Freescale Semiconductor
Application Note

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MC1319x Physical Layer Lab Test Description

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1 Introduction

The MC1319x device is a ZigBee™ and IEEE® 802.15.4 Standard compliant transceiver meant to operate in the 2.4GHz Industry, Scientific and Medical (ISM) unlicensed band. This application note describes the lab test equipment for the Physical Layer testing of the MC1319x as defined in IEEE 802.15.4 Standard. An excerpt from the 802.15.4 standard is referenced for each test presented. Refer to the complete 802.15.4 standard for further details.

The MC1319x registers that are relevant to Physical (PHY) Layer testing are also included in this document. For a complete list of registers and descriptions of operation, refer to the appropriate MC1319x reference manual. For detailed PHY performance results, refer to the appropriate MC1319x data sheet.

Contents

2 Receiver Tests

Packet Error Rate (PER), Reported Energy Value, and Clear Channel Assessment (CCA) are used to assess and characterize the receiver. Specifically, PER is used as the measurement criteria for the following tests: Data Rate/Symbol Rate, Receiver Sensitivity, Maximum Input Power, and Adjacent and Alternate Channel Rejection. The Reported Energy Value is used as the measurement criteria for Energy Detect and Link Quality.

Both the packet length of 20 bytes for the PSDU and threshold value of <1% are defined in the standard when testing for PER. A successful packet is indicated by register 24 bit 7 for Rx Packet Received and bit 0 for valid CRC. When a packet is successfully received, bit 7 equals 1. When the received packet has error-free data, a good CRC is indicated when bit 0 equals 1. In addition to the read of the status of register 24, the Rx RAM is also read and compared against the known packet RAM that was downloaded to the signal generator. For all PER testing, the transceiver is set to receive mode by setting register 6, bits 0:2 to 2.

The transceiver is set to Link Quality mode by setting register 6 bits 0:2 to 2 and register 6 bits 4:5 to 1. The Reported Energy Value is indicated by register 29 bits 8:15. The reported energy value is translated to a power level (dBm) by negating the reported value and dividing by two (2). The reported energy is an output of the Energy Detect (ED) and Link Quality Indicator (LQI) modes. The transceiver is set to Energy Detect mode by setting register 6 bits 0:2 to 1 and register 6, bits 4:5 to 2.

The CCA value is indicated by register 24 bit 5. If the power level transmitted by the signal generator to the transceiver RF input is higher than the CCA threshold, the CCA value read should equal 1. Conversely, if the power level is less than the CCA threshold, the CCA value read should equal 0 indicating that the channel is not busy. The transceiver is set to CCA mode by setting register 6, bits 0:2 to 1 and register 6, bits 4:5 to 1.

2.1 Measurement Equipment

The set-up for receiver testing consists of a signal generator whose output is connected to the RF input of the transceiver as shown in Figure 1.

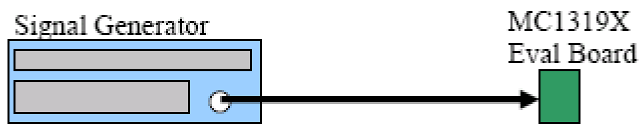

Figure 1. Desired Carrier Setup

The equipment list for the receiver tests are shown in Table 1.

Table 1. Equipment Required for Receiver Tests

Test Parameter	Signal Generator	Frequency Counter
Data Rate/Symbol Rate	1	1
Receiver Sensitivity	1	
Maximum Input Power	1	
Adjacent Channel Rejection	2	
Alternate Channel Rejection	2	
Energy Detect	1	
Link Quality	1	
Clear Channel Assessment	1	

Equipment options for the receiver tests are shown in Table 2.

Table 2. Equipment Options for Receiver Tests

Signal Generator	Frequency Counter
RS SMIQ	HP 53150A
AT E4438C	ANR MF2421B

2.2 Test Parameter Details

2.2.1 Data Rate/Symbol Rate

The following quoted text taken from reference P802.15.4/D18-6.5.3.2 of the 802.15.4 Standard:

(6.5.3.2) "The 2450 MHz PHY symbol rate shall be 62.5 ksymbols/s ±40 ppm."

For the data rate/symbol rate testing, the crystal may be centered as follows:

1. Change the crystal output to 16MHz. At register A bits 0:2, change default value of 6 to value of 0.
2. Measure the crystal output with a frequency counter.
3. Vary the crystal trim at register A bits 8:15 until 16MHz, or as close as possible to 16MHz, is measured at the frequency counter.

The signal generator is varied from 0 ppm to +/-100ppm with the output power level set to the sensitivity level. The PER is measured on the transceiver to determine the ppm deviation that the transceiver can tolerate.

2.2.2 Receiver Sensitivity

The following quoted text and table are taken from reference P802.15.4/D18-6.1.6, 6.5.3.3 of the 802.15.4 Standard:

"Under the conditions specified in Clause 6.1.6, a compliant device shall be capable of achieving a sensitivity of -85 dBm or better."

Clause 6.1.6

Packet Error Rate (PER)	Average Fraction Of Transmitted Packets That Are Not Detected	Average Measured Over Random PSDU Data
Receiver sensitivity	Threshold input signal power that yields a specified packet error rate.	• PSDU length = 20 octets. • PER < 1%. • Power measured at antenna terminals. • Interference not present.

The power level of the signal generator is lowered from a higher than -85dBm power level until the PER < 1% is no longer measured at the receiver.

2.2.3 Maximum Input Power

The following quoted text and table are taken from reference P802.15.4/D18-6.7.6, 6.1.6 6.7.6 of the 802.15.4 Standard.

(6.7.6) "The receiver maximum input level is the maximum power level of the desired signal, in dBm, present at the input of the receiver for which the error rate criterion in 6.1.6 is met. A compliant receiver shall have a receiver maximum input level greater than or equal to -20 dBm."

Clause 6.1.6

Packet Error Rate (PER)	Average Fraction Of Transmitted Packets That Are Not Detected	Average Measured Over Random PSDU Data
Receiver sensitivity	Threshold input signal power that yields a specified packet error rate.	• PSDU length = 20 octets. • PER < 1%. • Power measured at antenna terminals. • Interference not present.

The power level of the signal generator is raised from a lower than 0dBm power level until the PER < 1% is no longer measured at the receiver.

2.2.4 Adjacent And Alternate Channel Rejection

The following quoted text and tables are taken from reference P802.15.4/D18-6.5.3.4, 6.5.3.3, 6.1.6 1 of the 802.15.4 Standard.

(6.5.3.4) "The minimum jamming resistance levels are given in Table 22. The adjacent channel is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel is one more removed from the adjacent channel. For example, when channel 13 is the desired channel, channels 12 and 14 are the adjacent channels and channels 11 and 15 are the alternate channels.

Table 22 Minimum Receiver Jamming Resistance Requirements For 2450 Mhz PHY

Adjacent Channel Rejection	Alternate Channel Rejection
0 dB	30 dB

The adjacent channel rejection shall be measured as follows. The desired signal shall be a compliant 2450 MHz IEEE 802.15.4 signal of pseudo-random data. The desired signal is input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity given in 6.5.3.3.

In either the adjacent or alternate channel a IEEE 802.15.4 compliant signal is input at the relative level specified in Table 22. The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 6.1.6 under these conditions."

(6.5.3.3) "Under the conditions specified in Clause 6.1.6, a compliant device shall be capable of achieving a sensitivity of -85 dBm or better."

Clause 6.1.6

Packet Error Rate (PER)	Average Fraction Of Transmitted Packets That Are Not Detected	Average Measured Over Random PSDU Data
Receiver sensitivity	Threshold input signal power that yields a specified packet error rate.	• PSDU length = 20 octets. • PER < 1%. • Power measured at antenna terminals. • Interference not present.

The set-up for adjacent and alternate channel testing requires two signal generators and a combiner as shown in Figure 2. The output of the combiner is connected to the RF input of the transceiver. One signal generator is designated as the desired carrier, which is set to the sensitivity level plus 3dB. The other signal generator is used as the interferer signal, and the power level of this generator is lowered until a PER < 1% is measured at the receiver.

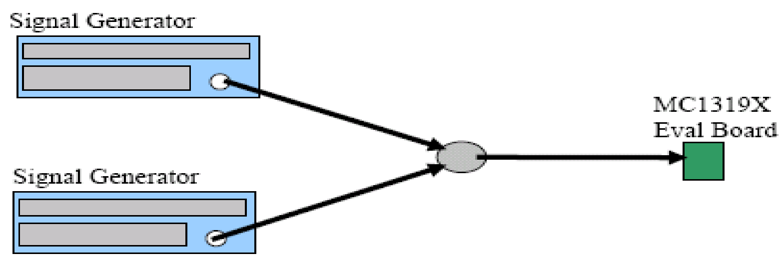

Figure 2. Desired Carrier and Interferer Set-Up

2.2.5 Energy Detect

Standard Requirements

The following quoted text is taken from reference P802.15.4/D18-6.7.7 of the 802.15.4 Standard:

(6.7.7) "The receiver energy detection (ED) measurement is intended for use by a network layer as part of a channel selection algorithm. It is an estimate of the received signal power within the bandwidth of an IEEE 802.15.4 channel. No attempt is made to identify or decode signals on the channel. The energy detection time shall be equal to 8 symbol periods.

The ED result shall be reported to the MLME using PLME-ED.confirm (6.2.2.4) as an 8-bit integer ranging from 0x00 to 0xff. The minimum ED value (0) shall indicate received power less than 10 dB above the specified receiver sensitivity (6.5.3.3 and 6.6.3.4), and the range of received power spanned by the ED values shall be at least 40 dB. Within this range the mapping from the received power in dB to ED value shall be linear with an accuracy of +/- 6 dB."

The signal generator power level is swept across the dynamic range. The reported energy value will be compared against the power level input to the transceiver RF input. The reported energy value should be within +/- 6dB of the input power level. The reported energy value is translated to a power level (dBm) by negating the reported value and dividing by 2.

2.2.6 Link Quality Indicator (LQI)

The following quoted text is taken from reference P802.15.4/D18-6.7.8 of the 802.15.4 Standard:

(6.7.8) "The link quality indication (LQI) measurement is a characterization of the strength and/or quality of a received packet. The measurement may be implemented using receiver energy detection, a signal-to-noise ratio estimation, or a combination of these. The use of the LQI result by the network or application layers is not specified in this standard.

The LQI measurement shall be performed for each received packet, and the result shall be reported to the MAC sublayer using PD-DATA.indication (6.2.1.3) as an integer ranging from 0x00 to 0xff. The minimum and maximum LQI values (0x00 and 0xff) should be associated with the lowest and highest quality IEEE 802.15.4 signals detectable by the receiver, and LQ values in between should be uniformly distributed between these two limits. At least 8 unique values of LQ shall be used."

The signal generator power level is swept across the dynamic range. The reported energy value will be compared against the power level input to the transceiver RF input. The reported energy value should be within +/- 6dB of the input power level. The reported energy value is translated to a power level (dBm) by negating the reported value and dividing by 2.

2.2.7 Clear Channel Assessment

The following quoted text is taken from reference P802.15.4/D18-6.7.9 of the 802.15.4 Standard:

(6.7.9) "The energy detection threshold shall be at most 10 dB above the specified receiver sensitivity (6.5.3.3 and 6.6.3.4)."

The signal generator power level is varied across the dynamic range. The CCA Threshold value is set to the sensitivity level. The CCA value is read from register 24 bit 5. The CCA value should read busy if the input power level is above the CCA Threshold value. Conversely, the CCA value should read not busy if the input power level is below the CCA Threshold value. According to the standard, the CCA should indicate a busy channel for any power level 10dB above the receiver sensitivity.

3 Transmitter Tests

The transmitter test list includes the following parameter measurements:

- Power Spectral Density (PSD)
- Transmit Center Frequency Tolerance
- Transmit Power
- Error Vector Magnitude (EVM)

All measurements, with the exception of EVM, may be done with a Spectrum Analyzer or a Vector Signal Analyzer (VSA). The EVM measurements may be done on the VSA. For all transmitter testing, the transceiver is set to transmit mode by setting register 6, bits 0:2 to 3.

3.1 Measurement Equipment

The equipment list for the transmitter tests is shown in Table 3.

Table 3. Equipment Required for Transmitter Tests

Test Parameter	Spectrum Analyzer	Vector Signal Analyzer
Power Spectral Density	1	1
Error Vector Magnitude		1
Transmit Center Frequency Tolerance	1	1
Transmit Power	1	1

Equipment options for the transmitter tests are shown in Table 4

Table 4. Equipment Options for Transmitter Tests

Spectrum Analyzer	Vector Signal Analyzer
AT E4440A	AT 89641A
AT 856X	AT N4010A
AT E4407B	RS FSQ
RS FSEM	
RS FSU	

3.1.1 Power Spectral Density (PSD)

The following quoted text and table are taken from reference P802.15.4/D18-6.5.3.1 of the 802.15.4 Standard:

(6.5.3.1) "The transmitted spectral products shall be less than the limits specified in Table 21. For both relative and absolute limits, average spectral power shall be measured using a 100 kHz resolution bandwidth. For the relative limit, the reference level shall be the highest average spectral power measured within +/- 1 MHz of the carrier frequency."

Table 21 Transmit PSD Limits

Frequency	Relative Limit	Absolute Limit
|f-fc| > 3.5 MHz	20 dB	-30 dBm

The power spectral density is measured by the following steps:

1. Enable continuous mode by setting register 30, bit 15 from default value of 0 to 1.
2. Enable transmit mode by setting register 6, bits 0:2 to value of 3.
3. Measure spectrum on spectrum analyzer.

3.1.2 Error Vector Magnitude

The following quoted text is taken from reference P802.15.4/D18-6.7.3.1 of the 802.15.4 Standard:

(6.7.3.1) “A compliant transmitter shall have EVM values of less than 35% when measured for 1000 chips. The error vector measurement shall be made on baseband I and Q chips after recovery through a reference receiver system. The reference receiver shall perform carrier lock, symbol timing recovery and amplitude adjustment while making the measurements.”

Several packets are transmitted and captured on the VSA as shown in Figure 3.

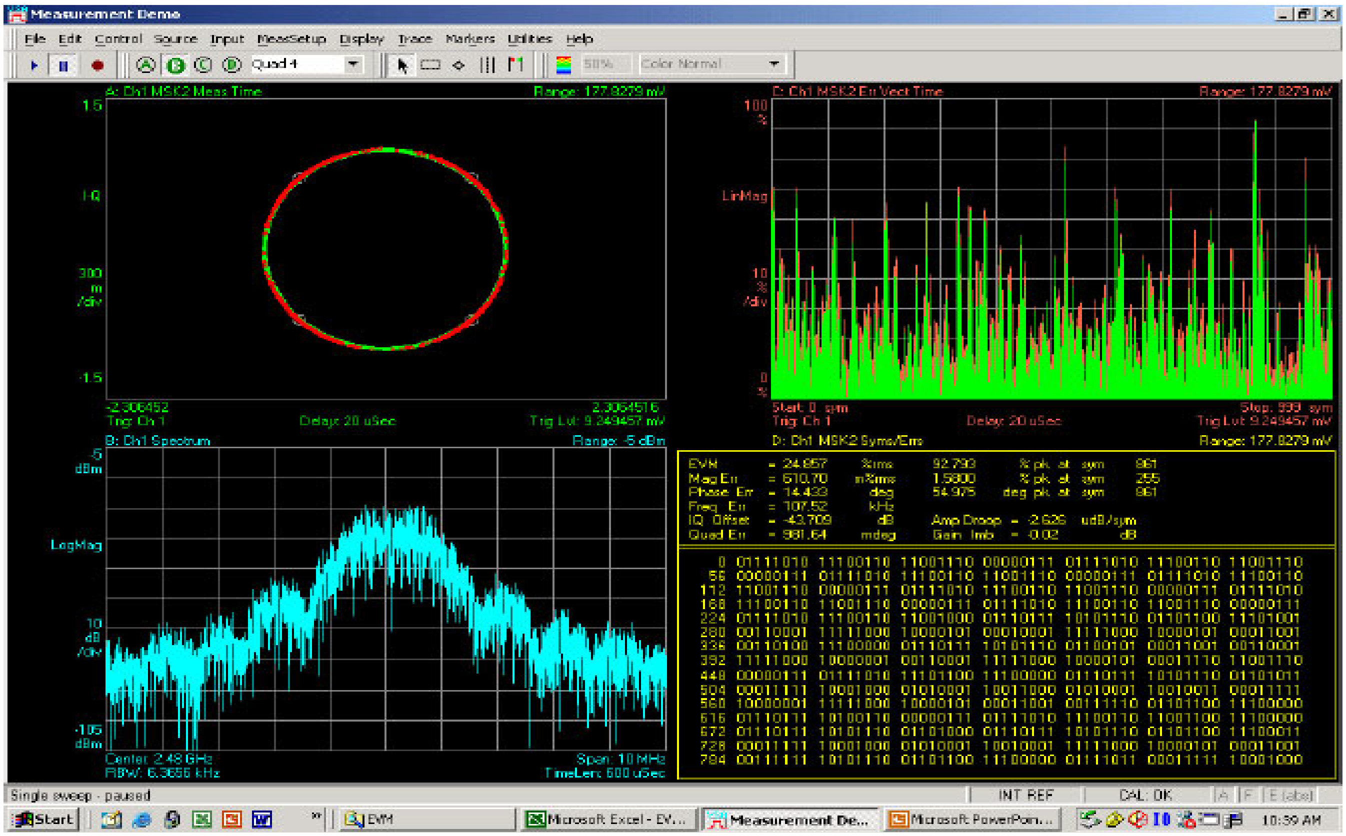

Figure 3. VSA Screen Capture

3.1.3 Transmit Center Frequency Tolerance

The following quoted text is taken from reference P802.15.4/D18-6.5.3.2 of the 802.15.4 Standard:

(6.5.3.2) “The 2450 MHz PHY symbol rate shall be 62.5 ksymbols/s ±40 ppm.”

The transmit center frequency tolerance is measured by the following steps:

1. Enable continuous mode by setting register 30, bit 15 from default value of 0 to 1.
2. Enable CW mode by setting register 31, bits 3:5 from default value of 0 to 1.
   Default value results in a modulated Tx output.
3. Enable transmit mode by setting register 6, bits 0 to 2 to value of 3.
4. Measure deviation of signal from expected center frequency on spectrum analyzer.

3.1.4 Transmit Power

The following quoted text is taken from reference P802.15.4/D18-6.7.5 of the 802.15.4 Standard:

(6.7.5) "A compliant transmitter shall be capable of transmitting at least -3dBm. Devices should transmit lower power when possible in order to reduce interference to other devices and systems. The maximum transmit power is limited by local regulatory bodies."

The output power is measured by the following steps:

1. Enable continuous mode by setting register 30 bit 15 from default value of 0 to 1.
2. Enable CW mode by setting register 31, bits 3:5 from default value of 0 to 1. Default value results in a modulated Tx output.
3. Enable transmit mode by setting register 6, bits 0:2 to value of 3.
4. Measure output power on spectrum analyzer.
5. The PA output power may be adjusted at register 12, bits 0:7.
   The 0 dBm nominal output power (default value) is bits 0:7 set to BC.
   The 4 dBm output power (maximum value) is bits 0:7 set to FF.

4 Complete Measurement Equipment List

The complete list of measurement equipment is shown in Table 5.

Table 5. Equipment Options for PHY Layer Tests

Type	Quantity	Vendor Options	
Power Meter	1	ANR ML2438A	AT 34401A
Signal Generator	2	RS SMIQ, SMU200A	AT E4438C
Frequency Counter	1	AT 53150A	ANR MF2421B
Spectrum Analyzer	1	AT E4440A, 856X, E4407B	RS FSEM, FSQ
Vector Signal Analyzer	1	AT 89600, N4010A	RS FSQ

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