Specification

Z-Wave PHY Layer Test Specification

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REVISION RECORD

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0.5	2020.04.07	CSWG	Sections: 1, 3.15	Inputs from initial review added: Added abbreviations, clarified test description
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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
SOF	Start of Frame

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 protocol on a non-Silicon Labs chip / device adheres to the requirements given in the ITU specification ITU G.9959.

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 ITU specification: ITU-T G.9959 (01/2015):

3.1 General assumptions

All references to tables in ITU-T G.9959 (01/2015) in the following sections will be preceded an ITU header, e.g. ITU table 7.5 will refer to the table 7.5 in the document ITU-T G.9959 (01/2015).

All references to sections in ITU-T G.9959 (01/2015) in the following sections will be preceded an ITU header, e.g. ITU section 7.1.2.5.2 will refer to section 7.1.2.5.2 in the document ITU-T G.9959 (01/2015).

It is assumed, that a Z-Wave device can transmit a modulated RF signal according to the ITU-T G.9959 (01/2015) 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 ITU-T G.9959 (01/2015) ITU table 7.5 and 7.6.

3.2 RF profiles

A Z-Wave device must support all RF profiles as defined in ITU table 7.1.

The RF frequency for all RF 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 RF profiles as listed in ITU table 7.1
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 RF profile as defined in ITU table 7.1

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}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average

The RF frequency of each RF 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 RF profile.

The RF frequency for each RF profile may not differ more than the accuracy given in ITU section 7.1.2.5.1.

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 ITU table 7.1 could be measured
2. All RF frequencies measured are within the accuracy limits stated in ITU table 7.2 / ITU section 7.1.2.5.1

3.2.5 Fail criteria

The Z-Wave device shall fail the test if:

1. A frequency as defined in ITU table 7.1 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 ITU table 7.2 / ITU section 7.1.2.5.1

3.3 Symbol rates

A Z-Wave device must support all the symbol rates / data rates as defined in ITU table 7.2 and at each of the RF profiles as shown in ITU table 7.1.

The modulation parameters for each data rates are given in ITU tables 7.4, 7.5 and 7.6

The data rates for the RF profiles listed in ITU table 7.1 must be measured and verified.

3.3.1 Prerequisites

1. A Z-Wave device capable of transmitting a stream of modulated 0 and 1 symbols at the rates defined in ITU table 7.2 and the modulation properties given in ITU tables 7.4, 7.5 and 7.6
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 RF profiles and data rates as listed in ITU table 7.1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
5. An analog demodulator option installed on the spectrum analyzer with the capabilities of at least Keysight option “N9063A Analog Demod Measurement”.

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 ITU table 7.1.

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}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average
Analog demodulation type	FSK
Demodulation time (time across screen)	200us
IF filter	700 kHz
Trigger option	RF burst

The symbol rate of each RF profile must be measured using the marker features of the spectrum analyzer:

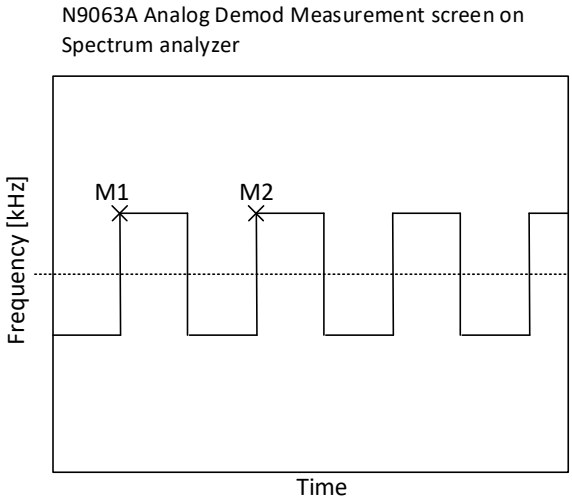

Figure 1, Data rate measurement

3.3.3 Measurement result

The measurement result of the test is the measured time for two transmitted symbols divided by two.

The measured symbol time may not differ more than 1 / (nominal symbol rate) +/- the accuracy as given in ITU table 7.2.

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. The correct symbol rate for each RF profile as stated in ITU table 7.1 could be measured
2. All symbol rates are within the accuracy limits as stated in ITU 7.2

3.3.5 Fail criteria

The Z-Wave device shall fail the test if:

1. A frequency as defined in ITU table 7.1 could not be initialized by the Z-Wave device and not measured in the measurement setup
2. The accuracy of a measured symbol rate did not pass the specification as given in ITU table 7.2

3.4 Modulation and encoding

Data transmitted by a Z-Wave device must be modulated according to the ITU tables 7.4, 7.5 and 7.6

The modulation parameters for each of the data rates listed in ITU table 7.4 must be measured and verified.

3.4.1 Prerequisites

1. A Z-Wave device capable of transmitting a stream of modulated 0 and 1 symbols at the rates defined in ITU table 7.2 and the modulation properties given in ITU tables 7.4, 7.5 and 7.6
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 RF profiles and data rates as listed in ITU table 7.1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
5. An analog demodulator option installed on the spectrum analyzer with the capabilities of at least Keysight option “N9063A Analog Demod Measurement”.

3.4.2 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 ITU table 7.1.

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 ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average
Analog demodulation type	FSK
Demodulation time (time across screen)	200us
IF filter	700 kHz
Trigger option	RF burst

The modulation properties of each data rate must be measured using the marker features of the spectrum analyzer and the readings of the spectrum analyzer:

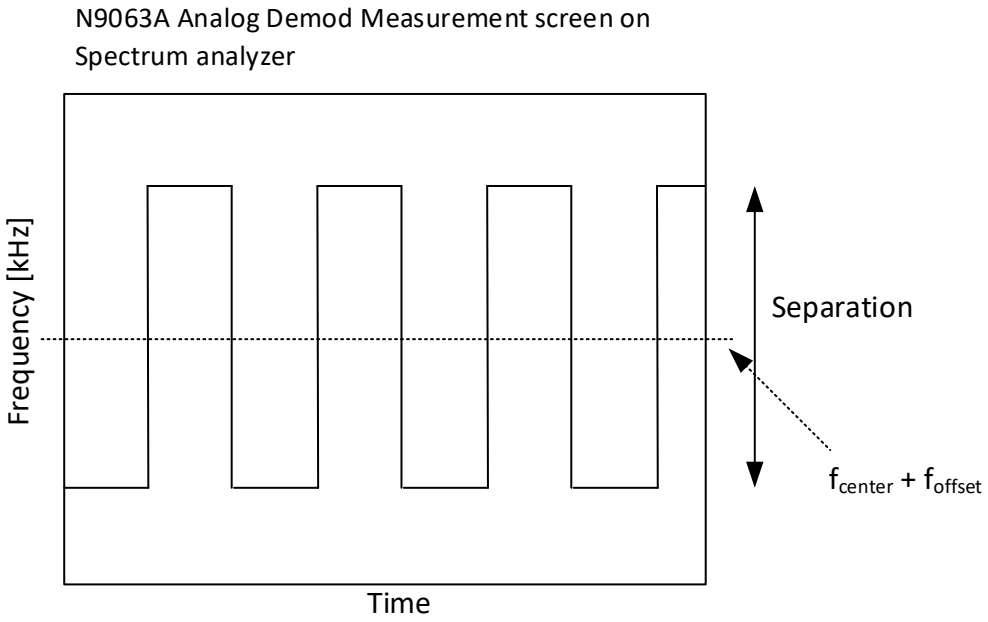

Figure 2, Modulation format measurement, FSK Data Rate R1 and R2.

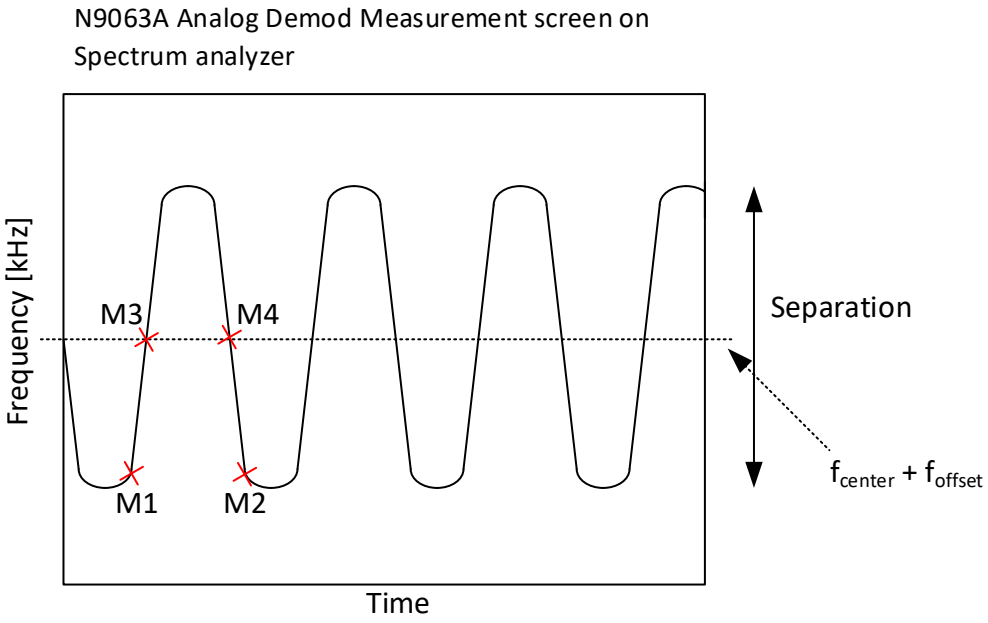

Figure 3, Modulation format measurement, GFSK Data Rate R3

3.4.3 Measurement result

For data rates R1, R2 and R3 the measurement result of the test is measured frequency separation and the $f_{center} + f_{offset}$.

For data rate R3, a further measurement result is the BT ratio:

$$BT_{ratio} = (t_{M4} - t_{M3}) / (t_{M2} - t_{M1})$$

The measured values must be within the limits given by ITU table 7.4.

3.4.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For data rates R1, R2 and R3: At no time within the duration of a symbol may the frequency of the symbol exceed the requirements of the Separation as given in ITU table 7.4
2. For data rates R1, R2 and R3: The measured $f_{center} + f_{offset}$ must be measured to match what can be calculated for the particular data rate with the precision as stated in ITU table 7.2.
3. For data rate R3, the BT_{ratio} must be measured to value XXX .

3.4.5 Fail criteria

The Z-Wave device shall fail the test if:

1. For data rates R1, R2 and R3: At any time within the duration of a symbol, the frequency of the symbol exceeds the requirements of the Separation as given in ITU table 7.4
2. For data rates R1, R2 and R3: The measured $f_{center} + f_{offset}$ does no match with the calculated center frequency for the particular data rate with the precision as stated in ITU table 7.2.
3. For data rate R3, the BT_{ratio} was measured to a value different from XXX .

3.4.6 Exception

When measuring the modulation and coding format, a transient frequency separation error for the first transmitted symbol in a data stream is allowed, this to cater for the initialization and regulation loop of the frequency synthesis of the Z-Wave device.

3.5 Symbol mapping

Data bits transmitted by a Z-Wave device must be mapped / coded into RF frequencies according to the ITU tables 7.5 and 7.6

The symbol mapping / coding for each of the data rates listed in ITU table 7.4 must be measured and verified.

3.5.1 Prerequisites

1. A Z-Wave device capable of transmitting a stream of modulated '10001000'$_{binary}$ data bits at the rates defined in ITU table 7.2 and the modulation properties and coding properties given in ITU tables 7.4, 7.5 and 7.6
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 RF profiles and data rates as listed in ITU table 7.1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
5. An analog demodulator option installed on the spectrum analyzer with the capabilities of at least Keysight option "N9063A Analog Demod Measurement".

3.5.2 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 ITU table 7.1. The data bits modulated must be a stream of '10001000'$_{binary}$.

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

The spectrum analyzer must be initialized to:

Table 4, Symbol mapping Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average
Analog demodulation type	FSK
Demodulation time (time across screen)	Data rate R1: 2000us; Data rate R2: 500us; Data rate R3: 300uS
IF filter	700 kHz
Trigger option	RF burst

The symbol mapping properties of each data rate must be measured using the readings of the spectrum analyzer:

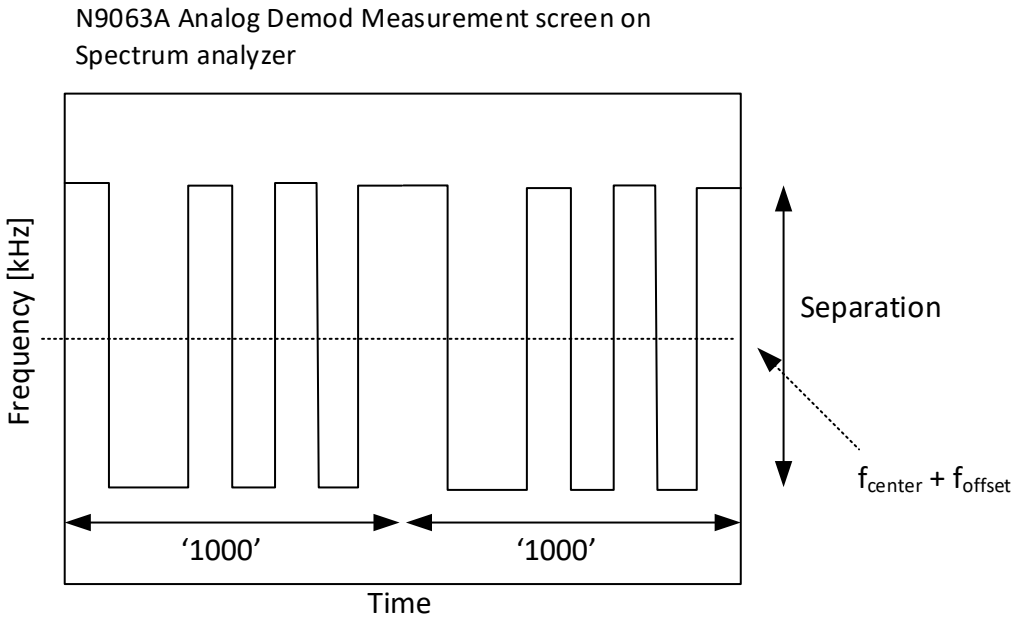

Figure 4, Symbol mapping measurement, FSK Data Rate R1, Manchester Coding.

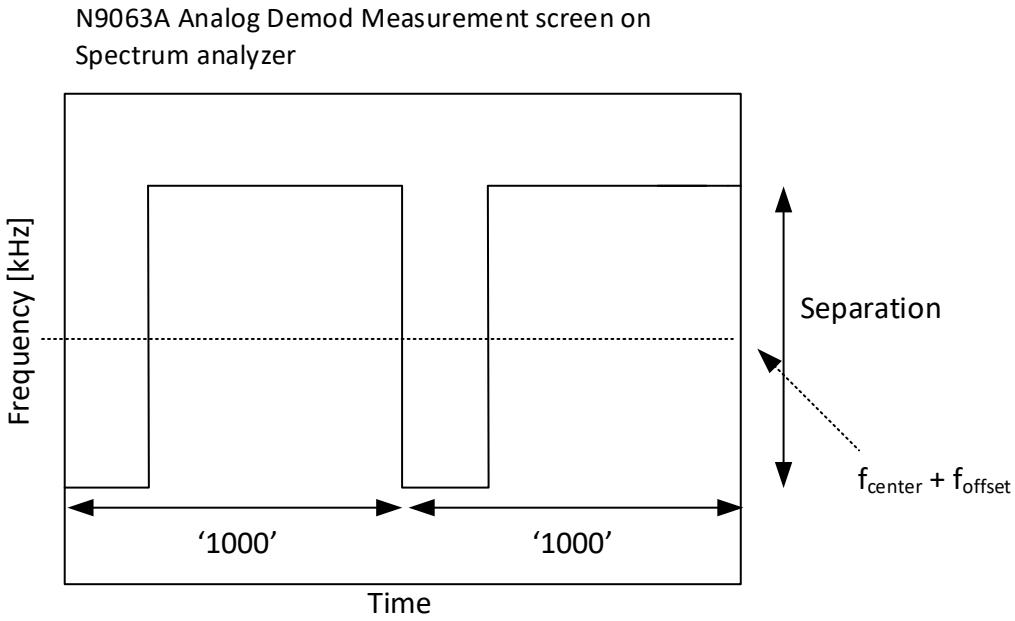

Figure 5, Symbol mapping measurement, FSK Data Rate R2, NRZ coding

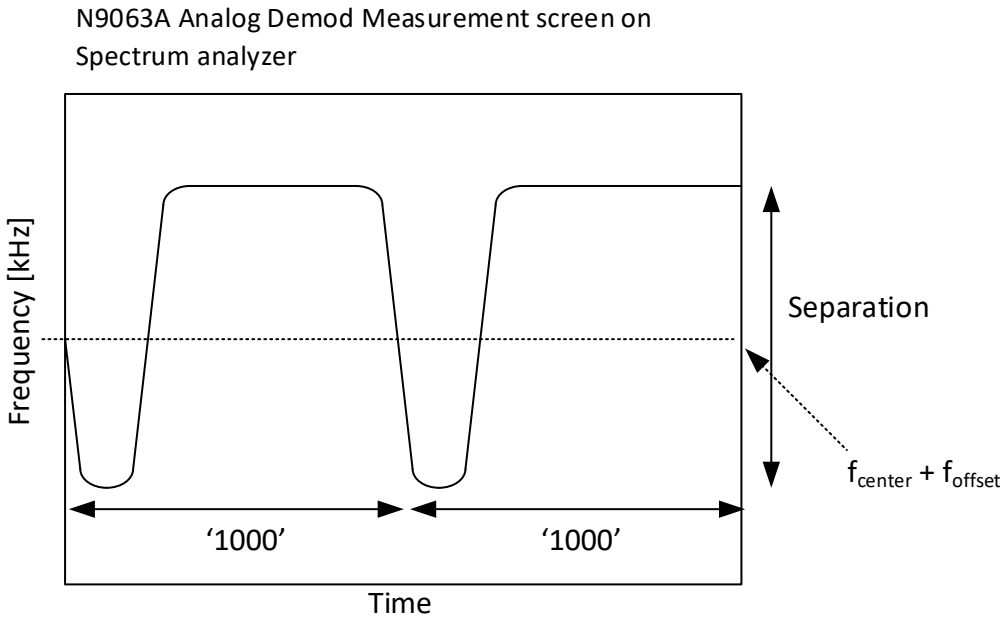

Figure 6, Symbol mapping measurement, FSK Data Rate R3, NRZ coding

3.5.3 Measurement result

For data rates R1, R2 and R3 the measurement result of the test is a clear pattern of the demodulated data stream identical to Figure 4, Figure 5 and Figure 6 and with frequency shifts according to ITU tables 7.5 and 7.6.

3.5.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For data rate R1: The demodulated data stream has frequency shifts according to ITU table 7.6.
2. For data rates R2 and R3: The demodulated data stream has frequency shifts according to ITU table 7.5.
3. For data rates R1, R2 and R3: The measured $f_{center} + f_{offset}$ must be measured to match what can be calculated for the particular data rate with the precision as stated in ITU table 7.2.

3.5.5 Fail criteria

The Z-Wave device shall fail the test if:

1. For data rate R1: The demodulated data stream has frequency shifts different from ITU table 7.6.
2. For data rates R2 and R3: The demodulated data stream has frequency shifts different from ITU table 7.5.
3. For data rates R1, R2 and R3: The measured $f_{center} + f_{offset}$ does not match what can be calculated for the particular data rate with the precision as stated in ITU table 7.2.

3.6 Transmit power adjustment

The RF output power transmitted by a Z-Wave device must be adjustable according to ITU section 7.1.2.5.2.

The output power adjustability must be measured and verified.

3.6.1 Prerequisites

1. A Z-Wave device capable of transmitting a CW RF signal at frequencies specified in ITU table 7.1
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

3.6.2 Measurement setup

The Z-Wave device must be initialized to transmit a CW RF signal at the nominal output power, denoted OP_{nom} at each RF profile as defined in ITU table 7.1.

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

The spectrum analyzer must be initialized to:

Table 5, Transmit power Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	1MHz
Resolution Bandwidth	300kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
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.

3.6.3 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 full fill the statements in the ITU section 7.1.2.5.2

3.6.4 Pass criteria

The Z-Wave device shall pass the test if:

1. It is possible to adjust the output power with a granularity of 2dB or better for power settings down to OP_{nom} – 10dB
2. It is possible to adjust the output power down to a value less than or identical to OP_{nom} – 20dB

3.6.5 Fail criteria

The Z-Wave device shall fail the test if:

1. It is not possible to adjust the output power with a granularity of 2dB or better for power settings down to OP_{nom} – 10dB
2. It is not possible to adjust the output power down to a value less than or identical to OP_{nom} – 20dB

3.7 Receiver sensitivity

The receiver of a Z-Wave must, under the test conditions given in ITU table 7.7, have a conducted sensitivity identical to or better than described in ITU table 7.8. The sensitivity measurements must be tested for all RF profiles listed in ITU table 7.1

3.7.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. The output power of the transmitter must be adjustable to reach the power levels stated in ITU table 7.8 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.
5. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.7.2 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:

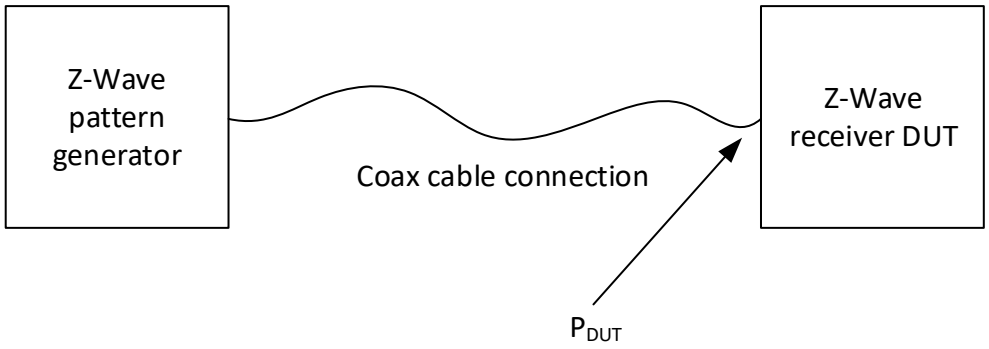

Figure 7, Sensitivity measurement setup

The received power at the Z-Wave DUT, P_{DUT}, must be adjusted to match the sensitivity requirements as stated in ITU table 7.8.

3.7.3 Measurement result

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

3.7.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each data date and power setting given in ITU table 7.8, the frame error rate (FER) is < 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.7.5 Fail criteria

The Z-Wave device shall fail the test if:

1. For each data date and power setting given in ITU table 7.8, the frame error rate (FER) is > 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.8 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 ITU section 7.1.2.5.4. The clear channel assessment must be tested for all RF profiles listed in ITU table 7.1

3.8.1 Prerequisites

1. A Z-Wave device capable of both receiving and transmitting Z-Wave frames formatted according to ITU section 7.1.3. 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 ITU section 7.1.2.5.4. 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 ITU section 7.1.2.5.4. 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.

3.8.2 Measurement setup

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

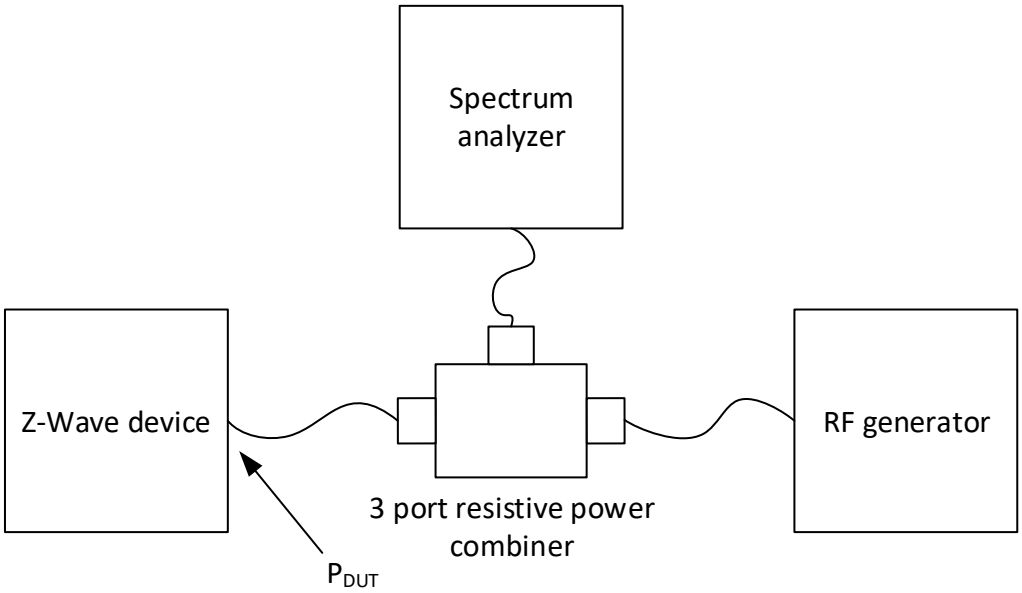

Figure 8, Clear channel assessment measurement setup

The spectrum analyzer must be initialized to:

Table 6, Clear channel assessment Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
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 ITU section 7.1.2.5.4. When the input power to the Z-Wave device is < threshold, the Z-Wave device will 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:

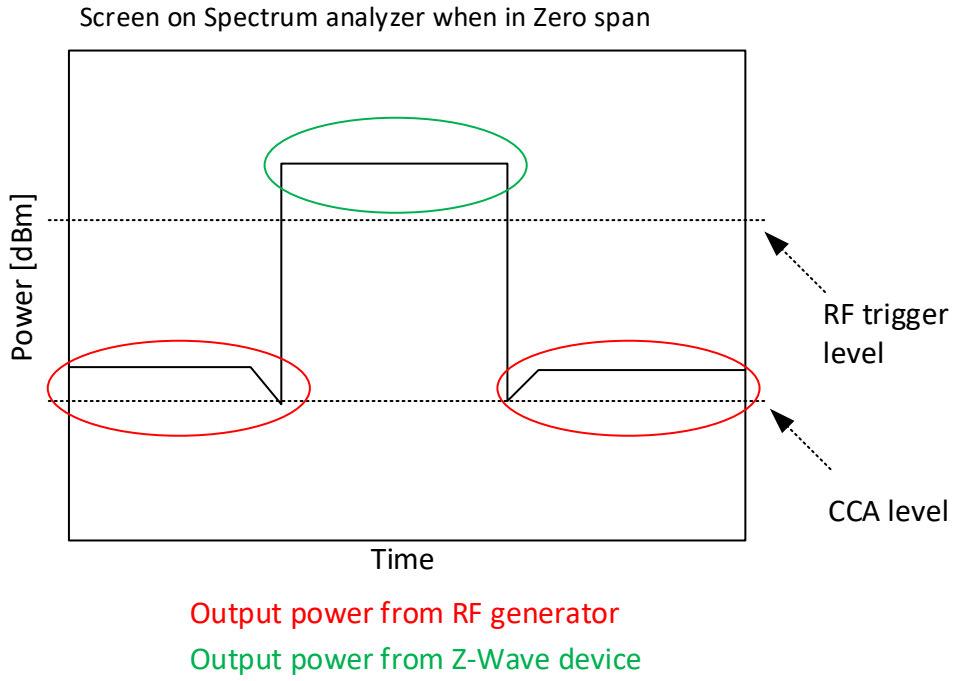

Figure 9, CCA spectrum analyzer measurement

3.8.3 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.

3.8.4 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 ITU section 7.1.2.5.4

3.8.5 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 ITU section 7.1.2.5.4.

3.9 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 ITU section 7.1.2.5.5. The receiver spurious must be tested for all RF profiles listed in ITU table 7.1

3.9.1 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 RF profiles and data rates as listed in ITU table 7.1
4. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.9.2 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 7, Receiver spurious requirements Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	2 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.

3.9.3 Measurement result

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

3.9.4 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 ITU section 7.1.2.5.5.

3.9.5 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 ITU section 7.1.2.5.5.

3.10 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 ITU section 7.1.2.5.6 and the frequency location and signal strength of the blocking CW RF signals must be adjusted to match the requirements given in ITU table 7.9. The blocking measurements must be tested for all RF profiles listed in ITU table 7.1

3.10.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. The output power of the transmitter must be adjustable to reach the power levels 3dB higher than stated in ITU table 7.8 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.
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 ITU table 7.9 when measured at the input of the DUT. The frequency offsets stated in ITU table 7.9 are relative to the RF frequency of each RF profile in ITU table 7.1.
7. A 3 port resistive RF combiner

3.10.2 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 $P_{DUT\_Z\text{-}Wave\ traffic}$ is 3dB above the level stated in ITU table 7.8 (please refer to Figure 10). The frequency of the CW RF generator is adjusted to: $f_{center\ frequency\ of\ RF\ profile\_x\ in\ ITU\ table\ 7.1}$ +/- $f_{frequency\ offset\ in\ ITU\ table\ 7.9}$, the amplitude is adjusted to the RF level as stated in ITU table 7.9 for each offset, and the RF level is $P_{DUT\_blocking\ signal}$ when measured at the input of the DUT (please refer to Figure 10). Once the setup has been configured, for each frequency offset entry in ITU table 7.9, 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 10 below:

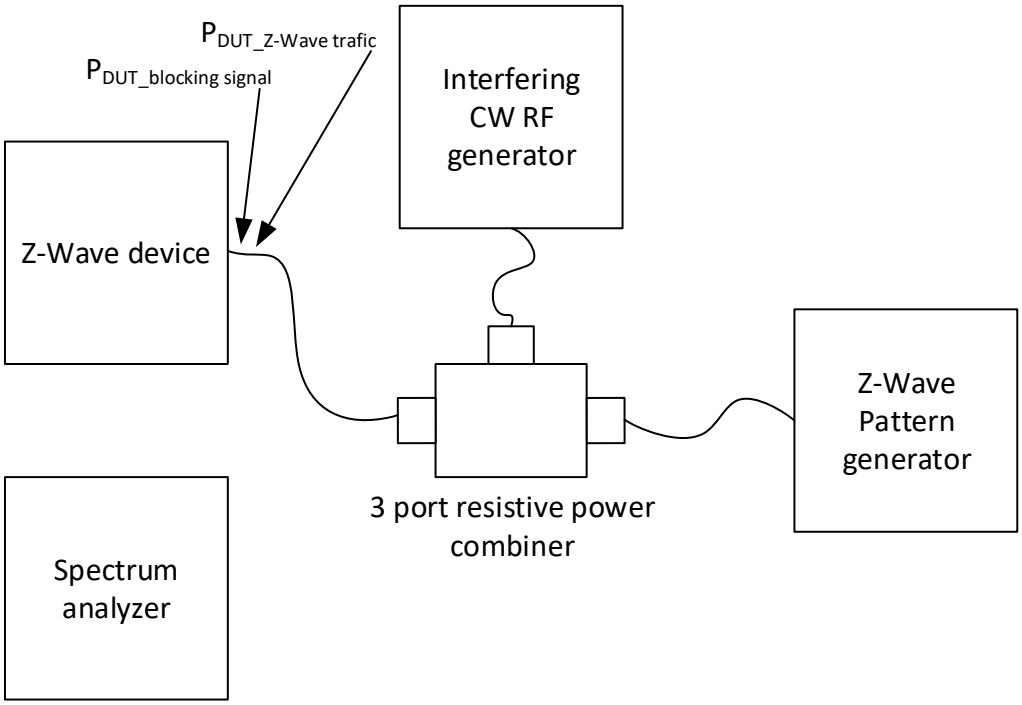

Figure 10, Blocking measurement setup

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 Z-Wave device 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.

3.10.3 Measurement result

For each of the RF profiles in ITU table 7.1 and frequency offsets in ITU table 7.9, at least 1000 frames 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:

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

For each (RF profile, Frequency offset), the frame error rate must be calculated, and the result must be below the criterion stated in ITU table 7.7.

3.10.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each (RF profile, Frequency offset) given in ITU table 7.9, the frame error rate (FER) is < 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.10.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any (RF profile, Frequency offset) given in ITU table 7.9, has a frame error rate (FER) which is > 0.01:
   FER = (Number of frames with errors received) / (Number of frames transmitted)

3.11 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 ITU section 7.1.2.5.7. The receiver saturation measurements must be tested for all RF profiles listed in ITU table 7.1

3.11.1 Prerequisites

1. A Z-Wave device capable of receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. The output power of the transmitter must be adjustable to reach the power level stated in ITU section 7.1.2.5.7 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.
5. A spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz

3.11.2 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:

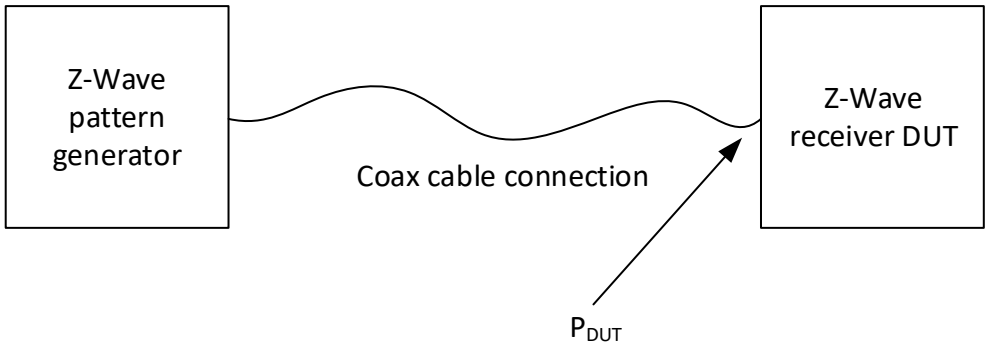

Figure 11, Receiver saturation measurement setup

The received power at the Z-Wave DUT, P_{DUT}, must be adjusted to match the RF level as stated in ITU section 7.1.2.5.7.

3.11.3 Measurement result

For each of the RF profile, at least 1000 frames must be transmitted by the test pattern generator and received by the DUT at the RF level stated in ITU section 7.1.2.5.7.

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

3.11.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each RF profile in ITU table 7.1, 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 ITU section 7.1.2.5.7

3.11.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any RF profile given in ITU table 7.1, 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 ITU section 7.1.2.5.7

3.12 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 ITU section 7.1.2.5.8. The TX-to-RX turnaround time measurements must be tested for all RF profiles listed in ITU table 7.1

3.12.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. 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.

3.12.2 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.

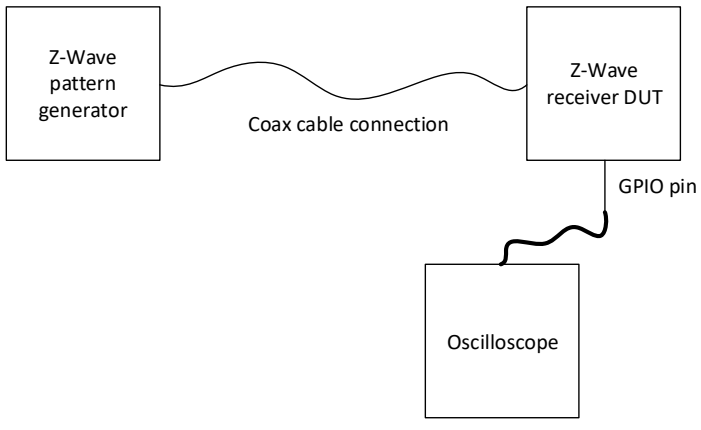

Figure 12, TX-to-RX turnaround time setup

Table 8, Oscilloscope settings for TX-to-RX turnaround measurements

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

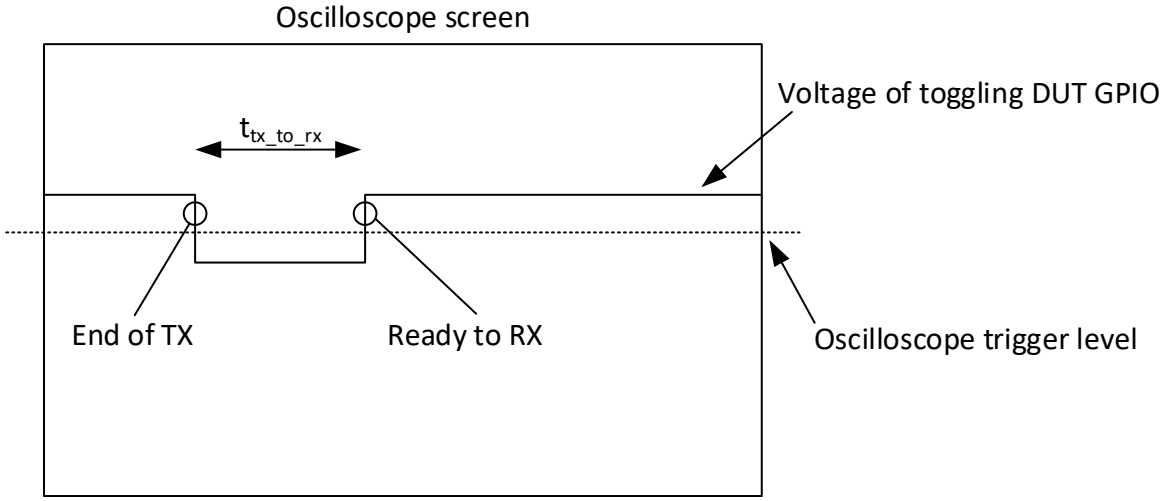

Figure 13, TX-to-RX turnaround measurement result

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.

3.12.3 Measurement result

The measurement result is the duration, $t_{tx\_to\_rx}$ in Figure 13, 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 state changes.

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 TX-to-RX turnaround time, $t_{tx\_to\_rx}$ for at least 10 samples are less than stated in ITU table 7.27 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 TX-to-RX turnaround times, $t_{tx\_to\_rx}$ for at least 10 samples were higher than stated in ITU table 7.27 or not all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.13 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 ITU section 7.1.2.5.8. The TX-to-RX turnaround time measurements must be tested for all RF profiles listed in ITU table 7.1

3.13.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. 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
6. A 3 port RF resistive power combiner.

3.13.2 Measurement setup

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

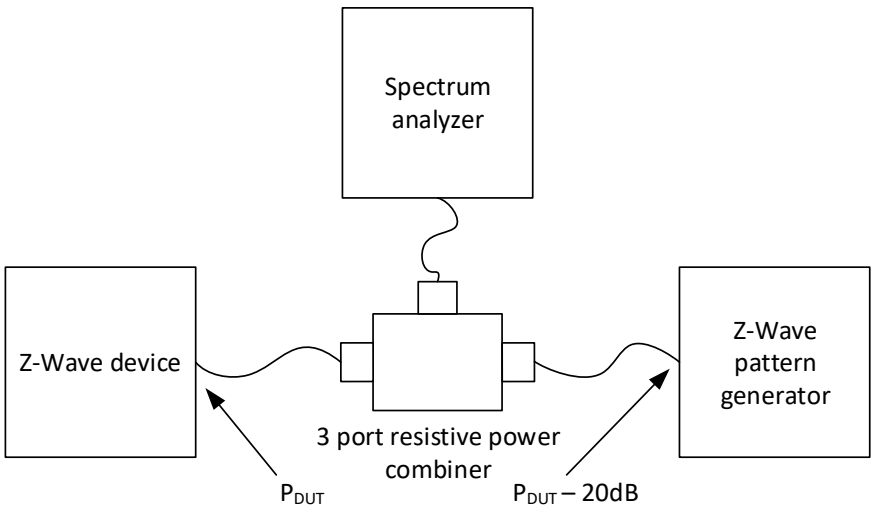

Figure 14, RX-to-TX turnaround time measurement setup

The spectrum analyzer must be initialized to:

Table 9, RX-to-TX turnaround time Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
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:

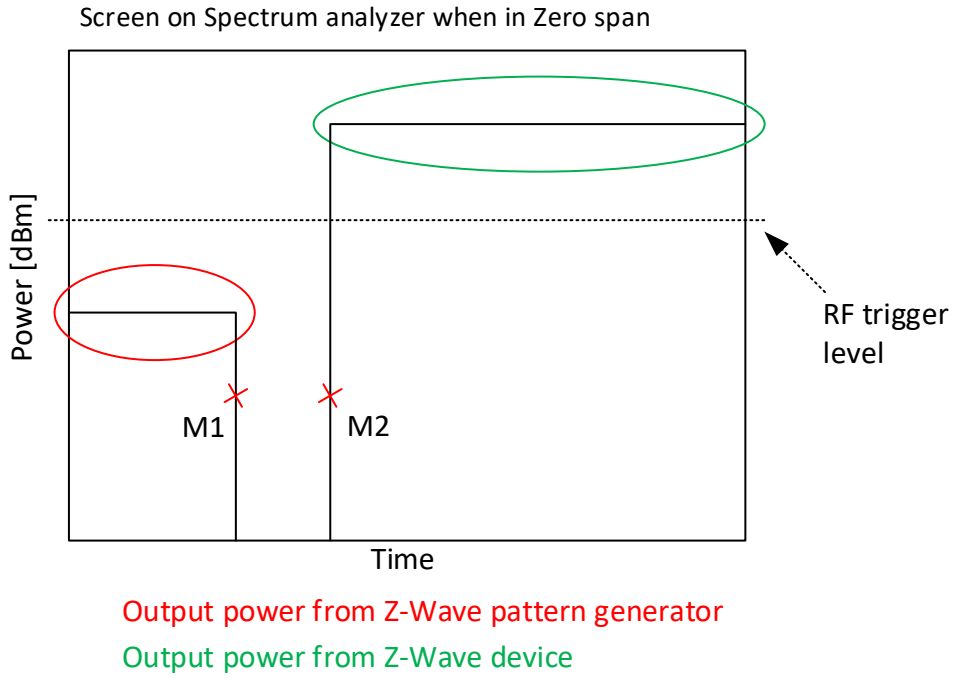

Figure 15, RX-to-TX turnaround measurement

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.

3.13.3 Measurement results

The measurement result is the time difference between the two markers in Figure 15, measured for at least 10 transmissions.

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

3.13.4 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 ITU table 7.27 and all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.13.5 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 ITU table 7.27 or not all transmitted frames by the Z-Wave generator were received and acknowledged by the Z-Wave device.

3.14 Preamble field

Data frames transmitted by a Z-Wave device be formatted as described in ITU section 7.1.3.1: With a preamble field, a Start of Frame delimiter, payload and an End of Frame delimiter. The requirements for the number of preamble bytes to transmit are stated in ITU table 7.10.

The preambles are coded according to ITU tables 7.2, 7.4, 7.5 and 7.6.

The number of preamble types transmitted for each type of Z-Wave frame must be tested according to ITU table 7.10 and tested for all RF profiles listed in ITU table 7.1

3.14.1 Prerequisites

1. A Z-Wave device capable of transmitting Z-Wave packages correctly formatted according to ITU section 7
2. The Z-Wave device must be able to transmit each of the various types of Z-Wave frames described in ITU table 7.10.
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 Keysight CXA N9000A, 7.5GHz
5. An analog demodulator option installed on the spectrum analyzer with the capabilities of at least Keysight option “N9063A Analog Demod Measurement”.

3.14.2 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 ITU table 7.10.

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

The spectrum analyzer must be initialized to:

Table 10, Preamble Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average
Analog demodulation type	FSK
Demodulation time (time across screen)	t_{demod_time}
IF filter	700 kHz
Trigger option	RF burst

t_{demod_time} = 1/BitRate x #Preamble Bytes x 8 + 1/BitRate x 2 x 8

E.g. t_{demod_time} for Single Cast frame at data rate R1:

According to ITU table 7.2 R1 = 9600 bit/s
According to ITU table 7.10, Single Cast frame at R1 = minimum 10 preamble bytes
t_{demod_time} = 1/9600 x 10 x 8 + 1/9600 x 2 x 8 = 10ms

The sweep time of the spectrum analyzer has now been set to capture the minimum number of preambles to expect + 2 more bytes:

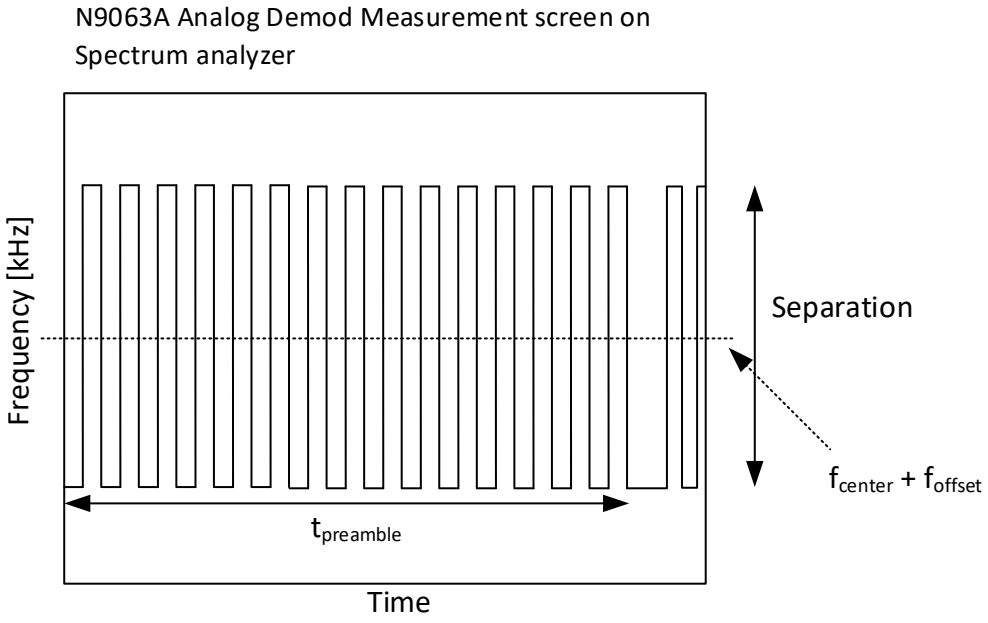

Figure 16, Preamble field length measurement

Within the minimum time duration of the preamble bytes to be expected to be transmitted according to ITU table 7.10 :

$t_{preamble}$ = 1/BitRate x #Preamble Bytes x 8

Nothing but alternating bits with a symbol duration of 1/BitRate may be observed.

3.14.3 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 ITU table 7.10. If any irregularities are found within the time periode $t_{preamble}$, the Z-Wave device has failed the test.

3.14.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The duration of the preambles transmitted according to ITU table 7.10 are at least equal to: $t_{preamble}$ = 1/BitRate x #Preamble Bytes x 8

2. No preamble bits are measured to have a symbol duration different from 1/SymbolRate with the accuracy stated in ITU table 7.2.

3.14.5 Fail criteria

The Z-Wave device shall fail the test if:

1. The duration of the preambles transmitted according to ITU table 7.10 is shorter than: $t_{preamble}$ = 1/BitRate x #Preamble Bytes x 8
2. Preamble bits are measured to have a symbol duration different from 1/SymbolRate with the accuracy stated in ITU table 7.2.

3.14.6 Exception

The number of preamble bytes can be higher than stated in ITU table 7.10.

3.15 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 ITU section 7.1.3.3. The data content of the Start of Frame field is described in ITU table 7.11. The handling of Start of Frame field in Z-Wave frames must be tested for all RF profiles listed in ITU table 7.1

3.15.1 Prerequisites

1. A Z-Wave device capable of transmitting and receiving, decoding and error handling Z-Wave frames formatted according to ITU section 7.1.3. The Z-Wave device must be able to decode and data process at transmissions rates stated in ITU table 7.2. 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 Silicon Labs Z-Wave device which can transmit and receive Z-Wave coded data messages. Data must be transmitted according to ITU tables 7.2 to 7.6 and formatted at described in ITU section 7.1.3. 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.

3.15.2 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:

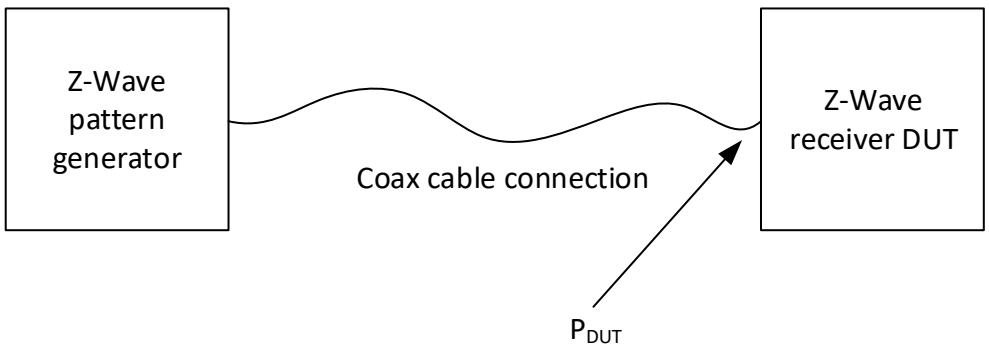

Figure 17, Start of Frame measurement setup

The received power at the Z-Wave DUT, P_{DUT}, must be set to -50 dBm.

3.15.3 Measurement result

For each of the RF 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 RF profile by both the Z-Wave pattern generator and the DUT.

3.15.4 Pass criteria

The Z-Wave device shall pass the test if:

1. For each RF profile in ITU table 7.1, 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)

3.15.5 Fail criteria

The Z-Wave device shall fail the test if:

1. Any RF profile given in ITU table 7.1, 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)

3.16 End of Frame field

Data frames transmitted by a Z-Wave device be formatted as described in ITU section 7.1.3.1: With a preamble field, a Start of Frame delimiter, payload and an End of Frame delimiter. If the Z-Wave packet is transmitted with the data rate R1, the requirements for End of Frame field is given in ITU section 7.13.5.

The End of Frame delimiter for data rate R1 must be tested for all RF profiles listed in ITU table 7.1

3.16.1 Prerequisites

1. A Z-Wave device capable of transmitting Z-Wave packages correctly formatted according to ITU section 7 at the data rate R1.
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 spectrum analyzer with better or identical specifications to a Keysight CXA N9000A, 7.5GHz
4. An analog demodulator option installed on the spectrum analyzer with the capabilities of at least Keysight option “N9063A Analog Demod Measurement”.

3.16.2 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 ITU table 7.10.

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

The spectrum analyzer must be initialized to:

Table 11, End of Frame field Spectrum Analyzer settings

Spectrum analyzer parameter	Setting
f_{center}	$f_{\text{center frequency}}$ according to ITU table 7.1
Span	200kHz
Resolution Bandwidth	1kHz
Video Bandwidth	Auto
Amplitude reference level	10dBm
Detector type	Average
Analog demodulation type	FSK
Demodulation time (time across screen)	220us
IF filter	700 kHz
Trigger option	RF burst
Trigger delay	t_{delay}

$t_{delay} = t_{preamble\_duration} + t_{SOF\_duration} + t_{payload\_duration}$

t_{delay} = 1/9600 x #Preamble Bytes x 8 + 1/9600 x 1 x 8 + 1/9600 x (#payload Bytes-1) x 8

E.g. t_{delay} for Single Cast frame at data rate R1:

According to ITU table 7.2 R1 = 9600 bit/s
According to ITU table 7.10, Single Cast frame at R1 = 10 preamble bytes
The test frame has 6 bytes of payload data

t_{delay} = 1/9600 x 10 x 8 + 1/9600 x 1 x 8 + 1/9600 x (6-1) x 8 = 13.33ms

The delay of the trigger is now set in such a way, that the two last bytes or the captured Z-Wave frame are shown on the screen of the spectrum analyzer:

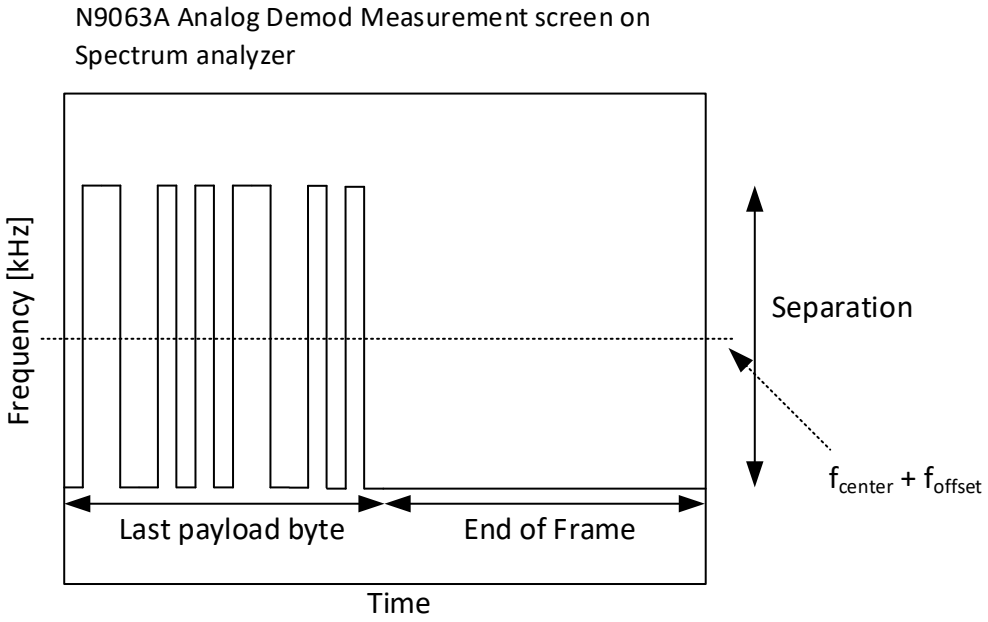

Figure 18, End of Field measurement

The duration of the End of Frame Manchester code violation must be at least : t_{EOF} = 833uS

3.16.3 Measurement result

The measurement result is an analysis of the demodulated Z-Wave frame by using the analog demodulation capabilities of the spectrum analyzer. The trigger of the spectrum analyzer is set in such a way, that the last two bytes transmitted are visible on the screen of the spectrum analyzer.

The measurement result is the duration of the end of Frame, t_{EOF}.

3.16.4 Pass criteria

The Z-Wave device shall pass the test if:

1. The duration of the End of Frame field, t_{EOF} is >= 833uS

3.16.5 Fail criteria

The Z-Wave device shall fail the test if:

1. The duration of the End of Frame field, t_{EOF} is < 833uS

3.16.6 Exception

The duration of the End of Frame field can be longer than the duration of a byte transmitted at data rate R1, as long as the TX-to-RX turnaround time can be fulfilled. Please refer to section 3.12.

REFERENCES

[1] ITU-T, G9959 (01/2015)

