	Revision	Changes
03-Jan-2017	1	Initial release.