Specification

Z-Wave Long Range PHY Layer Test Specification

Version:	1.0
Description:	This documents outlines how to ensure, that a Z-Wave Long Range PHY is compliant with the Z-Wave Long Range PHY Specification
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Z-Wave Alliance Board of Directors

REVISION RECORD				
Doc. Rev	**Date**	**By**	**Pages affected**	**Brief description of changes**
0.1	2020.09.29	CSWG	ALL	Initial Version
0.3	2020.10.09	CSWG	All	Content added
0.31	2020.10.20	CSWG	p.1 p.1 3.2.4 3.3.1 3.5.4 3.5.5 3.6.1 3.6.3 3.7.6 Table 6 3.9.1 3.9.3 Table 7 3.12.1 3.12.6 3.13.1 3.13.4 3.13.5 3.14.2	Added LRF to abbreviations list Exchanged “on a non-Silicon…. / device” with “on a RF transceiver” Added condition for pass criteria Added the words “randomly mixed” in first item. Changed wording of pass criteria Changed wording of fail criteria Corrected wording in entire section Added reference to ZWALR table 5-7 Added an exception to the test results to allow for up to 3dB lower threshold Changed RBW to 100kHz Changed wording in this section Added reference to ZWALR table 5-7 Corrected to Oscilloscope Added “zero-span” to spectrum analyzer requirements Added exception to account for high output powered systems. Deleted reference to a Keysight Spectrum analyzer Changed wording of pass criteria Changed wording of fail criteria Changed description of measurement setup
0.5	2020.10.23	CSWG	Appendix	Removed Appendix from document
0.7	2020.11.18	CSWG	3.2, 3.2.1, 3.3, 3.3.1, 3.4.1, 3.6	Corrected from LFR to LRF
0.8	2021.03.01	CSWG	None	Updated to revision 0.8 for TC review
0.9	2021.03.29	CSWG	Frontpage Figure 1 Section 3.4	Cleanup for IPR review • Corrected spelling • Correct to “offset EVM” (and not only “EVM”)
1.0	2021.08.27	ZWA Board		Approved for Publication

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1 ABBREVIATIONS

Abbreviation	Explanation
BT	The filter coefficient in a Gaussian filter
CW signal	Carrier Wave (RF) signal
DUT	Device Under Test
FER	Frame Error Rate
LRF	Z-Wave Long Range Radio Frequency Profiles
MAC	Media Access Control
PHY	Physical (layer)
SOF	Start of Frame
VSA	Vector Signal Analysis (software)

2 INTRODUCTION

2.1 Purpose

The purpose of this document is to outline a series of test cases which can prove, that an implementation of the Z-Wave Long Range protocol on RF transceiver adheres to the requirements given in the Z-Wave Long Range PHY and MAC Specification as defined in the Z-Wave Alliance.

The test cases described in the following sections are not detailed descriptions. The purpose of the descriptions is to be able show what is needed and to discuss how it can be obtained, and once a suitable level of understanding is found, the work detailing the individual tests can begin.

2.2 Audience and prerequisites

Test Body / test lab with the capabilities to perform detailed RF measurements and with the experience of conducting measurements according to e.g. Bluetooth / Zigbee / Thread standards.

3 PHY TEST CASE DESCRIPTIONS

The test cases described in this section are all referring to the PHY requirements stated in the Z-Wave Alliance "Z-Wave Long Range PHY and MAC Specification", [1].

3.1 General assumptions

All references to tables in [1] in the following sections will be preceded an ZWALR header, e.g. ZWALR table 7-5 will refer to the table 7-5 in the document [1].

All references to sections in [1] in the following sections will be preceded an ZWALR header, e.g. ZWALR section 7.1.2.5.2 will refer to section 7.1.2.5.2 in the document[1].

It is assumed, that a Z-Wave device can transmit a modulated RF signal according to the [1] with any data content as well as a non-modulated signal, a Carrier Wave signal (CW signal) at an RF frequency identical to $f_{center\_frequency}$ according to[1].

3.2 LRF profiles

A Z-Wave device must support all LRF profiles as defined in ZWALR table 5-1.

The RF frequency for all LRF profiles must be measured.

3.2.1 Prerequisites

1. A Z-Wave device capable of transmitting a CW signal
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A method to initialize the transmitted RF frequency of the Z-Wave device, or pre-programmed Z-Wave devices to cover all LRF profiles as listed in ZWALR table 5-1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.2.2 Measurement setup

The Z-Wave device must be initialized to transmit a constant carrier wave RF signal at each LRF profile as defined in ZWALR table 5-1

The Z-Wave device must be connected to a spectrum analyzer with a coaxial cable.

The spectrum analyzer must be initialized to:

Table 1, RF Profile Spectrum Analyzer settings

Spectrum analyzer parameter	**Setting**
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	30dBm
Detector type	Average

The RF frequency of each LRF profile must be measured using the “Peak search” feature of the spectrum analyzer.

3.2.3 Measurement result

The measurement result of the test is the measured peak RF frequency for each LRF profile.

The RF frequency for each LRF profile may not differ more than the accuracy given in ZWALR table 5-2 / ZWALR section 5.2.2.

This accuracy is given as a maximum allowed frequency deviation after 5 years of operation and under extreme temperature conditions.

3.2.4 Pass criteria

The Z-Wave device shall pass the test if:

1. All RF frequencies as stated in ZWALR table 5-1 could be measured
2. All RF frequencies measured are within the accuracy limits stated in ZWALR table 5-2 / ZWALR section 5.2.2 when taken into consideration, that those requirements are after 5 years of operation and under extreme temperature conditions.

3.2.5 Fail criteria

The Z-Wave device shall fail the test if:

1. A frequency as defined in ZWALR table 5-1 could not be initialized by the Z-Wave device and not measured in the measurement setup
2. A frequency measured on the Z-Wave device was measured to be less accurate than stated in ZWALR table 5-2 / ZWALR section 5.2.2

3.3 Symbol rates

A Z-Wave device must support all the symbol rates / data rates as defined in ZWALR table 5-2 and at each of the LRF profiles as shown in ZWALR table 5-1.

The modulation and coding parameters for each data rates are given in ZWALR tables 5-4, 5-5 and 5-6

The data rates for the LRF profiles listed in ZWALR table 5-2 must be measured and verified.

3.3.1 Prerequisites

1. A Z-Wave device capable of transmitting a stream of modulated randomly mixed 0 and 1 data bits at the rates defined in ZWALR table 5-2 and the modulation and coding properties given in ZWALR tables
   5-4, 5-5 and 5-6
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A method to initialize the transmitted modulation type of the Z-Wave device, or pre-programmed Z-Wave devices to cover all listed LRF profiles and data rates as listed in ZWALR table 5.1
4. A spectrum analyzer with better or identical specifications to a Rhode & Schwartz FSV3007, 7.5GHz
5. A digital VSA installed on the spectrum analyzer with the capabilities of at least Rhode & Schwartz option FSV3-K70.

3.3.2 Measurement setup

The Z-Wave device must be initialized to transmit a constant stream of modulated RF signal at each RF profile as defined in ZWALR table 5-1.

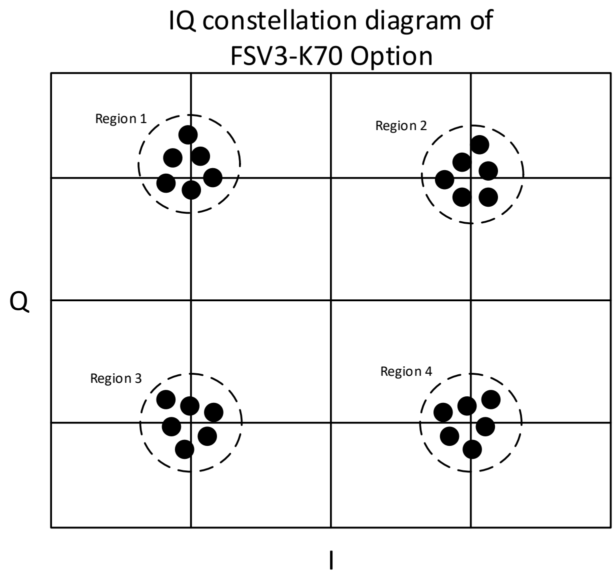
The Z-Wave device must be connected to a spectrum analyzer with a coaxial cable.

The spectrum analyzer must be initialized to:

Table 2, Symbol Rate Spectrum Analyzer settings

Spectrum analyzer parameter	**Setting**
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	1MHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	30dBm
Detector type	Average
Digital demodulation type	Offset QFSK
Symbol rate	400 ks/s
Trigger type	IF power
Symbol Rate Error	Checked

The symbol rate of each LRF profile must be measured using IQ constellation diagram option of the spectrum analyzer as well as the “Symbol Rate Error” from the Results Summary table of the VSA software:



Result Summary table				
		Current	Peak	Unit
EVM Offset	RMS	xxx	xxx	%
	Peak	xxx	xxx	%
MER	RMS	xxx	xxx	dB
	Peak	xxx	xxx	dB
Phase Error	RMS	xxx	xxx	deg
	Peak	xxx	xxx	deg
Magnitude Error	PMS	xxx	xxx	%
	Peak	xxx	xxx	%
Carrier Frequency Error		xxx	xxx	Hz
Symbol Rate Error		xxx	xxx	ppm
I/Q Skew		xxx	xxx	ps
Rho		xxx	xxx	
I/Q Offset		xxx	xxx	dB
I/Q Imbalance		xxx	xxx	dB
Gain Imbalance		xxx	xxx	dB
Quadrature Error		xxx	xxx	deg
Amplitude Droop		xxx	xxx	dB/sym
Power		xxx	xxx	dBm

Figure 1, Data rate measurement

3.3.3 Measurement result

The measurement result of the test is the appearance of the IQ constellation diagram and the reading of the Symbol Rate Error from the Results Summary table of the VSA software.

There must be a clear distinction of dots between the 4 regions, and the distance between the center of the regions must be identical and centered in the constellation diagram.

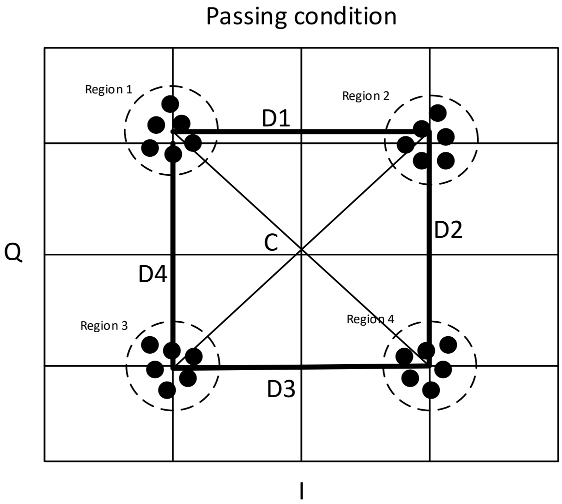
The Symbol Rate Error must be within the limits stated in ZWALR table 5-2.

This accuracy is given as a maximum allowed frequency deviation after 5 years of operation and under extreme temperature conditions.

3.3.4 Pass criteria

The Z-Wave device shall pass the test if:

1. Constellation diagram shows 4 clear regions with no overlap between the regions 1 to 4, and the distance from the region centers are identical: D1 = D2 = D3 = D4
2. If the geometric center of the four regions is identical to the center of the constellation diagram, shown in Figure 2 below at C
3. Item #1 and #2 is valid for each LRF profile as stated in ZWALR table 5-1
4. Item #1 and #2 is valid for all symbol rates as stated in ZWALR table 5-2
5. The analyzed Symbol Rate Error by the VSA software is within the accuracy stated in ZWALR table 5-2



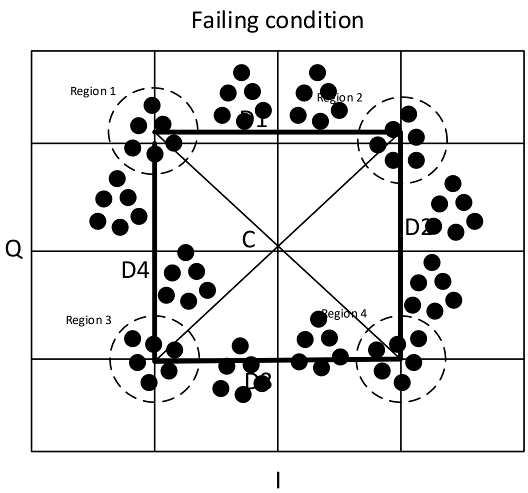
Result Summary table				
		Current	Peak	Unit
EVM Offset	RMS	xxx	xxx	%
	Peak	xxx	xxx	%
MER	RMS	xxx	xxx	dB
	Peak	xxx	xxx	dB
Phase Error	RMS	xxx	xxx	deg
	Peak	xxx	xxx	deg
Magnitude Error	PMS	xxx	xxx	%
	Peak	xxx	xxx	%
Carrier Frequency Error		xxx	xxx	Hz
Symbol Rate Error		YYY	ZZZ	ppm
I/Q Skew		xxx	xxx	ps
Rho		xxx	xxx	
I/Q Offset		xxx	xxx	dB
I/Q Imbalance		xxx	xxx	dB
Gain Imbalance		xxx	xxx	dB
Quadrature Error		xxx	xxx	deg
Amplitude Droop		xxx	xxx	dB/sym
Power		xxx	xxx	dBm

Figure 2, Passing condition for symbol rate measurements

3.3.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Constellation diagram does not show 4 clear regions or there are overlap between the regions 1 to 4, or the distance from the region centers not identical: D1 <> D2 <> D3 <> D4
2. If the geometric center of the four regions is not identical to the center of the constellation diagram, shown in **Error! Reference source not found.** below at C
3. Item #1 and #2 was not valid for each LRF profile as stated in ZWALR table 5-1
4. Item #1 and #2 was not valid for all symbol rates as stated in ZWALR table 5-2
5. The analyzed Symbol Rate Error by the VSA software is above the accuracy stated in ZWALR table 5-2



Result Summary table				
		Current	Peak	Unit
EVM Offset	RMS	xxx	xxx	%
	Peak	xxx	xxx	%
MER	RMS	xxx	xxx	dB
	Peak	xxx	xxx	dB
Phase Error	RMS	xxx	xxx	deg
	Peak	xxx	xxx	deg
Magnitude Error	PMS	xxx	xxx	%
	Peak	xxx	xxx	%
Carrier Frequency Error		xxx	xxx	Hz
Symbol Rate Error		OOO	PPP	ppm
I/Q Skew		xxx	xxx	ps
Rho		xxx	xxx	
I/Q Offset		xxx	xxx	dB
I/Q Imbalance		xxx	xxx	dB
Gain Imbalance		xxx	xxx	dB
Quadrature Error		xxx	xxx	deg
Amplitude Droop		xxx	xxx	dB/sym
Power		xxx	xxx	dBm

Figure 3, Failing condition for symbol rate measurements

3.4 Modulation, encoding and symbol mapping

Data transmitted by a Z-Wave device must be modulated and coded according to the ZWALR tables 5-4, 5-5 and 5-6

The modulation parameter offset EVM for each of the data rates listed in ZWALR table 5-2 must be measured and verified.

3.4.1 Prerequisites

1. A Z-Wave device capable of transmitting a known stream containing all the symbols shown in ZWALR table 5.5 at the rates defined in ZWALR table 5-2 and the modulation and coding properties given in ZWALR tables 5-4, 5-5 and 5-6
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A method to initialize the transmitted modulation type of the Z-Wave device, or pre-programmed Z-Wave devices to cover all listed LRF profiles and data rates as listed in ZWALR table 5.1
4. A spectrum analyzer with better or identical specifications to a Rhode & Schwartz FSV3007, 7.5GHz
5. A digital VSA installed on the spectrum analyzer with the capabilities of at least Rhode & Schwartz option FSV3-K70.

3.4.2 Measurement setup

The Z-Wave device must be initialized to transmit a constant stream of modulated RF signal at each LRF profile as defined in ZWALR table 5-1.

The Z-Wave device must be connected to a spectrum analyzer with a coaxial cable.

The spectrum analyzer must be initialized to:

Table 3, Modulation and encoding Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ZWALR table 5-1
Span	1MHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	30dBm
Detector type	Average
Digital demodulation type	OQFSK
Symbole rate	400 ks/s
Trigger type	IF power

The modulation properties of each data rate must be measured using demodulation feature of the VSA FSV3-K70 option of the spectrum analyzer. Below is shown an example of how a demodulated data stream could appear on the screen of the spectrum analyzer:

Example of Demodulation
view of FSV3-K70 Option

Row/ Line	1	2	3	4	5	6	7	8
1	0	2	1	3	3	0	2	1
2	1	0	1	3	0	0	1	3
3	2	0	1	1	3	1	3	2
4	3	3	0	1	3	2	1	0
5	2	2	3	0	1	0	2	1
6	1	2	3	2	1	0	3	2

Figure 4, Example of demodulated symbols from OQPSK data stream

Further, the offset EVM must be measured for each of the data rates listed in ZWALR table 5-2.

3.4.3 Measurement result

The result of the measurement is a table with demodulated symbols shown on the screen of the spectrum analyzer as well as the offset EVM measurement.

For the data rate LR1 the demodulated symbols must be identical to the known transmitted data stream when the timing and frequency settings of the VSA demodulator option is within the limits given by the limits in ZWALR table 5-2.

For the offset EVM measurement, this must be below the number mentioned in ZWALR section 5.2.4

3.4.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For data rate LR1: The demodulated symbols and the sequence of the demodulated symbols must match the known transmitted data pattern
2. All the symbols given in the ZWALR table 5-5 must be received and demodulated by the VSA option of the spectrum analyzer.
3. The measured offset EVM is below the number given in ZWALR section 5.2.4

3.4.5 Fail criteria

The Z-Wave device shall fail the test if:

1. For data rate LR1: The VSA option of the spectrum analyzer fails to demodulate the transmitted data stream.

2. Not all the symbols given in the ZWALR table 5-5 are received and demodulated by the VSA option of the spectrum analyzer.
3. The offset EVM is measured to be above what is stated in ZWALR section 5.2.4.

3.5 Transmit power adjustment

The RF output power transmitted by a Z-Wave device must be adjustable according to ZWALR section 5.2.5.2.

The output power adjustability must be measured and verified.

3.5.1 Prerequisites

1. A Z-Wave device capable of transmitting a CW RF signal at frequencies specified in ZWALR table 5-1
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A method to initialize the transmitted output power of the Z-Wave device, or pre-programmed Z-Wave devices to cover all possible output powers for the Z-Wave device.
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.5.2 Measurement setup

The Z-Wave device must be initialized to transmit a CW RF signal at each LRF profile as defined in ZWALR table 5-1.

The Z-Wave device must be connected to a spectrum analyzer with a coaxial cable.

The spectrum analyzer must be initialized to:

Table 4, Transmit power Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	1MHz
Resolution Bandwidth	300kHz
Video Bandwidth	Auto
Amplitude reference level	30dBm
Detector type	Max hold

A series of power measurements must now be performed for each of the possible output power settings of the Z-Wave device.

The measurements are performed using the “Peak search” functionality of the spectrum analyzer.

3.5.3 Measurement result

The measurement result will be a table showing the measured output power for each possible output power setting.

The relationship between the measured output powers must fulfill the statements in the ZWALR section 5.2.5.2

3.5.4 Pass criteria

The Z-Wave device shall pass the test if:

1. It is possible to adjust the output power with the granularity and ranges as described in ZWALR section 5.2.5.2.

3.5.5 Fail criteria

The Z-Wave device shall fail the test if:

1. It is not possible to adjust the output power with the granularity and ranges as described in ZWALR section 5.2.5.2.

3.6 Receiver sensitivity

The receiver of a Z-Wave device must, under the test conditions given in ZWALR table 5-7, have a conducted sensitivity identical to or better than described in ZWALR table 5-8. The sensitivity measurements must be tested for all LRF profiles listed in ZWALR table 5-1

3.6.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.1.3. The Z-Wave device must be able to decode and data process at transmission rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received. The Z-Wave receiver device is hereafter called DUT
2. The DUT must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the DUT.
3. A Z-Wave transmitter, either a RF frequency generator which can transmit Z-Wave coded data messages or a golden Z-Wave device. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted at described in ZWALR section 5.3.1. The output power of the transmitter must be adjustable to reach the power levels stated in ZWALR table 5-8 when measured at the input of the DUT. The Z-Wave transmitter is here after called test pattern generator.
4. A means to control the transmitted output power from the test pattern generator to the receiver DUT.

3.6.2 Measurement setup

The Z-Wave receive device, the DUT, is connected to the Z-Wave pattern generator with a coax cable. The pattern generator transmits Z-Wave test packages back to back to the DUT. The number of correctly received packages and wrongly received packages must be recorded and the Frame Error Rate can be calculated:

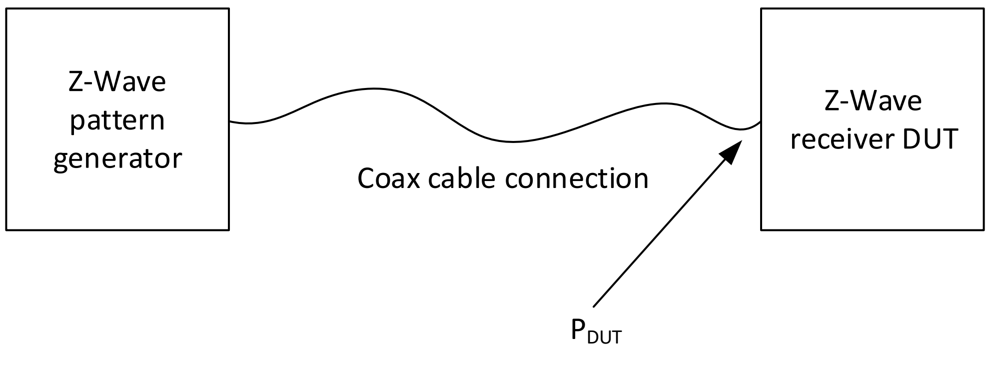


Figure 5, Sensitivity measurement setup

The received power at the Z-Wave DUT, P_{DUT}, must be adjusted to match the sensitivity requirements as stated in ZWALR table 5-8.

3.6.3 Measurement result

At least 1000 frames formatted according to ZWALR table 5-7 must be transmitted by the test pattern generator and received by the DUT.

3.6.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each data rate and power setting given in ZWALR table 5-8, the frame error rate (FER) is < 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.6.5 Fail criteria

The Z-Wave device shall fail the test if:

1. For each data rate and power setting given in ZWALR table 5-8, the frame error rate (FER) is > 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.7 Clear channel assessment

The Z-Wave device must be able to sample the RF input level, judge the received power level, and only start to transmit if the received power level is less than what is stated in ZWALR section 5.2.5.4. The clear channel assessment must be tested for all LRF profiles listed in ZWALR table 5-1

3.7.1 Prerequisites

1. A Z-Wave device capable of both receiving and transmitting Z-Wave frames formatted according to ZWALR section 5.1.3. The Z-Wave device must be able to perform a clear channel assessment and transmit data if the level of received power is below the limit given in ZWALR section 5.2.5.4. The Z-Wave device is here after called DUT.
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A RF frequency generator which can transmit a CW RF signal. The output power of the generator must be adjustable to reach the level stated in ZWALR section 5.2.5.4. when measured at the input of the DUT.
4. A means to control the transmitted CW signal power from the test pattern generator to the receiver DUT.
5. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
6. A 3 port RF resistive power combiner.

3.7.2 Measurement setup

The DUT, RF generator and spectrum analyzer are all connected through the 3 port RF power combiner:

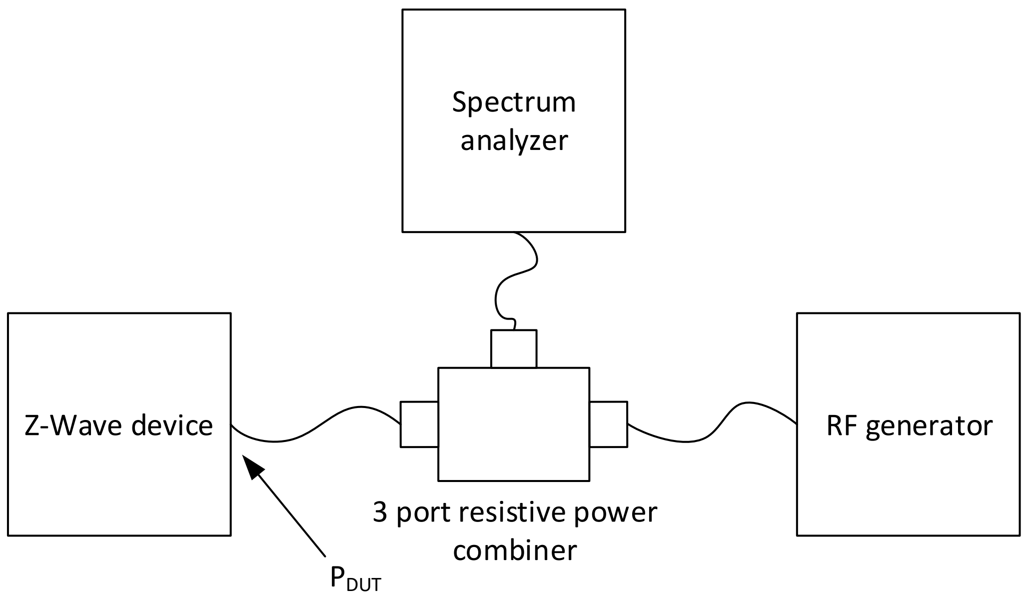


Figure 6, Clear channel assessment measurement setup

The spectrum analyzer must be initialized to:

Table 5, Clear channel assessment Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	Zero span
Resolution Bandwidth	0
Video Bandwidth	Auto
Amplitude reference level	Depending on $P_{nominal}$
Detector type	Clear/write
Trigger	RF burst
RF trigger level	-20dBm
Sweep Time	1 second

The Z-Wave device must be initialized to transmit Z-Wave data packets. The output level of the RF generator is adjusted around the threshold stated in ZWALR section 5.2.5.4. When the input power to the Z-Wave device is < threshold, the Z-Wave device must transmit, and this will be captured by the spectrum analyzer. When the input to the Z-Wave device is > threshold, the transmission of data from the Z-Wave device must stop:

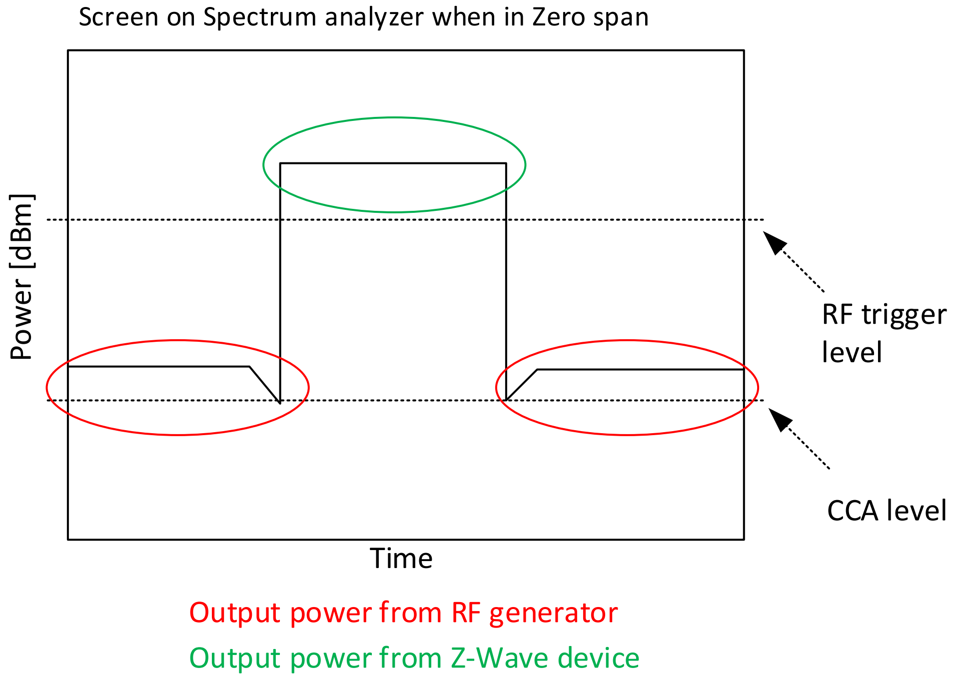


Figure 7, CCA spectrum analyzer measurement

3.7.3 Measurement result

The measurement result is an assessment of when the Z-Wave device starts to transmit Z-Wave frames given the output power of the RF generator.

3.7.4 Pass criteria

The Z-Wave device shall pass the test if:

1. Transmission of Z-Wave frames from the Z-Wave device starts when the input power to the Z-Wave device is < CCA threshold as stated in ZWALR section 5.2.5.4

3.7.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Transmission of Z-Wave frames from the Z-Wave device starts when the input power to the Z-Wave device is > CCA threshold as stated in ZWALR section 5.2.5.4.

3.7.6 Exception

The Z-Wave device shall also pass the test if the transmission started / stopped within a 3dB lower level than stated in ZWALR section 5.2.5.4.

3.8 Receiver spurious requirement

A Z-Wave device in receive state may not desensitize other nearby Z-Wave receivers. The emitted LO leakage may thus not exceed the level stated in ZWALR section 5.2.5.5. The receiver spurious must be tested for all LRF profiles listed in ZWALR table 5-1

3.8.1 Prerequisites

1. A Z-Wave device in constant receive state.
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A method to initialize the receiver the Z-Wave device, or pre-programmed Z-Wave devices to cover all listed LRF profiles and data rates as listed in ZWALR table 5-1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.8.2 Measurement setup

The Z-Wave device must be connected to the spectrum analyzer with a coax cable.

The spectrum analyzer must be initialized to:

Table 6, Receiver spurious requirements Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	1 MHz
Resolution Bandwidth	100kHz
Video Bandwidth	Auto
Amplitude reference level	-50dBm
Detector type	Max Hold

A receiver spurious signal is found by using the Peak Search functionality of the spectrum analyzer.

3.8.3 Measurement result

The measurement result is the power level of an RF spur found within the measurement bandwidth of the spectrum analyzer.

3.8.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The highest found RF spur within the measurement bandwidth is < the limit stated in ZWALR section 5.2.5.5.

3.8.5 Fail criteria

The Z-Wave device shall fail the test if:

1. The highest found RF spur within the measurement bandwidth is > the limit stated in ZWALR section 5.2.5.5.

3.9 Receiver blocking

The receiver of a Z-Wave must be able to receive Z-Wave frames even when subjected to blocking CW RF signals transmitted by other RF devices. The level of the test Z-Wave RF communication must be set according to ZWALR section 5.2.5.6 and the frequency location and signal strength of the blocking CW RF signals must be adjusted to match the requirements given in ZWALR table 5-9. The blocking measurements must be tested for all LRF profiles listed in ZWALR table 5-1

3.9.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received. The Z-Wave receiver device is hereafter called DUT
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the DUT.
3. A Z-Wave transmitter, either a RF frequency generator which can transmit Z-Wave coded data messages or a golden Z-Wave device. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted as described in ZWALR section 5.3.1. The output power of the transmitter must be adjustable to reach the power level stated in ZWALR section 5.2.5.6 when measured at the input of the DUT. The Z-Wave transmitter is here after called test pattern generator.
4. A means to control the transmitted output power from the test pattern generator to the receiver DUT.
5. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
6. A CW RF generator to generate the interfering blocking signals at frequency locations and signal strengths described in ZWALR table 5-9 when measured at the input of the DUT. The frequency offsets stated in ZWALR table 5-9 are relative to the RF frequency of each LRF profile in ZWALR table 5-1.
7. A 3 port resistive RF combiner

3.9.2 Measurement setup

The Z-Wave receive device, the DUT, the Z-Wave pattern generator and the interfering CW RF generator are all connected to the 3 port RF combiner with coax cables. The pattern generator transmits Z-Wave test packages back to back to the DUT, and the output power of the pattern generator must be adjusted so that $P_{\text{DUT\_Z-Wave traffic}}$ is matching the level stated in ZWALR section 5.2.5.6 (please refer to Figure 8). The frequency of the CW RF generator is adjusted to: $f_{\text{center frequency of LRF profile\_x in ZWALR table 5-1}}$ +/- $f_{\text{frequency offset in ZWALR table 5-9}}$, the amplitude is adjusted to the RF level as stated in ZWALR table 5-9 for each offset, and the RF level is $P_{\text{DUT\_blocking signal}}$ when measured at the input of the DUT (please refer to Figure 8). Once the setup has been configured, for each frequency offset entry in ZWALR table 5-9, the number of correctly received packages and wrongly received packages must be recorded and the Frame Error Rate can be calculated. The measurement setup is shown in Figure 8 below:

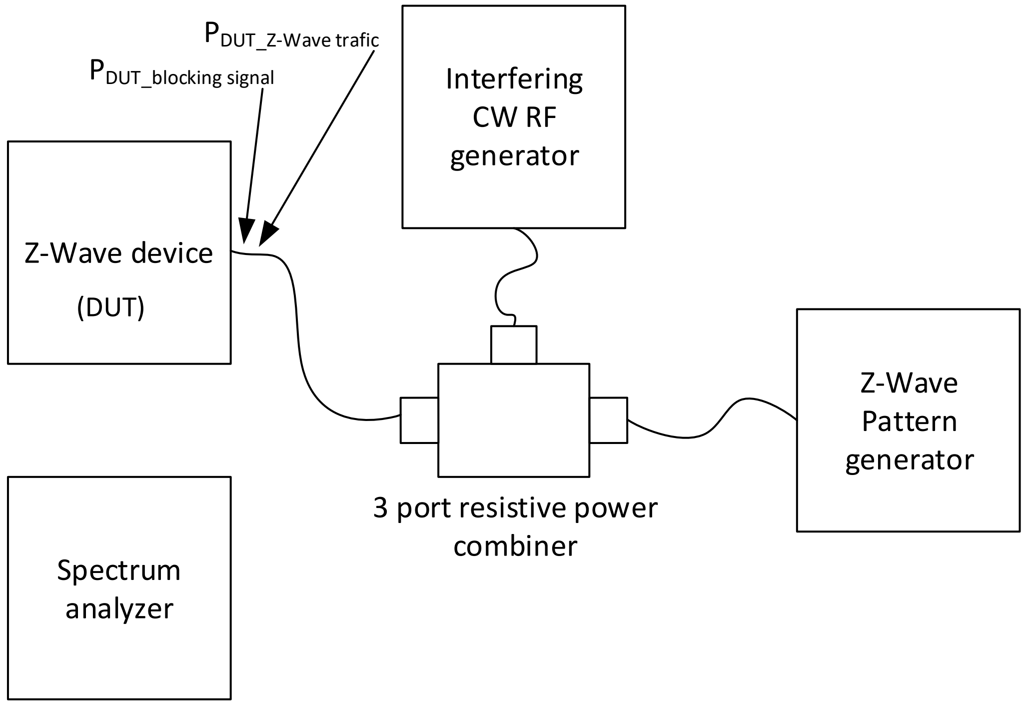


Figure 8, Blocking measurement setup

The RF levels $P_{DUT\_Z\text{-}Wave\ traffic}$ and $P_{DUT\_blocking}$ signal must be verified, and for this, the coax connection between the DUT and the 3 port combiner can be disconnected and the 3 port combiner can be connected to the spectrum analyzer for RF power level verification and RF CW interferer frequency verification.

3.9.3 Measurement result

For each of the LRF profiles in ZWALR table 5-1 and frequency offsets in ZWALR table 5-9, at least 1000 frames formatted according to ZWALR table 5-7 must be transmitted by the test pattern generator and received by the DUT.

The test results will be a series of test observations which should include the following data:

(LRF profile; Frequency offset; Number of frames with errors received; Number of frames transmitted)

For each (LRF profile, Frequency offset), the frame error rate must be calculated, and the result must be below the criterion stated in ZWALR table 5-9.

3.9.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each (LRF profile, Frequency offset) given in ZWALR table 5-9, the frame error rate (FER) is < 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.9.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any (LRF profile, Frequency offset) given in ZWALR table 5-9, has a frame error rate (FER) which is > 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.10 Receiver saturation

The receiver of a Z-Wave must be able to receive Z-Wave frames transmitted at RF levels as described under the test conditions given in ZWALR section 5.2.5.7. The receiver saturation measurements must be tested for all LRF profiles listed in ZWALR table 5-1

3.10.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received. The Z-Wave receiver device is here after called DUT
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A Z-Wave transmitter, either a RF frequency generator which can transmit Z-Wave coded data messages or a golden Z-Wave device. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted as described in ZWALR section 5.1.3. The output power of the transmitter must be adjustable to reach the power level stated in ZWALR section 5.2.5.7 when measured at the input of the DUT. The Z-Wave transmitter is here after called test pattern generator.
4. A means to control the transmitted output power from the test pattern generator to the receiver DUT.

3.10.2 Measurement setup

The Z-Wave receive device, the DUT, is connected to the Z-Wave pattern generator with a coax cable. The pattern generator transmits Z-Wave test packages back to back to the DUT. The number of correctly received packages and wrongly received packages must be recorded and the Frame Error Rate can be calculated:

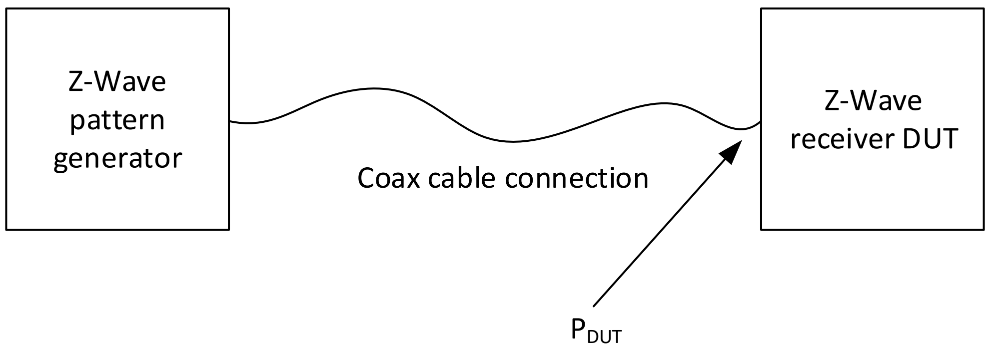


Figure 9, Receiver saturation measurement setup

The received power at the Z-Wave DUT, P_{DUT}, must be adjusted to match the RF level as stated in ZWALR section 5.2.5.7.

3.10.3 Measurement result

For each of the LRF profile, at least 1000 frames must be transmitted by the test pattern generator and received by the DUT at the RF level stated in ZWALR section 5.2.5.7.

The measurement result is the number of correctly and wrongly received Z-Wave frames for each LRF profile.

3.10.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each LRF profile in ZWALR table 5-1, the frame error rate (FER) is < 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)
   at the input power level stated in ZWALR section 5.2.5.7

3.10.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any LRF profile given in ZWALR table 5-1, the frame error rate (FER) is > 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)
   at the input power level stated in ZWALR section 5.2.5.7

3.11 TX to RX turnaround time

The transceiver of a Z-Wave device must be fast enough to switch from transmission mode to receive mode, the so-called TX-to-RX turnaround time. The TX-to-RX turnaround time must be measured under the test conditions given in ZWALR section 5.2.5.8. The TX-to-RX turnaround time measurements must be tested for all LRF profiles listed in ZWALR table 5-1

3.11.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.3.1. The Z-Wave device must be able to decode and data process at transmissions rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received, and all incoming Z-Wave frames must be acknowledged. The Z-Wave device must set a GPIO, available for measurements with an oscilloscope, to a state when exciting its transmission state and reverse the state of the GPIO when the receiver of the Z-Wave device is fully initialized. The Z-Wave receiver device is here after called DUT
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. The PCB must further enable a measurement using an oscilloscope on the designated GPIO pin used for measuring TX-to-RX turnaround time measurements.
4. A golden Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted as described in ZWALR section 5.3.1. The test pattern generator must acknowledge all incoming Z-Wave traffic. The Z-Wave transmitter is here after called test pattern generator.
5. A means to control the transmission of a Z-Wave frame from the pattern generator.
6. An oscilloscope, equivalent to a R&S RTO 1204 or better.

3.11.2 Measurement setup

The DUT and the Z-Wave pattern generator are connected to each other through a coax cable. The oscilloscope is connected to the GPIO pin of the DUT. The Z-Wave pattern generator is started, and the pulse widths of the pulsing GPIO pin is measured with the oscilloscope.

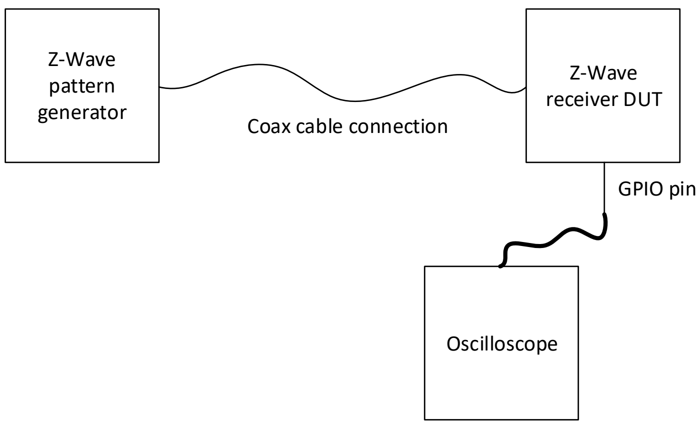


Figure 10, TX-to-RX turnaround time setup

Table 7, Oscilloscope settings for TX-to-RX turnaround measurements

Oscilloscope parameter	Setting
V/div	1
Time Base	200us
Trigger	Edge triggered

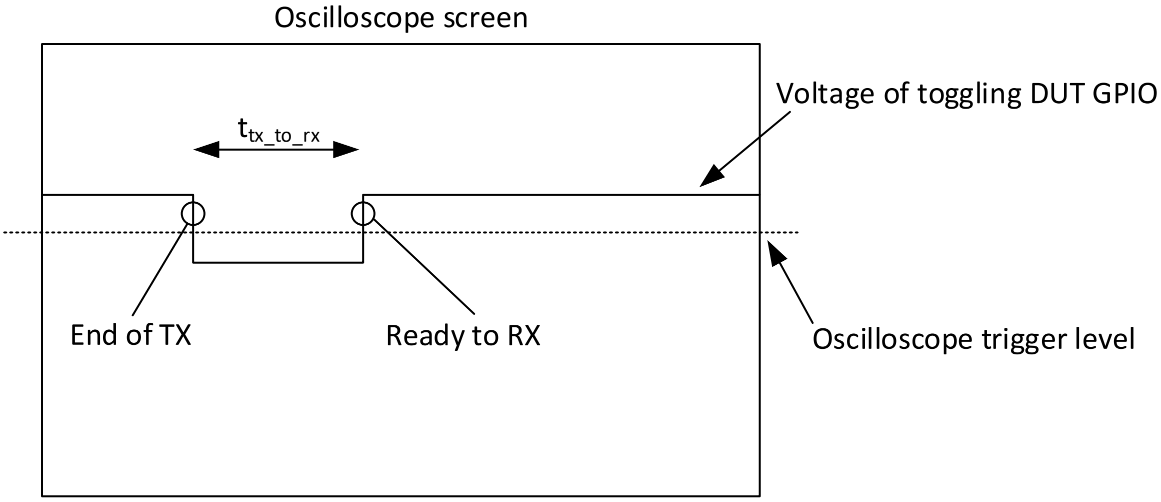


Figure 11, TX-to-RX turnaround measurement result

The number of transmitted frames from the Z-Wave pattern generator as well as the number of received frames at the DUT must be recorded.

3.11.3 Measurement result

The measurement result is the duration, $t_{tx\_to\_rx}$ in Figure 11, of the state change of the GPIO pin of the DUT during the communication between the DUT and the Z-Wave pattern generator measured for at least 10 consecutive state changes.

The DUT must have received and acknowledged all the frames transmitted by the Z-Wave pattern generator.

3.11.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The TX-to-RX turnaround time, $t_{tx\_to\_rx}$ for at least 10 samples are less than stated in ZWALR table 5.27 and all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.11.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any of 10 sampled TX-to-RX turnaround times, $t_{tx\_to\_rx}$ for at least 10 samples were higher than stated in ZWALR table 5.27 or not all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.12 RX-to-TX turnaround time

The transceiver of a Z-Wave device must be fast enough to switch from receive mode to transmit mode, the so-called RX-to-TX turnaround time. The RX-to-TX turnaround time must be measured under the test conditions given in ZWALR section 5.2.5.9. The RX-to-TX turnaround time measurements must be tested for all LRF profiles listed in ZWALR table 5-1

3.12.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.3.1. The Z-Wave device must be able to decode and data process at transmissions rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received, and all incoming Z-Wave frames must be acknowledged. The Z-Wave receiver device is here after called DUT.
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A golden Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted as described in ZWALR section 5.3.1. The test pattern generator must acknowledge all incoming Z-Wave traffic. The Z-Wave transmitter is here after called test pattern generator.
   The output power of the Z-Wave pattern generator must be 20dB below the output power of the DUT.
4. A means to control the transmission of a Z-Wave frame from the pattern generator.
5. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz, with the capability to measure zero-span.
6. A 3 port RF resistive power combiner.

3.12.2 Measurement setup

The DUT, RF generator and spectrum analyzer are all connected through the 3 port RF power combiner:

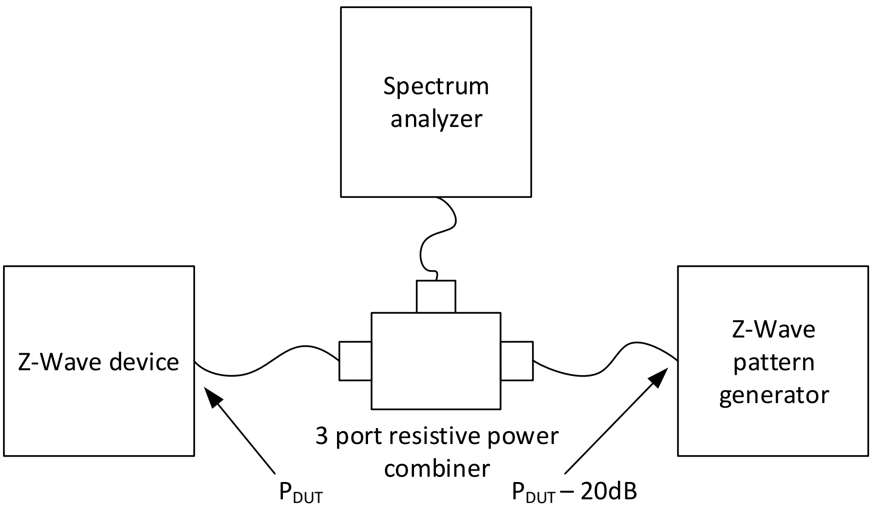


Figure 12, RX-to-TX turnaround time measurement setup

The spectrum analyzer must be initialized to:

Table 8, RX-to-TX turnaround time Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	Zero span
Resolution Bandwidth	0
Video Bandwidth	Auto
Amplitude reference level	Depending on $P_{nominal}$
Detector type	Clear/write
Trigger	RF burst
RF trigger level	P_{DUT} – 10 and accounting for the loss of the 3 port resistive power combiner.
Sweep Time	10ms second

The Z-Wave pattern generator must be initialized to transmit Z-Wave data packets. A received Z-Wave packet at the DUT will prompt the DUT to transmit a acknowledge packet. Since the trigger threshold of the spectrum analyzer is set to trigger when the DUT transmits, the following can be observed on the spectrum analyzer:

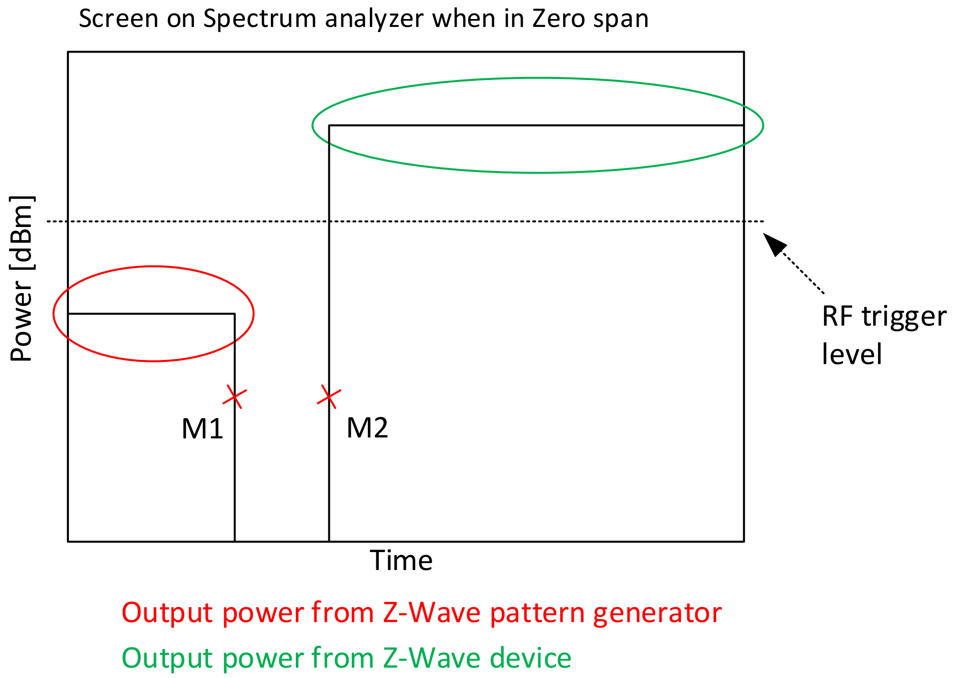


Figure 13, RX-to-TX turnaround measurement

The reply from the DUT will trigger the spectrum analyzer. Using the marker functionality of the spectrum analyzer, the RX-to-TX turnaround time can be calculated as $t_{rx\_to\_tx} = t_{M2} - t_{M1}$.

Further, the number of transmitted and received frames by the DUT must be recorded.

3.12.3 Measurement results

The measurement result is the time difference between the two markers in Figure 13, measured for at least 10 transmissions.

The DUT must have received and acknowledged all the frames transmitted by the Z-Wave pattern generator.

3.12.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The RX-to-TX turnaround time, $t_{rx\_to\_tx}$ for at least 10 samples are less than stated in ZWALR table 5-27 and all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.12.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any of 10 sampled RX-to-TX turnaround times, $t_{rx\_to\_tx}$ for at least 10 samples were higher than stated in ZWALR table 5-27 or not all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.12.6 Exception

The output power transmitted by the parts in this test must be adjusted in order to ensure, that no receivers are overstressed or saturated. To avoid this, RF attenuators may be required to be inserted in the measurement setup as shown in Figure 13.

3.13 Preamble field

Data frames transmitted by a Z-Wave device be formatted as described in ZWALR section 5.3.1: With a preamble field, a Start of Frame delimiter and payload. The requirements for the number of preamble bytes to transmit are stated in ZWALR table 5-10.

The preambles are coded according to ZWALR tables 5-2, 5-4, 5-5 and 5-6.

The number of preamble types transmitted for each type of Z-Wave frame must be tested according to ZWALR table 5-10 and tested for all LRF profiles listed in ZWALR table 5-1

3.13.1 Prerequisites

1. A Z-Wave device capable of transmitting Z-Wave packages correctly formatted according to ZWALR section 5
2. The Z-Wave device must be able to transmit each of the various types of Z-Wave frames described in ZWALR table 5-10.
3. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
4. A spectrum analyzer with better or identical specifications to a Rhode & Schwartz FSV3007, 7.5GHz
5. A digital VSA installed on the spectrum analyzer with the capabilities of at least Rhode & Schwartz option FSV3-K70.

3.13.2 Measurement setup

The Z-Wave device must be initialized to transmit a constant stream of Z-Wave packets of the correct types and data rates are defined in ZWALR table 5-10.

The Z-Wave device must be connected to a spectrum analyzer with a coaxial cable.

The spectrum analyzer must be initialized to:

Table 9, Preamble Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{center\ frequency}$ according to ZWALR table 5-1
Span	1MHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	30dBm
Detector type	Average
Digital demodulation type	OQFSK
Symbole rate	400 ks/s
Trigger type	IF power

The number of preambles transmitted for each type of transmission-type must be measured using the demodulation feature of the VSA FSV3-K70 option of the spectrum analyzer. Below is shown an example of how a demodulated data stream could appear on the screen of the spectrum analyzer:

Example of Demodulation
view of FSV3-K70 Option

Row/ Line	1	2	3	4	5	6	7	8
1	0	2	1	3	3	0	2	1
2	1	0	1	3	0	0	1	3
3	2	0	1	1	3	1	3	2
4	3	3	0	1	3	2	1	0
5	2	2	3	0	1	0	2	1
6	1	2	3	2	1	0	3	2

Figure 14, Example of demodulated symbols from OQPSK data stream

The demodulated data pattern must match with expected pre-amble pattern.

3.13.3 Measurement result

The measurement result is an analysis of the preamble pattern for each type of Z-Wave frame type transmitted at each data rate as stated in ZMALR table 5-10. If any irregularities are found within the demodulated data, the Z-Wave device has failed the test.

3.13.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The demodulated data pattern must match with expected pre-amble pattern as described in ZWALR table 5-10

3.13.5 Fail criteria

The Z-Wave device shall fail the test if:

1. The demodulated data pattern does not match with expected pre-amble pattern as described in ZWALR table 5-10

3.14 Start of Frame field

The transceiver of a Z-Wave must be able to correctly transmit and correctly receive Z-Wave start of frame information as described in ZWALR section 5.3.3. The data content of the Start of Frame field is described in ZWALR table 5.11. The handling of Start of Frame field in Z-Wave frames must be tested for all LRF profiles listed in ZWALR table 5-1

3.14.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ZWALR section 5.3.1. The Z-Wave device must be able to decode and data process at transmissions rates stated in ZWALR table 5-2. The Z-Wave device must be able to indicate when a frame is not correctly received, and all incoming Z-Wave frames must be acknowledged. The Z-Wave receiver device is here after called DUT.
2. The Z-Wave device must be mounted on a PCB enabling a cabled RF connection between a RF measurement device and a 50 Ohms matched output of the Z-Wave device.
3. A golden Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ZWALR tables 5-2 to 5-6 and formatted as described in ZWALR section 5.1.3. The test pattern generator must acknowledge all incoming Z-Wave traffic. The Z-Wave transmitter is here after called test pattern generator.
4. A means to control the transmission of a Z-Wave frame from the pattern generator.

3.14.2 Measurement setup

The Z-Wave receive device, the DUT, is connected to the Z-Wave pattern generator with a coax cable. The pattern generator transmits Z-Wave test packages to the DUT and the DUT must acknowledge the incoming Z-Wave frame. The number of correctly received packages and wrongly received packages must be recorded for both the Z-Wave pattern generator and the Z-Wave DUT and for both, the Frame Error Rate can be calculated:

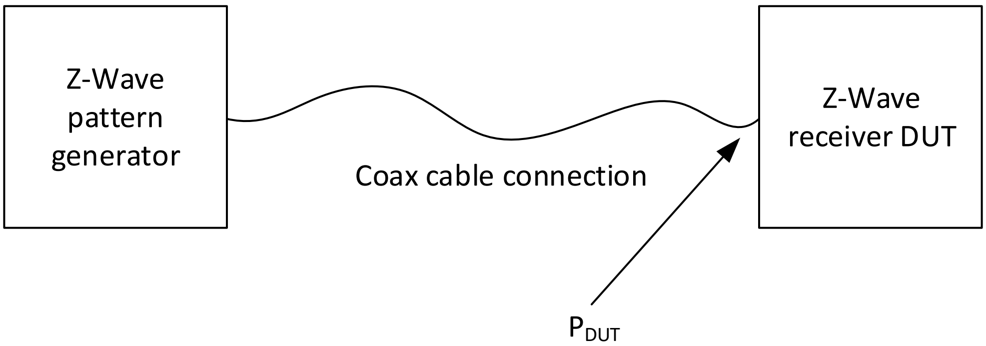


Figure 15, Start of Frame measurement setup

Attenuation must be added to ensure that the received power at the DUT, P_{DUT}, is between -60 dBm and -50 dBm.

3.14.3 Measurement result

For each of the LRF profile, at least 1000 frames must be transmitted by the test pattern generator and received by the DUT.

The measurement result is the number of correctly and wrongly received Z-Wave frames for each LRF profile by both the Z-Wave pattern generator and the DUT.

3.14.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each LRF profile in ZWALR table 5-1, the frame error rate (FER) is < 0.002 for both the DUT and for the Z-Wave pattern generator:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.14.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any LRF profile given in ZWALR table 5-1, the frame error rate (FER) is > 0.002 for either the Z-Wave DUT or the Z-Wave pattern generator:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

REFERENCES

[1] Z-Wave Long Range PHY and MAC Specification, Z-Wave Alliance