WIRELESS & SENSING PRODUCTS

Application Note:

SX126x CAD Performance Evaluation

AN1200.48
Rev 1.0
November 2018

Table of Contents

List of Figures

List of Tables

1. Introduction

The use of a spread spectrum modulation technique presents challenges in determining whether the channel is already in use by a signal that may be below the noise floor of the receiver. The use of the RSSI in this situation would clearly be impracticable. To this end the channel activity detector is used to detect the presence of other LoRa® signals.

On the SX1261/2, the channel activity detection mode is designed to detect the presence of a LoRa® preamble or data symbols while the previous generations of products were only able to detect LoRa® preamble symbols.

Once in CAD mode, the SX1261/2 will perform a scan of the channel for a user-selectable duration (defined in number of symbols) and will then return with the *channelActivityDetected* Flag if LoRa® symbols have been detected during the CAD.

The parameters *cadDetPeak* and *cadDetMin* define the sensitivity of the LoRa modem when trying to correlate to actual LoRa symbols. These two settings depend on the LoRa spreading factor and bandwidth, but also depend on the number of symbols (*cadSymbolNum*) used to validate or not the presence of signal.

The test flow used to determine the combination of parameters is the following. Every 2 seconds, the DUT opens a window for CAD detection. It runs 100 times and calculates the *channelActivityDetected* percentage and the *OnRxDone* percentage, the first one representing a successful CAD, the second one a proper packet reception ensuing a positive CAD.

2. Test Procedure

2.1 Test Bench Setup

All the tests were done in conducted mode, with the signal generator connected to the DUT by a coaxial cable. A host is used to generate LoRa waveforms with different spreading factors, and control the signal generator connected to the DUT with different parameters, such as power level. The DUT performs a CAD a 100 times, and if a LoRa carrier is detected, it switches on the receive mode. At the end of the 100 loops, it notifies the host by a COM port interface how many CADs have been detected and how many packets have been received.

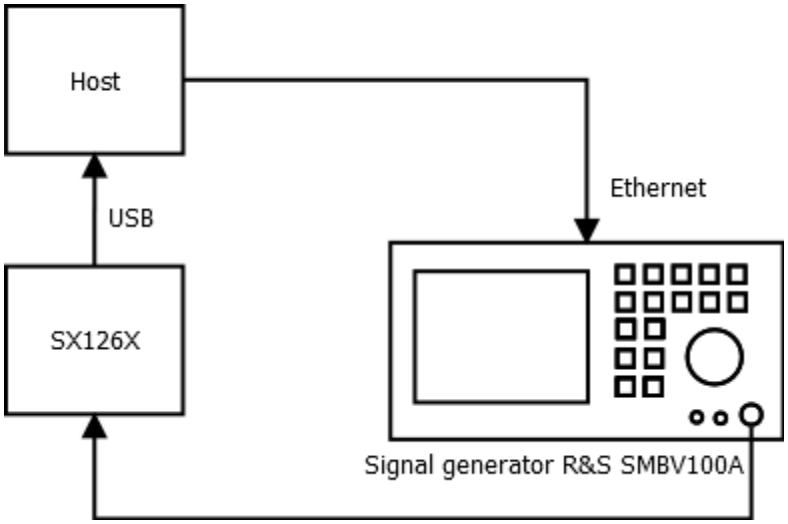

Figure 1: Test Bench Diagram

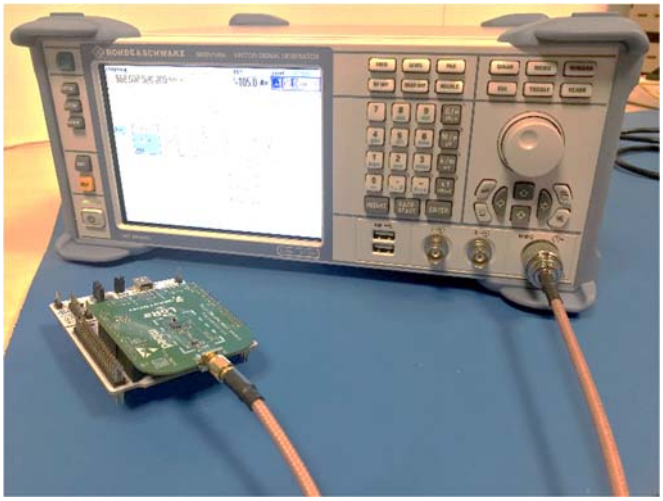

Figure 2: Test Bench Picture

2.2 Program Flow

The CAD/RX sequence on the DUT is run 100 times for each configuration. For each run, the parameters of the transmitted frame are modified. Note that the frames are sent in a row, with no down time between frames. Also, there is no synchronization between the DUT and the start of frame, meaning that the CAD evaluation may be done on Preamble or Data. Here is the program flow, DUT side.

In these tests, *cadDetMin* is fixed, all optimizations are done with *cadDetMin* = 10. There is no need to change this value.

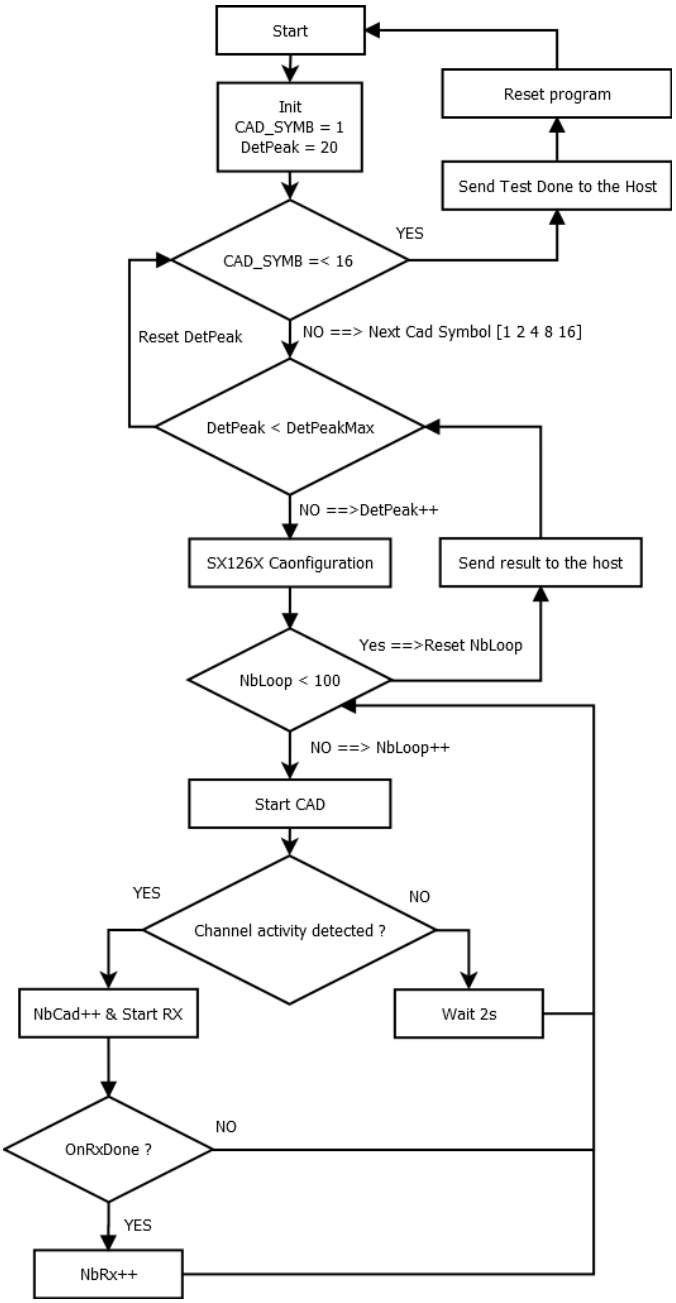

Figure 3: DUT Program Flow

And here is the test flow, on the host side:

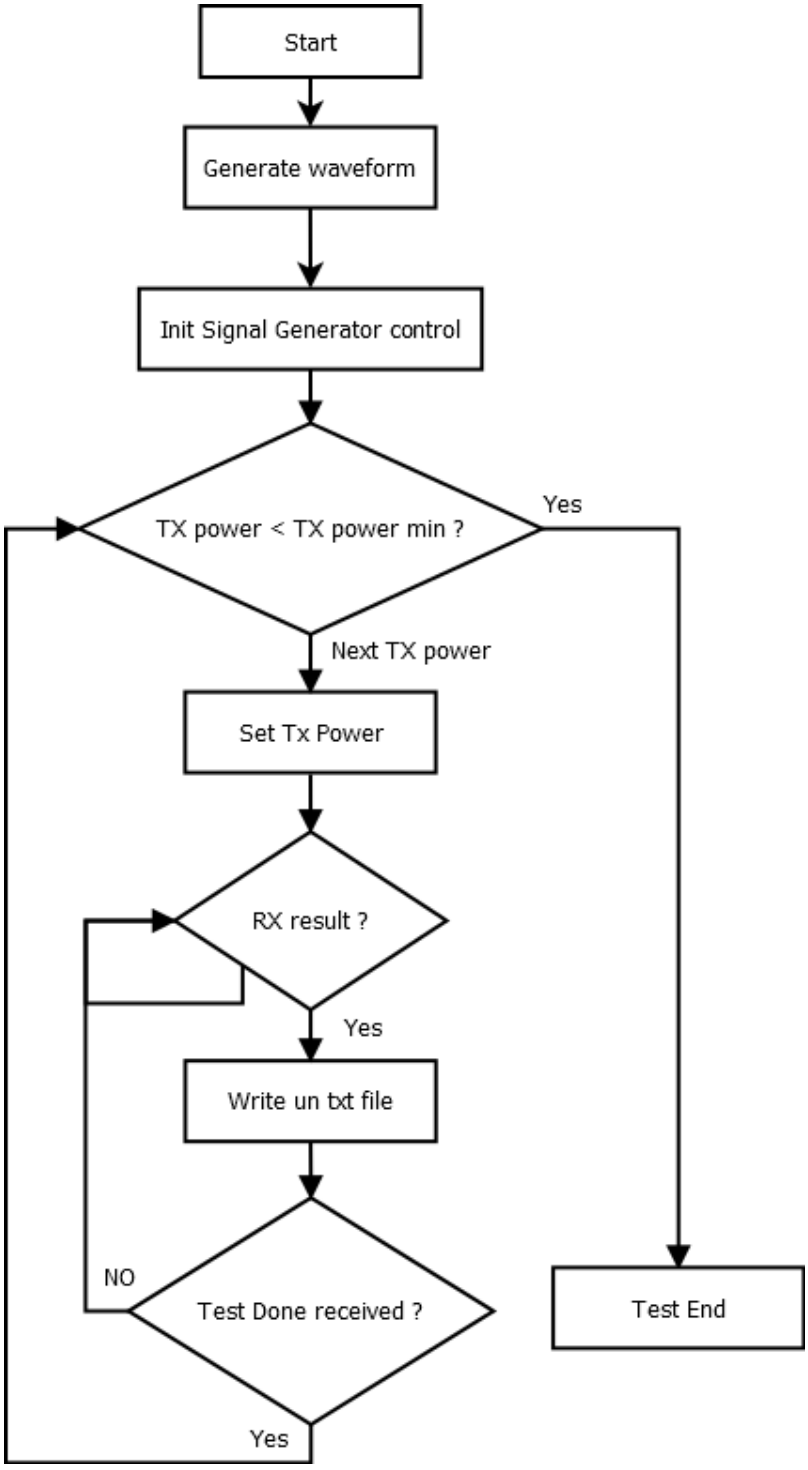

Figure 4: Host-side Program Flow

3. Results

3.1 CAD & PER

3.1.1 Best Settings

Hereafter is presented a summary of the best settings to detect a LoRa activity and limit the false detection, using the number of symbols as a parameter, too:

Note: A detection is considered to be false if a CAD is detected and no packet is received.

Spreading Factor	Best CAD settings			CAD consumption (nAh)
	cadDetMin	*cadDetPeak*	*cadSymbolNum*	
SF7	10	22	2 Symbols	2.84
SF8	10	22	2 Symbols	5.75
SF9	10	23	4 Symbols	20.44
SF10	10	24	4 Symbols	41.36
SF11	10	25	4 Symbols	134.55

Table 1: CAD/PER Best Settings

3.1.1.1 SF7

Here are the details for SF7, 2 symbols are enough to have a good detection without false detections, LoRa Settings: SF7 | BW = 125 kHz | Fo = 868.1 MHz | CR=4/5 | *cadDetMin* = 10.

CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
0	100	100	100	100	100
-40	100	100	100	100	100
-110	100	100	100	100	100
-120	100	100	100	100	100
-122	100	100	100	100	100
-123	96	97	97	97	95
-125	94	79	74	58	48
-130	17	8	1	0	0
-140	2	2	1	0	0
OFF	4	0	0	0	0

Table 2: SF7 CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
0	0	0	0	0	0
-40	0	0	0	0	0
-110	0	0	0	0	0
-120	0	0	0	0	0
-122	0	0	0	0	0
-123	6	6	5	3	5
-125	9	29	29	45	54
-130	100	100	100	100	100
-140	100	100	100	100	100
OFF	100	100	100	100	100

Table 3: SF7 PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

SF7, 868.1MHz, 4/5, 125 kHz 2 Symbols, *cadDetPeak* =22, *cadDetMin*=10		
Power (dBm)	Cad Detected (%)	PER (%)
0	100	0
-40	100	0
-110	100	0
-120	100	0
-122	100	0
-123	97	5
-125	74	29
-130	1	100
-140	1	100
OFF	0	100

Table 4: SF7 Best setting 2 Symbols

In order to validate these best settings for sensitivity, here is a 10% PER test, performing the same sequence than previously but 10000 time instead of 100:

CAD SYMBOL = LORA_CAD_02_SYMBOL | cadDetPeak = 22 | cadDetMin = 10					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
-123	10000	9861	9844	1.6	0.17

Table 5: SF7 Best Settings for PER 10%

In order to validate the false detection rate, a slightly different test is then performed: an antenna is connected to the board, but no more packets are transmitted by the signal generator. One thousand CAD attempts are done in order to validate the false detection rate below 1%

CAD SYMBOL = LORA_CAD_02_SYMBOL | cadDetPeak = 22 | cadDetMin = 10 | 868.1MHz | Antenna					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
OFF	1000	0	0	100	0

Table 6: SF7 False Detection Rate 1% Test

These tests indicate that the above setting fulfills all requirement of a robust CAD, which is a very low probability of false detection in the absence of incoming packet, and a very high probability of proper detection when a packet is in the air, even at very low signal levels (close to sensitivity).

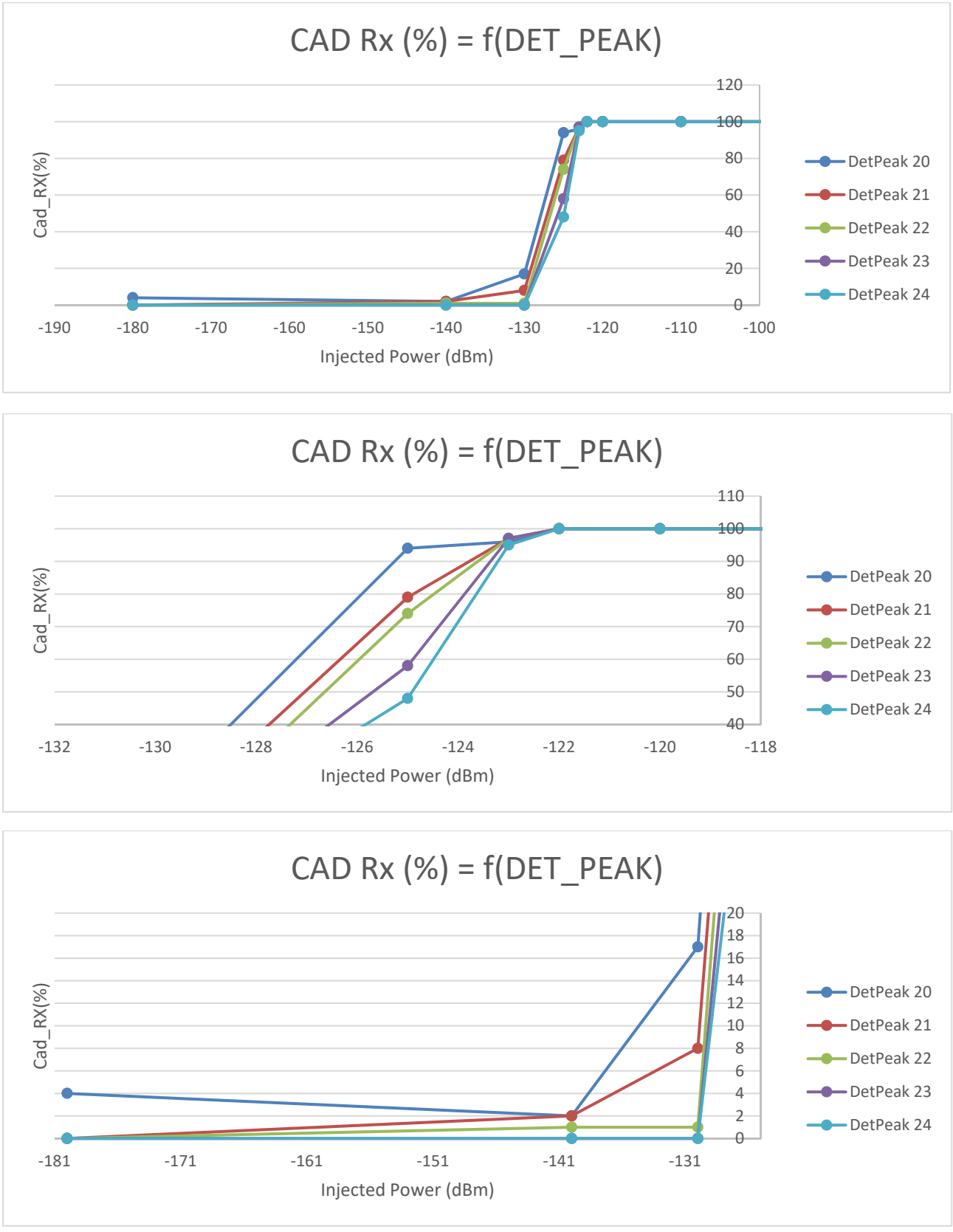

Figure 5: SF7 CAD 2 Symbols vs. *DetPeak*

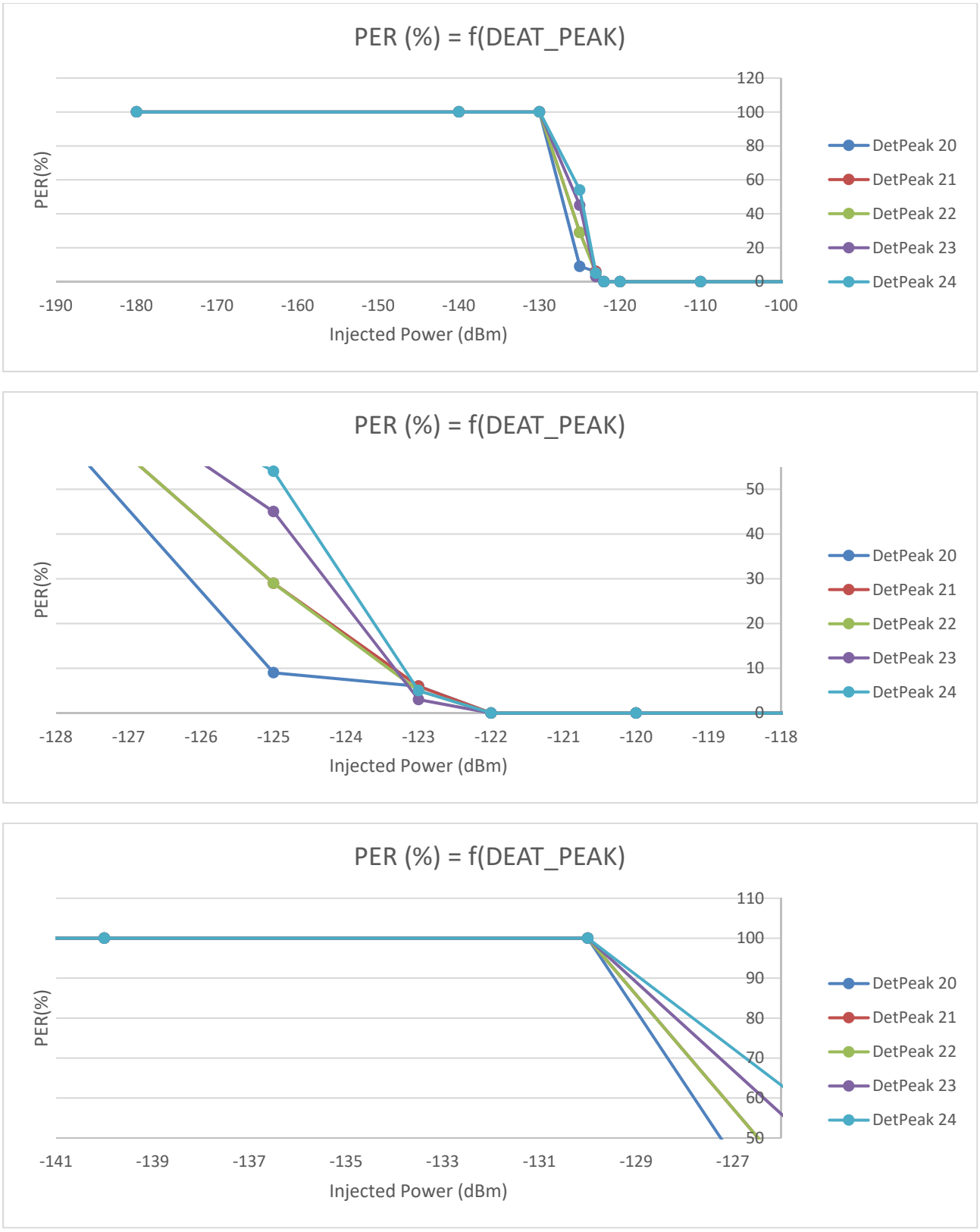

Figure 6: SF7 PER 2 Symbols vs. *DetPeak*

3.1.1.2 SF8

Here are the details for SF8, 2 symbols are enough to have a good detection without significant false detection. LoRa Settings: SF8 | BW = 125 kHz | Fo = 868.1 MHz | CR=4/5 | cadDetMin = 10.

CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
0	100	100	100	100	100
-40	100	100	100	100	100
-110	100	100	100	100	100
-120	100	100	100	100	100
-123	100	100	100	100	100
-125	100	100	100	97	97
-126	99	99	99	92	86
-130	64	43	23	8	10
-140	16	6	1	0	0
OFF	15	9	0	1	0

Table 7: SF8 CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
0	0	0	0	0	0
-40	0	0	0	0	0
-110	0	0	0	0	0
-120	1	1	1	1	1
-123	0	0	1	0	0
-125	1	3	2	4	6
-126	4	7	2	13	17
-130	94	91	96	100	98
-140	100	100	100	100	100
OFF	100	100	100	100	100

Table 8: SF8 PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

SF8, 868.1MHz, 4/5, 125 kHz 2 Symbols, CadDetPeak =22, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
0	100	0
-40	100	0
-110	100	0
-120	100	1
-123	100	1
-125	100	2
-126	99	2
-130	23	96
-140	1	100
OFF	0	100

Table 9: SF8 Best Setting 2 Symbols

In order to validate these best settings for sensitivity, here it a PER test performing the same sequence than previously but 10000 time instead of 100:

CAD SYMBOL = LORA_CAD_02_SYMBOL | cadDetPeak = 22 | cadDetMin = 10					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
-125	10000	9974	9847	1.5	1.27

Table 10: SF8 Best Settings PER 10%

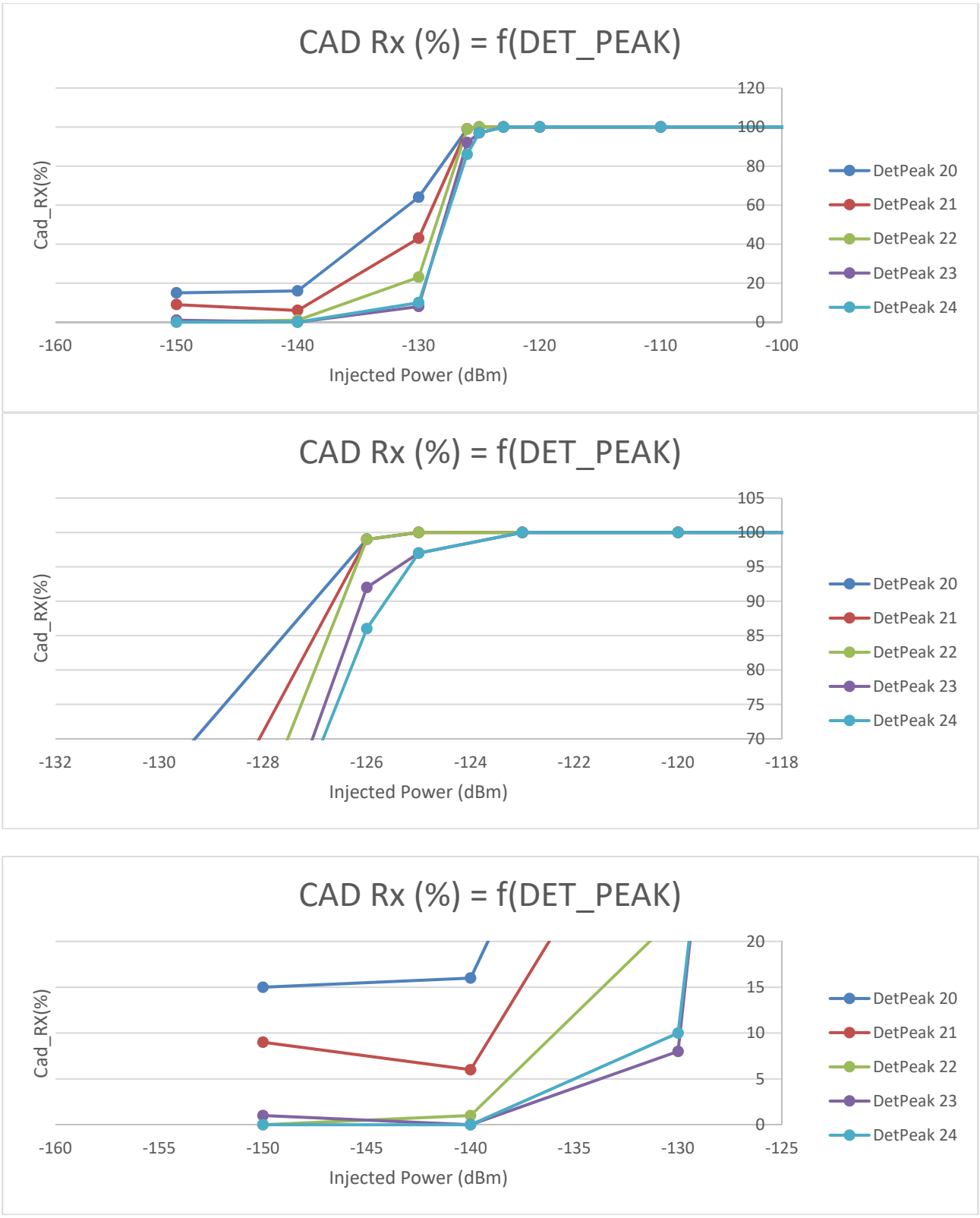

Figure 7: SF8 PER 2 Symbols vs. DetPeak

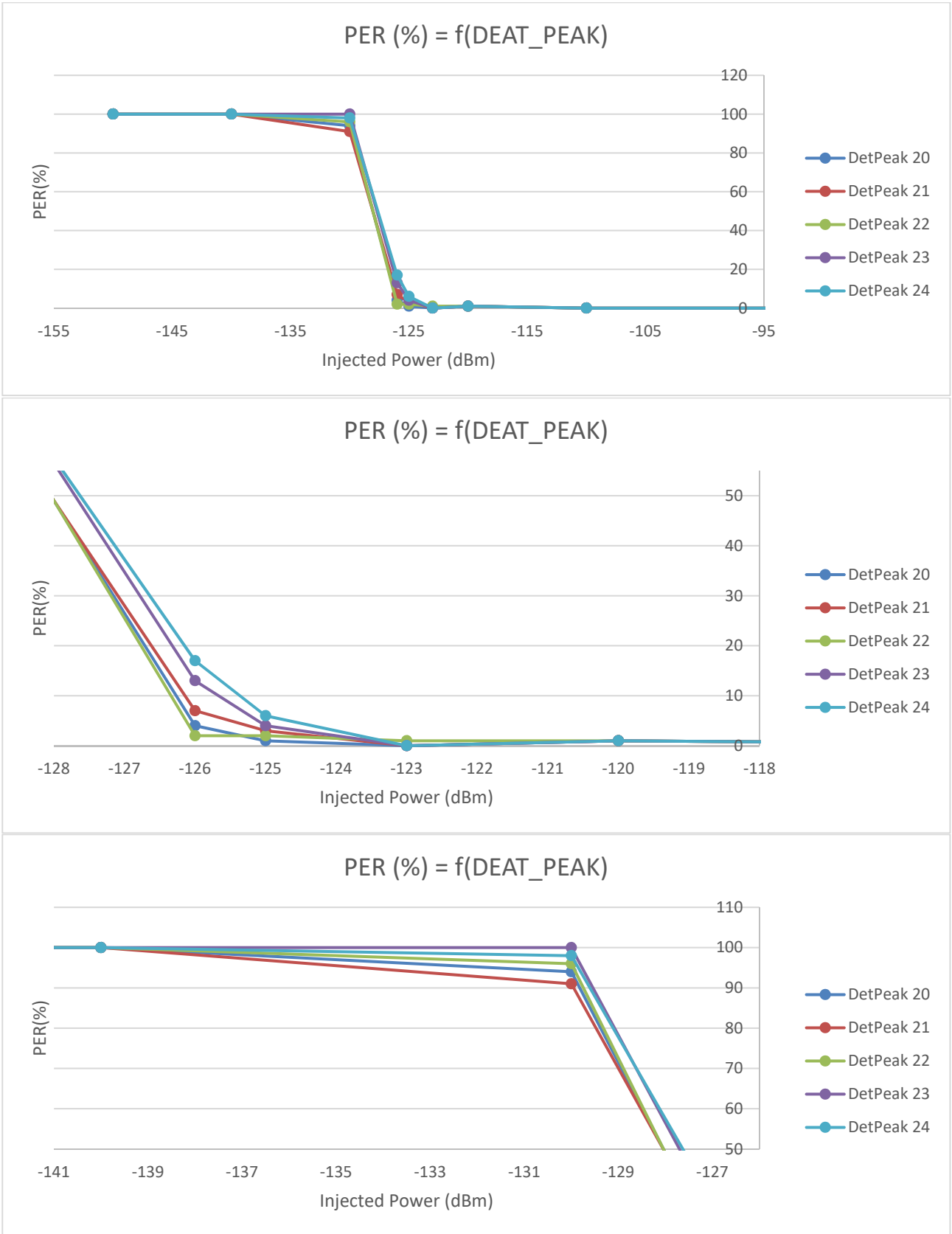

Figure 8: SF8 PER 2 Symbols vs. DetPeak

3.1.1.3 SF9

Here are the details for SF9, 4 symbols are necessary to have a good performance without false detection, LoRa Settings: SF9 | BW = 125 kHz | Fo = 868.1 MHz | CR=4/5 | cadDetMin = 10.

CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
-120	100	100	100	100	100
-125	100	100	100	100	100
-127	100	100	100	100	100
-128	100	100	100	100	100
-129	100	100	100	100	99
-130	99	99	91	93	74
-132	96	95	81	63	42
-135	79	56	18	4	3
-140	48	29	4	0	0
OFF	57	19	4	0	0

Table 11 SF9 CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
-120	0	0	0	0	0
-125	0	0	0	0	0
-127	1	0	0	0	0
-128	1	1	0	0	2
-129	1	1	2	0	3
-130	7	7	11	11	33
-132	58	75	70	76	88
-135	100	100	100	100	100
-140	100	100	100	100	100
OFF	100	100	100	100	100

Table 12: SF9 PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

SF9, 868.1MHz, 4/5, 125 kHz 4 Symbols, CadDetPeak =23, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-120	100	0
-125	100	0
-127	100	0
-128	100	0
-129	100	0
-130	93	11
-132	63	76
-135	4	100
-140	0	100
OFF	0	100

Table 13: SF9 Best Setting 4 Symbols

In order to validate these best settings for sensitivity, here is a 10% PER test, performing the same sequence than previously but 10000 time instead of 100:

CAD SYMBOL = LORA_CAD_04_SYMBOL | cadDetPeak = 23 | cadDetMin = 10					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
-129	10000	9751	9566	4.3	1.90

Table 14: SF9 Best Settings PER 10%

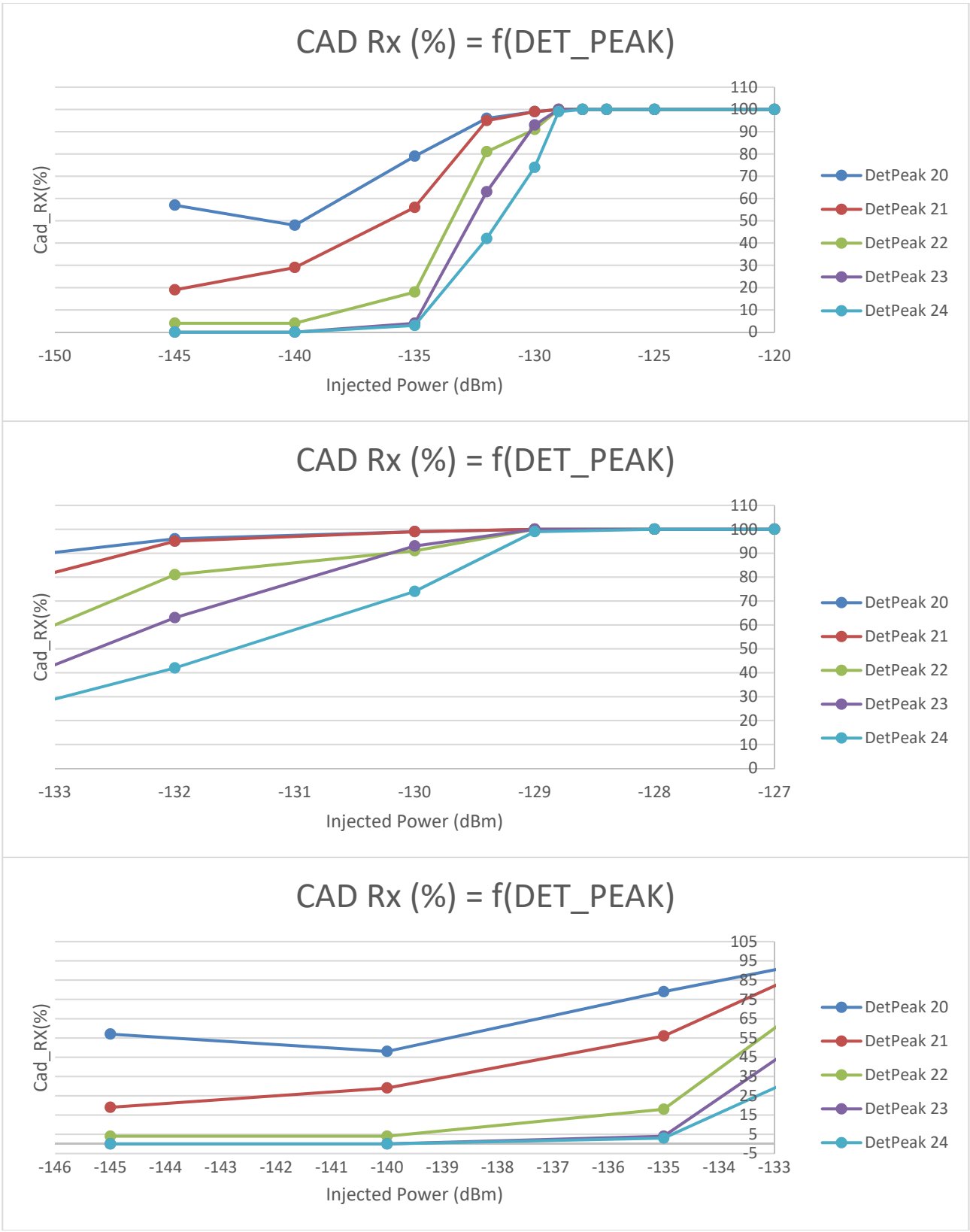

Figure 9: SF9 CAD 4 Symbols vs. DetPeak

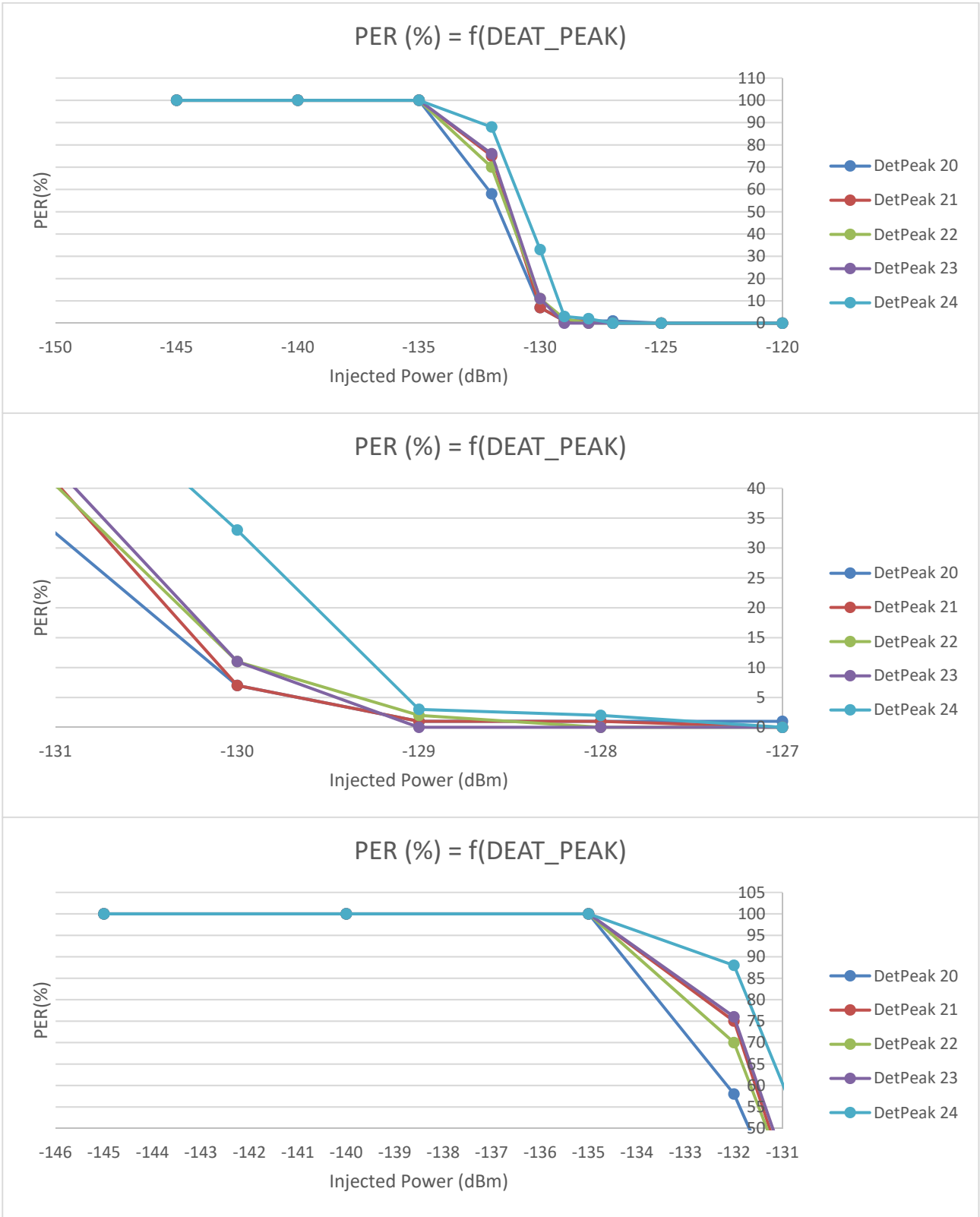

Figure 10: SF9 PER 4 Symbols vs. DetPeak

3.1.1.4 SF10

Here are the details for SF10, 4 symbols are necessary to have a good detection without false detection, LoRa Settings: SF10 | BW = 125 kHz | Fo = 868.1 MHz | CR=4/5 | cadDetMin = 10.

CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)				
Power (dBm)	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25
-120	100	97	100	100
-125	100	100	100	100
-127	100	100	97	100
-128	100	100	100	100
-129	100	100	100	100
-130	100	100	99	99
-132	100	99	86	78
-135	87	67	5	2
-140	30	10	0	0
OFF	9	3	0	0

Table 15 SF10 CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)				
Power (dBm)	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25
-120	0	7	0	0
-125	0	0	0	0
-127	0	0	3	0
-128	3	0	0	0
-129	1	1	0	0
-130	1	2	1	1
-132	6	7	14	22
-135	89	94	95	95
-140	100	100	100	100
OFF	100	100	100	100

Table 16: SF10 PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

SF10, 868.1MHz, 4/5, 125 kHz 4 Symbols, CadDetPeak =24, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-120	100	0
-125	100	0
-127	97	3
-128	100	0
-129	100	0
-130	99	1
-132	86	14
-135	5	95
-140	0	100
OFF	0	100

Table 17: SF10 Best Setting 4 Symbols

In order to validate these best settings for sensitivity, here is a 10% PER test, performing the same sequence than previously but 10000 time instead of 100:

CAD SYMBOL = LORA_CAD_04_SYMBOL | cadDetPeak = 24 | cadDetMin = 10					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
-130	10000	9977	9877	1.2	1.00

Table 18: SF10 Best Settings PER 10%

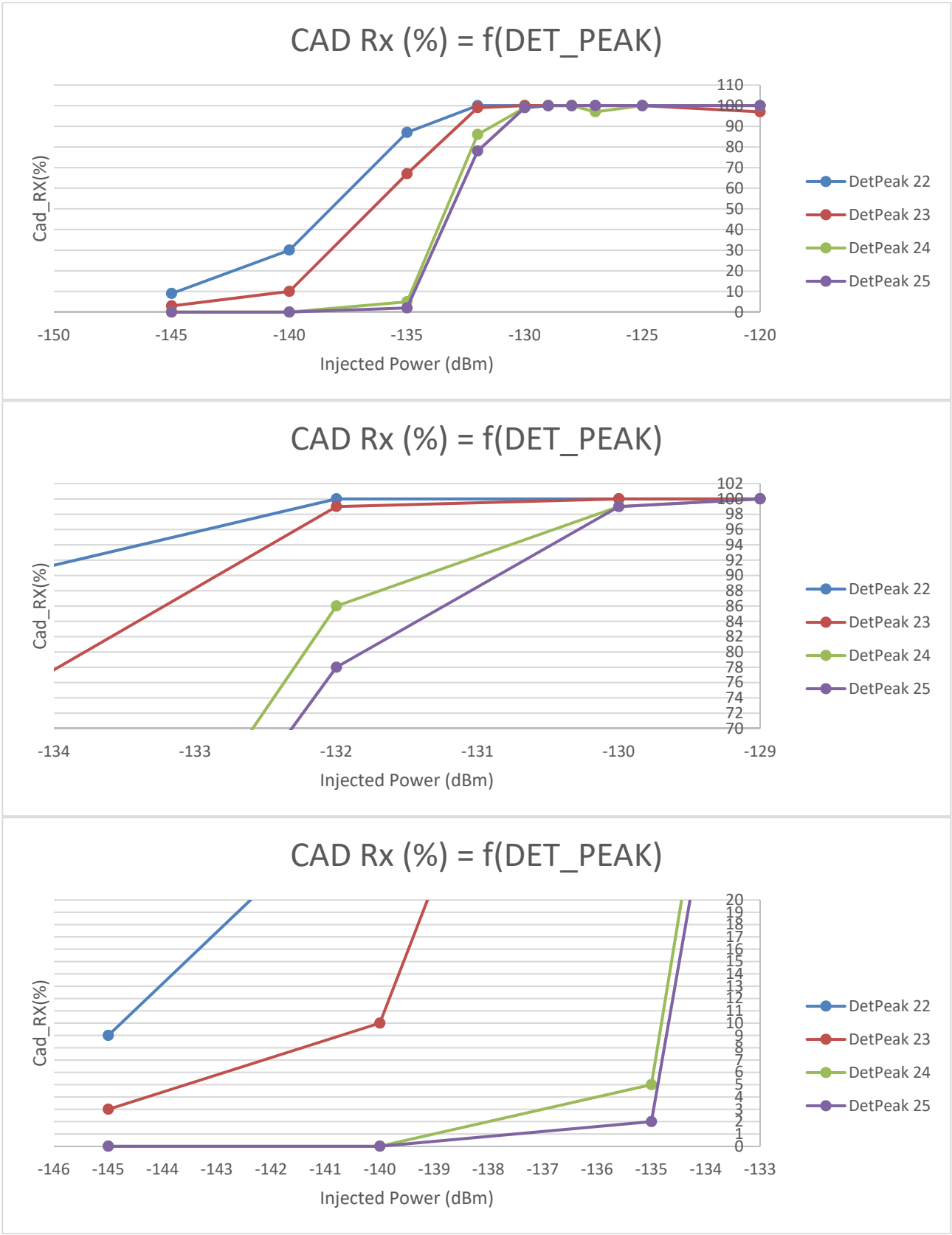

Figure 11: SF10 CAD 4 Symbols vs. DetPeak

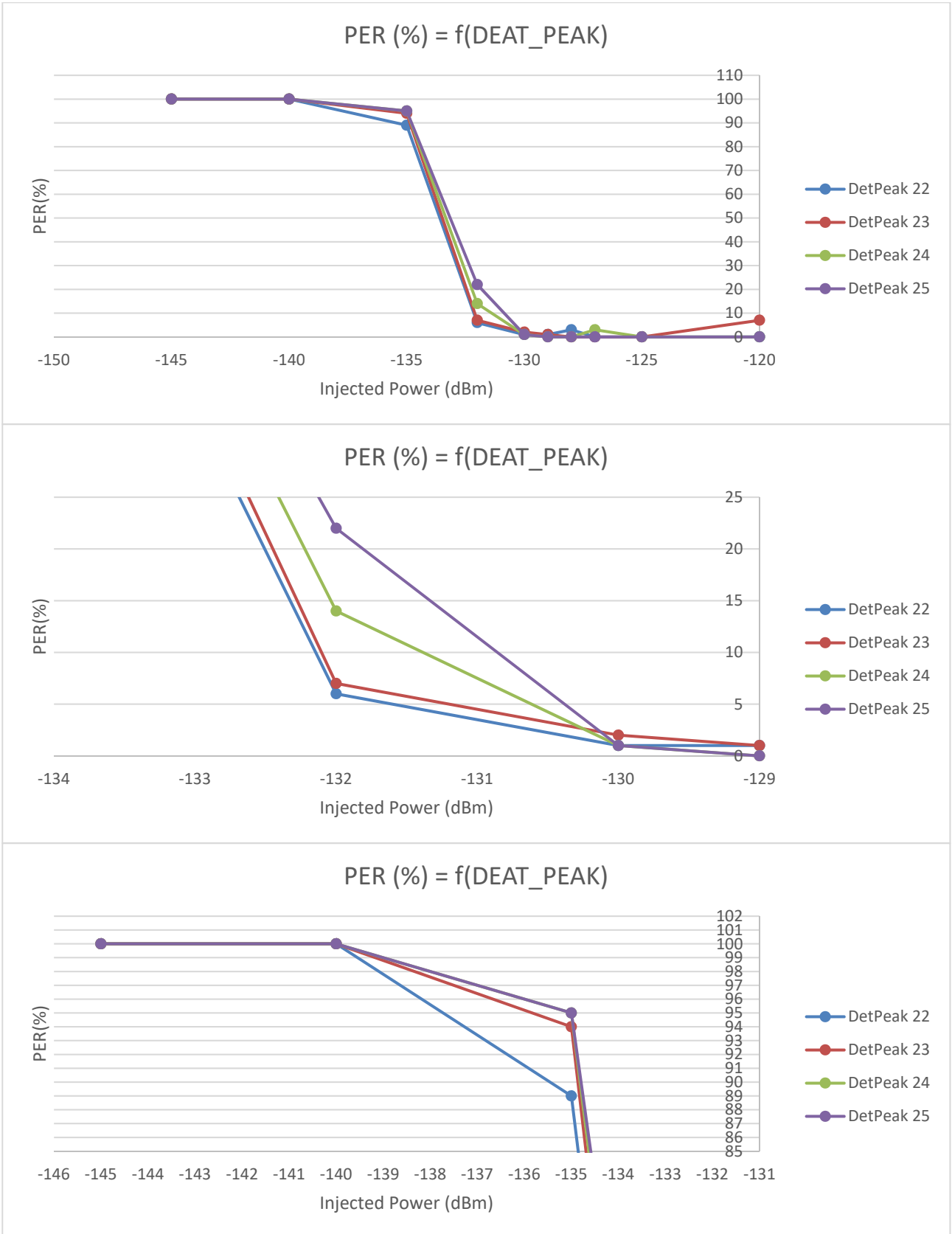

Figure 12: SF10 PER 4 Symbols vs. DetPeak

3.1.1.5 SF11

Here are the details for SF11, 4 symbols are necessary to have a good performance without false detection, LoRa Settings: SF10 | BW = 125 kHz | Fo = 868.1 MHz | CR=4/5 | cadDetMin = 10.

CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)									
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25	DetPeak 26	DetPeak 27	DetPeak 28
-125	100	100	100	100	100	100	100	100	100
-130	100	100	100	100	100	100	100	100	100
-132	100	100	100	100	100	100	100	100	100
-133	100	100	100	100	100	100	100	99	100
-134	100	100	100	98	100	98	95	93	94
-136	100	100	99	96	83	84	67	41	15
-140	98	90	66	25	3	2	0	0	0
OFF	95	73	28	5	1	1	0	0	0

Table 19: SF11 CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)									
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25	DetPeak 26	DetPeak 27	DetPeak 28
-125	0	0	1	0	0	0	0	0	0
-130	0	1	0	1	0	0	0	0	0
-132	3	1	0	0	0	0	0	0	0
-133	0	0	0	0	0	0	0	1	0
-134	16	3	8	11	0	2	5	7	6
-136	8	13	7	8	22	20	33	59	85
-140	100	100	100	100	100	100	100	100	100
OFF	100	100	100	100	100	100	100	100	100

Table 20: SF11 PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)

SF11, 868.1MHz, 4/5, 125 kHz 4 Symbols, CadDetPeak =25, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-125	100	0
-130	100	0
-132	100	0
-133	100	0
-134	98	2
-136	84	20
-140	2	100
OFF	1	100

Table 21: SF11 Best Setting 4 Symbols

In order to validate these best settings for sensitivity, here is a 10% PER test, performing the same sequence than previously but 10000 time instead of 100:

CAD SYMBOL = LORA_CAD_04_SYMBOL | Det_Peak = 25 | Det_Min = 10					
RX input level [dBm]	Nb Try	CAD [%]	RX OK [%]	PER (%)	False detect (%)
-134	10000	9944	9935	0.7	0.09

Table 22: SF11 Best Settings PER 10%

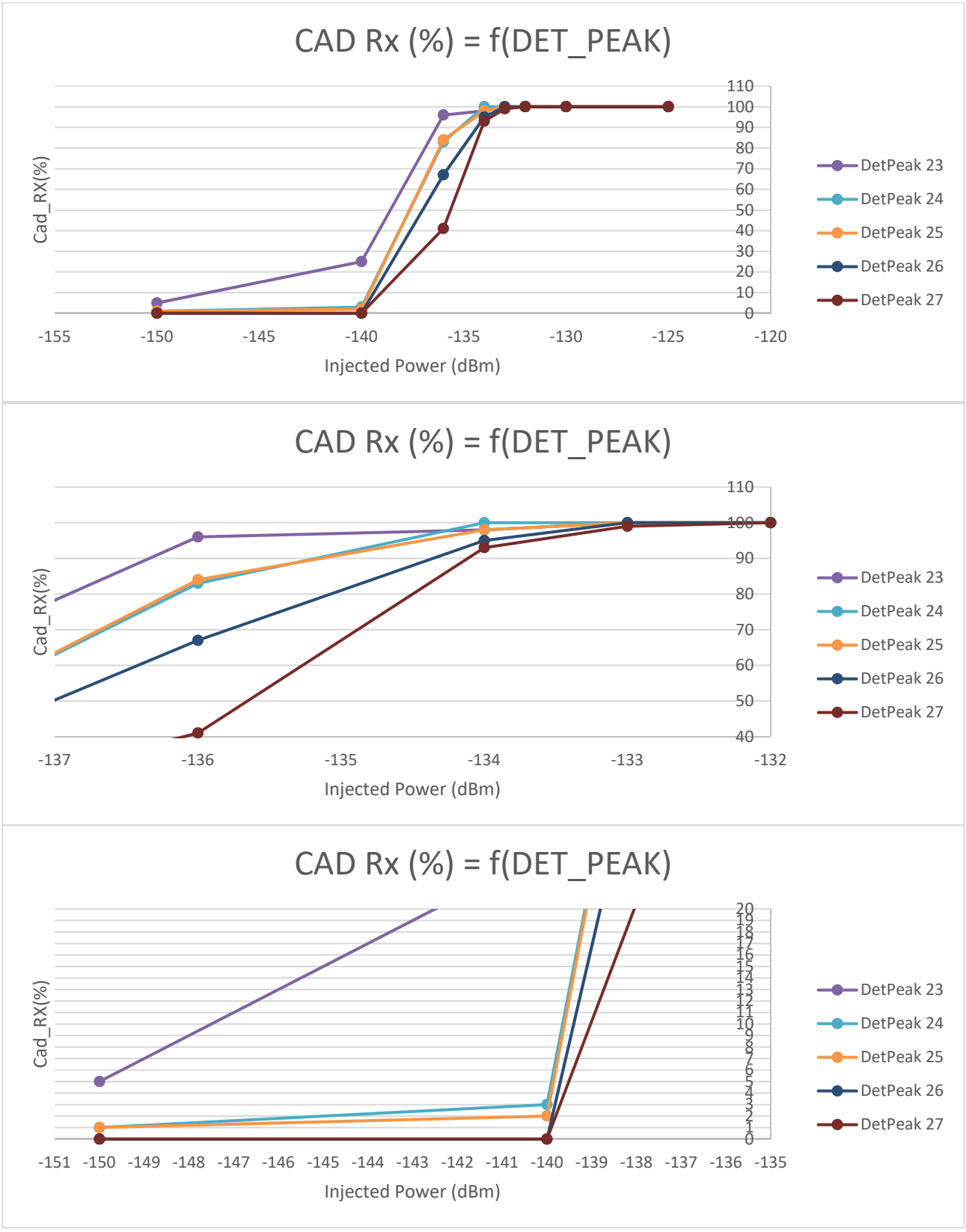

Figure 13: SF11 CAD 4 Symbols vs. DetPeak

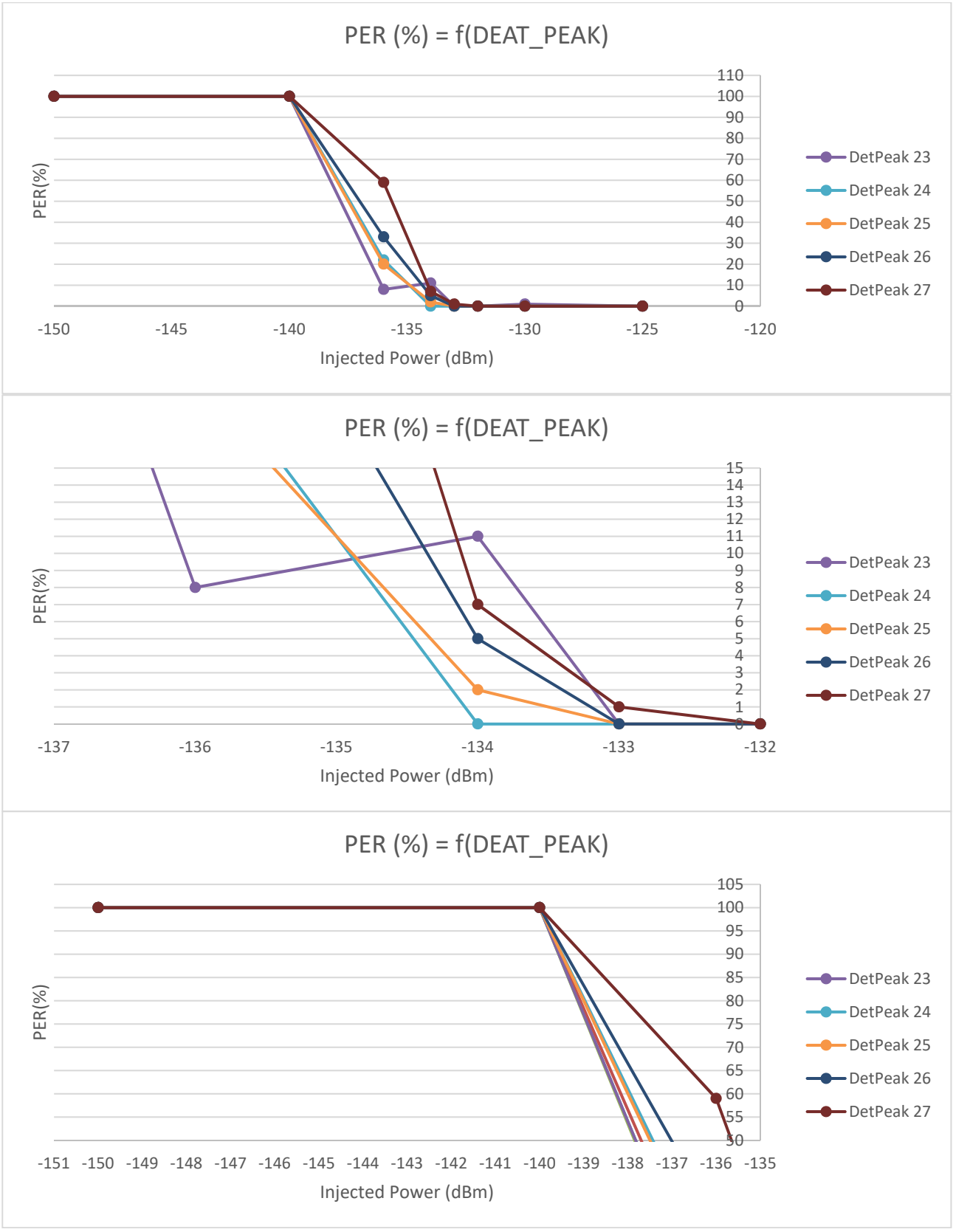

Figure 14: SF11 CAD 4 Symbols vs. DetPeak

3.1.1.6 SF12

The case SF12 is still under evaluation, this one is not treated in this Application note version, once the evaluation done this document will be updated.

3.1.2 Best Settings Using 2 Symbols

The consumption is a really important criterion, so here it is the best settings using only 2 Symbols.

Spreading Factor	Best CAD settings			CAD consumption (nAh)
	cadDetMin	*cadDetPeak*	*cadSymbolNum*	
SF7	10	22	2 Symbols	2.84
SF8	10	22	2 Symbols	5.75
SF9	10	24	2 Symbols	11.7
SF10	10	25	2 Symbols	23.86
SF11	10	26	2 Symbols	48.79

Table 23: CAD/PER Best Settings

3.1.2.1 SF7

Please refer to SF7

3.1.2.2 SF8

Please refer to SF8

3.1.2.3 SF9

CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
-120	100	100	100	100	100
-125	100	100	100	100	100
-127	100	100	100	100	100
-128	100	100	100	99	100
-129	100	100	99	100	96
-130	99	95	91	84	65
-132	88	75	61	51	37
-135	63	49	30	10	0
-140	34	21	13	2	2
OFF	45	32	17	4	0

Table 24: SF9 CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)					
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24
-120	0	0	0	0	0
-125	0	0	0	0	0
-127	0	1	0	0	0
-128	1	1	2	1	1
-129	1	0	1	2	4
-130	5	9	17	25	37
-132	68	65	76	79	87
-135	100	100	100	100	100
-140	100	100	100	100	100
OFF	100	100	100	100	100

Table 25: SF9 PER (%) = f(CAD_SYMBOL_02 cadDetPeak_n)

SF9, 860MHz, 4/5, 125 kHz 2 Symbols, CadDetPeak =24, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-120	100	0
-125	100	0
-127	100	0
-128	100	1
-129	96	4
-130	65	37
-132	37	87
-135	0	100
-140	2	100
OFF	0	100

Table 26: SF9 Best Setting 2 Symbols

Compared to the "perfect" settings (4 symbols used) the performance is slightly degraded but is still acceptable. The PER is still under 10% and the false detection rate is between 0 and 2 % with a low power signal.

	2 Symbols, CadDetPeak =24, CadDetMin=10		4 Symbols, CadDetPeak =23, CadDetMin=10	
Power (dBm)	Cad Detected (%)	PER (%)	Cad Detected (%)	PER (%)
-120	100	0	100	0
-125	100	0	100	0
-127	100	0	100	0
-128	100	1	100	0
-129	96	4	100	0
-130	65	37	93	11
-132	37	87	63	76
-135	0	100	4	100
-140	2	100	0	100
OFF	0	100	0	100

Table 27: SF9 2 Symbols vs. Best settings

3.1.2.4 SF10

CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)				
Power (dBm)	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25
-120	100	100	100	100
-125	100	100	100	100
-127	100	100	100	100
-128	100	100	99	99
-129	100	100	100	99
-130	100	100	98	96
-132	98	97	89	84
-135	71	55	8	5
-140	19	13	0	0
OFF	23	13	0	0

Table 28: SF10 CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)				
Power (dBm)	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25
-120	0	0	0	0
-125	1	0	0	0
-127	0	1	0	0
-128	3	0	1	1
-129	4	0	0	1
-130	1	0	2	4
-132	7	7	11	16
-135	90	90	92	95
-140	100	100	100	100
OFF	100	100	100	100

Table 29: SF10 PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

SF10, 868.1MHz, 4/5, 125 kHz 2 Symbols, CadDetPeak =25, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-120	100	0
-125	100	0
-127	100	0
-128	99	1
-129	99	1
-130	96	4
-132	84	16
-135	5	95
-140	0	100
OFF	0	100

Table 30: SF10 Best Settings 2 Symbols

Compared to the "perfect" settings (4 symbols used), the performance is slightly degraded but is still acceptable. The PER is still under 10% and the false detection rate is still 0% with a low power signal.

	2 Symbols, CadDetPeak =25, CadDetMin=10		4 Symbols, CadDetPeak =23, CadDetMin=10	
Power (dBm)	Cad Detected (%)	PER (%)	Cad Detected (%)	PER (%)
-120	100	0	100	0
-125	100	0	100	0
-127	100	0	97	3
-128	99	1	100	0
-129	99	1	100	0
-130	96	4	99	1
-132	84	16	86	14
-135	5	95	5	95
-140	0	100	0	100
OFF	0	100	0	100

Table 31: SF10 2 Symbols vs. Best settings

3.1.2.5 SF11

CAD Rx(%) = f(CAD_SYMBOL_04 cadDetPeak_n)									
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25	DetPeak 26	DetPeak 27	DetPeak 28
-125	100	100	100	100	100	100	100	100	100
-130	100	100	100	100	100	100	100	100	100
-132	100	100	99	100	100	99	100	100	99
-133	100	100	100	100	100	100	99	98	88
-134	100	100	100	100	98	97	86	81	67
-136	100	98	96	94	87	76	59	57	37
-140	97	84	42	26	5	6	0	0	0
OFF	89	60	33	9	3	1	0	0	0

Table 32: SF11 CAD Rx(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

PER(%) = f(CAD_SYMBOL_04 cadDetPeak_n)									
Power (dBm)	DetPeak 20	DetPeak 21	DetPeak 22	DetPeak 23	DetPeak 24	DetPeak 25	DetPeak 26	DetPeak 27	DetPeak 28
-125	0	0	0	0	0	0	0	0	0
-130	0	0	0	2	0	0	0	0	0
-132	0	0	3	0	2	1	0	0	1
-133	0	0	0	0	0	0	1	2	12
-134	2	0	10	11	13	3	14	19	33
-136	13	12	13	13	18	30	41	43	63
-140	100	100	100	100	100	100	100	100	100
OFF	100	100	100	100	100	100	100	100	100

Table 33: SF11 PER(%) = f(CAD_SYMBOL_02 cadDetPeak_n)

SF11, 868.1MHz, 4/5, 125 kHz 2 Symbols, CadDetPeak =26, CadDetMin=10		
Power (dBm)	Cad Detected (%)	PER (%)
-125	100	0
-130	100	0
-132	100	0
-133	99	1
-134	86	14
-136	59	41
-140	0	100
OFF	0	100

Table 34: SF11 Best Setting 2 Symbols

Compare to the "perfect" setting the performance is slightly degraded, PER < 10% is is now achieved at -133dBm instead of -134dBm but the false detection rate is still quite good.

	2 Symbols, CadDetPeak =26, CadDetMin=10		4 Symbols, CadDetPeak =25, CadDetMin=10	
Power (dBm)	Cad Detected (%)	PER (%)	Cad Detected (%)	PER (%)
-125	100	0	100	0
-130	100	0	100	0
-132	100	0	100	0
-133	99	1	100	0
-134	86	14	98	2
-136	59	41	84	20
-140	0	100	2	100
OFF	0	100	1	100

Table 35: SF11 2 Symbols vs. Best Settings

3.1.3 CAD & PER Conclusion

Looking at the different test results, we can see that an increase of the *cadDetPeak* value will reduce the number of false detections, as well as the CAD sensitivity. It means *cadDetPeak* should be changed with caution to avoid deteriorating the receiver performance. It is advised to change *cadDetPeak* by steps of 1.

For each spreading factor, a combination of *cadDetPeak*/ *cadDetMin* and *cadSymbolNum* is defined with good PER and low false detection.

Notes:

1. On the SX126X family, the CAD detects reliably not only on preambles but also modulated data (header and payload). Therefore, in the tests presented in the document, a small fraction of the PER is certainly due to a late preamble detection, or detection over modulated data, which therefore represents a worse case PER scenario.

2. The CAD over 1 symbol is very prone to false detection, leading to bad PER. It is therefore not recommended to use this setting.

3.2 Consumption

A really important facet of CAD is its energy consumption, as it is typically used in very low-power applications. The current is measured using a shunt as following:

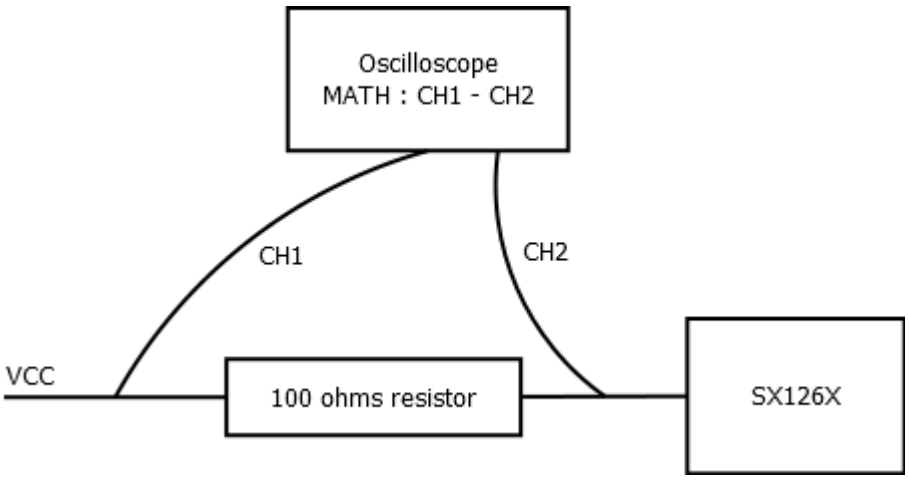

Figure 15: Current Measurement

Below is tabulated the energy consumption data for each spreading factor, depending on *cadSymbolNum*:

	SF7 BW125						
NbSymbol	Cad Time measured (ms)	Cad Time measured (Symbols)	Cad Time Theorical (ms)	Thoery/ Measured	Ampl (mV)	I (mA)	Consumption (nAh)
1	1.6439	1.61	1.024	0.62	378.13	3.78	1.73
2	2.6641	2.60	2.048	0.77	384.38	3.84	2.84
4	4.7155	4.60	4.096	0.87	384.38	3.84	5.03
8	8.8088	8.60	8.192	0.93	384.38	3.84	9.41
16	17.01	16.61	16.384	0.96	384.38	3.84	18.16

Table 36: SF7 BW125 Energy Consumption Data

Here it the consumption profile of a 2-symbol CAD, SF7 BW125 kHz:

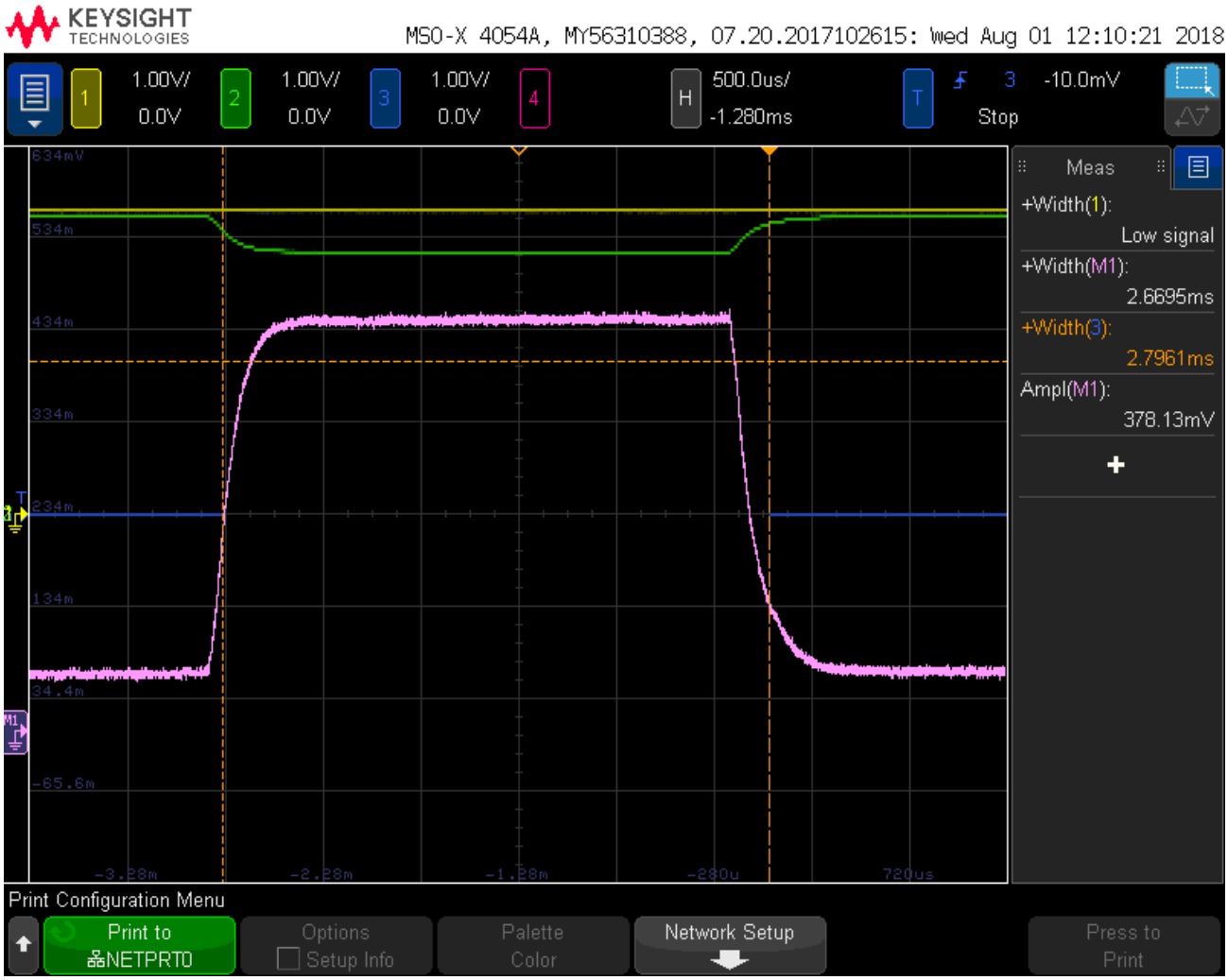

Table 37: CAD 2 Symbols SF7 BW125 kHz consumption prof

	SF8 BW125						
NbSymbol	Measured Consumption (ms)	Cad Time measured (Symbols)	Cad Time Theorical (Symbols)	Thoery/Measured	Ampl (mV)	I (mA)	Consumption (nAh)
1	3.3384	1.63	2.048	0.61	384.38	3.84	3.56
2	5.3872	2.63	4.096	0.76	384.38	3.84	5.75
4	9.4806	4.63	8.192	0.86	384.38	3.84	10.12
8	17.676	8.63	16.384	0.93	384.38	3.84	18.87
16	34.057	16.63	32.768	0.96	384.38	3.84	36.36

Table 38: SF8 BW125 BW125 Energy Consumption Data

	SF9 BW125						
NbSymbol	Measured Consumption (ms)	Cad Time measured (Symbols)	Theorical (ms)	Thoery/Measured	Ampl (mV)	I (mA)	Consumption (nAh)
1	6.8625	1.68	4.096	0.60	384.38	3.84	7.33
2	10.955	2.67	8.192	0.75	384.38	3.84	11.70
4	19.145	4.67	16.384	0.86	384.38	3.84	20.44
8	35.531	8.67	32.768	0.92	384.38	3.84	37.94
16	68.29	16.67	65.536	0.96	384.38	3.84	72.91

Table 39: SF9 BW125 BW125 Energy Consumption Data

	SF10 BW125						
NbSymbol	Measured Consumption (ms)	Cad Time measured (Symbols)	Theorical (ms)	Thoery/Measured	Ampl (mV)	I (mA)	Consumption (nAh)
1	14.156	1.73	8.192	0.58	384.38	3.84	15.11
2	22.345	2.73	16.384	0.73	384.38	3.84	23.86
4	38.732	4.73	32.768	0.85	384.38	3.84	41.36
8	71.496	8.73	65.536	0.92	384.38	3.84	76.34
16	137.03	16.73	131.072	0.96	384.38	3.84	146.31

Table 40: SF10 BW125 BW125 Energy Consumption Data

	SF11 BW125						
NbSymbol	Measured Consumption (ms)	Cad Time measured (Symbols)	Theorical (ms)	Thoery/Measured	Ampl (mV)	I (mA)	Consumption (nAh)
1	29.26	1.79	16.384	0.56	384.38	3.84	31.24
2	45.64	2.79	32.768	0.72	384.38	3.84	48.73
4	78.409	4.79	65.536	0.84	384.38	3.84	83.72
8	143.95	8.79	131.072	0.91	384.38	3.84	153.70
16	275.02	16.79	262.144	0.95	384.38	3.84	293.64

Table 41: SF11 BW125 BW125 Energy Consumption Data

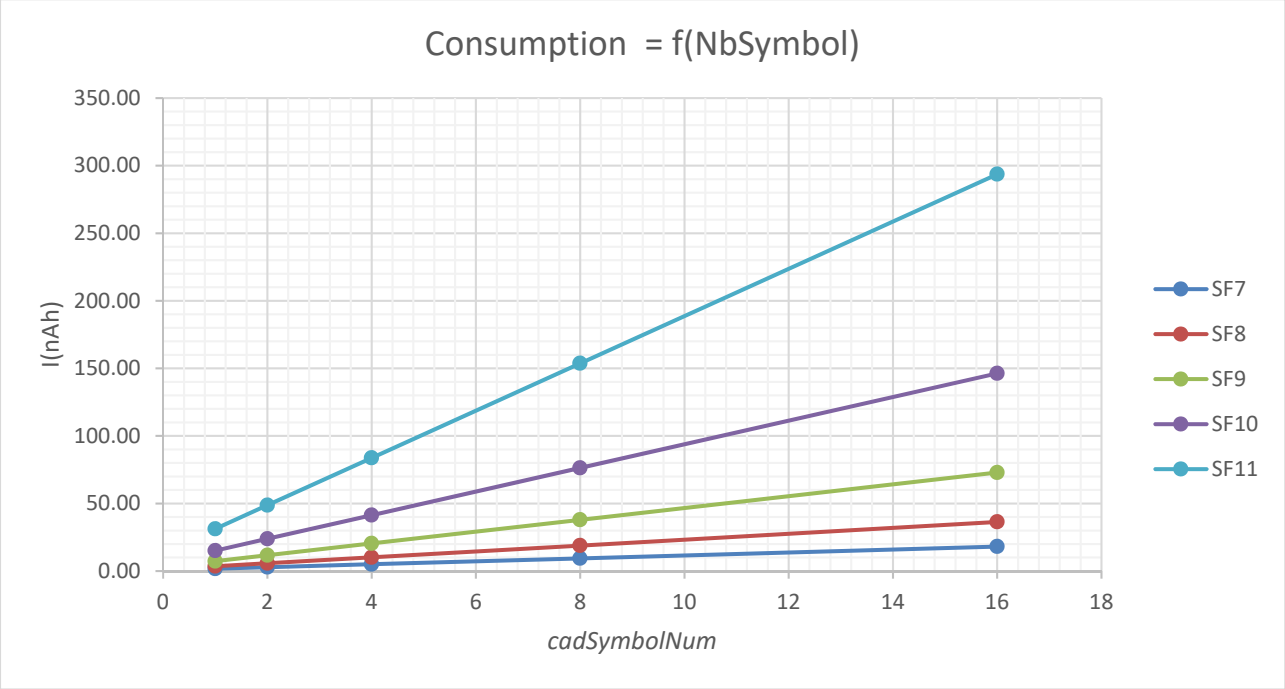

Figure 16: Consumption = f(*cadSymbolNum*)

3.2.1 Consumption Conclusion

As anticipated, the more symbols are used, the more the energy consumption will be. Up to 4 symbols, SF7/8/9 remain quite low power, but for higher spreading factors, system current consumption should be carefully looked into to save energy.

4. Revision History

Version	Date	Modifications
1.0	November 2018	First Release

5. Glossary

BW	BandWidth
CAD	Channel Activity Detection
DUT	Device Under Test
LoRa®	LOng RAnge modulation technique
LoRaWAN™	LoRa® low power Wide Area Network protocol
PSD	Power Spectral Density
RF	Radio-Frequency
BW	BandWidth
TX	Transmitter
RX	Receiver

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