Application Note AN1200.73:

SX126x/LR11xx

SIGFOX® Modulation

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1 Introduction

The SX1261/2 and LR11xx transceivers have capabilities that facilitate data transmission using BPSK modulation.

1.1 Purpose of This Document

This document explains how to transmit data using the BPSK (Binary Phase-Shift Keying) modulator implemented in the SX1261/62 and the LR11xx transceivers. BPSK and Sigfox® (Differential Binary Phase-Shift Keying) modulations are simple digital modulation schemes where the phase positions (0 or Pi radians) are used to encode a binary value (0 or 1). For the BPSK modulation, the phase itself represents a binary value (0 or 1) while in the case of the Sigfox modulation described here, a binary value of zero is represented by a change in phase, and a binary value of one is represented by an unchanging phase.

BPSK modulation is implemented in the hardware, and Sigfox is implemented via some software preprocessing and the BPSK hardware modulator.

1.2 Scope of This Document

It is recommended to read this document in conjunction with the following resources:

- Transceiver drivers embedding Sigfox support:
  - SX126x: https://github.com/Lora-net/sx126x_driver/releases/tag/v2.2.0
  - LR11xx: https://github.com/Lora-net/SWDR001/releases/tag/v2.3.0

1.3 Disclaimer

Any code or code snippet provided in this application note is provided as an example on an “as is” basis. The user must ensure that the settings are correct to meet their required protocol/certification tests. Semtech is not liable for any performance issues or field returns related to BPSK modulation support.

2 Sigfox Library

The Sigfox library provides utilities to convert a BPSK payload to Sigfox. This makes it possible to recover the payload when there is a phase error that cannot be determined by the receiver.

The Sigfox library is available here:

https://github.com/Lora-net/SWSD003/tree/master/libs/smtc_dbpsk_driver/src

2.1 API Functions

The Sigfox library code provides the following principal API functions:

Table 1: API Functions

Function	Description
smtc_dbpsk_encode_buffer ()	Perform differential encoding for DBPSK modulation.
smtc_dbpsk_get_pld_len_in_bytes()	Given the length of a BPSK frame, in bytes, calculate the space necessary to hold the frame after differential encoding, in bytes.
smtc_dbpsk_get_pld_len_in_bits()	Given the length of a BPSK frame, in bits, calculate the space necessary to hold the frame after differential encoding, in bits.

2.2 Sigfox Library Usage

1. Add the following directories to your C or C++ compiler include path:

lib\sigfox_dbpsk_driver\src

2. Include the following in your application source code files:

#include “smtc_dbpsk.h”

3. Compile and link your software with:

smtc_dbpsk.c

3 Sigfox Code Example

Sigfox example code is available:

- For LR11xx: https://github.com/Lora-net/SWSD003/tree/master/lr11xx/apps/sigfox
- For SX126x: https://github.com/Lora-net/SWSD003/tree/master/sx126x/apps/sigfox

4 Sending BPSK Packets With SX126x

Follow these steps to use the BPSK modulator on the SX126x:

1. Select the BPSK packet type by executing:

   ```
   sx126x_set_pkt_type( context, SX126X _PKT_TYPE_BPSK );
   ```

2. Set the RF frequency, PA configuration, TX params, DioIrqParams, and TCXO configuration as you would for any other modulation. For further information, please see the transceiver data sheet.

3. Set the BPSK modulation params (bit rate and modulation shaping filter) by executing:

   ```
   sx126x_set_bpsk_mod_params( context, &mod_params );
   ```

   Note that only 100bps and 600bps are supported. The modulation shaping filter is a raised-cosine filter with a BT of 0.7.

4. Prepare the packet in a data array by concatenating the separate parts of the packet (preamble, sync word, device id, application payload, CRC, etc.).

   If the packet is meant to be transmitted using Sigfox, then execute:

   ```
   dbpsk_encode_buffer( data_in, bpsk_pld_len_in_bits, data_out );
   ```

   to represent zeros as phase changes and to represent ones as unchanging phase. One additional bit of data is added to keep track of the phase, and one additional bit is added to the end of the data to make it possible to slightly extend the last bit. This function assumes that *data_out* is large enough to store *bpsk_pld_len_in_bits* + 2 bits of data.

5. Set the BPSK packet params (payload length and ramp tuning parameters) by executing:

   ```
   sx126x_set_bpsk_pkt_params( context, &pkt_params_bpsk );
   ```

   For the ramp tuning parameters, use one of these:

   - *SIGFOX_DBPSK_RAMP_UP_TIME_100_BPS* / *SIGFOX_DBPSK_RAMP_DOWN_TIME_100_BPS*
   - *SIGFOX_DBPSK_RAMP_UP_TIME_600_BPS* / *SIGFOX_DBPSK_RAMP_DOWN_TIME_600_BPS*

   Note that the physical packet length is specified both in bytes (indicating total storage space), and in bits, since the latter is not necessarily a multiple of 8. If the physical payload was processed with *dbpsk_encode_buffer*, above, then use the following two API functions to get these packet lengths:

   - `dbpsk_get_pld_len_in_bytes( bpsk_pld_len_in_bits )`
   - `dbpsk_get_pld_len_in_bits( bpsk_pld_len_in_bits )`

6. To write the physical payload, execute:

   ```
   sx126x_write_buffer( context, 0, buffer, length );
   ```

7. To start transmission, execute:

   ```
   sx126x_set_tx( context, timeout );
   ```

5 Sending BPSK Packets With LR11xx

Follow these steps to use the BPSK modulator on the LR11xx:

1. Select the BPSK packet type by executing:

   ```
   lr11xx_radio_set_pkt_type( context, LR11XX_RADIO_PKT_TYPE_BPSK );
   ```

2. Set the RF frequency, PA configuration, TX params, DioIrqParams, and TCXO configuration as you would for any other modulation. For further information, please see the transceiver user manual.

3. Set the BPSK modulation params (bit rate and modulation shaping filter) by executing:

   ```
   lr11xx_radio_set_bpsk_mod_params( context, &mod_params );
   ```

   Note that only 100bps and 600bps are supported. The modulation shaping filter is a raised-cosine filter with a BT of 0.7.

4. Prepare the packet in a data array by concatenating the separate parts of the packet (preamble, sync word, device id, application payload, CRC, etc.).

   If the packet is meant to be transmitted using Sigfox, then execute:

   ```
   dbpsk_encode_buffer( data_in, bpsk_pld_len_in_bits, data_out );
   ```

   to represent zeros as phase changes and to represent ones as unchanging phase. One additional bit of data is added to keep track of the phase, and one additional bit is added to the end of the data to make it possible to slightly extend the last bit. This function assumes that *data_out* is large enough to store *bpsk_pld_len_in_bits* + 2 bits of data.

5. Set the BPSK packet params (payload length and ramp tuning parameters) by executing:

   ```
   lr11xx_radio_set_bpsk_pkt_params( context, &pkt_params_bpsk );
   ```

   For the ramp tuning parameters, use either:

   - *SIGFOX_DBPSK_RAMP_UP_TIME_100_BPS / SIGFOX_DBPSK_RAMP_DOWN_TIME_100_BPS*
   - *SIGFOX_DBPSK_RAMP_UP_TIME_600_BPS / SIGFOX_DBPSK_RAMP_DOWN_TIME_600_BPS*

   Note that the physical packet length is specified both in bytes (indicating total storage space), and in bits, since the latter is not necessarily a multiple of 8. If the physical payload was processed with *dbpsk_encode_buffer*, above, then use the following two API functions to get these packet lengths:

   - `dbpsk_get_pld_len_in_bytes( bpsk_pld_len_in_bits )`
   - `dbpsk_get_pld_len_in_bits( bpsk_pld_len_in_bits )`

6. To write the physical payload, execute:

   ```
   lr11xx_regmem_write_buffer8( context, buffer, length );
   ```

7. To start transmission, execute:

   ```
   lr11xx_radio_set_tx( context, timeout );
   ```

6 Sigfox Compliance

The Sigfox Radio Signal Analyzer tool was used to perform all the following tests.

All tests were done at ambient temperature, with the transceiver powered by the Nucleo board.

The transceiver PA ramp time was set to 200us, with 40dB of attenuation placed at the input of the Sigfox Radio Signal Analyzer tool.

When a TCXO was present, it was powered at 1.8V by the transceiver, with a startup time of 150ms.

In the Sigfox Radio Signal Analyzer tool, all three oscillator accuracy parameters were set to 5ppm.

The payload that was sent for these tests was 'sample1', found in the Sigfox payload samples, below:

```
// data = =01
const uint8_t sample0[] = { 0xaa, 0xaa, 0xa0, 0x8d, 0x01, 0x05, 0x98, 0xba,
                            0xdc, 0xfe, 0x01, 0x9a, 0x09, 0xfe, 0x04 };
// data = 0123
const uint8_t sample1[] = { 0xaa, 0xaa, 0xa3, 0x5f, 0x81, 0x3c, 0x98, 0xba,
                            0xdc, 0xfe, 0x01, 0x23, 0xea, 0xd3, 0xe1, 0xdb,
                            0xd4, 0xf0 };
// data = 0123456789
const uint8_t sample2[] = { 0xaa, 0xaa, 0xa6, 0x11, 0xc1, 0x3d, 0x98, 0xba,
                            0xdc, 0xfe, 0x01, 0x23, 0x45, 0x67, 0x89, 0x11,
                            0xe3, 0x3d, 0x2e, 0x3e, 0xf9, 0x28 };
// data = 0123456789ABCDEF01
const uint8_t sample3[] = { 0xaa, 0xaa, 0xa9, 0x4c, 0xc1, 0x3e, 0x98, 0xba,
                            0xdc, 0xfe, 0x01, 0x23, 0x45, 0x67, 0x89, 0xab,
                            0xcd, 0xef, 0x01, 0xef, 0xeb, 0x05, 0x5f, 0xc6,
                            0x91, 0x08 };
```

6.1 General Compliance Notes

The following tests are known to either fail or be inconclusive.

All other executed tests pass, as can be seen in the Verdict sections of the measurement results in Sections 6.2 to 0.

6.1.1 PRS-RFP-004, Static Frequency Tolerance

4	[PRS-RFP-004]	Static Frequency Tolerance		Vnom	-20 ppm	20 ppm	0.331748 ppm	10.3317 ppm	INCONCLUSIVE	Declared Aging for 5 years : 5.00...

Specification description

UUT carrier frequency (absolute value) must be at +/- 20ppm for operational bands.

Temperature Frequency tolerance added to Aging frequency tolerance and Static Frequency Tolerance

(static imprecision of the UUT) must be less or equal to +/- 20ppm during all the product life.

The above must be verified by taking into consideration the temperature and aging properties of the TCXO.

6.1.2 PRS-RFP-010, Sigfox Modulation

7	[PRS-RFP-010]	DBPSK Modulation		Vnom					FAILED	Wrong payload received -

This test fails because the test code does not know what payload is expected by the RSA tool. The Sigfox Test Mode software is proprietary.

6.1.3 PRS-RFP-011, Phase Measurement

10	[PRS-RFP-011]	Phase Measurement		Vnom	10 °	30 °	0.798708 °	3.43242 °	PASSED	

With the current version of the RSA tool, the phase test sometimes fails (See Section 6.3.12). On the phase plot, one notices relatively significant phase change very early in the measurement. It is possible that the Sigfox dongle is not sufficiently reliable for these tests, as mentioned in Sigfox documentation.

6.1.4 PRS-RFP-016, Power Spectral Density For Class 0 and 1

25	[PRS-RFP-016]	Power Spectral Density For Class 0 And 1		Vnom					INCONCLUSIVE	

With the current version of the Sigfox Radio Signal Analyzer (RSA) and the Sigfox dongle used for these tests, the power spectral density test is inconclusive. It is possible that the Sigfox dongle is not sufficiently reliable for these tests, as mentioned in Sigfox documentation.

6.1.5 PRS-RFP-017, Power Spectral Density For Class 0 and 1

28	[PRS-RFP-017]	Power Spectral Density For Class 2 And 3		Vnom					INCONCLUSIVE	

This test is inconclusive because class 2 and class 3 are not tested.

6.1.6 PRS-RFP-018

31	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vnom	-30 Hz/s	30 Hz/s		18.4304 Hz/s	PASSED	

The current version of the RSA does not appear to accurately measure the drift for RC2 cases, and the plots are incomplete. The verdict may contain incorrect information for the RC2 cases.

6.1.7 PRS-RFP-070

63	[PRS-RFP-070]	Modulated Conducted Output Power		Vnom			-28.3067 dBm	-28.2999 dBm	INCONCLUSIVE	

The Sigfox dongle is not appropriate for making precise power measurements. A 40dB attenuator and approximately 1dB of additional attenuation were used when taking these measurements.

6.2 LR11xxMB1DJS Measurement Results, TCXO, Radio Configuration RC1

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

6.2.1 Device Configuration

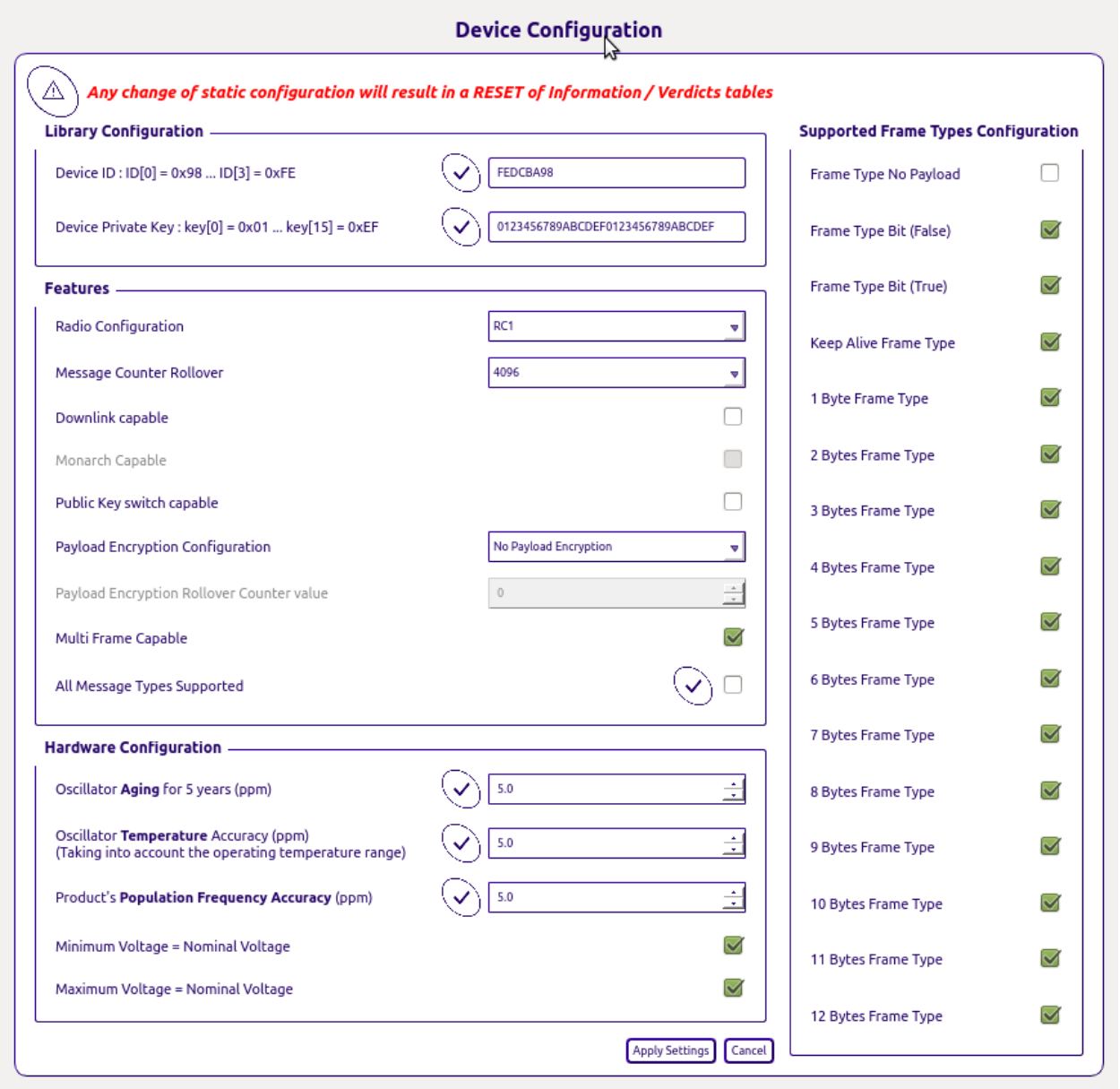


Figure 1: LR11xxMB1DJS RC1 Device Configuration

6.2.2 FFT

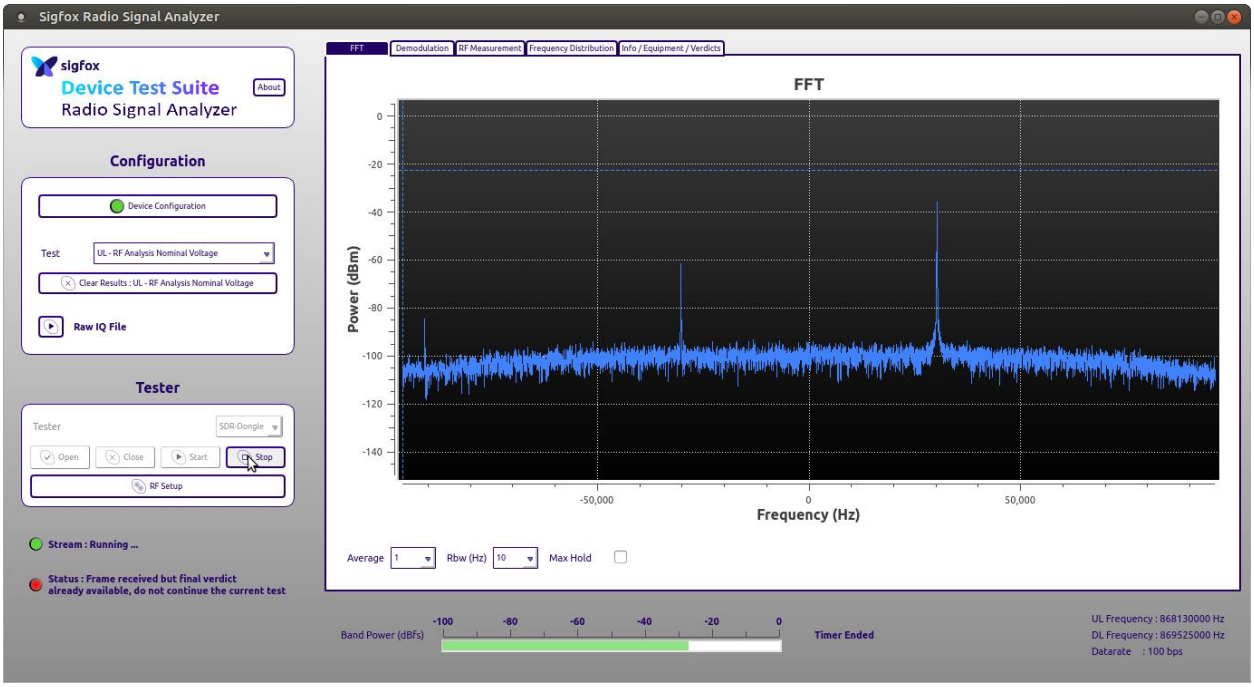


Figure 2: LR11xxMB1DJS RC1 FFT

6.2.3 Demodulation

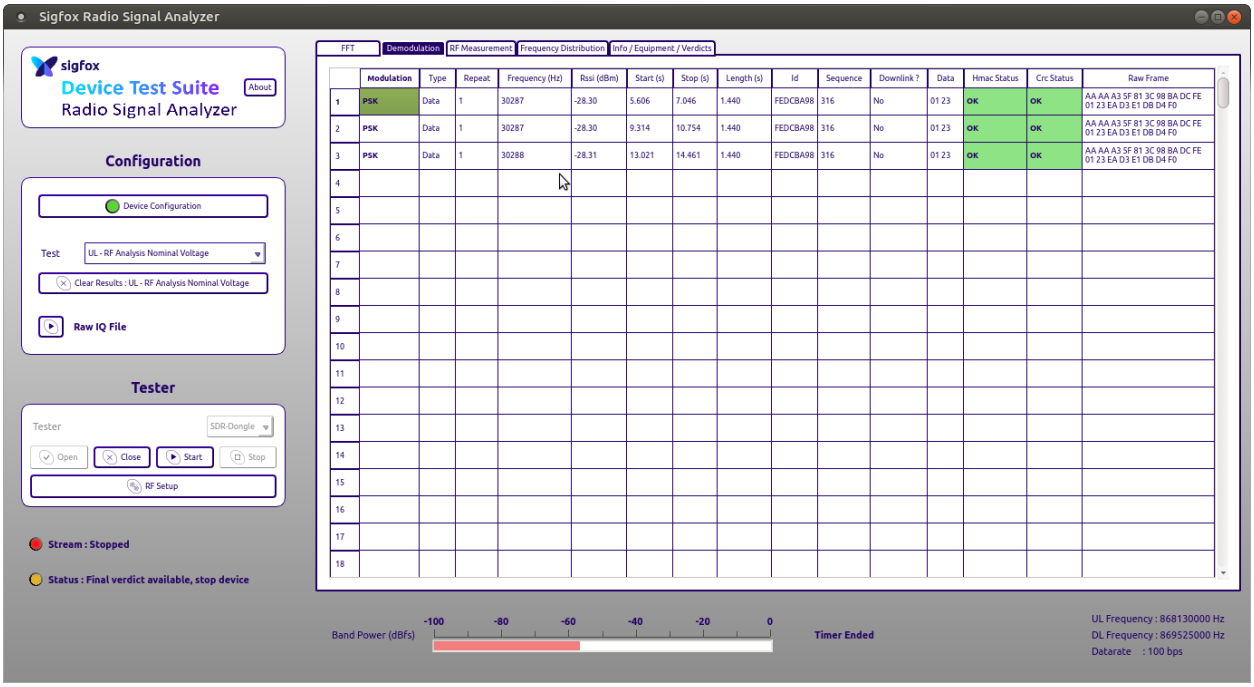


Figure 3: LR11xxMB1DJS RC1 Demodulation

6.2.4 Power Spectral Density for Class 0 & 1

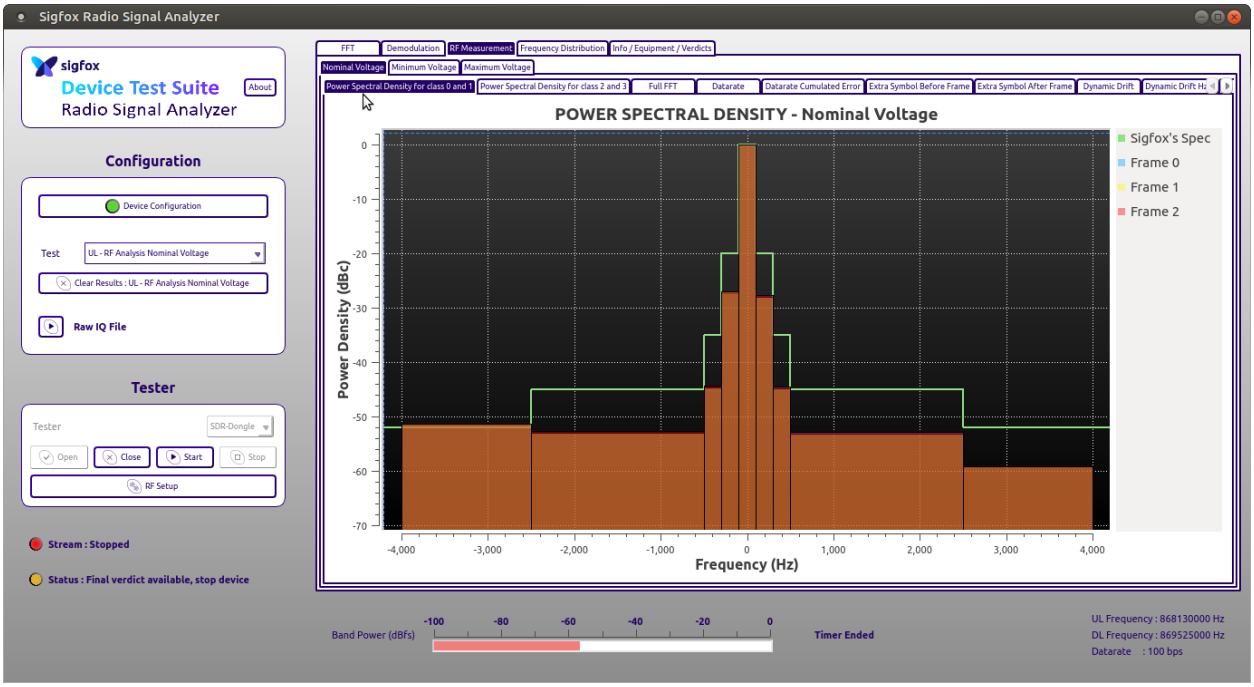


Figure 4: LR11xxMB1DJS RC1 Power Spectral Density for Class 0 & 1

6.2.5 Full FFT

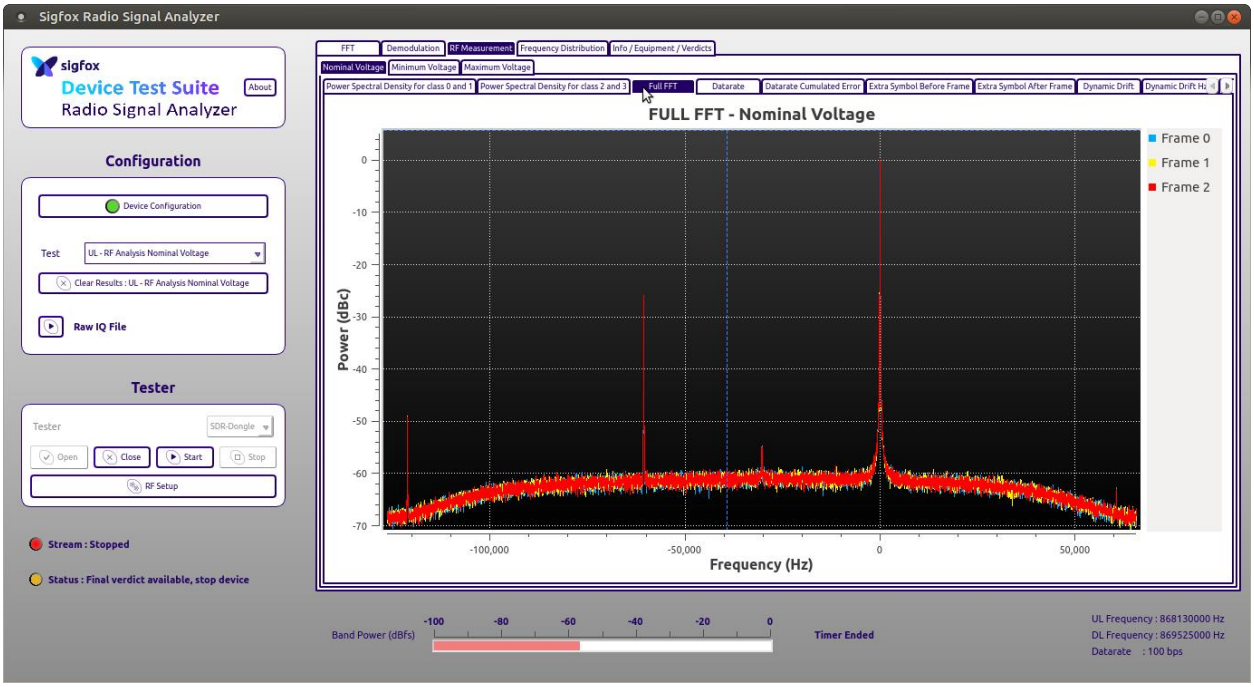


Figure 5: LR11xxMB1DJS RC1 Full FFT

6.2.6 Data Rate

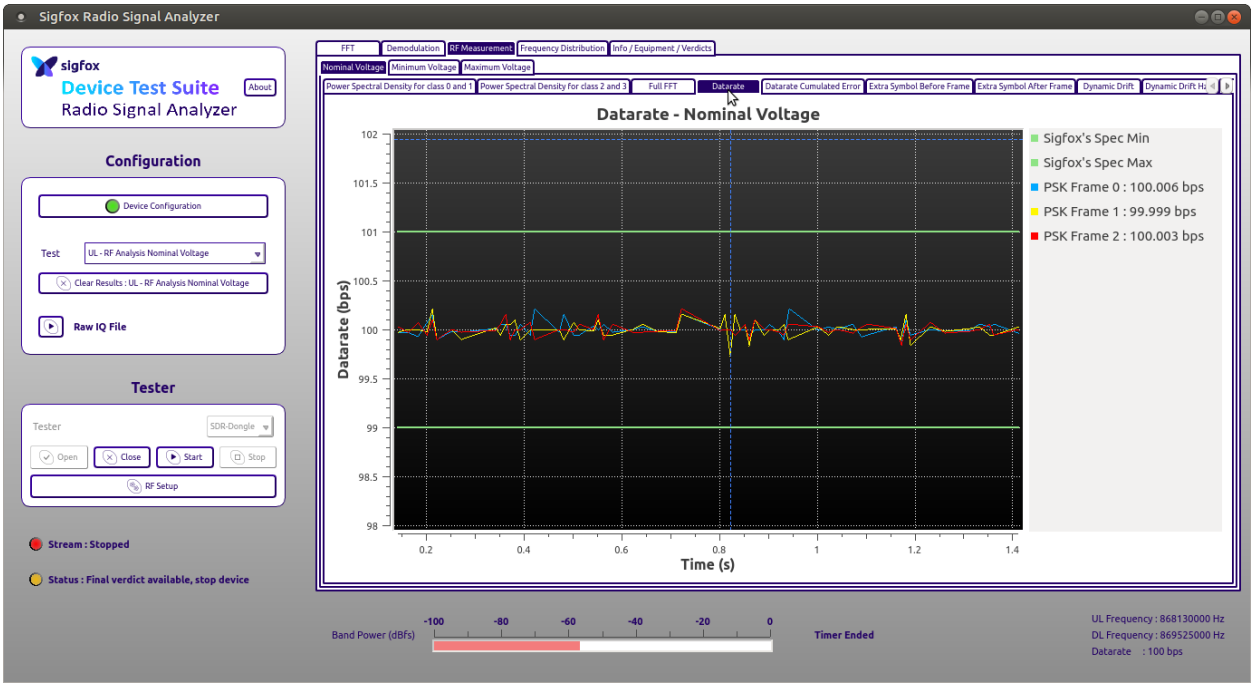


Figure 6: LR11xxMB1DJS RC1 Data Rate

6.2.7 Data Rate Cumulated Error

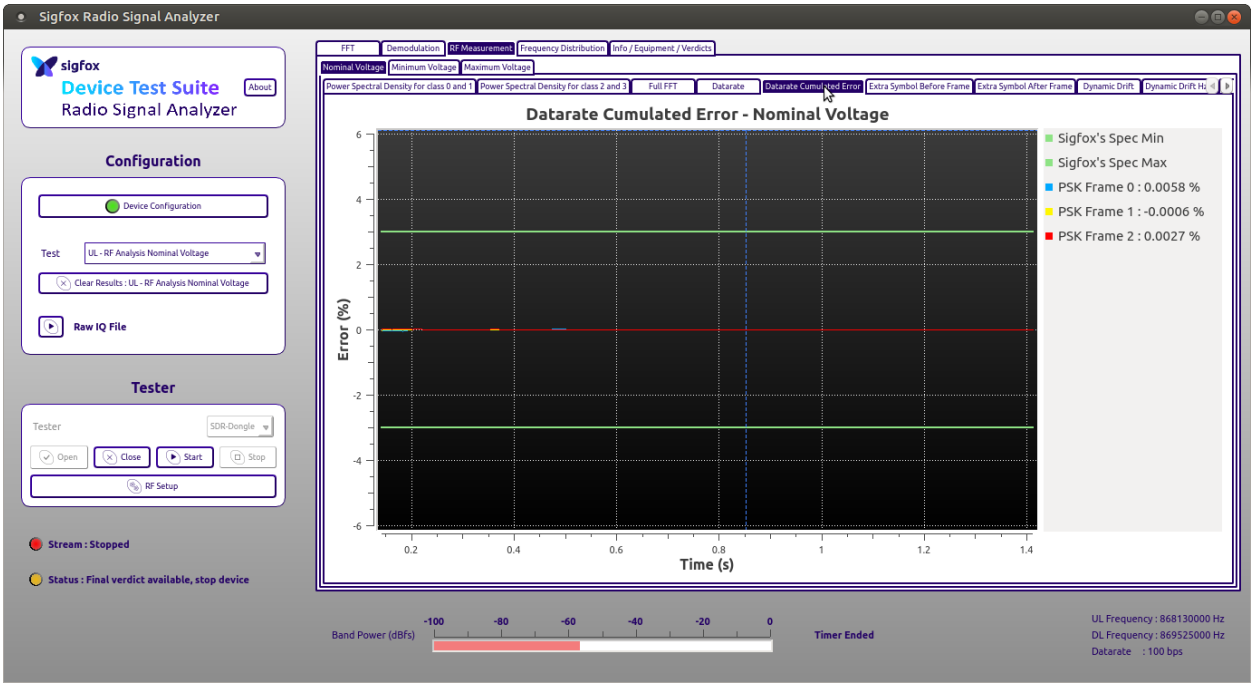


Figure 7: LR11xxMB1DJS RC1 Data Rate Cumulated Error

6.2.8 Extra Symbol Before Transmission

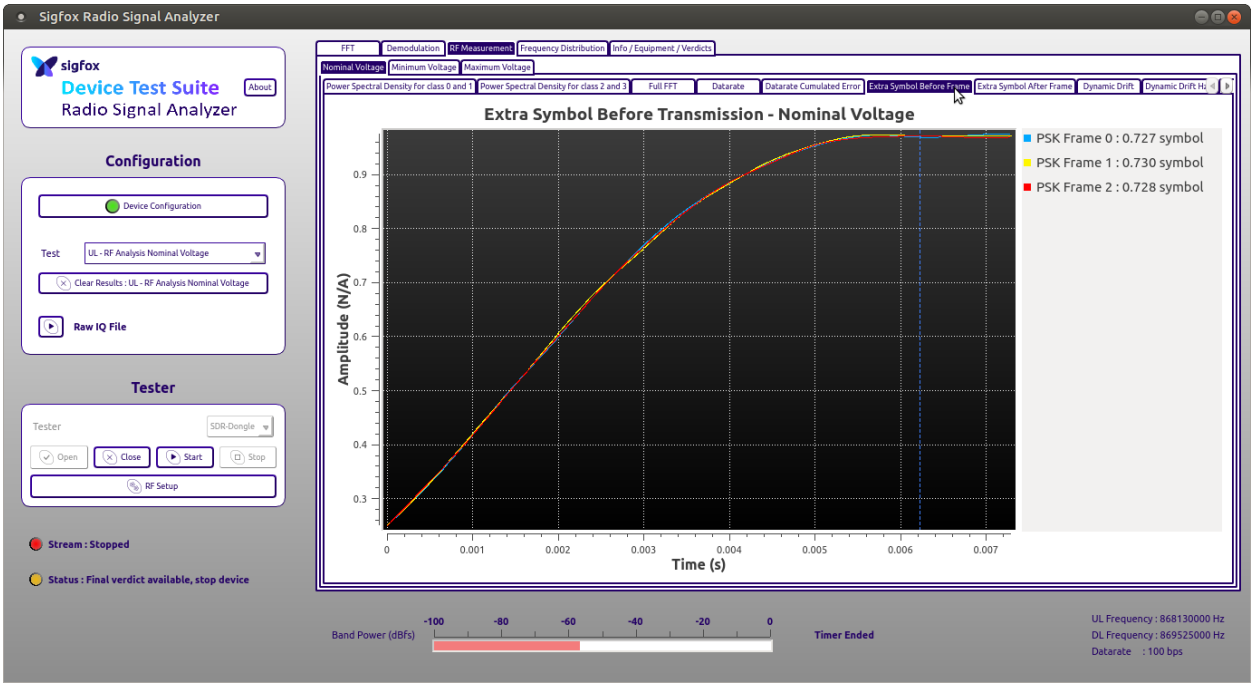


Figure 8: LR11xxMB1DJS RC1 Extra Symbol Before Transmission

6.2.9 Extra Symbol After Transmission

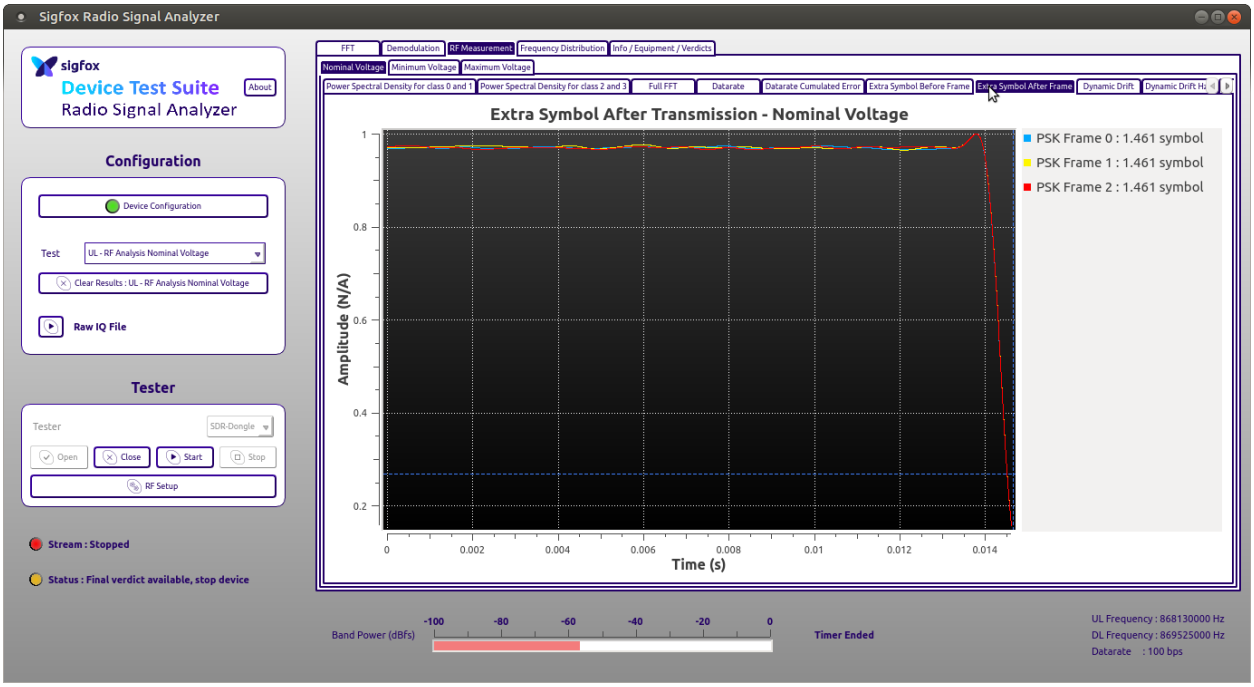


Figure 9: LR11xxMB1DJS RC1 Extra Symbol After Transmission

6.2.10 Dynamic Drift

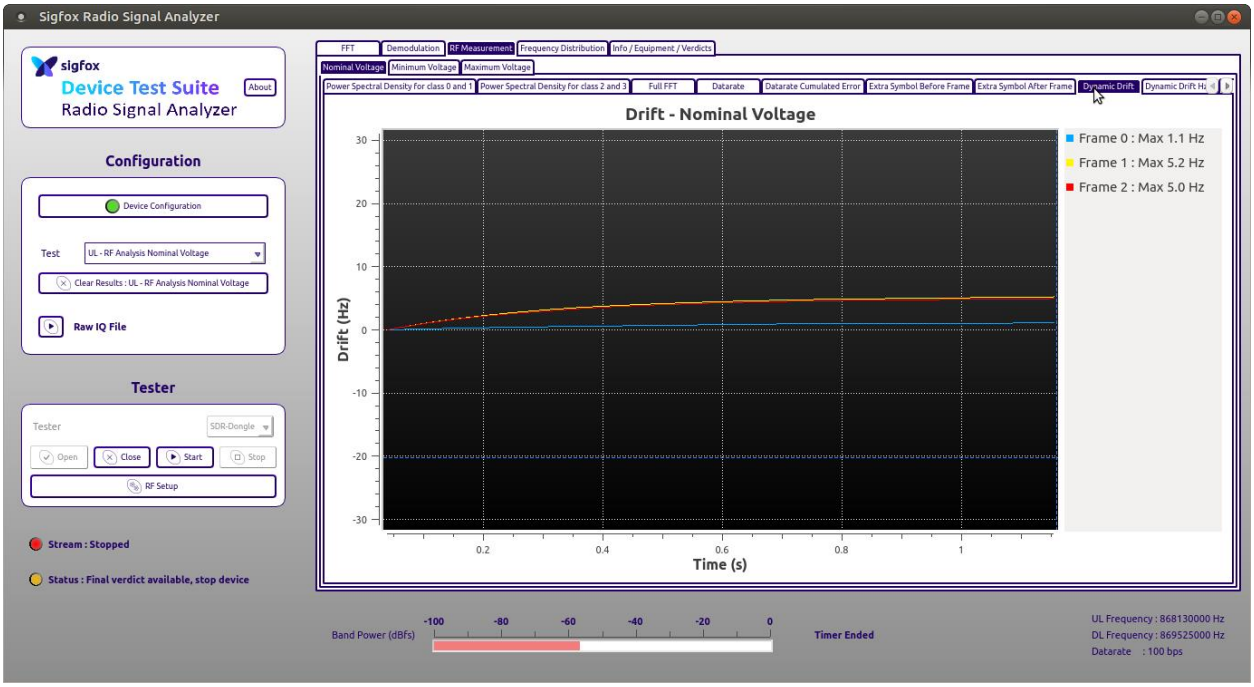


Figure 10: LR11xxMB1DJS RC1 Dynamic Drift

6.2.11 Dynamic Drift per Second

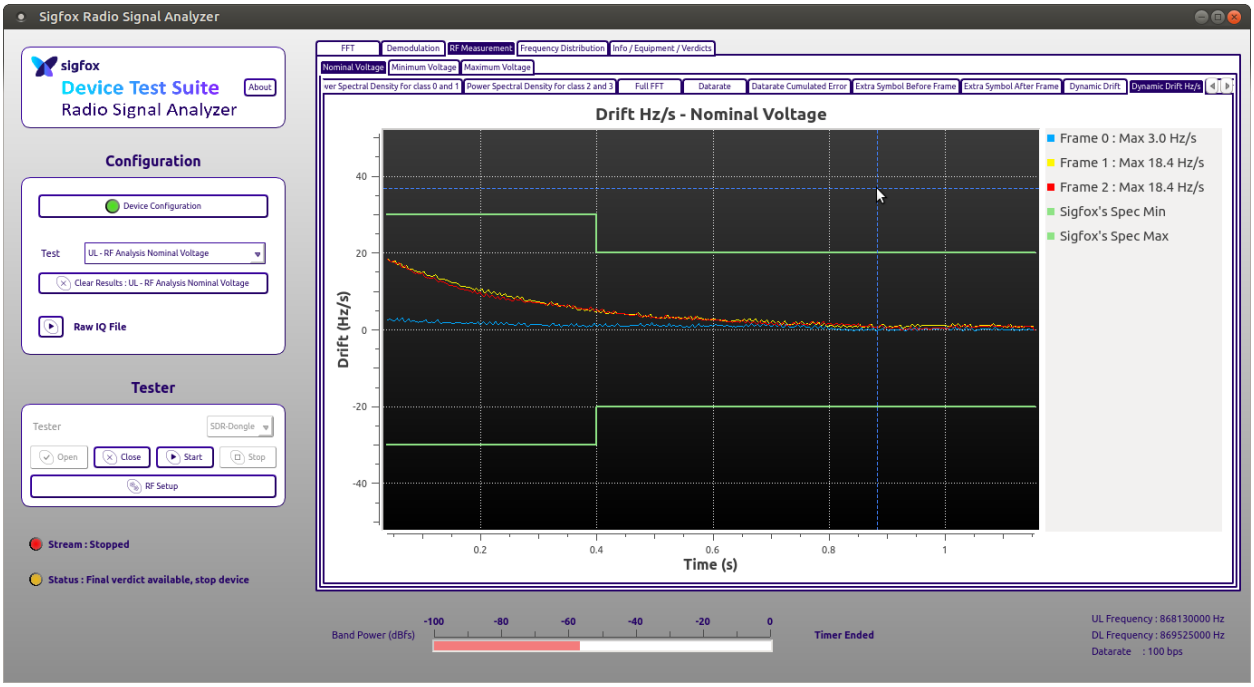


Figure 11: LR11xxMB1DJS RC1 Dynamic Drift per Second

6.2.12 Phase

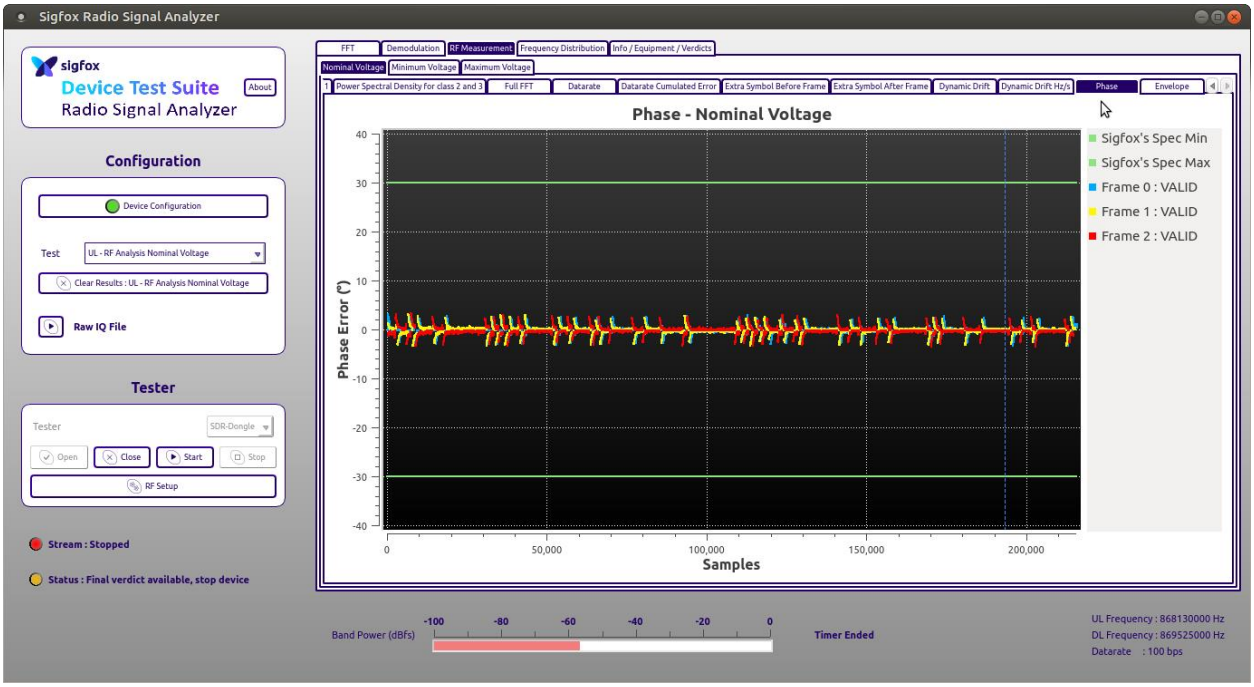


Figure 12: LR11xxMB1DJS RC1 Phase

6.2.13 Envelope

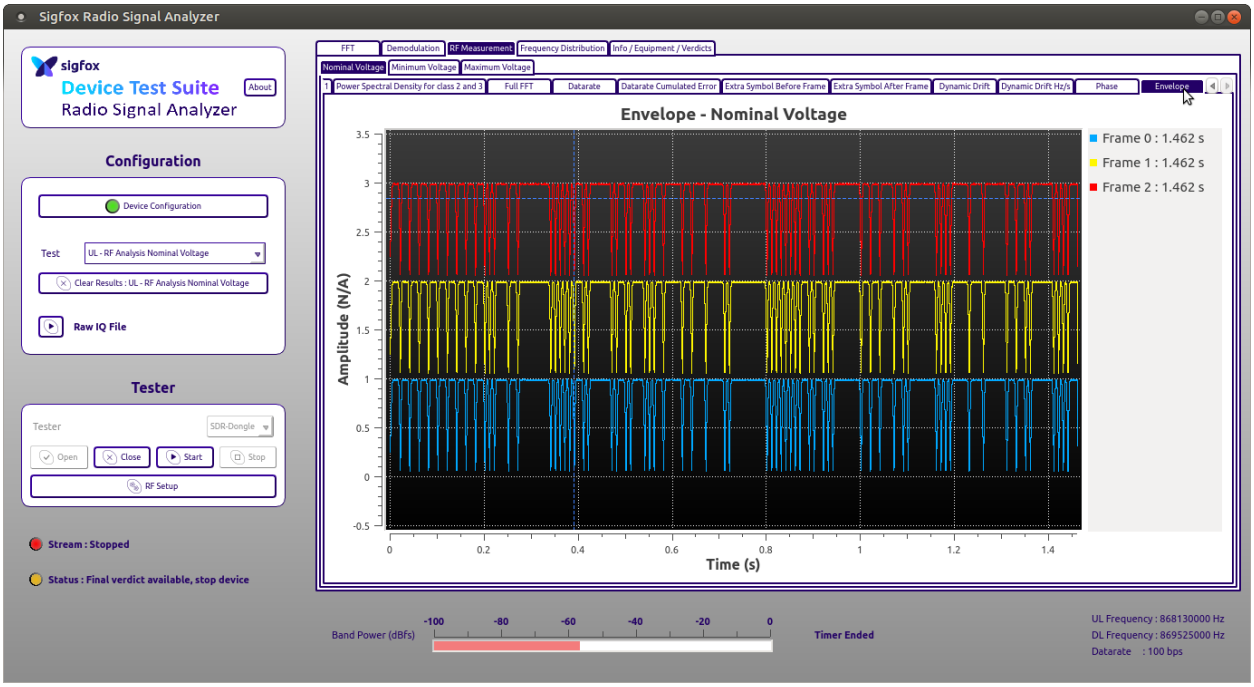


Figure 13: LR11xxMB1DJS RC1 Envelope

6.2.14 Verdict

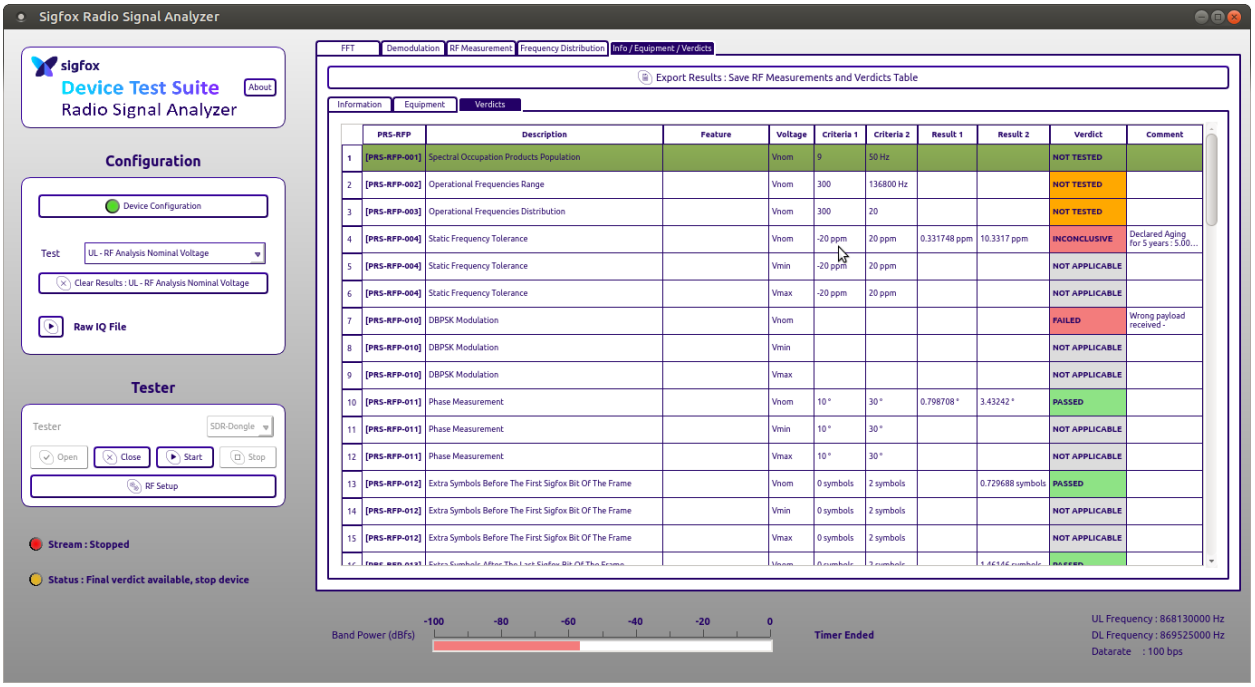


Figure 14: LR11xxMB1DJS RC1 Verdict page 1

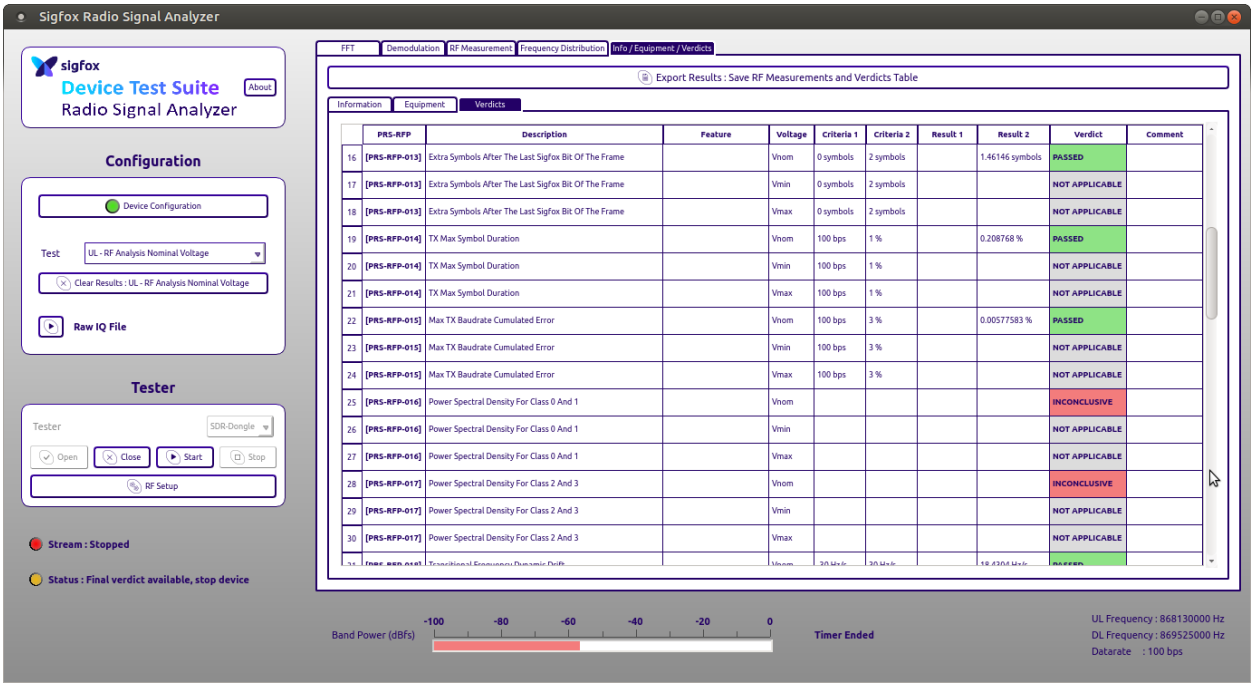
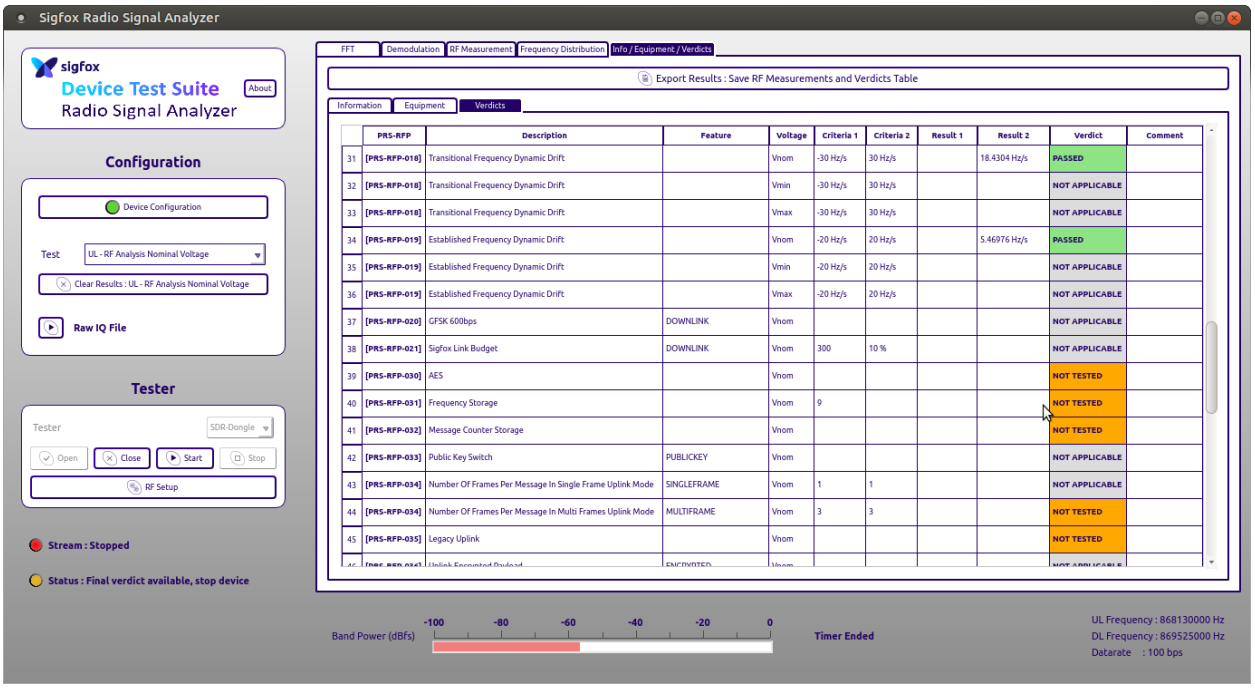
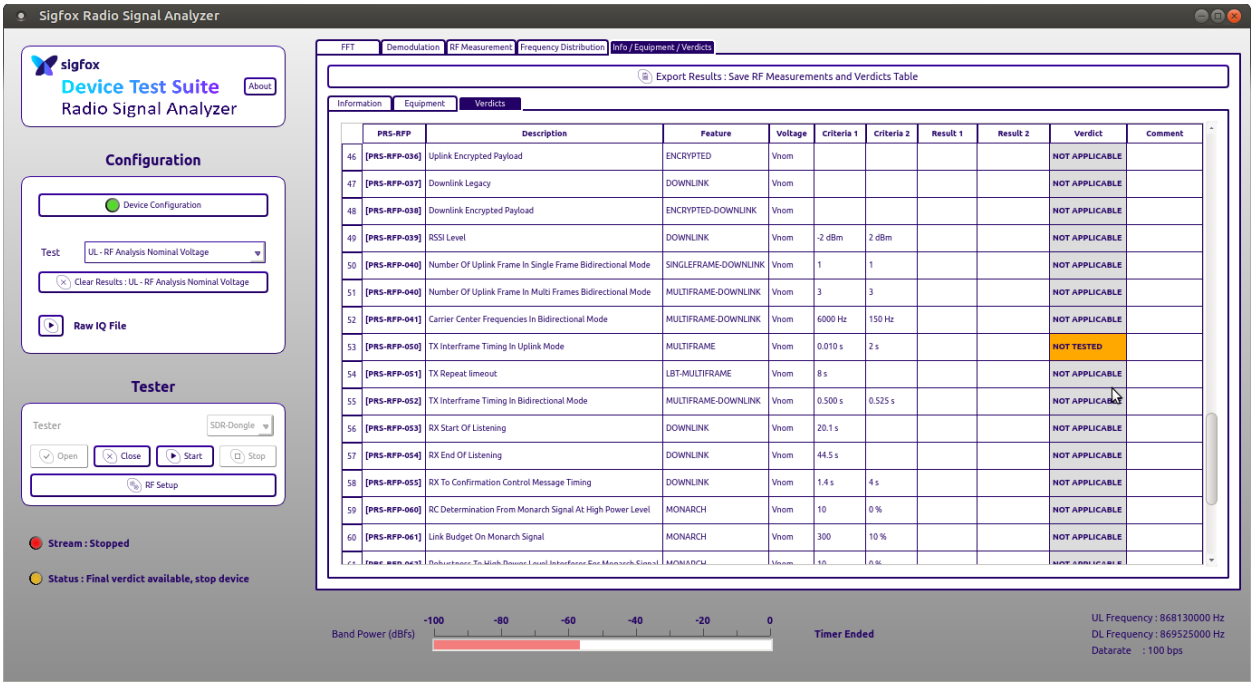


Figure 15: LR11xxMB1DJS RC1 Verdict page 2



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
31	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vnom	-30 Hz/s	30 Hz/s		18.4304 Hz/s	PASSED	
32	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmin	-30 Hz/s	30 Hz/s			NOT APPLICABLE	
33	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmax	-30 Hz/s	30 Hz/s			NOT APPLICABLE	
34	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vnom	-20 Hz/s	20 Hz/s		5.46976 Hz/s	PASSED	
35	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmin	-20 Hz/s	20 Hz/s			NOT APPLICABLE	
36	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmax	-20 Hz/s	20 Hz/s			NOT APPLICABLE	
37	[PRS-RFP-020]	GFSK 600bps	DOWNLINK	Vnom					NOT APPLICABLE	
38	[PRS-RFP-021]	Sigfox Link Budget	DOWNLINK	Vnom	300	10 %			NOT APPLICABLE	
39	[PRS-RFP-030]	AES		Vnom					NOT TESTED	
40	[PRS-RFP-031]	Frequency Storage		Vnom	9				NOT TESTED	
41	[PRS-RFP-032]	Message Counter Storage		Vnom					NOT TESTED	
42	[PRS-RFP-033]	Public Key Switch	PUBLICKEY	Vnom					NOT APPLICABLE	
43	[PRS-RFP-034]	Number Of Frames Per Message In Single Frame Uplink Mode	SINGLEFRAME	Vnom	1	1			NOT APPLICABLE	
44	[PRS-RFP-034]	Number Of Frames Per Message In Multi Frames Uplink Mode	MULTIFRAME	Vnom	3	3			NOT TESTED	
45	[PRS-RFP-035]	Legacy Uplink		Vnom					NOT TESTED	

Figure 16: LR11xxMB1DJS RC1 Verdict page 3



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
46	[PRS-RFP-036]	Uplink Encrypted Payload	ENCRYPTED	Vnom					NOT APPLICABLE	
47	[PRS-RFP-037]	Downlink Legacy	DOWNLINK	Vnom					NOT APPLICABLE	
48	[PRS-RFP-038]	Downlink Encrypted Payload	ENCRYPTED-DOWNLINK	Vnom					NOT APPLICABLE	
49	[PRS-RFP-039]	RSSI Level	DOWNLINK	Vnom	-2 dBm	2 dBm			NOT APPLICABLE	
50	[PRS-RFP-040]	Number Of Uplink Frame In Single Frame Bidirectional Mode	SINGLEFRAME-DOWNLINK	Vnom	1	1			NOT APPLICABLE	
51	[PRS-RFP-040]	Number Of Uplink Frame In Multi Frames Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	3	3			NOT APPLICABLE	
52	[PRS-RFP-041]	Carrier Center Frequencies In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	6000 Hz	150 Hz			NOT APPLICABLE	
53	[PRS-RFP-050]	TX Interframe Timing In Uplink Mode	MULTIFRAME	Vnom	0.010 s	2 s			NOT TESTED	
54	[PRS-RFP-051]	TX Repeat timeout	LBT-MULTIFRAME	Vnom	8 s				NOT APPLICABLE	
55	[PRS-RFP-052]	TX Interframe Timing In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	0.500 s	0.525 s			NOT APPLICABLE	
56	[PRS-RFP-053]	RX Start Of Listening	DOWNLINK	Vnom	20.1 s				NOT APPLICABLE	
57	[PRS-RFP-054]	RX End Of Listening	DOWNLINK	Vnom	44.5 s				NOT APPLICABLE	
58	[PRS-RFP-055]	RX To Confirmation Control Message Timing	DOWNLINK	Vnom	1.4 s	4 s			NOT APPLICABLE	
59	[PRS-RFP-060]	RC Determination From Monarch Signal At High Power Level	MONARCH	Vnom	10	0 %			NOT APPLICABLE	
60	[PRS-RFP-061]	Link Budget On Monarch Signal	MONARCH	Vnom	300	10 %			NOT APPLICABLE	

Figure 17: LR11xxMB1DJS RC1 Verdict page 4

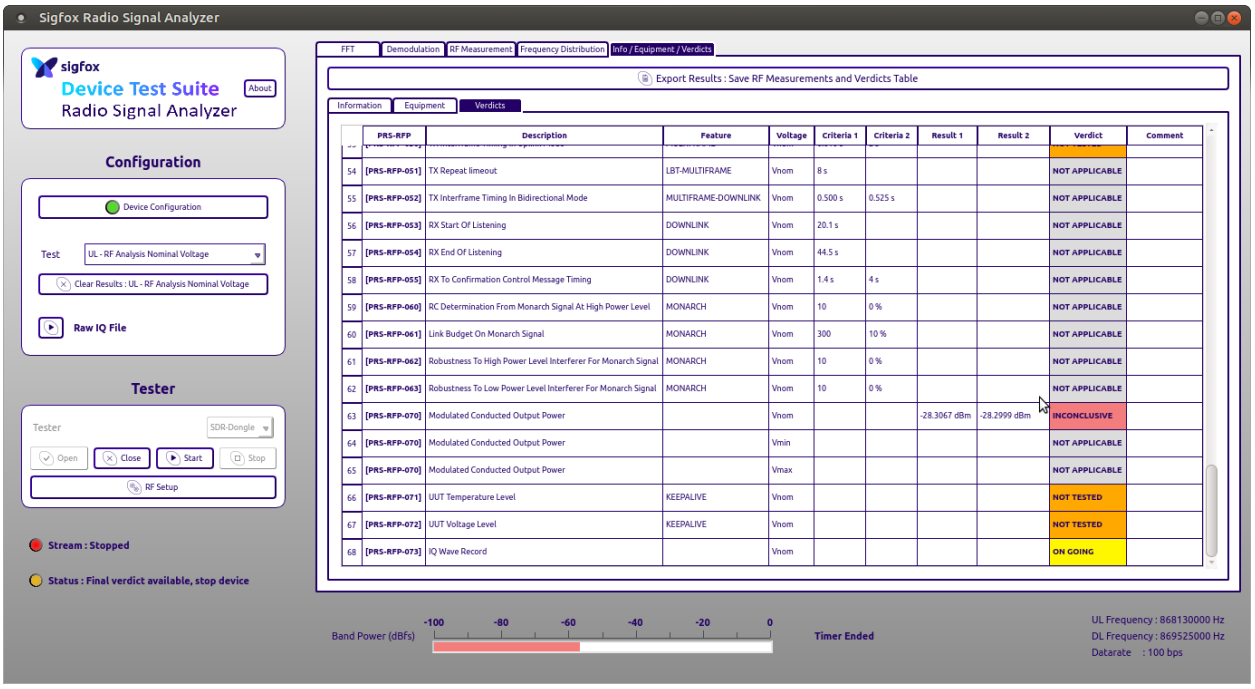


Figure 18: LR11xxMB1DJS RC1 Verdict page 5

6.3 LR11xxMB1DJS Measurement Results, TCXO, Radio Configuration RC2

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

For the RC2 case, note in Figures 6.3.10 and 6.3.11 that the Sigfox Radio Signal Analyzer tool fails to properly measure drift.

6.3.1 Device Configuration

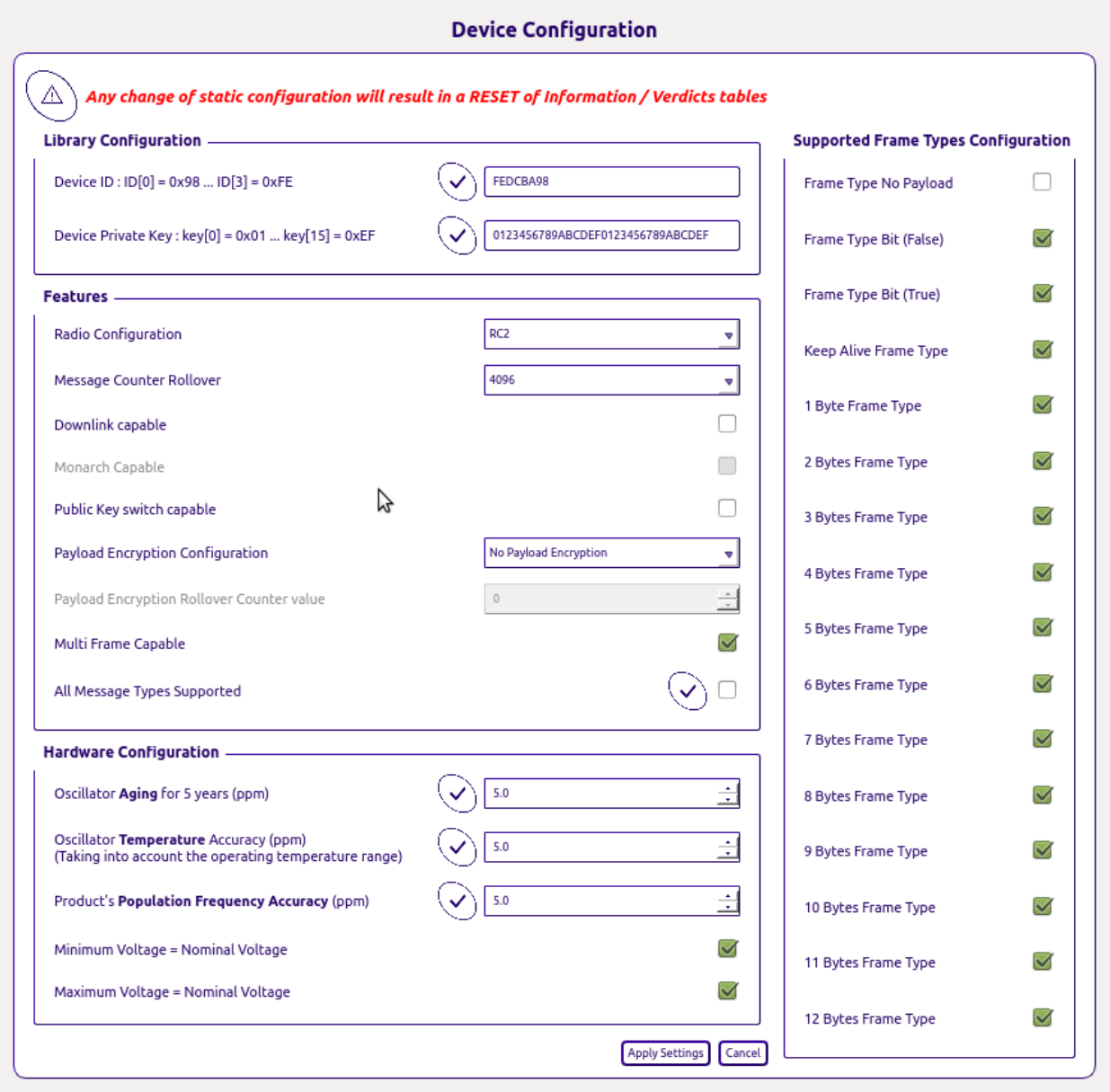


Figure 19: LR11xxMB1DJS RC2 Device Configuration

6.3.2 FFT

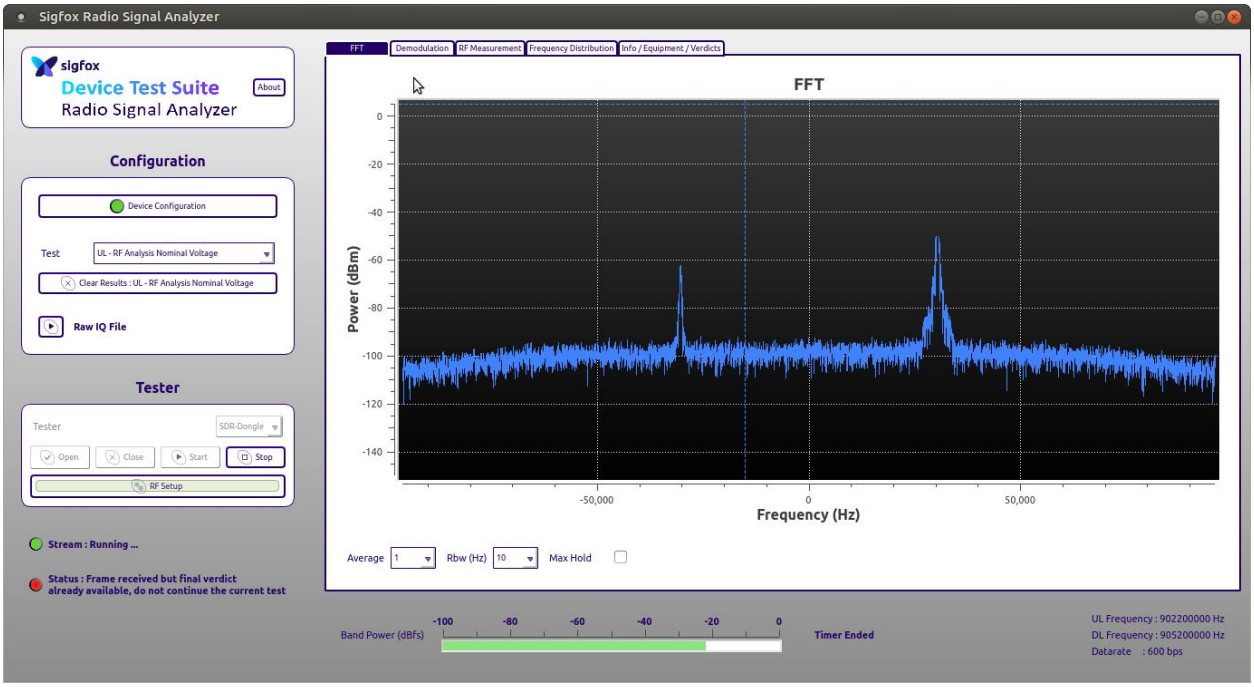


Figure 20: LR11xxMB1DJS RC2 FFT

6.3.3 Demodulation

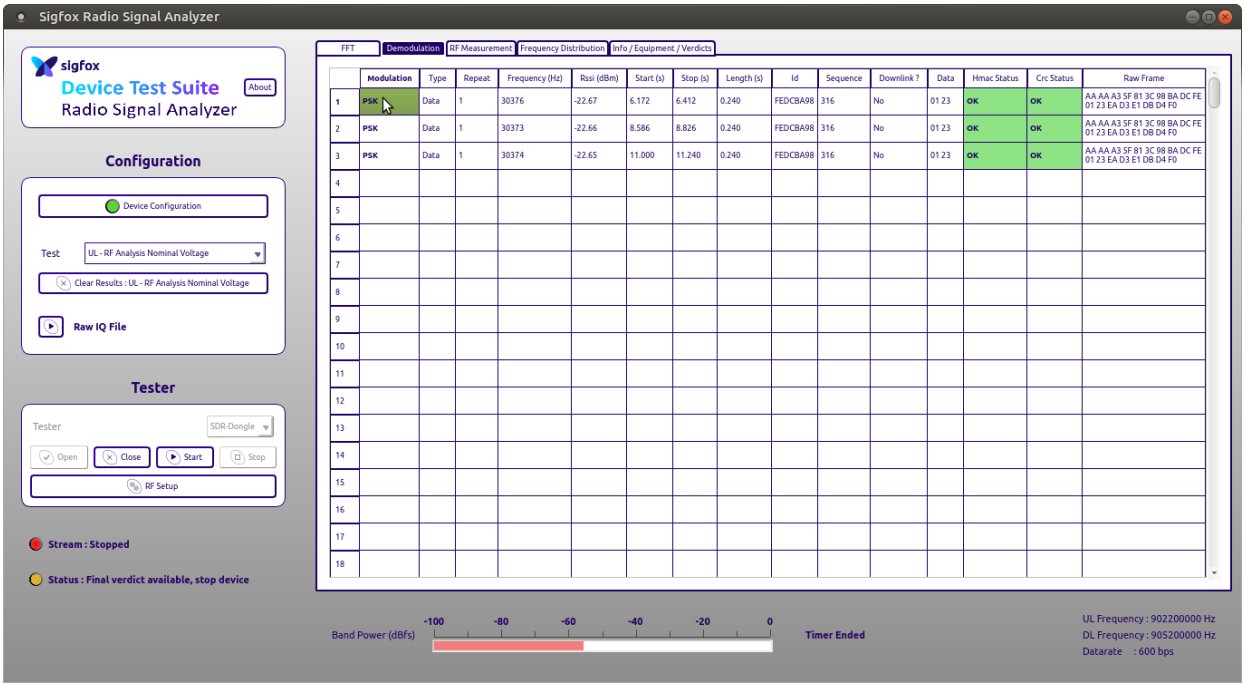


Figure 21: LR11xxMB1DJS RC2 Demodulation

6.3.4 Power Spectral Density for Class 0 & 1

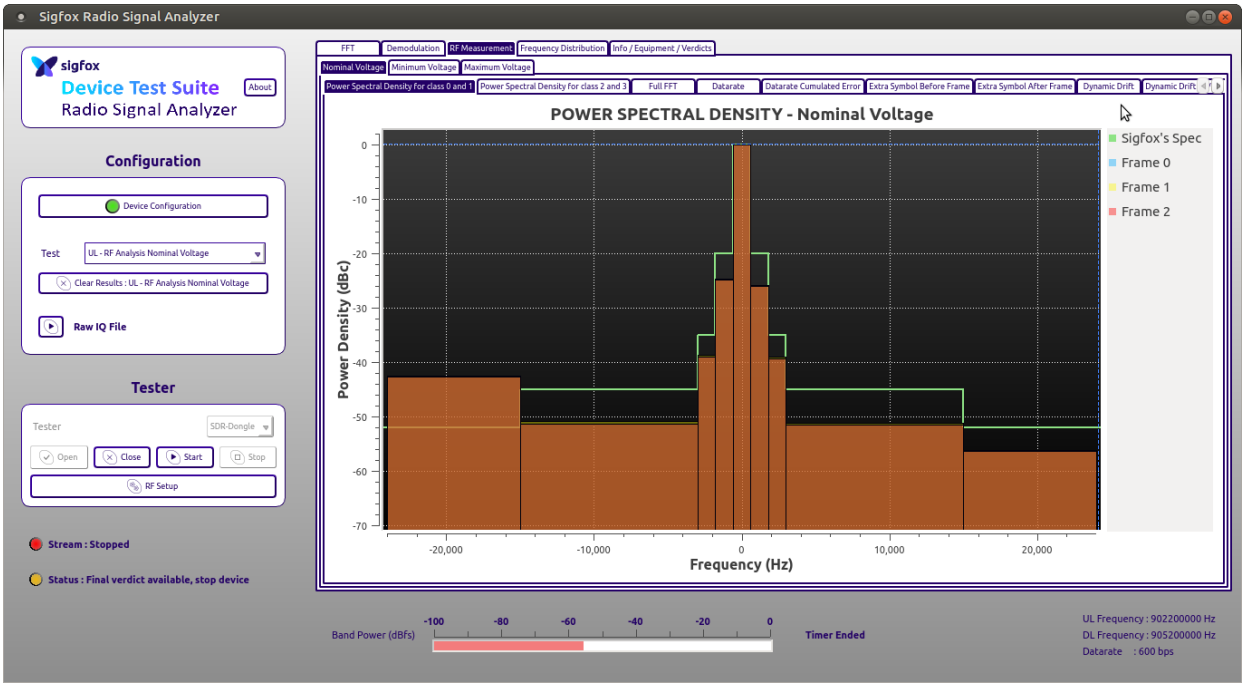


Figure 22: LR11xxMB1DJS RC2 Power Spectral Density for Class 0 & 1

6.3.5 Full FFT

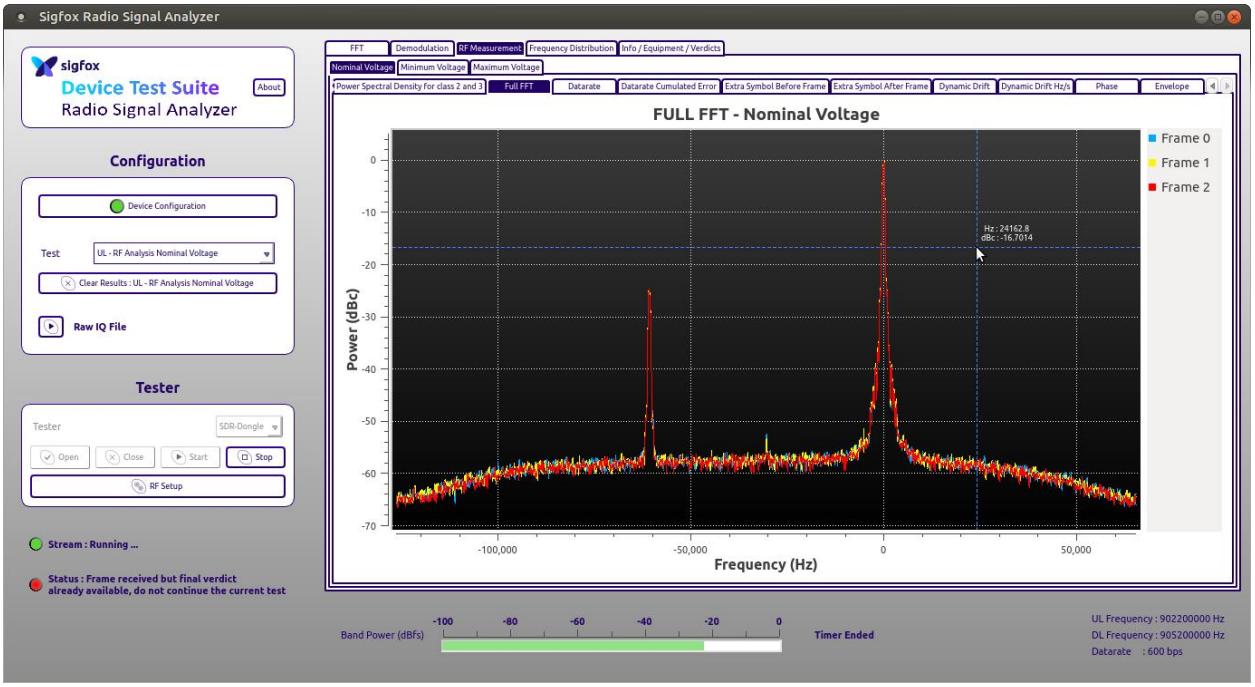


Figure 23: LR11xxMB1DJS RC2 Full FFT

6.3.6 Data Rate

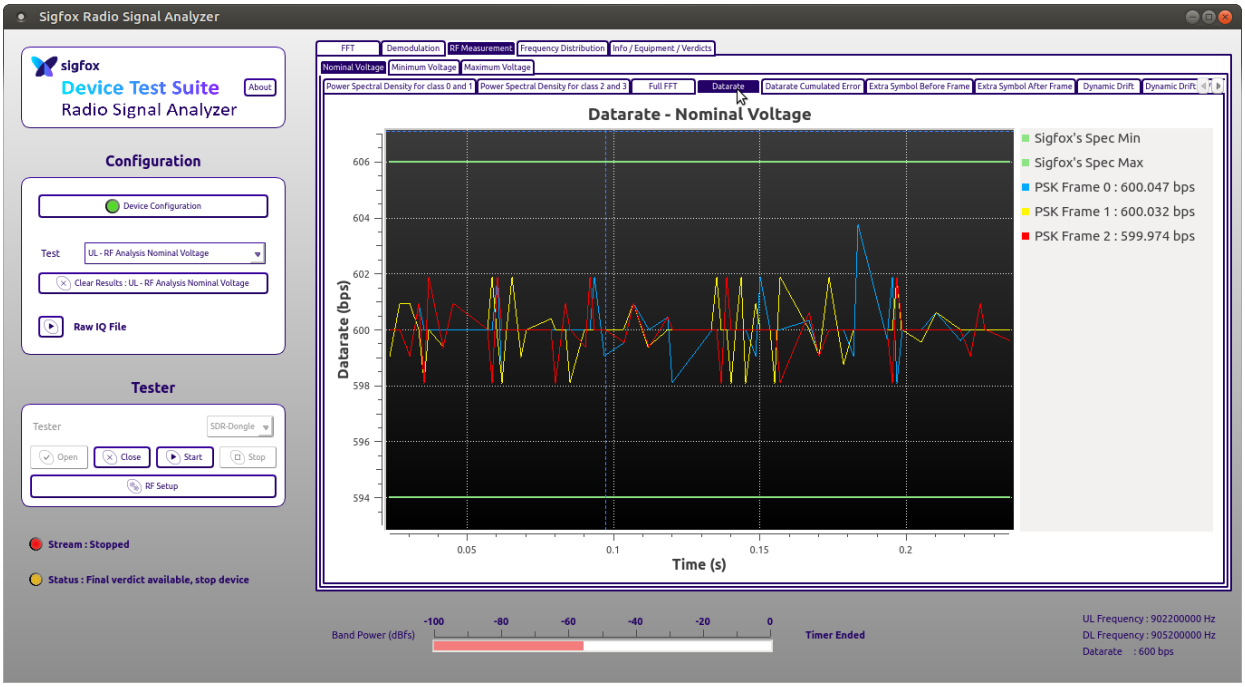


Figure 24: LR11xxMB1DJS RC2 Data Rate

6.3.7 Data Rate Cumulated Error

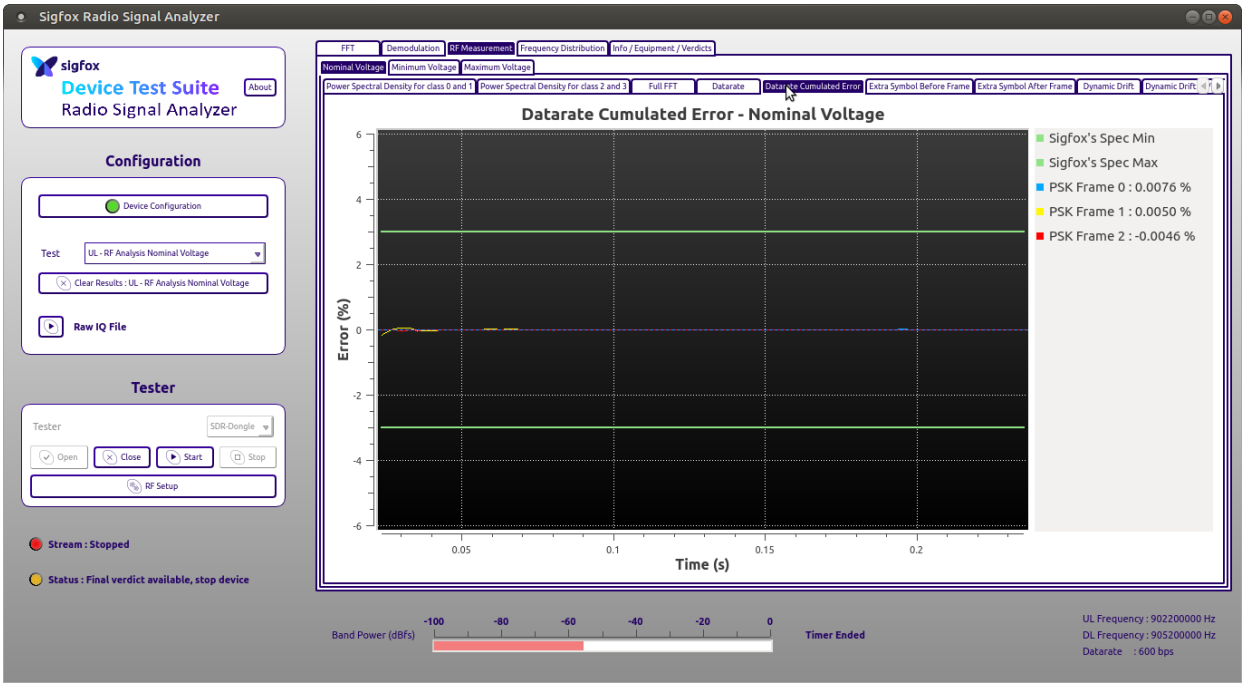


Figure 25: LR11xxMB1DJS RC2 Data Rate Cumulated Error

6.3.8 Extra Symbol Before Transmission

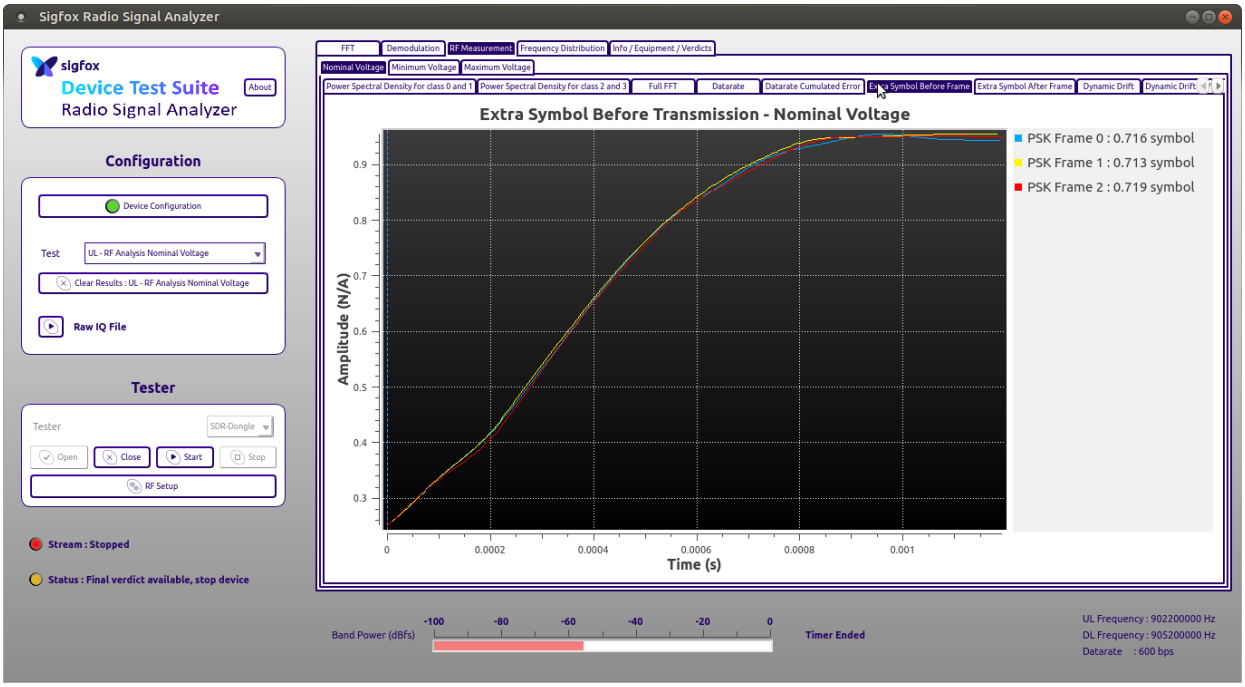


Figure 26: LR11xxMB1DJS RC2 Extra Symbol Before Transmission

6.3.9 Extra Symbol After Transmission

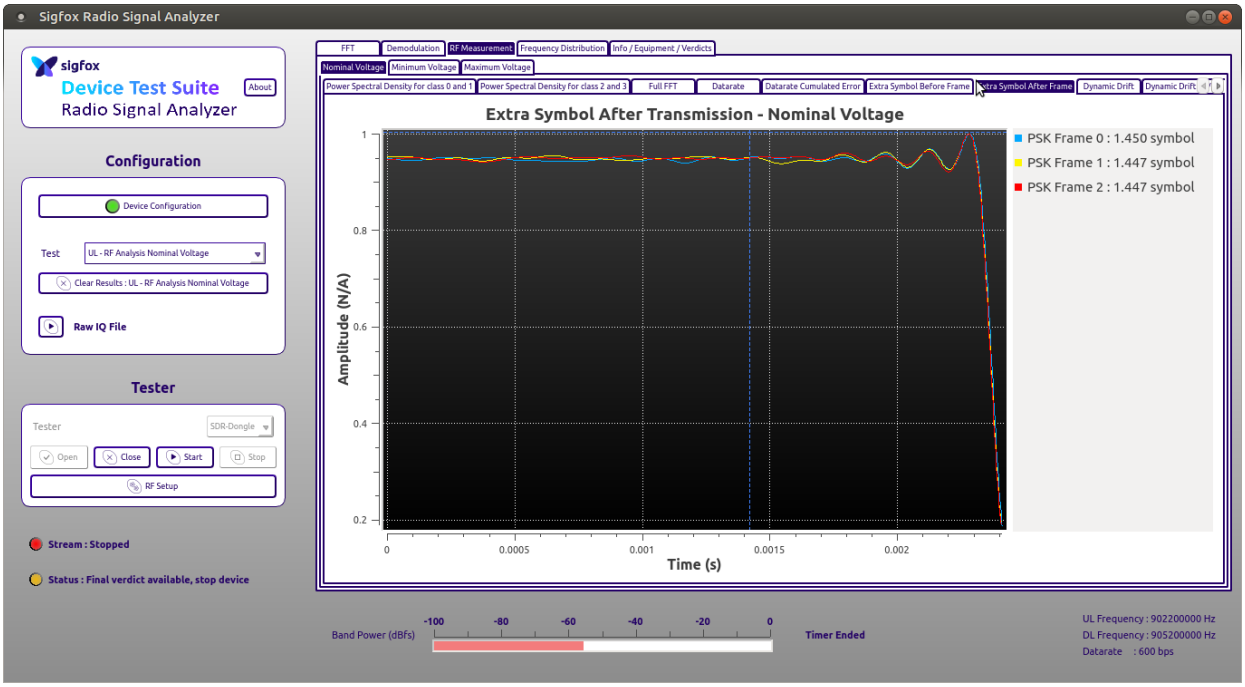


Figure 27: LR11xxMB1DJS RC2 Extra Symbol After Transmission

6.3.10 Dynamic Drift

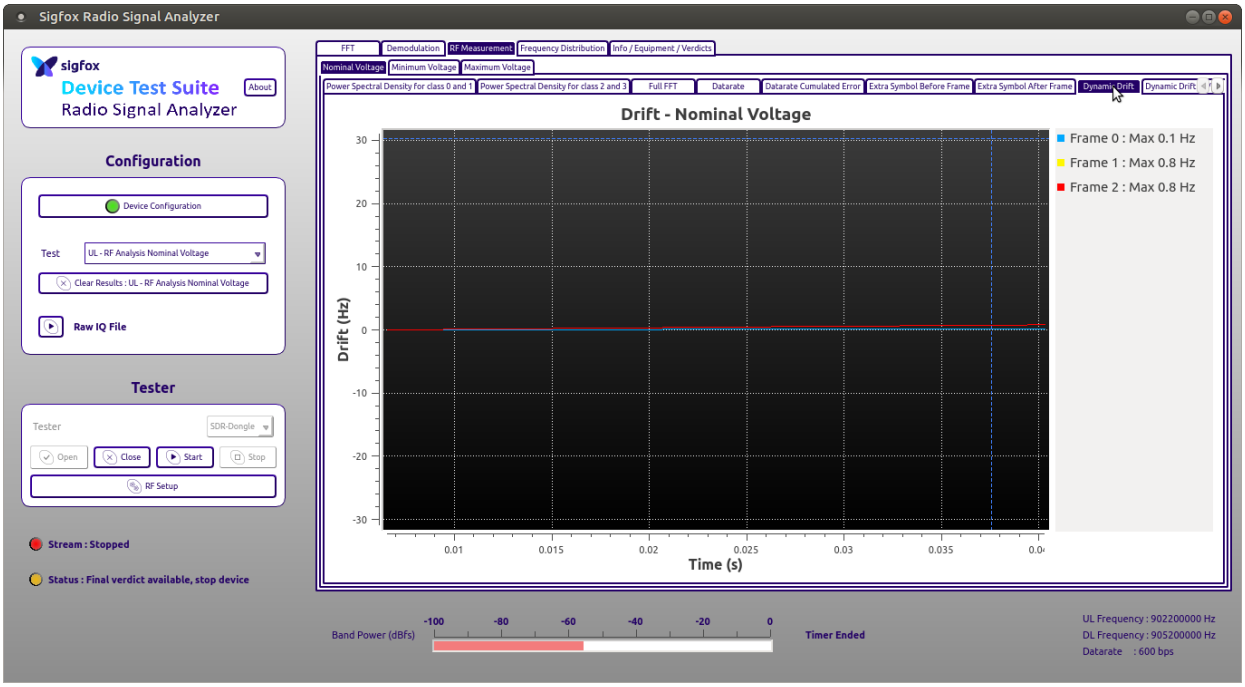


Figure 28: LR11xxMB1DJS RC2 Dynamic Drift

6.3.11 Dynamic Drift per Second

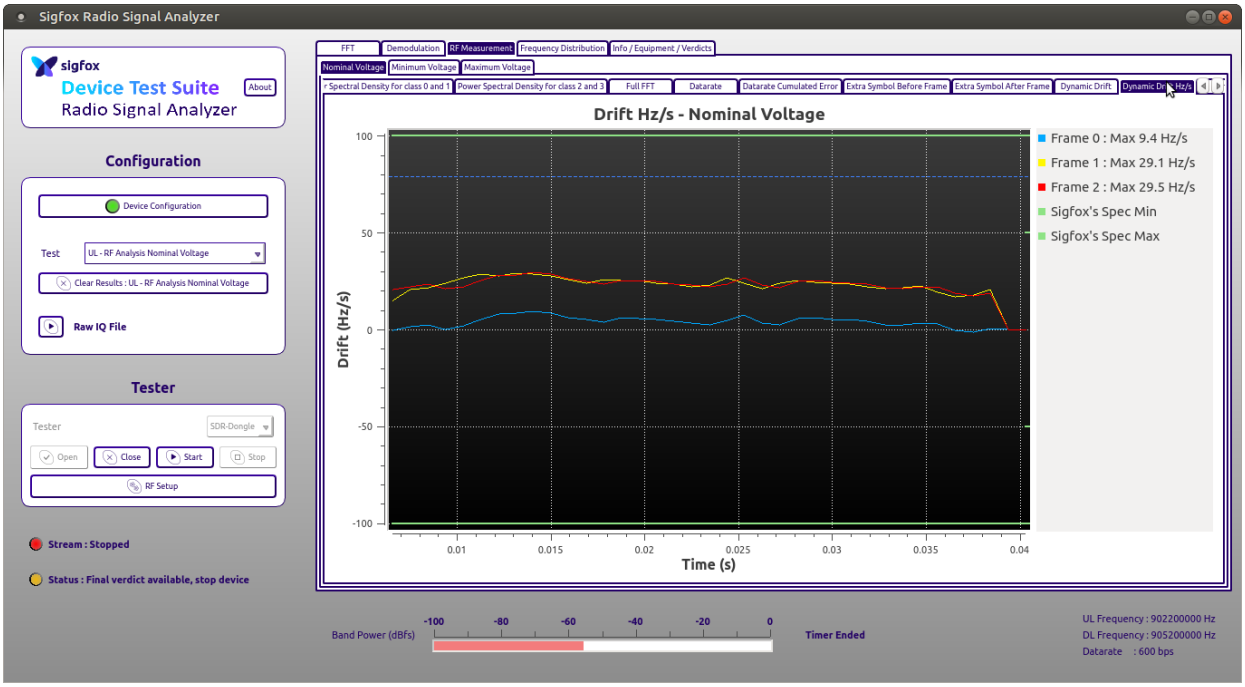


Figure 29: LR11xxMB1DJS RC2 Dynamic Drift per Second

6.3.12 Phase

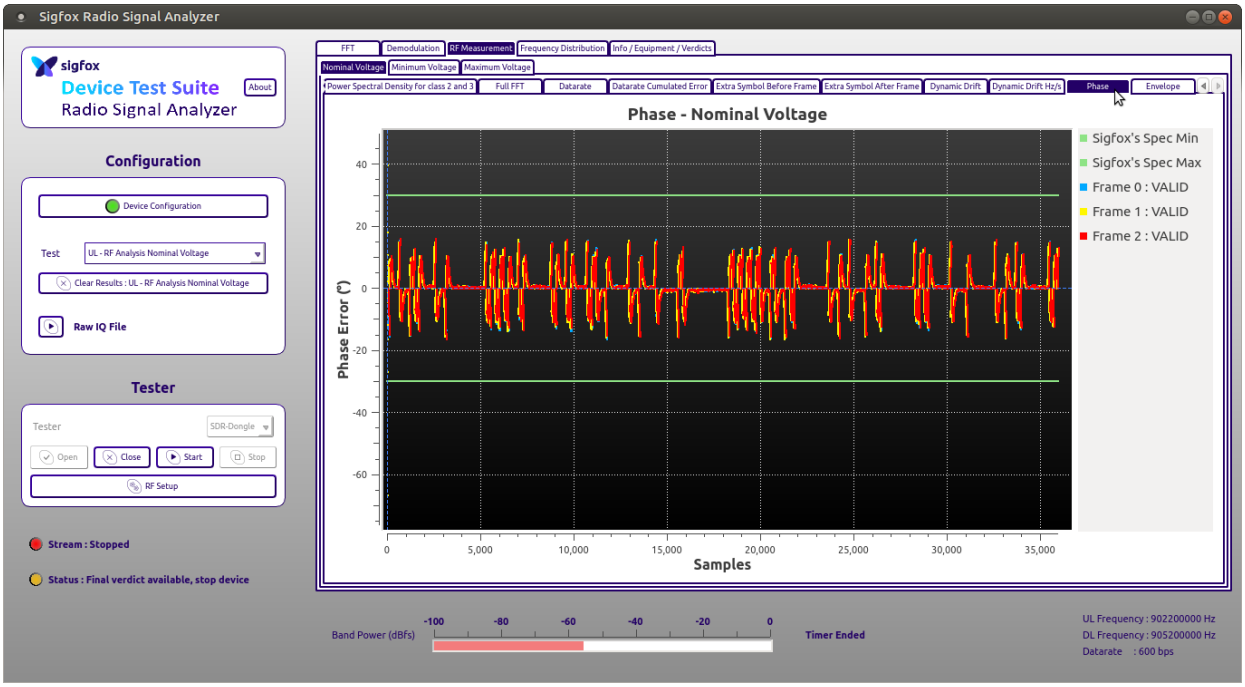


Figure 30: LR11xxMB1DJS RC2 Phase

6.3.13 Envelope

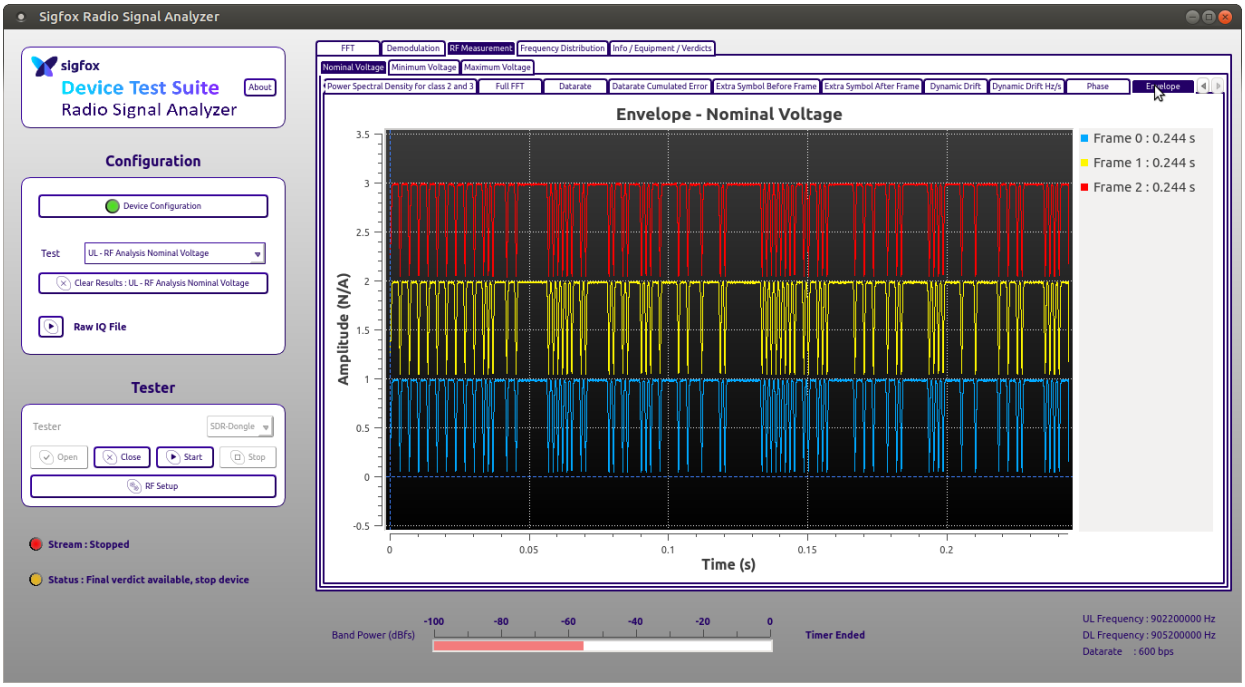


Figure 31: LR11xxMB1DJS RC2 Envelope

6.3.14 Verdict

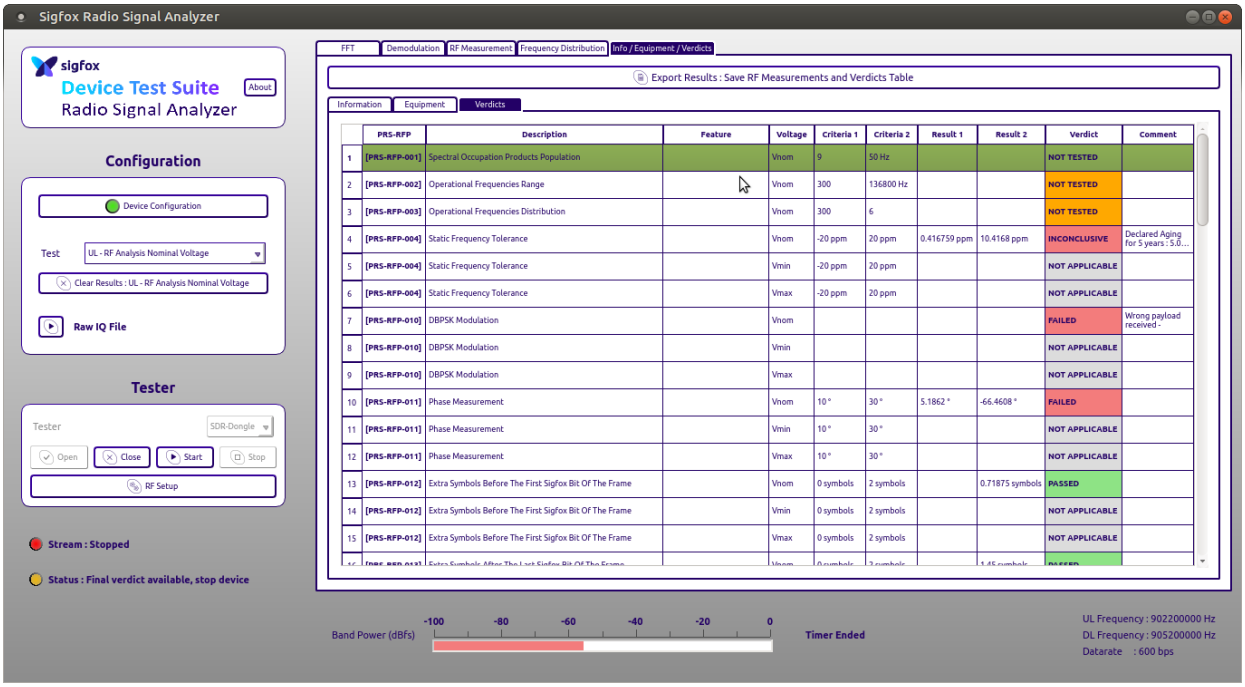


Figure 32: LR11xxMB1DJS RC2 Verdict page 1

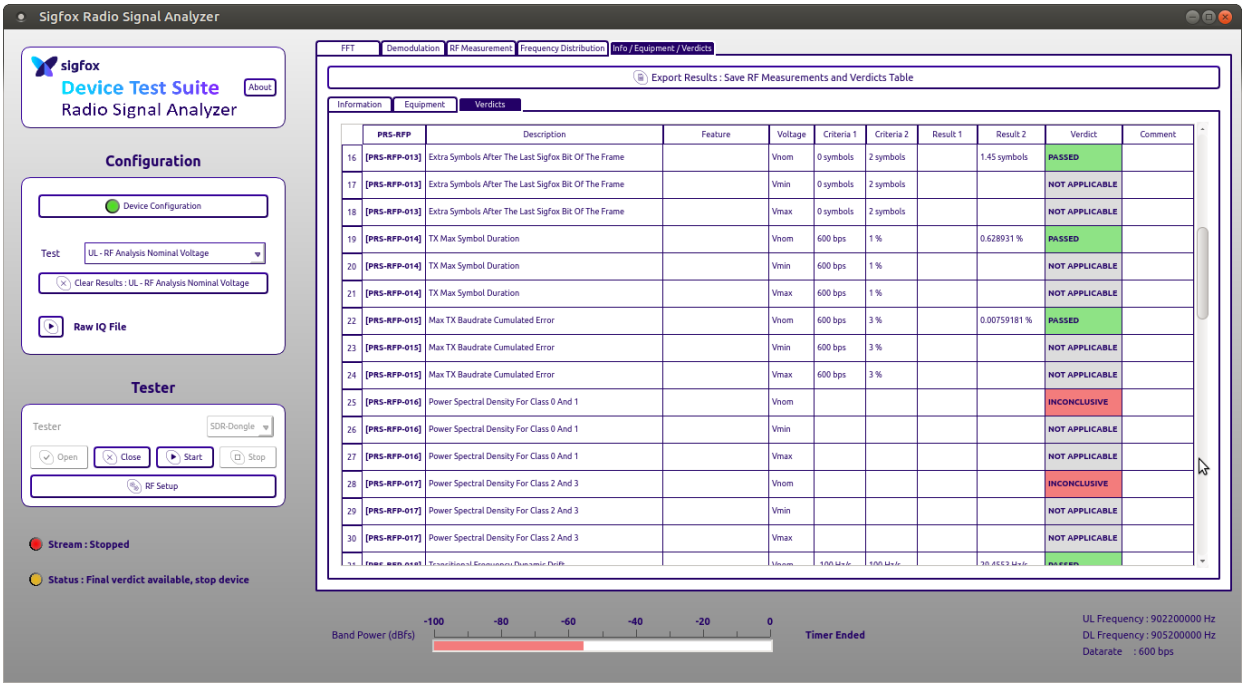
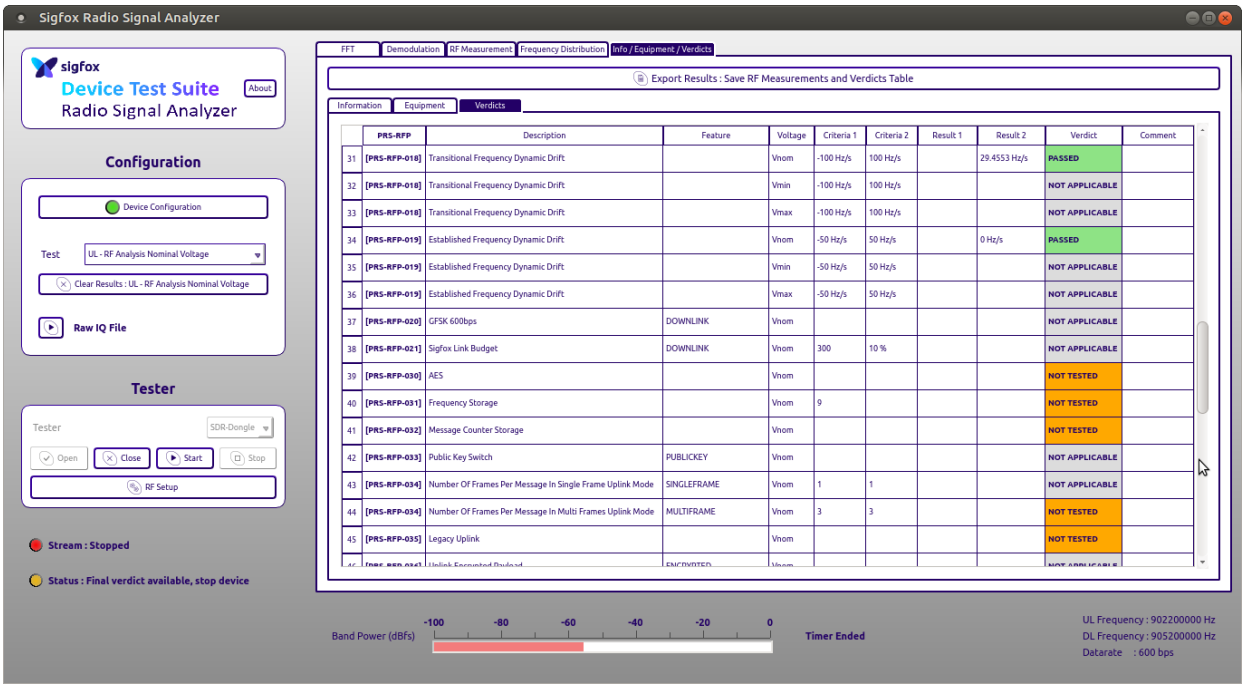
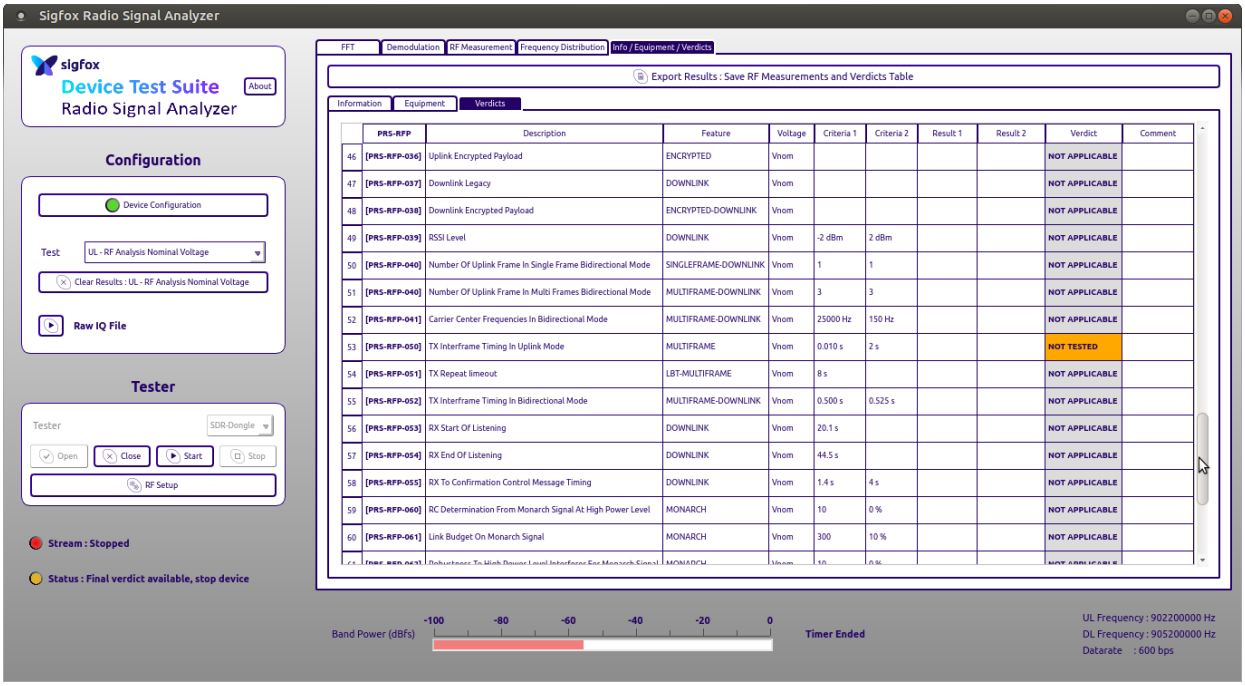


Figure 33: LR11xxMB1DJS RC2 Verdict page 2



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
31	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vnom	-100 Hz/s	100 Hz/s		29.4553 Hz/s	PASSED	
32	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmin	-100 Hz/s	100 Hz/s			NOT APPLICABLE	
33	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmax	-100 Hz/s	100 Hz/s			NOT APPLICABLE	
34	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vnom	-50 Hz/s	50 Hz/s		0 Hz/s	PASSED	
35	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmin	-50 Hz/s	50 Hz/s			NOT APPLICABLE	
36	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmax	-50 Hz/s	50 Hz/s			NOT APPLICABLE	
37	[PRS-RFP-020]	GFSK 600bps	DOWNLINK	Vnom					NOT APPLICABLE	
38	[PRS-RFP-021]	Sigfox Link Budget	DOWNLINK	Vnom	300	10 %			NOT APPLICABLE	
39	[PRS-RFP-030]	AES		Vnom					NOT TESTED	
40	[PRS-RFP-031]	Frequency Storage		Vnom	9				NOT TESTED	
41	[PRS-RFP-032]	Message Counter Storage		Vnom					NOT TESTED	
42	[PRS-RFP-033]	Public Key Switch	PUBLICKEY	Vnom					NOT APPLICABLE	
43	[PRS-RFP-034]	Number Of Frames Per Message In Single Frame Uplink Mode	SINGLEFRAME	Vnom	1	1			NOT APPLICABLE	
44	[PRS-RFP-034]	Number Of Frames Per Message In Multi Frames Uplink Mode	MULTIFRAME	Vnom	3	3			NOT TESTED	
45	[PRS-RFP-035]	Legacy Uplink		Vnom					NOT TESTED	

Figure 34: LR11xxMB1DJS RC2 Verdict page 3



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
46	[PRS-RFP-036]	Uplink Encrypted Payload	ENCRYPTED	Vnom					NOT APPLICABLE	
47	[PRS-RFP-037]	Downlink Legacy	DOWNLINK	Vnom					NOT APPLICABLE	
48	[PRS-RFP-038]	Downlink Encrypted Payload	ENCRYPTED-DOWNLINK	Vnom					NOT APPLICABLE	
49	[PRS-RFP-039]	RSSI Level	DOWNLINK	Vnom	-2 dBm	2 dBm			NOT APPLICABLE	
50	[PRS-RFP-040]	Number Of Uplink Frame In Single Frame Bidirectional Mode	SINGLEFRAME-DOWNLINK	Vnom	1	1			NOT APPLICABLE	
51	[PRS-RFP-040]	Number Of Uplink Frame In Multi Frames Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	3	3			NOT APPLICABLE	
52	[PRS-RFP-041]	Carrier Center Frequencies In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	25000 Hz	150 Hz			NOT APPLICABLE	
53	[PRS-RFP-050]	TX Interframe Timing In Uplink Mode	MULTIFRAME	Vnom	0.010 s	2 s			NOT TESTED	
54	[PRS-RFP-051]	TX Repeat timeout	LBT-MULTIFRAME	Vnom	8 s				NOT APPLICABLE	
55	[PRS-RFP-052]	TX Interframe Timing In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	0.500 s	0.525 s			NOT APPLICABLE	
56	[PRS-RFP-053]	RX Start Of Listening	DOWNLINK	Vnom	20.1 s				NOT APPLICABLE	
57	[PRS-RFP-054]	RX End Of Listening	DOWNLINK	Vnom	44.5 s				NOT APPLICABLE	
58	[PRS-RFP-055]	RX To Confirmation Control Message Timing	DOWNLINK	Vnom	1.4 s	4 s			NOT APPLICABLE	
59	[PRS-RFP-060]	RC Determination From Monarch Signal At High Power Level	MONARCH	Vnom	10	0 %			NOT APPLICABLE	
60	[PRS-RFP-061]	Link Budget On Monarch Signal	MONARCH	Vnom	300	10 %			NOT APPLICABLE	

Figure 35: LR11xxMB1DJS RC2 Verdict page 4

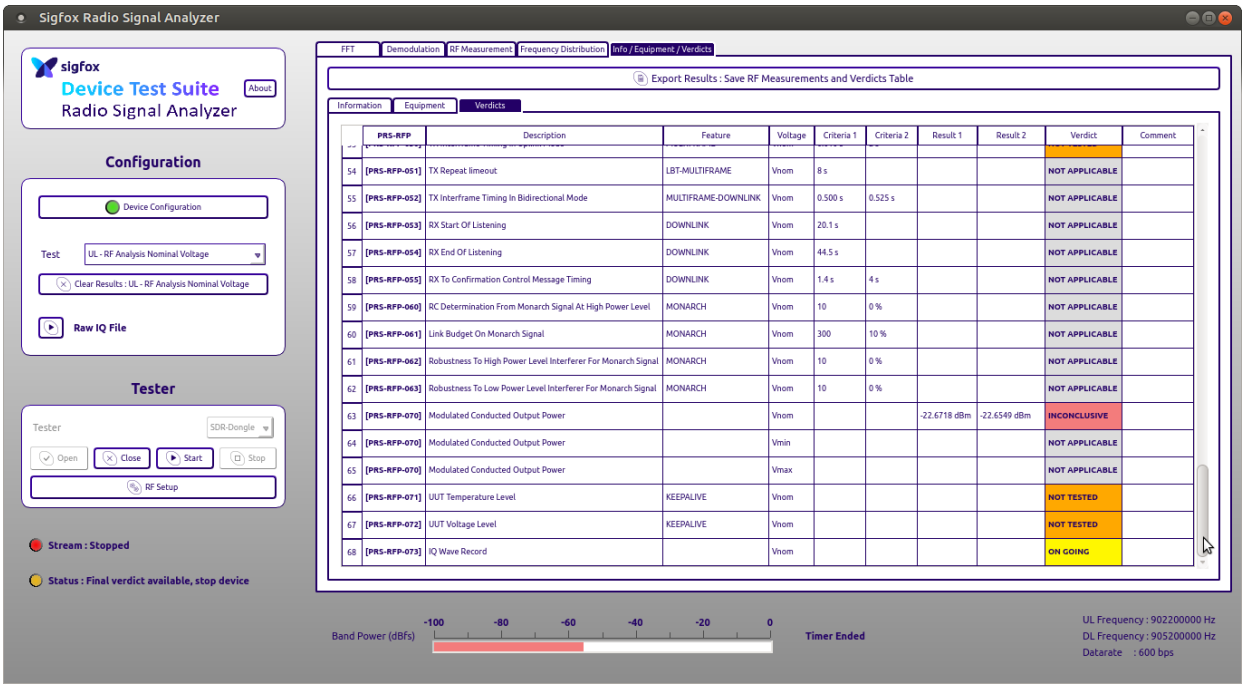


Figure 36: LR11xxMB1DJS RC2 Verdict page 5

6.4 SX1261MB1BAS Measurement Results, XTAL, Radio Configuration RC1

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

6.4.1 Device Configuration

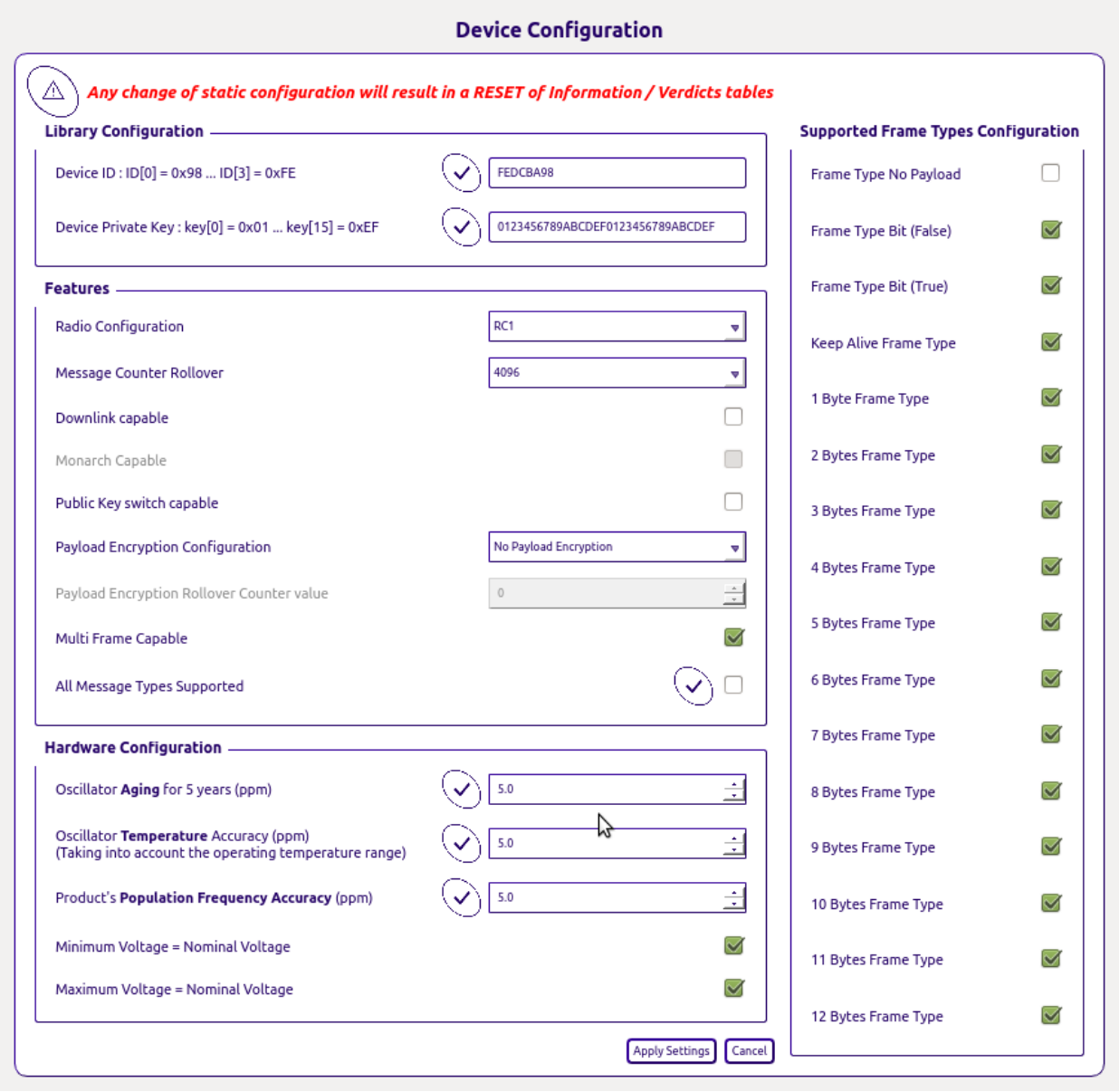


Figure 37: SX1261MB1BAS RC1 Device Configuration

6.4.2 FFT

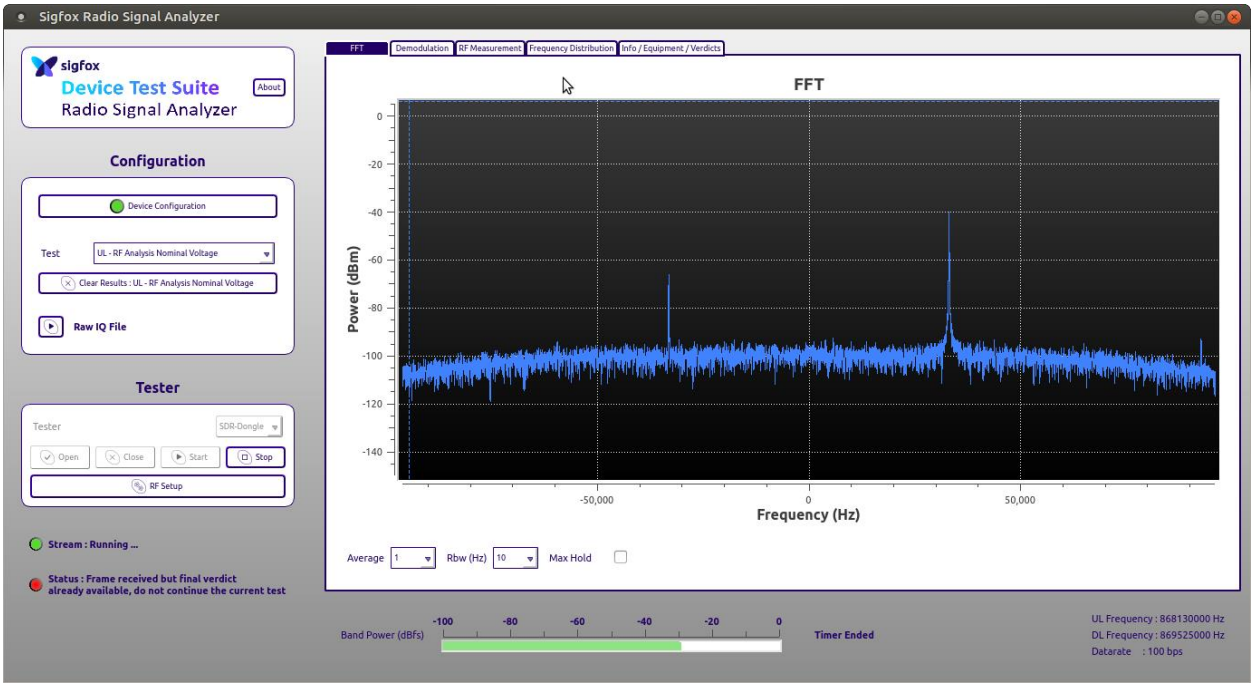


Figure 38: SX1261MB1BAS RC1 FFT

6.4.3 Demodulation

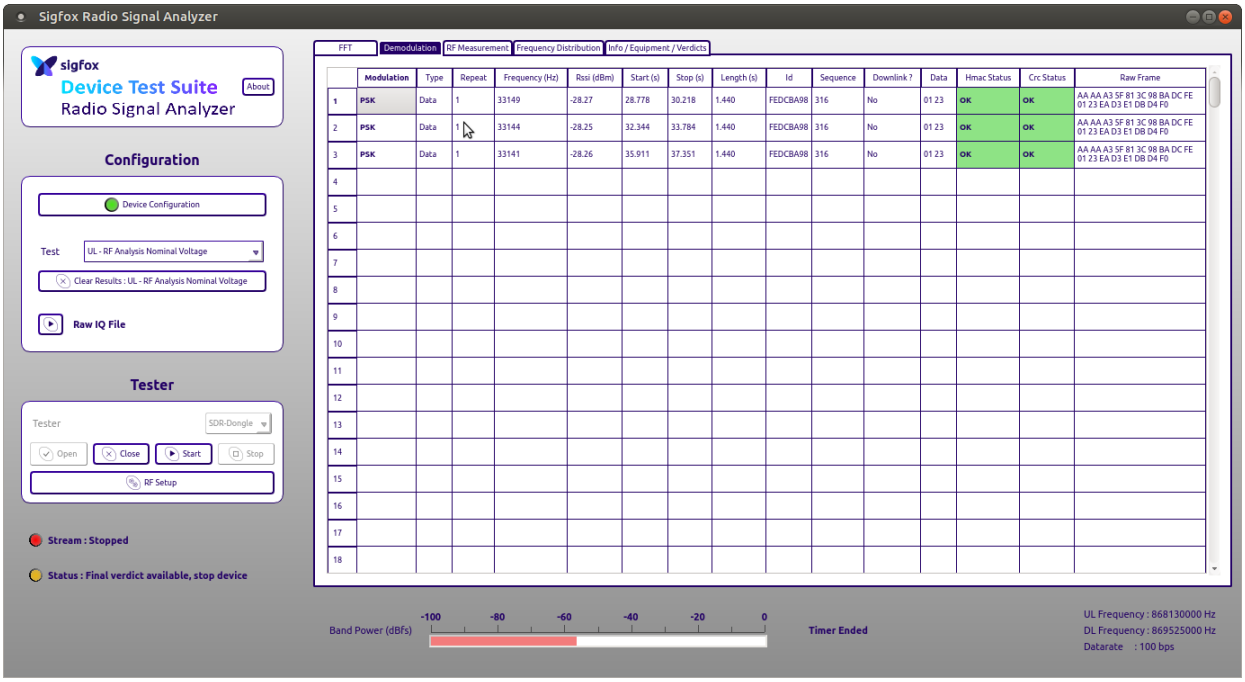


Figure 39: SX1261MB1BAS RC1 Demodulation

6.4.4 Power Spectral Density for Class 0 & 1

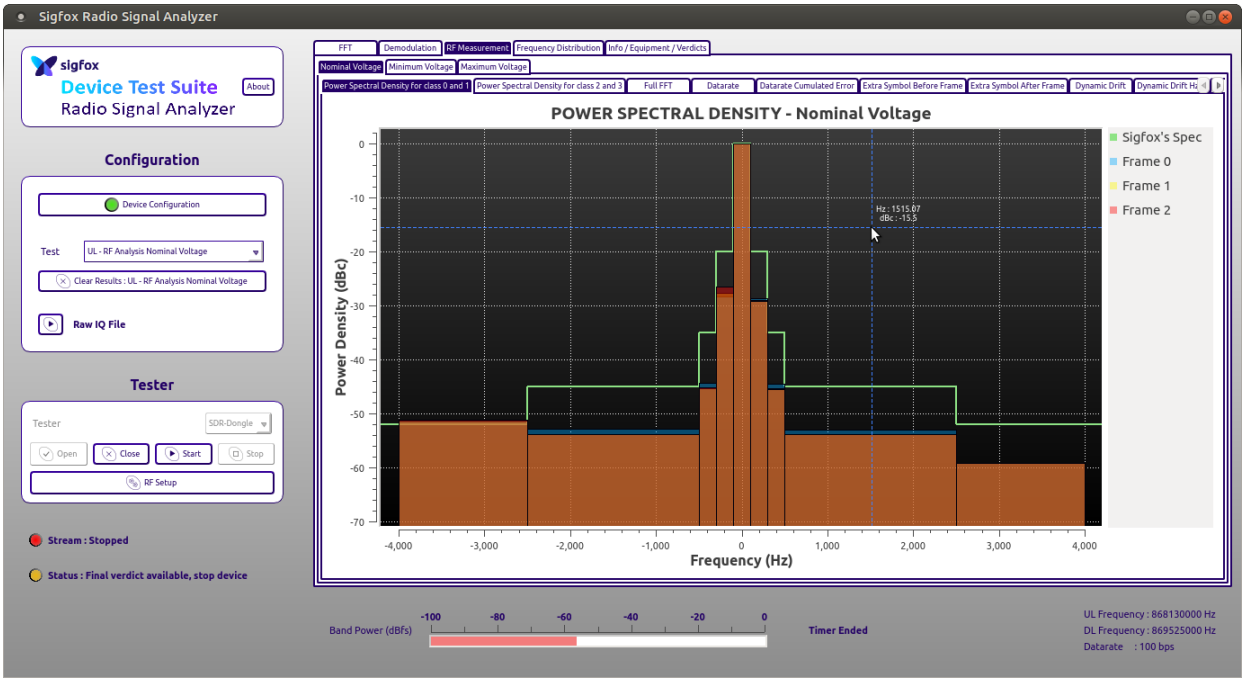


Figure 40: SX1261MB1BAS RC1 Power Spectral Density for Class 0 & 1

6.4.5 Full FFT

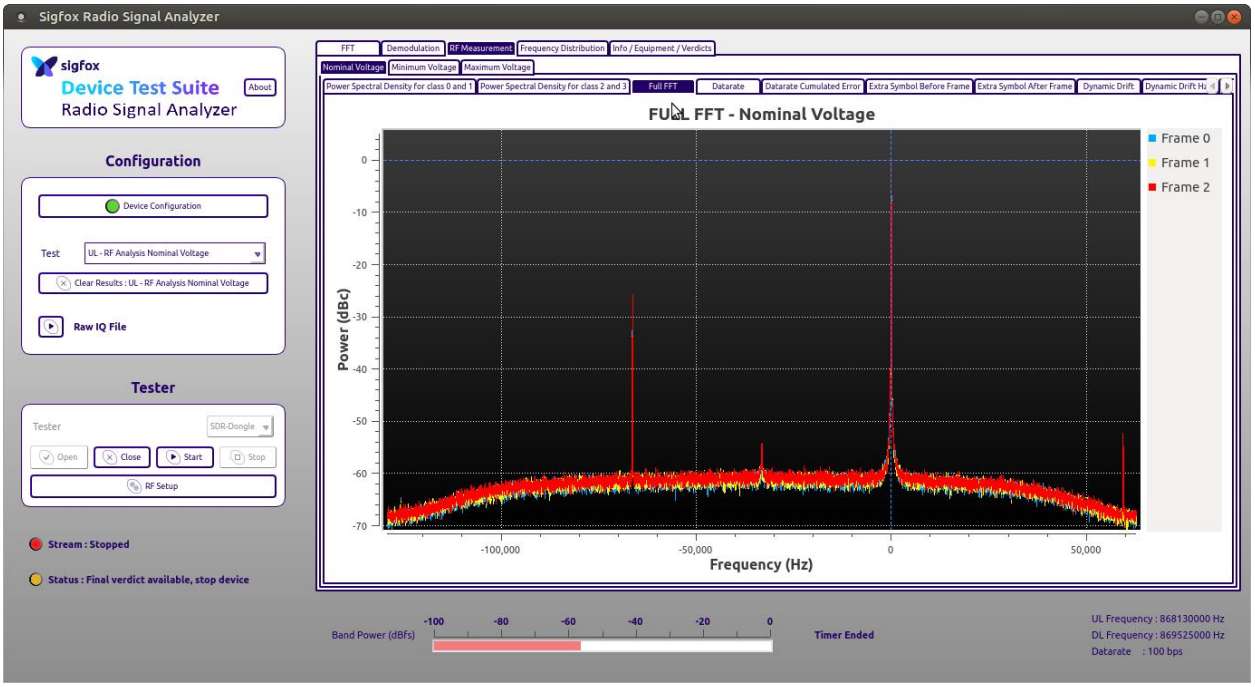


Figure 41: SX1261MB1BAS RC1 Full FFT

6.4.6 Data Rate

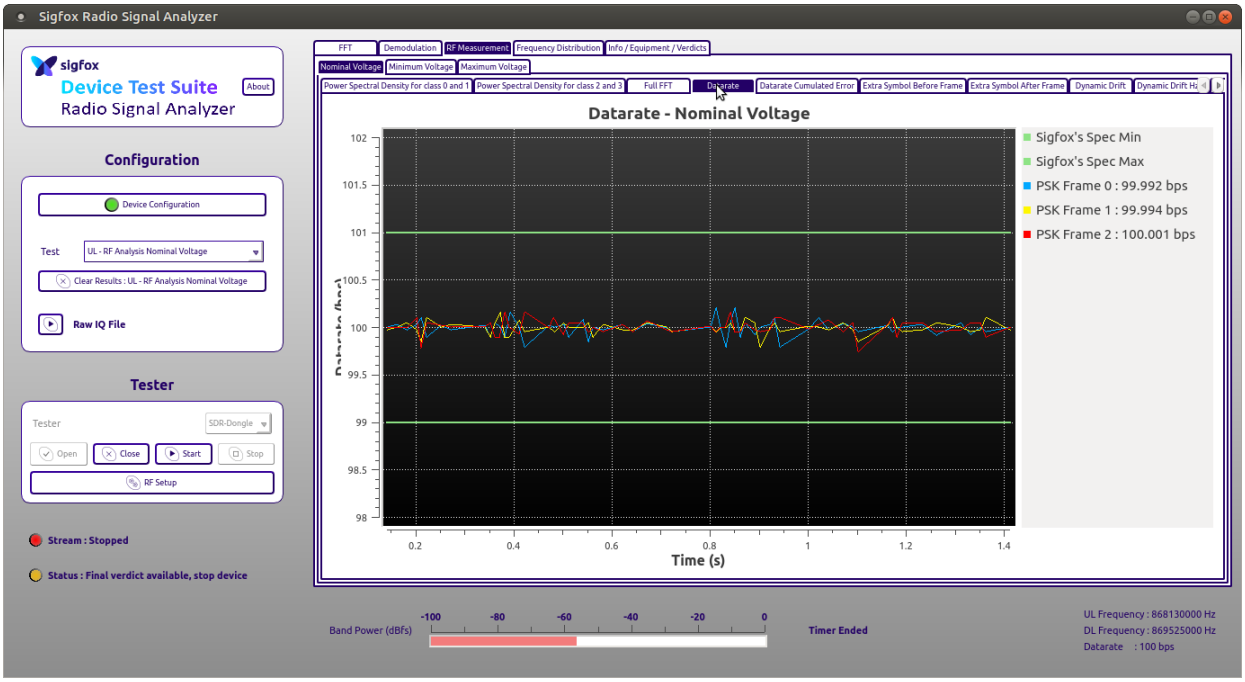


Figure 42: SX1261MB1BAS RC1 Data Rate

6.4.7 Data Rate Cumulated Error

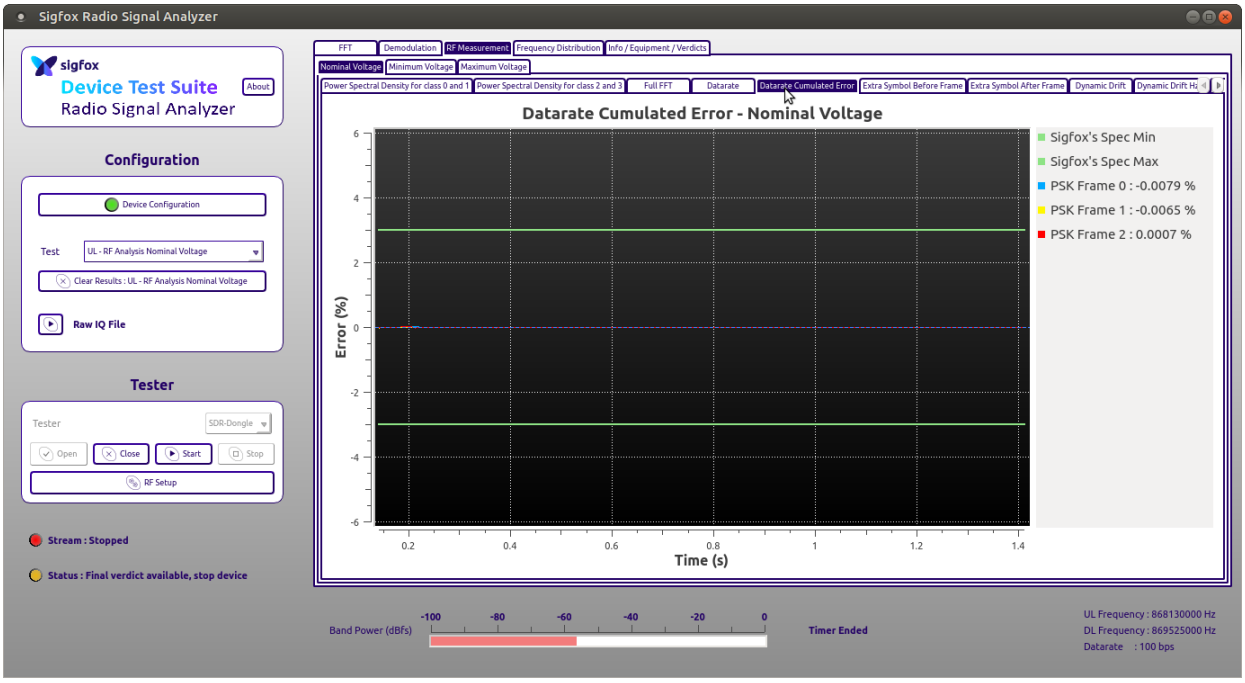


Figure 43: SX1261MB1BAS RC1 Data Rate Cumulated Error

6.4.8 Extra Symbol Before Transmission

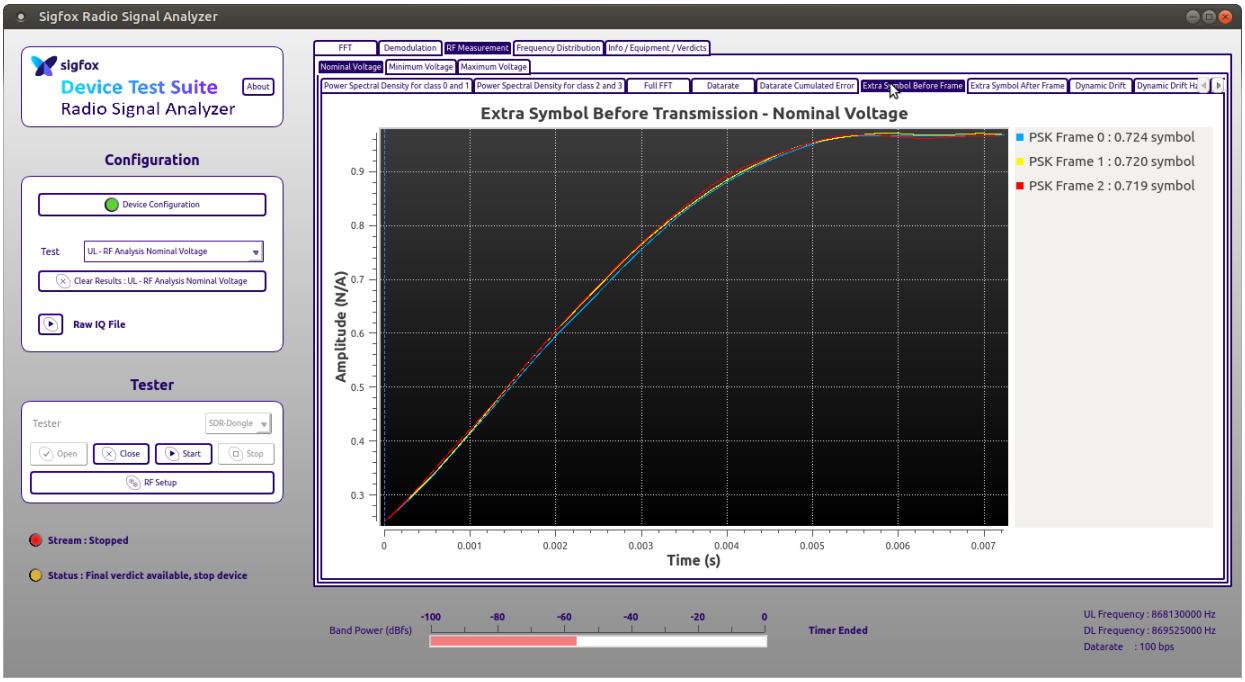


Figure 44: SX1261MB1BAS RC1 Extra Symbol Before Transmission

6.4.9 Extra Symbol After Transmission

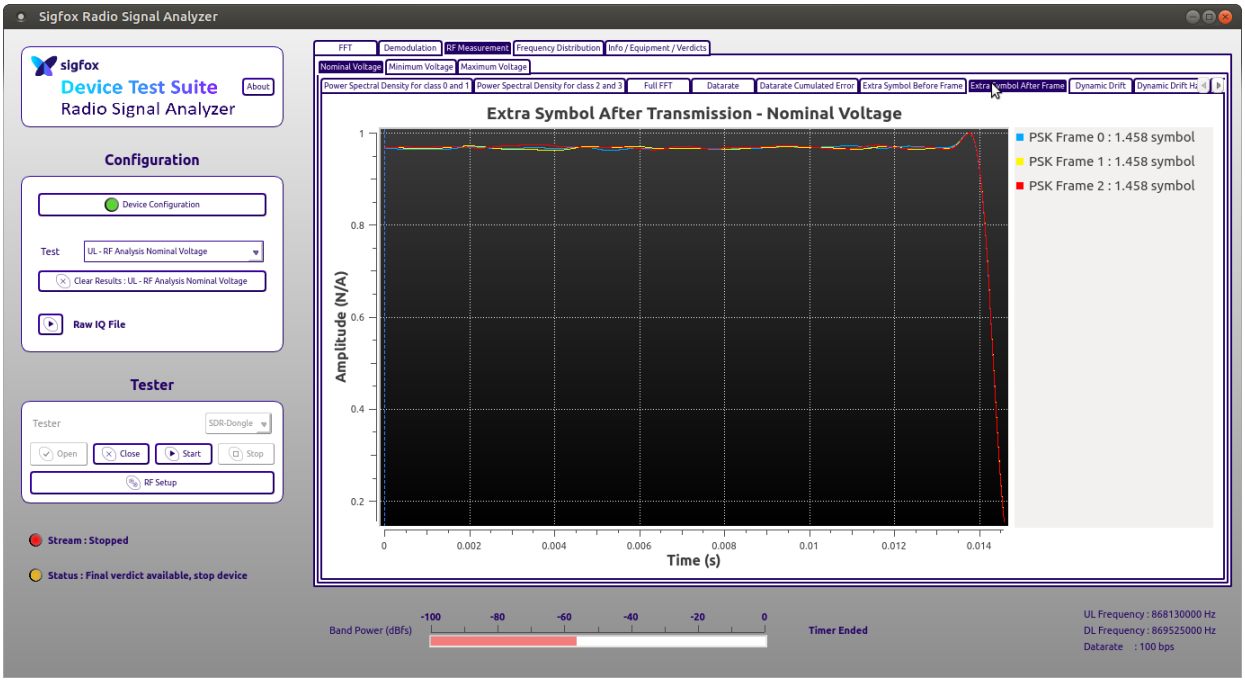


Figure 45: SX1261MB1BAS RC1 Extra Symbol After Transmission

6.4.10 Dynamic Drift

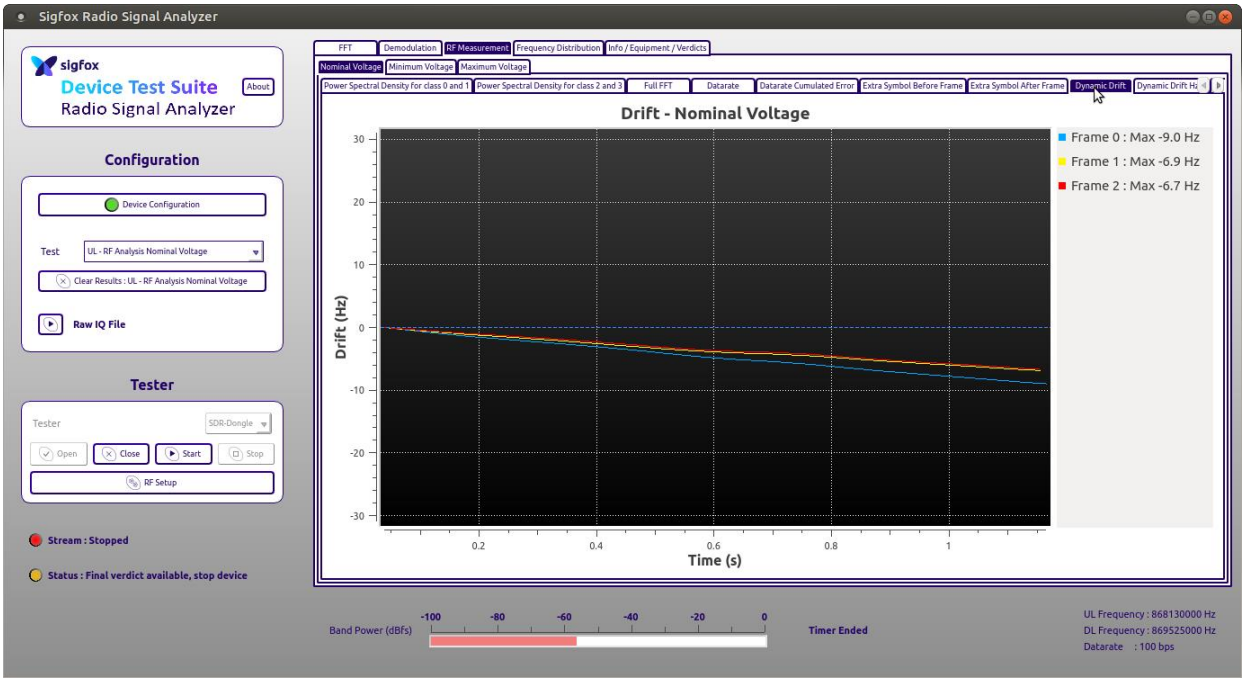
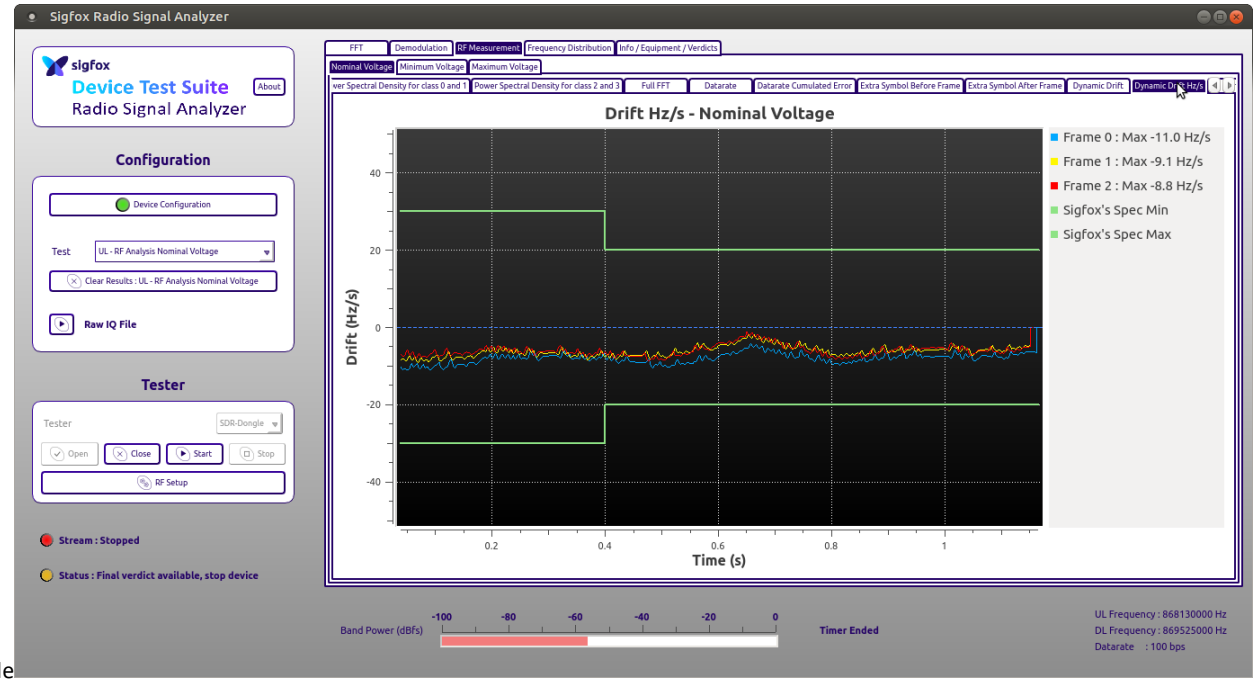


Figure 46: SX1261MB1BAS RC1 Dynamic Drift

6.4.11 Dynamic Drift per Second



ede

Figure 47: SX1261MB1BAS RC1 Dynamic Drift per Second

6.4.12 Phase

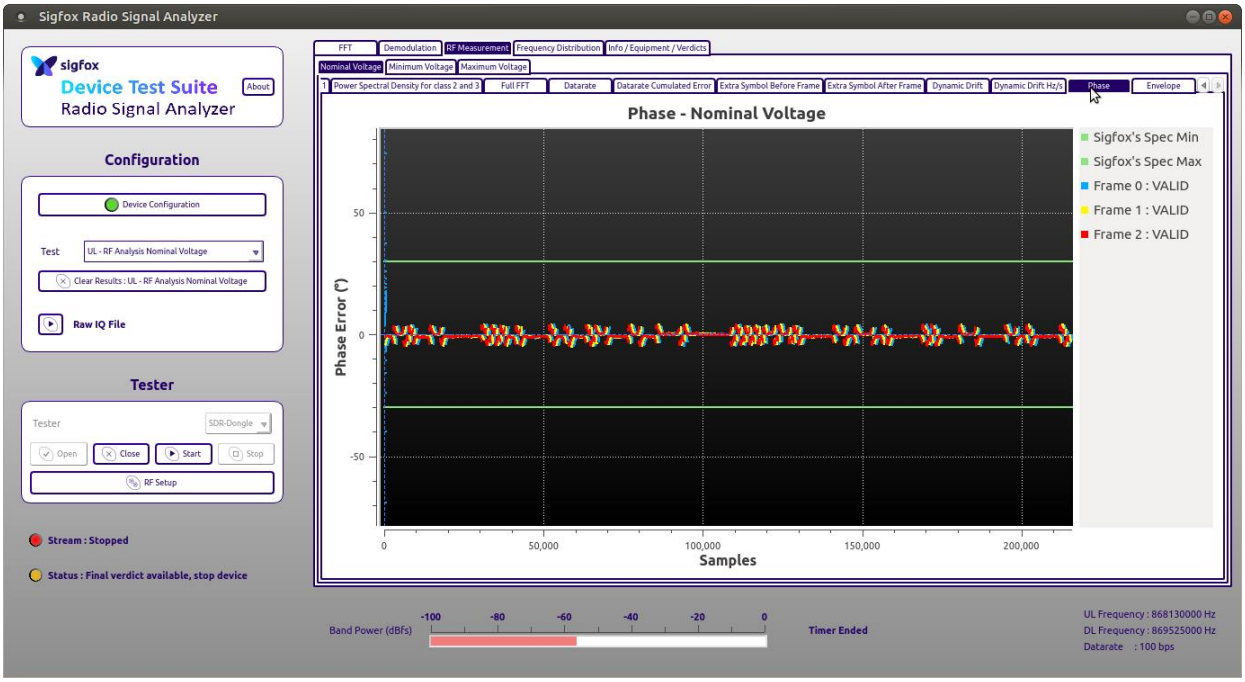


Figure 48: SX1261MB1BAS RC1 Phase

6.4.13 Envelope

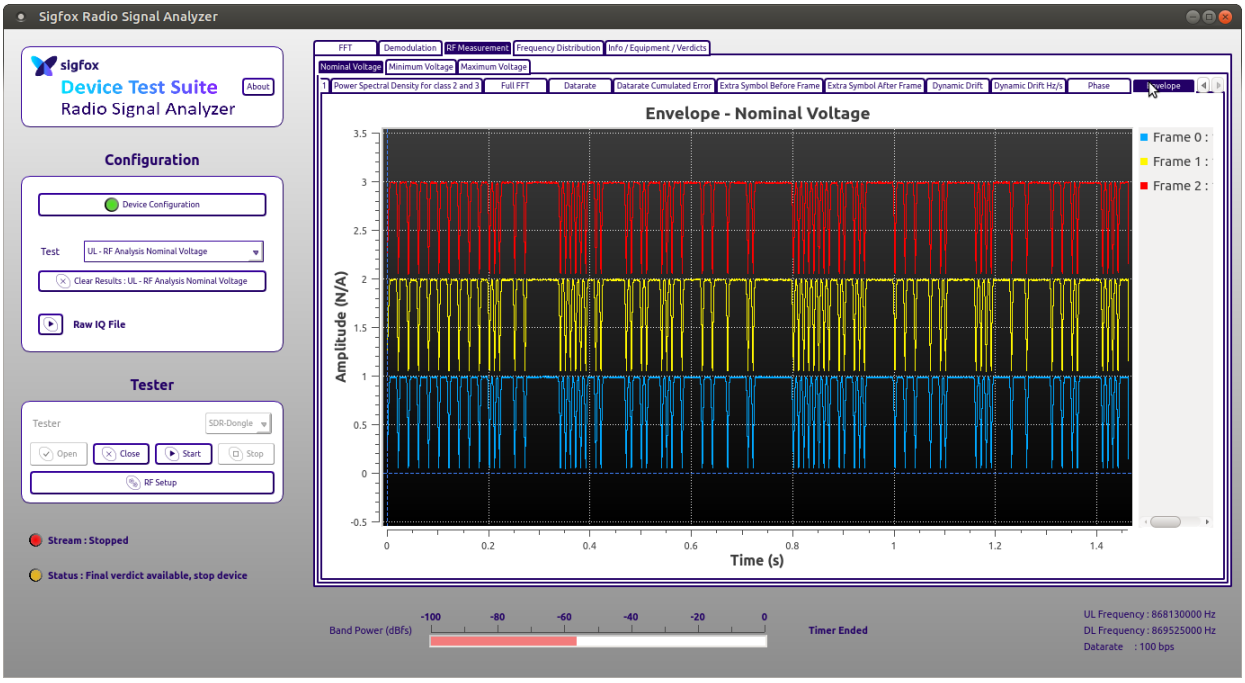


Figure 49: SX1261MB1BAS RC1 Envelope

6.4.14 Verdict

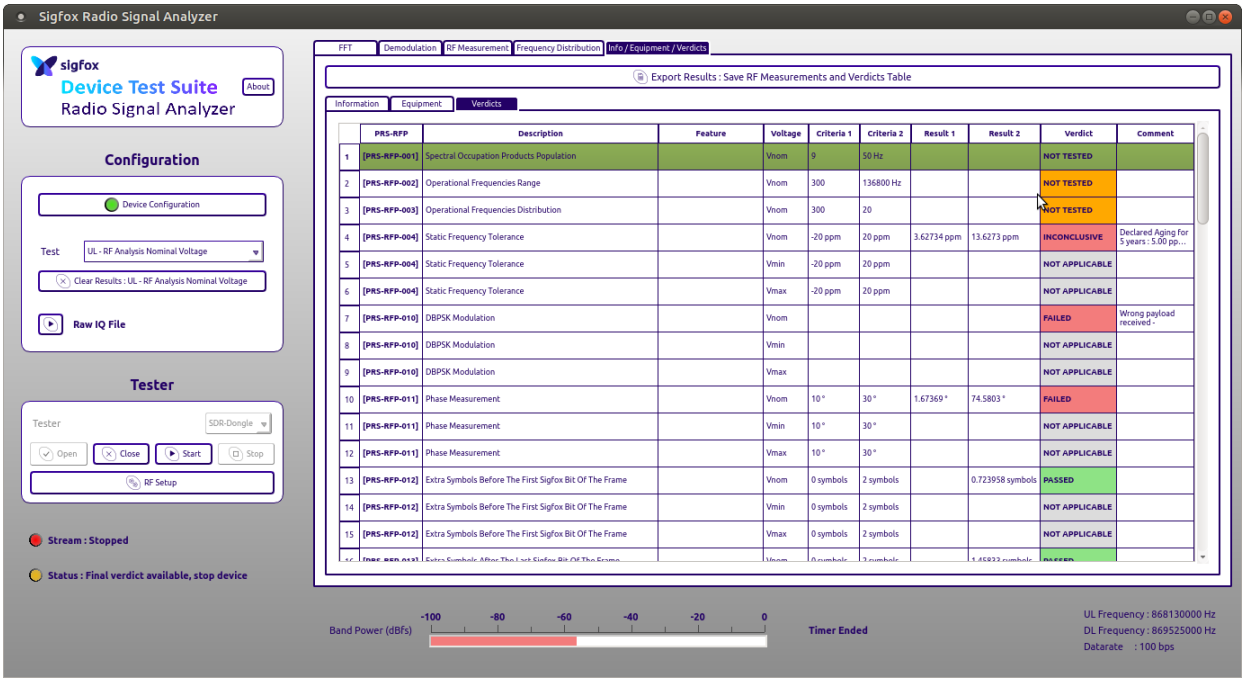


Figure 50: SX1261MB1BAS RC1 Verdict Page 1

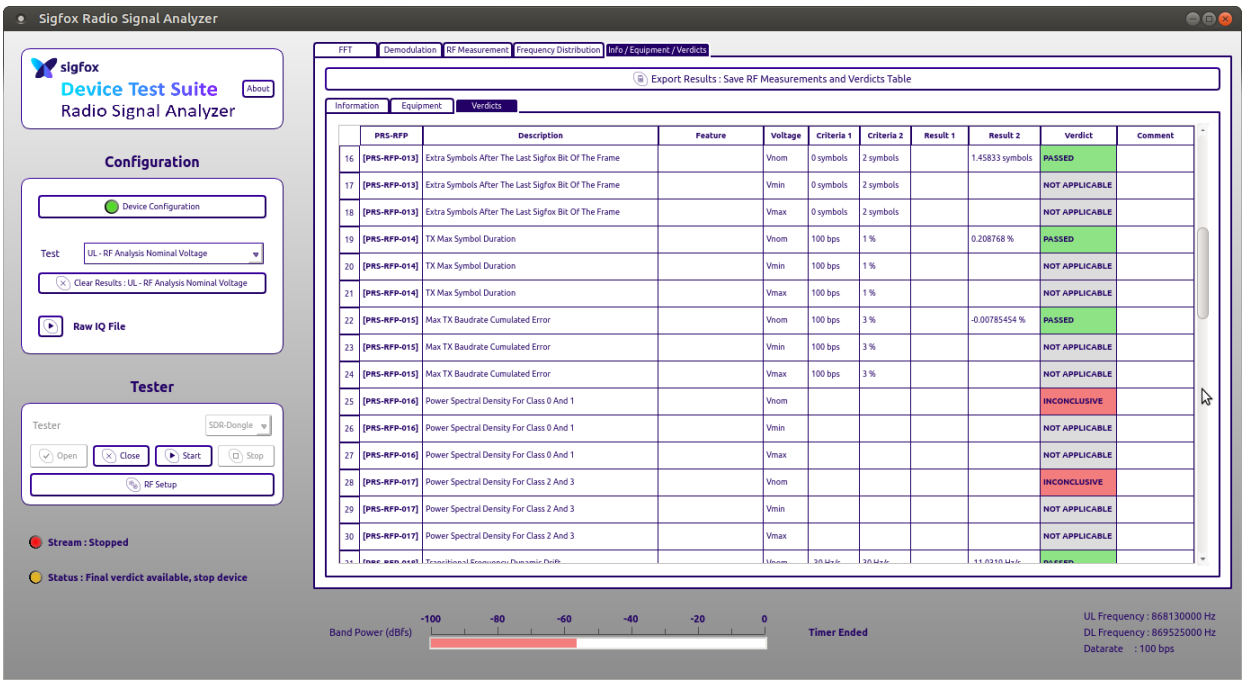


Figure 51: SX1261MB1BAS RC1 Verdict Page 2

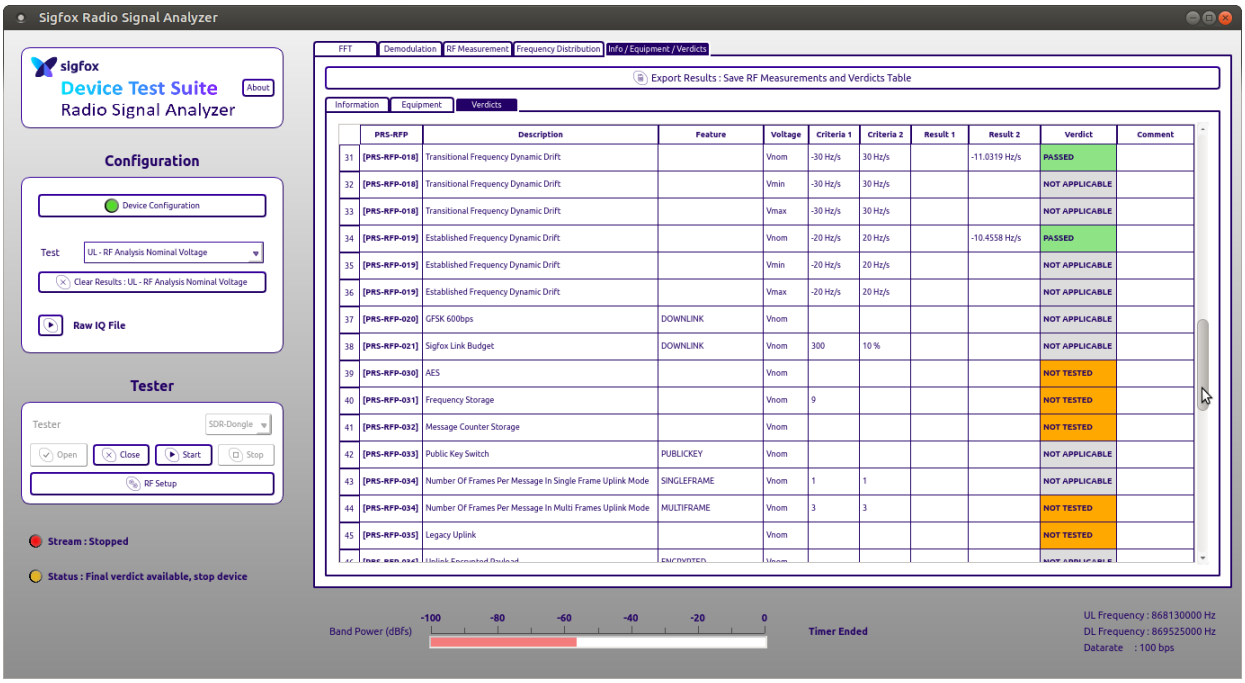


Figure 52: SX1261MB1BAS RC1 Verdict Page 3

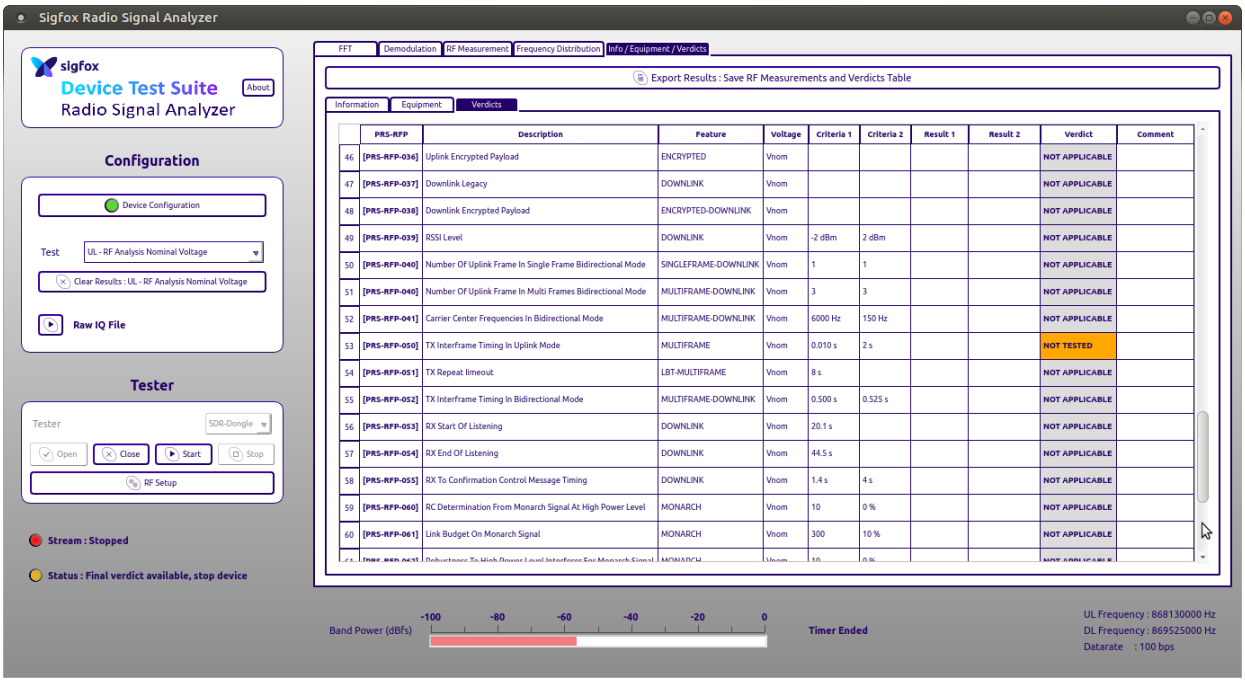


Figure 53: SX1261MB1BAS RC1 Verdict Page 4

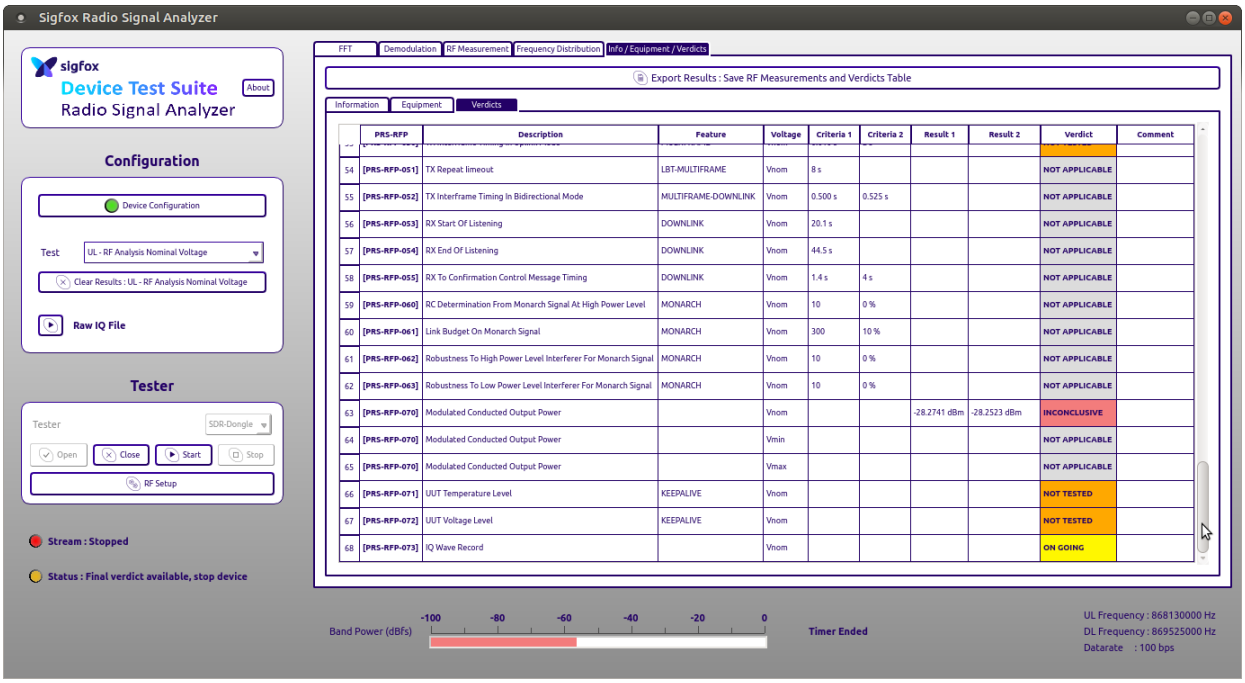


Figure 54: SX1261MB1BAS RC1 Verdict page 5

6.5 SX1261MB1BAS Measurement Results, XTAL, Radio Configuration RC2

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

For the RC2 case, note:

- in Figures 6.5.6 and 6.5.14, the test “PRS-RFP-014: Tx Max symbol duration” fails due to XTAL inaccuracy.
- in Figures 6.5.10 and 6.5.11, the Sigfox Radio Signal Analyzer tool fails to properly measure drift.

6.5.1 Device Configuration

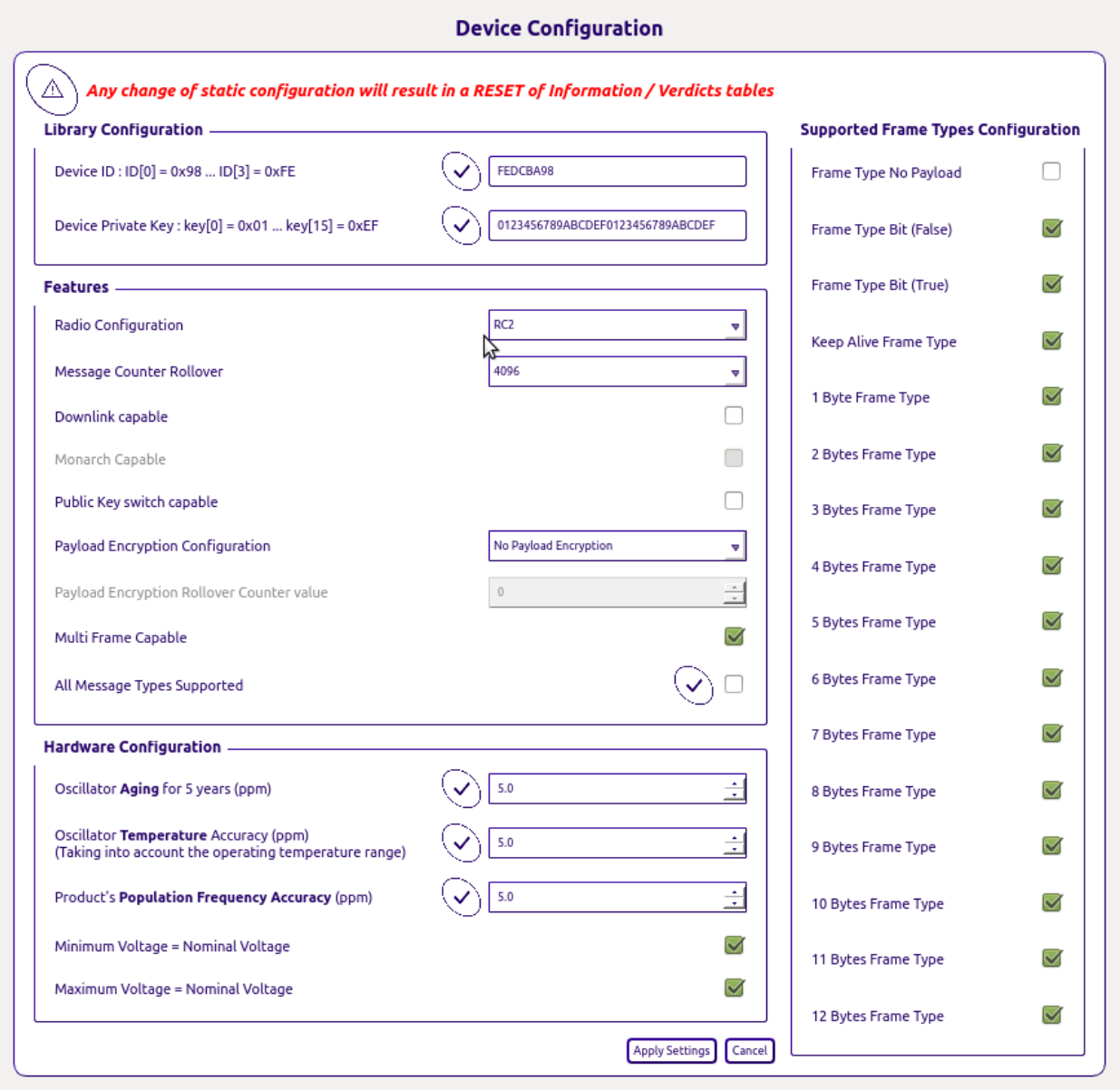


Figure 55: SX1261MB1BAS RC2 Device Configuration

6.5.2 FFT

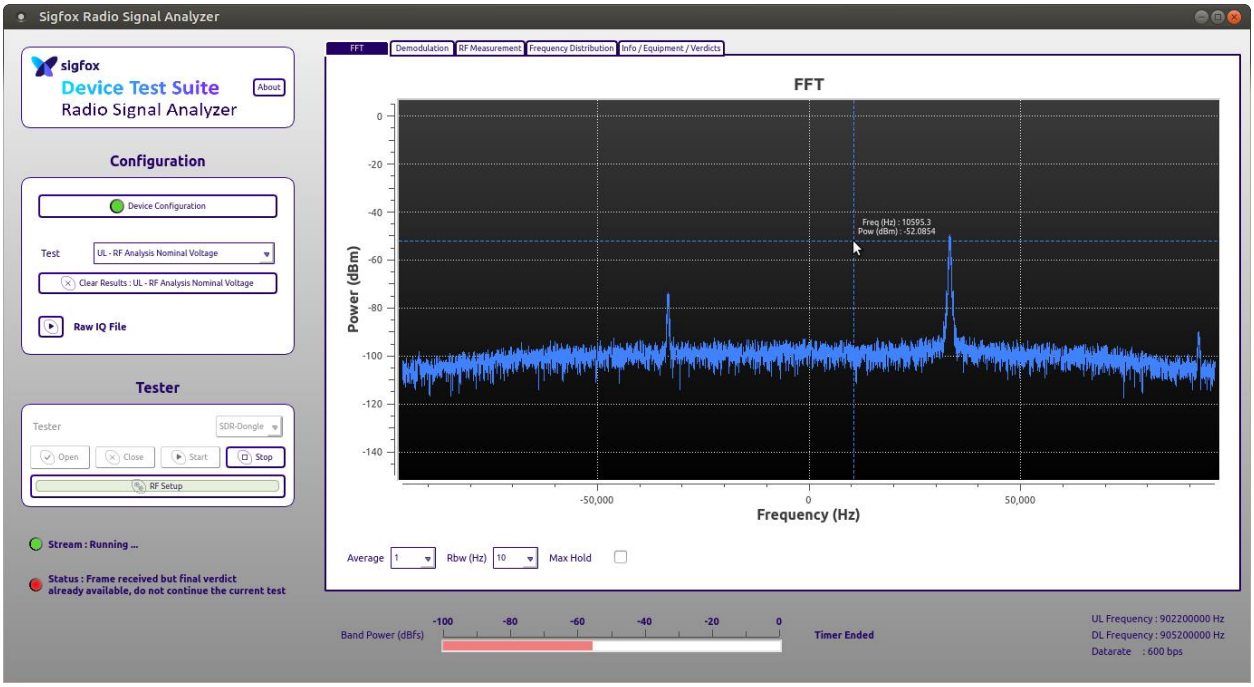


Figure 56: SX1261MB1BAS RC2 FFT

6.5.3 Demodulation

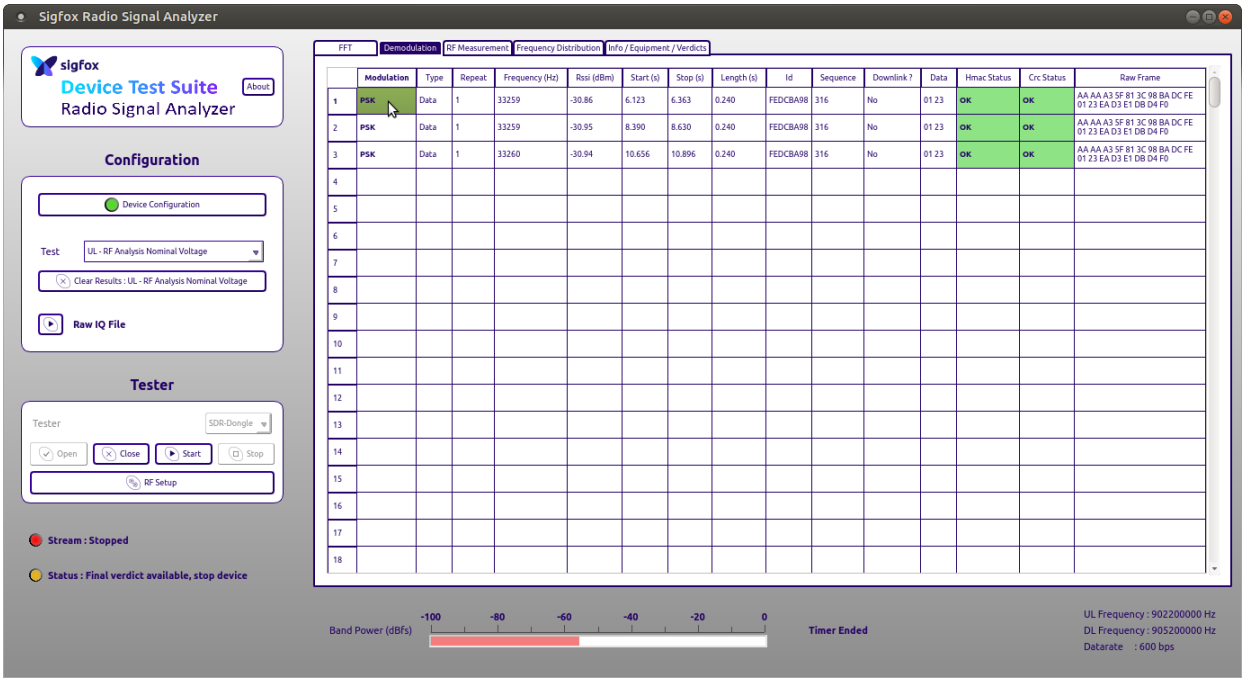


Figure 57: SX1261MB1BAS RC2 Demodulation

6.5.4 Power Spectral Density for Class 0 & 1

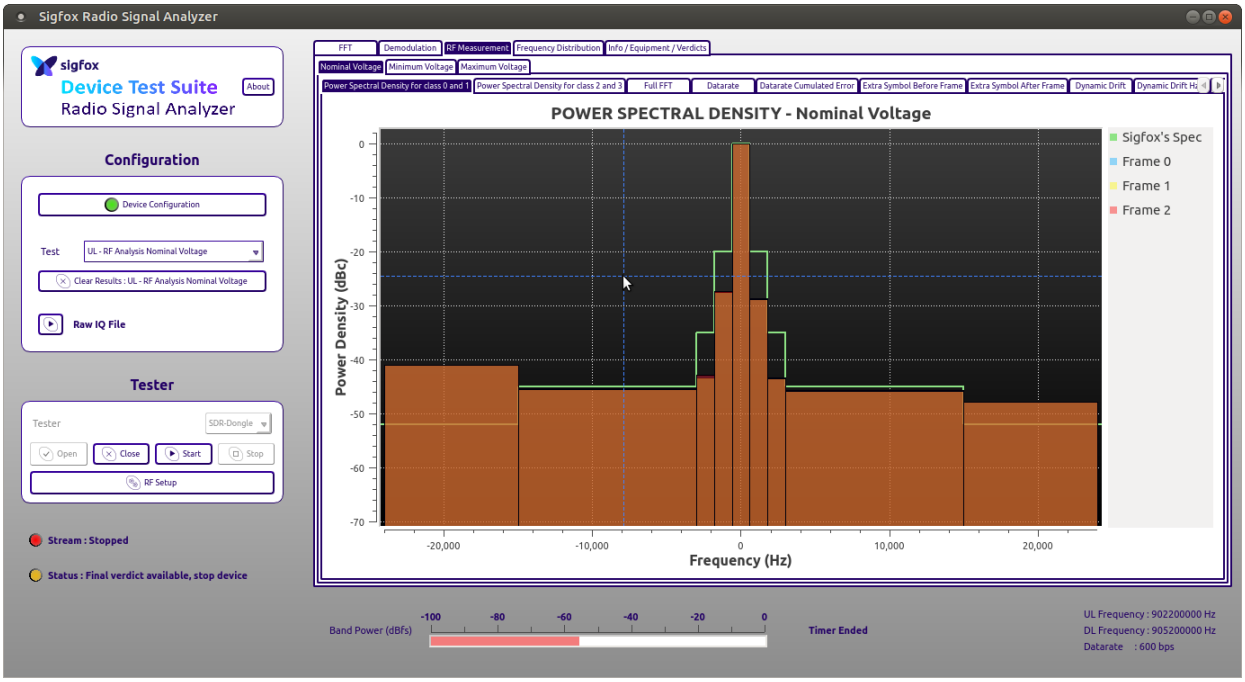


Figure 58: SX1261MB1BAS RC2 Power Spectral Density for Class 0 & 1

6.5.5 Full FFT

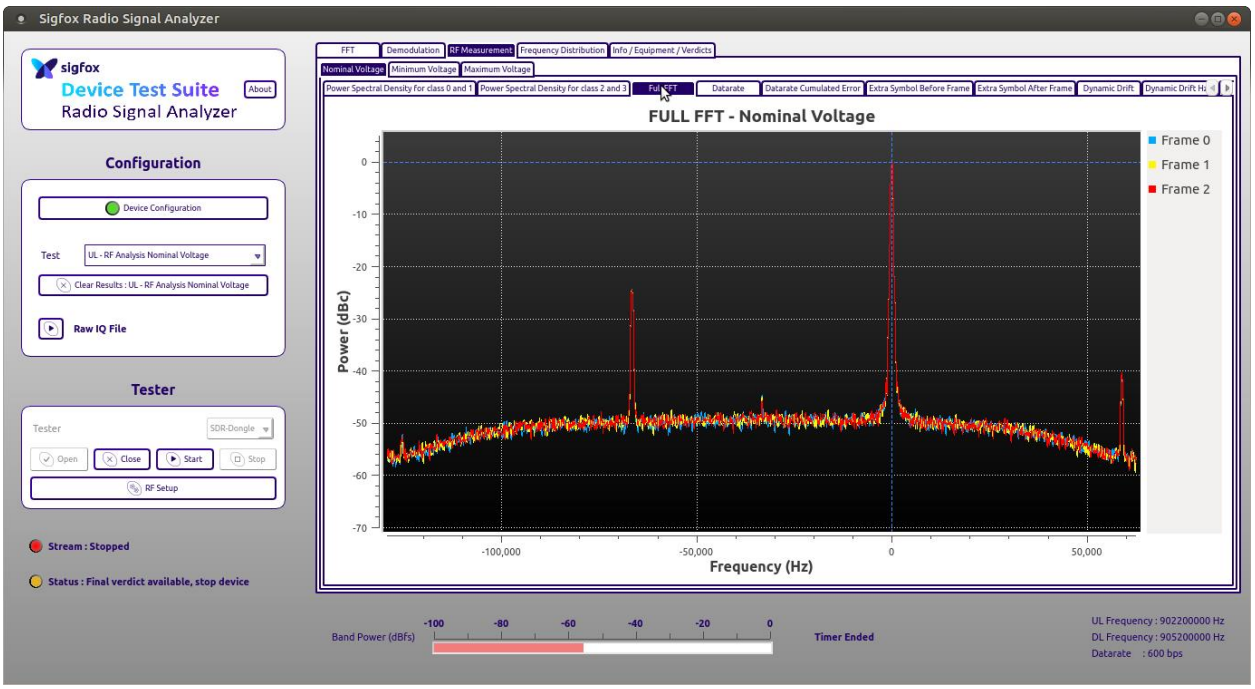


Figure 59: SX1261MB1BAS RC2 Full FFT

6.5.6 Data Rate

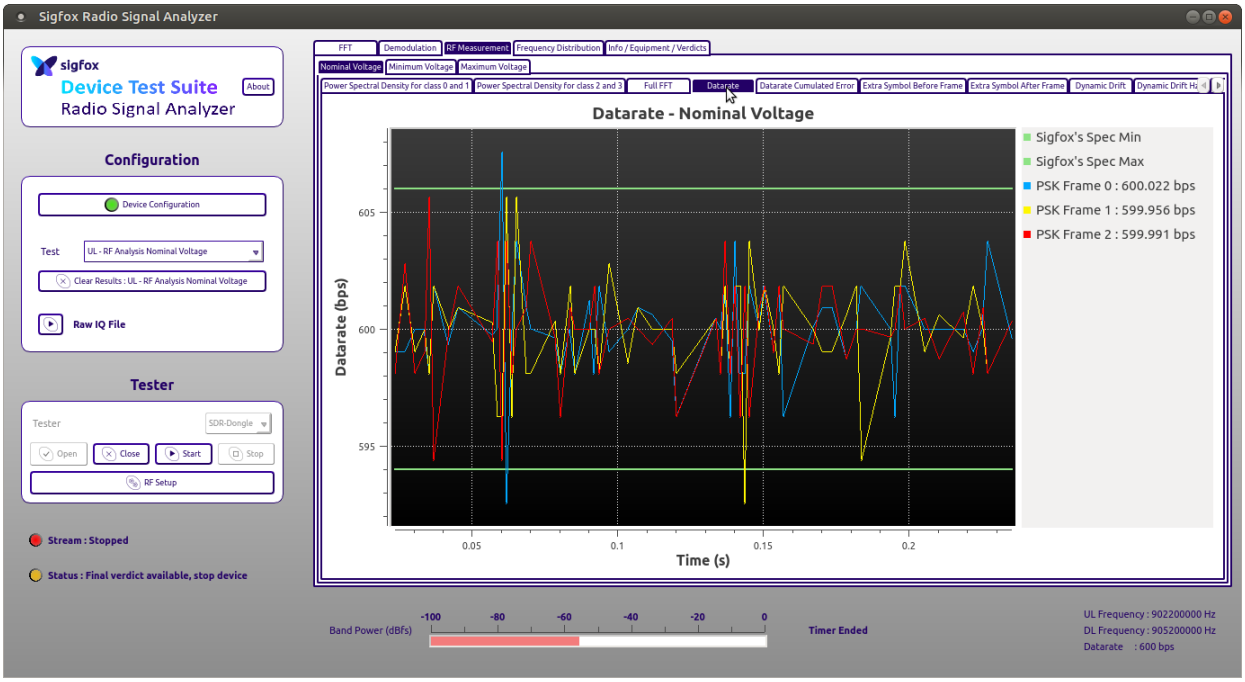


Figure 60: SX1261MB1BAS RC2 Data Rate

6.5.7 Data Rate Cumulated Error

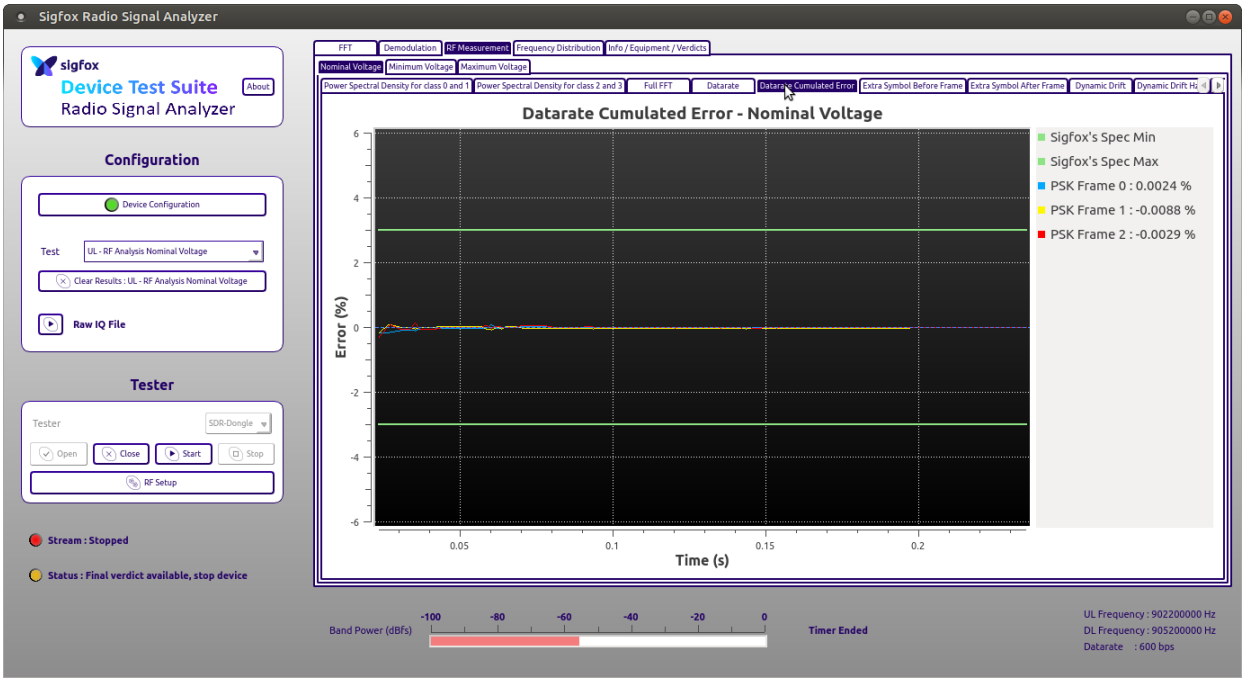


Figure 61: SX1261MB1BAS RC2 Data Rate Cumulated Error

6.5.8 Extra Symbol Before Transmission

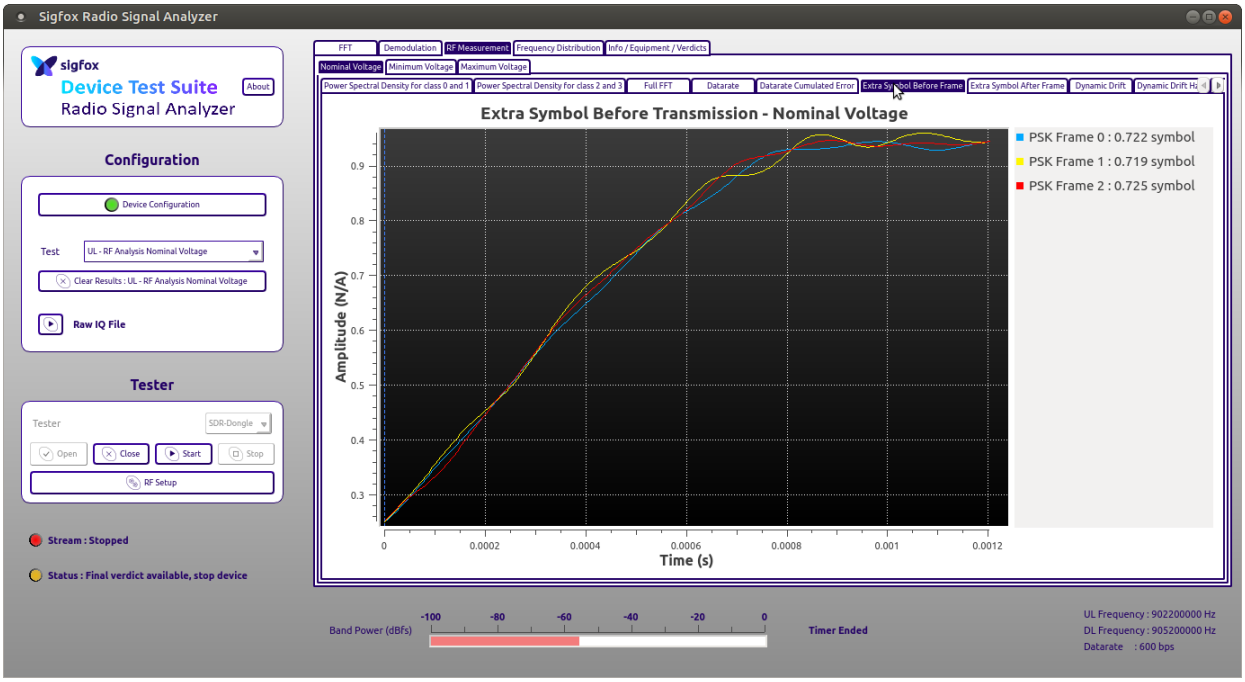


Figure 62: SX1261MB1BAS RC2 Extra Symbol Before Transmission

6.5.9 Extra Symbol After Transmission

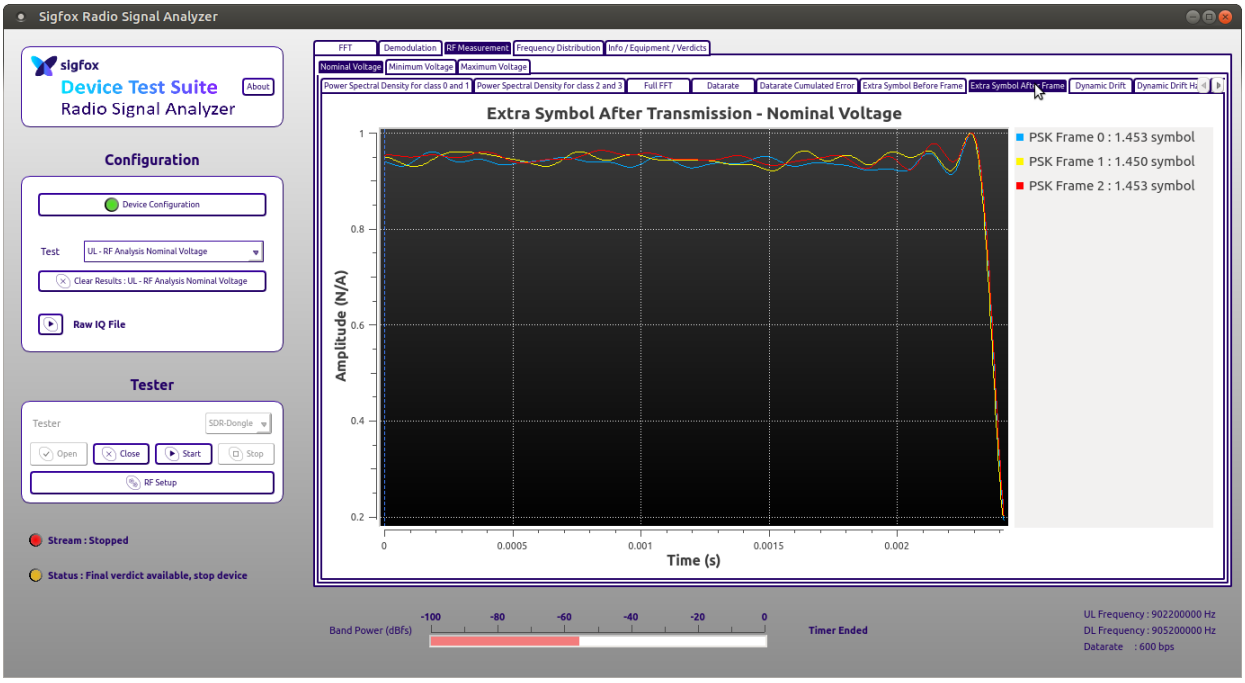


Figure 63: SX1261MB1BAS RC2 Extra Symbol After Transmission

6.5.10 Dynamic Drift

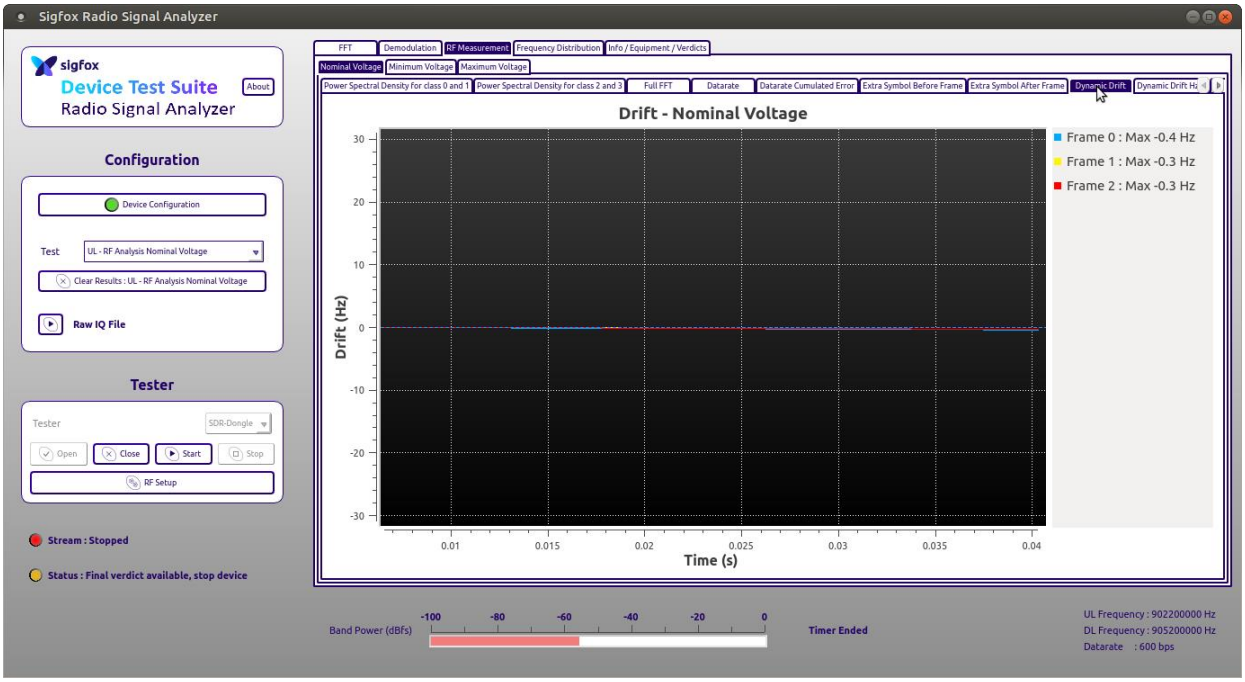


Figure 64: SX1261MB1BAS RC2 Dynamic Drift

6.5.11 Dynamic Drift per Second

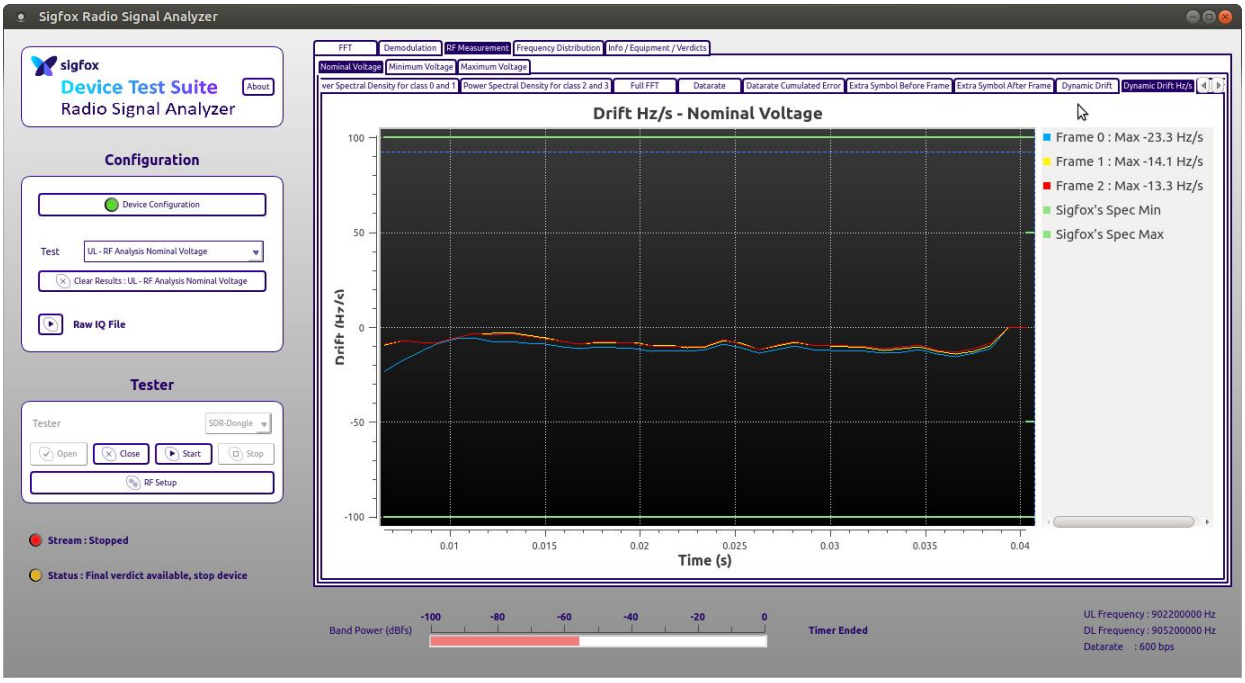


Figure 65: SX1261MB1BAS RC2 Dynamic Drift per Second

6.5.12 Phase

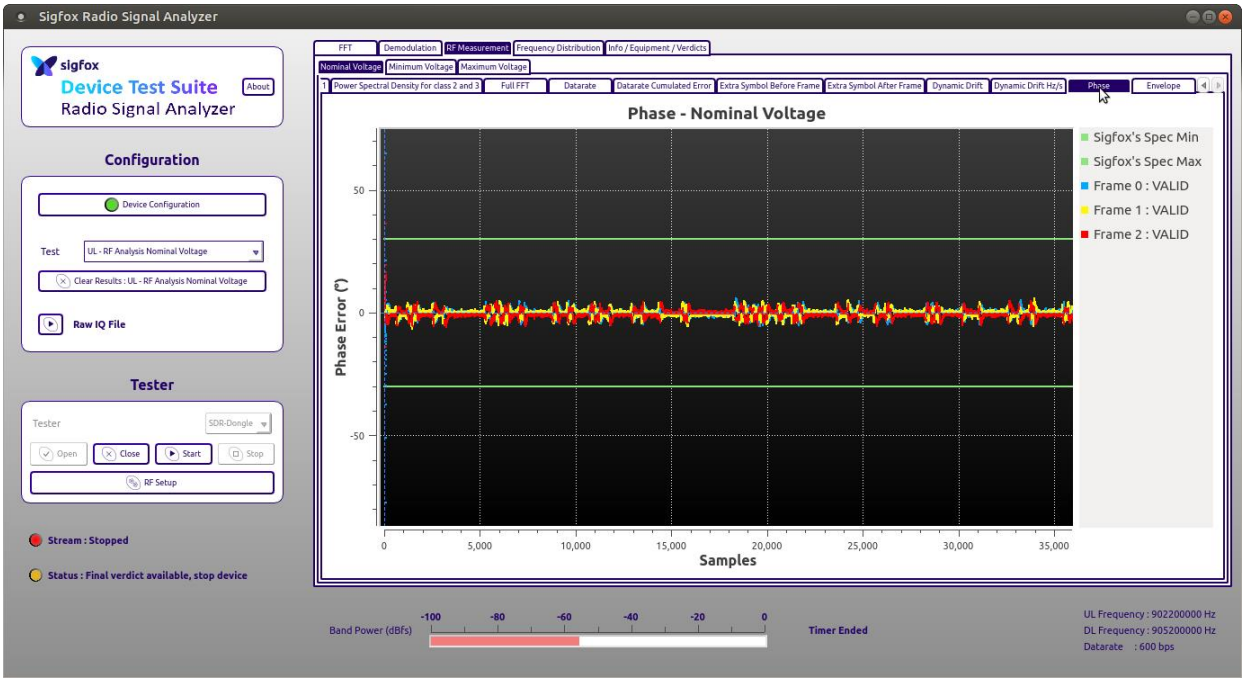


Figure 66: SX1261MB1BAS RC2 Phase

6.5.13 Envelope

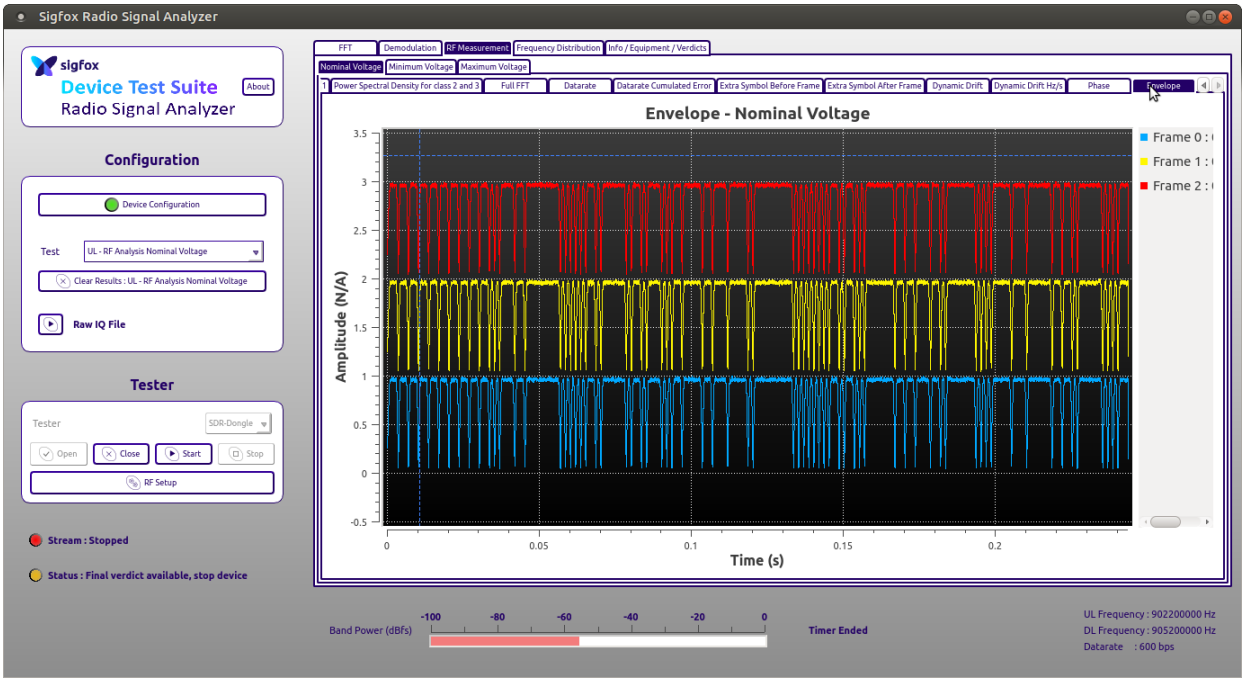


Figure 67: SX1261MB1BAS RC2 Envelope

6.5.14 Verdict

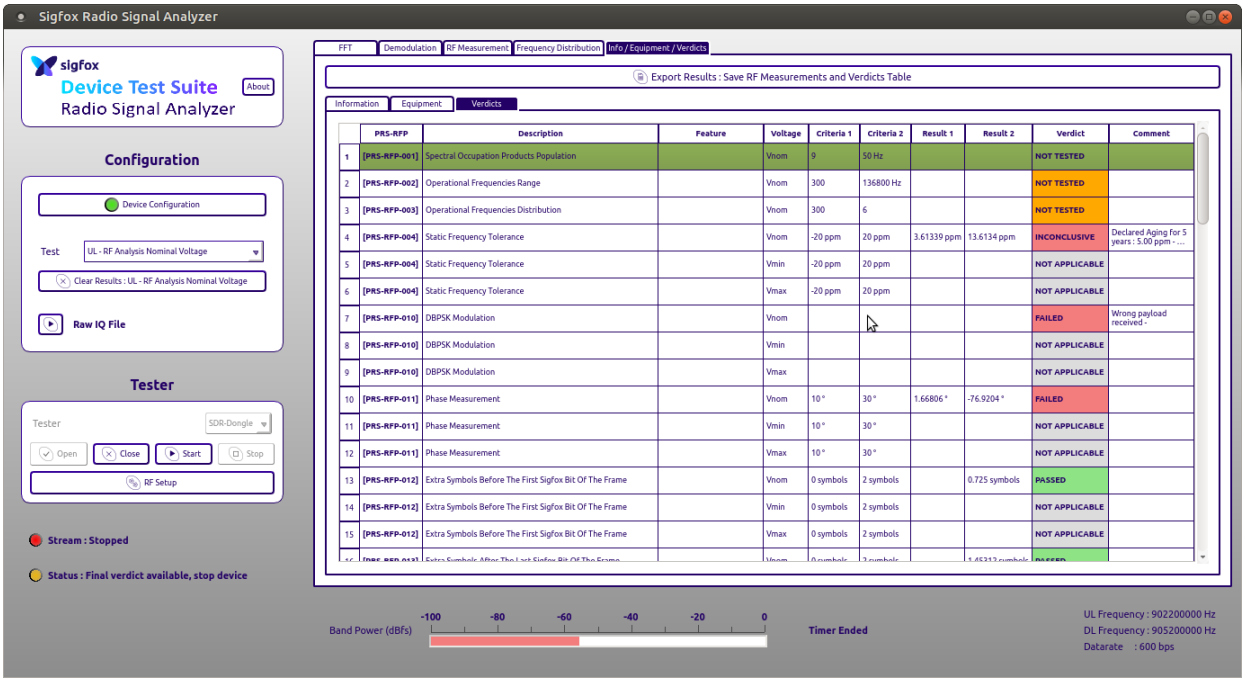


Figure 68: SX1261MB1BAS RC2 Verdict Page 1

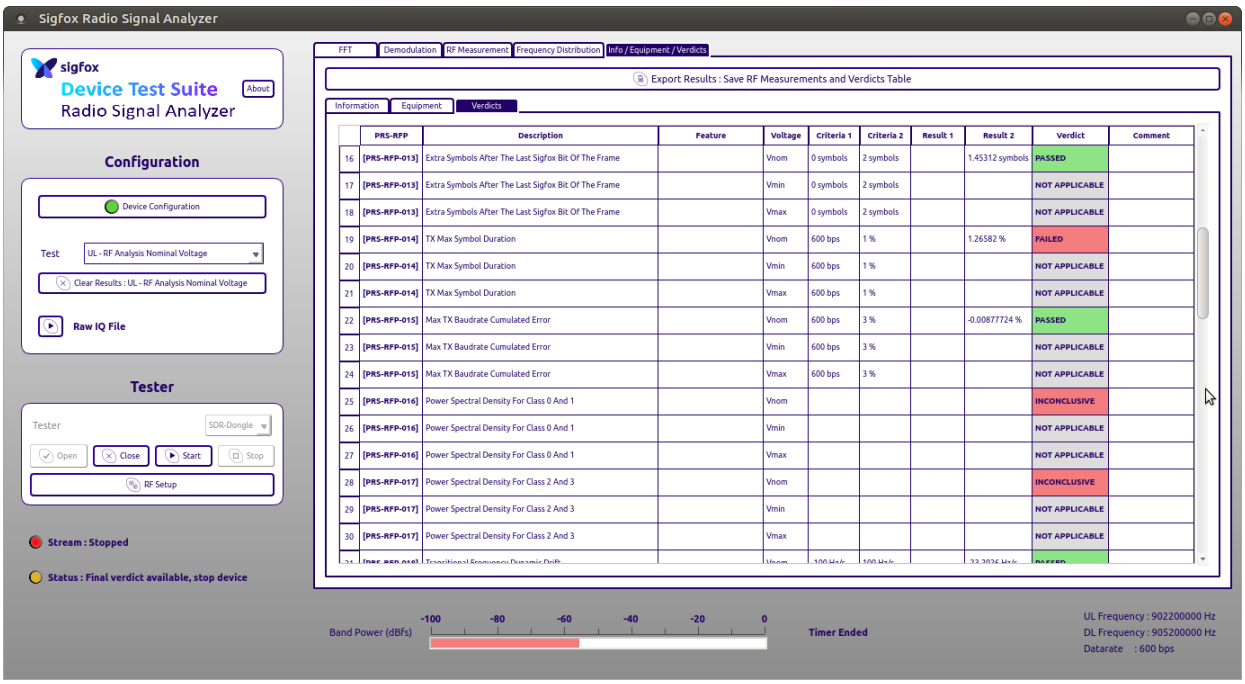
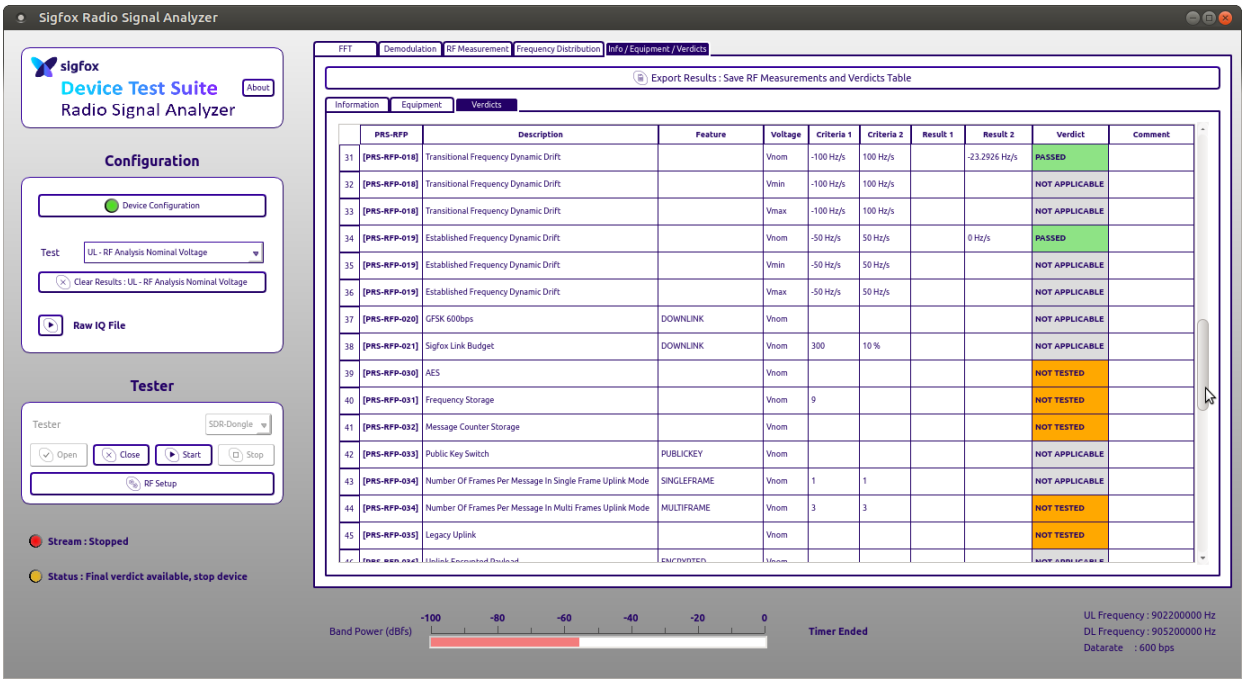
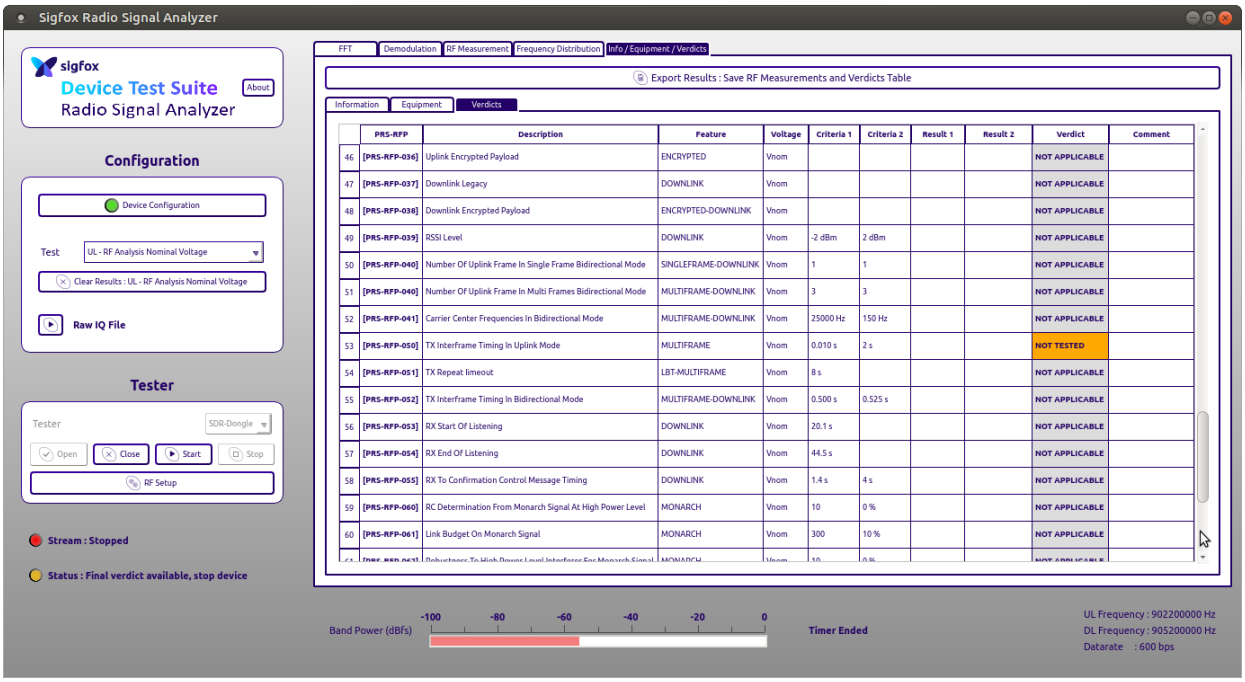


Figure 69: SX1261MB1BAS RC2 Verdict Page 2



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
31	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vnom	-100 Hz/s	100 Hz/s		-23.2926 Hz/s	PASSED	
32	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmin	-100 Hz/s	100 Hz/s			NOT APPLICABLE	
33	[PRS-RFP-018]	Transitional Frequency Dynamic Drift		Vmax	-100 Hz/s	100 Hz/s			NOT APPLICABLE	
34	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vnom	-50 Hz/s	50 Hz/s		0 Hz/s	PASSED	
35	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmin	-50 Hz/s	50 Hz/s			NOT APPLICABLE	
36	[PRS-RFP-019]	Established Frequency Dynamic Drift		Vmax	-50 Hz/s	50 Hz/s			NOT APPLICABLE	
37	[PRS-RFP-020]	GFSK 600bps	DOWNLINK	Vnom					NOT APPLICABLE	
38	[PRS-RFP-021]	Sigfox Link Budget	DOWNLINK	Vnom	300	10 %			NOT APPLICABLE	
39	[PRS-RFP-030]	AES		Vnom					NOT TESTED	
40	[PRS-RFP-031]	Frequency Storage		Vnom	9				NOT TESTED	
41	[PRS-RFP-032]	Message Counter Storage		Vnom					NOT TESTED	
42	[PRS-RFP-033]	Public Key Switch	PUBLICKEY	Vnom					NOT APPLICABLE	
43	[PRS-RFP-034]	Number Of Frames Per Message In Single Frame Uplink Mode	SINGLEFRAME	Vnom	1	1			NOT APPLICABLE	
44	[PRS-RFP-034]	Number Of Frames Per Message In Multi Frames Uplink Mode	MULTIFRAME	Vnom	3	3			NOT TESTED	
45	[PRS-RFP-035]	Legacy Uplink		Vnom					NOT TESTED	

Figure 70: SX1261MB1BAS RC2 Verdict Page 3



	PRS-RFP	Description	Feature	Voltage	Criteria 1	Criteria 2	Result 1	Result 2	Verdict	Comment
46	[PRS-RFP-036]	Uplink Encrypted Payload	ENCRYPTED	Vnom					NOT APPLICABLE	
47	[PRS-RFP-037]	Downlink Legacy	DOWNLINK	Vnom					NOT APPLICABLE	
48	[PRS-RFP-038]	Downlink Encrypted Payload	ENCRYPTED-DOWNLINK	Vnom					NOT APPLICABLE	
49	[PRS-RFP-039]	RSSI Level	DOWNLINK	Vnom	-2 dBm	2 dBm			NOT APPLICABLE	
50	[PRS-RFP-040]	Number Of Uplink Frame In Single Frame Bidirectional Mode	SINGLEFRAME-DOWNLINK	Vnom	1	1			NOT APPLICABLE	
51	[PRS-RFP-040]	Number Of Uplink Frame In Multi Frames Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	3	3			NOT APPLICABLE	
52	[PRS-RFP-041]	Carrier Center Frequencies In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	25000 Hz	150 Hz			NOT APPLICABLE	
53	[PRS-RFP-050]	TX Interframe Timing In Uplink Mode	MULTIFRAME	Vnom	0.010 s	2 s			NOT TESTED	
54	[PRS-RFP-051]	TX Repeat timeout	LBT-MULTIFRAME	Vnom	8 s				NOT APPLICABLE	
55	[PRS-RFP-052]	TX Interframe Timing In Bidirectional Mode	MULTIFRAME-DOWNLINK	Vnom	0.500 s	0.525 s			NOT APPLICABLE	
56	[PRS-RFP-053]	RX Start Of Listening	DOWNLINK	Vnom	20.1 s				NOT APPLICABLE	
57	[PRS-RFP-054]	RX End Of Listening	DOWNLINK	Vnom	44.5 s				NOT APPLICABLE	
58	[PRS-RFP-055]	RX To Confirmation Control Message Timing	DOWNLINK	Vnom	1.4 s	4 s			NOT APPLICABLE	
59	[PRS-RFP-060]	RC Determination From Monarch Signal At High Power Level	MONARCH	Vnom	10	0 %			NOT APPLICABLE	
60	[PRS-RFP-061]	Link Budget On Monarch Signal	MONARCH	Vnom	300	10 %			NOT APPLICABLE	

Figure 71: SX1261MB1BAS RC2 Verdict Page 4

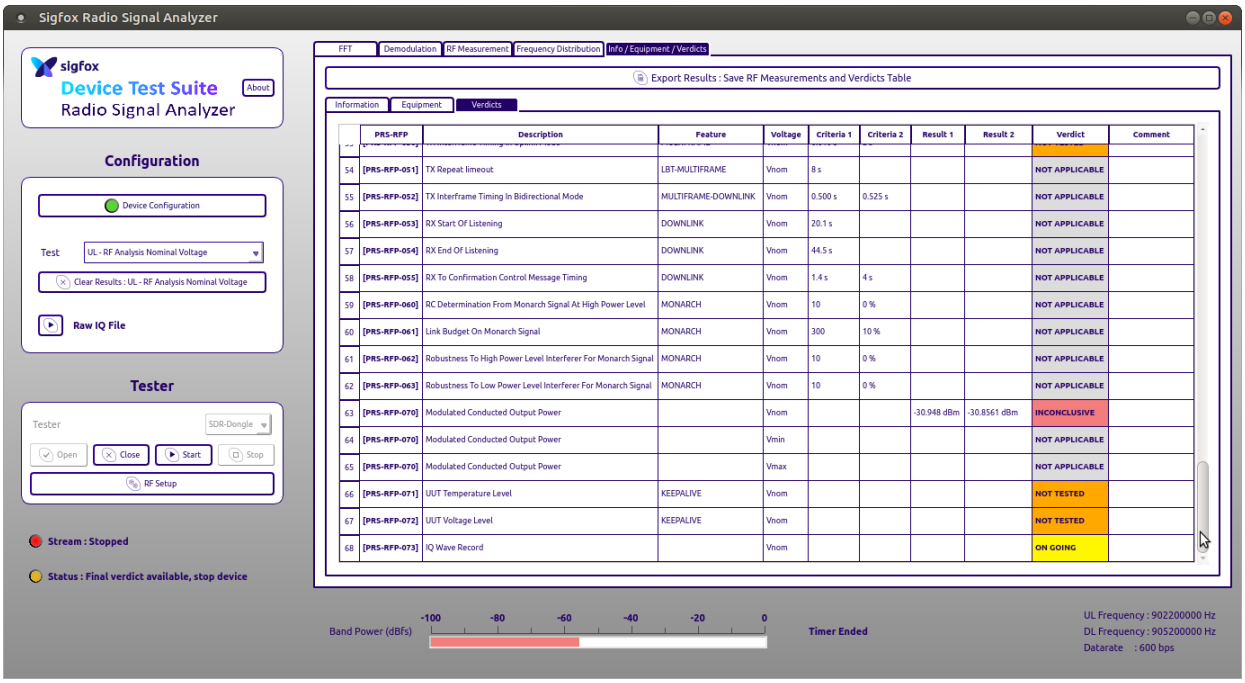


Figure 72: SX1261MB1BAS RC2 Verdict page 5

6.6 SX1262DVK1DAS Measurement Results, TCXO, Radio Configuration RC1

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

6.6.1 Device Configuration

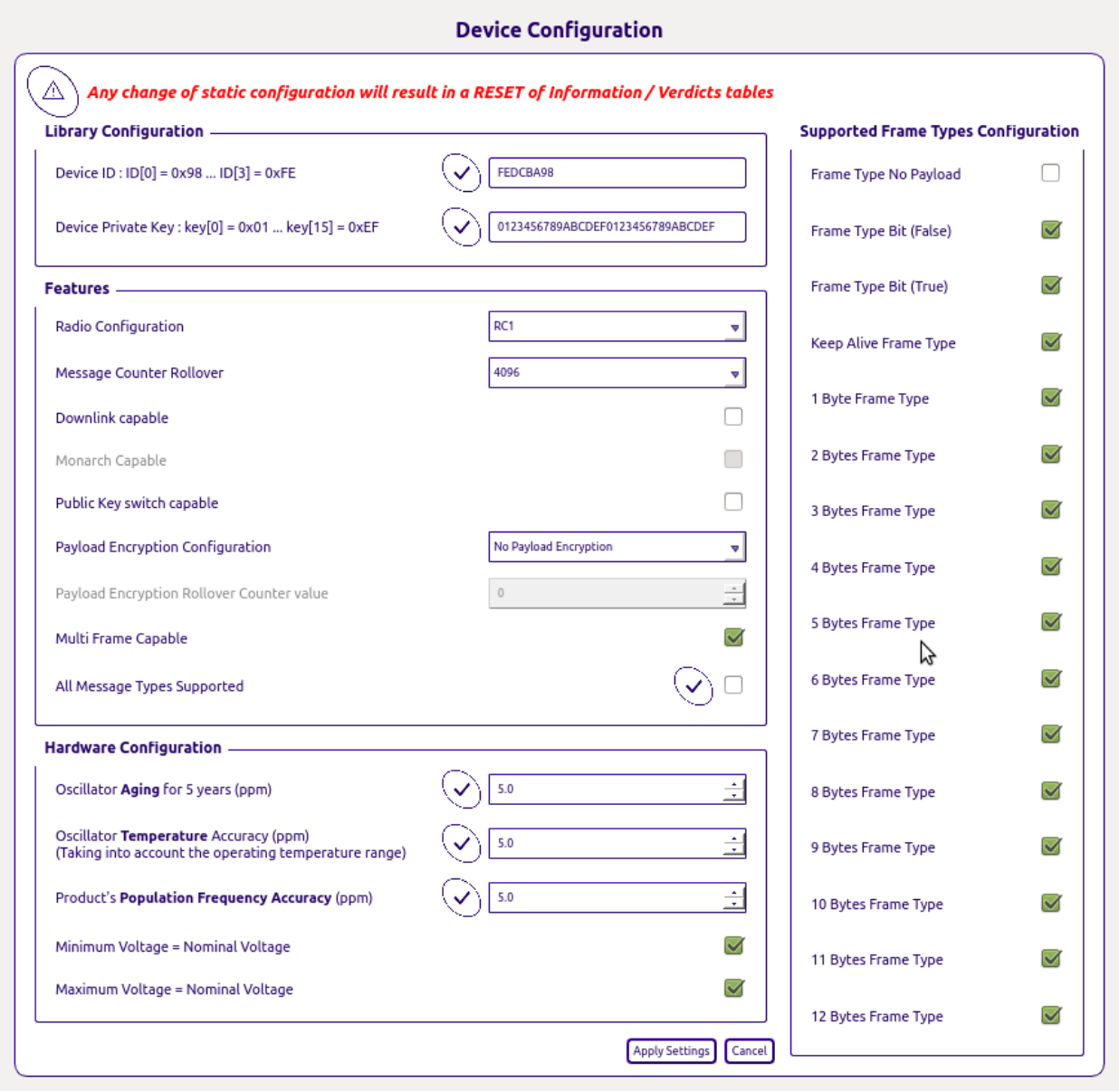


Figure 73: SX1262DVK1DAS RC1 Device Configuration

6.6.2 FFT

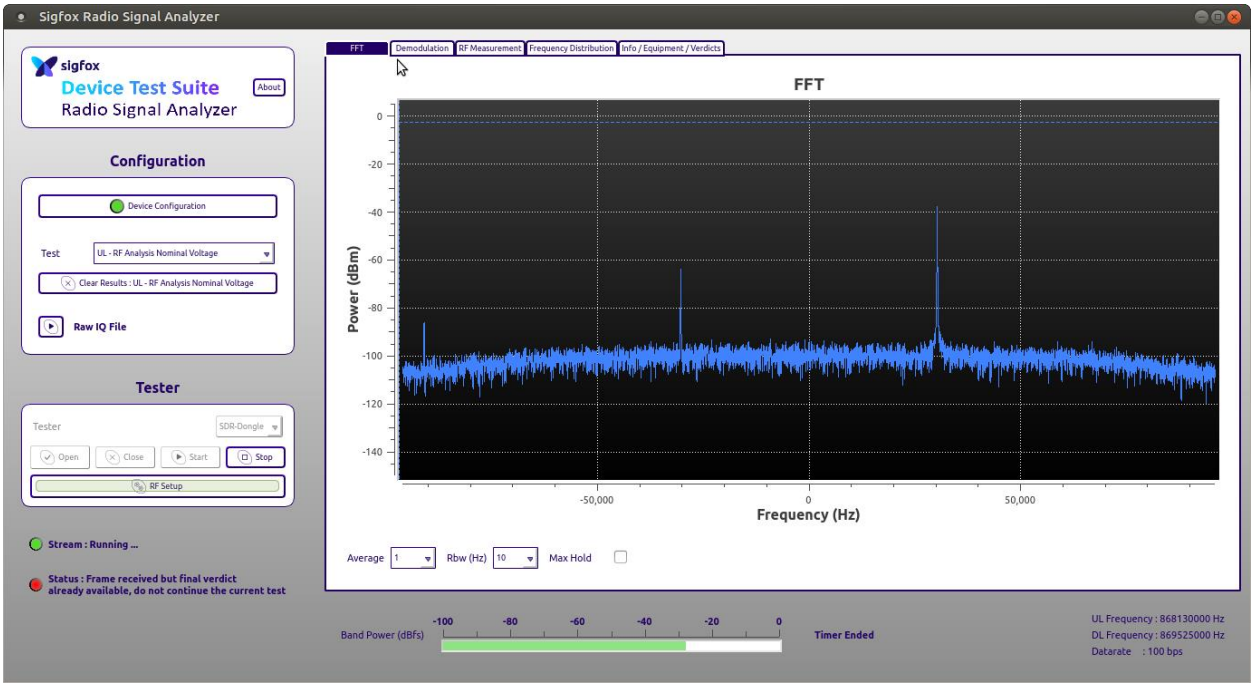


Figure 74: SX1262DVK1DAS RC1 FFT

6.6.3 Demodulation

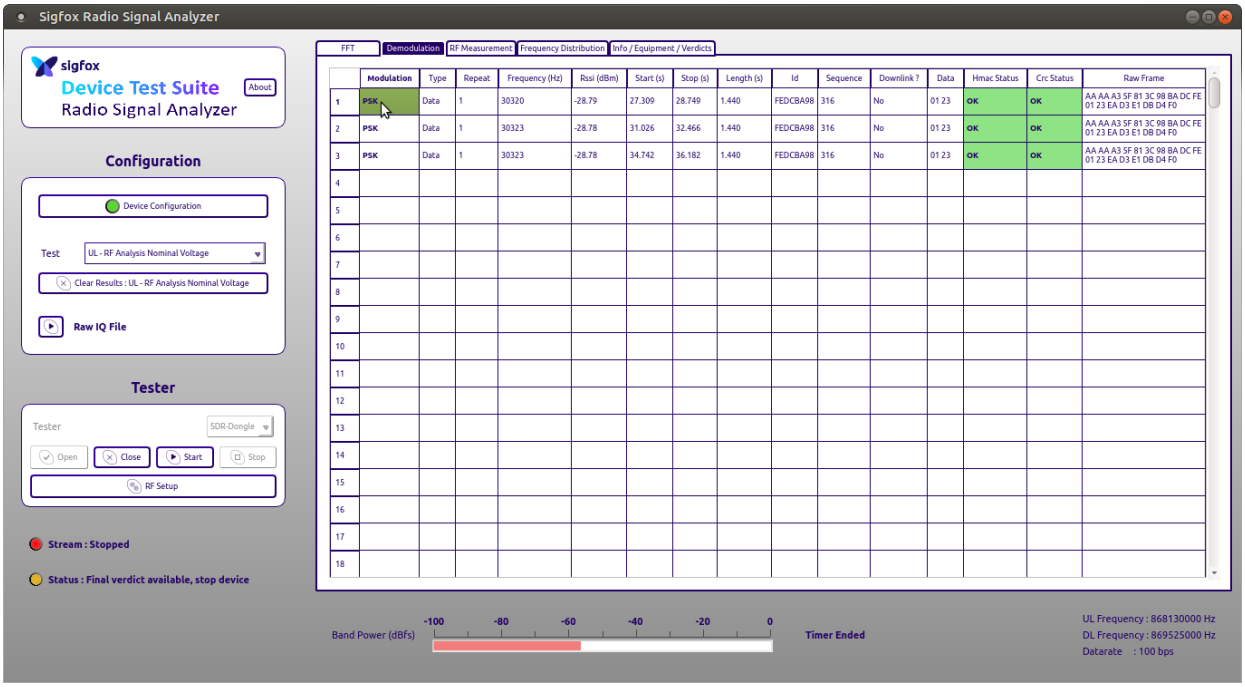


Figure 75: SX1262DVK1DAS RC1 Demodulation

6.6.4 Power Spectral Density for Class 0 & 1

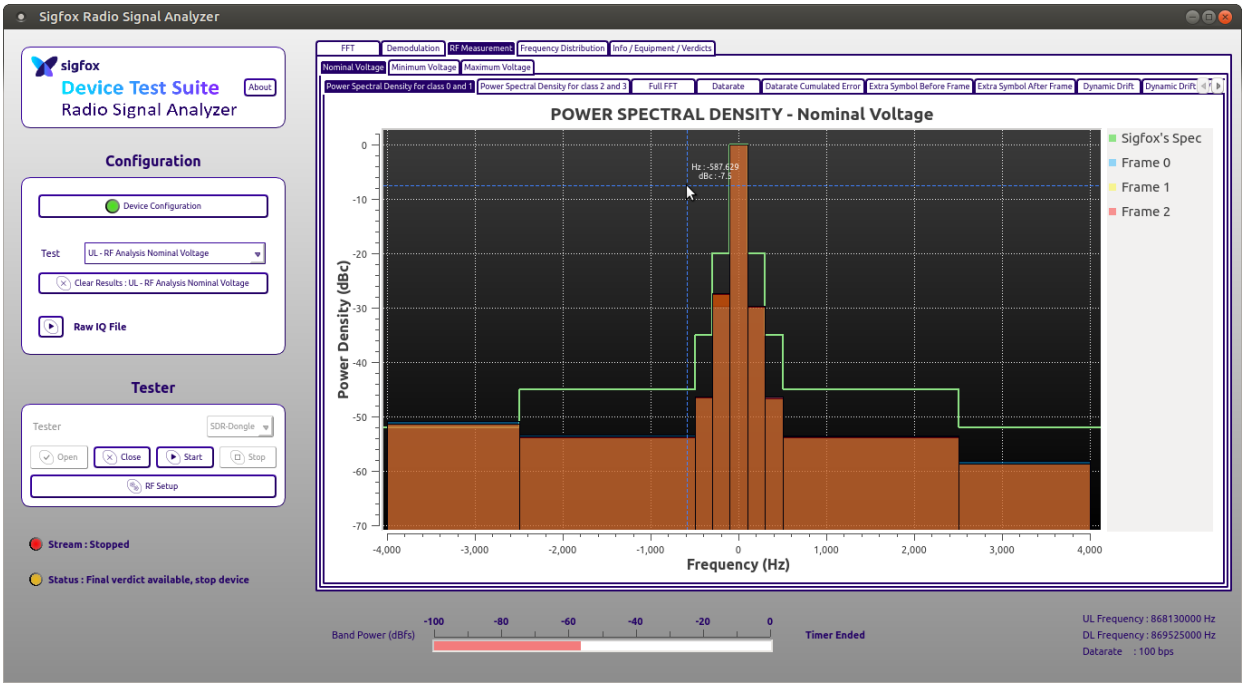


Figure 76: SX1262DVK1DAS RC1 Power Spectral Density for Class 0 & 1

6.6.5 Full FFT

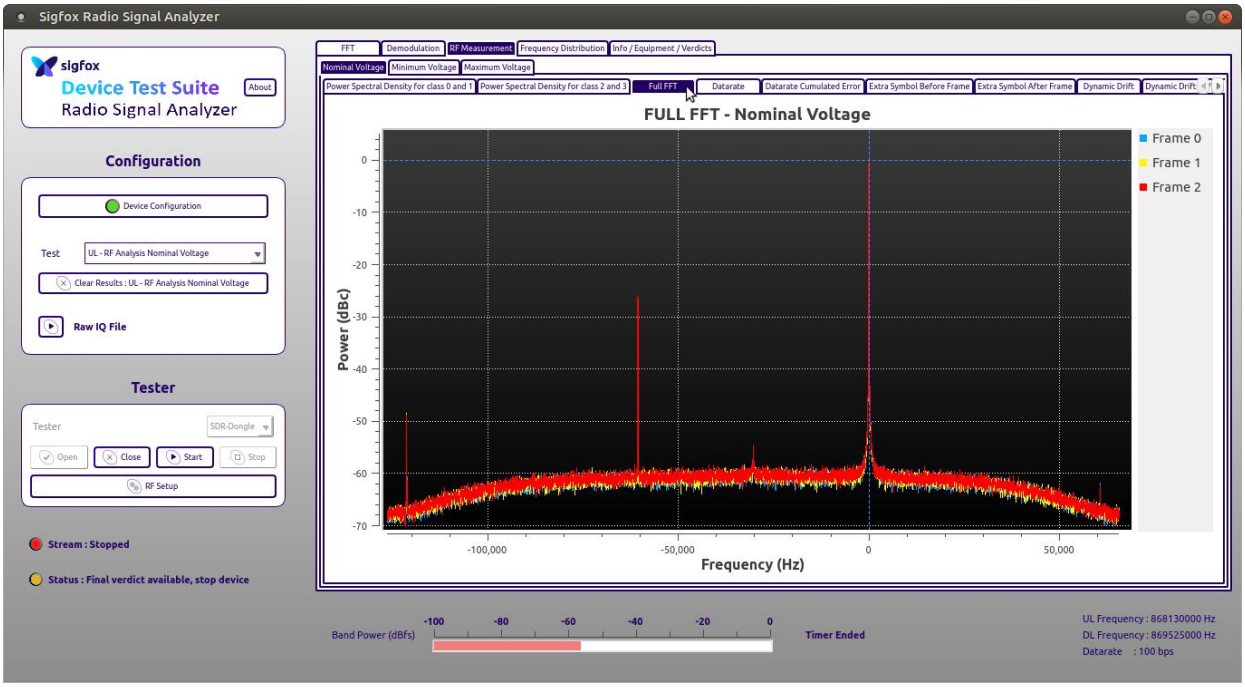


Figure 77: SX1262DVK1DAS RC1 Full FFT

6.6.6 Data Rate

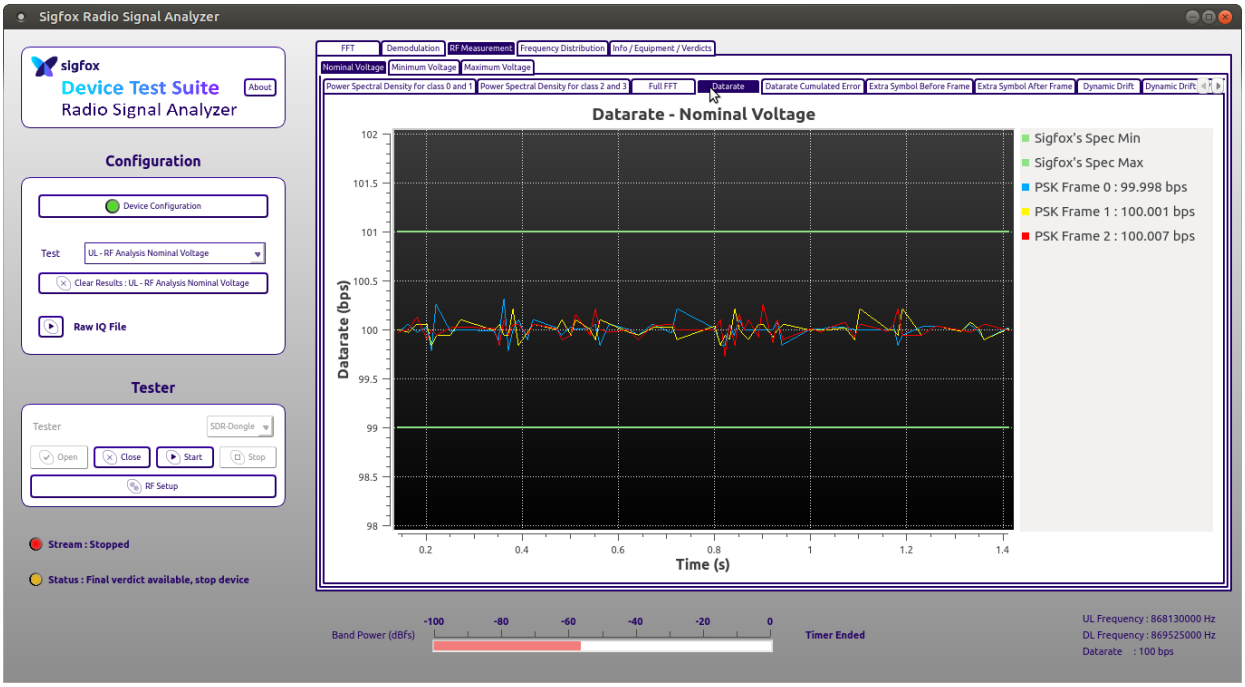


Figure 78: SX1262DVK1DAS RC1 Data Rate

6.6.7 Data Rate Cumulated Error

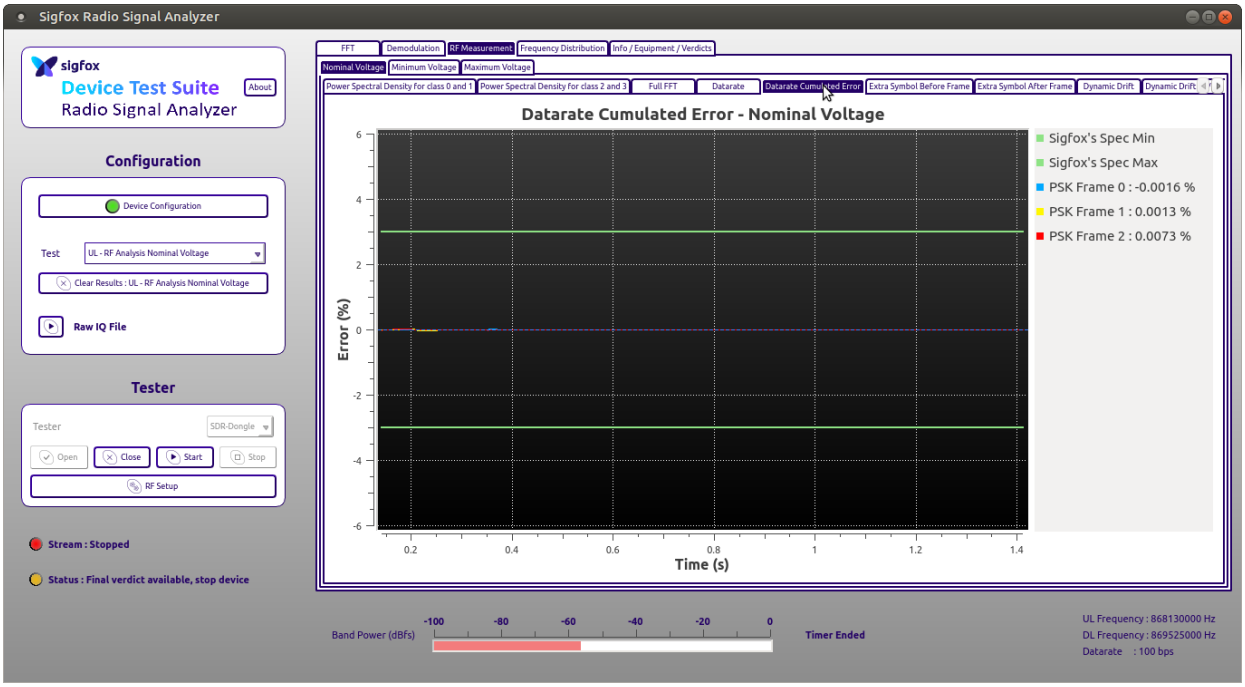


Figure 79: SX1262DVK1DAS RC1 Data Rate Cumulated Error

6.6.8 Extra Symbol Before Transmission

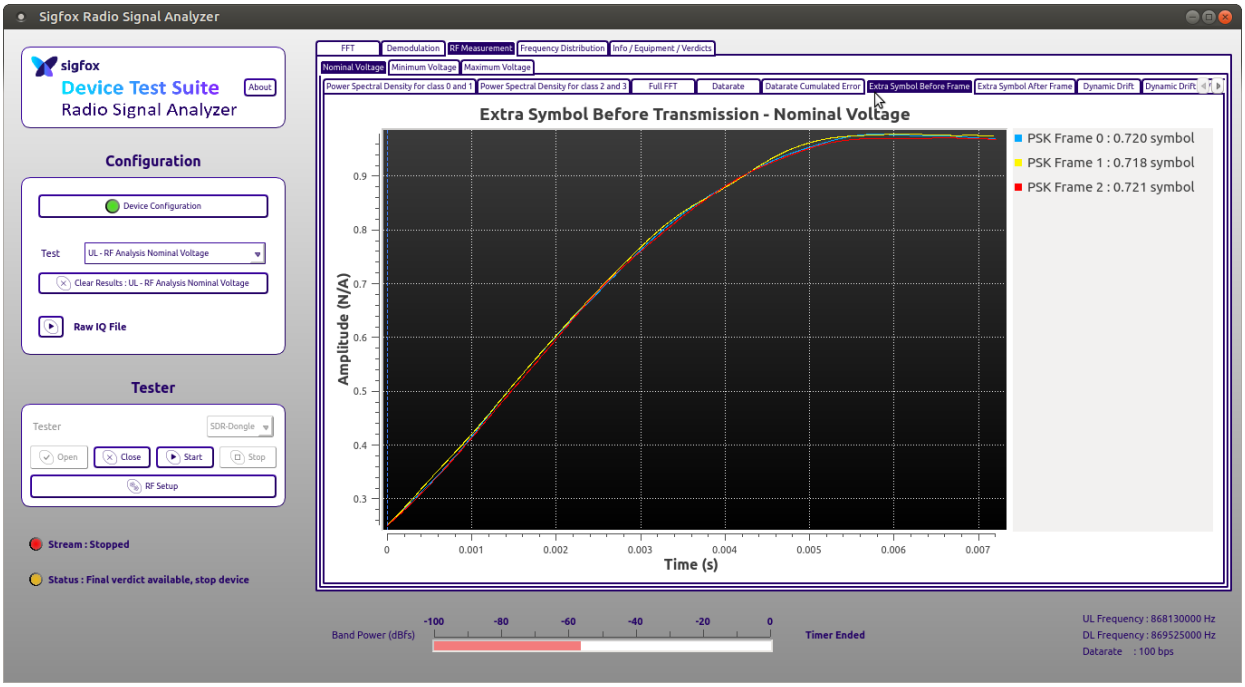


Figure 80: SX1262DVK1DAS RC1 Extra Symbol Before Transmission

6.6.9 Extra Symbol After Transmission

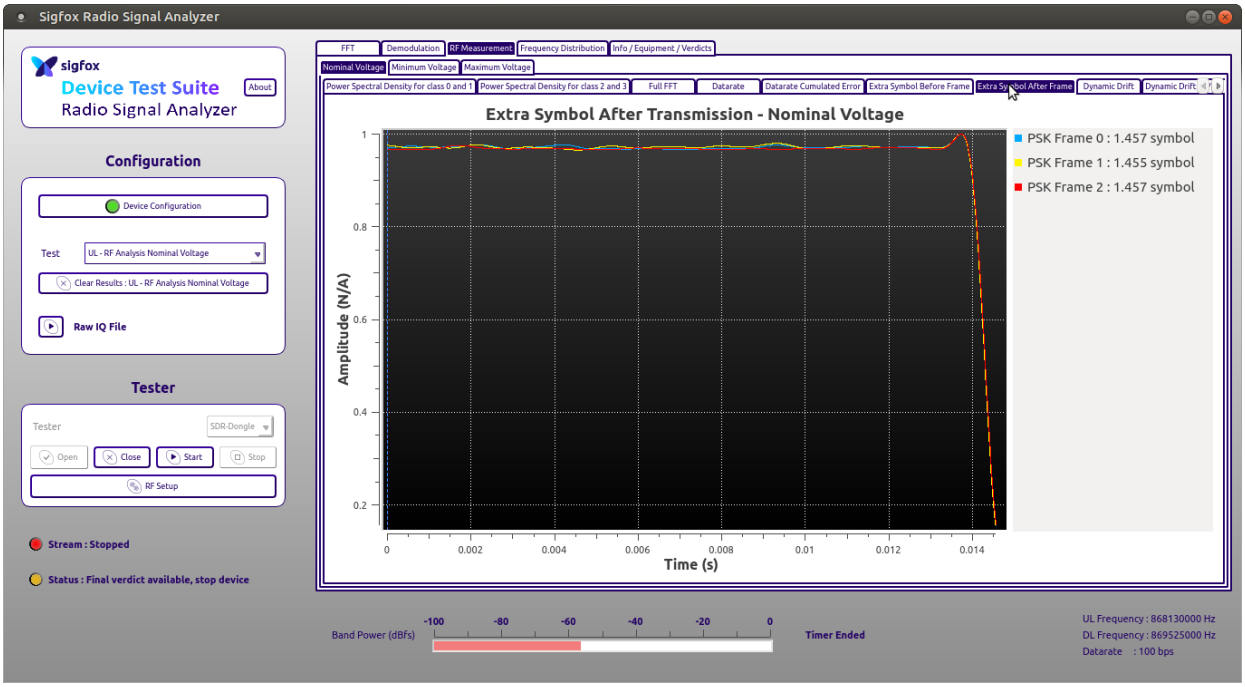


Figure 81: SX1262DVK1DAS RC1 Extra Symbol After Transmission

6.6.10 Dynamic Drift

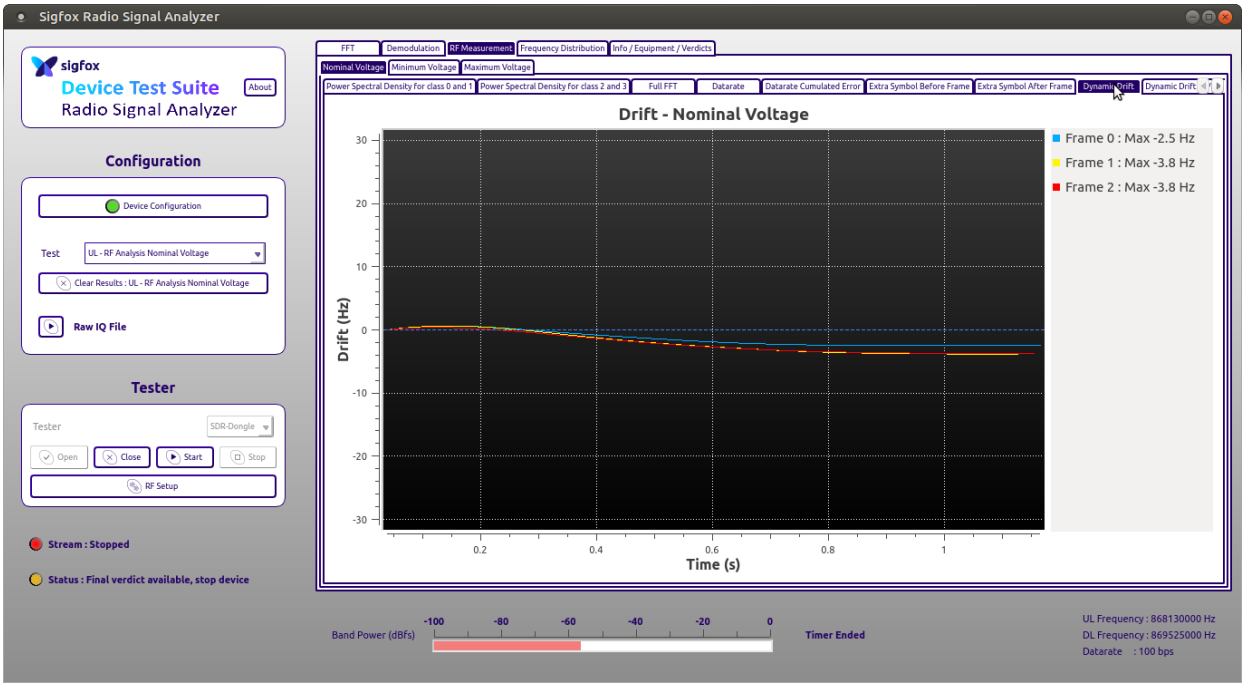


Figure 82: SX1262DVK1DAS RC1 Dynamic Drift

6.6.11 Dynamic Drift per Second

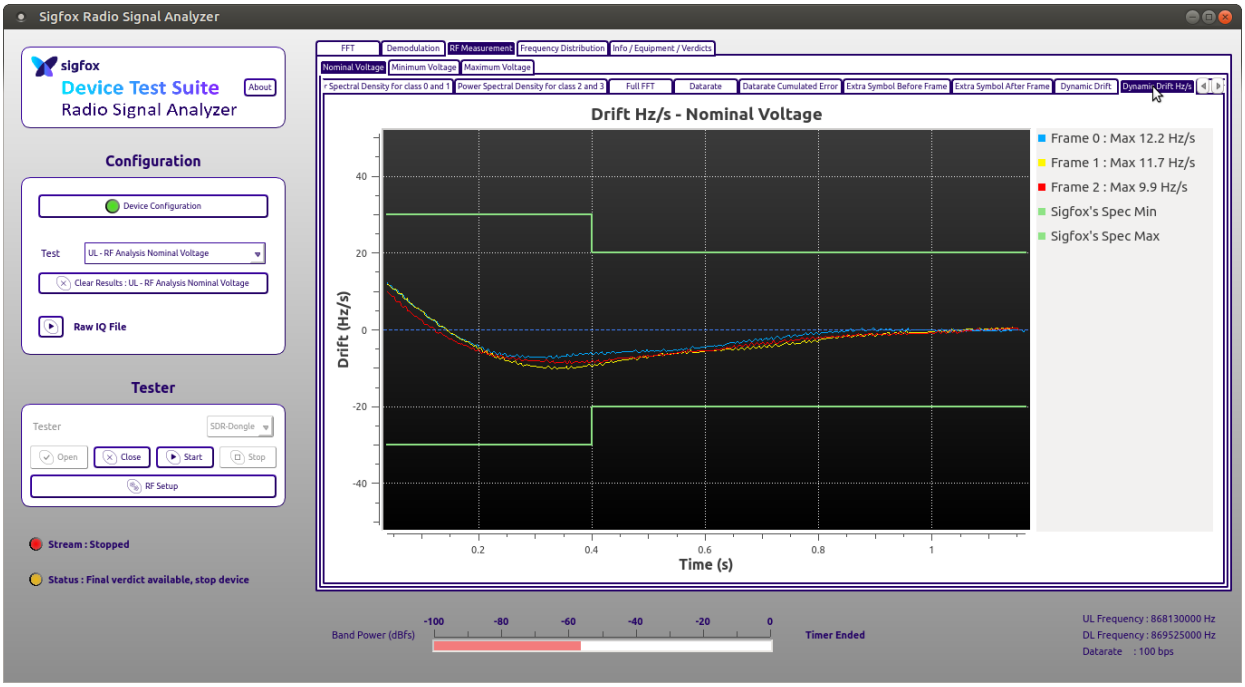


Figure 83: SX1262DVK1DAS RC1 Dynamic Drift per Second

6.6.12 Phase

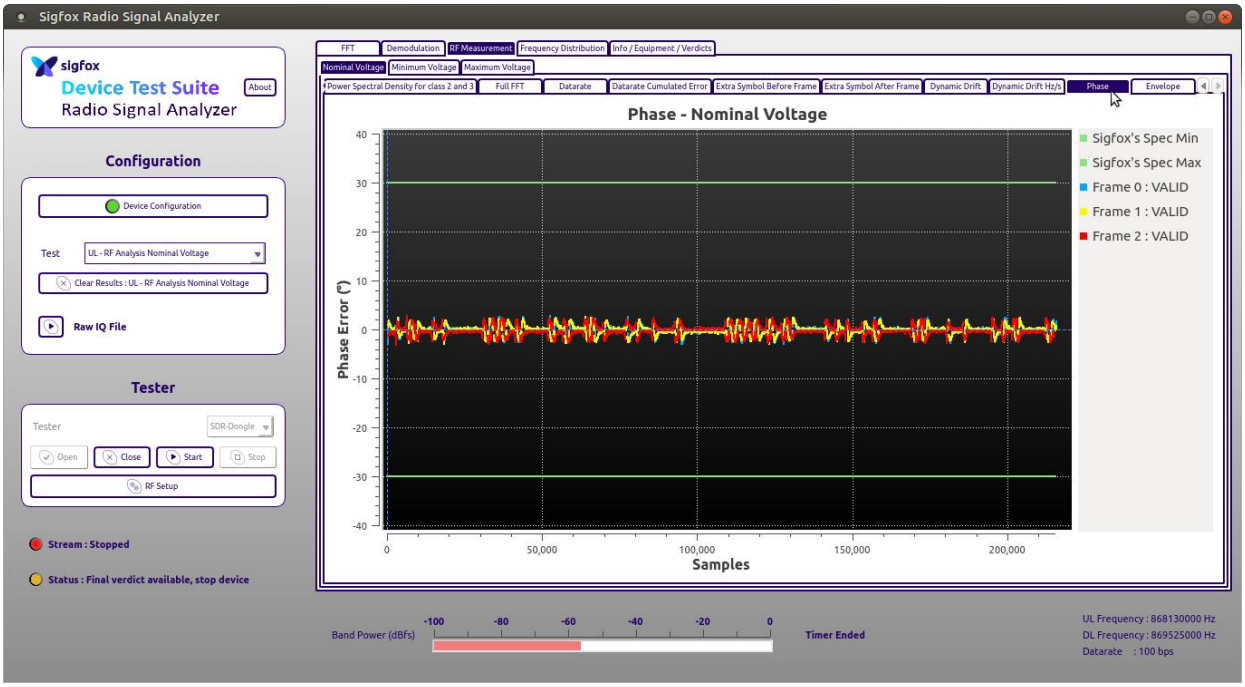


Figure 84: SX1262DVK1DAS RC1 Phase

6.6.13 Envelope

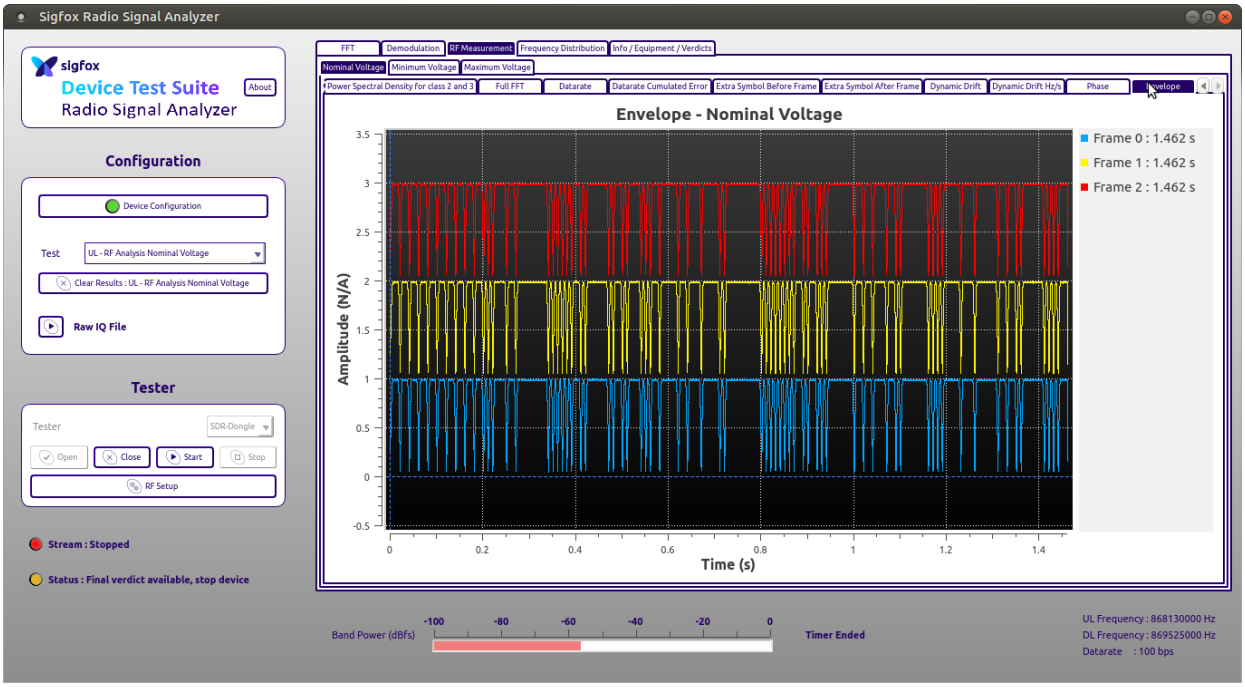


Figure 85: SX1262DVK1DAS RC1 Envelope

6.6.14 Verdict

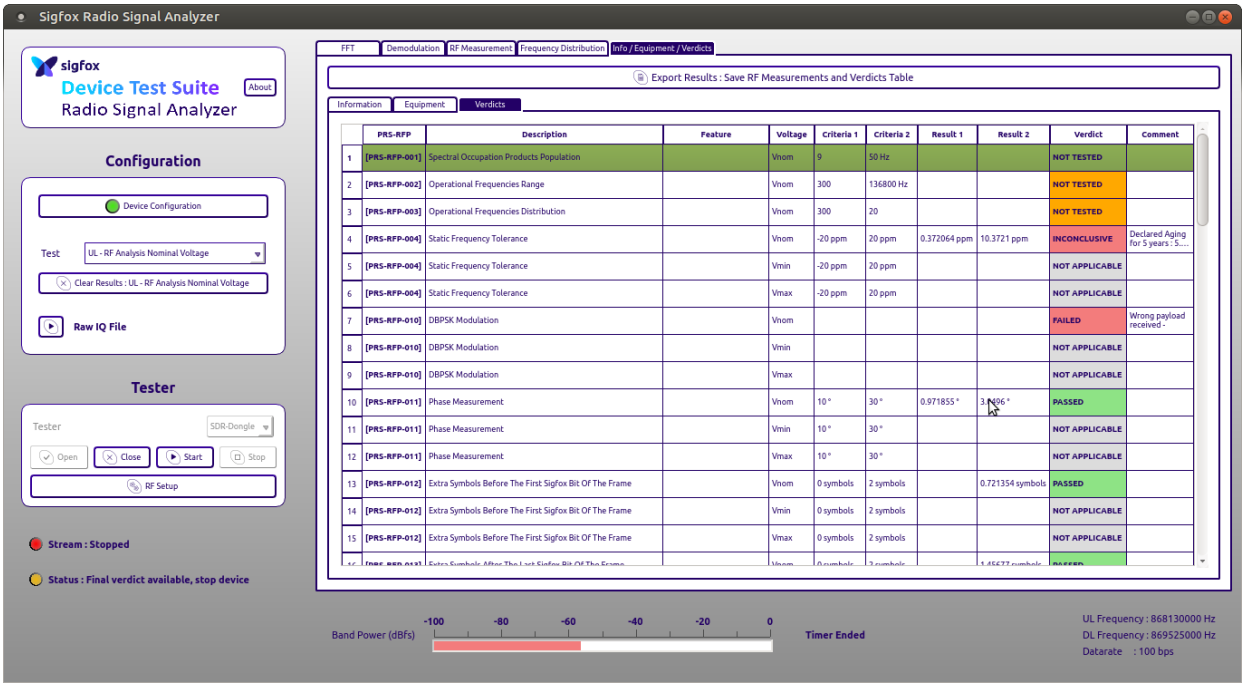


Figure 86: SX1262DVK1DAS RC1 Verdict Page 1

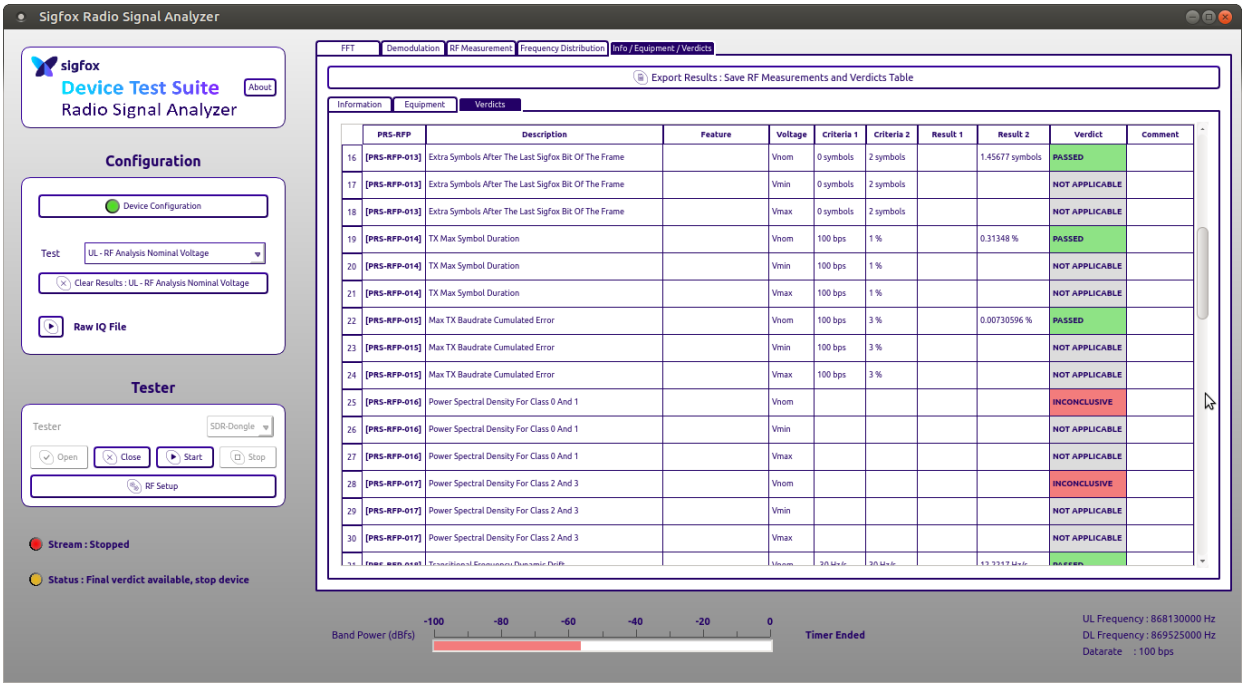


Figure 87: SX1262DVK1DAS RC1 Verdict Page 2

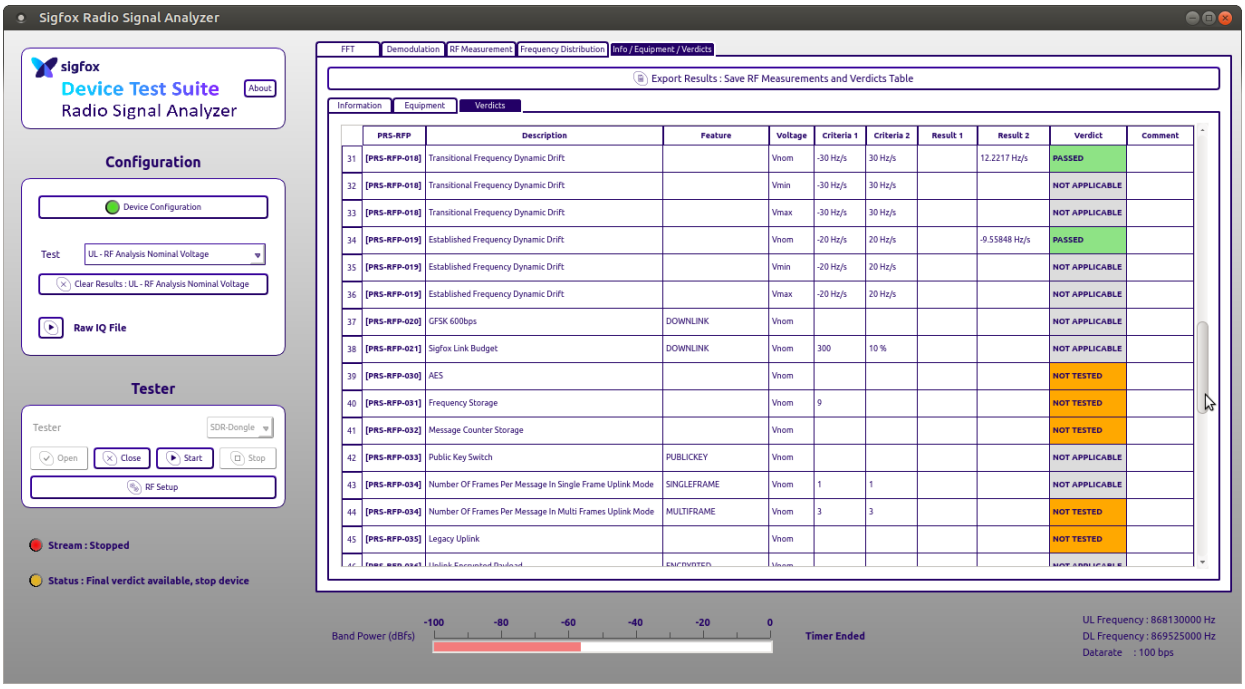


Figure 88: SX1262DVK1DAS RC1 Verdict Page 3

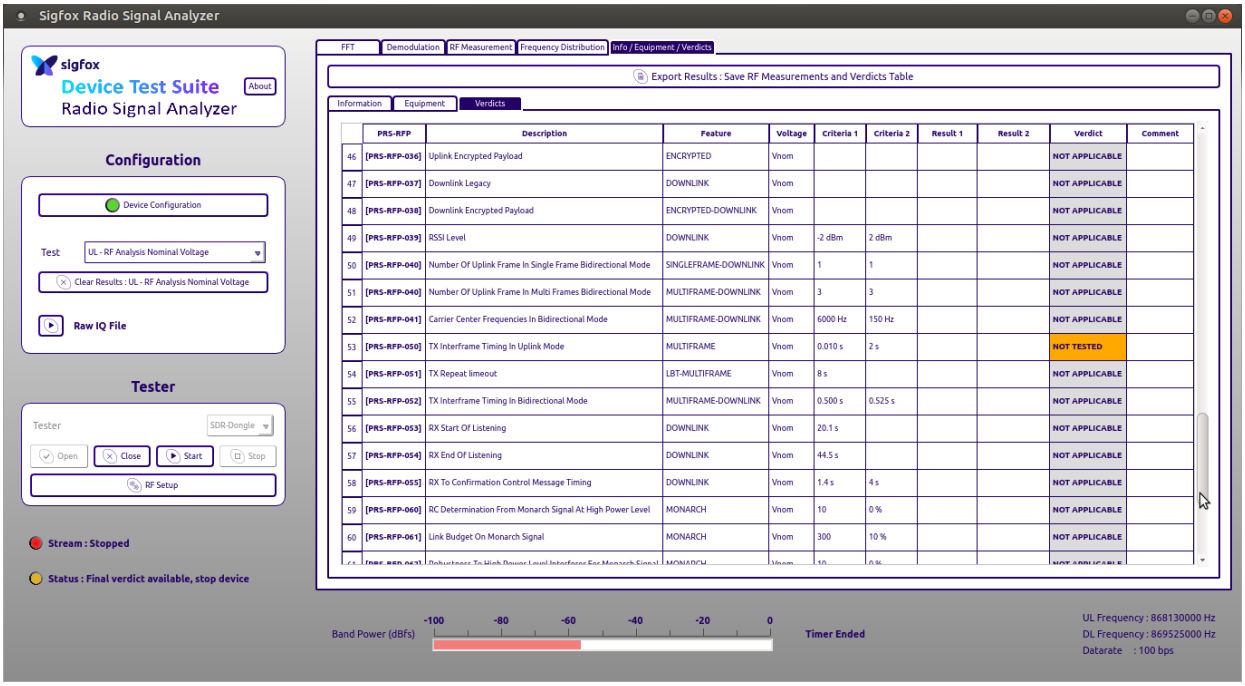


Figure 89: SX1262DVK1DAS RC1 Verdict Page 4

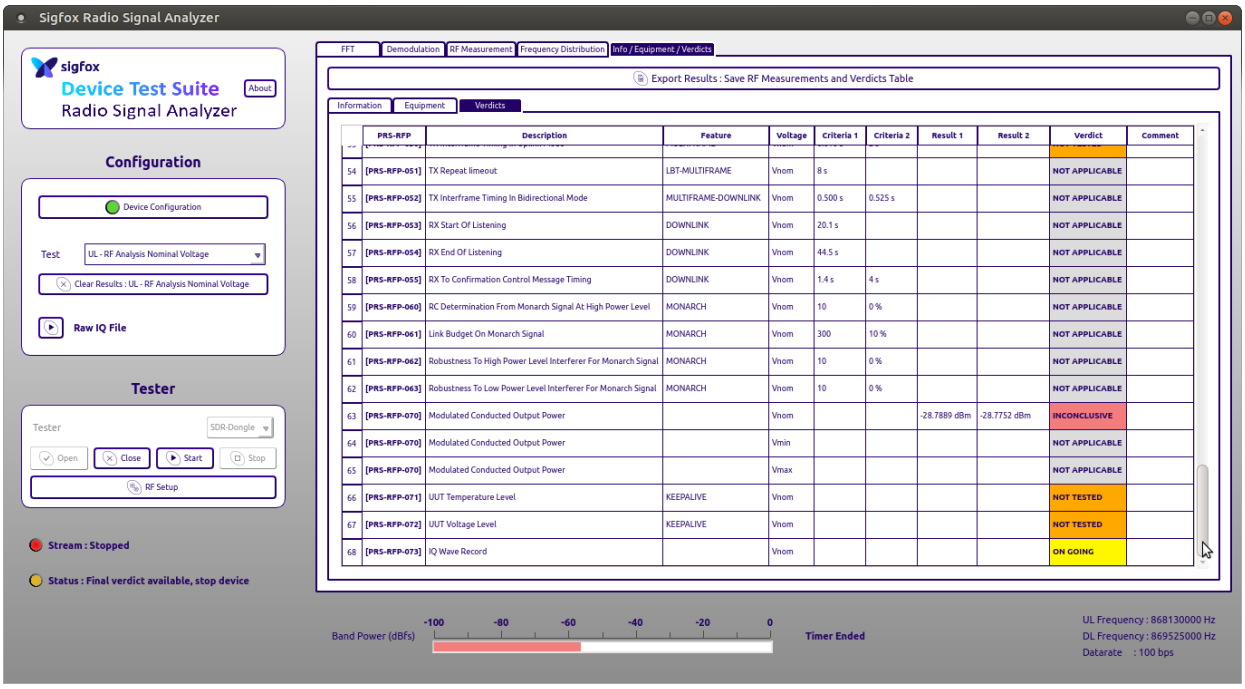


Figure 90: SX1262DVK1DAS RC1 Verdict page 5

6.7 SX1262DVK1DAS Measurement Results, TCXO, Radio Configuration RC2

See Section 6.1 for general information about the Sigfox Radio Signal Analyzer tool test results.

For the RC2 case, note that in Figures 6.7.10 and 6.7.11, the Sigfox Radio Signal Analyzer tool fails to properly measure drift.

6.7.1 Device Configuration

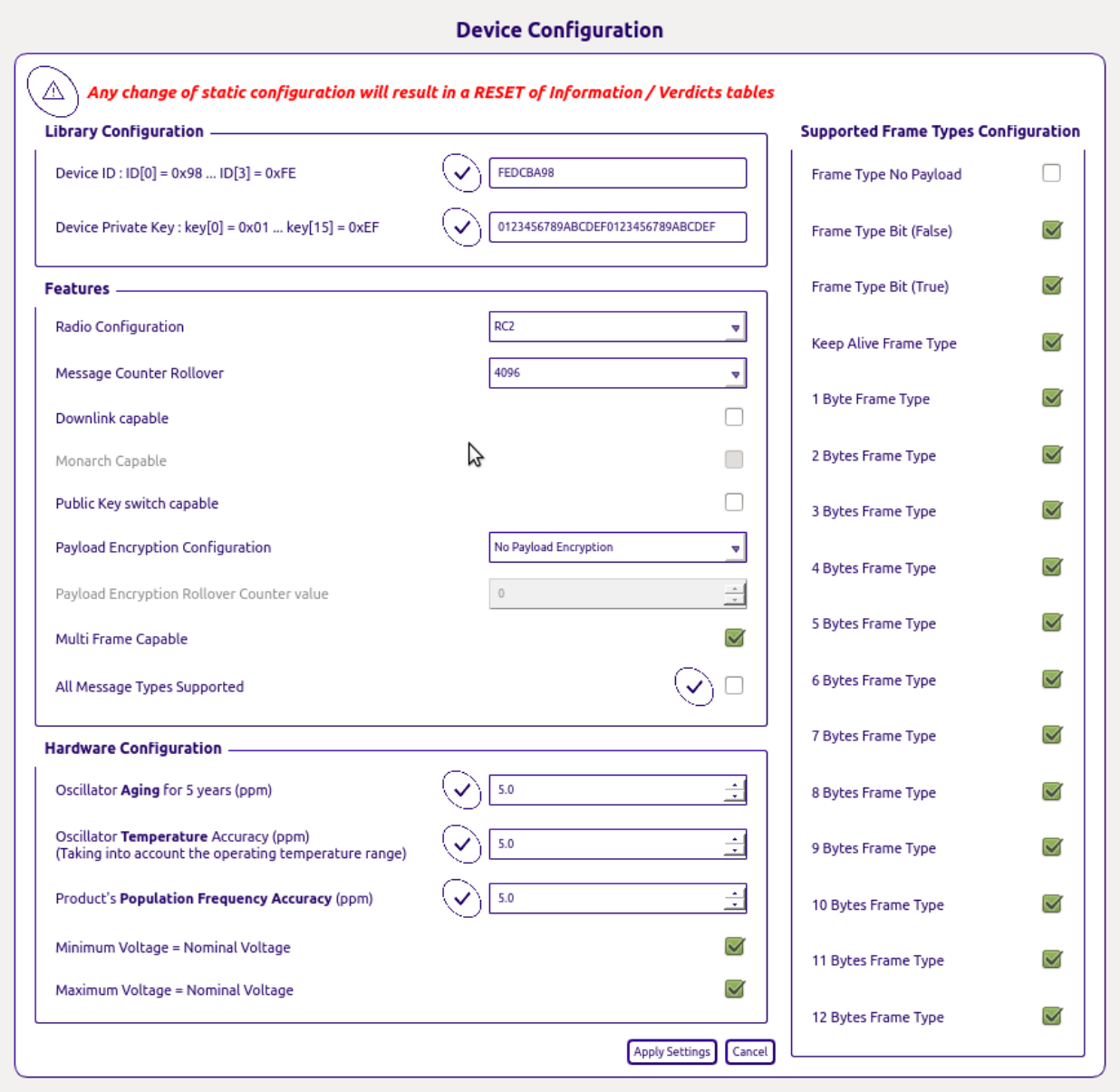


Figure 91: SX1262DVK1DAS RC2 Device Configuration

6.7.2 FFT

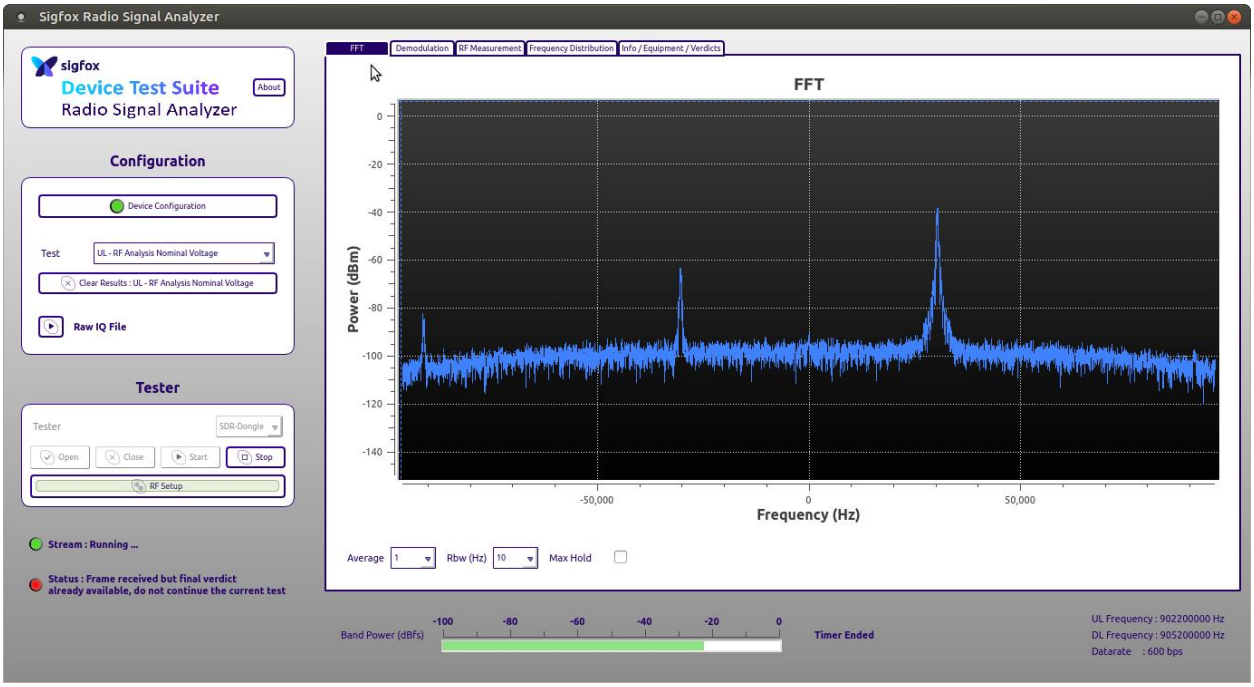


Figure 92: SX1262DVK1DAS RC2 FFT

6.7.3 Demodulation

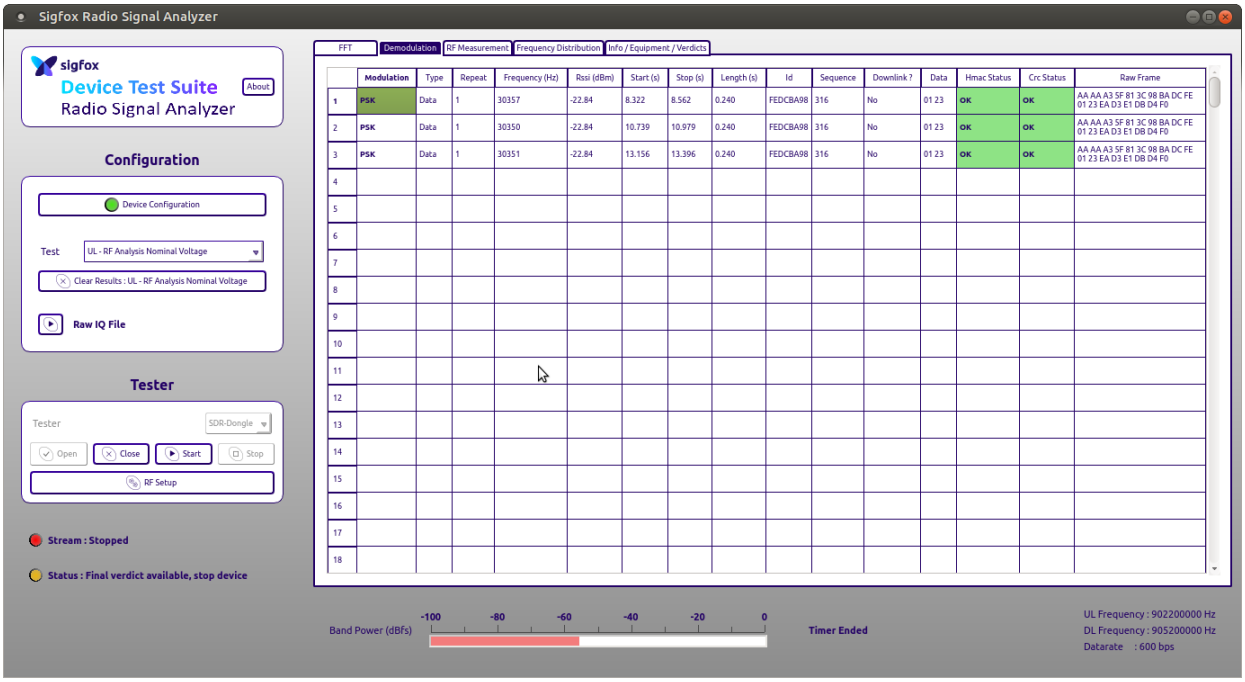


Figure 93: SX1262DVK1DAS RC2 Demodulation

6.7.4 Power Spectral Density for Class 0 & 1

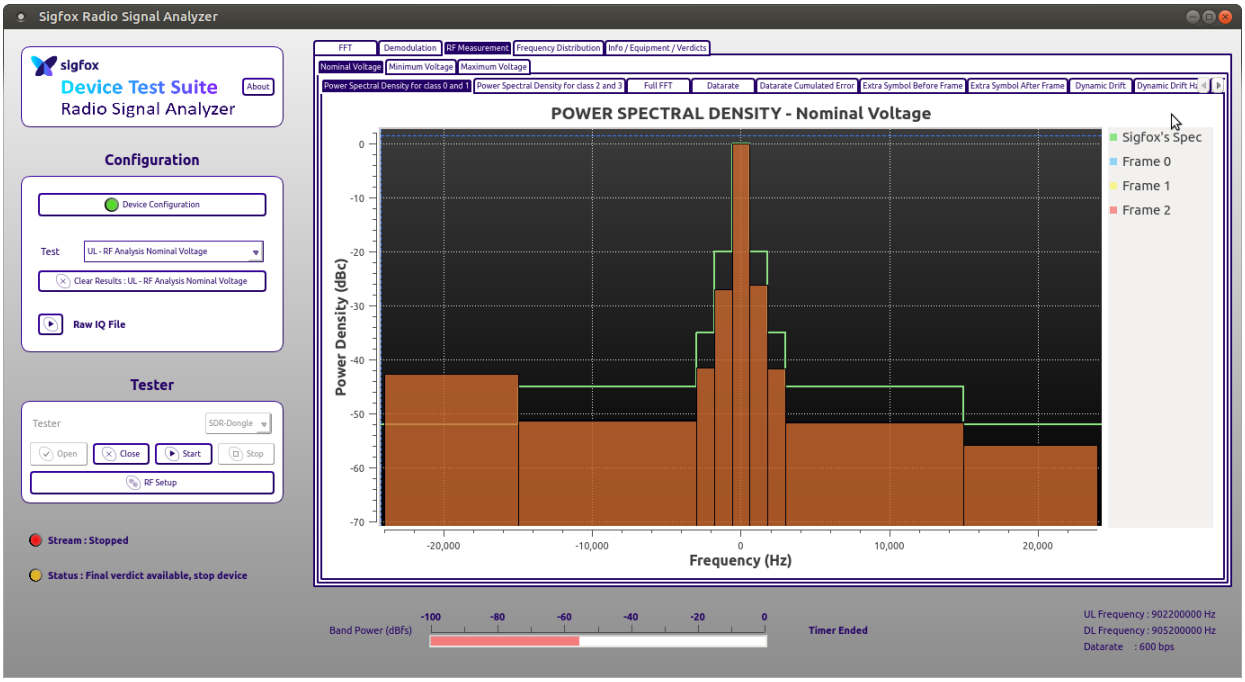


Figure 94: SX1262DVK1DAS RC2 Power Spectral Density for Class 0 & 1

6.7.5 Full FFT

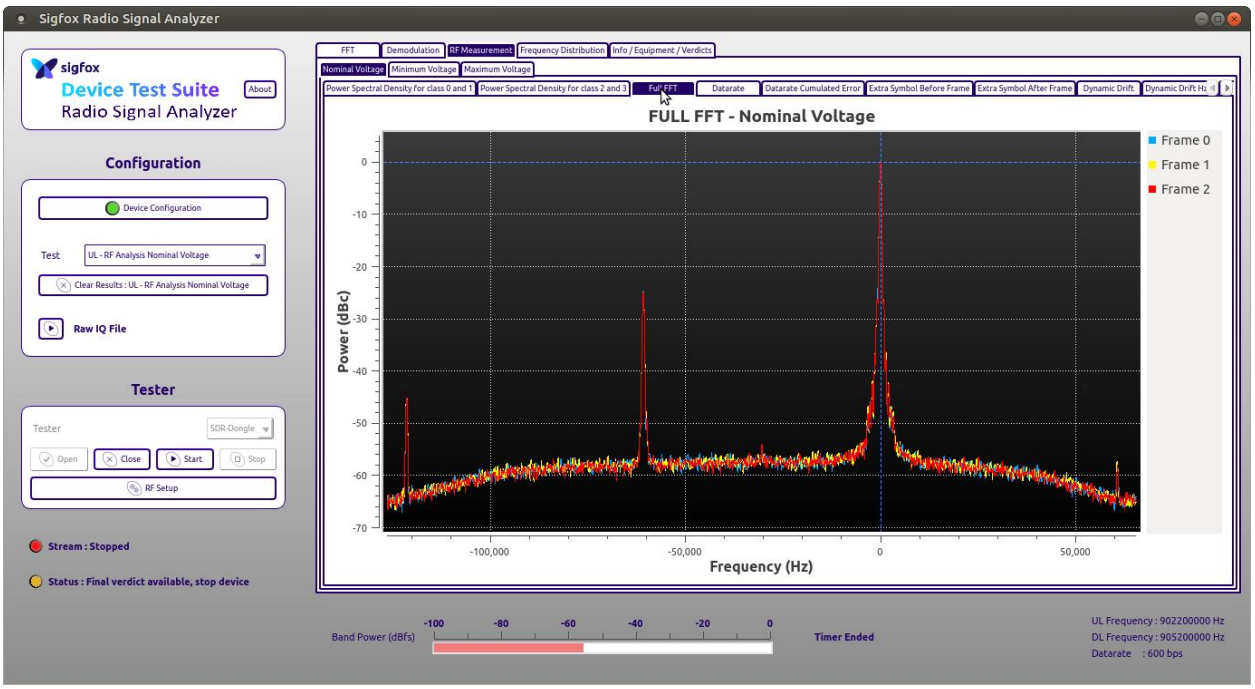


Figure 95: SX1262DVK1DAS RC2 Full FFT

6.7.6 Data Rate

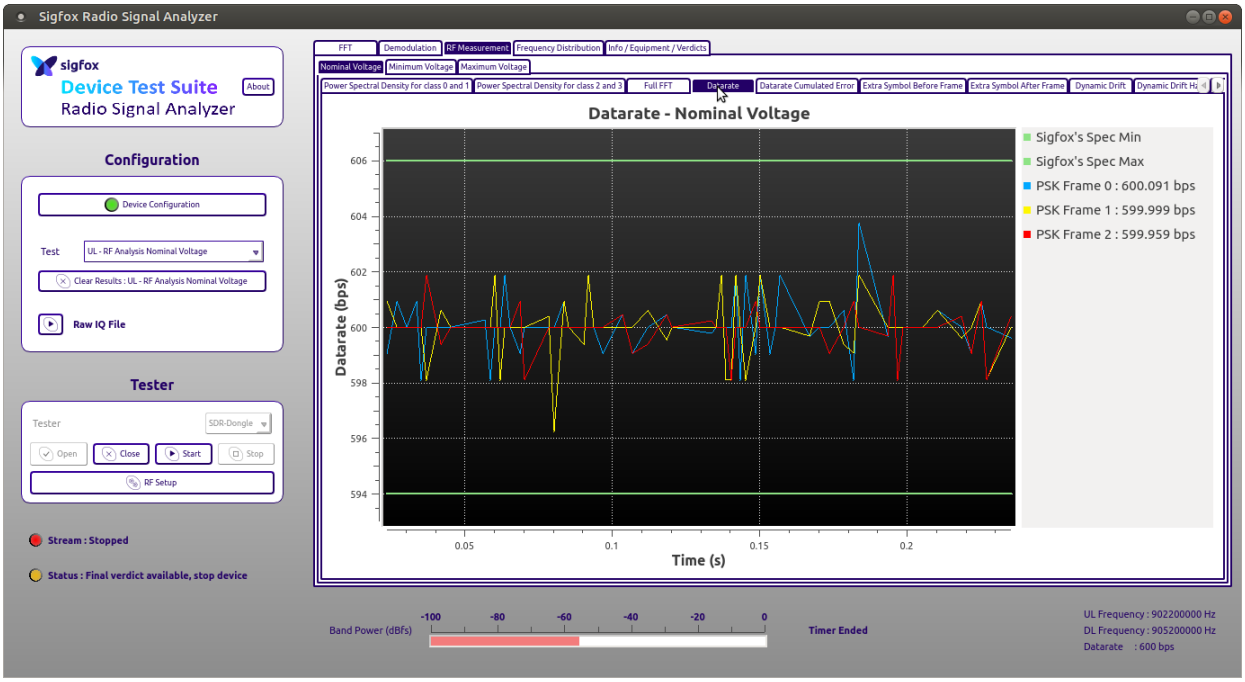


Figure 96: SX1262DVK1DAS RC2 Data Rate

6.7.7 Data Rate Cumulated Error

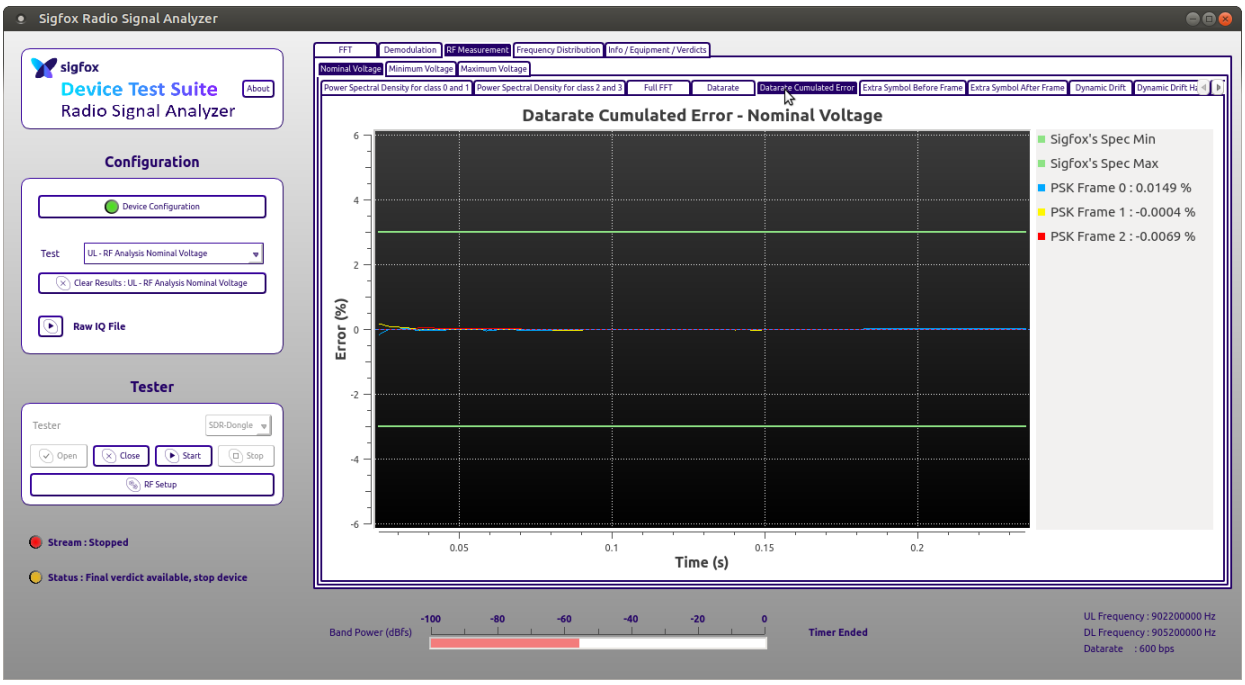


Figure 97: SX1262DVK1DAS RC2 Data Rate Cumulated Error

6.7.8 Extra Symbol Before Transmission

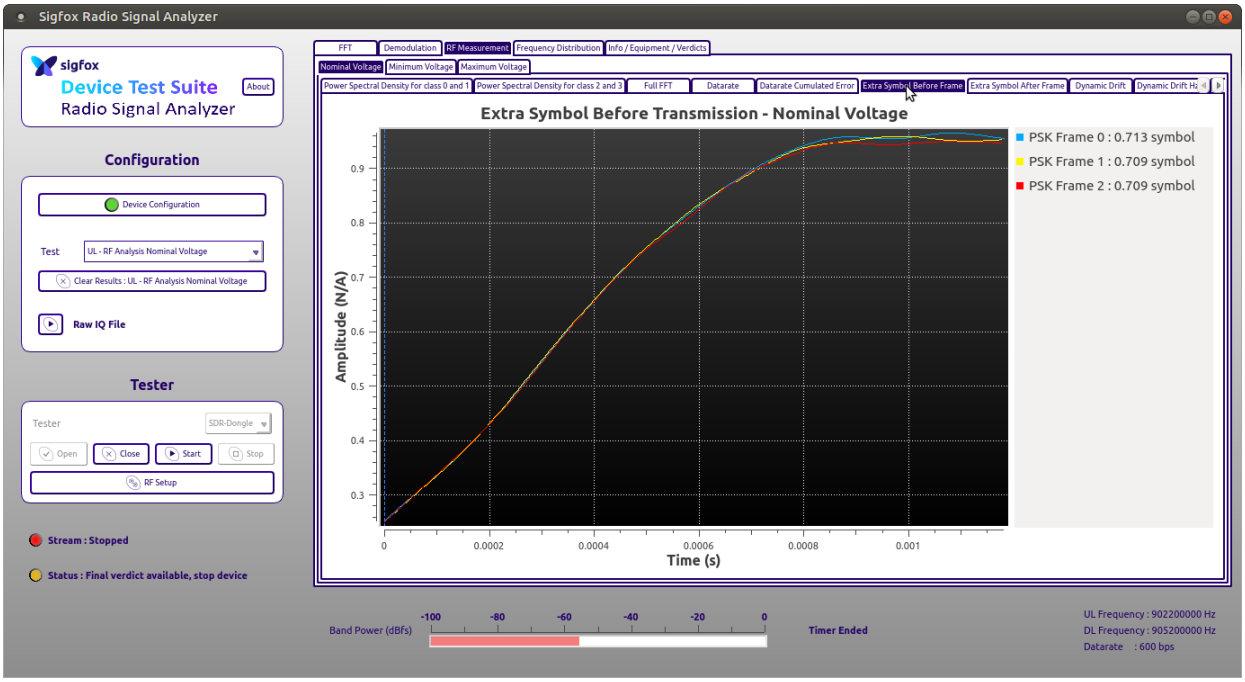


Figure 98: SX1262DVK1DAS RC2 Extra Symbol Before Transmission

6.7.9 Extra Symbol After Transmission

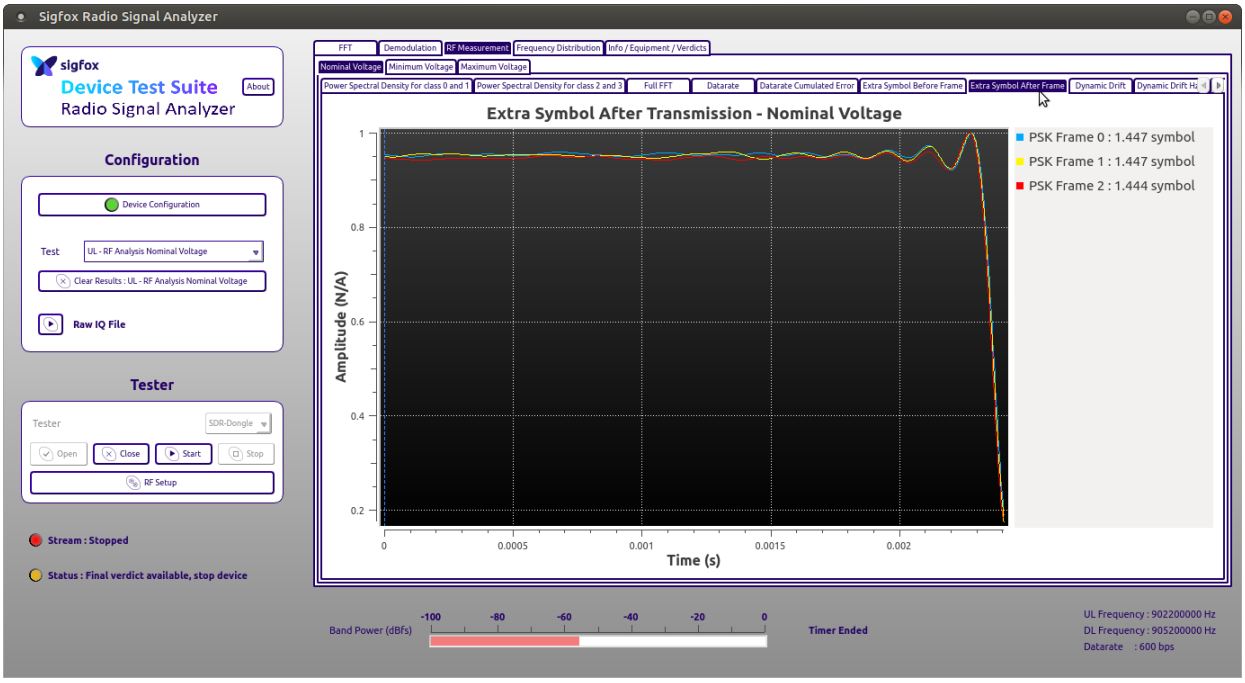


Figure 99: SX1262DVK1DAS RC2 Extra Symbol After Transmission

6.7.10 Dynamic Drift

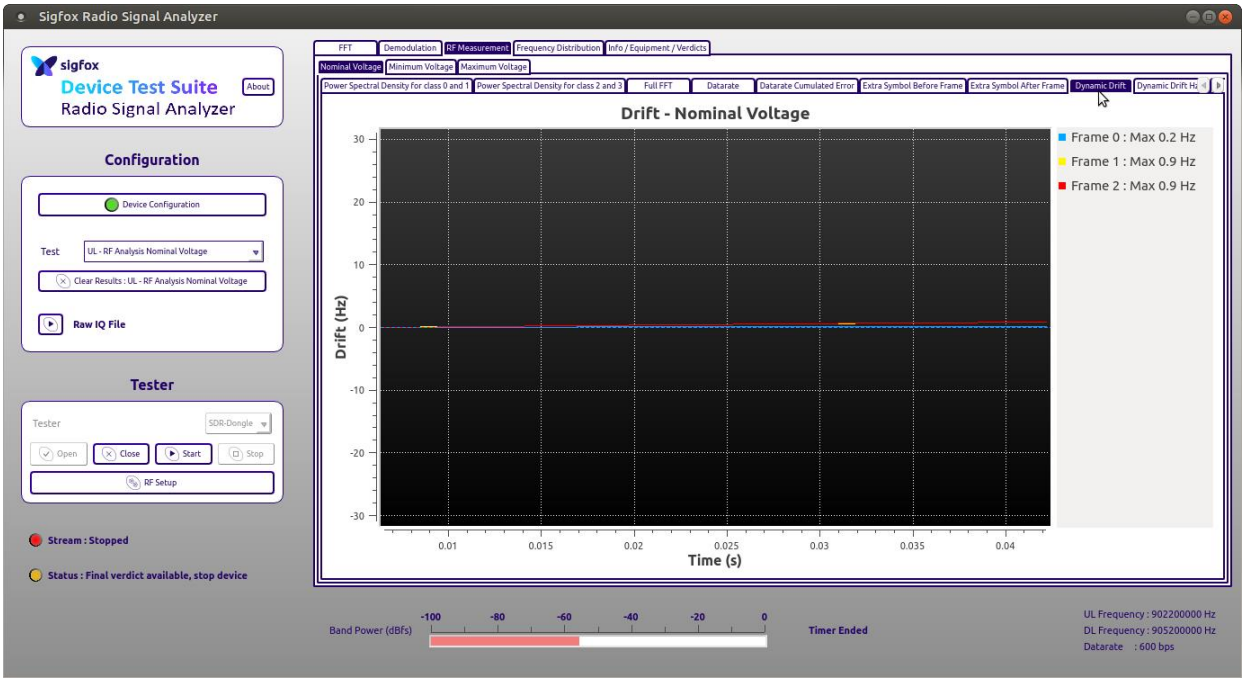


Figure 100: SX1262DVK1DAS RC2 Dynamic Drift

6.7.11 Dynamic Drift per Second

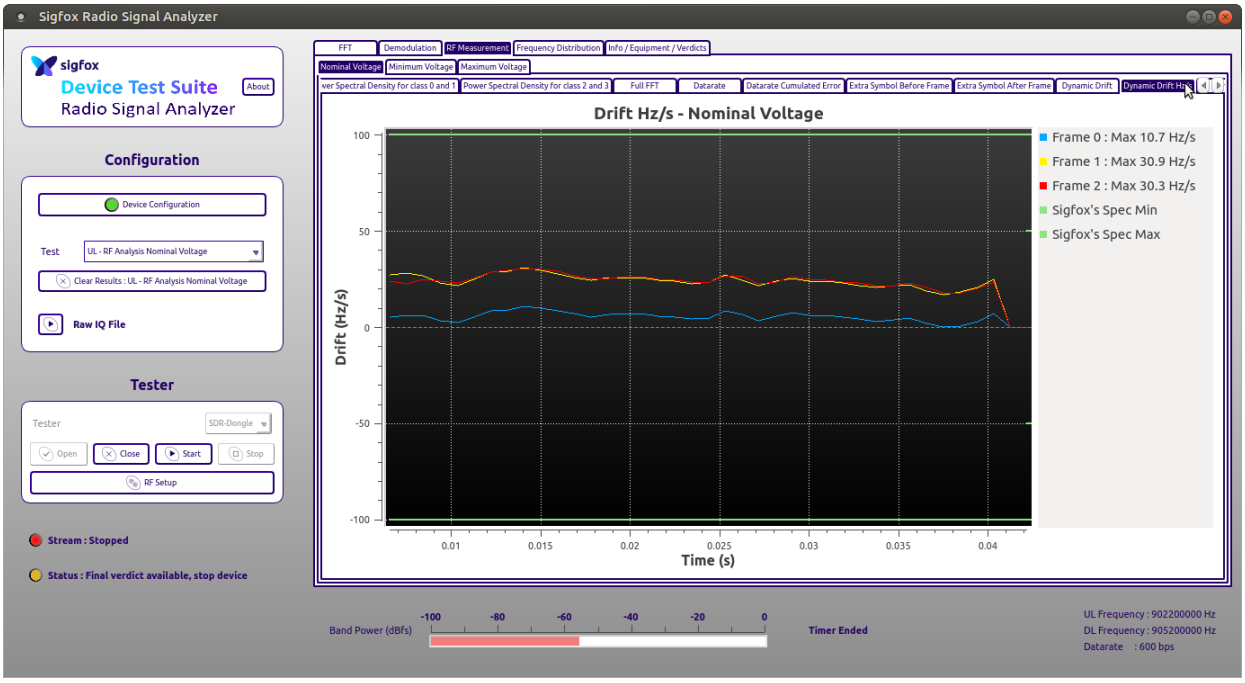


Figure 101: SX1262DVK1DAS RC2 Dynamic Drift per Second

6.7.12 Phase

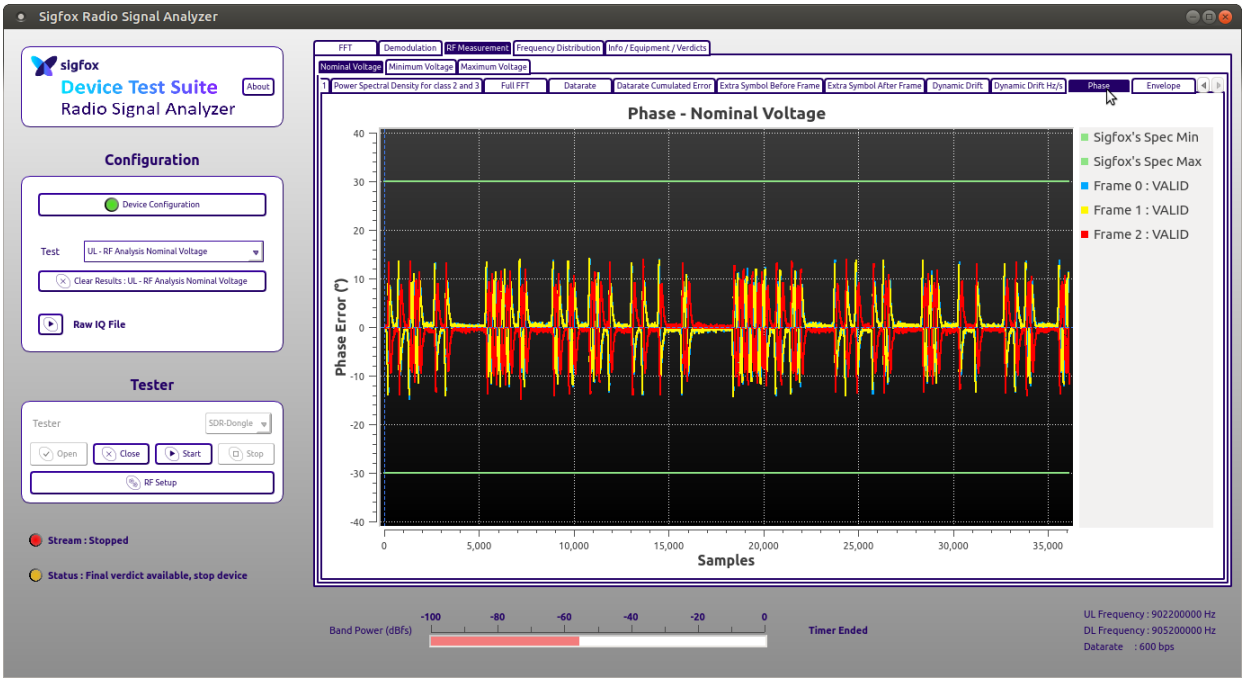


Figure 102: SX1262DVK1DAS RC2 Phase

6.7.13 Envelope

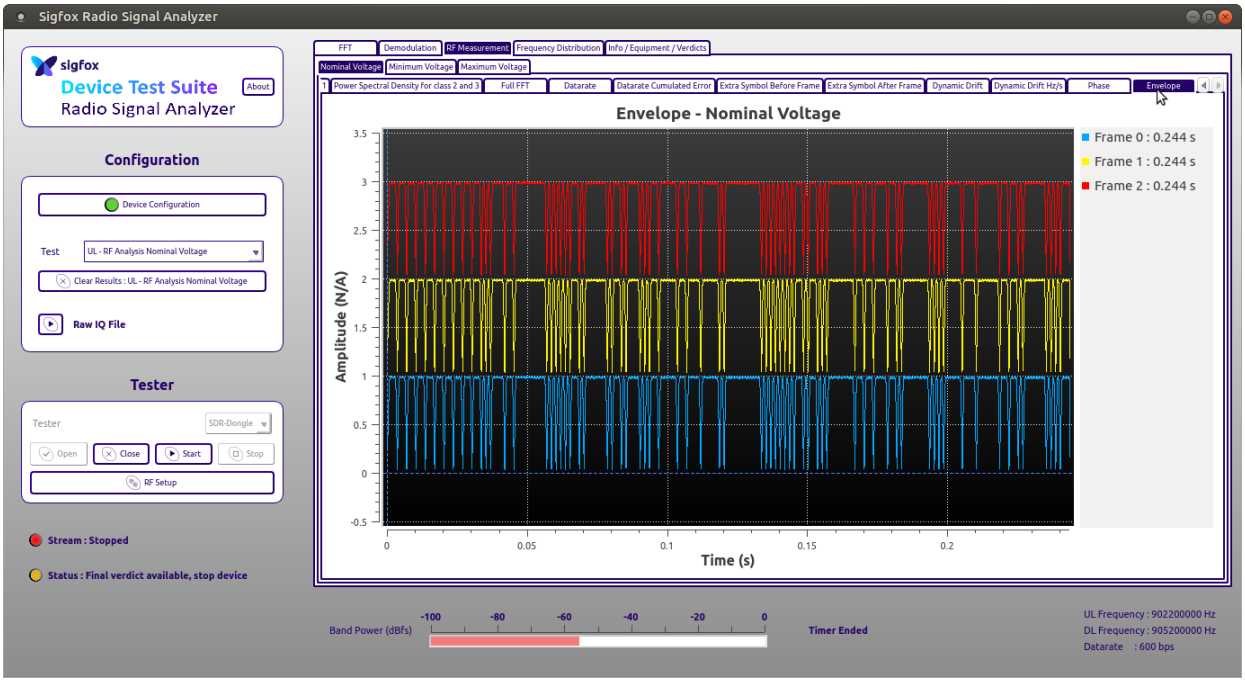


Figure 103: SX1262DVK1DAS RC2 Envelope

6.7.14 Verdict

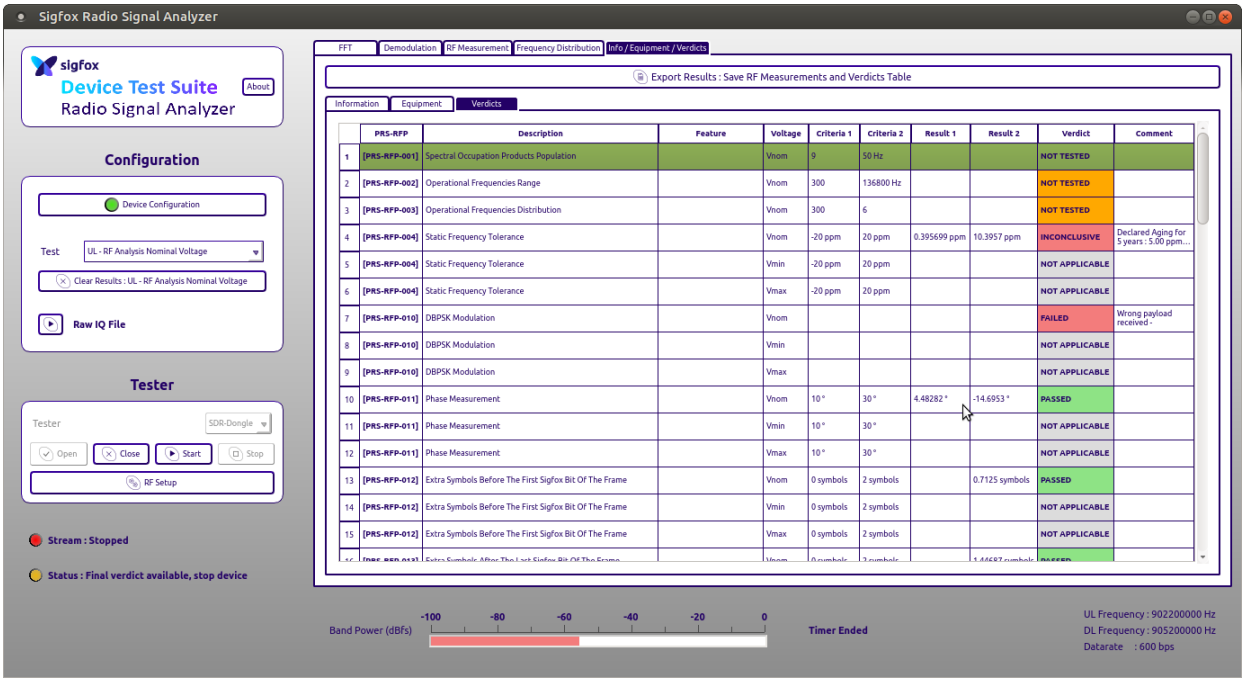


Figure 104: SX1262DVK1DAS RC2 Verdict Page 1

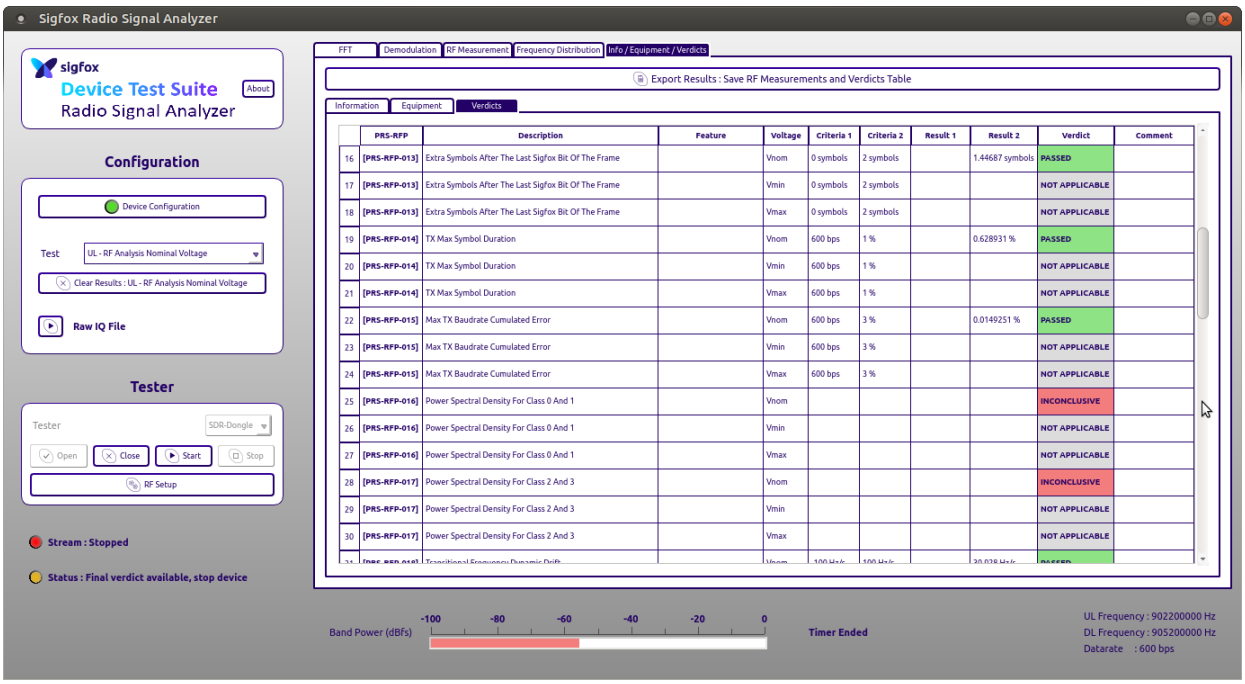


Figure 105: SX1262DVK1DAS RC2 Verdict Page 2

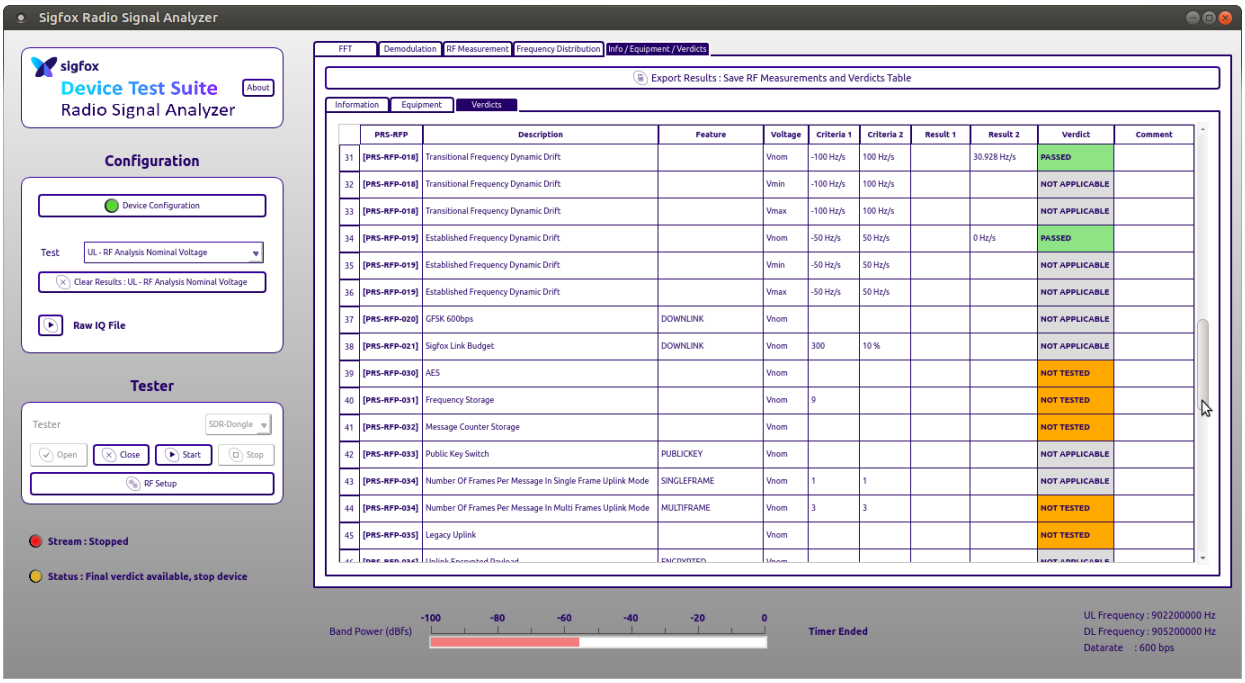


Figure 106: SX1262DVK1DAS RC2 Verdict Page 3

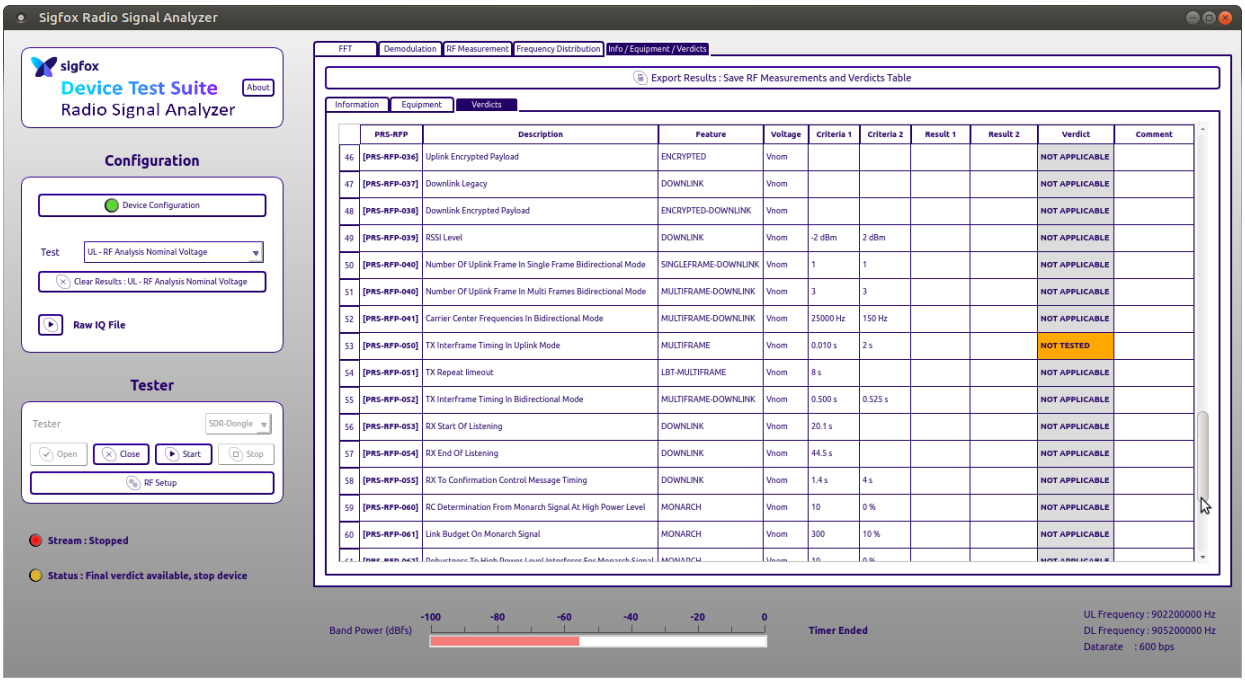


Figure 107: SX1262DVK1DAS RC2 Verdict Page 4

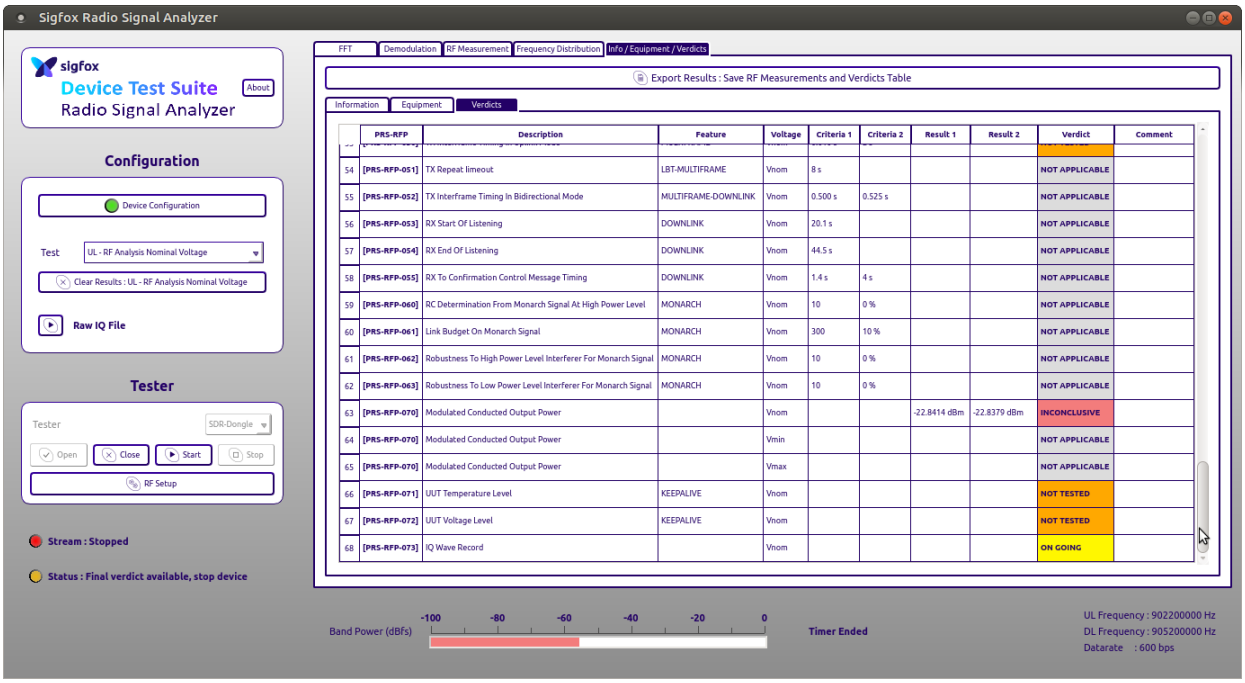


Figure 108: SX1262DVK1DAS RC2 Verdict Page 5

7 Conclusion

This application note has shown how to transmit BPSK packets using a Semtech SX1261/2 or LR11xx radio shield.

Compliance to the Sigfox specification has also been tested on Semtech SX26x and LR11xx shields. However, the user is responsible for performing Sigfox certification of his final hardware and software application.

8 Glossary

Term	Description
API	Application Programming Interface
BPSK	Binary Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
GPIO	General Purpose Input Output
LoRa®	Long Range Communication The LoRa® Mark is a registered trademark of the Semtech Corporation
MCU	Micro-Controller Unit
SIGFOX®	SIGFOX is a registered trademark of SIGFOX
SPI	Serial Peripheral Interface
TCXO	Temperature Compensated Crystal Oscillator
UART	Universal Asynchronous Receiver/Transmitter

9 Revision History

Version	ECO	Date	Modifications
0.1	(Private)	July 2022	Initial version
1.0	068776	Dec 2023	First Public version

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